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Definition and assessment of relay based cellular deployment concepts for future radio scenarios considering 1st protocol characteristics

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Abstract:

Following the WINNER vision of a ubiquitous radio system providing wireless access for a wide range of services and applications across all environments, D3.4 has continued the evolution of relay-based deployment concepts presented in D3.1 and D3.2 towards an understanding of the best deployment concepts for the envisioned WINNER scenarios. Continued work on concepts harmonization is reported as well as evolved relaying concepts.

Keyword list:

Relay based deployment, deployment concept, multi-mode radio network architecture, logical node architecture, fixed relay node, homogeneous relay nodes, heterogeneous relay nodes, cooperative relaying, point-to-multi-point, mesh network, multi-hop deployment concept, mobile relay nodes, multi-hop.

Disclaimer:

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Executive Summary

The development of efficient deployment concepts plays an essential role to provide efficient ubiquitous radio coverage with high spectral efficiency and low cost per bit. A deployment concept for a wireless system based on the WINNER system concept has to integrate several modes related to different scenarios, which most probably partly overlap. These modes have to be integrated in one flexible protocol architecture as well as to fit into one flexible WINNER RAN architecture.

Deliverable D3.1 presented relaying concepts, benchmarks of new concepts against today's systems and a protocol concept based on generic and mode specific user and control plane functionalities. The next deliverable D3.2 presented an evolved flexible node architecture and initial concepts harmonization work in the form of a categorisation of deployment concept proposals in D3.1 into logical groups. Further results on the comparison between single-hop and multi-hop were shown along with related routing strategies. Also cooperative relaying concepts were evolved. Next to multi-hop, the single-hop based deployment concepts were elaborated partly with respect to the new air interface technologies and finally a system level simulation methodology was developed to simulate the deployment concepts based on the new WINNER air interface taking the agreed scenarios into account.

This deliverable presents evolved work on these issues for relay based deployment concepts, such as hierarchical point-to-multi-point (PmP) multi-hop relaying, "TDMA clustering" defining a relaying concept based on MAC frame by frame relaying, Movable relays (or alternatively named as Temporarily Fixed Relays), heterogeneous relays and mobile relays. In addition, the current state of the harmonization work across different concepts is given with an evolved understanding of their applicability to different WINNER scenarios. In addition, extensions to relay based deployment concepts are presented such as cooperative relaying techniques and a technique called coded bi-directional relaying. These techniques have the possibility to improve the performance of the presented relay-based concepts.

The overall aim of the deliverable is to describe the most suitable relay-based deployment concepts with respect to the main WINNER scenarios and a discussion on these choices. However, continued work towards the final deliverable D3.5 might indicate that ideas in the previous deliverables D3.1 and D3.2 should be revisited. In addition, note that single-hop concepts are not discussed in this deliverable, but single-hop deployment is the base-line deployment concept for all scenarios. Further work is needed on single-hop deployment of the emerging WINNER air interface developed in WP2.

A number of fixed relay-based deployment concepts/ approaches are investigated, along with their advantages and disadvantages with reference to their actual performance and their applicability for the main WINNER scenarios. Relays have been proven to substantially extend the radio coverage of a base station, especially in highly obstructed service areas, and gain antennas at fixed relays have been established to substantially contribute to increase the throughput at cell areas far away from a base station. Heterogeneous relays are most promising for scenarios with different mobility, propagation and traffic characteristics like for example any scenario with outdoor-indoor and vice versa transitions. Nevertheless rural and urban environments with LOS or near-LOS conditions are scenarios where the applicability of heterogeneous relaying option should be evaluated and compared with other alternatives, like a fair solution for these kind of scenarios.

Mobile Relays can provide coverage to a large number of users e.g. commuters with trains, could be used for multicast/broadcast services and they could be used in an Ad-Hoc solution for applications which don't require large resources. Extensions to the relaying concepts are presented, bi-directional relaying and cooperative relaying. These techniques are shown to be able to enhance the conventional relaying techniques, but they need further integration into the WINNER system concept.

1. Introduction

The WINNER project follows the vision of a ubiquitous radio system providing wireless access for a wide range of services and applications across all environments, from short range to wide area with one single adaptive system concept for all envisaged environments. Therefore, the WINNER system concept aims at adapting to multiple scenarios by using different modes of a common technology basis. To make the WINNER system concept economically successful, the costs per bit have to be minimised. The development of efficient deployment concepts plays an essential role to provide efficient ubiquitous radio coverage.

In the context of WINNER a radio network deployment concept has been defined as a description of network element types and their functions (i.e. logical network elements),

a) how these network element types are linked in a network topology,
b) how logical network elements are mapped onto physical network elements (and thereby WINNER modes) and
c) where physical network elements are deployed according to the radio propagation scenarios for which the deployment concept is applicable.

A deployment concept for a wireless system based on the WINNER system concept has to integrate several modes related to different scenarios, which most probably partly overlap. These modes have to be integrated in one flexible protocol architecture as well as they have to be fit into one flexible WINNER RAN architecture.

Furthermore, the deployment concept has to make the envisaged high capacity of the new WINNER air interface available in a large area in a cost-efficient manner and support all envisaged service capabilities. Thereby the range for broadband air interfaces that aim at covering densely populated areas is expected to be very limited due to severe attenuation in the expected high frequency band (3.4GHz-5GHz), the limited transmission power (regulatory constraints) and the unfavourable radio propagation conditions, e.g. in urban areas.

Finally the developed deployment concept has to be assessed in terms of traffic performance by means of system level simulations modelling the capabilities of the assumed WINNER air interface technologies as developed by WP2. To solve the challenges of a WINNER deployment concept WP3 has presented several multi-hop concepts in D3.1 and D3.2. They show the potential of relay based deployment concept in terms of bringing the capacity of a base station into the area, balancing the capacity distribution in the area and providing coverage to otherwise shadowed areas. Also, first steps to the RAN- and protocol-architecture have been provided.

Deliverable D3.1 presented relaying concepts, benchmarks of new concepts against today's systems and a protocol concept based on generic and mode specific user and control plane functionalities. Deliverable D3.2 presented an evolution of the flexible node architecture, initial concepts harmonisation work in the form of a categorisation of deployment concept proposals in D3.1 into logical groups. Further results on the comparison between single-hop and multi-hop were shown along with related routing strategies. Also the cooperative relaying concepts were evolved. Next to multi-hop, the single hop based deployment concepts were elaborated partly with respect to the new air interface technologies and finally a system level simulation methodology was developed to simulate the deployment concepts based on the new WINNER air interface taking the agreed scenarios into account.

This deliverable describes the most suitable relay-based deployment concepts with respect to the main WINNER scenarios and a discussion on these choices. However, continued work towards the final deliverable D3.5 might indicate that ideas in the previous deliverables D3.1 and D3.2 should be revisited. In addition, note that single-hop concepts are not discussed in this deliverable, but single-hop deployment is the base-line deployment concept for all scenarios.

The outline of this deliverable is as follows. In Chapter 1, the current WINNER terminology is given followed by a revisit of the logical node architecture along with a functional description of the logical network elements. In Chapter 2, the WINNER scenarios are briefly presented. Chapter 3 presents a number of the most promising fixed relay-based concepts that have been presented in the previous deliverables D3.1 and D3.2 - hierarchical PmP multi-hop relaying, "TDMA clustering" defining a relaying concept based on MAC frame by frame relaying, Movable relays (or alternatively named as Temporarily Fixed Relays) and heterogeneous relays. The chapter ends with a concept harmonization section.

Chapter 4 addresses three mobile relay-based deployment concepts and a harmonisation process of those concepts is presented. Techniques that can be used to enhance the relaying concepts are discussed in Chapter 5 and 6, Coded Bi-directional Relaying and different Cooperative relaying techniques.

Finally, Annex I and II provides additional details on the WINNER scenarios and Relaying techniques respectively. Table 1-1 gives an overview of the content in the deliverable.

Table 1-1: Overview of content in the deliverable

Main category	Sub-category	Notes
Multi-Hop Fixed Relay	Homogeneous	Sections 3.1 and 3.2 New sub-categorization proposal: "Hierarchical PmP" and "Mesh" (section 3.5) Each concept can be realized through "Time" "Time- and Frequency" "Space-Time-Frequency" based relaying, as in the D3.2 classification.
	Heterogeneous	Section 3.4 (was considered conceptually together with homogeneous relaying in deliverable D3.2)
	Movable relays	Section 3.3
Multi-Hop Mobile Relay	Dedicated Relay - Type I	Section 4 classification exactly as in D3.2
	Dedicated Relay - Type II	
	Terminals acting as Relays	
Extended Relaying	Coded Bi-directional and Cooperative Relay	Section 5 and 6.

1.1 Terminology and Definitions

The following WP3 related definitions are an extract of the common WINNER definitions and terminology document.

Term and Definition	**Not preferred synonyms used in previous documents**
Access System: The access system is used to connect the WINNER user terminals to the base station either directly or via relay nodes. The elements of the access system are the WINNER base stations and the WINNER relay nodes.	
Base Station: A base station (BS) is a stationary physical network element serving relay nodes or user terminal in a given geographical area via its radio access capabilities. It provides the interface towards the core network via a feeder system.	Note that **Access Point** has been used synonymously for **Base Station** in some previous documents
Cell: A cell is defined by the geographical coverage area of its broadcast channel. E.g., the cell as defined by 3GPP is a radio network object that can be uniquely identified by a User terminal (UT) from a (cell) identification that is broadcast over a geographical area from one UTRAN Node B.	
Chunk: A chunk represents the basic resource unit on the radio channel and comprises a number of timeslots (e.g. OFDM symbols) and subcarriers.	
Deployment Concept: The term “Deployment Concept” describes network element types and their functions (i.e. logical network elements), (a) how these network element types are linked in a network topology, (b) how logical network elements are mapped onto physical network elements and (c) where physical network elements are deployed according to the radio	

propagation scenarios for which the deployment concept is applicable.

Feeder System: The feeder system is the system used to feed the base stations. The distinctive characteristic compared to the access system is that WINNER users shouldn't connect to this network directly. The transmission technology used by the feeder system could be wireless or wired and is irrelevant and transparent for the final user.

Handover: A Handover is the process in which the radio access network changes the radio transmitters or radio mode or radio system used to provide bearer services, while maintaining a defined bearer service QoS and minimum added system load.

Heterogeneous Relay Node: A heterogeneous relay node is a relay node that uses different radio access technologies using common or different sets of transmission resources (e.g. RF channels) for its connections (BS-RN, RN-RN, RN-UT). The radio access technologies that a heterogeneous relay incorporates can be different modes of the same RAT (i.e. in the WINNER context), one WINNER RAT-mode and another (possibly legacy) RAT, or two (legacy) RATs, where the latter case is not in the WINNER scope of research.

Note that **Heterogeneous Relay** has been used synonymously for **Heterogenous Relay Node** in some previous documents

Homogeneous Relay Node: A homogeneous relay node is a relay node that uses the same radio access technology in a common set of transmission resources (e.g. RF channels) for all its connections (BS-RN, RN-RN, RN-UT).

Note that **Homogeneous Relay** has been used synonymously for **Homogeneous Relay Node** in some previous documents

Horizontal Handover: A Horizontal Handover is an intra-system handover between two different radio cells within the same system on the same layer or between cells belonging to different layers in a system with overlay structure (e.g. handover between macro-cell and micro-cell/pico-cell in GSM).

Inter-mode Handover: An Inter-mode Handover is the switching process between two cells of different operational modes within the same radio access system e.g. UMTS FDD⇔UMTS TDD.

Inter-system Handover: An Inter-System handover is the switching process between different radio access systems e.g. UMTS⇔WLAN, UMTS⇔GSM.

Intra-mode Handover: An Intra-mode Handover is the switching process between two cells of the same operational mode within the same radio access system e.g. UMTS FDD⇔UMTS FDD.

Link: A link is the physical radio connection between two physical network elements of the WINNER access system. It subdivides into relay link between base station and relay node or between relays and the user link between user terminal and radio access point.

Logical Channel: A logical channel is an information stream dedicated to the transfer of a specific type of information over the radio interface. Logical Channels are provided on top of the MAC layer. Logical channels are furthermore divided into two main categories, which are control channels and traffic channels. Control channels are used for transfer of control plane information whereas traffic channels are used for transfer of user plane information.

Logical Deployment Concept: The term “Logical Deployment Concept” describes logical network element types and their functions and how these network element types are linked in a network topology.

Logical Network Elements: A logical network element denotes a logically existing functionality in the radio access network that serves a certain purpose, e.g. an entity that terminates a certain set of protocols. Logical network elements may be mapped to physical elements in a one-to-one manner or they may be grouped to form physical network elements.

Physical Channels: Physical Channels are defined by air interface specific physical resources such as a specific carrier frequency and specific subsets of resources in the spectral, temporal, spatial and signal space domain.

Physical Deployment Concept: The term “Deployment Concept” describes the physical network element types, how the physical network element types are linked in a network topology, how logical network elements are mapped onto physical network elements and where physical network elements are deployed according to the radio propagation scenarios for which the deployment concept is applicable.

Physical Network Element: A physical network element denotes a physically existing device in the access system that incorporates certain functionality, thereby representing one or possibly even more logical network elements. Physical network elements are base station, relay node and user terminal.

Radio Access Network: Current 2G and 3G cellular radio system comprise the core network and the radio access network (RAN). The RAN is the network that provides the connection between mobile terminals and core network. In the case of UMTS the RAN is called UTRAN and is composed of node Bs and RNCs. The clear functional split between RAN and core might disappear in future mobile and wireless radio systems.

Radio Access Point: A Radio Access Point (RAP) is a physical network element in radio access network responsible for radio transmission and reception to or from the user terminal via its radio access capabilities. A RAP can be either a relay node or a base station.

Radio Access Technology: The radio access technology (RAT) is the air interface that is used to allow the link between end user terminal and Base Station or Relay Node of the RAN. This includes also multi-hop/relaying elements. In current cellular systems, one RAT is usually associated to a RAN, e.g. UMTS RAN uses radio access technology WCDMA.

Radio Resource Management: Radio resource management (RRM) refers to network controlled mechanisms and architectures that support intelligent admission of calls, sessions, distribution of traffic, QoS, power and the variances of them, thereby aiming at an optimized usage of radio resource and maximized system capacity.

Relay Node: A relay node (RN) is a physical network element serving other relay nodes or user terminal in a given geographical area via its radio access capabilities. It is wirelessly connected to a base station, another relay node and/or a user terminal and forwards data packets between these network elements. Depending on whether its connections (BS-to-RN and RN-to-RN or RN-to-UT) are established with the same radio access technology in the same pool of transmission resources (e.g. RF channels) or not, one may distinguish between homogeneous relay nodes and heterogeneous relay nodes.

Note that **Relay** has been used synonymously for **Relay Node** in some previous documents

Site: A site is defined as the physical co-location of base station hardware serving a set of antennas. Users may be connected to a site either directly or through relay nodes.

Transport channel: The channels offered by the physical layer to data link layer (corresponding to the MAC layer) for data transport between peer physical layer entities are denoted as Transport Channels. Different types of transport channels are defined by how and with which characteristics data is transferred on the physical layer, e.g. whether using dedicated or common physical channels.

User Terminal: User terminal (UT) refers to physical network elements

Note that **Mobile**

used by the end user to access a service or a set of services.

Terminal has been used synonymously for **User Terminal** in some previous documents

Vertical Handover: A Vertical Handover is an inter-system handover between two different radio systems on different layers of the overlay structure (e.g. UMTS FDD to WLAN). A downward vertical handover is a handover to a cell of smaller size. An upward vertical handover is a handover to a cell of larger size.

1.2 Logical Network Element Definition

This section will briefly outline the current view of the node architecture (for a detailed description and protocol termination points, the reader is referred to [2].The main goal of the logical node architecture model presented in this section is to assist in grouping functions, between which there may be a need for defining open interfaces. In particular, the logical node architecture needs to support all envisioned deployment scenarios for WINNER (as well as not yet foreseen deployment scenarios) without introducing too many logical nodes and/or interfaces. Note that the list of reference logical nodes presented here is preliminary, and logical nodes may have to be added, removed or combined during the development of the WINNER architecture. Even though the logical node architecture includes protocol termination points, they do not suggest a certain physical placement of functional entities. Figure 1-1 proposes a preliminary logical node architecture model. Here, dashed lines indicate control relations whereas solid lines indicate user plane data transport. N.B. the Access Router (AR) is outside the primary focus of WINNER.

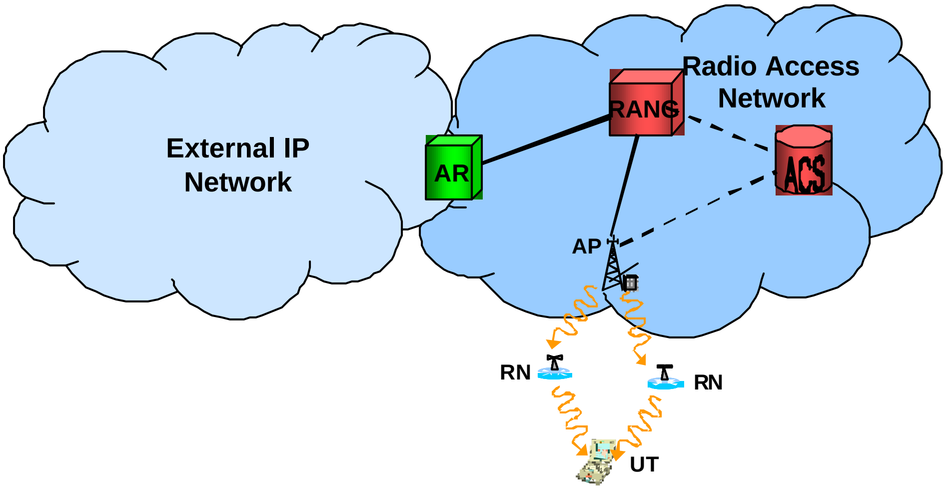

Figure 1-1: Logical nodes

User Terminal Logical Node (UT$_{\mathrm{LN}}$) is a logical node comprising all functionality necessary for it to communicate directly with another UT or the network.

Access Point Logical Node (AP$_{\mathrm{LN}}$) is a logical node terminating the transport network layer protocols on the network side as well as mode specific radio protocols on the UT side.

Radio Access Network Gateway Logical Node (RANG$_{\mathrm{LN}}$) is a logical network node terminating the data link layer. It terminates generic data link layer user plane protocols.

Access Router Logical Node (AR$_{\mathrm{LN}}$) is a logical IP layer node that performs the tasks attributed to an Access Router as defined in relevant IETF specifications.

Relay Node Logical Node (RN$_{\mathrm{LN}}$) is a logical network node with relaying capabilities that is wirelessly connected to an AP$_{\mathrm{LN}}$, UT$_{\mathrm{LN}}$ or another RN$_{\mathrm{LN}}$. Hence, one major difference to an AP$_{\mathrm{LN}}$ is that it does not terminate the transport network layer protocols. In many cases this classification is not sufficient and the RN$_{\mathrm{LN}}$ may need to be further partitioned, e.g. depending on whether it is mobile or not (i.e. classified as a

Fixed Relay Node (FRN_{LN}) or Mobile Relay Node (MRN_{LN})) or on what layer it is performing forwarding on (e.g. classified as a RN with layer 3 routing capabilities ($RN_{3,LN}$)). The number of necessary logical RNs is not currently known and is left for future work. In the remainder of this section the more detailed partitioning will be used only in those cases where it is deemed necessary.

Access Control Server Logical Node (ACS_{LN}) is a logical network node that controls the access to the radio interface resources. It terminates generic control plane protocols.[1]

Consequently, the radio interface is, on the network side, terminated in the ACS_{LN} and in the $RANG_{LN}$.

The subsections below further explain the roles, functions and interfaces of the different nodes.

Note that as the definition of the WINNER system and related protocols progress refinement of the above definitions is likely. The aim of the above definitions is to afford the nodes a distinct identity.

1.3 Functional Description of Logical Network Elements

1.3.1 Radio Access Gateway ($RANG_{LN}$)

The Radio Access Network Gateway Logical Node ($RANG_{LN}$) is responsible for data link layer termination and performs e2e ARQ. The $RANG_{LN}$ routes data to and from the respective APs where UEs are located thereby dealing with user mobility.

Note: Need for policy enforcement and charging data collection in the $RANG_{LN}$ are for further studies.

1.3.2 Access Control Server (ACS_{LN})

The Access Control Server (ACS_{LN}) is a network node that controls the access to the radio interface resources. It therefore terminates generic control plane protocols. The ACS_{LN} is responsible for AP configuration and ensures that AP's, with overlapping coverage areas are assigned orthogonal resources. I.e., the RRM ensures and controls the spatial re-use of the transmission resource between different APs.

Furthermore the ACS_{LN} is in charge of synchronising APs attached to it in order to ensure that different portions of the RAN can be assigned orthogonal transmission resources. The level of synchronisation needed (i.e. frame-, slot, symbol, chip-level synchronisation) depends on the physical layer transmission scheme and is to be defined.

Handover between different Multi Hop clusters is also coordinated by the ACS_{LN} based on measurements, individual load and QoS situations etc.

1.3.3 Access Point (AP_{LN})

The AP_{LN} provides access to the fixed line part of the Radio Access Network (RAN) and is therefore connected to the backbone network by cable or via a feeder link.

On the air interface side it coordinates access to the transmission medium of UTs associated to the AP_{LN} in a centralized manner. In the downlink direction it performs routing of the user data for the whole data path including relay nodes, based on individual QoS constrains and respective information about mutual interference of connected relay nodes. In order not to interfere with other APs_{LN} or RNs, which use the same physical transmission resource, the AP_{LN} has a fixed channel configuration possibility over the backbone network (by the ACS) and configures associated RN based on this information.

The overall network load is controlled by an Admission Control (AC) function in the AP which controls the load by rejecting resource requests in case of excessively high loads. Handover control of UTs between AP_{LN} and relays or between relays belonging to the same Multi Hop cluster is maintained by the AP_{LN}.

1.3.4 Bridging Relay Node (BRN_{LN})

The BRN_{LN} relays data traffic to/from UTs. The BRN_{LN} transmit resource is configured by the AP and may be changed based on the individual interference and load conditions.

Note: The BRN_{LN} is a logical node only. Physical network elements shall always be fixed or mobile. Please use FBRN (fixed bridging relay node) or MBRN (mobile bridging relay node) depending on the mobility of the node.

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[1] N.B. certain generic control plane functions may also be allocated to the $RANG_{LN}$ and/or AP_{LN} under the supervision of the ACS_{LN} (see [1]).

1.3.5 Routing Relay Node (RRN$_{LN}$)

The RRN$_{LN}$ relays data traffic to/from UTs. The RRN$_{LN}$ transmit resource is configured by the AP and may be changed based on the individual interference and load conditions.

Note: The RRN$_{LN}$ is a logical node only. Physical network elements shall always be fixed or mobile. Physical network elements shall always be fixed or mobile Please use FRRN (fixed routing relay node) or MRRN (mobile routing relay node) depending on the mobility of the node.

1.3.6 User Terminal (UT$_{LN}$)

UTs$_{LN}$ are subscriber owned devices which terminate the multi-hop connections. Their access to the transmission medium is controlled either by the AP's, or the relay which they are attached to.

2. WINNER Scenarios

2.1 Basic Deployment Scenarios

Table 2-1 WINNER High-level deployment scenarios

	Name	Coverage	#	Propagation Conditions	Mobility	Traffic Density (Indicative)
Scenario A	In and around building	Localised and non-ubiquitous coverage	A.1	Indoor	0-5 km/h	[High]
			A.2	Indoor to outdoor		
Scenario B	Hot Spot/Area	Area wide but non-ubiquitous coverage	B.1	Typical Urban	0-70 km/h	[High]
			B.2	Bad Urban		
			B.3	Indoor	0-5 km/h	
			B.4	Outdoor to Indoor		
			B.5	LOS – Stationary	0 km/h	[High]
Scenario C	Metropolitan	Ubiquitous coverage	C.1	Suburban	0-70 km/h	[Medium]
			C.2	Typical Urban		[Medium]/[High]
			C.3	Bad urban		
			C.4	Outdoor to Indoor		[Low]-[High]
			C.5	LOS – Stationary	0 km/h	[Low]/[Medium]
Scenario D	Rural	Ubiquitous coverage	D.1	Rural	0-200 km/h	[Low]
			D.2	LOS – Moving Networks	0-300 km/h	[High]

2.2 Related WINNER Test Configurations

Table 2-2: WINNER test configurations

	A.1	B.1	C.2	D.1	D.2
Max. Speed	3 km/h	5 km/h	60 km/h	120 km/h	
Mean Speed		3 km/h	60 km/h	120 km/h	
Standard Deviation		0.3 km/	0 km/h	0	
Min. Speed		0 km/h	60 km/h	120 km/h	
User Device Classes (cf. Sec.8.1)	Class 2	Class 2	Class 2	Class 2	
User distribution	Uniform	Uniform	Uniform; In the central 10% of the simulated area the user density is 5 times higher than in the remaining area	Uniform	
Max. RAP Tx power	1 W	4 W	20 W	20 W	
Max. UT Tx power	1 W	4 W	20 W	20 W	

Carrier Frequency	5 GHz	5 GHz	5 GHz	5 GHz	5 GHz
Propagation Model (cf. Sec.8.2)	Model 1	Model 2	Model 3		
Min Delay					
Max Throughput					

3. Fixed Relay Concepts

This section lists a number of fixed relay-based concepts. It aims to list concepts that have been proposed in previous deliverables for WP3 i.e. [1] and [2]. In the first part a concept on hierarchical PmP multi-hop relaying is presented. This is a simplified Hierarchical PmP topology, obtained by combining a linear deployment of Relay Nodes (RN), from a logical viewpoint, along different branches and PmP last hop connections towards the UT around each RN. The proposed structure is studied in the context of the standard IEEE 802.16. It specifies two operation modes, PmP and Mesh. The PmP mode has been specified for single-hop communication while the Mesh mode supports multi-hop communications. Results are also presented. Another section addresses the concept of a centralized MAC architecture known as the “TDMA clustering” concept. In this concept relaying is based on MAC frame by frame relaying. An analytical performance investigation in the Manhattan scenario and comparison with a Single hop approach is addressed. However, at this point only a short summary is included. For more information for the concept and the results please refer to [1] and [2] respectively. The concept of Movable relays (or alternatively named as Temporarily Fixed Relays) is also shortly described. It addressed issues related to user/usage and challenges/requirements that movable relays should be able to cope with. Another section is dedicated on heterogeneous relays. This section deals with the description of heterogeneous relay concept focused on the conversion modes, the resource-scheduling problem and the frame structure problem for the operation of this kind of deployment concept. The heterogeneous relaying deployment concept described here is centred on the case of two hops (BS-RN and RN-UT links) and using the feeder link mode (duplexing scheme TDD) for the BS-RN connection. Finally, the section on fixed relaying concepts ends with the harmonization part. This work was started in D3.2 [2] where a first general classification of Deployment Concepts was introduced. The basic classification in D3.2 is kept in this deliverable and focuses on the "Fixed Relaying" category in this section. It has been agreed that the basic logical topology is a discriminating variable that allows a more effective way of classifying the concepts. Therefore, the Fixed Relay Deployment Concept will be clustered in the **Hierarchical PmP** and **Mesh** as the main categories in this document., which is actually addressed in that section. As part of this analysis, a section is also dedicated on the mesh approach. This approach relies on the possibility of relaying the information between the nodes to increase to overall system performance. The primary results released in the first two deliverables [1], [2] have indeed showed the applicability as well as the efficiency of the mesh techniques for the attainment of the WINNER goals.

3.1 Simplified Hierarchical PmP Multi-Hop Relaying

In this section, an example of Deployment Concept has been chosen to represent the "Fixed Multi-Hop Relaying".

The reported example is referred to an activity which is still ongoing. However, some results of the simulation-based analyses that have been carried out on this concept are reported in this section (in addition to the Deployment Concept description and to a qualitative investigation of its positioning with respect to WINNER scenarios), in order to allow a first concept validation.

The considered Deployment Concept is defined as "**Simplified Hierarchical PmP Multi-Hop Relaying"**, in that it belongs to the general category of Hierarchical PmP concepts (for the definition of the category see Section 3.5) moreover, it is based on the combination of PmP and Multi-Hop concepts.

The considered Deployment Concept can be in principle based on different methods for discrimination of Multi-Hop and Last-Hop connections, by Time-domain, or Combined Time-Frequency domain, or Combined Space-Time-Frequency domain based relaying.

A specific investigation is reported in the following sub-sections on the option of Combined Time and Frequency Domain based relaying, that is considered sufficiently realistic and significant.

3.1.1 Description of the Network Deployment Concept Example

As anticipated in the introduction, the considered "**Simplified Hierarchical PmP Multi-Hop Relaying**" Deployment Concept is characterized by the following aspects.

- Simplified Hierarchical PmP topology, obtained by combining a linear deployment of Relay Nodes (RN), from a logical viewpoint, along different branches; and PmP last hop connections towards the UT around each RN.

  It is simplified, with respect to a generic hierarchical PmP model, in that the connection pattern to be handled by each RN is limited by the constraint that each RN is connected to two other RNs at most. On the other hand, several RN can be connected to the Base Station (BS), originating several branches (four linear branches are considered in this example). A multiplicity of terminals (UT) can be handled by each RN in the last-hop.

  Therefore, this example is studied as a good trade-off between the limitations of two-hops relaying and the complexity of more general hierarchical PmP structures.

  Moreover, the logical topology here considered can represent a wide variety of physical deployments, taking into account that the linear displacement of RN is only a logical requirement, not a physical one.

- The multi-hop traffic is transmitted between one BS, which is connected to a fixed backbone network, and fixed relay nodes (RNs). The last hop traffic, takes place between the RN and a variable number of user terminals.

- Discrimination between Multi-Hop and Last-Hop links is performed in the Frequency domain. More specifically, in the reported example it is assumed to use two frequencies: one is reserved for BS to RN and RN to RN (i.e., multi-hop links); one is used for the Last Hop link between RN and UT. The latter frequency is "reused" for all the "last-hop" area around each RN. The time domain is used for discriminating between uplink and downlink (TDD).

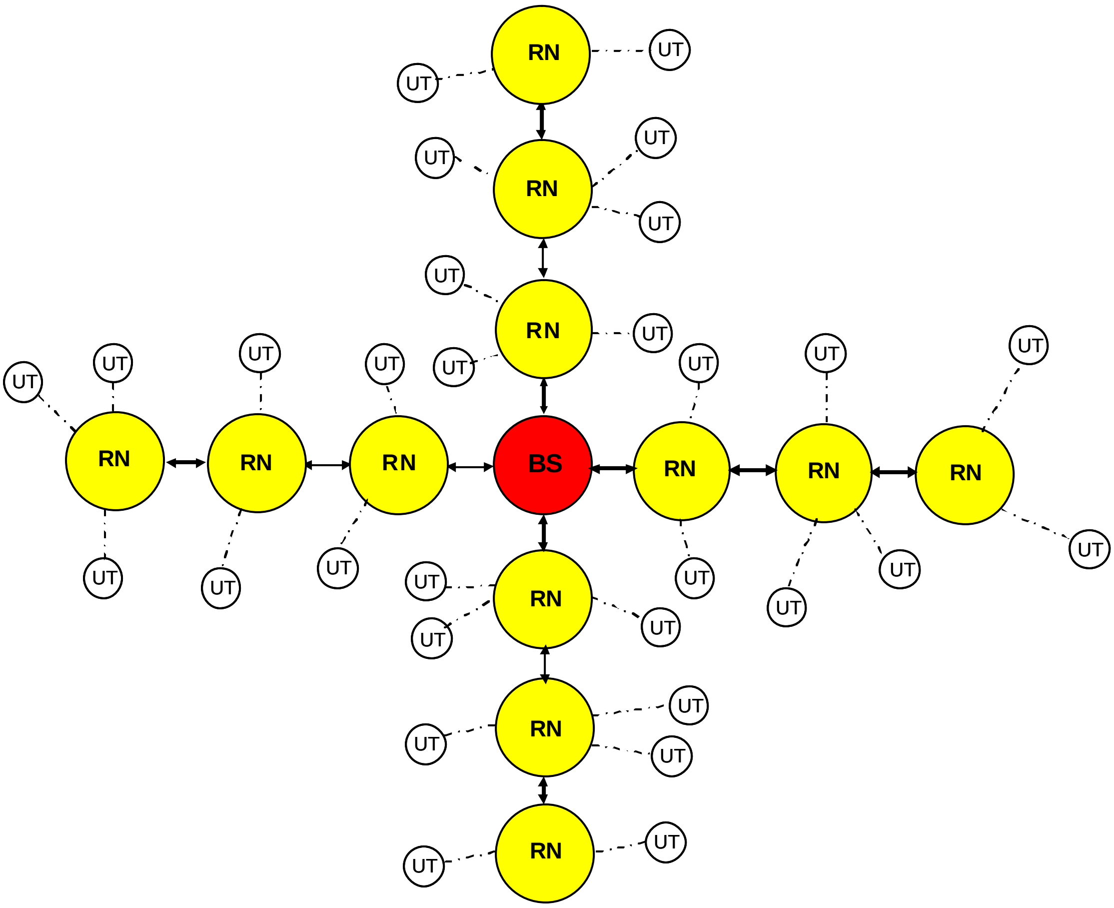


Figure 3-1: Simplified hierarchical PmP multi-hop relaying concept

3.1.2 Performance Evaluations

In order to have a realistic basis for specific simulation based studies, the proposed structure is studied in the context of the standard IEEE 802.16-2004, being this one a promising standards where protocol elements are defined, worth of being considered when designing a new 4G air-interface.

It specifies two operation modes, PmP and Mesh. The PmP mode has been specified for single-hop communication while the Mesh mode supports multi-hop communications.

Therefore, the approach of using combined PmP and Mesh operation modes is adopted, to support the topology depicted in Figure 3-1.

The end-to-end delay is affected in a different manner by data transmission on the multi-hop and single-hop topology. Therefore, algorithms for reducing the delay are individually designed.

The performance comparison among developed schemes is presented by means of event-driven simulations. The IEEE 802.16 MAC protocol has been implemented in ns-2 tool [3]. Simulation results are obtained assuming the system parameters reported in Table 3-1 [3].

In summary, the Mesh air-interface is applied as efficient multi-hop communication link between the BS and fixed RNs and between fixed RNs with a limited number of hops [4]. Hence, the Mesh mode efficiently supports multi-hop communications, which is one key feature of the WINNER air-interface. A centralized scheduling for the mesh mode has been chosen because it has been demonstrated to outperform distributed scheduling in multi-hop scenario; in particular, the efficiency gap increases with the number of hops [5].

Several User Terminals (UTs) shall be served by one RN. For this purpose, the PMP air-interface is applied on the last hop towards the UT, since it performs quite well for many single-hop connections with dynamic resource allocation demands [2].

Table 3-1: System parameters.

Parameter	Variable	Value
FFT size	N_{FFT}	256
Number of data sub-carriers	N_{SD}	192
Frame duration	T_{FRAME}	10 ms
Total channel bandwidth	BW	20 MHz
Channel bandwidth for PMP	BW_{PMP}	10 MHz
Channel bandwidth for Mesh	BW_{Mesh}	10 MHz
Ratio between the cyclic prefix and the useful time	G	1/4
Ratio between the sampling frequency and the BW	n	57/50
Useful symbol time	T_b	22*(146/357) µs
Number of bandwidth request opportunities	N_{BR}	10
Number of initial ranging opportunities	N_{RNG}	4

$T_{symbols}$ is the duration of the OFDM symbol that depends on the chosen OFDM parameters and the channel bandwidth BW.

PmP and Mesh share a total bandwidth of 20 MHz. The cooperation between heterogeneous air-interfaces is performed in Frequency Division mode, therefore 10 MHz bands are assigned to PmP and Mesh respectively.

3.1.2.1 Protocols for Point-to-Multi-Point Areas

The uplink traffic delay on the PmP air-interface for different number of active UTs is shown in Figure 3-2. . The load is defined as the sum of data rates offered from UTs divided by the supported data rate of the PMP air-interface Obviously, the delay for downlink traffic is below one T_{FRAME} if the offered load is below the system capacity.

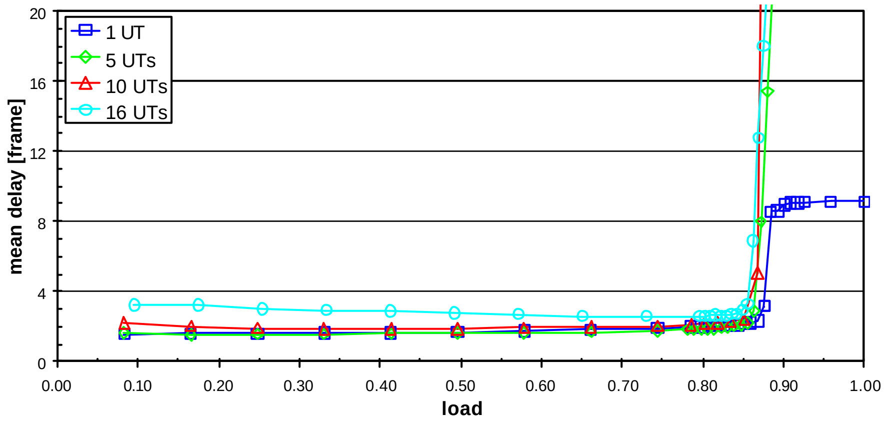


Figure 3-2: Uplink end-to-end delay on the PmP air-interface

We can observe that, for low load, increasing the number of active user terminals (UTs), the delay increases. In order to understand the reasons of this poor performance the probability that a bandwidth request message collides is shown in Figure 3-3 for a number of active UTs equal to 5 and 16. Requests for resource allocation change may come as a stand-alone bandwidth request message or it may come as a piggyback request. The first is used by UTs both to decrease or increase the actual resource allocation, while the piggyback message is only incremental. We can see that the collision probability increases according to the number of active UTs since more terminals access the limited number of bandwith request opportunities. Moreover, the collision probability (or equivalently the number of bandwidth request messages) decreases when the load increases.

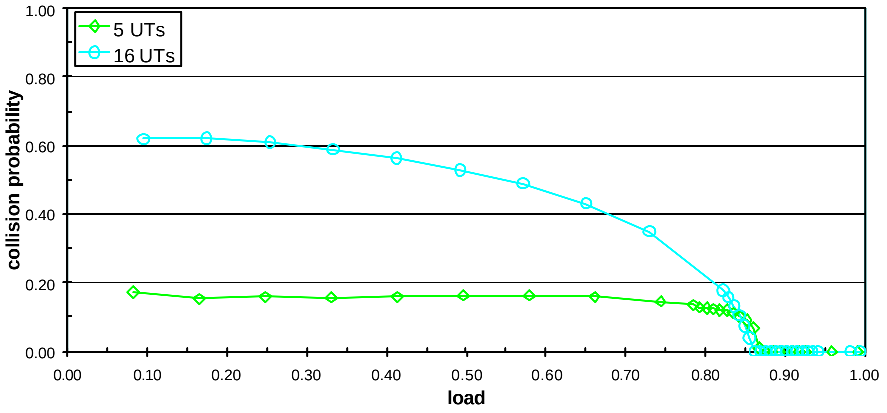


Figure 3-3: Collision probability of bandwidth request messages

The following strategy can be adopted in order to reduce the delay increase due to the number of collisions at low load.

- **Min Booking**

The UT keeps a minimum resource allocation for a time interval longer than one T_{FRAME}. The request sent from the UT is not equal to 0 even if the queue is empty. However, the allocation is released after a certain number of frames that can be tuned based on traffic characterization. In Figure 3-4 we can see that the protocol is fair for every traffic load.

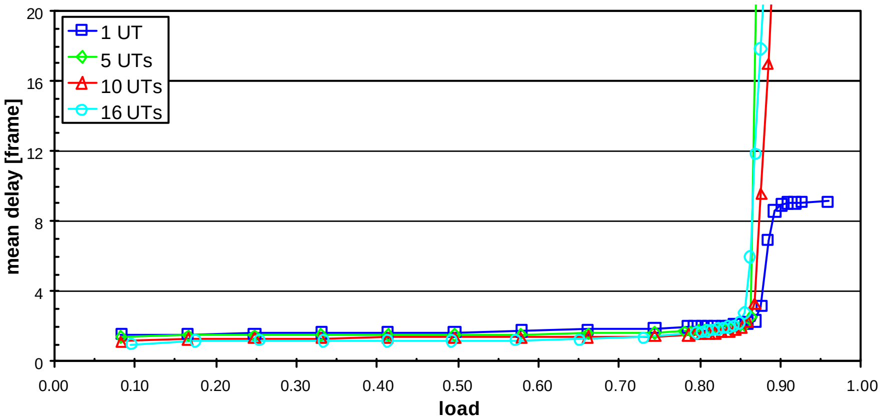


Figure 3-4: Uplink delay on PmP air-interface with Min Booking

Request algorithms based on the number of packets in the queue do not take into account traffic dynamics. Therefore, we can design strategies that reduce this effect.

- **Over Providing**

The effect of traffic dynamics on the delay becomes smooth assigning more resources, if available, to active connections both in downlink and uplink direction. Of course, this strategy can improve performance only if the load is below the system capacity, as shown in Figure 3-5.

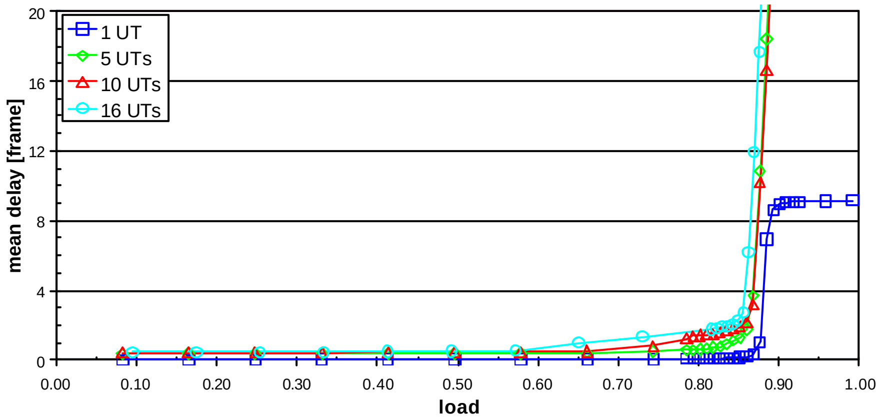


Figure 3-5: Uplink delay on PmP air-interface with Min Booking and Over Providing

3.1.2.2 Protocols for Mesh Network

In Figure 3-6 and Figure 3-7 the delay on Mesh air-interface with Min Booking is presented for different number of hops. The load is defined as the sum of data rates offered at RNs and BS divided by the supported data rate of the Mesh air-interface. Simulation results are obtained considering a linear topology. In the scenario depicted in Figure 3-1, the saturation point only shifts towards a lower load since the topology is symmetric with respect to the BS.

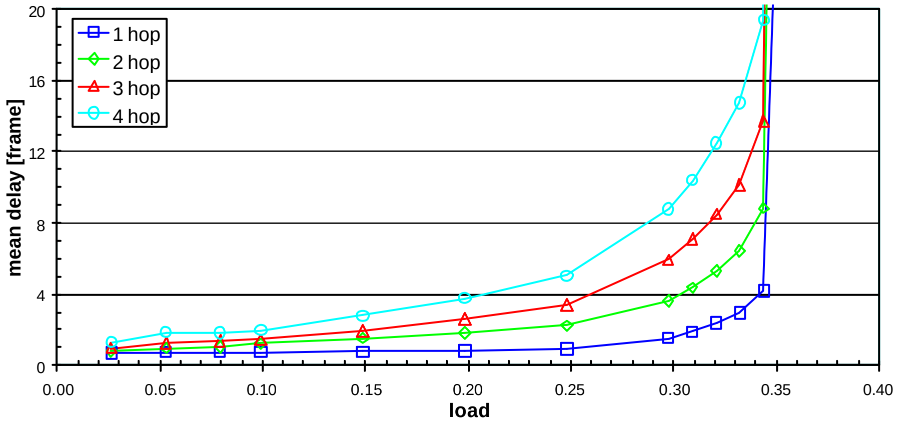


Figure 3-6: Downlink delay on Mesh air-interface with Min Booking

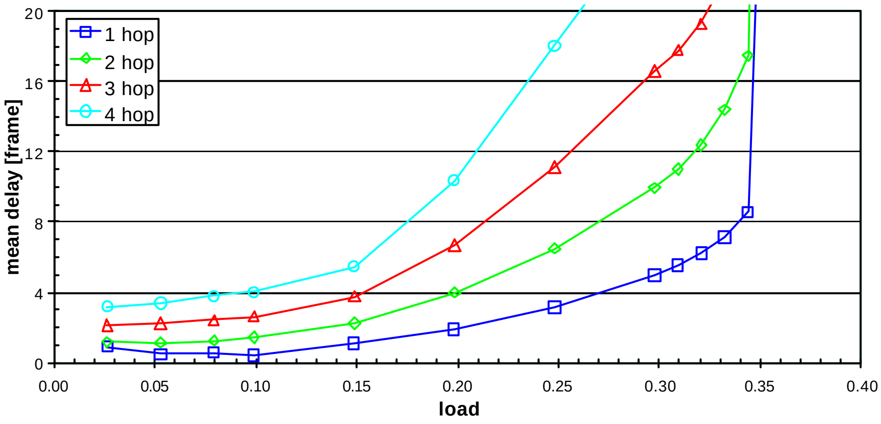


Figure 3-7: Uplink delay on Mesh air-interface with Min Booking

- **Connection-based Scheduling**

In this section a scheduling strategy is proposed in order to reduce the delay on the multi-hop topology. The request is computed in the terminals to require resources for data transmission. The request can be computed on the end-to-end connection instead of only the next link towards the destination. For instance, focusing on the uplink connection between UT 2 and BS, the request sent from UT 2 contains resource requests not only for the next hop but also for each link towards the destination, as shown in Figure 3-8. Therefore, UT 2 set up an uplink request both on the link 2 ($R_{2,2}$) and link 1 ($R_{2,1}$). The resource allocation provided by the BS is computed in the UTs using the same algorithm.

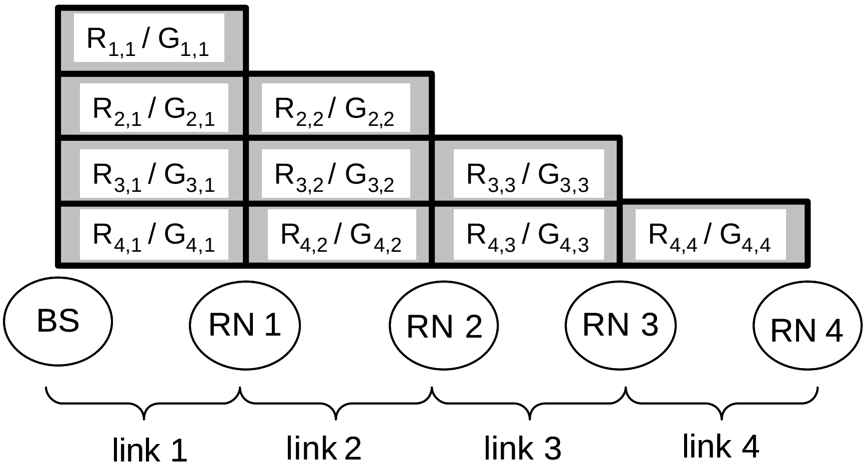


Figure 3-8: Connection based request and allocation mechanism

$R_{i,j}$ and $G_{i,j}$ are respectively the request and grant on link j for the connection (uplink and/or downlink) between the BS and the UT i.

The order of data transmission for downlink and uplink traffic is shown in **Figure 3-9**. This approach is similar to the Alternating Scheduling within 2 frames presented in [6]. Portions of the Data sub-frame are assigned to the terminals according to topology. Within the portion assigned to the downlink traffic a terminal that is closer to the BS is served before than one more apart from the BS. On the contrary, within the portion assigned to the uplink traffic, the reverse order is applied. Adopting this approach, packets wait for being transmitted only in the source nodes and not in the forwarding nodes. Therefore, they are delivered to the destination in one frame once they are sent from the source.

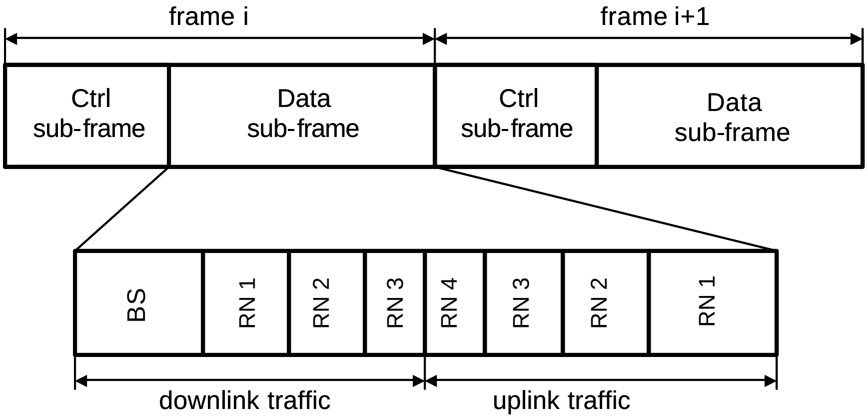


Figure 3-9: Data transmission order within the Data sub-frame

In the following Figure 3-10 and Figure 3-11 delays with Connection based Scheduling are presented for downlink and uplink communications respectively. The delay is remarkably decreased below one T_{FRAME} in downlink and 2 T_{FRAME} in uplink.

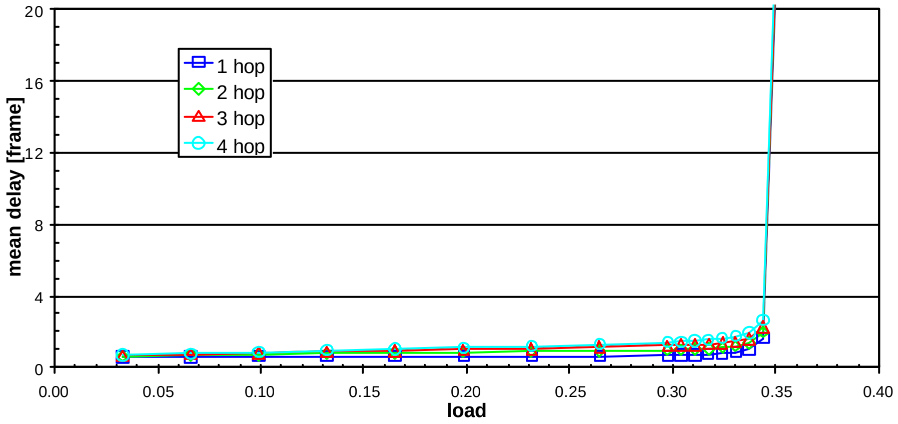


Figure 3-10: Downlink delay on MESH air-interface with connection based scheduling

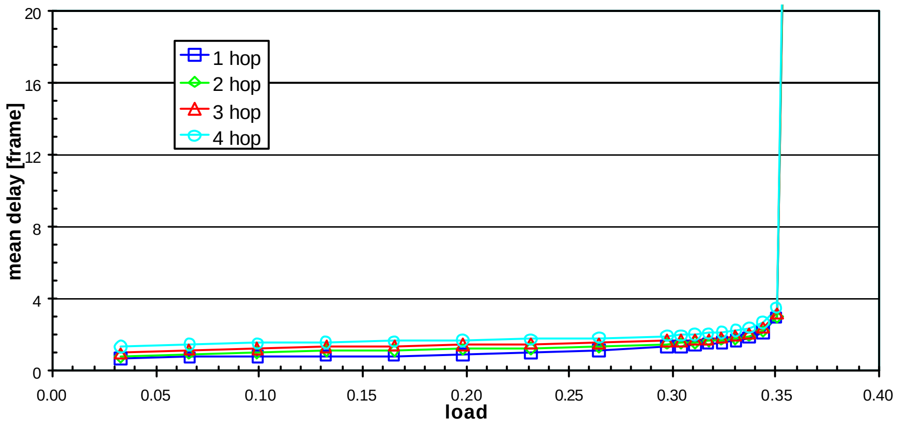


Figure 3-11: Uplink delay on MESH air-interface with connection based scheduling.

3.1.3 Concluding Remarks

In the previous sub-sections, the delay over hybrid multi-hop wireless network has been investigated. To reduce the end-to-end delay, the contribution introduced by every air-interface has to be separately considered. By means of event driven simulator implemented in ns-2 tool, it has been shown that proposed resource request and allocation strategies can reduce the end-to-end delay.

Future works will consist of evaluating the end-to-end throughput and the overall system capacity. Moreover, performance evaluation will be performed assuming a realistic channel model.

A final general remark should highlight the possible extensions of the presented concept. Although a specific simulation based study has been carried out on the "Time and Frequency domain based" relaying, the "Simplified Hierarchical PmP multi-hop relaying" can be in principle deployed in several different ways, by exploiting different variables.

In particular, it could be conceived an OFDMA based relaying, where different sub-carriers are assigned to Multi-Hop and Last Hop connections. In this case, a good trade off between increased complexity and enhanced flexibility in bandwidth assignment should be found [2].

Another important enhancement could be the use of the spatial dimension, even in its simplest form: i.e., the use of directional antennas between the BS and the surrounding RN. In this way, each branch would be allowed to use the entire capacity of the frequency assigned to the multi-hop connections.

3.1.4 Applicability to Main WINNER Scenarios

Table 3-2 Applicability of the concept to the main WINNER scenarios

	A.1 (Indoor)	**B.1** (Hot Area)	**C.2** (Wide area)	**D.1** (Rural)	**B.5** (LOS Feeder)
SIMPLIFIED HIERARCHICAL PMP MULTI-HOP		**X**	**X**	**(X)**	

3.1.4.1 Scenario C.2. Wide Area (Ubiquitous Coverage), Typical Urban

This seems to be the main application scenario for this Deployment Concept.

In fact, this Deployment Concept can be seen as an extension of the single-hop Manhattan concept (typically suited to this scenario), allowing increased flexibility for the operator coverage strategies. More specifically, instead of having just four RN surrounding a BS (resulting in a two-hop system), the considered topology allows a "linear extension" of the relay chain, and therefore it can be properly adapted to real cases in the wide variety of urban structures.

It should be recalled that the "logical topology structure" shown in Figure 3-1 can be deployed in many different ways from the physical viewpoint: given an arbitrary physical displacement of RN (allowing optimized coverage) these RN can be connected through the multi-linear logical topology depicted in Figure 3-1.

According to the needs, the coverage flexibility ensured by this Deployment Concept can be exploited either to guarantee ubiquitous coverage, or to optimally cover some specific areas (see scenario -B1).

3.1.4.2 Scenario B.1. Hot Area (Wide Area But Non-ubiquitous Coverage), Typical Urban

The main basic arguments reported in the previous section are still valid.

Therefore, even the scenario B1 can be considered relevant for this Deployment Concept.

In this case, the coverage flexibility allowed by this DC can be exploited in particular for optimally cover hot-zones (i.e., where traffic peaks are likely to be required).

For completeness, it is also noted that a non-ubiquitous coverage may be useful also for zones that are particularly difficult to be reached. In this case, this Deployment Concept may be applied in an additional and complementary way with respect to a traditional single-hop coverage.

3.1.4.3 Scenario D.1. Rural (Ubiquitous Coverage)

Under the assumption that RN are Network Elements owned by an operator, the rural ubiquitous scenario does not seem particularly relevant for this Deployment Concept. In fact, it is difficult to justify a full multi-hop deployment in large rural zones, with respect to traditional single-hop solutions (without excluding, obviously, that this can be true in particular cases).

A partial exploitation of this concept, in a rural zone, not ubiquitously, but additionally with respect to a ubiquitous single hop deployment, may be investigated too. It may be the case of low-density population zones included in completely non-populated territories; or wherever a severe lack of transmission infrastructure (backhauling for BS) is to be considered. Even in this case, however, it seems that the "wireless feeder solution" (i.e., exploiting wireless transmission technologies, but NOT in the multi-hop sense) seems to provide more attractive solutions.

However, if the scenario of privately owned RN is considered, the application of the Deployment Concept could become interesting even in the rural case. In this scenario, the fixed wireless terminals at the subscriber houses are enhanced to provide also Relaying functionalities; it is a case of combination of RN and UT functions in one physical network element. From a technical viewpoint, this is certainly an attractive application, altough it must be checked against regulatory issues, business model sustainability, acceptance by private customers, etc.

3.1.4.4 Scenario A.1. Indoor Hot-Spot

Not applicable

3.1.4.5 Scenario B.5. LOS Stationary Feeder for Hot Area

Not applicable

3.2 TDMA Clustering

3.2.1 Description and Analysis

A system concept with relaying capabilities has been proposed in D3.1. In this proposal a centralized MAC architecture is used that is known as “TDMA clustering” concept. One node per cluster, called Central Controller (CC), controls the collision free access to the medium of all the nodes within the cluster based on a Resource Request/Resource Grant method similar to 802.16a and Hiperlan. In this concept relaying is based on Mac frame by frame relaying. The CCs in one hop distance communicate directly with each other in a way that a CC behaves like a normal node in the neighbouring cluster (cf. Figure 3-12). Data that needs to be send to another CC is transmitted in the downlink resource of the sending CC to avoid unwanted interference. Each CC listens to the control channels of neighbouring CCs in order to notice data needs to be received. Data forwarding has been assumed to occur at Layer 3. A more detailed concept description can be found in D3.1 [1].

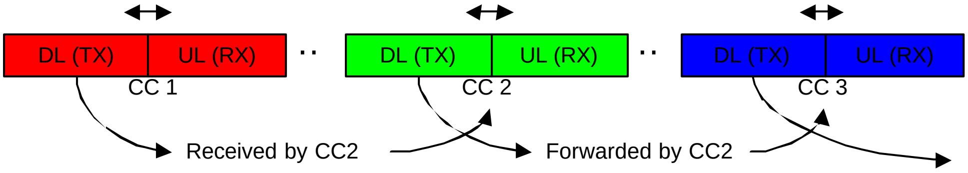


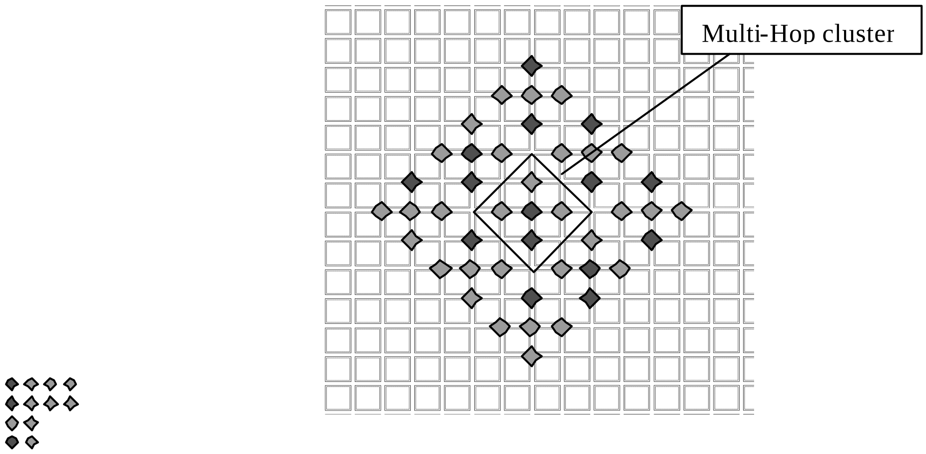
Figure 3-12: Forwarding concept

3.2.2 Performance Results

An analytical performance investigation in the Manhattan scenario and comparison with a Single hop approach was conducted in D3.2 [2]. It was found that the Multi hop approach yields twice the capacity of the Single Hop approach but requires 5 times as many network elements. Please refer to D3.2 for a detailed description of the investigation.

3.2.3 Applicability to Main WINNER Scenarios

A deployment based on this concept in a Manhattan structure relevant for WINNER scenario B.1 was introduced within the performance investigation in D3.2 (cf. Figure 3-13). This deployment makes use of the regular Manhattan structure ensuring LOS conditions on UT to RN/AP and RN to AP links. For cost reasons and simplicity only omni-directional antennas have been used. The number of hops was selected to be two; hence one relay was maximal involved in user data transfer. The applicability for scenarios A.1, C.1 and D.1 has not been investigated so far. It is expected that the area addressed by scenario C.1 could be covered with a similar deployment as used in B.1 although a hexagonal cellular structure is assumed in this scenario, which might not be feasible depending on the constraints that may arise if the system is deployed in the 5GHz band.



Reuse cluster scheme

Multi Hop Deployment

Figure 3-13: Multi-hop deployment in Manhatten scenario

3.3 Movable Relays/Temporarily Fixed Relays

3.3.1 Introduction

The term “Movable” defines the “opportunity” of a relay to “be moved”. In that sense, movable relays can be defined as those relays that “can” be moved from one place/location to another based on the needs to cover. Effectively, the word defines more a kind of “Ad Hoc” use of those relays (upon our discretion), rather than the fact that during the time that they are functioning they *might* move. Under this approach, initially two concepts were defined. [1]

- Relays that are mobile, but for a long period of time are stationary which effectively diminishes the “mobility” dimension and means that mobility related functionalities can be “temporarily” stopped/ceased and
- Relays that are always stationary when functioning but can be used in multiple occasions e.g. geographical locations/deployment cases.

Out of the two, as long as the first type can be considered as a mobile relay which for a long time is stationary, then the second type actually “qualifies” as a movable relay. Thus, in terms of “actual” functionalities it is effectively a fixed relay. Another term which can be used interchangeably for movable relays is that of “temporarily fixed relays”. Movable relays effectively address the reusability in multiple occasions/locations based on the user’s (e.g. person, company) discretion.

3.3.2 Description of Concept of Movable Relays

Some of the “usage” cases that movable relays could be used are to provide coverage in residential areas, conference locations, tourist attractions, football grounds, accident scenes or in other similar events. They effectively cover a plurality of types of areas like indoors, hot spots, wide area and possibly rural areas. The above classification addresses another dimension, closely related to the usage cases, that of “ownership”. With this term we define the group/owner which can make use of the relay. Specifically, the main examples are the following

- Network Operators →Coverage when requested by others e.g. exhibitions etc
- Every day users →Coverage in back garden
- Organisations/Companies →Coverage within their premises for conferences.

The above short analysis shows that movable relays would be required to cover diverse types of needs. Those needs crystallise in the following group of requirements for support of

- Multiple legacy and future RATs/Systems e.g. UMTS/GSM/WLAN/WINNER-based
- Multiple Environments e.g. Urban (bad, typical), Metropolitan (Manhattan scenario, other)
- Multiple applications: High/Low data rates

- "Channel" characteristics e.g. cope with LOS/NLOS, Shadowing
- Types of traffic e.g. Voice/Data
- Needs: Coverage Vs Capacity
- Services: Multicast/Broadcast Vs Unicast
- Coverage e.g. different areas from 50m to 500 meters
- Heterogeneity. E.g. BS-Movable_Relay link: RAT1 and Movable_Relay-UT link: RAT2

The above can be portrayed in the next Figure 3-14.

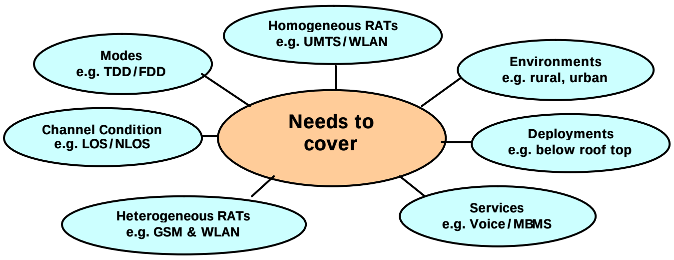


Figure 3-14: Needs to be covered/requirements for movable relays

3.3.3 Applicability to Main WINNER Scenarios

The applicability of Temporarily Fixed Relays (TFR) is shown in the next table:

Table 3-3 Applicability of movable /temporarily fixed relays to WINNER scenarios

	A.1 (Indoor)	**B.1** (Hot Area)	**C.2** (Wide area)	**D.1** (Rural)	**B.5** (LOS Feeder)	**Notes & Characteristics**
Temporarily Fixed Relays (Movable Relays)	XXX	XXX	XX	X		

Comment: The number of "X" define the higher level of the applicability to those scenarios.

The main comments based on the previous Table 3-3 are the following

- If TFR are cheap to build then they could be used to provide indoors coverage and could be commercially available to simple users/companies
- More complex movable relays could additionally target hot spots /wide area deployments. However, issues of power Tx, interference etc should be taken into account
- For rural areas, movable relays do not seem at this point such an attractive solution for two main reasons. The larger the area to cover the more probable that these scenarios can be covered by fixed relays. Additionally issues, with reference to Tx power and interference could imply that only operators can actually perform the deployment, which in the end, might mean that fixed relays could be deployed instead of movable relays to cover those needs or that that number of deployed movable relays will be very low.

The main thing is that the larger the area to cover is, the higher the need is for proper dimensioning/planning. Thus, as long as it is envisaged that movable relays could be used by non experts, then either they need to have incorporated mechanisms (along with similar mechanism in the other parts of the network e.g. BS) to cope with in-perfect/not ideal deployment of those relays or to limit their coverage, which inevitably makes them a more attractive option for indoors/hotspots/ areas.

3.3.4 Conclusion

Movable relays are an intermediate concept to those of fixed and mobile relays. The main advantage is the possibility of users (i.e. people, companies, operators) to place them on a temporary basis in multiple locations, thus, reuse them in multiple occasions. As such, a number of issues should be evaluated in terms of applicability to many scenarios, coverage, complexity, along with a number of issues related to policy, regulatory if we go down the road of a more “mass market” commercial availability. Another interesting concept which could be investigated along with temporarily fixed relays is that of which concept would address quite handily the “reusability of those relays in multiple instances”

3.4 Heterogeneous Relaying

A heterogeneous relay node is a network element that is wirelessly connected to another relay node or a BS by means of a given radio access technology, and serves to another relay node or to a UT using a different radio access technology. The radio access technologies that a heterogeneous relay incorporates can be different physical layer modes of the same RAT (i.e. in the WINNER context), one WINNER RAT and another (possibly legacy) RAT, or two (legacy) RATs, where the latter is not inside the WINNER scope of research.

In the harmonization process, the fixed heterogeneous multi-hop deployment concepts constitute a new category that basically differs from homogeneous relaying concept in the fact that the multi-hop communication between a base station and a certain user terminal is composed by two or more segments, implemented by different wireless technologies. Besides, inside WINNER context the radio access technologies that a heterogeneous relay incorporates can be different modes of the common WINNER RAT (main focus of our research), or one particular mode of this RAT and another legacy RAT. The case of heterogeneous relay interworking two different current legacy RATs is not inside the WINNER scope of research, and so this last case is not contemplated at the moment. In the IST-STRIKE project [11] was already investigated the interworking mechanisms for two different standards, in particular, HiperMAN and HiperLAN/2.

It is important to note that the motivation for opening a new category for heterogeneous relaying concept is based on the use of different air interface modes, but not in the fact to exploit any other different domain for multi-hop purposes, of those which were before explained for the case of fixed homogeneous relays. So the deployment concepts previously described in the context of fixed homogeneous relaying and based on multi-hop exploiting different domains (i.e. time domain, combined time and frequency domain, and combined time, frequency and space domain), are also applicable for the heterogeneous relaying category.

The fixed heterogeneous relay should be considered as one separated concept, since it could itself require some class of functional harmonization between the different modes involved in the heterogeneous relay node (HERN). Therefore the heterogeneous concept has been included as a complementary category inside the major category called “Fixed Multi-Hop Deployment Concepts”. However it should be noted that the protocol functions and elements used by a HERN are not different to those used for the homogeneous case working in a certain mode. The distinctive aspect is that the HERN has to coordinate the two modes involved in its operation. In this way, the multi-mode protocol architecture reference model, which is currently being developed in WINNER, facilitates transition and coexistence of different modes, thanks to the separation of the protocol into generic and specific parts, enabling this way a protocol stack for multiple modes in an efficient way. The management and complete handling of the protocol stack operation in different modes, will be performed by means of the Stack Management, as was explained in D3.2 [2]. When different modes are involved, like in the case of a HERN, a Cross Stack Management will be needed through the use probably of a Stack Modes Convergence Manager (Stack-MCM), which controls the management functionally in the respective protocol layers in a hierarchical manner.

Summarizing, this section deals with the description and analysis of heterogeneous relay concept focused on the applicability to the main WINNER scenarios, the simulation results showing its feasibility, the resource-scheduling problem and the frame structure problem for the operation of this kind of deployment concept. In the Annex 9.2 it is also included a brief description of the functionality for modes conversion as well as the mapping of protocol functions for this network deployment to the WINNER multi-mode architecture.

It should be remarked that so far, modes in WINNER project have been defined as a synonym for adaptation of the system to different application scenarios, radio environments, spectrum bands, etc. Besides a system mode is a combination of physical layer mode and deployment concept (SH, MH or P2P). Each system mode should serve a specific clear purpose.

3.4.1 Assumptions

For the description of deployment concept based on multi-hop using heterogeneous relaying, the following assumptions are applicable:

- In a two hop scenario the heterogeneous RN (HERN) is always connected to BS.
- The mode connecting the HERN with the BS or another HERN is further denoted in this document as F1 mode, that is, a particular WINNER mode specifically though for feeding wirelessly the RNs.
- In order to achieve a high re-use of frequency in the BS-RN link, it is assumed in some cases to use beamforming and high directive antennas whenever line of sight conditions can be assured. This way, it is possible to exploit also the space domain at least for the connection between the BS and the heterogeneous relay nodes dependent of it.
- Due to the stationary characteristics of the BS-RN link along with the use of a mode specifically thought for this purpose (with different characteristics to the RN/BS-UT link), some kind of advanced relaying concept with optimised BS-RN link is envisioned. In other words, the heterogeneous relaying deployment concept will allow a best exploitation of the static link between the BS and the fixed RN by using a physical layer mode tailored for the static link conditions, and by using more advanced antenna systems since fixed relay does not suffer from limited battery power or strict size constraints.

In the context of heterogeneous relaying, it is important to remark that initially it was thought to investigate the cooperative relaying concept using different air interfaces, and the opportunistic routing mechanism with different air interfaces. Nevertheless based on preliminary research it was decided to abandon the investigations of both concepts in the heterogeneous context.

Basically the discussion about cooperative relaying using different air interfaces shown that complexity does not seem to justify the benefits that we would achieve with heterogeneous cooperation. There were two main reasons, both related to complexity and difficulty of implementation, for abandoning this line of investigation.

1. Cooperative relaying calls for combining the transmissions from different nodes. In the context of heterogeneous air interface modes, this requires combining signals from different air interfaces or, more generally, combining signals of different physical layer modes (PLM). The arising complexity seems to be intolerably high as the receiving terminal must be able to simultaneously or consecutively synchronize, demodulate and detect two possibly fundamentally different air interfaces.
2. At the network level, the corresponding transmissions and receptions must be coordinated. This coordination in terms of routing, scheduling, and resource assignment already constitutes challenges for conventional store-and-forward relaying and homogeneous air interfaces. These should be tackled first, thereby eventually paving the way for cooperative relaying over heterogeneous interfaces.

Concerning the development of new novel routing schemes for heterogeneous relay nodes, due to the current definition of heterogeneous relaying that in some way blurs the difference between homogeneous and heterogeneous relaying, along with the current definition of modes (specific for one link type), it was discussed the possibility to perform MMPD (Multi Mode Path Diversity), or hardly even routing in its traditional meaning, since it is thought that the UT will always be associated with one RN (with some associated mode for UT communication) or one BS (with some associated mode for UT communication) at every point in time. Therefore routing and handover (especially in conjunction with mode selection) may be seen as somewhat overlapping, and then it has been decided to abandon this activity and concentrate all the efforts in the detailed description of deployment concepts concerning the heterogeneous relaying topic.

3.4.2 Deployment Concept Description and Analysis

This section describes and analyses the deployment concept based on multi-hop communications through heterogeneous RNs, using different WINNER physical layer modes. In particular the F1 mode is always used for the BS-RNs links, and two different alternatives are contemplated depending on the mode used for the last hop or communication between the HERN and its final users. This mode could be one of the used for short-range or one of the used for wide area. It would be possible even to add other dimension in this classification, if we contemplate the overlapping characteristic of coverage areas corresponding to the own BS and its associated heterogeneous relays.

The definition of modes is an ongoing process in WINNER. Therefore the descriptions are left out at this point and refer to WP7 work to be published.

3.4.2.1 Introduction

The heterogeneous relaying deployment concept described here is centred on the case of two hops (BS-RN and RN-UT links) and using the F1 mode (duplexing scheme TDD) specifically thought for the BS-RN connection. So the DL and UL phases of this connection use different time slots with the possibility to assign in asymmetric manner the slots depending on needs of each phase.

The fact to use two different modes in the heterogeneous logical nodes could allow us make independent the distribution problem of radio resources utilized by each of these modes. That is the availability of radio resources for the first mode (i.e. BS-RN link) does not depend on the radio resources used or available for the second mode (i.e. RN-UT link) and vice versa. However this would be true only for the case that mode used by the HERNs for serving its final users utilize a different frequency band to the assigned at the F1 mode. So far this mode shares band with the mode used for short-range, and then if the mode used by the HERNs for last hop is precisely the used for short-range, it should be necessary to discriminate between the resources allocated for the BS-HERNs links, and the used for the last hop (different mode but same frequency band, multiple access technique and duplexing scheme). Therefore for this case the discrimination will be based on the frequency domain (OFDMA), assigning a part of the sub-carriers for relaying purposes and another part of remaining sub-carriers for the communications of last hop. The most appropriate solution will be to distribute, in a dynamic way, the total available resources between each of these links in terms of their needs. Other important aspect is the possibility to re-use the same fraction of sub-carriers in the coverage areas associated to each HERN, assuming areas without overlapping, or re-use the same sub-carriers only for HERNs located in opposite places.

Similar reasoning we would have to do when the BS is using also the mode for short-range for serving directly to final users in its coverage area. Some fraction of the total sub-carriers used by all the modes devoted to short-range, should be dynamically assigned for this purpose depending on the resources required by the users directly connected to the BS.

In the current deployment concept it would be possible in principle to exploit the three kinds of domain previously explained for fixed homogeneous relaying concept, whenever some advanced antenna system be implemented such as beamforming or directive antennas. In this sense, if in the geographical area covered by this deployment concept, is not envisioned to use the TDD frequency band (modes for short-range) save for the F1 mode (BS-HERNs links), it could be contemplated the possibility to reuse the same radio resources for the communication between the BS and each one of its associated HERNs, although of course we should analyze carefully the insulation between antennas in the BS side in order to avoid coupling and interference problems. For other cases where, for instance, the BS and/or HERNs are using some of the modes dedicated to short-range for serving at final users, this possibility would be very risky and then it is not recommended. In this situation, it would be more appropriate to exploit the time domain or even the combined time and frequency domain.

Assuming always the use of F1 mode (TDD as duplex scheme) for the BS-RN link, , depending on that the mode used by the HERN for serving at final users be the devoted to short range (referred to as B1 and using TDD), or the devoted to wide area (referred to as A1 and using FDD), we may distinguish two different situations: one using the same duplex scheme (TDD-TDD) and the other one using different duplex schemes (TDD-FDD). At the same time depending on the mode used by BS for serving at final users in its coverage area, we may distinguish other two cases for each of the previous situations. In this way, Figure 3–15 illustrates for instance the two possibilities for the case of HERN using different duplex schemes (pure TDD and H-FDD). In the first one, the BS is working in the same mode used by the RN to give service at its final users, that is mode A1 (mode used for wide area). And in the second one, the BS is working in a different mode of the used by the RN, that is mode B1 (mode used for short range). Of course these are just examples and more scenarios may be envisioned. Half duplex FDD (H-FDD) here should be understood as the communication where the RN can transmit simultaneously in DL and UL, while the UTs served by RN have only the possibility to transmit or receive in a given interval of time. This way the terminal does not need to incorporate a duplexer for transmitting and receiving simultaneously, even only one local oscillator would be enough, and then it would be possible to decrease the costs, the hardware complexity and the power consumption of this element. However from a RN perspective, the fact to have to implement two different frequency bands, one for the TDD mode and another one for the FDD mode, as well as to have to transmit and receive at the same time, increase clearly the HW complexity of this kind of relay.

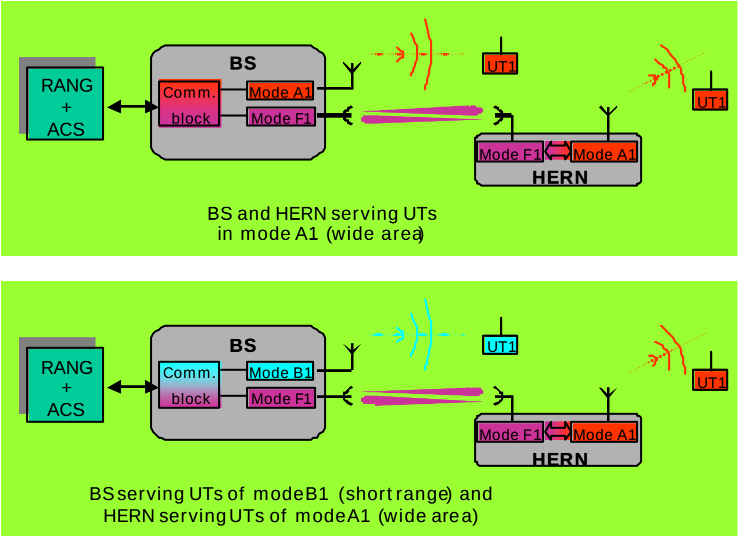


Figure 3–15: Two possible cases for heterogeneous RN using different modes with different duplexing scheme

Concerning the BS design, it should be noted in all the cases, the presence of a functional block referred to as “Communication and Signal Process Block”. The purpose of this part, in general terms, is to process the data coming from the transport network (RANG + ACS) through its corresponding interface, and deliver this processed data to the radio frequency part of the BS. Obviously, in the other direction this block has to perform the opposite process. In other words, this block performs the process relative to the communications between the BS and its controller. Though there are different possibilities to distribute the functionality of a BS between its own elements, to follow we list some of the functions to implement within the communication block.

- Multiplexing and de-multiplexing of the communication flows.
- Process of the signalling for the allocation of the RF channels to the traffic channels.
- Process of the information concerning to the Operation and Maintenance of the radio network.
- Ciphered and deciphering of the information. Also it is possible to implement these functions in the radio frequency block.

Of course, the final design of this block as well as its functionality ought to be harmonized with the current protocol architecture proposed in [1] and [2], as well as the scheduling architecture, which is currently being investigated in different work packages of the WINNER project.

For a concrete example of deployment concept composed by four HERNs, which are using the mode for short-range for serving final users, and considering the current idea proposed for this mode, of splitting in four time slots, both in DL and UL phases, one simple possibility would be to use every time slot for a given HERN (time domain), and inside to distribute dynamically the sub-carriers between the required for the BS-RN link and the final users served by this HERN (frequency domain). Besides the antennas of HERNs for the mode used for short-range could be omni-directional or sectorial, since the assigned sub-carriers for this mode are different to the used for the BS-HERN link and the allocated time slot does not coincide with the assigned to the rest of the relay nodes involved in this deployment concept. Figure 3–16 illustrates graphically this particular example where the assignment of time slots is fixed for each of the HERNs, and the allocation of radio resources (number of sub-carriers or set of chunks) in a given time slot is dynamically allocated between the BS-HERN link and the communications of this HERN with its respective UTs. It is assumed that the mode devoted to short-range is only used by the HERNs for serving at final users in their respective coverage areas, and the BS for serving at final users is using other mode, which utilize a different frequency band. If the BS is also using a mode in the same frequency band, then the total radio resources must be shared among all the links involved in this deployment. It would be possible also to think in a more flexible and effective distribution of time slots considering, in terms of needs, some asymmetry between DL and UL phases, even to assign more than one time slot for a given HERN during the same frame.

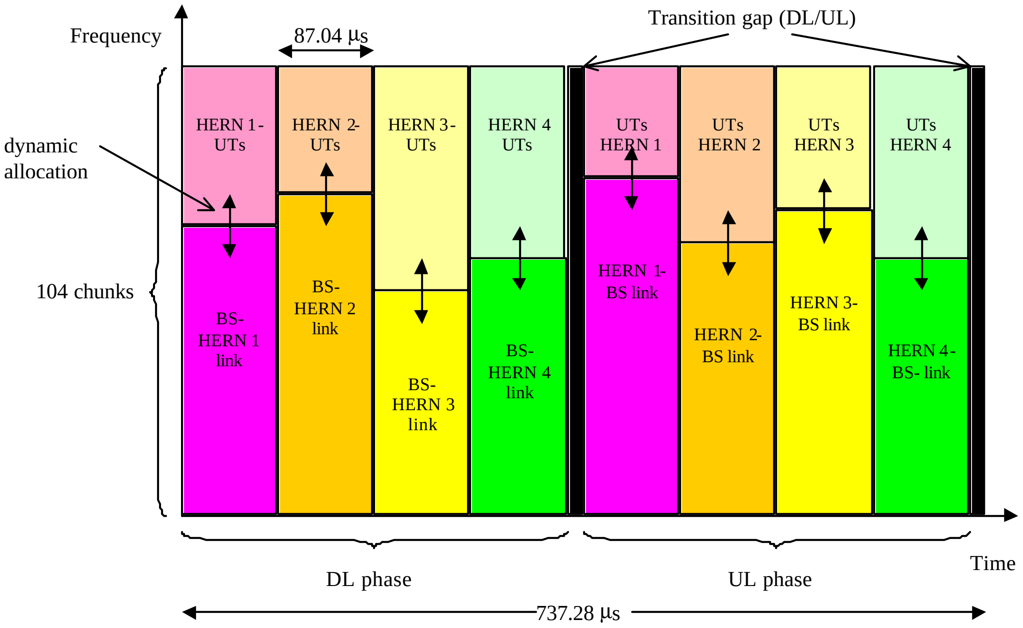


Figure 3–16: Exemplary time slots distribution and dynamic allocation of sub-carriers in a multi-hop deployment concept based on the use of 4 HERNs and TDD/OFDMA system

3.4.2.2 Mapping of Logical to Physical Network Elements

According to the network architecture proposed for WINNER system and explained in [1]and [2], the deployment concept included in this section is characterized by the use of heterogeneous RNs logical nodes. So, in general terms, the deployment concept based on HERNs would be composed by the Access Control Server Logical Node (ACS_{LN}), the Radio Access Network Gateway Logical Node ($RANG_{LN}$), the Base Station Logical Node (BS_{LN}), the HEterogeneous Relay Node Logical Node ($HERN_{LN}$), and the User Terminal Logical Node (UT_{LN}).

The ACS_{LN} will control the access and allocation of radio resources for the different modes implemented in the BS and in the HERNs wirelessly connected and associated to this BS. These modes will be the used by the BS for serving directly final users, the used also by the BS for feeding its HERNS (the F1 mode), and the used by the HERNs for serving at final users in its respective coverage areas. The $RANG_{LN}$ will be where the generic user plane protocols of modes involved in this kind of deployment terminate. The BS_{LN} for this deployment concept will implement at least two modes, one for serving directly final users and another for feeding wirelessly (F1 mode) the HERNs associated to it. The $HERN_{LN}$ is a logical network node with relaying capabilities that is wirelessly connected on the one hand to the BS_{LN} by means of the F1 mode, and on the other side to the UTs_{LN} using a particular mode (used for short-range or wide area). The number of deployed HERNs will depend on the particular case to cover. Moreover the relay node could not be of amplify & forward type because the relay has to handle the signals at level upper than physical layer and to perform the protocol conversion in order to forward the received signal in a mode to another one. So the HERNs will be of decode & forward type.

Depending on the scenario for what the deployment concept is intended, the physical location of the various logical nodes, which form this network deployment, may be different. For example, in short-range scenarios, the ACS_{LN}, the $RANG_{LN}$ and the BS_{LN} can be co-located in the same physical node. On the other hand, in wide area scenarios the ACS_{LN}, and the $RANG_{LN}$ can be centralized in a same physical node, far from the physical location of different BSs_{LN}, all served by that physical node (ACS_{LN}/$RANG_{LN}$). In the same way, the $HERNs_{LN}$ may share the same physical node with other kind of RN logical node. In other words the same physical node could behave sometimes like a heterogeneous relay logical node and other times like a homogeneous relay logical node, in terms for instance of distance from the UT to the relay physical node, assuming of course a multi-mode UT.

3.4.2.3 Network Topology and Deployment Characteristics

The way to connect the different network elements, which are involved in the present deployment concept and were described above, assuring the correct interconnection of all the elements could be seen like star topology (PTM) from a BS-HERNs links perspective, or like tree topology from an user terminal perspective establishing one communication through certain HERN. Figure 3–17 illustrates graphically theses two points of view, as well as a general vision of a network deployment based on multi-hop transmission (two hops) using HERNs. The physical topology is that what defines the transmission medium, whereas the logical topology is that what follows the MAC algorithm.

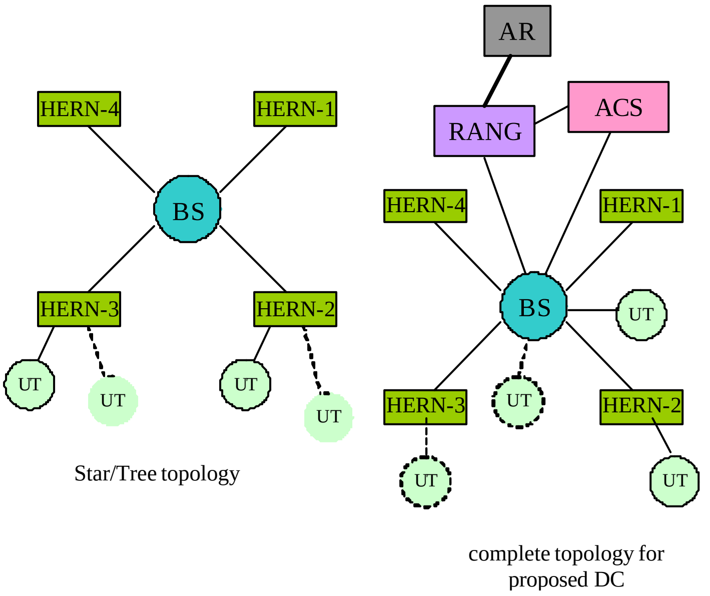


Figure 3–17: Different views of topology proposed for deployment concept based on multihop transmission using heterogeneous relaying

Another application of HERNs could be in fixed wireless mesh networks as shown in Figure 3–18. A fixed wireless mesh network composed of on fixed (or movable) relay nodes (RN), in this context HERN, and Base Station (BS). Thus the UTs are most likely not involved in the mesh itself, but are connected to it as shown in Figure 3–18. The figure shows a mesh network where the Radio Access Points (RAP), which can be either a RN or a BS are connected with its neighbouring RAP. Thereby the BS denotes the RAP, which is connected to the backbone network (most likely the Internet).

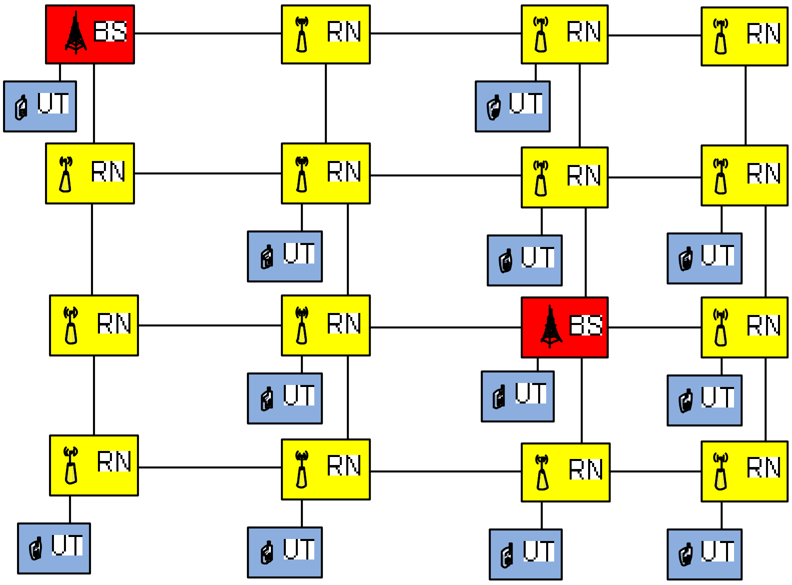


Figure 3–18: HERNs (RN) in a mesh topology: Mesh network based on fixed Relay Nodes (RN) with User Terminals (UT) connected to it. Base Station (BS) are connected directly to the Internet.

Concerning the generic vision of the heterogeneous relaying concept, Table 3–4 shows the general characteristics of this kind of network deployment.

Table 3–4: General deployment characteristics for the heterogeneous relaying category

Logical network elements	Physical network elements	
	Scenario	Physical layer assumptions
BS implementing at least two different WINNER physical layer modes: particular mode specifically thought for connections to HERNs and any other mode for serving at UTs.	In principle for any WINNER scenario (probably for rural does not have so much meaning save moving network solution based on RN inside the vehicle using different RI modes for connections with BS and UTs). Nevertheless the feasibility study included in section 3.4.4 will show the possibility to use this deployment concept in a rural scenario. Anyway theoretically it would be more appropriate for outdoor-indoor and vice versa transitions, or in general terms, for any scenario where is envisioned different propagation, mobility and/or traffic characteristics.	Beamforming or directive antennas for BS-HERNs links. Omni-directional or sectorial antennas for connections with UTs. Location in lampposts, rooftop or on facade of buildings. TDD duplex scheme for BS-HERNs links. UT direct connection to BS or through HERN, may use either TDD or H-FDD duplex scheme. Maximum distance of 1 Km for BS-HERN link, adjustable by means of power control. Possible overlapping of BS and HERNs coverage areas (seamless service) or isolated coverage areas with the possibility of frequency reuse near one.

3.4.3 Protocol Functions and Elements

The heterogeneous relays do not have particular protocol architecture, and it should be embedded in the common WINNER approach to be developed in T3.3. In order to ease the heterogeneous relay design is important that the QoS parameter be maintained on the transition from one mode to another. WINNER approach is considering the same QoS classes for the whole system concept. On the other hand the most promising idea of the heterogeneous relay is to exploit the particular characteristics of the F1 mode in order to increase the capacity of the multi-hop system.

The main objective of the resource scheduler element is to maximize throughput and minimize packet loss, taking the different priority levels into account for allocating prioritised packets into the available radio resources in each instant of time. The resource scheduling location in the deployment concept based on multi-hop transmission using different modes according to the possibilities currently contemplated in the project, should be a combination of centralized and decentralized scheduling working on different timescales. A good strategy for this case would be that BS organizes the network operation, since it knows the global traffic conditions and the needs of overall RNs. However in order to avoid too much overhead, the HERNs should control the final scheduling.

On the one hand due to the stationary properties of BS-RN links (multiplexing gain), and on the other hand the fact that the BS has a general view over all HERNs connected to it, the BS should control the data rate and the scheduling orders for its HERNs. Moreover the control of the resource allocation should be done by the BS over a longer time period, whereas the HERNs in the last hop (note that in this network deployment we are contemplating only two hops) should schedule on a shorter time scale their own resources, which are the radio resources of the mode used by the RN for serving at its UTs, of course based on the resources assigned by the BS for the first hop.

According to the reasons presented before, it is clear that the scheduling algorithm for the radio resources belonging to the mode specific link layer used in BS-RN link, will be almost all the times based on adaptive transmission, using the channel state information, that is taking the changing time, frequency and antenna specific channel properties into account, in order to increase the data rate of this link.

However for the mode used by HERNs for serving at final users, the resource-scheduling algorithm will be likely based on non-adaptive transmission, which takes priorities and buffer level into account, but does not trust on CSI feedback for each user terminal. Anyway the type of resource scheduler to choose will depend on the mode used by HERN, since for example if this is the used for short-range instead of wide area, the terminals will probably have semi-static characteristics so that the channel state information should be available, and then adaptive transmission could be applied.

Due to the different propagation conditions envisioned in multi-hop transmission over heterogeneous relays, it is also considered for some particular situations, the need of extra segmentation in RNs when the scheduling unit size used for the first hop (BS-RN link) is larger than the maximum radio resources available for the last hop in a given interval of time.

3.4.3.1 MAC Frame Structures

Though several tentative approaches have been made about the WINNER physical layer modes as well as the basic OFDM parameters to be used in each mode, so far there is not a firm decision regarding both topics. Therefore at the moment in this section we outline some examples of how to tackle certain issues concerning the MAC frame structure problem in a deployment concept based on heterogeneous relaying using the same or different duplex scheme. It should be noted that different modes as well as different duplex schemes might involve different frame format, different payload sizes, and different data rates.

In this kind of network deployment and from the HERN perspective we have to note that two MAC structures are present, since two different modes, using the same or different duplex scheme, are also present. The final idea is to get the best option for the structure of both MAC frames (two modes) in terms of different criteria (i.e. spectral efficiency).

Considering one of the last proposals about the OFDM parameters used in different modes, Figure 3–19 illustrates an example of possible MAC frame structure for modes devoted to wide area and short-range, assuming 1:1 asymmetry for this last mode, and from a perspective of physical layer characteristics.

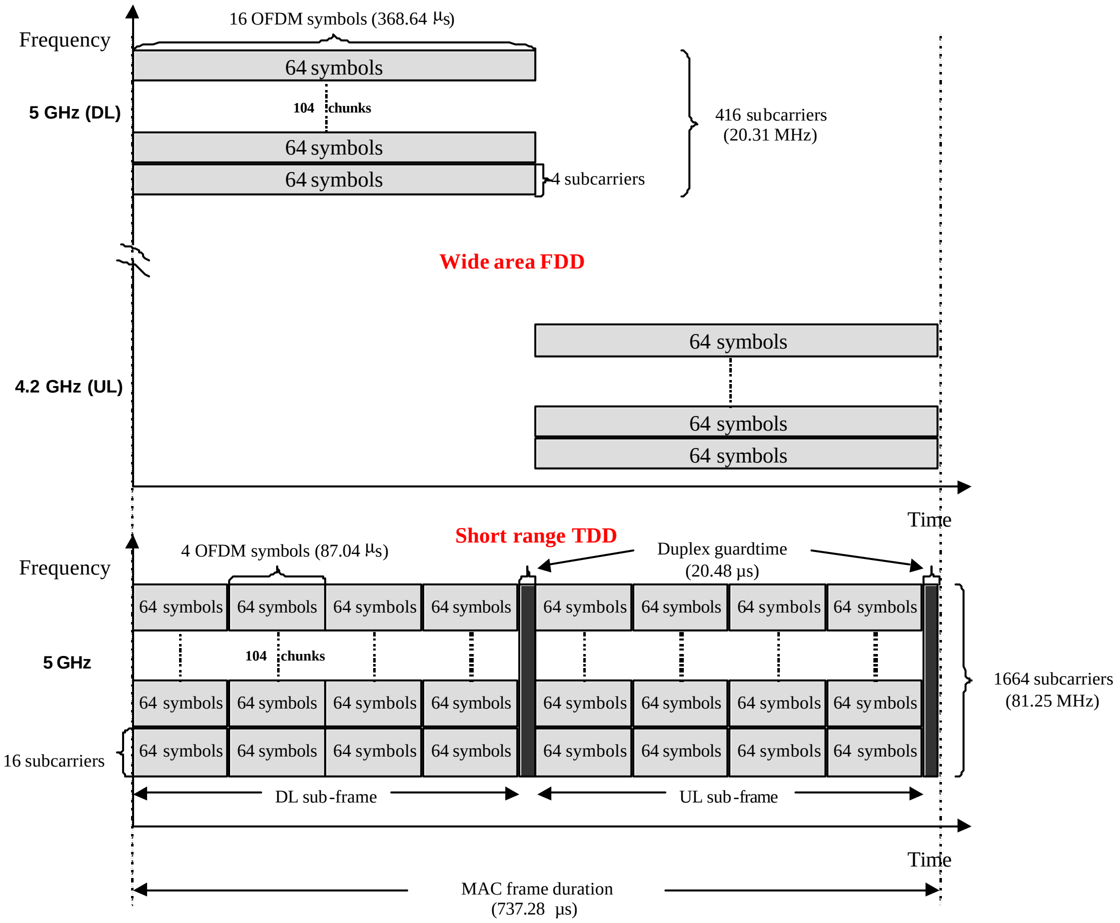


Figure 3–19: Possible MAC frame structure for modes thought for wide area and short-range, assuming 1:1 asymmetry for this last mode, from a perspective of physical layer characteristics

Figure 3–20 describes one possible frame structure, from BS and RN perspectives, for this class of radio network deployment, where all the involved air interface modes are using the same duplexing method

(TDD) and the same frequency band. As it can be seen, the frame is split in TX/RX transition gaps (black boxes) and in two sub-frames, one for BS downlink connections, and another one for BS uplink connections. Likewise, for each of these phases and from BS point of view, there is an idle period of time, which is used by the RNs to broadcast frame control and transmit user data to the UTs connected at the respective RN, in the DL sub-frame, and to receive the requests (contention phase) and user data from the UTs camped on the RN coverage area, in the UL sub-frame. In the same way, from the BS perspective, the useful part of the DL sub-frame is distributed between the frame control and user data for both, UTs directly served by the BS and RNs. Alike, the useful part of the UL sub-frame is distributed between the requests and user data for both, UTs and RNs connected to the BS. Concerning the radio resources distribution between the UTs directly served by the BS and the RNs, although in Figure 3–20 is shown an arrangement based on the use of a variable group of sub-carriers, it seems more favourable to use a distribution in time, since for the uplink direction in order to avoid overlapping and interference problems, mainly between different UTs (the RNs have a fixed position and so it is not needed any sub-carriers group as guard band), it is necessary to leave a certain number of sub-carriers as guard band, being thereby an alternative with less spectral efficiency than the distribution in time because in this case the BS is able to determine more exactly the time where the UT has to transmit, shortening the guard-time between UTs.

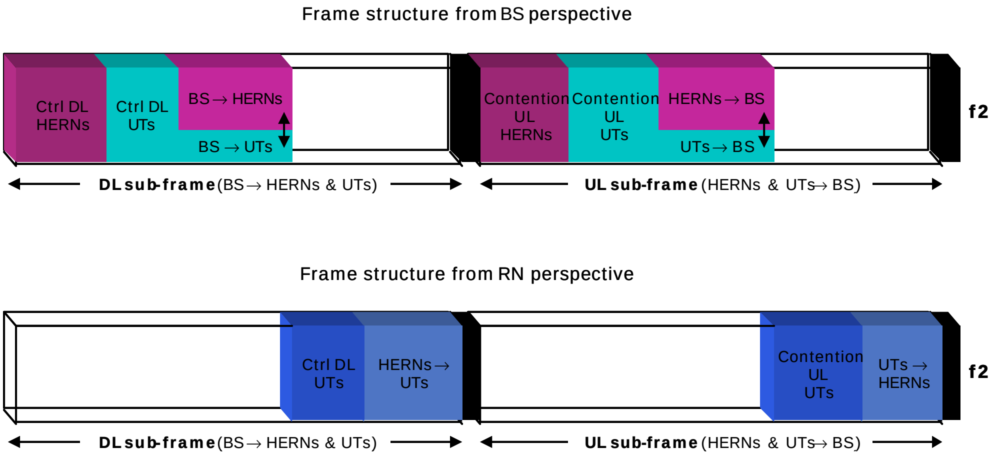


Figure 3–20: Frame structure for heterogeneous relaying concept using the same duplex scheme for the case of BS and RN are serving at final users by means of mode B1 (TDD short range)

Likewise one possible frame structure for a network deployment, where the BS and RNs are using the mode A1 for serving the final users and the BS-RNs links are implemented by means of the mode F1, is shown in Figure 3–21. Due to the TDD channel, in this case, is used only for the BS-RNs links, the total bandwidth of this channel (100 MHz) is distributed between the RNs. The frame is split in downlink and uplink sub-frames, and in TX/RX transition gaps (black boxes). The RNs located in opposite sites, could re-use the same radio resources, and so RN3 is using the same resources of RN1, and RN4 the same resources of RN2. In the same way, the mode A1 used by both, BS and RNs, for serving at UTs should be shared by means of different frequency groups, or like in this particular example by means of different code group.

Concerning the frame structure, one important consideration to take into account is that the length of the frame should be equal in both modes and start in the same time, although of course the frame's length could be variable.

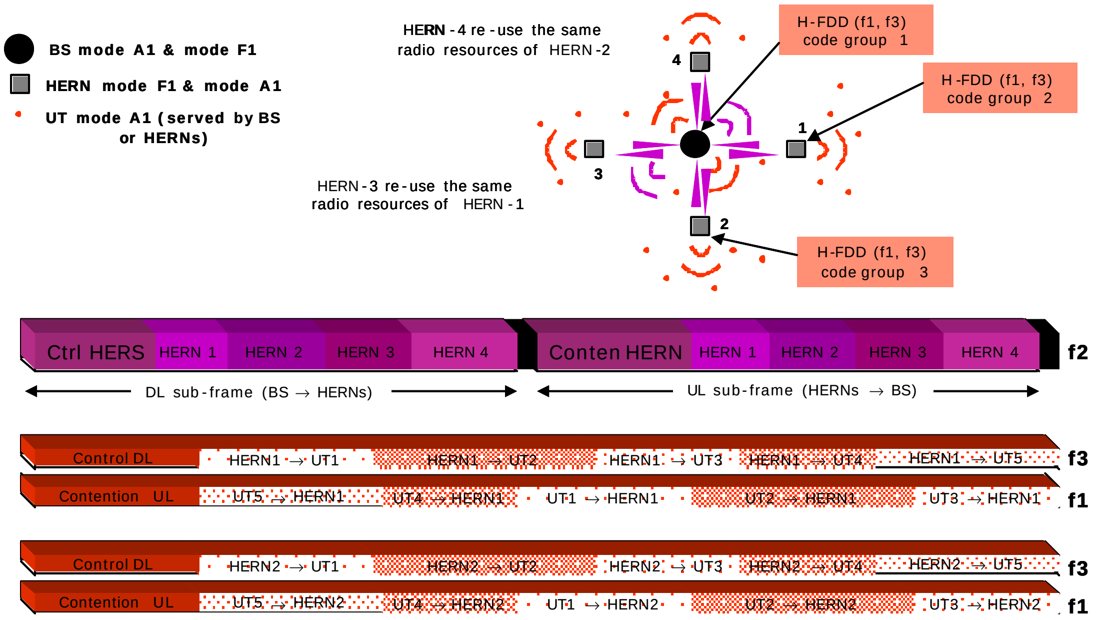


Figure 3–21: Frame structure for heterogeneous relaying concept using different duplex scheme for the case of BS and RN are serving at final users by means of mode A1 (FDD wide area)

Although in the previous cases, we have generally used the time as parameter for distributing the total radio resources between the UTs and RNs, of course there are more possibilities like for example in a system based on OFDM-CDMA, the use of sub-carriers or codes group, or even a combination of these three parameters (time, frequency and code), for allocating the available resources. It is clear that every solution has its own advantages and disadvantages, which should be analyzed in terms of spectral efficiency. For instance, in an OFDM system the radio resources for the downlink could be distributed between all the UTs and RNs connected to the BS, splitting in a continuous way the total useful carriers in different sub-carriers groups. However, for the uplink it would be necessary to leave a certain number of sub-carriers as guard band between every communication, in order to avoid overlapping in the reception. In any case, there will be to do evaluations and simulations for each alternative and under different conditions, in order to determine the best way to distribute the radio resources.

The big handicap to solve in any kind of deployment based on relaying, is the control of the delay produced in the multi-hop communication, since in downlink direction the data transmit from the BS to the RN in mode F1, has to be translated to the another mode, A1 or B1. Likewise in uplink direction, the data transmit from the UTs to the RN in mode A1 or B1, has to be translated to the mode F1. Hence the data received in mode F1 by the RN from the BS in the frame n, will be forwarded in mode A1 or B1 to the respective UT in the following frame, as well the data received in mode A1 or B1 by the RN from the UT in the frame n, will be forwarded in mode F1 to the BS in the following frame. Anyway, the delay in a RN working in F1 (TDD) and A1 (FDD) compared to a pure TDD case could be actually shortened as it should be possible to perform that translation very fast due to the fact that the RN may transmit and receive at the same time.

3.4.4 Feasibility Analysis for the Use of HERN

This section provides very simple simulations showing the feasibility of heterogeneous relaying for wide area and rural scenarios, but not limited thereto, using a particular mode specifically thought for the connections of RNs with the respective BS (here referred to as mode F1).

3.4.4.1 Introduction

In deliverables D3.1 [1] and D3.2 [2] several studies have been presented that show the potential benefits of introducing relay nodes, mainly in terms of increased throughput and/or increased cell ranges but also in terms of deployment cost. This section complements the previous studies in that it investigates the potential benefits of using heterogeneous two-hop relaying, exploiting that the (fixed) BS and (fixed) RN may be deployed in line-of-sight as well as that the BS and RNs may be equipped with directional or beamforming antennas.

In previous studies (see e.g. [2]) it was found that the cell ranges in single-hop scenarios are limited to a few hundred meters (though the exact figures heavily depend on the investigated scenario). Not very surprisingly it is furthermore found that the uplink is the limiting factor and this may at least partly be explained by SAR (Specific Absorption Rate) regulations and practical UT constraints as well as the high attenuation at 5 GHz. In deliverables D3.1 [1] and D3.2 [2] several different proposals on how to extend the range of RECs (Relay Enhanced Cell) have been described and investigated. Some of these proposals employ multi-hopping (i.e. allowing more than two hops) between the UT and BS, however supporting multi-hop networks implies more complex algorithms/protocols as well as (at least in most cases) increased round trip times and increased overhead. As a way to alleviate these problems, concepts that limit the number of hops to two have been proposed. These schemes are generally less complex but on the other hand the covered area is usually much smaller. In this section we investigate the possibility to increase the coverage of two-hop relaying systems using directional or beamforming antennas to feed the RNs. Based on these investigations a new deployment concept will be proposed that targets extending the coverage area of a (relay enhanced) cell by introducing multiple tiers of relays all fed from one single BS.

The remainder of this section is organised as follows. First we will investigate (by means of simple simulations) what cell ranges that may be achieved in a single-hop deployment scenario. These investigations will mainly serve as benchmarking for the forthcoming investigations on two-hop relaying. In section 3.4.4.3 a new deployment concept that targets extending the coverage area of a (relay enhanced) cell by introducing multiple tiers of relays in a two-hop relaying scenario is proposed and evaluated.

3.4.4.2 Single-hop Simulations

In this section we will investigate upper limits for the cell range in a single-hop deployment scenario. The cell range is assumed to be the range at which the UT is able to both receive and transmit at a 100 Mbps in a single UT and single cell scenario (i.e. we are not considering any interference in the simulations). Due to this simplified model, please note that the figures presented below are only upper limits for the investigated deployment concepts and hence, the actual perceived user throughput as well as cell ranges will be much lower than what is presented here. Nevertheless, it is assumed that the relative difference between the different deployment concepts will remain roughly the same also in more realistic scenarios.

Moreover, as discussed above it is assumed that the uplink will be the limiting factor for any deployment scenario and hence we will restrict the simulations in the forthcoming sections to the uplink. In all of the following simulations we will furthermore assume that the UT is transmitting using an omni-directional antenna.

The remainder of this section is organised as follows. First the upper bound (i.e. the Shannon limit) for the average rate versus range is investigated and thereafter the same set of simulations but with more realistic modulation and coding schemes are performed. The section is concluded by a short discussion around potential solutions to the range and rate problems encountered. The assumptions made in the first set of simulations are given in Table 3–5.

Table 3–5: Assumptions for single-hop simulations

Parameter	**Description/Value**
Carrier frequency (f)	5 GHz
UT max TX power (P_{UT})	0.125 W
Max UT antenna gain (G_{UT})	0 dB
Max BS antenna gain (G_{BS})	16 dB
BS noise factor	5 dB
Temperature (T_{Ant})	273+25 ºK
Channel bandwidth	100 MHz
Channel model	1 tap (simplification but assumed OK)
d_{BP}	{15,65} dB @ {10,20} m rooftop height
σ	8 dB STD. Log normal fading

Furthermore, the employed path loss model and performance metric are given in equations (1) and (2) respectively.

$$PL(D) = 32.4 + 20 \cdot \log_{10}(\mathrm{d}_{\mathrm{BP}}/\mathrm{Km}) + 38 \cdot \log_{10}(\mathrm{D}/\mathrm{d}_{\mathrm{BP}}) + 20 \cdot \log_{10}(\mathrm{f}/\mathrm{MHz}). \quad (1)$$

$$\mathrm{Rate} = \mathrm{E}\left[\mathrm{B} \cdot \lg_2(1 + \mathrm{SNR})\right] \quad (2)$$

It is also assumed that the transmitter has perfect knowledge of the receiver SNR (i.e. perfect rate control) and that the maximum rate is limited to 4 bps/Hz (this limit seems reasonable but since it is arbitrarily set higher values might also be considered).

Four different cases are simulated in the following and are distinguished by whether diversity is exploited or not and the height of the rooftops as follows:

- Case 1:
  - Rayleigh fading without diversity.
  - BS height 30 meters, rooftop height 10 meters.
- Case 2:
  - Rayleigh fading without diversity.
  - BS height 30 meters, rooftop height 20 meters.
- Case 3:
  - Rayleigh fading with diversity (two branch maximum-ratio-combining with uncorrelated channels).
  - BS height 30 meters, rooftop height 10 meters.
- Case 4:
  - Rayleigh fading with diversity (two branch maximum-ratio-combining with uncorrelated channels).
  - BS height 30 meters, rooftop height 20 meters.

The results of the simulations may be found in Figure 3–22. As can be seen here, the maximum cell range for case 1 is approximately 960 meters, for case 2 the cell range is approximately 480 meters, for case 3 the cell range is just above 1000 meters, and finally for case 4 the cell range is approximately 600 meters.

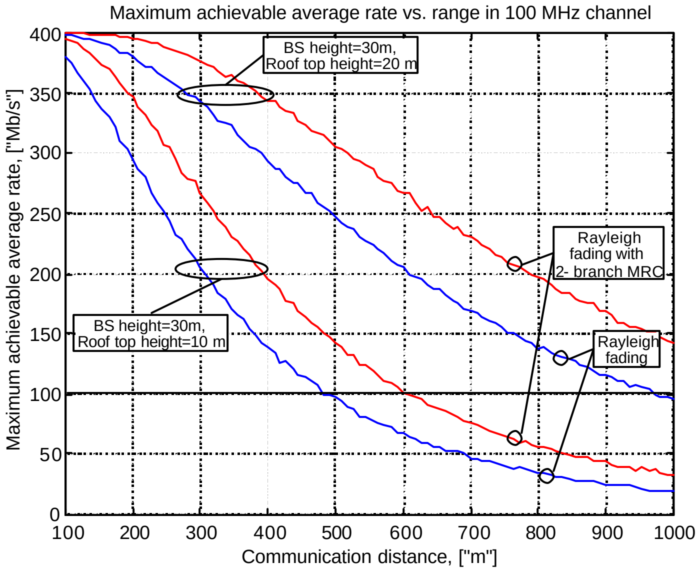


Figure 3–22: UT-to-BS transmission: upper bound (Shannon) for average rate vs. range

The results in Figure 3–22 are of course optimistic and we will now try to estimate more realistic numbers by employing more realistic modulation and coding schemes. The OFDM parameters used in these simulations as well as used modulations and coding rates are given in Table 3–6 and

Table 3–7 respectively. In Figure 3–23 the rates used in the subsequent simulations for the different modulation and coding schemes are plotted against the SNR. It should be noted that these curves are assuming an ideal selective-repeat ARQ retransmission strategy.

Table 3–6: OFDM parameters used in simulations

Parameter	Description/Value
No. of sub-carriers	3072
Inter-carrier spacing	32 kHz
Cyclic prefix	3.75 µs

Table 3–7: Modulation and code rates supported in the simulations

Modulation	BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM
Code rates	1/3, 1/2, 2/3, 4/5, 19/20 (turbo codes)

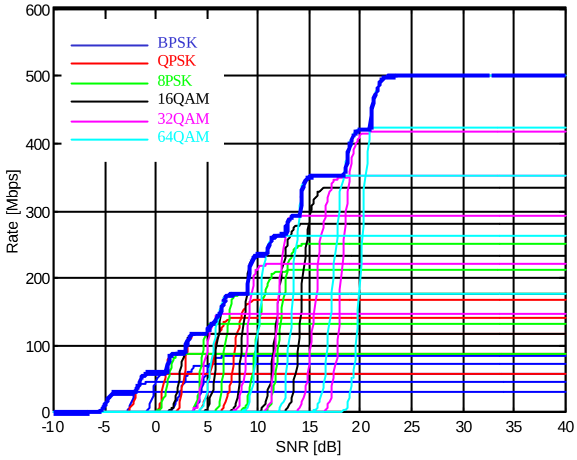


Figure 3–23: Achievable rates for different combinations of modulation and coding schemes

In the following simulations it is furthermore assumed that we have perfect Channel State Information (CSI) knowledge at the transmitter and hence that we are able to follow the envelope of the rate curves in Figure 3–23.

The results of the simulations may be found in Figure 3–24. As can be seen in the figure the ranges now vary between approximately 380 meters (for case 2) to 960 meters (for case 3).

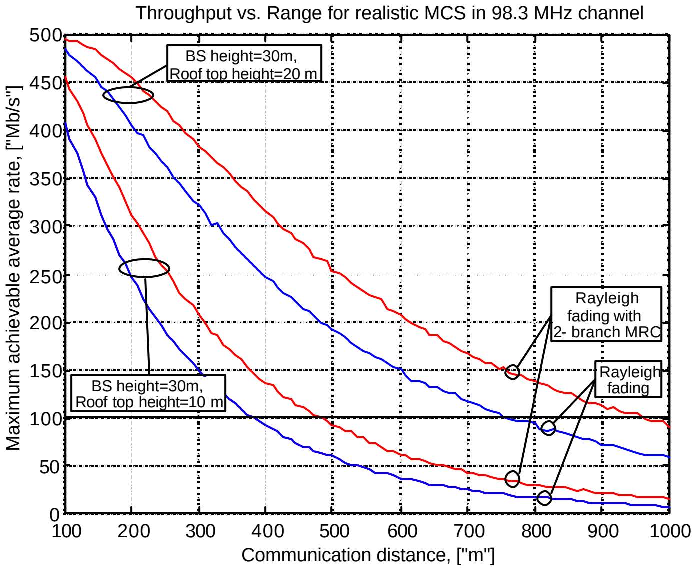


Figure 3–24: UT-to-BS transmission: rate vs. range for realistic modulation and coding schemes

From the previous simulations it is evident that the cell ranges that may be supported are limited to a few hundred meters (potentially up to 1000 meters with Maximum Ratio Combining (MRC)). In these simulations we have assumed that the full 100 MHz spectrum is employed in every scenario. Nevertheless, as have been shown in D3.2 [2] the cell range is still limited to a few hundred meters even if a more narrowband channel is employed. The limited coverage may be especially severe for the wide-area and rural scenarios where coverage is very important in order to have a cost-efficient solution.

Potential solutions for the uplink rate and range problems are:

- Increase PA power at UT.
    - Not advisable due to SAR as explained above.
- Improve antenna gains.
    - Two potential solutions:
        - At BS.
            - Already very high in the performed simulations.
        - At UT.
            - Possible, but wavelength in relation to size of the UT limits any potential gain.
- Use macro-diversity combining.
    - Probably a good solution but puts large requirements on the transport network.
- Use dense BS deployment.
    - Deployment of transport networks may be very costly.
- Split path in multiple hops.

Below we will investigate a two-hop relaying scheme as a potential solution to increase the coverage of a BS. Nevertheless, this solution will later on need to be benchmarked against the other potential solutions listed above (especially to any solution based on macro-diversity combining and a more dense deployment of BSs that in our opinion also may be a viable solution to the problem of coverage).

3.4.4.3 Multi-tier Relaying

The proposed deployment concept is based on the assumption that the RNs does not have as tight restrictions as the UT when it comes to transmit power and advanced antenna schemes. Thereby it is assumed that the distance between the BS and RNs may be many times larger than the distance between the BS and any of its connected UTs (this assumption is verified below). This is exploited to deploy multiple tiers of RNs around the BS employing directional or beamforming antennas to connect the BS and any RN (F1 mode) over large distances, i.e. the here proposed solution is based on two-hop heterogeneous relaying. The main advantages of restricting the number of hops to two are, reduced complexity and reduced round-trip-time (also the interference reuse pattern may be improved but this is not verified so far).

The proposed deployment may be further refined into two different deployment concepts depending on whether asymmetric connections between the BS and UT may be allowed. In the symmetric case the same number of hops are always used for both downlink and uplink whereas the number of hops utilised may differ between the uplink and downlink in the asymmetric case (remember that the limiting factor is assumed to be the uplink connection). Nevertheless, there may be good reasons for not supporting asymmetric connections (e.g. ARQ states in intermediate nodes) and more in depth evaluations need to be performed in order to decide if this is a viable solution or not.

As is shown below, the RN-to-BS link is not a limiting factor for the proposed deployment concept mainly due to the high gain antennas and the low path-loss (line-of-sight or near-line-of-sight conditions) assumed for the mode used for this link (i.e. link between the RN and BS). The proposed deployment concept is depicted in Figure 3–25, where it is assumed that the coverage area of an RN is similar in size to the coverage area of the BS, however the deployment concept is equally suitable in cases were this assumption does not apply.

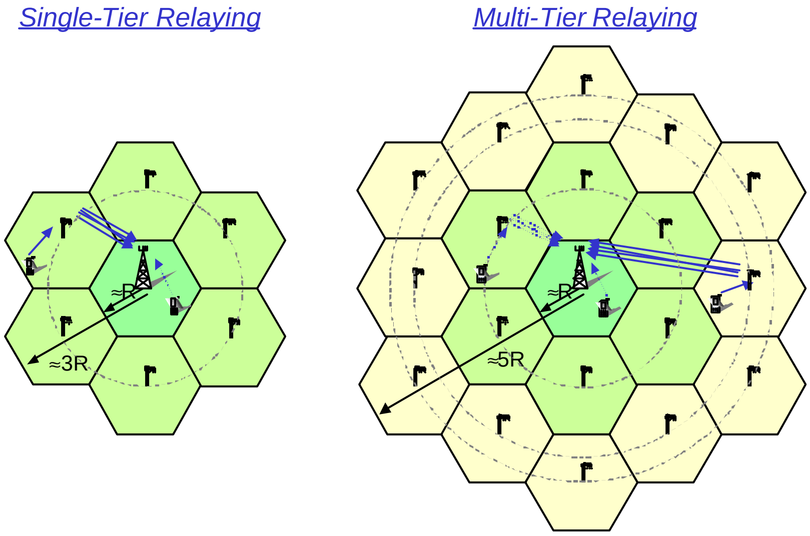


Figure 3–25: Relay deployment concept exploiting range (path loss and antenna gain) asymmetry for BS-to-RN and RN-to-UT paths

One question that needs to be answered is whether the BS-to-RN link is good enough for multi-tiered relaying (i.e. if it is able to support more than one tier of relaying). In order to answer this question we performed a simple set of simulations. The assumptions are as given in Table 3–5, though with the following amendments: $P_{RN} = 125 mW$, i.e. the output power for the RN is the same as for a UT, and $G_{RN} = 0 dB$. These values may seem very conservative but were selected in order to investigate what is achievable with very simple and low cost RNs (assuming that the cost of the RN is proportional to the output power and gain). It is furthermore assumed that the RN and BS are in line-of-sight and that the path-loss model is given by:

$$PL(D) = 32.4 + 20 \cdot \log_{10}(\mathrm{D/Km}) + 20 \cdot \log_{10}(\mathrm{f/MHz}). \tag{3}$$

The results are given in Figure 3–26 and as can be seen here the cell range may be roughly extended 6-12 times as compared to the single-hop case even with these very conservative values. Hence, multi-tier relaying seems like a viable option to extend the range of a BS.

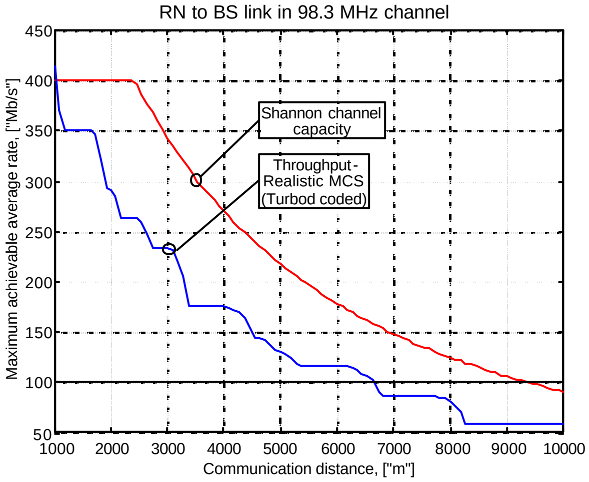


Figure 3–26: RN-to-BS link ranges

In order to have simulation results more comparable to the ones performed for the single-hop case a second set of simulations were performed.

Here, it is assumed that the RNs are deployed like BSs (at least as seen in the UL) and resources are shared between the UT-to-RN and RN-to-BS links. Moreover, $G_{RN} = 16dB$ (i.e. the gain between the RN and BS) and the path-loss model between the UT and RN is like for the single-hop case i.e.:

$$PL(D) = 32.4 + 20 \cdot \log_{10}(\mathrm{d_{BP}/Km}) + 38 \cdot \log_{10}(\mathrm{D/d_{BP}}) + 20 \cdot \log_{10}(\mathrm{f/MHz}). \quad (4)$$

where $d_{BP} = 65dB$ at 20 meters rooftop height. For the rest of the parameters the same assumptions as above applies.

The simulation results are depicted in Figure 3–27 and as can be seen here the coverage area of a single BS may be extended more than six times. The distance between the BS and neighbouring RNs as well as the distances between neighbouring RNs have been chosen in such a way that the minimum rate any UT may experience should be at least 100 Mbps for the case where diversity is not employed (i.e. blue curves in the figure). Moreover, the throughput have been calculated as follows:

$$1/T_{eff} = 1/T_{UT-RN} + 1/T_{RN-BS} \quad (5)$$

where T_{XX-YY} is the average throughput on the link between node XX and node YY.

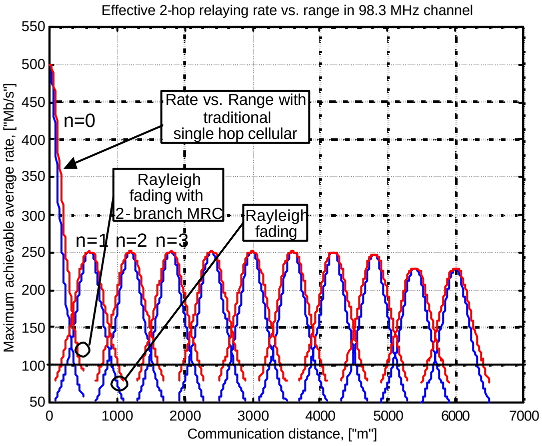


Figure 3–27: Effective relaying rate vs. range

Nevertheless, it should be noted that the BS will in the end limit the number of RNs that may be supported and hence the number of supported tiers will most likely be much lower than what is depicted here. To exemplify this the following example is given: assuming a hexagonal pattern and *n* tiers the number of supported RNs may be calculated as follows:

$$\# RNs = \sum_{k=1}^{n} 6k \tag{6}$$

This means that in a four tier scenario the number of supported RNs equal 60 which means that the available resources needs to be divided in between the 60 RN to BS links and the UT to RN/BS links in the 61 cells and hence the resources given to one cell will be very limited in this case (though taking multiplexing gains into account this may still be found to be a viable number of tiers).

3.4.5 Applicability to Main WINNER Scenarios

To follow it is outlined the assessment of proposed deployment concept based on the use of heterogeneous relay nodes, in the target scenarios initially identified for WINNER system. First of all it is described in general terms the applicability of this deployment concept in the basic deployment scenarios, and then a final matching of HERN deployment on the main scenarios is included. General considerations and harmonization process for determining the suitability of the HERN deployment concept are based on the basic deployment scenarios and related test configurations described in the section 2.1 devoted to basic WINNER scenarios.

3.4.5.1 General Vision

The basic deployment scenarios identified in WINNER, where the HERN concept could be useful, are those where the requirements of the different segments which composed a multi-hop communication, are so different as for example from mobility or propagation characteristics points of view. These differences can justify in some situations the use of a network deployment based on heterogeneous relaying, implementing a certain mode for the BS-RN link as well as for the direct communications between the BS and the final users (e.g. mode used for short range), and another different mode for the communication of user terminal through the RN (e.g. mode used for wide area). Therefore, mixed environments with different mobility and propagation characteristics are in principle, clear candidates for the use of heterogeneous relaying concept. Thus and according to the WINNER basic deployment scenarios, the most promising scenarios for the heterogeneous deployment concept will be those where transitions from outdoor to indoor or vice versa are envisaged.

It is clear that the HERN solution does not rely on only one specific Physical Layer Mode (PLM), since by definition a HERN always involved the use of two different modes. Just this fact implies a more complex and expensive RN, since it needs support for the different modes implemented in the HERN. Certainly the complexity and cost of HERN as opposed to homogeneous alternative could restrict the use of HERNs to certain scenarios, although theoretically they could be deployed in any of the identified WINNER basic scenarios. In this way, some very simple simulations, explained in section 3.4.4 above, showed the feasibility of a potential deployment scenario specifically tailored for the wide area case, but not limited thereto, that falls under the category of heterogeneous relaying using a mode specifically thought for BS-RN link.

On the other hand one attractive advantage of the HERN solution is the provision in a certain mixed coverage area of different access modes (adapted and convenient for different environmental conditions), in a decentralized manner by means of a proper distribution of heterogeneous relay nodes around the BS. This means that the BS would be providing service to final users directly via a given mode (more suitable for the characteristics of the region around the BS), or through the RN using a different mode (more suitable for the characteristics of the BS boundary). Moreover, only one connection to the fixed network would be necessary, since provision of the distributed mode in geographical spots far from BS location, is performed by the RNs, which are wirelessly fed from the BS.

3.4.5.2 Final Matching on Main WINNER Scenarios

Hereinafter it is performed the assessment of proposed concept (multi-hop with heterogeneous relaying) in priority scenarios selected for phase I of WINNER project.

- A.1. This is a particular case for scenario A (In and around building) characterized by indoor propagation conditions, low mobility (0-5 km/h) and high traffic density. For multi-hop communications in this scenario does not seem very suitable the use of HERN concept since both connections, BS-RN and RN-UT links, usually are characterized by NLOS propagation conditions and the use of smart antennas like MIMO techniques. In our case is assumed the use of highly directive antennas for the BS-RN link, and so the homogeneous alternative should be more advantageous. However for especial cases where might be assured a certain line of sight conditions between the BS and its respective RNs (open areas in offices), and the BS border presents other different propagation conditions and/or different mobility requirements, the HERN concept could be a good option for localized and non ubiquitous coverage.

- B.1. This is a particular case for scenario B (Hot spot/area) characterized by typical urban propagation conditions, medium mobility (0-70 km/h) and high traffic density. At first the multi-hop deployment concept based on the use of homogeneous relaying appears like more suitable for this scenario than the heterogeneous solution, due in principle to the more complex and expensive of HERN as opposed to HORN since the first has to support two different modes in its operation. Anyway it should be noted that due to the advanced relaying concept with optimised BS-RN link assumed for the HERN operation, the heterogeneous relaying deployment concept provides a best exploitation of the static link between the BS and the fixed RN by means of the use of a mode tailored for this kind of link. In this way the maximum throughput reachable in the first hope for the heterogeneous case could be higher than for the homogeneous case, and so more traffic might be supported in the coverage areas of respective relay nodes. Therefore before adapting a concrete solution, it seems reasonable to make some simulations in order to compare both deployment concepts, and depending on the results to decide the best option. Save the delay problem, which will be usually a little more severe for the case of heterogeneous relaying, the HERN deployment concept meets full well with the rest of requirements established for this WINNER scenario from different points of view such as propagation conditions, traffic characteristics, user behaviour and spectrum regulatory constraints. The simulation environment and the values of parameters to be used for comparing both concepts could be the same (Manhattan-like structure will be utilized as physical environment), except for the delay and BS-RN link models to implement in simulations, which should be different for each of the alternatives.
- C.2. This is a particular case for scenario C (Metropolitan) characterized by typical urban propagation conditions, medium mobility (0-70 km/h) and medium/high traffic density. The same reasons provided for including the HERN concept in B.1 scenario and explained before, are also applicable for contemplating this deployment concept in the metropolitan scenario. Besides the preliminary simulation results presented in previous section 3.4.4 could justify in some cases the possibility to use the heterogeneous alternative (in particular the Multi-tier relaying option) instead of the homogeneous, as long as the extra delay introduced by the heterogeneous solution does not exceed the delay requirements demanded for this scenario. So it is proposed the inclusion of heterogeneous relaying concept, with comparison purposes, in the simulations to be performed according to the characteristics of C.2 scenario (hexagonal cell layout and area around 20 km^2).
- D.1. This is a particular case for scenario D (Rural) characterized by rural propagation conditions, high mobility (0-200 km/h) and low traffic density. In a rural environment where the coverage radius usually is from 1.5 to 20 km (macro-cells), and due to the mode proposed for the BS-RN link in a HERN deployment concept has so far a maximum range around 1 km, the use of homogeneous option seems more convenient than the heterogeneous alternative. Nevertheless as we have mentioned for the case C.2, in section 3.4.4 was outlined a two-hop heterogeneous deployment concept specifically targeted for the wide-area and rural scenarios. In fact the proposed deployment concept (Multi-tier relaying) may be utilized in any scenario where it is guaranteed that the RNs are in LOS (or at least in near-LOS) of the BS. Therefore the heterogeneous relaying concept is proposed also for covering some particular cases of this scenario.
- D.2. This is other particular case for scenario D (Rural) characterized in this occasion by LOS – moving networks propagation conditions, very high mobility (0-300 km/h) and high traffic density. A typical example for this case is the train scenario. In general terms, the problem for providing Internet services inside vehicles at high speed could be divided in two parts; the external segment and the internal segment, with clear differences of propagation and mobility conditions so that the heterogeneous alternative should be contemplated. In this way the external segment deals with the difficulties for vehicles in motion at very high speeds (higher than 200 km/h), whereas the internal segment deals with the problem of the distribution inside the wagons of the train, in order to provide access to all the passengers. During the last years, some initiatives have appeared in order to supply Internet services in mobile vehicles at high speeds. Most of these initiatives, according to [12], are based on the use of 802.11 with its different versions for the communication inside the vehicle (internal segment), and the use of some cellular technology combined with satellite system for the external connection of the vehicle (external segment). Furthermore, to maintain the access and service inside the tunnels along the

train path, currently some solution based on radiating cable (leaky feeders or slotted cables) is usually adopted, although the problem at present is the high cost of the deployment of this technology. It should be noticed that one of the most important advantages of this technology is the absence of Doppler effect in the area covered by the radiating cable, and so it is very convenient for the coverage of high velocity vehicles inside tunnels. From a WINNER point of view, the problem of the train scenario, at least at first look, could be solved by means of relay nodes installed on the top of the train. Initially the deployment for solving the external segment could vary from one per train to one per wagon, changing the distribution inside the train in terms of the selected option. Of course, it seems more appropriate to use only one RN for the external connection of the train (for example installed in the central wagon), and then to perform the distribution inside the train to the final users, by means of other simpler and cheaper RNs. On the other hand, it is clear that the handicap of the train scenario, in addition to the common problems of any radio communication (i.e. interferences, attenuation, fading and coverage), is the negative effect of the high velocity of the train. As a result of this velocity, the Doppler effect and the handover time between cells should take into account. Therefore for the selection of the WINNER air interface mode used in the external segment in train scenario, it is very important we take into account the characteristics of the mode, in order to fit adequately with the requirements from a handover and Doppler effect points of view. For instance, it could be proposed something similar to soft handover technique, wherein the train during the handover cell, remains a certain time under the two cells, provoking a slight traffic load, but decreasing considerably the handover time. So, in principle the HERN alternative for this kind of scenario could be a good choice, but using for the BS-RN link a mode different to the mode proposed initially in this sub-chapter for HERN deployment (F1). This new mode should contemplate a high mobility support and ranges around several kms, in order to minimize the deployment costs. In respect of these pre-requisites, it should be noted that the F1 mode does not contemplate both high mobility support and large ranges. Therefore, one possible solution for the train scenario could be the inclusion of other particular mode for BS-RN link, based on some mode devoted to wide area but contemplating of course high mobility support and higher ranges.

3.4.6 Conclusions and Further Activities

This section will be dedicated to summarize the main conclusions concerning the description and analysis of deployment concepts based on multi-hop transmission using the heterogeneous relaying approach. As well as the further work foreseen for this topic will be outlined.

In the current sub-chapter, devoted to the definition and analysis of heterogeneous relaying deployment concept, the distinguishing aspects from homogeneous case have been identified and described, mainly the necessary functionality coordination between the two modes involved in the HERN's operation (multi-mode protocol architecture included in Annex II section 9.2), and the possibility to exploit the special characteristics of the mode used for BS-HERN link (F1 mode with different characteristics to the RN/BS-UT link), which will permit to use some kind of advanced relaying concept in order to increase the capacity of the multi-hop system.

The three domains to be exploited in a multi-hop communication (time domain, combined time and frequency domain, and combined time, frequency and space domain), and contemplated for the homogeneous case, are also applicable for the heterogeneous alternative. The exploitation of these domains will depend on the particular features of the targeted scenario (whether or not the radio resources of mode used on the link between BS and RN have to be shared by other modes involved in the scenario).

The most promising scenarios, where the HERN deployment concept could be applicable, are those with different mobility, propagation and traffic characteristics like for example any scenario with outdoor-indoor and vice versa transitions (A.2, B.4 and C.4 but so far not contemplated as priority WINNER scenarios). Besides it has been shown that the two-hop heterogeneous deployment concept based on a multitier relaying is specifically targeted (as long as may be guaranteed that the RNs are in LOS or at least in near-LOS of the BS) for using in wide-area and rural scenarios (C.2 and D.1), which are two of the main WINNER scenarios identified for phase I of the project.

Finally, once the physical and MAC characteristics of different physical layer modes to be developed in WINNER system be more definitive, the following activities should be contemplated and discussed:

- Study of MAC frame and super-frame structure for different cases of HERN (with same and different duplexing schemes), trying to identify the best option for each case by means of evaluations and simulations for each alternative and under different conditions.

- Analysis of how to do the best resource partitioning between all the nodes involved in different types of scenarios, as well as to decide the scheduling procedure more appropriate from several points of view (e.g. complexity, spectral efficiency).
- To perform more simulations for comparing the multi-tier relaying solution with other potential solutions, in particular any solution based on macro-diversity combining and a more dense deployment of BSs.
- In addition to the simulation results it would be convenient to carry out a preliminary deployment cost analysis (based for example on current deployment costs for similar technologies to the proposed), in order to compare the heterogeneous relaying concept with other alternatives.

3.5 Concept Harmonization

3.5.1 Introduction

The concepts described in this chapter represent the "work in progress" of the current WP3 harmonization work. This work was started in D3.2 [2] where a first general classification of Deployment Concepts was introduced. The basic classification in D3.2 is kept in this deliverable and focuses on the "Fixed Relaying" category in this section.

In D3.2 concepts where discriminated by the multiple access scheme in Time-domain, Time-Frequency domain and Space-Time-Frequency domain. While progressing in the harmonization work, and making reference to the definition of Deployment Concept that has been consolidated (ref. chapter 1), it has been agreed that the basic logical topology is a discriminating variable that allows a more effective way of classifying the concepts. Therefore, the Fixed Relay Deployment Concept will be clustered in the **Hierarchical PmP** and **Mesh** main categories in this document.

Harmonization between the different concepts in the category is performed in the sections 3.5.2 and 3.5.3 for hierarchical PmP and Mesh respectively.

For each of these main categories:

- the concepts described in D3.1 have been, or going to be analysed, harmonized in terms of assumptions, logical and physical nodes and the network topology
- relationships/applicability to the WINNER network scenarios (with reference to section 2 of this document) will be discussed

It should be noted that each categories can include concepts realized via Time-based, Time-Frequency-based, Space-Time-Frequency based approaches (as anticipated in D3.2)

All concept descriptions in this chapter are presented in relation to the WINNER WP3 agreed architectural elements. The functions and elements of the respective concept are mapped on the elements of the logical node architecture and are described in more detail. To conform to the WINNER multi-mode architecture, the concepts should ideally identify functions that are common to other proposals and give a clear definition of the interfaces between common and mode-specific functions in the respective concepts proposed for a mode.

3.5.2 Hierarchical PmP Deployment Concept

3.5.2.1 Introduction

When it comes to the trends for a next generation system, using multiple (radio) hops (henceforth referred to as a multi-hop network) can be seen as on option to handle the small cell sizes that are likely to appear when moving to the envisaged operating frequencies and data rates. Fixed hierarchical PmP relaying concepts have been proposed in the past mainly because the operator has the general ability to engineer and design the network properly that reliable links can be ensured. Although most of the investigations focused on the classical Manhattan scenario, the concepts are in general applicable to hotspot, indoor and wide area coverage as well. Because most of the proposals address this category it is considered as the main harmonization task within WP3.

3.5.2.2 Assumptions

General assumptions are:

- the network will be operator owned,
- the operator will conduct necessary network planning and
- reliable links between APs and RN will be provided.

3.5.2.3 Mapping of Logical to Physical Network Elements

Section 1.3 defines the following logical network elements that are relevant for this deployment concept. Their mapping to physical network elements is given in Table 3-8 below.

Table 3-8 Logical to Physical Element mapping

Logical Network Element Name	Physical Network Element Name	Notes and comments
AP_{LN}	AP	Note: The antenna configuration may require the additional definition of other AP physical network elements.
RRN_{LN}	FRRN	The FRRN is a RN with relaying capabilities on layer 3 (routing). Size, weight and efficiency limitations may apply in typical deployments e.g. if mounted on lampposts. Note: The antenna configuration may require the additional definition of other AP physical network elements.
BRN_{LN}	FBRN	The FBRN is a RN with relaying capabilities on layer 2 (bridging). Size, weight and efficiency limitations may apply in typical deployments e.g. if mounted on lampposts. Note: The antenna configuration may require the additional definition of other AP physical network elements.
UT_{LN}	UT	

Note: Cases in which $FRRN_{LN}$ or $FBRN_{LN}$ and UT_{LN} are grouped to a new physical network element are for further studies.

$RANG_{LN}$ and ACS_{LN} are mapped to the RANG and ACS physical network elements. RANG and ACS physical network elements are used in the sections below of this deployment concept for reasons of completeness. It should be noted that they may implemented as different physical network elements (e.g. collocated in a single device) in practical realization.

3.5.2.4 Network Topology and Resulting Deployment Characteristics

The network topology for the hierarchical PmP deployment concept is given in the Figure 3-28 below. APs of a certain coverage area are connected to the same ACS and RANG and provide access to the backbone network for associated relays and UTs. Relaying is performed by the FRRN and FBRN network elements based on performance and cost constrains. FRRNs contain routing functionality likely yielding higher performance at higher costs, whereas FBRNs will likely be simpler, cheaper and have less performance. QoS constrains will be taken into account by these nodes.

The maximum number of hops for FRRNs is left undetermined and can be quite large if the delay introduced can be tolerated. The maximum number of hops for FBRN relays is for further study.

UT will perform handover between the AP, FRRN and FBRN network elements.

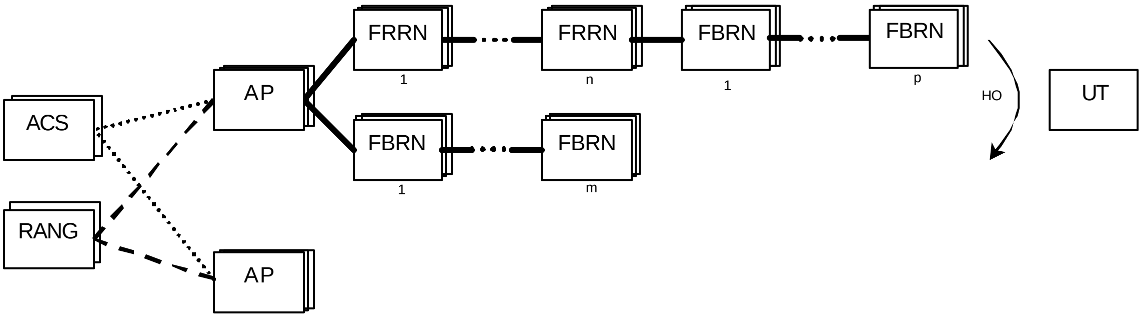


Figure 3-28: Network topology

3.5.3 Mesh Deployment Concept

3.5.3.1 Introduction

One of the emerging technologies in the wireless telecommunication landscape is currently represented by the mesh deployments of systems. This approach relies on the possibility of relaying the information between the nodes to increase to overall system performance from several points of view.

Roughly speaking, a mesh network is a network that employs one of two connection arrangements, full mesh topology or partial mesh topology. In the full mesh topology, each node is connected directly to each of the others. In the partial mesh topology, nodes are connected to only some, not all, of the other nodes. On the basis of this definition it is clear that mesh networking is not a new concept. In certain ways, the Internet is a mesh network. A Wireless Mesh Network (WMN) is a mesh network that handles many-to-many connections wirelessly and is capable of dynamically updating and optimizing these connections. An ideal WMN is a dynamically self-organizing, self-configuring, and self-healing network.

The certainly most evident advantage of the mesh deployment concept is the possibility of extending the range of a given radio access technology. The increase of the covering area allows consequently to serve a larger number of users and to better support the ubiquity of the applications. Many realizations of a mesh deployment can be envisioned, since a lot of parameters can be varied in accordance with the applications that the system is designed for.

Besides the technical aspects, the deployment easiness and cost-effective and the scalability provide to this mode an indubitable appeal with the respect to the operators, since these characteristics allow to reach and cover certain area that would normally be considered unprofitable as well as offering a solution for the easy deployment of high-speed ubiquitous wireless Internet. More precisely, the possibility of extending the range of a service without the need of expensive investments in infrastructures and equipments, is feeding the research in this domain.

So far the usage models and the radio access technologies that have been associated to this deployment approach have mainly concerned the domain of the LANs or the MANs, respectively involving evolutions of the IEEE 802.11 [9] and the IEEE 802.16 [10] standards. The latter has been approved in its latest version in 2004 and contains a mesh option for both MAC and PHY layers, whereas within the 802.11 committee the newly created task group *s* is in charge of the definition of the mesh extension for the most successful WLAN standard to date. However these two technologies rely on very different technical bases that seem to make them hardly compatible.

Differently from the mentioned research trend that limited the investigation of the mesh approach to the local and metropolitan areas, the WINNER project extended the consideration of the mesh and relay technologies to a larger scope, including the Wide Area Networks (WANs) as well as particular scenarios such as the feeder one, the aim being to support ubiquitous communication with a higher performance.

The primary results released in the first two deliverables [1], [2] have indeed showed the applicability as well as the efficiency of the mesh techniques for the attainment of the WINNER goals.

The mesh/relay deployment concept mainly refers to the design of the DLC and network layers and, within the WP3, investigations have been conducted on the related mechanisms usually located in these two layers. Nevertheless, the PHY layer parameters somehow involved in a cross layer optimization cannot be completely neglected. More precisely the impact on the above layers of issues such as the potentiality of the modulation scheme, the duration of the OFDM symbols (when this transmission technique is retained) or the sensibility to propagation condition of the transmission technique, can affect the deployment approach. Though all the PHY variants are still being considered, it seems evident that some configurations may ease the mesh deployment in certain scenarios. Typically, when the meshing terminals are fixes the usage of directive antennas to relay the information could be beneficial. Similarly, in wide area scenarios the use of those technologies or of MIMO ones could increase the coverage of the mesh network. Obviously techniques must be coupled with an adequate MAC scheme. On the contrary, in the mobile case a conservative choice may be to use the most robust transmission mode to avoid retransmissions. Finally, a strong influence on the deployment is performed by the working frequency of the network. It is well known that the high the frequency the shorter is the range of the transmission. This fact along with the rudeness of propagation condition in some scenarios lead somehow to the adoption of the OFDM transmission technique in relatively low frequency bands.

Generally it can be said that the mesh mode does not seem to be facilitated by one specific PHY solution. More precisely the mesh mode does not require specific PHY configuration but each one shall be investigated jointly with a specific MAC scheme and adapted to a specific scenario.

3.5.3.2 Topology/Architecture Issues and Applicability to Winner Scenarios

Mesh Network deployment presents many characteristics that recall the well known Mobile (multi-hop) Ad Hoc NETworks (MANETs). MANETs are commonly defined as collections of mobile nodes connected together over a wireless medium. These nodes can freely and dynamically self-organize into arbitrary and temporary ad hoc network topologies, allowing people and devices to seamlessly "internetwork" in areas with no pre-existing communication infrastructure (e.g., disaster recovery and battlefield environments).

However, this type of network did not impact our way of using wireless networks. Users seldom operate 802.11 in ad hoc mode and, except in laboratory test-beds, never use multi-hop ad hoc networks. From the users' point of view, scenarios consisting of a limited number of people wanting to form an ad hoc network for sharing some information or access to the Internet are much more interesting.

These considerations lead to relax one of the main constraints of MANETs, "the network is made of user's devices only and no infrastructure exists," toward networks neither isolated nor self-configured: mobile ad hoc networks rather emerge as a flexible and low-cost extension of wired infrastructure networks, coexisting with them. Indeed, a new class of networks is emerging from this view: mesh networks.

This brief explanation of the nature of mesh deployment gives a hint of the possible topology that this kind of network may assume. Mesh networks are built on a mix of fixed and mobile nodes interconnected via wireless links to form a multi-hop ad hoc network. Though several deployments of mesh network have been conceived by industry and academia, core building blocks and distinct features may easily be identified in mesh architecture. A wireless mesh network is a fully wireless network that employs multi-hop communications to forward traffic en route to and from wired Internet entry points. Users' devices dynamically join the network, possibly acting as both user terminals and routers for other devices, consequently further extending network coverage. For example, indoor mesh networks can be set up by wireless interconnected access points that can create extended WLANs without a wired infrastructure. Outside buildings, mesh networks can be used to provide wireless access across wide geographic areas by minimizing the number of wired ingress/egress points toward the Internet.

Different from flat ad hoc networks, a mesh network introduces a hierarchy in the network architecture with the implementation of dedicated nodes (called relaying node in the WINNER context) communicating among each other and providing wireless transport services to data travelling from users to either other users or access points (in mesh terminology, access points are often special wireless routers with a high-bandwidth wired connection to the Internet backbone). The network of wireless routers forms a wireless backbone (tightly integrated into the mesh network), which provides multi-hop connectivity between nomadic users and wired gateways.

This topology paradigm can be easily applied to many area networks and precisely they can cover all scenarios of the WINNER project. The following figures represent typical mesh deployments proposed in the context of the IEEE 802.11s TG covering respectively small/medium office and Hotzone scenarios. These two proposals can be easily adapted to the WINNER project since they represent roughly the scenarios conceived for the indoor and hot spot environments given in D7.2 [61]. With respect to the scenarios Metropolitan and Rural, WMN may represent an efficient alternative to the use of wired connection. The positioning of devices on top of the metropolitan building would allow covering areas that are usually served wirely. Moreover, the recently progress in the broadband wireless access systems and the research that the WINNER project will develop, will be able to satisfy the envisioned bit rate required in the definition of those scenarios.

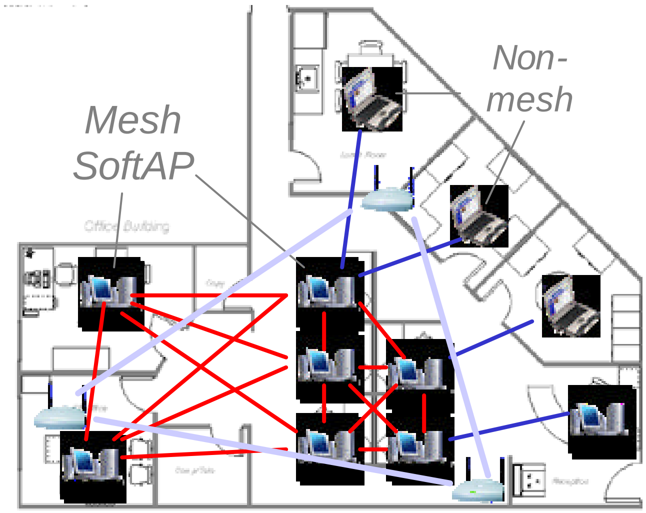


Figure 3-29: Relative throughput gain (in percent)

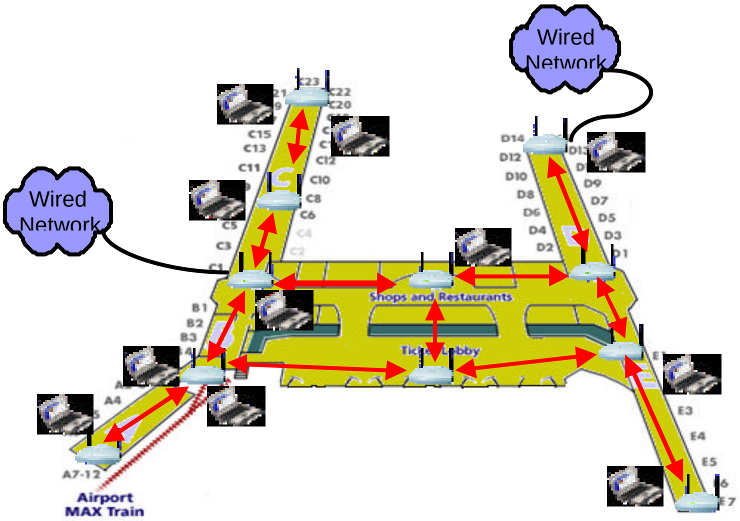


Figure 3-30: Example of mesh deployment in a Hotzone

On Figure 3-30, the meshing among wireless routers and access points creates a wireless backhaul communication system, which provides each mobile user with a low-cost, high-bandwidth, and seamless multi-hop interconnection service with a limited number of Internet entry points and with other wireless mobile users. Roughly and generally speaking, backhaul is used to indicate the service of forwarding traffic from the originator node to an access point from which it can be distributed over an external network. Specifically in the mesh case, the traffic is originated in the users' devices, traverses the wireless backbone, and is distributed over the Internet network. This type of configuration of a mesh network is often envisioned in the deployment of mesh systems[2]. To summarize, the Figure 3-31 illustrates the mesh network architecture, highlighting the different components and system layers.

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[2] Moreover, the wireless backbone can take advantage of non-mobile powered wireless routers to implement more sophisticated and resource-demanding transmission techniques than those implemented

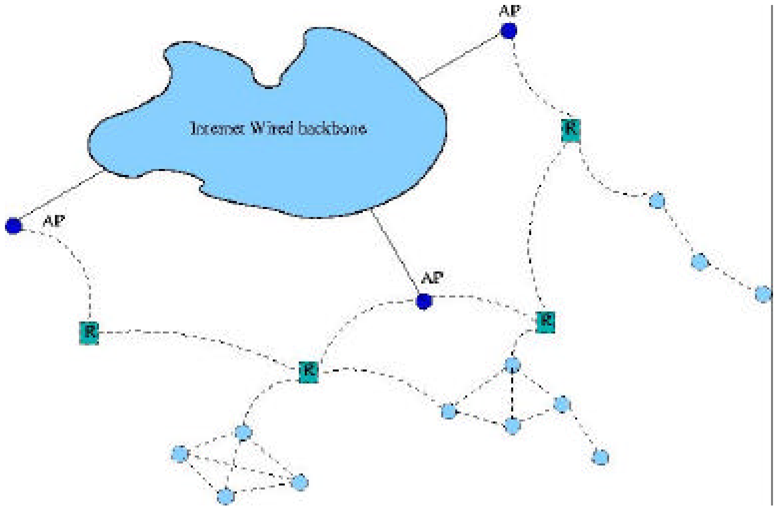

Figure 3-31: Typical mesh topology

3.5.4 Relays in the Context of WINNER Air Interface Characteristics

Among the scenarios where Relaying is expected to be beneficial are the hotspot scenarios characterized by relatively short transmission ranges. For operator controlled coverage in these scenarios, the WINNER project envisages an OFDM Time Division Duplex (TDD) based air interface with TDMA/OFDMA Multiple Access Scheme [62]. Discussions on the air interface will be ongoing beyond WINNER Phase I and the structure presented here may not be assumed to be final. However, Figure 3-32 - Figure 3-33 show the interim structure of the envisaged Medium Access Control (MAC) Resource Units (called Chunks) as currently under discussion within the cross WP group on MAC (XWP MAC) formed by members of WP2 and WP3. Frames and Superframe for the WINNER air interface for short-range operation in dedicated spectrum ("TDD dedicated" is one of the WINNER Physical Layer Modes, PLMs as defined by WP7). Table 3.9 summarizes the currently assumed parameters by WINNER WP2.

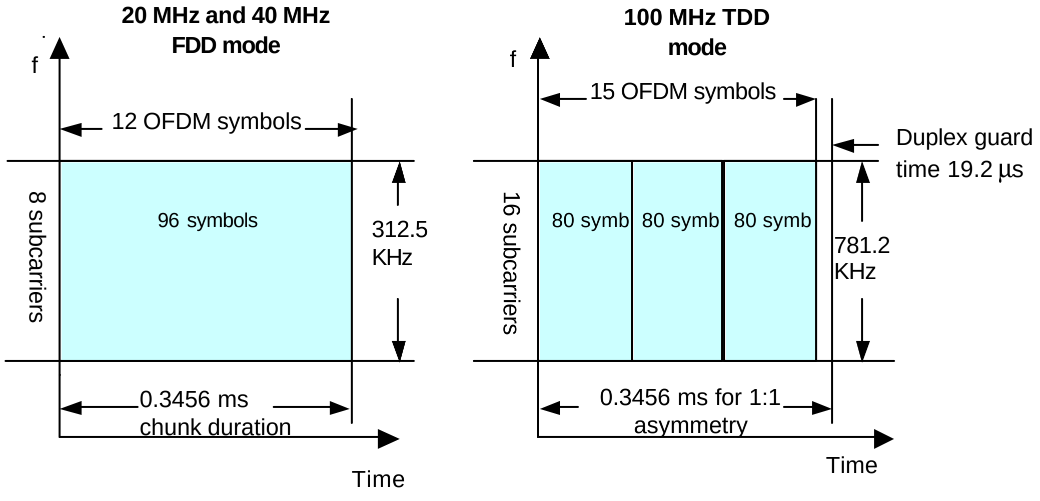

Figure 3-32: Summary of the chunk sizes in the two physical layer modes. The figures show a downlink slot (half of the frame) in each case. The uplink slot is identical at 1:1 TDD asymmetry.

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in user devices. Consequently, the wireless backbone can realize a high degree of spatial reuse and wireless links covering longer distance at higher speed than conventional WLAN technologies.

The proposed super frame concept is providing the means to exploit the advantages of both 2-hop relaying concepts as shown in Figure 3-32 and Figure 3-33. The "short" frames in the superframe could also be interpreted either as frames or as subframes without transmitting the BS control information per frame.

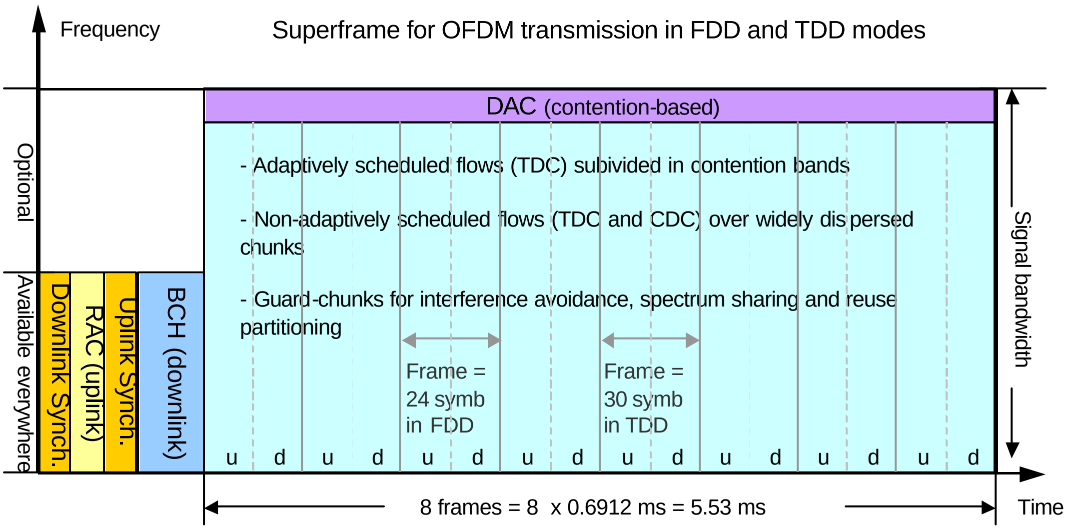


Figure 3-33: Superframe structure for both FDD and TDD physical layer modes. u = uplink transmission and d = downlink in TDD.

Table 3.9: Current "Snapshot" of assumed basic parameters for FDD and TDD physical layer modes

Parameter	FDD mode (2 x 20 MHz)	TDD mode	Units/notes
Centre frequency	4.2 UL, 5.0 DL	5.0	GHz [T27Spectr]
Number of subcarriers in OFDM	512	2048	Equals length of FFT
FFT BW	20.0	100.0	MHz
Signal BW	16.25, paired	81.25	MHz
Number of subcarriers in use	416	1664	[-208:208] and [-832:832] Subcarrier 0 not used
Subcarrier spacing	39062	48828	Hz
OFDM symbol length (Excluding guardtime)	25.60	20.48	µs
Guardtime /cyclic prefix	3.20	1.28	µs
Physical chunk size	312.5 x 345.6	781.25 x 108.0	KHz x µs
Chunk size in symbols	8 x 12 = 96	16 x 5 = 80	(Frequency x time)

3.5.4.1 Protocol Characteristics of Time-domain Based Relaying

As suggested in D3.1 [1], MAC frame based protocols as the one envisaged by WINNER show high potential to be applied to realise relaying in the time domain. The Logical Link Control (LLC) or MAC layer needs a store-and-forward function like that known from a bridge to connect LANs to each other. Alternatively, the forwarding can be performed on OSI Layer 3 to include routing functionality if the network topology can be subject to changes. When operating in the Forwarding Mode (FM) both signalling and user data have to be forwarded by the FRN. An FRN operating in FM ideally appears like a directly served UT to the BS. **Therefore, this does not preclude the possibility of allowing any UT to act as relay to become a Mobile Relay Node (MRN).**

To facilitate relaying, the capacity provided by the air interface (see Figure 3-33) has to be partitioned dynamically between the BS and the FRN. The degrees of freedom for resource partitioning are manifold:

- Time-domain (allocate different time-portions)

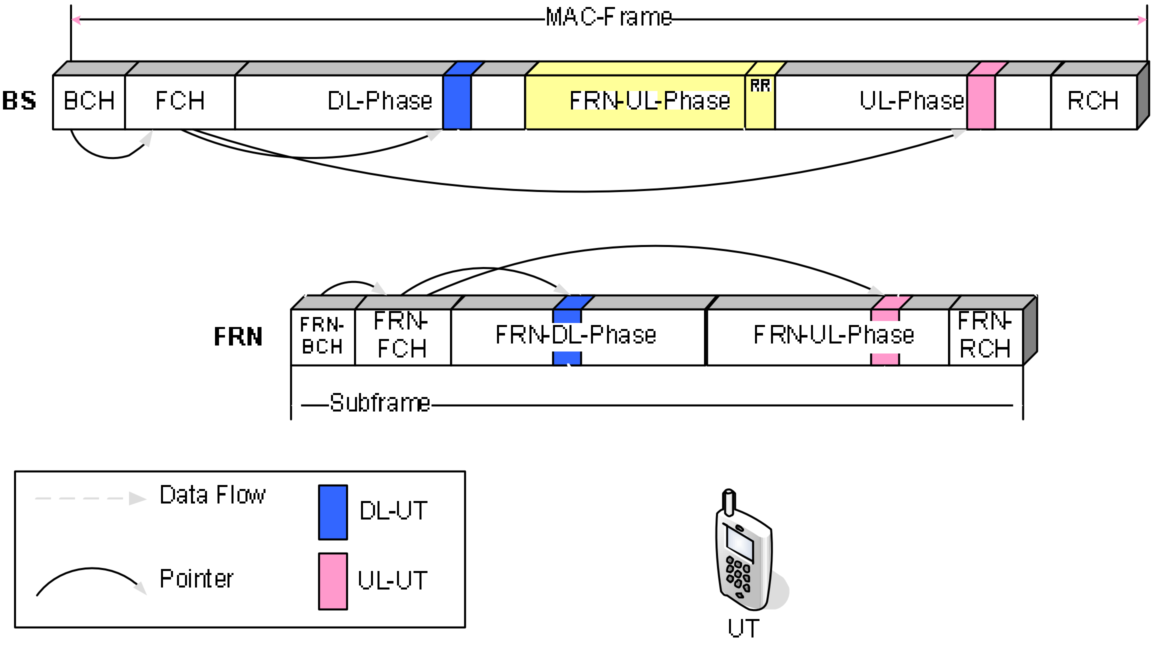
- Frequency-Domain (allocate different subcarriers)
- Spatial Domain (use smart antennas to transmit parallel, independent data streams and/or increase spatial re-use by exploiting mutual shadowing of FRN subcells)

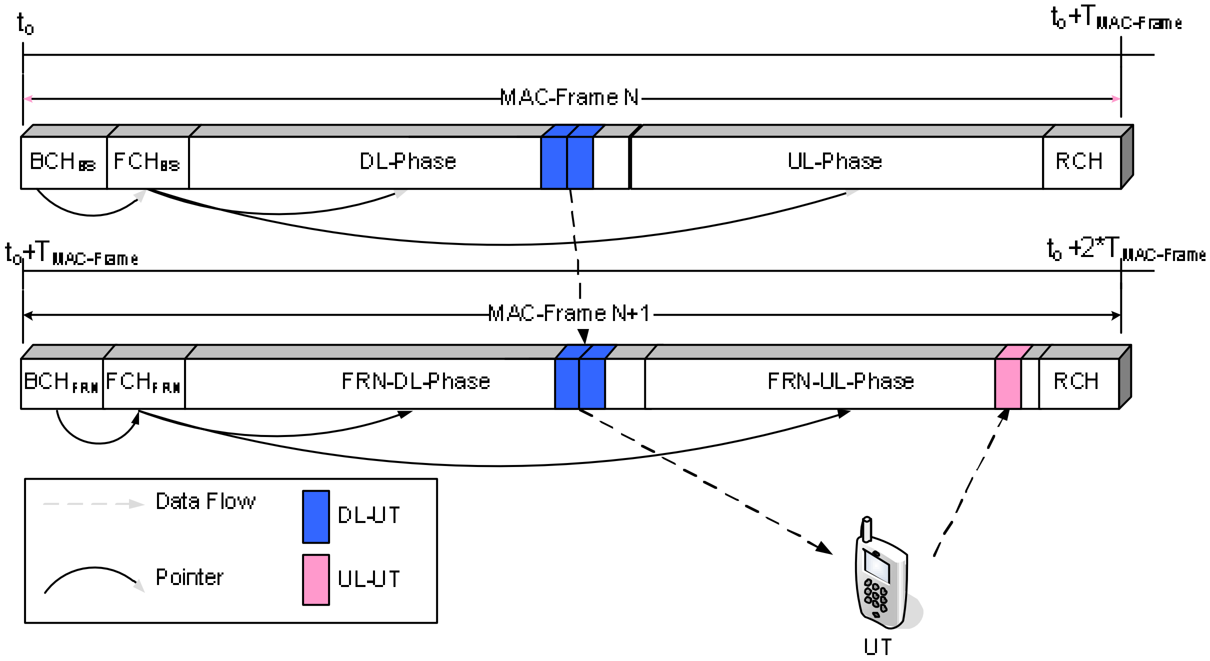
The versatile WINNER air interface theoretically allows exploiting all these dimensions. Even when concentrating on one dimension only as we will do in the following (as the majority of partners has so far concentrated on time-domain concepts), different concepts can be derived, each tailored to certain requirements. As two prototypical examples, we outline the straightforward solutions of

- Frame-In-Frame Relaying, and
- Frame-By-Frame Relaying

3.5.4.2 Frame-In-Frame Relaying

The Frame-In-Frame Relaying is based on the partitioning of one MAC-Frame (not Superframe) into Resources to be used at the BS and other, orthogonal resources (a so-called sub-frame, embedded into the original frame) to be used at the RN, the concept has been proposed and evaluated in Section 4.2.4.1 of D3.1 [1] and an overview of the data flow is shown in Figure 3-34. The advantages of this concept are that it allows for very short delays / round-trip times and that it can be cascaded.




t0
t0+TMAC-Frame
MAC-Frame N
BCHBS
FCHBS
DL-Phase
UL-Phase
RCH
t0+TMAC-Frame
t0 +2*TMAC-Frame
MAC-Frame N+1
BCHFRN
FCHFRN
FRN-DL-Phase
FRN-UL-Phase
RCH
Data Flow
Pointer
DL-UT
UL-UT
UT

4. Mobile Relay Concepts

In this section we address the three mobile relay-based deployment concepts for WINNER. The intention is to make a short introduction on those concepts, to present the logical/physical entities associated with these concepts and to find commonalities and differences under a harmonisation process of those concepts. Additionally, an initial evaluation is made based on some identified parameters. Some examples of technologies for current and "short-term" systems related to those DCs of Mobile Relays (MRs) which have been addressed in several fora (e.g. 3GPP) are presented and extrapolating from those, findings, proposals and suggestions are given as to the applicability of those three DCs for a WINNER-based system (Section 4.4). References are also made to the issue of power control/allocation for mobile relays extending the discussion included in [2]. Relevant results are included in Annex II.

In Section 4.2 a study on the multi-user diversity in the downlink of single-hop and multi-hop cellular networks will be performed. A base-station coordinated relaying method in a multi-hop cellular network will be proposed in order to overcome the fundamental limitations on the average achieved throughput per-user. In the proposed method, multi-user diversity is induced in a 2-hop forwarding scheme and then exploited to improve per user achieved data throughput. Simulation results will be also presented.

4.1 Description of Mobile Relay-based Deployment Concepts

Mobile relaying has been identified as another flavour of the relaying concept, researched under the WINNER project. Fixed relaying has been shown to provide a number of advantages in terms of addressing coverage and capacity issues for next phase generation networks. However, due to some special cases that have not been addressed e.g. Ad Hoc/unpredicted needs or due to the inability of fixed relays to address certain needs e.g. moving networks, the concept of mobile relaying has been addressed. Under this approach, three mobile relay-based Deployment Concepts (DCs) have been identified

- Concept 1 → Dedicated Mobile Relays Type I
- Concept 2 → Dedicated Mobile Relays Type II
- Concept 3 → Terminals acting as Mobile Relays (Type III)

A description of those concepts has also been made in [1] and [2].

4.1.1 Architecture / Logical-Physical Entities

Figure 4-1 shows the architecture of a multi-hop MR-based system. This figure shows the logical entities, which will affect the WINNER architecture.

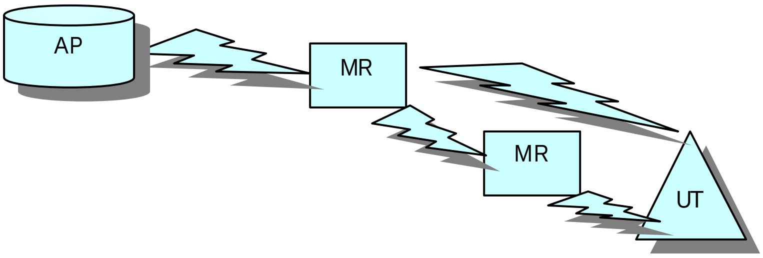


Figure 4-1: Mobile Relay-based architecture

Two types of physical entities can be assumed as the realisation of the logical entity of a MR: Terminals acting as mobile relays or elements built only for relaying purposes i.e. Dedicated Mobile Relays. This is portrayed in the next Figure 4-2.

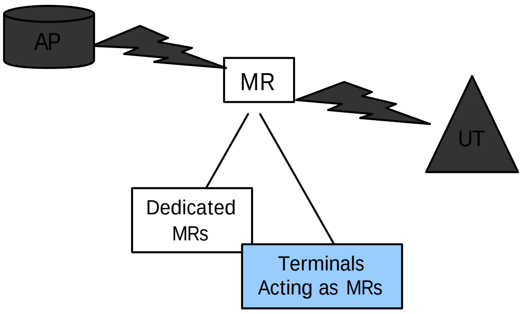


Figure 4-2: Physical entities of the logical MR entity

Those physical entities can be further "split" with reference to some general "usage cases". This is portrayed in the next Figure 4-3 where all the types of mobile relays are portrayed with reference to the "ownership", "movement" and "complexity". This is the main figure which the subsequent analysis/evaluation will be based on.

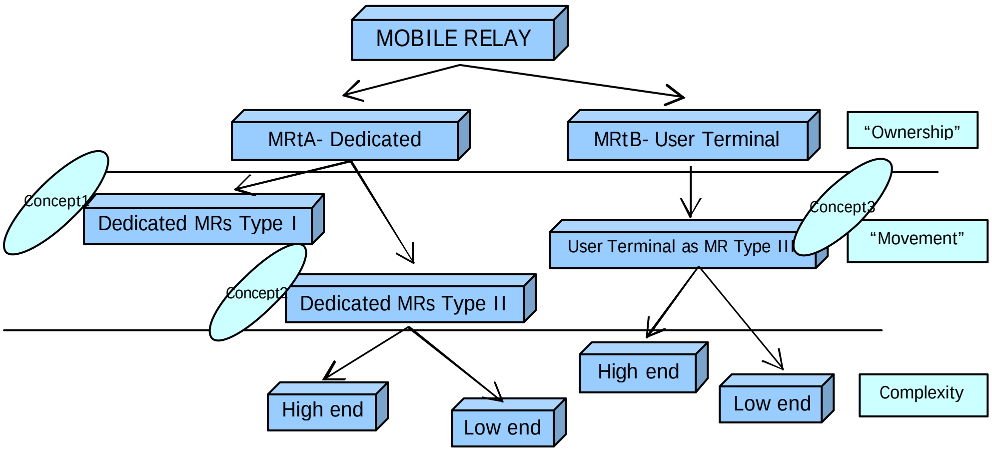


Figure 4-3: Mobile Relay types

Thus the above figure gives rise to the three basic MR-based deployment concepts pointed out before. Following the above discussion we further present a short description of those three concepts.

4.1.2 Description of Concepts

4.1.2.1 Concept 1 – Dedicated Mobile Relays Type I

The main characteristic with Type I is the fact that the mobility of those MRs is "correlated" with the UT population/target area to cover. A very typical example is that of MRs being fitted on trains to provide coverage inside the trains, the concept of moving networks.[2] [13] In Europe a large part of the population is commuting to work e.g. professionals spending a lot of time on trains, thus there is a need for high BW. Operators and train companies are lately interested in this area. Some basic characteristics of this type is that they will be built in relatively small numbers, be quite complex, thus more expensive, be required to support complex processes e.g. handover, be owned by operators or train companies. More information on moving networks will also be given in subsequent sections.

4.1.2.2 Concept 2 – Dedicated Mobile Relays Type II

Dedicated Mobile Relays Type II are mobile relays that are moving in an "uncorrelated" way with reference to the population of UTs/target area to cover. We have to state that the concept "target area"/ "population of UTs" can be used interchangeably. Some examples of this type of relays are the following

- Fitted on buses to provide coverage for areas outside the bus e.g. parks
- Police cars/ambulances to provide coverage in accident scenes/disaster areas.

- Ships e.g. riverboats

They are expected to be built in large numbers, be relatively simple and cheap to build, have low/medium complexity, be owned by operators or by other “public services-providers” e.g. police. They are expected to be below roof top on heights of e.g. 2-4 meters. Due to their reusability and the relatively low (compared to Type I) mobility, they are assumed to be cheap alternatives of providing coverage in multiple geographical areas e.g. parks, football grounds, streets or address coverage of Ad-Hoc/unpredictable/temporary needs e.g. accident scenes, rather than deterministic needs which are addressed by fixed relays.

4.1.2.3 Concept 3 – Terminals acting as Mobile Relays Type III

Mobile Relays Type III are user terminals that can additionally be used by the operators/network to provide relaying functionalities. They are expected to be medium/high end future terminals which not only will incorporate relaying functionalities, but at the same time will not jeopardise aspects of the user terminal e.g. cost, user experience, battery life and impose any restrictions. As it has been pointed out in [2], the bottle neck for this type of MRs is not that much any technological barriers, but rather the possibility of the users disabling this functionality or just switching their UTs off. Of course, the large population of available UTs might cancel this problem. Still, this is something that has to be taken into account. A similar concept, that of ODMA (Opportunity Drive Multiple Access), was proposed in 3GPP as part of the initial work towards Release 99. [14] Although not at that time such a mature technology, this concept can now be addressed, on a much broader case (i.e. BS functionalities and not just providing coverage to out-of-coverage UTs) under the MR Type III concept. Some more characteristics on Type III and on ODMA will be included in subsequent sections.

4.1.2.4 Cooperative Mobile Relaying

Cooperative relaying is another flavour of the relaying concept also under investigation within the WINNER project. It has been pointed out that cooperative relaying for fixed relays can add incremental gain for future systems. Under this study, effort was dedicated to address the Cooperative Mobile Relaying (CMR) concept. As it has been pointed out so far, some more complex processes should be implemented in the network. However, potentially CMR could be of advantage in the network e.g. exploit the existence of a MR when the channel conditions are becoming good due to its mobility.

4.1.2.5 Multi-hop

For fixed relays a number of schemes have been investigated with regards to the number of hops. It has been shown that the more the number of hops is, the more complex the system becomes, without providing, incremental gain. Under the perspective of mobile relays, we expect this complexity to increase even more, which in the end make any such multi hop scheme of many hops, very cumbersome. Thus, as we will present further, the number of hops should be kept to minimum, e.g. 2, and only under some very specific cases e.g. Type III, more hops e.g. could be supported.

4.1.3 Concept Harmonization

In this section what we intend to do is identify and list a number of parameters based on which an initial evaluation of those concepts will be done. Thus, what we have done is compose a Table which includes a number of parameters and values for each type of MR/DC Vs those parameters. Those parameters are mostly related to environment/topology/complexity. Additionally, the values presented are merely indicative to highlight the specific characteristics of each DC/types of MRs and effectively highlight commonalities and differences for each DC. A short description of those parameters in Table 4-1 is as follows

- % of the population. Percentage of the total number of MRs (of the same type) within the cell.
- Complexity: The complexity of each MR in terms of functionalities incorporated
- Velocity: Average velocity of that type of MR
- Mobility: Random or following certain trajectories
- User availability: The opportunity to be used when required without any user restrictions. Percentage of UEs available at each instance to be used by the network
- Pt(MR): MR transmission power as a percentage of Pt (AP). (One MR present in the cell, fixed power, Pt(AP)=10W)
- Range: Coverage in meters of the MR
- Power availability: Limited or unlimited power supply

- Processing power: Ability to support high functionalities
- Number of hops: Number of hops supported/intended
- Positioning: The opportunity to support GPS and/or other timing-based techniques. Accuracy in terms of how accurately their position can be calculated based on their deployment.
- CMR (Cooperative Mobile Relaying): Ability to support / Applicability on those DCs
- Trajectory Maps: Support of maps for trajectory calculation
- Cost : Production Cost

We will assume two classes of MR for the Type II and Type III, in order to assume high/low-end MRs. Thus, the table which will includes all the information is the following

Table 4-1 Mobile relay-based DCs related parameters

	Type I	**Type II**		**Type III**	
	Class I	**Class I**	**Class II**	**Class I**	**Class II**
% of population	100	70	30	80	20
Complexity	High	Low/Medium	High	Low	High /Medium
Velocity(km/h)	20-200	10-40	10-40	3	0
Mobility	Predicted	Predicted	Predicted	Random	NA/Stationary
User availability	NA	NA	NA	20%	50%
Pt(MR) (Watts)	1-2	2	3	0.2	0.5
Range (m)	Trains 100	300	500	Up to 100	Up to 300
Power availability	Always On	AO	AO	Limited	AO (?) Laptop
Processing Power	High	Medium	High	Low	Medium/High
Number of hops	2	2,3	2,3	2	2,4
Positioning Accuracy	GPS High	GPS/Timing High/Medium	GPS/Timing High	GPS/Timing Low/Medium	GPS/Timing Medium/High
CMR	YES/NO	YES/YES	YES/YES	Limited/Maybe	YES/YES
Trajectory MAPS	YES	YES	YES	NO	NO
Cost	High	Low/Medium	Medium/High	Low	Medium

The above will be used for the final discussion on those concepts on

- Applicability to the main WINNER scenarios
- Advantages and disadvantages
- Possible commonalities among those DCs
- Final suggestions

4.1.3.1 Applicability to Main WINNER Scenarios

In the previous section a list of some indicative parameters were presented for each MR-based DC, mostly on issues related to deployment/topology, complexity. Additionally, within WINNER a number of the most promising Scenarios have been identified. Thus, the applicability of those MR-based DC will be done with reference to those Scenarios.

The five Scenarios are the following.

- Scenario A.1. Indoor Hot-Spot
- Scenario B.1. Hot Area (wide area but non-ubiquitous coverage), typical urban
- Scenario C.2. Wide area (ubiquitous coverage), typical urban
- Scenario D.1. Rural (ubiquitous coverage)
- Based Scenario B.5. LOS Stationary Feeder for hot area

With the previous analysis of indicative parameters, effectively we picture the applicability of those concepts to the Scenarios. Some of the main parameters based on which this “mapping” will be done are the mobility, coverage, complexity.

- Type I -
    - Main characteristics→ High mobility, Small/medium coverage, High complexity
    - Applicability WINNER scenarios: The most applicable scenarios are those of Wide area/Rural areas where high velocities of trains are expected.
- Type II -
    - Main characteristics→ Medium/Low mobility, Large coverage, Medium complexity
    - Applicability to WINNER scenarios→ The most promising scenarios are those of hot spot and, mostly, wide area.
- Type III -
    - Main characteristics→ Low/zero mobility, Small coverage, Low/medium/High complexity
    - Applicability to WINNER scenarios→ The most applicable scenarios are those of indoors and hot spot, but some possible applicability also to wide area.

Comment: Where we have two “X”s we denote higher applicability for that DC.

Based on the above parameters and analysis we effectively come with the following Table 4-2 which shows the mapping of those DCs Vs the WINNER Scenarios.

Table 4-2 Applicability of mobile relay-based DCs to mainWINNER scenarios

	A.1 (Indoor)	**B.1** (Hot Area)	**C.2** (Wide area)	**D.1** (Rural)	**B.5** (LOS Feeder)	**Notes & Characteristics**
Dedicated Mobile Relays Type I			X	X		
Dedicated Mobile Relays Type II		X	XX			
Terminals as Mobile Relays Type III	XX	XX	X			

4.1.4 Related Technologies

Technologies related to the three MR-based DCs have already been proposed in other fora e.g. 3GPP. Thus, the intention in this section is to shortly elaborate on any similarities of those technologies with the three DCs. In this section we will only make some initial suggestions. The main discussion can be found in Annex II.

4.1.4.1 Mobile Positioning

Mobile relays could be used as an “enabler” to provide more accurate positioning estimates for UTs due to the probabilities of being closer to the UT, thus having better channels conditions e.g. LOS for the timing measurements e.g. RTT/OTDOA. Additionally, they can be used to overcome certain limitations in e.g. isolated sites, where either they can be used while they move to “mimic” a number of BSs or in conjunction with the BS for measurements.

4.1.4.2 MBMS

For Mobile Relays Type II, support for MBMS could be applicable so that that those MRs can be deployed to provide only multicast/broadcast services. As such, their functionalities are greatly simplified due to for instance, the no need for dedicated links with the UTs for e.g. power control, due to the “downlink” nature of those bearers.

4.1.4.3 ODMA

The ODMA concept proposed in 3GPP can now be seen under the Mobile Relay Type III deployment concept. So, it could be investigated how terminals can initially provide relaying functionalities to other terminals and then see how to extend this by having the mobile terminals providing more “enhanced” BS-like capabilities in the system.

4.1.4.4 Repeaters

Repeaters are part of Release99 for 3GPP. So, it would be interesting to study the possibility of deploying mobile repeaters i.e. very simple mobile relays and investigate how feasible such a solution is with reference to some issues e.g. topology/deployment

4.1.5 Power Control/Allocation Strategies for Mobile Relays (Type II)

In [2] it was shown that fixed power for the Mobile relays for the common channels can have substantial gain at the UT, with regards to the difference of the received power of the MR and the BS. However, there might be some implications e.g. increased interference or reduced coverage which in the end cancel the reason for the MR deployment. Thus, some other power strategies have been proposed i.e. the MR following predetermined power patterns with reference to a number of parameters e.g. its trajectory or following dynamic-power patterns which are being signalled continuously at the MR while this is moving. A more detailed analysis is done in Annex II which includes also some simulation results. This discussion is applicable to the Mobile Relays Type II and the support of multicast/broadcast bearers as stated in previous sections.

4.2 Multi-user Diversity in Multi-hop Cellular Networks

4.2.1 Abstract

In this section we study multi-user diversity in the downlink of single-hop and multi-hop cellular networks. We also propose a base-station coordinated relaying method in a multi-hop cellular network to overcome the fundamental limitations on the average achieved throughput per-user. In the proposed method, multi-user diversity is induced in a 2-hop forwarding scheme and then exploited to improve per user achieved data throughput. We show that using the proposed method, the downlink throughput per-user is significantly increased.

4.2.2 Introduction

A fundamental characteristic of wireless communications is the time variations of wireless channel. To mitigate the destructive effects of wireless channel time variations “*diversity*” is an important means, where the basic idea is to improve the system performance by creating several independent signal paths between the transmitter and the receiver.

In a wireless cellular network with multiple users, *multi-user diversity* is provided by having independent time-varying wireless channels between the base-station and different users in the cell coverage area (see Figure 4-4). The multi-user diversity gain arises from the fact that, in a system with many users whose channels vary independently, there is likely to be a user with a “very good” channel at any time. System throughput is then maximized by allocating the shared channel resource at any time to the user that can best exploit it [23], [24].

In this section, we first study multi-user diversity gain for average per-user throughput in a single-cell system. We consider a time domain scheduling scheme that exploits multi-user diversity by transmitting to the user with maximum channel gain in each time instant. We then show that for such method the main limiting factors are: number of users in the cell coverage area, base-station maximum transmit power, its maximum supported transmit bit-rate, and the average maximum channel gain.

We then consider multi-user diversity in multi-hop cellular networks with mobile relays. Multi-hop cellular networks are a promising combination of the dynamics of mobile ad-hoc networks and the reliability of cellular networks [25]. In multi-hop cellular networks, the data-units are transmitted to the destination through relays. By utilizing such transmission method an immediate advantage is the opportunity of exploiting multi-user diversity in each hop.

To exploit the multi-user diversity in a multi-hop network, a relaying method is proposed in [26]. In this method, multi-user diversity is exploited in each hop by selecting the next relay based on the instantaneous channel quality. However, the transmission to only one relay reduces the opportunity of finding a good channel between the selected relay and the next relay.

In this section, we propose a base-station coordinated relaying policy, Induced Multi-User Diversity Relaying (IMDR). IMDR uses the broadcast feature of wireless channel to induce multi-user diversity through a two-phase process. In the first phase, data-units are broadcasted by the base-stations with its maximum bit-rate. Some users in the cell coverage area are likely to receive the data-units. These users, acting as relays in the second phase, wait until the occurrence of a “good channel” to transmit data-units into the destination with maximum bit-rate. Transmitting to multiple relays in the first phase induces multi-user diversity into the system that can be exploited in the second-phase.

4.2.3 System Model

We consider a single-cell 2-hop data communication system with unit cell-coverage area that is a circles with radius $1/\sqrt{p}$. Base-station is located at the centre of the cell and its maximum transmit power is P_{max}. Air interface is based on Direct Sequence Coded Division Multiple Access (DS-CDMA) with chip-rate of W and maximum supported bit-rate of R_{max}.

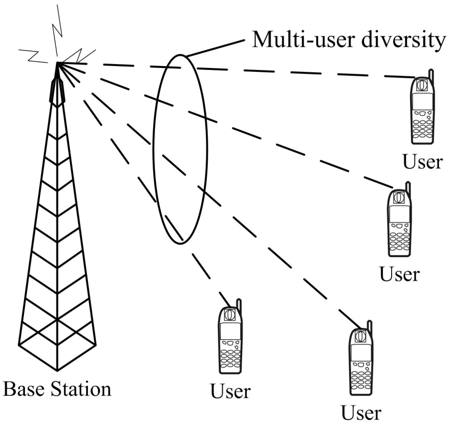


Figure 4-4: Multi-use diversity in a single-hop cellular network

Data-units can be transmitted directly from the base-station to the users, or they can go through one other mobile users serving as relays. There are n mobile users, indexed by i, distributed uniformly in the cell coverage area. Mobile users are able to receive, temporarily save and relay data-units in the same frequency band of base-station transmission. We assume each user has an infinite buffer to store relay data-units. Each data-unit has infinite delay tolerance and includes the identity of the destination user. Each user in the coverage area broadcasts a pilot signal to indicate its identity. This pilot signal is also utilized by other entities for channel estimation.

The wireless channel gain between the base-station and the ith user at time instant t is given by the process $\{g_i(t)\}$. We assume that the process $\{g_i(.)\}$ is stationary and ergodic. Moreover, for different users in the cell coverage area, the corresponding channel processes are assumed to be independent and identically distributed (i.i.d.).

At any time instant t, a resource allocation policy, Π , manages the data transmissions from the base-station to relays, or relays to destination users. For a resource allocation policy, Π , $\Gamma_i^{\Pi}(t)$ is the *achieved downlink throughput of user i* at time t, that is the number of bits received by users i at time t. For a resource allocation policy Π , we define *feasible long-term achieved per-user downlink throughput*, $\Gamma^{\Pi}(n)$, if for every i,

$$\liminf_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T}\Gamma_i^{\Pi}(t) \geq \Gamma^{\Pi}(n) \tag{7}$$

$\Gamma^{\Pi}(n)$ is a random quantity and it depends on the various factors including, base-station maximum transmit power and maximum supported bit-rate, number of users in the cell coverage are and their corresponding random channel condition. This definition in (7) is similar to that of presented in [27] for ad-hoc networks.

4.2.4 Multi-user Diversity

To exploit multi-user diversity in a single-hop cellular network, a time domain resource allocation policy, $\Pi_{\mathbf{D}}$, is used, in which, at each time, maximum base-station transmit power, P_{max}, is allocated to a user i^* where,

$$i^*(t) = \operatorname{argmax}\{g_i(t)\} \tag{8}$$

Therefore the aggregated interference due to simultaneous transmission to other users in the cell coverage area is simply eliminated. However, selecting i^*(t) only based on the channel condition may results in an unfair resource allocation. Some corrective scheduling methods are usually used to resolve the fairness issue (see e.g, [28], [29]). Since in this section our focus is on the multi-user diversity gain, we simply consider a long-term fairness requirement in which $\lim\inf_{T\to\infty} \frac{1}{T}\sum_{t=1}^{T}\Gamma_i^{\Pi}(t)$ for all user is the same, that is a direct consequence of the independent and identically distributed wireless channels across the different users in the cell coverage area.

In order to exploit multi-user diversity, according to $\Pi_{\mathbf{D}}$, data-units have to be delayed until the channel becomes "very good" relative to other users. Therefore, the time-scale of channel variations that can be exploited by $\Pi_{\mathbf{D}}$, is limited by the delay tolerance of the corresponding application.

It is shown that for resource allocation policy, $\Pi_{\mathbf{D}}$, the overall system throughput performance is significantly higher than that of simultaneous transmission [23]. The greater the number of users in the cell coverage area, the greater is the probability of occurrence of a good channel, which results in a greater improvement in the base-station downlink throughput. However, the achieved downlink throughput per-user is still limited by the maximum base-station transmit power, its maximum transmit bit-rate, and cell coverage area, thus limited by fundamental architectural constraints.

For transmission with rate $R_i(t)$ bits/s to user i, the basic bit-energy to the interference-plus-noise spectral density constraint should be satisfied. Thus

$$\frac{W}{R_i(t)}\frac{P_{\max}\, g_i(t)}{N_0} \geq r_i(t) \tag{9}$$

where N_0 is the background noise spectrum density, and $r_i(t)$ is the minimum required bit-energy to the interference-plus-noise spectral density for reception the data transmission with bit-rate $R_i(t)$. For a user i that is selected for transmission, using (9) we write,

$$R_i(t) \leq x_0 W g_i(t) \tag{10}$$

where $x_0 = P_{\max} /(\max\{ r_i(t)\} N_0)$. Therefore, for user i,

$$\lim_{T\to\infty}\inf \frac{1}{T}\sum_{t=1}^{T}\Gamma_i^{\Pi}(t) = \lim_{T\to\infty}\inf \frac{1}{T}\sum_{t=1}^{T} a_i(t)R_i(t) \tag{11}$$

where $a_i(t)$ is the selection indicator; $a_i(t)$=1, if user i is selected for transmission at time t, and 0 otherwise. Summing (11) over all users, we have

$$\Gamma^{\Pi_{\mathbf{D}}}(n) \leq \frac{x_0 W}{n}\lim_{T\to\infty}\inf \frac{1}{T}\sum_{i=1}^{n}\sum_{t=1}^{T} a_i(t) g_i(t) \tag{12}$$

$$= \frac{x_0 W}{n}\lim_{T\to\infty}\inf \frac{1}{T}\sum_{t=1}^{T} g_{i^*}(t) \tag{13}$$

Eq. (13) shows that the downlink throughput per-user is bounded by the values of $g_{i^*}(t)$.

To increase multi-user diversity gain, in [28] multiple transmit antennas are used to induces large and fast channel fluctuations, i.e., greater $g_{i^*}(t)$. Also in a multiple-cell scenario, the independent time variations of the channels between a user and the neighbouring base-stations is introduced in [30] as a new dimension in multi-user diversity. This form of diversity is exploited by joint base-station assignment and packet scheduling, which results in greater $g_{i^*}(t)$ and thus greater multi-user diversity gain per-user.

4.2.5 Multi-user Diversity in Multi-hop Cellular Communication

In multi-hop cellular networks, there is an opportunity to exploit multi-user diversity in each hop. Here, we consider a 2-hop cellular system (Figure 4-5:). In the first hop, between the base-station and the relay, the base-station transmits with its maximum bit-rate. Data-units are received by *m* users in the cell coverage area. These users act as relays for the communication in the next hop. In the second hop, a relay transmits a data-unit to its corresponding destination upon observing strong channel. Since by this scenario we *induce* multi-user diversity through generating independent paths between the destination user and *m* relays we name it Induced Multi-user Diversity Relaying (IMDR). A brief description of IMDR in the simplest case is presented in the followings.

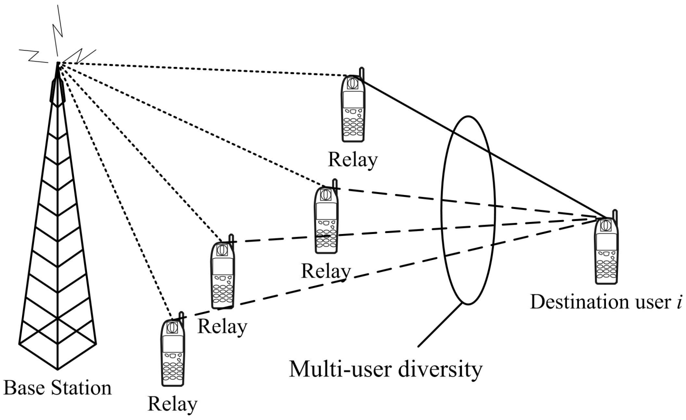


Figure 4-5: IMDR for single-relay

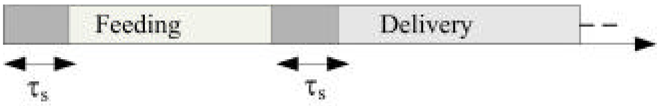


Figure 4-6: IMDR two-phases

The proposed scenario, $\Pi_{\mathbf{I}}$, has two phases: the *feeding phase* and the *delivery phase*. These two phases occur sequentially in time (Figure 4-6:). The time-span of each phase is assigned based on the network traffic and the communication environment characteristics. In each phase, t_s seconds of each time-slot is considered for signalling purpose.

4.2.5.1 Feeding Phase

In the feeding phase, data-units are broadcasted by the base-station with the maximum bit-rate and maximum transmit power. Any user which receives a data-unit in the feeding phase acts as a relay in the delivery phase. The selection of the order of transmission of the queued data-units in the base-station is managed by a higher-layer functionality. If the destination user, is among those users who receive data-units in the feeding phase, it sends a received acknowledge signal, R-ACK, to the base-station. Consequently, the base-station broadcasts a data release signal, D-REL, and all other relays release that data-unit.

4.2.5.2 Delivery Phase

In the delivery phase, base-station is kept inactive and only the transmissions from the relays to the final destinations are allowed. Each relay continuously tracks the quality of the wireless link to the neighboring users as well as their identity. If a relay is able to achieve a transmission bit-rate, greater than or equal to a system parameter R_0, over the channel to the destined user, that relay transmits the data-units to the destination user. Medium access control can be either a contention-based method or a base-station coordinated non-contention based method. Upon successful transmission, destination user sends an R-ACK signal to the base-station. Consequently, the base-station broadcasts a D-REL signal and other relays release that data-unit. If the base-station does not receive R-ACK corresponds to a data-unit in a predefined time interval, $t_{\max}$ seconds, that data-unit is considered lost and a D-REL signal is broadcasted by the base-station. That data-unit may be considered for retransmission in a later time.

Note that, in the feeding phase data-units are fed with the highest bit-rate into the users in the cell coverage area. Therefore, the base-station time is only allocated for transmission with the highest bit-rate. For a large number of users in the cell coverage area, it is likely that some users have a channel state that supports the base-station highest bit-rate.

In the delivery phase, we exploit multi-user diversity by transmission only on the channels with the highest achieved bit-rate. Note that in practice the transmit bit-rate may be adjusted based on the channel status which is fed back into the base-station by the users. An intelligent directional relaying based on the location of the users can also be considered for more improvement in the total throughput.

In IMDR, we also utilize the benefits of cellular architecture through utilizing the base-station knowledge of cell-wide channel state information for medium access coordination in the delivery phase. The parameters $t_{\max}$, the time span of each phase, and R_0 can be also adjusted by the base-station or an upper-layer mechanism based on different environmental factors and/or traffic demand.

In IMDR for $R_0 \le R_{\max}$, and large number of users in the cell coverage area, *n*, it is simple to show that

$$\Gamma^{\Pi_{\mathbf{I}}}(n) \le \frac{x_1 W}{n}\breve{g} \tag{14}$$

where x_1 is defined similar to x_0 in (10)correspondingly. In (14), we assume that within the interval [1, *T*] for $T \to \infty$, the data-units transmitted to the relays will be delivered to the users. $\breve{g}$ is the minimum time-average value of $g_i(t)$ between the base-station and a relay that is needed for transmission with the maximum bit-rate, note that

$$\lim_{T\to\infty}\inf \frac{1}{T}\sum_{t=1}^{T} g_{i^*}(t) \le \breve{g} \tag{15}$$

which directly results in $\Gamma^{\Pi_{\mathbf{I}}}(n) \ge \Gamma^{\Pi_{\mathbf{D}}}(n)$. In other words, using IMDR, the achieved average throughput per user is increased.

4.2.6 Simulation Results

We simulate a single-cell DS-CDMA system based on UMTS standard [65] with *n* active users. Users are uniformly distributed in the cell coverage area. The simulation parameters are presented in Table 4-3. To show the effect of multi-user diversity, we consider three different systems: in System I, for each user the base-station transmits data-units in first-come-first-serve fashion using a time domain scheduling scheme i.e., each user at a time instant. In System II, data-units are scheduled based on $\Pi_{\mathbf{D}}$. Transmission in System III is based on $\Pi_{\mathbf{I}}$, with a non-contention based medium access method in the delivery phase.

We normalize the average achieved throughput of Systems II and III by the average achieved throughput of System I. Figure 4-7: illustrates the normalized average achieved throughput versus number of users in the cell coverage area. The difference between the throughput gains of System II and III indicates the achieved multi-user diversity gain resulting from exploiting the induced multi-user diversity by IMDR. As it is expected, this gain is increased by the number of users. Note that normalized throughput curve will saturate because of the base-station total throughput constraint.

Table 4-3 Simulation parameters

Parameter	**Value**
Physical layer	Based on UMTS
Cell radius	100 m
Base-stations transmit power	10 W

Standard dev. of log-normal fading	8 dB
Bckground noise density	-174.0 dBm/Hz
Propagation loss exponent	4
Time-slot length	10 ms
Minimum required E_b/I_0	2 dB

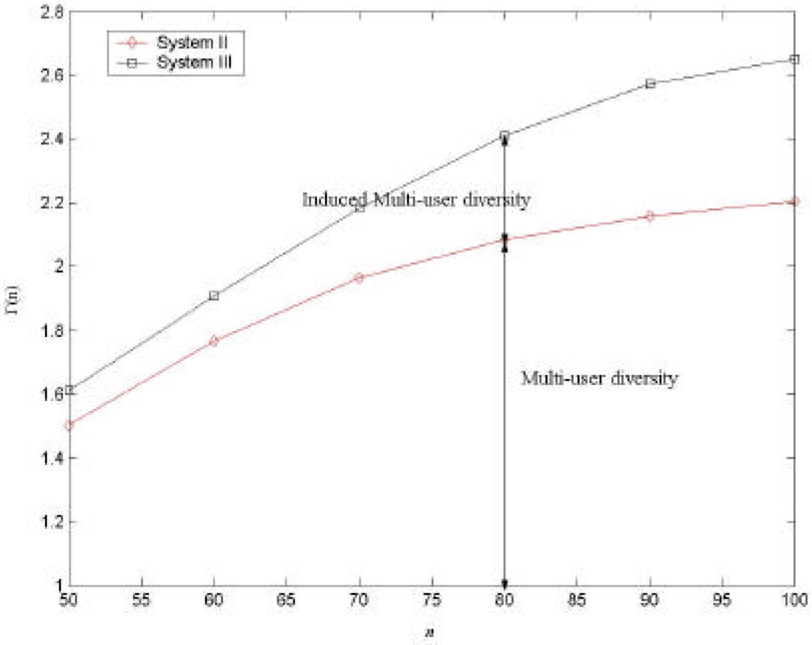


Figure 4-7: Normalized average achieved throughput versus the number of users

4.2.7 Conclusions

In this section we studied the multi-user diversity in the downlink of single-hop and multi-hop cellular networks. For a 2-hop cellular network with mobile relays, we proposed a base-station coordinated relaying method, induced multi-user diversity relaying. IMDR is a two-phase process in which multi-user diversity is induced in the first phase through forwarding the data-units into a number of relays, and then exploited in the next step through transmission on the best link between the relays and the destination users. We showed that using the proposed method, per-user throughput is significantly increased.

4.3 Concept Harmonization

Because fixed relaying concepts are considered as the main category for the WINNER deployment scenarios, the main focus w.r.t. harmonization has been in this area, and the work on concept harmonization for mobile relays has therefore not been started yet.

4.4 Conclusions

In the previous sections we have presented the three mobile relay – based deployment concepts proposed within WINNER WP3. What we have done is

- Provide a description for each of them
- Present physical/logical entities associated with those concepts
- Define some usage cases that could be applicable
- Identify a number of parameters that could be used for evaluation

From the above discussion some initial recommendations can be proposed, which are the following:

- Mobile Relay Type I: This is a quite promising approach, which can provide coverage to a large number of users e.g. commuters with trains. However, it is somewhat limited in terms of usage cases. Train commuting is quite frequent in central/Northern Europe, and is more biased towards high speed, and business users. However, in other areas e.g. South Europe is not as common. Thus, in order to be able to make a good business case it would be interesting to investigate other usage cases e.g. buses/ships, in order to provide a more holistic solution. At the same time it could be interesting to find any commonalities with Type II MRs so that e.g. production cost can be reduced.
- Mobile Relays Type II could be used for multicast/broadcast services. The whole process of using them for dedicated purposes could complicate the deployment concept and also internal processes e.g. L1/2/3 functionalities. However, by having MRs which are dedicated only to common/broadcast channels then a more cheap, easy to build & deploy solution is provided. For instance, no dedicated power control with the UTs is required and effectively the mobile relays could be left to Tx continuously. Of course BS-MR coordination is required, e.g. to reduce interference or not to waste resources. However, this is only with one of the two links.
- Mobile Relays Type III: Due to the type of terminals (limited relaying functionalities, limited power) it may be the case that we cannot rely on them for "deterministic" needs. Additionally, at any time the user can switch off the UE/ disable the functionalities which in the end might be a more important drawback compared to e.g. limited functionalities. It is anticipated that future mobile phones will incorporate more functionalities and in the end some simple type relaying function could be provided by those. For these reasons it is anticipated that the network can make use of those MRs more on an Ad-Hoc basis for e.g. "fast" applications which don't require high resources. So, not only the handset is not required to perform high functionalities, but also it could be seamless to the user. Of course we have always to think, from the point of view of operators the incentives that should be given to the users. Otherwise, users who don't gain anything might as well switch this functionality off, if this is an option. Still, the main advantage is the plurality of terminals we can select from. In general, in the case of MR Type III a number of technical/usage-related, ownership issues need to be addressed. It is a more complex scheme than Type I or Type II, but provides more flexibility and potentially it could be extended to a semi-Ad-Hoc network supporting true multi-hop scenarios, where no hierarchical approach exist. Of course this may be out of scope of WINNER but could be considered for future.

Finally, we should always bear in mind other similar systems. For instance, as stated previously for automotive industry, commonalities of future-to-come vehicular-based networks with possible MR-based DCs could be highlighted and any Interworking would be interesting to investigate. In the end, synergies between such networks should be promoted. For instance, a car-to-car communication could be extended to a car-to-MR network and then to a MR-BS network, thus promoting Interworking of all networks.

Simulation results have also been presented, either in the past or within [2] and within this document (Section 5 and Annex II). Although relatively to a limited extend, they show that there are advantages which can only be offered by the mobile relaying approaches/concepts e.g. Type III-related (i.e. terminals acting as mobile relays), which means that some aspects of the mobile relaying could be further investigated. Additionally, in future networks, it is envisaged that more complex capabilities will be existing e.g. faster signalling procedures, more processing power, lower delays which means that mobile relay-based concepts and their related functionalities and processes would be more easily supported compared to the point of view we have from looking at today's networks.

What we have seen so far is an initial analysis of the mobile relay-based deployment concepts. Advantages and disadvantages were presented as an initial study of the "applicability" of those concepts in a real system. Additionally some parallels to those concepts related to current and short term systems were presented. The intention was to show the possibility of those concepts being extended through the MR concepts. However, this will part of a further analysis where more specific suggestions will be made. We should also keep in mind current technological advances so that any proposals for future extensions could be a smooth migration of current/short-term proposals for short term systems. Still, that does not mean that revolutionary steps can not be taken. One important area is 3GPP where work towards the Long Term Evolution of 3GPP is taking place. The intention is to provide a system "beyond 3G" which will provide a number of new perspective for cellular systems. [19] So, any commonalities/synergies with the WINNER work would be important to highlight.

5. Coded Bi-directional Relaying

5.1 Introduction

In this section, we consider bi-directional communication between two nodes communicating via one or several relay nodes. We present a novel communication method based on joint data packet encoding and exploitation of a priori known information that enables reduced number of transmissions by relay nodes, and consequently, the proposed method enhances the aggregate system throughput. In the following, communication via one relay node (i.e. two-hop forwarding) is primarily considered but extensions to cover more than one relay node is straightforward. The proposal was originally presented in [8].

5.2 Detailed Description

While the proposed scheme may be applied between any two nodes communicating via one or several nodes acting as relay nodes, the presentation in this section will be restricted to how the proposed scheme could be used in a two-hop cellular network with a base station, a relay node and a user terminal.

In a cellular system, traffic is normally communicated in both uplink and downlink between a base station and a user terminal. When introducing an intermediate relay node, the most straightforward extension to the notion of downlink and uplink is to use four orthogonal resources for BS-to-RN, RN-to-UT, UT-to-RN, and RN-to-BS transmissions (henceforth denoted classical relaying). It should be noted that these four phases (i.e. BS-to-RN, RN-to-UT, UT-to-RN, and RN-to-BS transmissions) not necessarily have to be arranged in this order. An example is shown in Figure 5-1 (left) where a) to d) represents different time instances (though not necessarily consecutive).

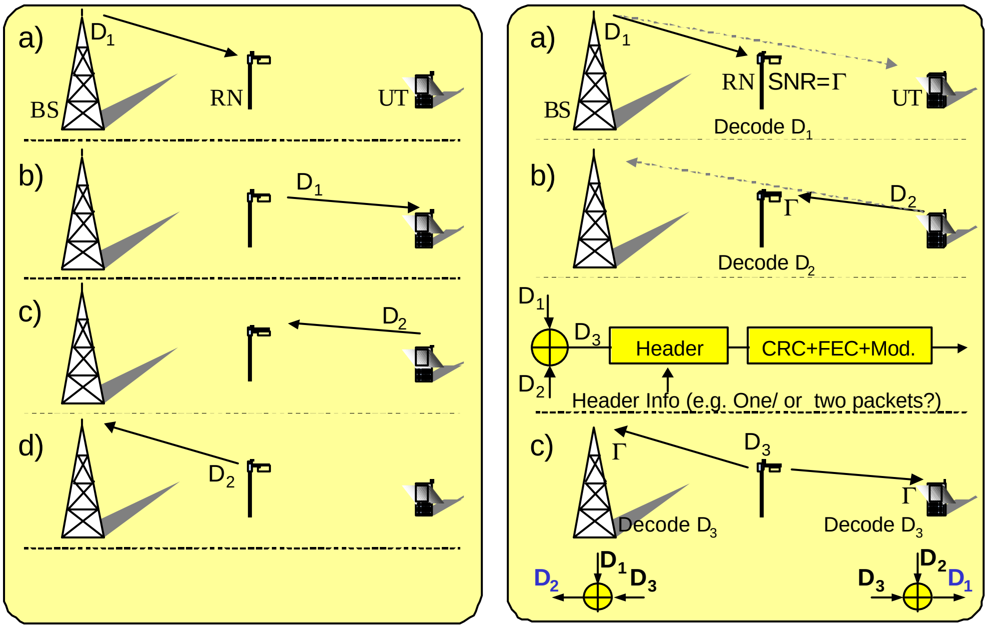


Figure 5-1: Classical (left) and proposed (right) scheme

We now propose a more (energy and/or capacity[3]) efficient relaying solution. The guiding observations towards the proposed method are:

- the wireless medium is of broadcast type, and
- the bi-directional topology itself.

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[3] In reality there is always a trade off between throughput and power/ energy consumption.

The basic idea is to jointly encode data received from the BS destined for some UT with data received from the same UT (destined for the BS) in the relay node into a jointly encoded data packet. When each node, i.e. the BS and the UT, receives the jointly encoded data packet, each exploits a priori information of its originally transmitted (and stored) data[4] to decode the jointly encoded data packet. This is also depicted in Figure 5-1 (Right).[5] In phase a) and b) transmissions takes place from BS-to-RN and UT-to-RN, and the relay node decodes the received data packets D_1 and D_2. In phase c), the relay node jointly encodes the data packets D_1 and D_2 with a bitwise XOR operation[6] into a common data packet D_3, i.e. prior to modulation and Forward Error Correction (FEC) encoding[7]. Subsequently the RN multicast D_3 to both the BS and the UT. Hence, instead of two transmissions from the relay node, only one transmission is used, but the same amount of data is transferred with the same energy expenditure as for one (the worst) transmission. At decoding at the BS, a bitwise XOR operation of the data packet D_3 (after error correction and demodulation) and the a priori information D_1 is performed, which then yields D_2. The UT performs the corresponding operation. If the data packets are of unequal length, zero-padding of the shorter data sequence is used. Moreover, when the link quality of the two links from the relay node differs, the relay node transmit power is preferably set according to the most stringent link requirement.

An example of a possible code-frame format is shown in Figure 5-2, where the packets from two nodes are bitwise XORed in the relay node. Note that it is possible (and preferred) to replace the individual Cyclic Redundancy Check (CRC) on D_1 and D_2 seen at reception at the relay node. Those CRCs are replaced with a common CRC over the bitwise XORed packet. Moreover, it may be advantageous to let the relay node append an extra header indicating characteristics of the relayed bitwise XORed packet (this information may also be signalled out of band). The composite header may for instance indicate if one or two packets are transmitted (e.g. if D_1 was in error, one may decide to only forward D_2). If the two packets are of unequal length, and if this is the case it also needs to indicate the length of the shortest packet and which of the two packets that is the shortest. In all, the extra header includes the necessary information to allow the receiver to identify and to exploit a previously sent packet, in order to extract the new information.

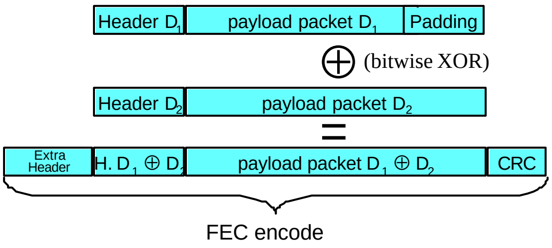

Figure 5-2: Encoding frame format

Several extensions of this basic scheme may be envisioned, e.g. the idea of bi-directional 2-hop relaying is trivially extended to multiple hops. In addition, the direct signals BS-to-UT and UT-to-BS can be exploited, e.g. through Incremental Redundancy and Chase Combining strategies.

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[4] N.B. also received-and-forwarded as well as overheard information can be exploited.

[5] N.B as for the classical four phase case, the phases here described do not necessarily have to be consecutive in time. Moreover, phase a) and phase b) may be interchanged.

[6] N.B. the method for encoding is preferably based on XOR bitwise encoding, due to its simplicity, but other codes (with the desired invertability) may also be used such as an erasure code like Reed Solomon. Moreover, more than two packets may also participate in the bitwise XOR operation.

[7] N.B. by performing the FEC encoding after the XOR operation no extra complexity is added in the receiving nodes (i.e. BS and UT).

5.3 Performance Evaluation

In the following, we analyze the proposed scheme by means of Shannon capacity bounds of the aggregate rate under an aggregate energy constraint. The proposed scheme is compared with a classical four-phase solution. A three-node system is considered, with nodes v_k, $k=\{1,2,3\}$. Nodes, v_1 and v_2 are nodes that have data packets of lengths L_1 and L_2 bits respectively queued for one another, whereas v_3 is a relaying node. Further, each node transmits a complex Gaussian signal with power P_k, $k=\{1,2,3\}$ over a flat channel with gain G_i, $i=\{1,2\}$, where G_1 and G_2 is the (reciprocal) gain between nodes v_1 and v_3 and nodes v_2 and v_3 respectively. At reception, complex Gaussian noise (and interference) with variance s_k^2 is added, however to make the analysis a bit easier we assume that the noise level is equal at all nodes. In the analysis, it is furthermore assumed that power and data packet lengths are the variables that we aim to optimise.

The transmission times for the proposed scheme is given by the number of bits transferred divided by the channel rate, i.e.:

$$t_1 = L_1 \big/ B\lg_2\left(1+P_1G_1 \big/ s^2\right) \tag{16}$$

$$t_2 = L_2 \big/ B\lg_2\left(1+P_2G_2 \big/ s^2\right) \tag{17}$$

$$t_3 = \max\{L_1, L_2\} \big/ B\lg_2\left(1+\min\{P_3G_1, P_3G_2\} \big/ s^2\right) \tag{18}$$

, where $t_k = T/3$, $k=\{1,2,3\}$ and T is the full frame duration. Here it is assumed that any packet transmitted must fit into one time-slot, where the slot length is equal to one-third of the frame duration for the three phase case (and one-fourth in the four phase case). In order to compare the two schemes, an aggregate energy constraint is imposed. In the three phase case, the constraint reads:

$$E = (P_1+P_2+P_3)T/3 \tag{19}$$

The aggregate rate is the total number of transferred bits divided by the frame duration:

$$R = (L_1+L_2)/T \tag{20}$$

After some algebra the optimum rate for the proposed scheme can be determined to be:

$$R_3^{(opt)} = 2/3 \cdot B\lg_2(1+3\Gamma_3^{(eff)}) \tag{21}$$

, where:

$$\Gamma_3^{(eff)} = \frac{\overline{\Gamma}_1' \cdot \overline{\Gamma}_2'}{\overline{\Gamma}_1' + 2\overline{\Gamma}_2'} \tag{22}$$

, and where:

$$\overline{\Gamma}_1' = \min\{\overline{\Gamma}_1, \overline{\Gamma}_2\} \tag{23}$$

$$\overline{\Gamma}_2' = \max\{\overline{\Gamma}_1, \overline{\Gamma}_2\} \tag{24}$$

$$\overline{\Gamma}_1 = \overline{P} \cdot G_1 \big/ s^2 \tag{25}$$

$$\overline{\Gamma}_2 = \overline{P} \cdot G_2 \big/ s^2 \tag{26}$$

$$\overline{P} = E/T \tag{27}$$

In a similar way, one may derive the optimum rate for a classical four-phase relaying scheme:

$$R_4^{(opt)} = 1/2 \cdot B\lg_2(1+2\Gamma_4^{(eff)}) \tag{28}$$

where,

$$\Gamma_4^{(eff)} = \frac{\overline{\Gamma}_1 \cdot \overline{\Gamma}_2}{\overline{\Gamma}_1 + \overline{\Gamma}_2} \tag{29}$$

The relative throughput improvement using the proposed three-phased scheme as opposed to a classical four phased relaying scheme is plotted in Figure 5-3 as a function of the experienced " mean signal-to-noise ratios" as defined in (25) and (26). As can be seen in the figure the gain is upper bounded by a 33% gain improvement (or the ratio 4/3) at equal signal-to-noise ratio and the gain is lower bounded to unit value when the path losses differ significantly. The throughput gain in bi-directional multihopping (with large number of hops) can be shown to be upper limited to a factor of two. Moreover, it was also found that when optimising the aggregate throughput under the current assumptions that the (end-to-end) rates in the uplink and downlink directions were equal (i.e. $L_1 = L_2$).

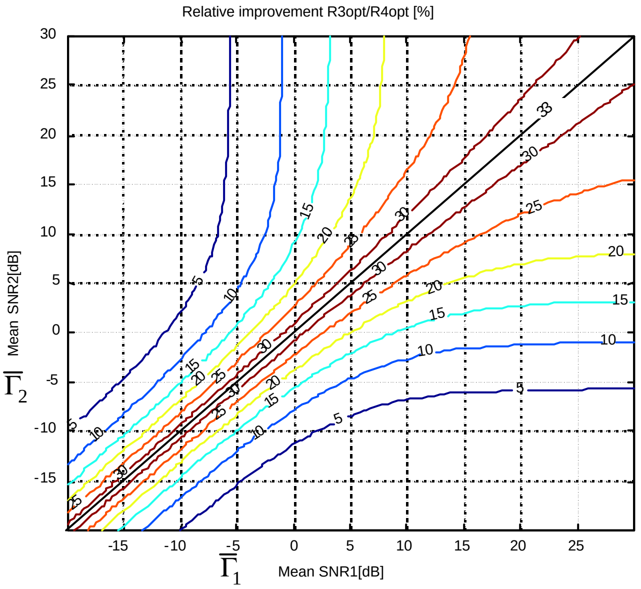


Figure 5-3: Relative throughput gain (in percent)

5.4 Observation

It can be argued that one could achieve the same goal of reduced number of transmissions with a beamforming solution, with one beam to the BS and one to the UT respectively (in essence a Spatial Division Multiplex Access (SDMA) solution). Obvious benefits exist for beamforming in general, but some disadvantages could also be seen relative the proposed scheme.

- Technical aspects
    - A disadvantage of a beamforming-enabled relay node is that two concurrent beams will at least to some extent, interfere with each other. If at least one of the beams allows for adaptive beamforming (and then the other is of fixed beam type), the algorithm(s) for finding antenna weights should consider the interference aspect. Finding antenna weights fulfilling this is non-trivial. Some channel/direction realization may not even have a solution.
    - Since multiple beams require multiple amplifiers, one must ensure that inter-modulation products due to back-coupling in the power amplifiers do not arise.
- Cost aspects
    - Supporting multiple concurrently transmitting beams, disregarding whether adaptive or fixed beam solutions are considered, requires more hardware than the proposed scheme. More hardware could be expected to be more costly. For example, in the adaptive beamforming case, multiple antennas and associated power amplifiers are required. In the fixed beam case, at least two antennas are needed as well as two different power amplifiers. In the proposed method, only one antenna and power amplifier is required.

Nevertheless, if one allow for beamforming, it could evidently also be combined with the proposed idea.

5.5 Conclusions

In this section, a new communication scheme for bi-directional relaying has been proposed that removes the need of forwarding data to the BS and the UT in two different transmissions, but instead uses only one transmission. The maximum gain for a simple two-hop forwarding scenario was found to be 4/3. Some extensions of the core idea have also been highlighted.

6. Cooperative Relaying

6.1 Introduction

Cooperative relaying is a concept that can – at least in principle – be applied on top of the relaying techniques discussed so far. This section serves two purposes: first, to discuss the ongoing work within the cooperative relaying group, and second, to summarize the concepts from the viewpoint of applicability to WINNER.

Recall from [1] and [2] that cooperative relaying differs from conventional store-and-forward relaying in that the source's transmission is taken into account at the destination. By doing so, the inherent diversity of the relay channel can be exploited - in addition to the benefits of reduced end-to-end path losses provided by conventional relaying.

We start in section 6.2 with a description of the ongoing work, which has focused on Cooperative Cyclic Delay Diversity, Fixed Relay-Assisted User Cooperation, and an in-depth consideration of Cooperative Connectivity Models. In section 6.3 we then briefly review the concepts that have been considered within WINNER, before drawing conclusions on applicability and harmonization in section 6.5.

Again, it is worth noting that some of the aspects discussed in this subsection are also applicable to and important for conventional relaying; this holds in particular for the system connectivity models (Annex II Section 9.4.1).

6.2 Concepts: Continued Work

6.2.1 Cooperative Cyclic Delay Diversity

A method that introduces artificial **frequency selectivity** and **spatial diversity** in a cooperative relaying wireless communication system is proposed. The artificial frequency selectivity is exploited in conjunction with forward error correction coding to provide a coding diversity gain. Each of the relay nodes consists of one or more antennas. The Access Point (AP) transmits to *M* Relay Nodes (RN) and the User Terminal (UT). The relay forward the information received from a first node (e.g. AP) to a second node (e.g. UT) using cycle delay diversity (CDD) [31], [32], [33]. This can be done in either with amplify and forward, decode and forward, or a hybrid.

An illustration of a cooperative relay system is shown in . In this example, one AP, one UT and *M* RNs are depicted. The relay nodes demodulate and/or decode the signal (decode and forward based relaying assumed) received from the AP and forward the information to the UT using cycle delay diversity. This is done in two steps:

- Step one: the AP transmits data which is decoded by 1) the relay nodes where the information is stored 2) by the UT.
- Step two: each relay node encodes the data and applies different cyclic shift on different antennas and adds the cyclic prefix before transmitting the signals. The UT receives the combined signals decodes the data which may be combined with the data obtained from step1.

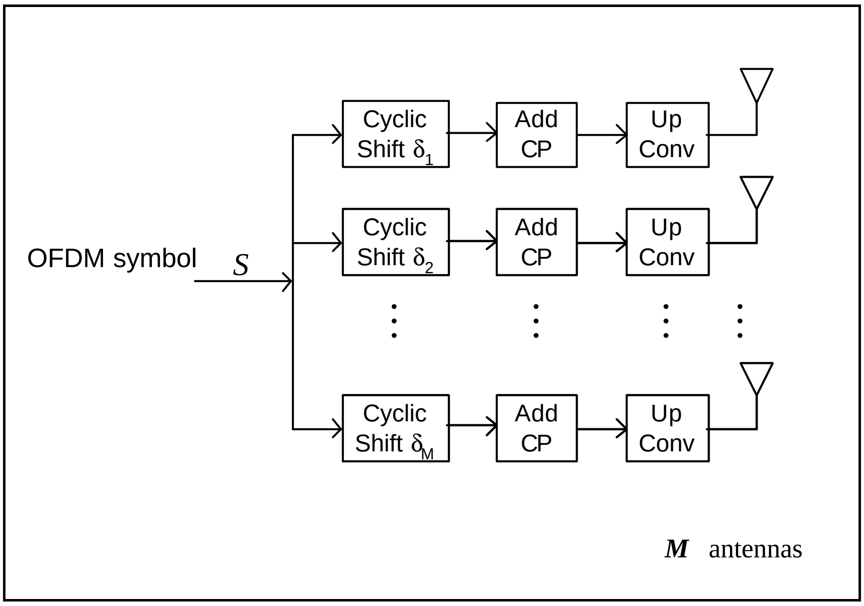


Figure 6-1: Transmitter at the AP

At the AP the OFDM symbol S is subject to CDD. This is implemented by simply cyclic shifting the OFDM symbol at each antenna. A different cyclic shift δ is applied on different antennas. Following the cyclic shift, a guard interval is applied on each branch. The GI is implemented using the Cyclic Prefix method. Then the signals are upconverted from the baseband into the RF-band and transmitted. Figure 6-1 shows the transmitter structure at the AP. Note that in case the AP is equipped with a single antenna, CDD does not need to be applied to the OFDM symbol.

The receiver structure at the RN is shown in the top of Figure 6-1. For each receive antenna, the data is first down-converted from the RF-band into base-band and then the CP is removed. The data is then subject to an FFT operation and equalized. The data estimates from all receive antennas may be combined using the Maximum Ratio Combining (MRC) method. The coded output data is then stored in order to be processed and forwarded at the next time slot. Here there are two possibilities:

- The coded output data is Modulated[8] and Forwarded (non regenerative relaying).
- The coded output data is Decoded, Re-Encoded, Modulated, and Forwarded (regenerative relaying).

Forwarding is implemented using the CDD method. An example of the transmitter in the RN is shown identical to the transmitter at the AP. The receiver at the UT is identical to the receiver in the RN.

6.2.1.1 A Relay CDD Ilustrative Example

In order to illustrate the proposed method, $\boldsymbol{M}$ RN nodes and one AP are plotted in Figure 6-2, where the AP and each relay node is equipped with one transmit and one receive antenna. Let $\boldsymbol{x}$ be the OFDM symbol of length $\boldsymbol{N}$. A cyclic shift of length d_0 and $d_{\boldsymbol{m}}$, $\boldsymbol{m} \in \{0,1,\cdots,\boldsymbol{M}\}$ is applied to $\boldsymbol{x}$ at the antenna of the AP and RN before transmission, respectively. Let $\boldsymbol{h}_{\boldsymbol{m}}$ and $\boldsymbol{H}_{\boldsymbol{m}}$ respectively denote the channel impulse response and the channel matrix from the $\boldsymbol{m}$th transmit antenna to the receive antenna of the UT. Assuming that the CP is greater than the channel order then the received signal $\boldsymbol{y}_0$ from the AP and $\boldsymbol{y}_1$ from the relay nodes can be expressed as:

$$\boldsymbol{y}_0 = \boldsymbol{H}_0 \boldsymbol{P}_{d_0} \boldsymbol{x} \quad , \qquad \boldsymbol{y}_1 = \sum_{\boldsymbol{m}=1}^{\boldsymbol{M}} \boldsymbol{H}_{\boldsymbol{m}} \boldsymbol{P}_{d_{\boldsymbol{m}}} \boldsymbol{x} \tag{30}$$

where $\boldsymbol{P}_{d_{\boldsymbol{m}}}$ is a permutation matrix, which applies a cyclic shift of length $d_{\boldsymbol{m}}$ to the data vector $\boldsymbol{x}$. Since $\boldsymbol{H}_{\boldsymbol{m}}$ is a circulant matrix, the channel matrix can be diagonalized as follows:

---

[8] The modulation is implemented using IFFT.

$$\boldsymbol{H}_{\boldsymbol{m}} = \boldsymbol{F}^{\boldsymbol{H}} \boldsymbol{D}(\boldsymbol{F}\boldsymbol{h}_{\boldsymbol{m}})\boldsymbol{F} \tag{31}$$

where, $\boldsymbol{D}(\boldsymbol{x})$ is a diagonal matrix with $\boldsymbol{x}$ on its main diagonal, and $\boldsymbol{F}$ is the unitary discrete Fourier transform matrix of size $\boldsymbol{N} \times \boldsymbol{N}$. The $(\boldsymbol{n}, \boldsymbol{m})$ th element of $\boldsymbol{F}$ is given by

$$\boldsymbol{F}\ (\boldsymbol{n}, \boldsymbol{m}) = \frac{1}{\sqrt{\boldsymbol{N}}} \exp\left(-\frac{\boldsymbol{j} 2\pi (\boldsymbol{n}-1)(\boldsymbol{m}-1)}{\boldsymbol{N}}\right) \tag{32}$$

$\boldsymbol{P}_{\boldsymbol{k}}$ is a right circulant matrix with $\boldsymbol{e}_{1+(1-\boldsymbol{k}) \bmod \boldsymbol{N}}$ as the first row i.e. $\boldsymbol{P}_{\boldsymbol{k}} = \mathrm{circ}(\boldsymbol{e}_{1+(1-\boldsymbol{k}) \bmod \boldsymbol{N}})$ where $\boldsymbol{e}_{\boldsymbol{k}}$ is column vector where all elements are equal to zero except the element at position $\boldsymbol{k}$ which is equal to one. Since $\boldsymbol{P}_{d_m}$ and $\boldsymbol{H}_{\boldsymbol{m}}$ are circulant matrices then $\boldsymbol{H}_{\boldsymbol{R}} = \sum_{\boldsymbol{m}=1}^{\boldsymbol{M}} \boldsymbol{H}_{\boldsymbol{m}} \boldsymbol{P}_{d_m}$ is also a circulant matrix[34] and can be decomposed as $\boldsymbol{H}_{\boldsymbol{R}} = \boldsymbol{F}^{\boldsymbol{H}} \boldsymbol{D}(\boldsymbol{F}\boldsymbol{h}_{\boldsymbol{R}})\boldsymbol{F}$ where $\boldsymbol{h}_{\boldsymbol{R}}$ can be called the effective channel impulse response from the relays, where

$$\boldsymbol{h}_{\boldsymbol{R}} = \sum_{\boldsymbol{m}=1}^{\boldsymbol{M}} \boldsymbol{h}_{\boldsymbol{m}} \circ \boldsymbol{F}\boldsymbol{e}_{\boldsymbol{m}} \tag{33}$$

where $\circ$ denotes the Hadamard product.

Taking the DFT of the received signal in Equation (30) yields:

$$\boldsymbol{F}\boldsymbol{y}_0 = \boldsymbol{D}(\boldsymbol{F}\boldsymbol{h}_0)\boldsymbol{F}\boldsymbol{x} \quad , \quad \boldsymbol{F}\boldsymbol{y}_1 = \boldsymbol{D}(\boldsymbol{F}\boldsymbol{h}_{\boldsymbol{R}})\boldsymbol{F}\boldsymbol{x} \tag{34}$$

The signals can be combined using MRC method. Note that the channels from each antenna do no need to be explicitly estimated. The effective channel impulse response and the channel response from the AP can be estimated using a common time-frequency pilot pattern, which are not antenna specific. The same conclusion is reached when multiple transmit antennas are used in the AP and/or the RNs.

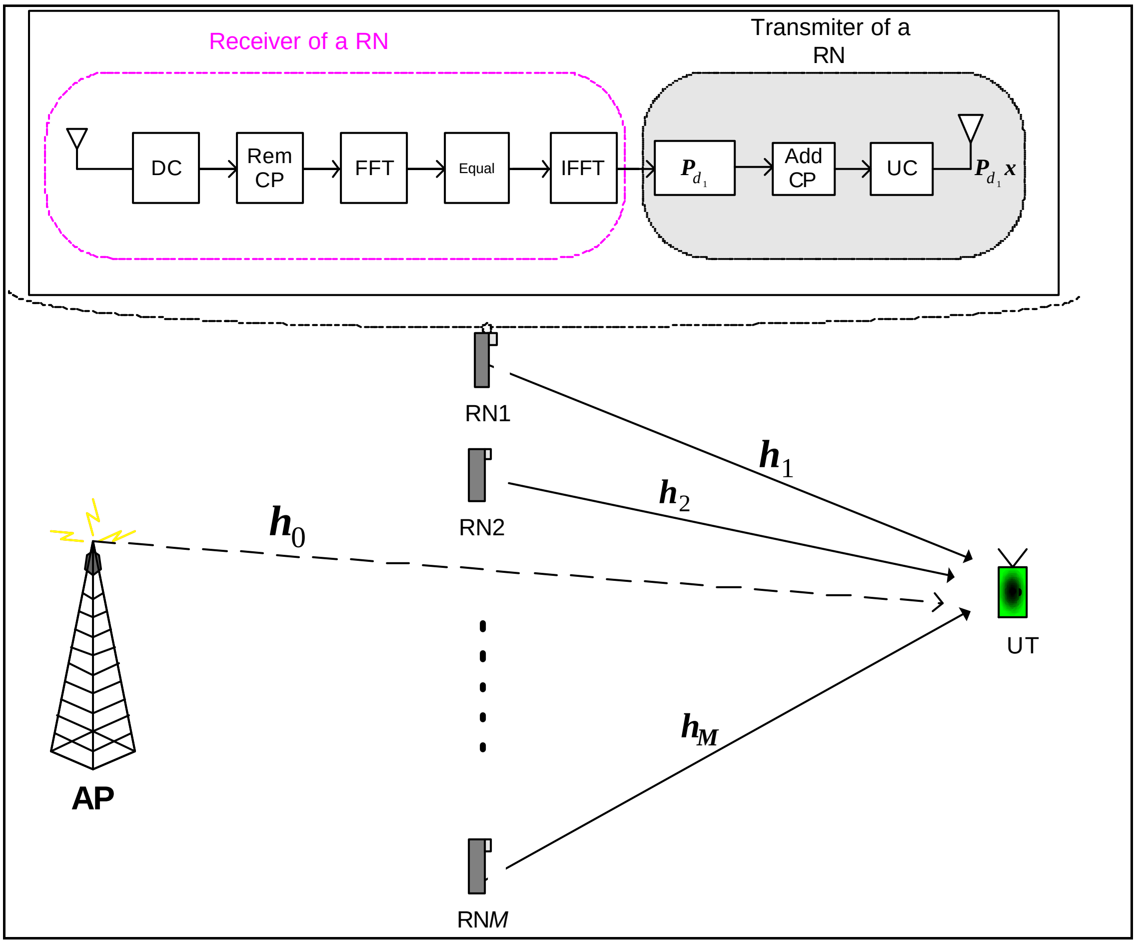


Figure 6-2: Example of CDD distributed relays

6.2.2 Fixed Relay-Assisted User Cooperation

User or terminal cooperative diversity requires that at least two users are in the network and willing to cooperate. Unless there is a way that these users can be coaxed (for example, through sanction) to enter into cooperation, this might be difficult especially if you have a greedy and selfish user. Furthermore, each user data have to be protected from (a mischievous) partner. To circumvent the problems of user-dependent cooperative diversity, we propose fixed relay-assisted user cooperation.

In the proposed relay-assisted user cooperation scheme, the users are ignorant of the cooperation. They do not need to be able to decode any user's data. Privacy is not an issue, sanction or incentive for user to agree to cooperation is not required. However, the relay may have to be given more processing power, which implies that certain functions of the BS can be decentralized which could translate into reduced base station cost. Most importantly, this technique can be used in any network, since there is no major change to terminals.

The relays in this scheme need to have multiuser detection (MUD) capability [37]. After performing MUD, the relays could enter into cooperation based on the level of information that the relays can exchange or based on pre-determined mode. Example of the latter form of cooperation could be distributed space-time coding [35]. A generic relay-assisted cooperative scheme is shown in Figure 6-3. To gain insights into the proposed scheme, the work is limited to minimal number of parameters that would bring out the salient features of the problem. Towards this end, we use a basic wireless network with two users and two fixed relays.

In D3.2 [2] we investigated the parallel fixed relay architecture engaged in a manner to exploit diversity. In the present development, a subset of these relays (two) could be selected based on either the reliability of the signals the relays detect or the state of the relay channels to the base station. For the latter case, the selection can be supervised by the base station in manner similar to opportunistic beamforming [31].

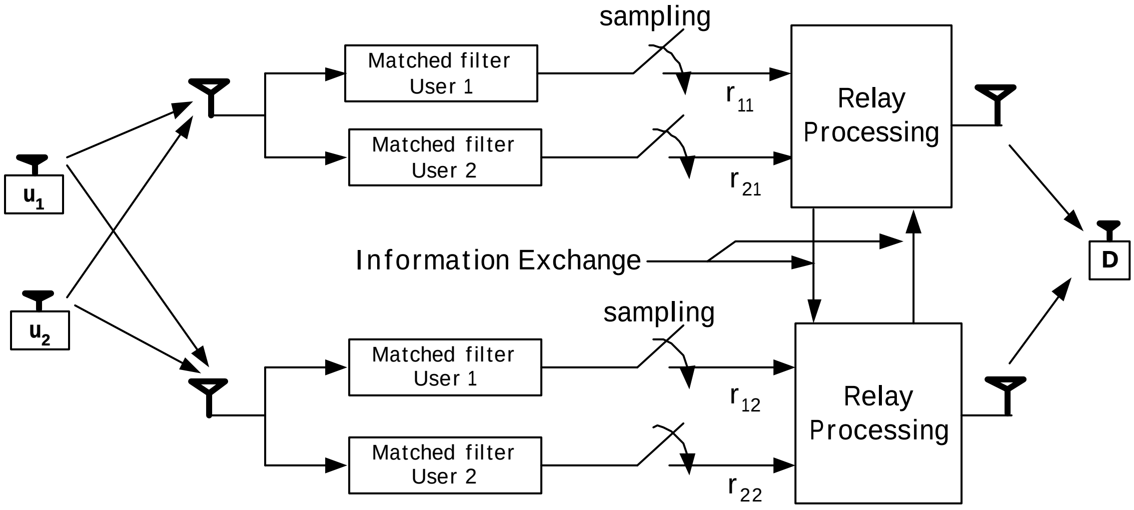


Figure 6-3: Relay-Assisted User Cooperation

6.2.2.1 Distributed Relay & MAC Model

In the discussion that follows, we will consider binary transmission and general asynchronous model. We then specialize the model to synchronous scenario. Let us consider a multiuser system with *K* users. User *k* transmits a data sequence $b_k(i) \in \{\pm 1\}$. This sequence has a length *N*. Let $s_k(t)$ be the unique signature waveform with support on [0, *T*]. The received signal *y(t)* at relay *r* can be expressed as

$$y^{(r)}(t) = \sum_{k=1}^{K}\sum_{i=1}^{N} a_k^{(r)} b_k(i) s_k(t - iT - t_k^{(r)}) + n^{(r)}(t),$$

where the superscript on $t_k^{(r)}$ explains the general case of the difference in the relative delays between the signals of users at the relays, *n(t)* is the additive white Gaussian noise (AWGN) with power spectral density N_0, and $a_k^{(r)}(i)$ independent wide-sense stationary process that can modeled using any of the following: Rayleigh, Ricean, Nakagami, lognormal, or composite fading. This multiple-access model is fairly general since it takes into account the changing propagation conditions due to mobility and other channel impairment.

As mentioned earlier it is always necessary to consider the system in its simplest form. Therefore, we continue with *K*-user synchronous case. This model is achieved by setting $\tau_1 = \tau_2, \ldots, \tau_K = 0$ in the model given above. Further, by setting *K=2*, we would establish a basis for employing both optimum and suboptimum detection strategies without the analysis, or even implementation complexity becoming unwieldy. By optimum, we imply a MUD which yields the minimum achievable probability of error or asymptotic multiuser efficiency and possibly optimum near-far resistance in the multiuser channels [36] [37]. However, for scalable network where more than two users are considered there will be need for suboptimum linear detection techniques such as single-user detection (SUD), decorrelating detector (DD), or minimum mean squared error detectors (MMSE). In this case the optimum detection has complexity that grows exponential with *K*, which could become undesirable.

In our studies we employed 8-PSK modulation scheme with the relay-assisted cooperative diversity scheme, which is then compared with BPSK based non-cooperative scheme. We also examined strategy to check the relays performing space-time coding based on erroneous detections. The relays request for retransmission each time the relays decisions are different. Although, one could do better than this strategy it has been used only as a test case. The detection request is captured in the throughput curve given in Figure 6-4. At high SNR (above 20 dB), the loss in retransmission is negligible. In these SNR regimes our initial error performance results show that the scheme significantly outperforms the baseline, which is a 2-user non-cooperative network. The two users communicate with the base station each employing BPSK modulation format.

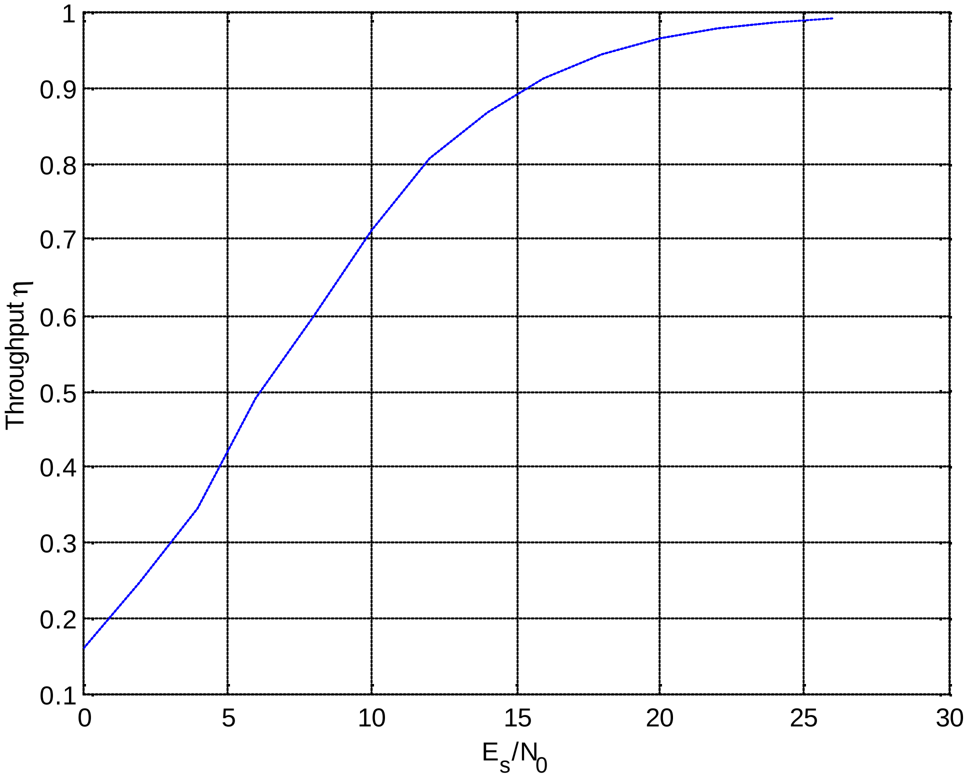


Figure 6-4: Throughput performance of retransmission-based 8-PSK relay-assisted user Cooperative diversity scheme

In conclusion, the throughput curve in Figure 6-4 shows that the crude transmission strategy we mentioned above will not be necessary at sufficiently high SNR. Whatever gains 8-PSK records over the baseline at these SNR regimes could justify the adoption of this cooperative scheme.

6.3 Cooperative Mobile Relaying

6.3.1 Introduction

As stated in Section 5 cooperative relaying could be seen under the mobile relay perspective. Thus, in this section we will discuss the cooperative mobile relaying concept for all the three MR-based DCs and provide a conclusion on the future work and the possibility of CMR being applied in a WINNER –based system.

6.3.2 CMR with Reference to the Three Mobile Relay-based DCs

As we have seen the main problem with mobile relays is that of the mobility. This complicates a number of processes, like forwarding/routing. This means that e.g. a continues mechanism for calculating the location of mobile relays and UTs should be in place, if we have a location-aided forwarding/routing algorithm. The three deployment concepts will be shortly seen under some basic aspects; those of coverage area, mobility, service/applications, location, multi-hop, probably some of the most important factors to deduce the applicability of Cooperative Relaying under the MR approach.

Type I:

- Coverage area: Coverage is within the train, thus 50-150m maximum. We assume that those MRs will be quite complex to support complex processes e.g. handover. In that sense, it is not expected the cooperative could be used. The BS-MR and MR-UTs links will always be good (e.g. fixed distance, LOS) so CMR is not expected to be used.
- Mobility: UEs with reference to the MR: Stationary→Good links, thus no need for cooperation. However, the fact that all distances of all the MRs with reference to the UTs/BS are "fixed" means that it could be relatively an easy task.
- Services/Applications: Due to the complex functionalities, any type of service/applications can be supported.
- Location: Location needs to be frequently performed only for the MR, at the MR-BS link. It is expected that due to favourable characteristics positioning would be a very straightforward process and very accurate due to e.g. GPS.
- Multi-hop: It is envisaged that only two-hop will be required.

Type II:

- Coverage area: Coverage can be stretched up to 500m, so in that sense we expect that a number of MRs will cover several UTs and that will help the CMR implementation.
- Mobility: We assume that velocities will be relatively high e.g. 30km/h, which means that it will be a drawback on the cooperative relaying, due to the high probabilities of MRs loosing connectivity with the target UTs.
- Services/Applications: Due to the medium/high complexity of those relays, they can support any type of services/applications
- Location: Positioning needs to be frequently performed. However, due to some favourable deployment characteristics e.g. high power, high computational power, power availability (thus enabling GSP receiver) we assume that location will be quite accurate.
- Multi-hop: Multi-hop could be supported, although the relatively high velocity means that frequent location updates will be required. Still, due to the relatively high coverage this drawback can be reduced/minimised.

Type III:

- Coverage area: The coverage area is assumed to be small. Although for high end terminal it could stretch up to e.g. 300m, it is expected that for reasons of limited power, interference etc the coverage area will be more "hot spot" e.g. 50-100 meters. In some cases larger radius could be supported but not so efficiently.
- Mobility. Type III MR will be either stationary or slow moving. Even with low velocity they are expected to remain in the same area for some period of time. This means that services/applications of low BW / small duration could be supported as long as the relay can cover some basic requirements. What is more, a large list of potential MRs could be there in order to provide those services when the currently-serving UT/MR becomes unavailable.
- Services/Applications. Due to the relatively limited relaying functionalities that a UE will incorporate it is probable that on an average basis no high end applications could not be supported. What it seems more probable that "small", low BW applications can be supported used e.g. packet based services, rather than voice.
- Location. It is assumed that positioning needs to be frequently performed. Additionally, due to the possibility of low complexity UEs/bad channels conditions e.g. NLOS, shadowing, it may be not so accurate. In general, this can be an issue to investigate more.
- Multi-hop. Due to the limited mobility, at each instance, multi-hop could be supported, as long as it targets less BW-hungry applications. However, for e.g. routing/forwarding, positioning

needs to be frequently performed. Thus, the less the hops the better. Possibly 2 hops and maximum 4 hops could be supported, although the complexity might increase quite substantially.

Of course, for a more through analysis on other parameters that directly or indirectly affect CMR being applied in any of those 3 DCs, please refer to the Table of Section 5.

6.3.3 Conclusion

From the above we see that a number of aspects need to be considered for the CMR schemes. As we saw, coverage, velocity, types of applications are important in order to address CMR. Based on the above we prioritise the three DCs with reference to the CMR concept.

- For short type of applications/services, supporting 2-hop strategy, Type III MRs are promising in providing CMR. The main advantage is the plurality of terminals out of which we can select the optimum to provide cooperative schemes and the low mobility. The main restrictions seem to be frequent positioning, low computational power and the possible reduction of the "user experience" and cost.
- For Type II, the problem is the relatively high mobility but this can be compensated by the large coverage of the MR, which means that in the end the connectivity will be in general similar to those of Type III. This is something that can be evaluated. So, these types of MRs could be applicable for more BW-hungry applications/services.
- Type I. CMR may not be that much applicable, due to the very good links we assume in the MR-BS and MR-UTs, which is the main reason for applying CMR. So, even though CMR could be supported it is not envisaged to be of high incremental gain to the performance. However, under a possible MIMO approach (multiply the bit rates by x times) it could be applicable.

6.4 Concept: Overview and Harmonization

The discussion [1] and in this report shows that a plurality of concepts have been suggested in the literature. In WINNER, a special focus was on adaptive decode and forward schemes (simple single-antenna case as well as generalized multi-antenna schemes), Alamouti diversity, cyclic delay diversity, and multi-hop concepts. In addition to that, a system connectivity analysis was conducted.

Figure 6-5 and Figure 6-6 provide an overview of the concepts and the involved parameters.

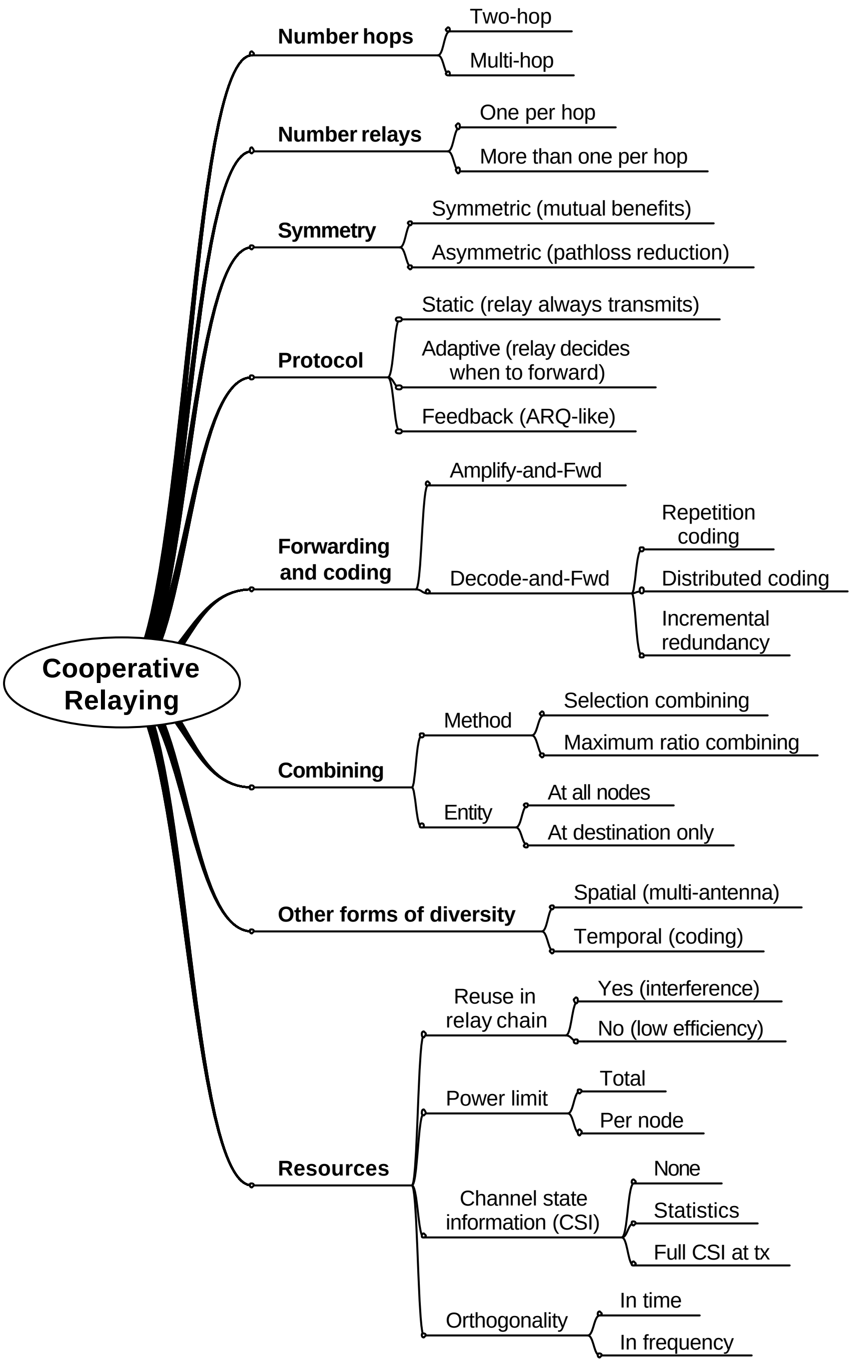


Figure 6-5: Classification of cooperative schemes

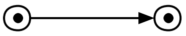
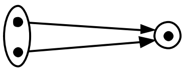
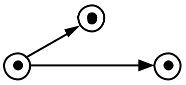
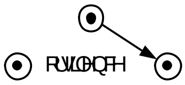
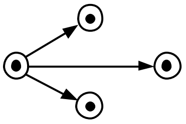
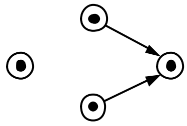
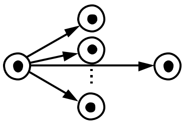
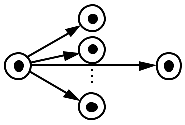
Protocol	Phase 1	Phase 2	Pathloss savings	Diversity order	Remark
' LUHFW			No	1	Known SISO
7 UDQVP LW GLYHUVLW\			No	2	Alamouti
& RQYHQWLRQDO UHOD\ LQJ			Yes	1	Store-and-Forward
6LP SOH $ GDSWLYH)			Yes	2	Simple extension of conv. Relaying< use of multiple antennas possible
' LVWULEXWHG $ OODP RXWL GLYHUVLW\			Yes	3	
& \ FOLFGHOD\ GLYHUVLW\ VFKHP H			Yes	K	See this report

Figure 6-6: Classification of cooperative schemes

6.4.1 Implementation and Application

We now turn to discussing implementation and strategies of application for cooperative relaying. In this section, we therefore reflect on some issues that are critical for real-world implementation of the proposed cooperative relaying schemes.

6.4.1.1 Amplify-and-Forward Systems

Resource assignment: Assigning orthogonal resources to the receive and transmit sub-channels of a relay station can *theoretically* be done in all domains: time, frequency, code, and even space. However, due to limitations in RF hardware (e.g., oscillations), only time- and frequency relaying are currently considered to be feasible.

Realizing *amplify-and-forward schemes* in the *frequency* domain requires (i) a conversion from one carrier to another in the relay stations, calling for increased hardware effort that is necessary for providing two transceiver chains, and (ii) a combining from two different carriers in the destination. A *time-division* approach would require storing or delaying an analog signal in the relay prior to retransmission, the same holds for the combining process. Cross-terminal synchronization then becomes an important aspect. This aspect currently receives attention for the design of the uplink of orthogonal frequency division multiple access (OFDMA) systems, where multiple access is achieved by assigning orthogonal subcarriers to individual users. There, symbol-level synchronization among various users shall be achieved.

Channel state information: It is important to note that many of the discussed concepts require various degrees of availability of channel state information.[9] Such knowledge of effective channels can be obtained by the use of training sequences sequences that pass through the same channel as the signals to be detected - these concepts have long been known and applied using pilots.

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[9] In fact, some of the concepts even require respective transmitters to possess channel state information.

Synchronization: The operation of amplify-and-forward networks remains challenged by different propagation and processing delays. Without reliable inter-terminal synchronization, schemes such as the distributed Alamouti coding are not feasible. Throughout we have assumed perfect synchronization, but successful real operation will to a strong degree depend on synchronization accuracy.

6.4.1.2 Decode-and-Forward Systems

Conventional relaying and the some of the proposed new cooperative building blocks exhibit many similarities: in its simplest form, they are static two-phase protocols that impose the same end-to-end delay.

Physical layer: It is worth recalling that in conventional relaying the relay always forwards, while in the simple cooperative adaptive decode-and-forward schemes the relay decides independently whether or not to forward. This decision can be based on a simple SNR measurement, or the relay uses cyclic redundancy checks (CRC) or low density parity check codes (LDPC) to detect errors in order not to propagate them. In contrast to other commonly employed forward error correction techniques (FEC), the decoding algorithm of LDPC codes offers the inherent capability to detect decoding errors for large blocklengths. No additional CRC is required. The decoding decision solely impacts the forwarding behavior of the relay, there is *no need for any feedback* to any other node in this protocol. The receiving node can use an indicator of the received signal strength (RSSI) in order to detect the intentionally introduced “silence” of the relay in the simple cooperative protocol. Combining from different resources is known from ARQ mechanisms, where redundancy from different time slots is taken into account.

The operation of the discussed cooperative protocols is based on information on long-term average pathlosses only; explicit knowledge of channel state information at transmitting nodes is not necessary. The receive collision scheme additionally requires *(i)* appropriate multi-user decoding at the destination to resolve the different signals from source and relay in phase two, and *(ii)* some form of rate adaptation, which may rely on channel state information.

MAC layer: We note that conventional relaying and cooperative relaying have the same number of transmitting nodes; the only difference is as to “who listens.” With respect to resource assignment and MAC scheduling, it was found that conventional and cooperative relaying require the same number of resources (e.g. time slots, frequencies) to be assigned if operated in the two-hop version or their cascaded multi-hop extension. Consequently, for the two-hop options, resource assignment and scheduling are equivalent for conventional and cooperative relaying.

Network layer: We have seen that the two relaying approaches have comparable requirements regarding optimum relay position. The examination of the usage region revealed that routing constraints are significantly more relaxed for cooperative than for conventional relaying. In other words, a routing scheme which is appropriate for conventional store-and-forward relaying will perform best for cooperative relaying.

6.4.1.3 Relaying Strategies

To summarize, we note that the lion's share of challenges, for example routing in mobile environments, is related to relaying itself, not to cooperation. Based on this, a viable strategy might be to *view cooperative relaying as an extension of conventional relaying* - not as a competing technology. Issues such as distributed routing, mobility management, and partly resource assignment, are challenges for both conventional and cooperative relaying, and hence should be tackled jointly. However, provisions should be made towards implementing the cooperative extensions.

Then, to take full benefits from both relaying methods, operation shall take place in a supplementary manner: conventional relaying serves as a means of providing coverage in areas where direct communication and cooperative relaying are not viable; for the remaining areas, cooperative relaying is used to improve network performance by lowering transmit powers, reducing effective interferences, or providing higher data rates. In this sense, cooperative and conventional relaying serve as extensions and fallback options for each other; see Figure 6-7. This may eventually emerge as a viable strategy for future wireless networks.

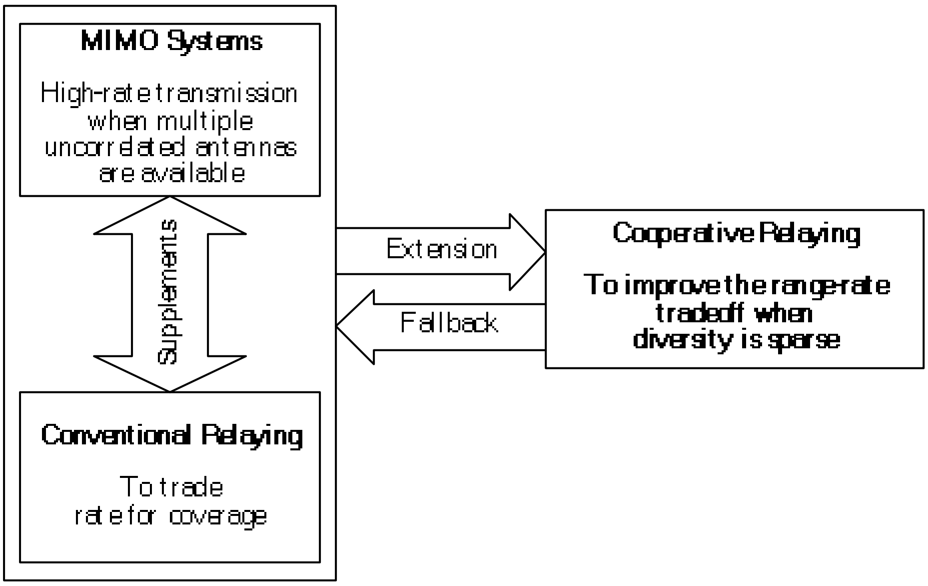

Figure 6-7: Cooperative relaying as extension and fallback option for MIMO systems and conventional relaying

6.4.1.4 Challenges

To summarize, we hope to have conveyed that the lion's share of challenges is related to conventional relaying; cooperative relaying can come as a low-complexity extension that promises attractive additional returns at low cost. These aspects are summarized in Table 6-1.

Table 6-1 Advantages and disadvantages of relaying and its cooperative extension: an overview

Advantages	**Disadvantages**
Conventional relaying as basis	
• Pathloss savings (gain proportional to the number of hops, and exponentional in the pathloss exponent) • Peer-to-peer communications enabled	• Rate increase and, in some scenarios, repetition coding • Interference increase from multiple retransmissions • Complexity (routing, resource allocation, mobility) • Security, billing
Cooperative relaying as extension	
Spatial diversity Exploitation of broadcast advantages	• Receiver complexity (combining) • System connectivity challenges • Resource allocation

6.5 Conclusions

We have discussed various aspects of cooperative relaying and provided corresponding summaries within the individual chapters of the reports. It remains to draw general conclusions.

1. Cooperative relaying exploits two advantages that are inherently offered by the relay channel: the spatial diversity and the ability to benefit from the broadcast nature of the wireless medium. Moreover, it can build on reduced end-to-end path losses as in conventional store-and-forward relaying.
2. Compared to conventional relaying, cooperative relaying requires (i) combining at the receiving nodes, (ii) potentially different resource allocation for networks with more than two hops, and (iii) a decision being made at relays whether or not to forward.

3. Cooperative relaying protocols can be classified according to their forwarding strategy (amplify-and-forward or decode-and-forward), according to their protocol nature (static, adaptive, feedback), and according to their network symmetry (symmetric, asymmetric). Conventional ``multi-hop" relaying belongs to the class of static, asymmetric, decode-and-forward protocols.
4. Amplify-and-forward networks offer full diversity in the number of (distributed) antennas. Yet, they suffer from noise amplification and serious implementation issues like adjusting amplification factors and obtaining channel state information.
5. Decode-and-forward networks offer diversity only if operated in an adaptive manner that prevents error propagation. A simple adaptive decode-and-forward protocol has been designed that exploits the potentials of cooperative relaying while being strongly similar to conventional relaying, thus allowing for simpler integration in novel network architectures. More generally, adaptive decode-and-forward protocols have been found to be promising for WINNER concepts. Their adaptive nature limits error propagation by forwarding only when a certain quality level (SNR, CRC check) can be guaranteed. Their decode-and-forward property makes them similar to conventional store-and-forward relaying, which is attractive from an implementation point of view.
6. At link level, conventional and cooperative relaying face the same fundamental challenge: for limited available bandwidth and allowed end-to-end delay, the individual links must operate at an increased spectral efficiency compared to direct transmission. This implies that relaying is viable for increasing transmission ranges and/or saving power in low-rate regimes, while direct transmission may eventually remain favourable for high-rate regimes. Thus, relaying serves as a means for adjusting the range-rate trade-off.
7. At system level, this translates into a similar trade-off: for a wide range of node densities and network loads, cooperative relaying can be shown to yield superior performance over conventional relaying and direct transmission. For very high network loads and node densities, however, repeated re-emissions and higher link rates of relaying systems deteriorate the system efficiency.
8. The system connectivity analysis has shown that for amplified relaying and decoded relaying without error propagation the priority is to maximize the connectivity of the destination terminal, while for decoded relaying with error propagation the priority is to equalize the connectivity of the destination and relay terminals.
9. In this respect, using multiple antennas at relays can significantly enhance the performance. Implementations using selection combining require only a single RF chain (receive or transmit); therefore, they offer a good trade-off between cost and performance.
10. Cooperative relaying should be viewed as an extension of conventional relaying. This enables to adaptively operate networks with the following strategy:
    a. Use direct/MIMO transmission for high-rate communications if available power ensures coverage. Use cooperative relaying to improve link- and network performance (coverage and/or data rates) in lower rate-regimes.
    b. Use simple conventional relaying to provide coverage in scenarios where direct transmission is not possible and cooperative relaying does not yield diversity benefits (e.g. in non-fading channels).
11. With respect to the number of hops, the following was found:
    a. For fading channels, it was shown that the optimum number of hops is two for a wide range of targeted rates and path loss exponents. This provides a trade-off between diversity gains and path loss reduction on the one hand and rate increase and repetition coding on the other hand.
    b. In cellular scenarios, the two-hop scheme leads to identical resource allocation for conventional and cooperative relaying.
    c. Limiting the number of hops strongly simplifies combining, resource allocation, and scheduling.
12. Main challenges related to relaying are routing and resource allocation in the presence of mobility. Yet, these can be addressed in a common way for conventional and cooperative relaying.
13. Mobile Cooperative Relaying could also be of gain under some scenarios. It seems that probably the Type III mobile relays (User terminals acting as mobile relays) are of particular interest, with the main advantages being the plurality in terms of types and numbers of those terminals that can be used

by the network for relaying purposes. Type II also could be of gain, but on a more larger scale, with the main advantage being the higher complexity and functionalities that can incorporated into them.

It is proposed that adaptive decode-and-forward protocols are investigated in cooperation with T3.3 and T3.5 and to pursue their integration into the WINNER system concept.

7. Conclusions and Future Work

This deliverable presented evolved work on relay based deployment concepts and the current state of the harmonization work across different concepts along with an evolved understanding of their applicability to different WINNER scenarios. In addition, some extensions to relay based deployment concepts were presented. These techniques have the possibility to improve the performance of the presented relay-based concepts.

The overall aim of the deliverable was to describe the most suitable relay-based deployment concepts with respect to the main WINNER scenarios and a discussion on these choices. However, continued work towards the deliverable D3.5 might indicate that ideas in the previous deliverables D3.1 and D3.2 should be revisited. In addition, note that single-hop concepts were not discussed in this deliverable, but single-hop deployment is the base-line deployment concept for all scenarios. Further work is needed on single-hop deployment of the emerging WINNER air interface developed in WP2.

A number of fixed relay-based deployment concepts/ approaches were investigated, along with their advantages and disadvantages with reference to their actual performance and their applicability for the main WINNER scenarios. With regards to the hierarchical approach it was suggested that an OFDMA based relaying could be applicable where different sub-carriers are assigned to Multi-Hop and Last Hop connections. In this case, a good trade off between increased complexity and enhanced flexibility in bandwidth assignment should be found. It was also pointed out that with reference to the TDMA clustering concept, the Multi hop approach yields twice the capacity of the Single Hop approach but requires 5 times as many network elements. With regards to heterogeneous relays, the multi-mode protocol architecture reference model, which is currently being developed in WINNER, facilitates transition and coexistence of different modes, thanks to the separation of the protocol into generic and specific parts. Moreover the possibility to exploit the special characteristics of the mode used for BS-HERN link, will permit to use some kind of advanced relaying concept in order to increase the capacity of the multi-hop system. The most promising scenarios, where the HERN deployment concept could be applicable, are those with different mobility, propagation and traffic characteristics like for example any scenario with outdoor-indoor and vice versa transitions. However it was demonstrated, by means of preliminary and simple simulations, that the two-hop heterogeneous deployment concept based on a multi-tier relaying is specifically targeted (as long as may be guaranteed that the RNs are in LOS or at least in near-LOS of the BS) for using in wide-area and rural scenarios (C.2 and D.1), which are two of the main WINNER scenarios identified for phase I of the project.

Mobile Relays (Type I) can provide coverage to a large number of users e.g. commuters with trains, but to extend the usage it would be interesting to investigate cases such as e.g. buses and ships. Mobile Relays (Type II) could be used for multicast/broadcast services, and by having Mobile Relays which are dedicated only to common/broadcast channels then a more cheap, easy to deploy solution is provided. Mobile Relays (Type III) could be used on an Ad-Hoc basis for e.g. “fast” applications which don’t require high resources. Although relatively limited, Mobile Relays show that there are advantages which can only be offered by the mobile relaying approaches/concepts.

Extensions to the relaying concepts were presented in the next two chapters. In Chapter 5, a new communication scheme for bi-directional relaying was proposed that removes the need of forwarding data to the base station and the user terminal in two different transmissions, but instead uses only one transmission. The maximum gain for a simple two-hop forwarding scenario was found to be 4/3. Cooperative relaying techniques were discussed in Chapter 6. Cooperative relaying protocols can be classified according to their forwarding strategy (amplify-and-forward or decode-and-forward), according to their protocol nature (static, adaptive, feedback), and according to their network symmetry (symmetric, asymmetric). Conventional ``multi-hop" relaying belongs to the class of static, asymmetric, decode-and-forward protocols. With respect to the number of hops, it was found that the optimum number of hops is two for fading channels for a wide range of channels. It was proposed that adaptive decode-and-forward protocols should be investigated further to pursue their integration into the WINNER system concept.

Relays have proven to substantially extend the radio coverage of a base station, especially in highly obstructed service areas, and gain antennas at fixed relays have been established to substantially contribute to increase the throughput at cell areas far away from a base station. The next steps towards deliverable D3.5 will focus on the further development and harmonization of the concepts and their positioning to WINNER scenarios. Thereby the integration of the identified radio interface technologies of WP2 will take an important role. The future work for the radio network and protocol architecture is highly dependent on the development of the WINNER radio interface and its different operating modes.

The architecture proposal is still preliminary and therefore some effort should be concentrated to clarify the radio interface specificities, its architecture, its functional elements and functional distribution.

8. Annex I: Details on WINNER Scenarios

8.1 Device Classes

Table 8-1 Definition of device class in terms of maximum transmission power and number of antennas

#	Type	antennas	Power	Maximum tx power (mW)	other
1	low end	1		200	narrower BW
2	Normal	2	2W power amplifier DC power consumption	200	size like current terminals
3	high end	4	bigger battery	200	larger size
4	laptop	>= 4	higher power/plugged in	400	higher order modulation like 64-QAM is possible

8.2 Propagation Related Characteristics

The following overview of the models suitable test scenarios considered in WINNER Phase I can be made: Further details and references can be found in the WINNER deliverable D5.2 [63].

The ‘Modified SCM’ model refers to the 3GPP/3GPP2 SCM model but modified by the WINNER project to a 100 MHz bandwidth model operating at 5GHz, see [63]. This model includes path loss and shadowing models.

The Modified 3GPP/3GPP2 SCM models are defined in detail in [63] and details how the models should be realized can be found in [64].

In the table below, explicit propagation cases involving mobile RS are missing. In all cases, any mobile RS will be treated like a UE from a propagation point of view.

Measurements are ongoing for the indoor and outdoor UE-UE propagation models, but the exact details of the models are TBD.

Table 8-2 Channel models

Model	Type of paths	Suitable for use in scenario	Reference to detailed description of setting or methodology
1	**AP-UE**: IEEE 802.11n, Setting: C-NLOS **UE-UE**: IEEE 802.11n, Setting: C-NLOS **AP-fix RS**: TBD **Fix RS-UE**: as for AP-UE	A1 Indoor	Indoor MIMO WLAN Channel models, IEEE 802.11-03/940r2
2	**AP-UE**: Modifed SCM Urban Micro **UE-UE**: TBD **AP-fix RS:** Free space propagattion (over the rooftop) or (below rooftop) **Fix RS-UE**: as AP-UE	B1 Typical Urban	Original 3GPP SCM document D5.2
	Feeder-AP: Free space propagation (over the rooftop)	B5 Feeder-AP	.
3	**AP-UE**: Modified SCM Urban Macro **UE-UE**: TBD **AP-fix RS**: Free space propagattion (over the rooftop) or X (below rooftop)	C2 Typical Urban	Original 3GPP SCM document D5.2

	Fix RS-UE: as AP-UE		
4	**AP-UE**: Modified SCM Rural **UE-UE**:TBD **AP-fix RS**: Free space propagattion (over the rooftop) or X (below rooftop) **Fix RS-UE**: as AP-UE	D1: Rural (TBD)	Original 3GPP SCM document D5.2. The Rural configuration is not described in the *original* SCM report, only for the Modified SCM model in D5.2. Currently the details are TBD.

Note that the Table 5.1 in the original SCM document is defined for a 1.9GHz carrier and using 5 MHz bandwidth and is NOT completely applicable for WINNER simulations with other carrier and bandwidth parameters. The corresponding modified table for WINNER can be found in D5.2 [63].

Since there are studies planned involving outdoor UE-UE communication, and since currently not all propagation paths involving relays have been defined the channel models need to be updated later on in Phase I in order to allow for comparison with solutions using outdoor UE-UEs . Hence, it is important that the discussion between WP7 and WP5 continues, and that work is ongoing in WP5 to settle these matters.

In principle, a free space propagation model can be used as a first approximation for these lacking models, but it has been decided to wait until a proper model has been made.

9. Annex II: Additional Information on Relaying

9.1 Wireless Fixed Relays Routing Optimization

9.1.1 Introduction

In D3.1 [1] a QoS routing for multi-hop wireless networks called Wireless Fixed Relay (WiFR) routing has been presented. In that proposal, a new model for the QoS routing problem in multi-hop wireless networks with bandwidth constraints and an algorithm for its solution suitable for Fixed Relay Networks (FRNs) is proposed. The model is an extension of the well known multi-commodity flow problem where link capacity constraints are replaced with new ones that take into account interference constraints among different radio links. The model guarantees that the rates of routed flows are compatible with radio channel capacity, but does not require to explicitly solve the scheduling problem. Since the characteristics of FRNs allow to control the path selection of each flow, in order to solve the proposed problem, a new routing algorithm based on a heuristic with some simulation results is presented in D3.1.

Moreover in in D3.2 [2] the introduction of a new interference models that consider the effect and the impact of smart antennas has been presented and discussed.

This paragraph is devoted to WiFR optimization, in particular the work is focused on a different kind of path search based on residual capacity of each link of the network. In addition an attempt of local search is presented in order to better distribute the routed flows and to create free space for new connections. The final result is an increase in the network throughput, as explained in the following.

9.1.2 Path Search Procedure

The first modification to WiFR algorithm is focused on path search, thus a new version of WiFR algorithm not entirely based on pure greedy has been developed. At the beginning this algorithm computes a sort of residual matrix from which it works out the new topological matrix used by Dijkstra algorithm in order to find the best route using weight as metric. The novelty is in the fact that Dijkstra algorithm does not act on the whole topological matrix but on a modified topological matrix which takes in consideration the only links on which the desired amount of traffic can flow with respect to the mathematical constraints.

As explained in D3.1 [1] central entity maintains precise information about the global network state using data structures that are updated each time a new connection is admitted in the FRN or when an existing one is rerouted or stops to flow. Some of these structures are listed below, assuming that the given network is represented through an undirected graph $G = (V,E)$ where V is the set of vertexes representing the relays while E is the set of edges representing existing radio links between relays: i) Topology matrix $\underline{\underline{T}}$ is a $N \times N$ matrix with $N = |V|$, i.e. number of relays constituting the FRN, where the generic element $t_{j,k}$ of matrix $\underline{\underline{T}}$ is set as follow:

$$t_{j,k} = \begin{cases} 1 \leftrightarrow (j,k) \in E \\ 0 \leftrightarrow (j,k) \notin E \end{cases} \tag{35}$$

Network is represented here as a mono directional graph where for each relay outgoing links are distinguished from incoming ones separating in this way transmission capacity from reception capacity and allowing a better use of network resources.

ii) The set of relays neighbours of given relay j, i.e. that can be directly reached by j 's transmission and the set of relays that are two hops away from given relay j, i.e. the set of relays that have a common neighbour with j. Respectively:

	$H_1(j) = \{k \in V \mid (j,k) \in E\}$	(36)
	$H_2(j) = \{l \in V \mid (k,l) \in E \wedge k \in H_1(j)\}$	

iii) Status tab $\underline{st}$ is a list of record that has $N = |V|$ entries, one for each relay in the network, used to stored information on relay state. For a given relay j the parameters stored in its record are:

$usedband(j) = ub \subset [0,1]$ which represents the fraction of provided bandwidth B, normalized to 1, that relay j "sees" as yet consumed either for its own transmissions or for receptions of other signals both addressed to it and both not addressed to it

$freerx(j) = fr \subset [0,1]$ which represents the fraction of provided bandwidth B, normalized to 1, that relay j has still free to receive without having collision with its own transmissions or with other received signals, this parameter depends only on what happens in relay j itself and in the set $H_1(j)$

$freetx(j) = ft \subset [0,1]$ which represents the fraction of provided bandwidth B, normalized to 1, that relay j has still free to transmit without causing collision with other relays transmissions and respecting all the constraints introduced in the mathematical model, this parameter depends not only on what happens in relay j itself and in the set $H_1(j)$, but also on what happens in the set $H_2(j)$

In the new version of WiFR algorithm other structures, updated each time a new route request arrives, have been introduced. These ones are:

i) Flow Unit is a record of $N = |V|$ entries, one for each relay of the network, where the generic element

$$flow\_unit(j) = fu \subset [0,1]$$

represents the amount of traffic that can be routed through the relay j taking in account the amount of available band of that node.

ii) Link Residual Capacity $\underline{\underline{LRC}}$ is a $N \times N$ matrix with $N = |V|$, which is similar to the residual capacity matrix $\underline{\underline{RC}}$ already presented in WiFR algorithm with the only difference this is built according to the position of the relays with respect to the couple source-destination of the flow whose a route request is arrived. The generic element $lrc_{j,k}$ of the matrix represents the residual capacity on radio link j to k; with term residual capacity is meant how fraction of bandwidth B, provided by lower layers could be transmitted from relay j to relay k without having overload of some relay and avoiding collision with other signals taking in account the possible previous and following links of the path we are searching for. Thus formalizing the generic element of the residual capacity matrix could assume the following value:

$$lrc_{j,k} = \begin{cases} r \subset [0,1] \leftrightarrow (j,k) \in E \\ 0 \leftrightarrow (j,k) \notin E \end{cases} \tag{37}$$

If $rlc_{j,k} = r$ it means not only that $r \cdot B$ bit/sec can be transmitted from j to k but $r \cdot B$ bit/sec can be transmitted from j to k whatever is the path which includes this link.

When a route request arrives at the central entity, a routine updates the flow_unit structure by computing for each relay of the network the amount of unit of traffic than can be routed through the selected relay taking in account the amount of free resources of the node and the role of the node in the path. In fact, as explained in D3.1, when updating the value of usedband for all the relays is to notice that a relay forming path $\underline{p}$ has its usedband updated up to three times as it may receive packets from the relay behind in the route, may transmit to his next hop and finally may receive the (useless for it) transmission of the next hop. For this reason the computation of flow_unit structure is done as follow:

- $flow\_unit(j) = tab\_status(j).freerx$ if relay j is the destination node or if relay j is the source node and it is one hop away from destination node;
- $flow\_unit(j) = tab\_status(j).freerx/2$ if relay j is the source node but it isn't one hop away from destination node (it has to transmit and to receive the useless signal of the next hop) or if relay j is not the source node but it is one hop away from destination node (it has to receive the signal from the previous hop and to transmit);
- $flow\_unit(j) = tab\_status(j).freerx/3$ if relay j is neither the source, neither the destination, neither one hop away from destination (it has to receive from the previous hop, to transmit and to receive the useless signal of the next hop);

If the value of flow_unit of a node is not equal or superior to the bandwidth required by the new connection, this node should be deleted from the modified topological matrix used by dijkstra algorithm because it has't sufficient resources to route the new flow. Nevertheless in a wireless network this can't be done because all transmissions, even unicast ones, are de facto made in physical broadcast and for this reason, by deleting the node, the neighbours lose one constraint related to the that node because they haven't to take in account the resources already used by this one resulting in apparent higher free network resources.

In order to solve this problem the $\underline{\underline{LRC}}$ matrix, containing the amount of unit of traffic than can be routed by each link instead of by each node, is used. This matrix is useful because, while a node can't be deleted from the modified topological matrix, the same operation can be done on links allowing Dijkstra algorithm to have fewer links to explore and to have all the constraints respected. In fact in the compute of the values of the generic element lrc_{ij} the resources already used by node i and by nodes belonging to the set $H_1(i)$ have been taken in account. $\underline{\underline{LRC}}$ is update by this equation:

$$link\_residual\_capacity(i)(j) = \min\left[flow\_unit(i); tab\_status(k).freerx\right] \quad \forall k \in H_1(i)$$

This equation considers both the amount of traffic that can be routed taking in account the free network resources of node i, i.e. *flow_unit(i)*, and the amount of traffic that can be routed taking in account the free network resources of the neighbours of transmitting node which, as known, receive the signal even if they aren't the next hop. In this way, as said before, the effect of consumed resources of neighbours relays has been considered and if a link cannot support the amount of traffic required by the new flow it can be deleted without losing some bonds. Before deleting these links from the modified topological matrix another operation occurs in order to simplify the operations. Each link i-j is bi-directional and for this reason two different values of lrc exist for each link. The lower value is selected because (Figure 9-1) lrc value for all links which starts from a common node is the same (for example links outgoing from *j* have the same value 0.3). Suppose now to choose the value 0.5; this amount of traffic can flow from node *i* to node *j*. Nevertheless node *j* isn't the destination one so it must select a next hop but, whether node *k* or node *z* is selected, only 0.3 units of normalized traffic can flow on those links. Thus it's useless to choose the value 0.5 because subsequently it would be limited by value 0.3.

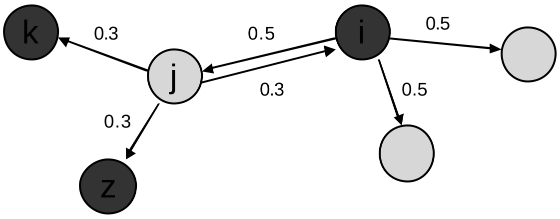

Figure 9-1: Network topology example

Besides all the directional links between destination and other neighbours haven't to be considered because the path surely flows in the opposite direction, i.e. toward the destination. For this reason the rlc value for these links is set to 1, value which is the upper bound and so it doesn't interfere in the choice of minimum between the two possible values.

As said before, the resulting matrix is a sort of residual matrix because it contains for each link the amount of traffic, in relation with a particular couple source-destination, that can flows through the selected link and in that particular direction. It assures that amount of traffic can flow across the link with respect to the available network resources with the only exception of the presence of common neighbours along the path. In this case it is not guaranteed there are sufficient available resources, however this control is made at the end.

As soon as this matrix has been computed a modified version of topology matrix is worked out without considering links which surely can't form the path because of the lack of resources. Now the FRN can be treated as a fixed network described by the modified topologicy matrix and the path is selected by a routine based on the classical Dijkstra algorithm which stops as soon as the destination is reached and labelled.

In this way Dijkstra algorithm can reduce the computational time and, when a route is not found for problems such as scheduling not found or lack of resources due to common neighbours, the links which cause these problems can be deleted so that Dijkstra can be re-called and it won't examine those paths anymore.

9.1.3 Local Search Procedure

The second and last step to enhance WiFR performances is a local search node by node which starts as soon as the attempt to route all the given connection is ended and at least one connection has been rejected because of insufficient network resources. The purpose of this local search is to better-distribute the routed flows and to create available resources to route some of the previously rejected flows. Thus for each rejected flow a routine starts. This routine orders the nodes by their used band. Then starting from the relay with the lowest available resources the algorithm searches which of the already routed flows are responsible for the node resources consumption, either because the node belongs to those paths or because the paths flow near the selected node. As soon as the routed flow to work on is found, the algorithm tries to find another path for this flow which consumes in general less network resources in that nodes which should be interested in the attempt to route the designated rejected flow. If a new path with that features is not found the routine examines, if it exists, another flow related to the selected node, otherwise, if it doesn't exist, the next node of the list ordered by used band is selected and the passages just described are repeated. All the nodes of the list can be examined by routine or only those nodes with usedband upper than a fixed quantity.

As soon as a flow is moved on another path which guarantees a total network weight lower than the previous one, an attempt to route the rejected flow is done and, even if a path can't still be found, all the network structures are updated taking in account the modified path just found and the routine starts again from the beginning creating the new list of nodes ordered by used band and examining them one by one. When a route for the rejected flow is found the routine stops and the following rejected flow is considered.

As said before, when an alternative path is found for an already routed flow, this one is accepted and all the structures updated only if less network resources have been consumed, that is if the sum of the weights of each node is lower than the actual network weight. For this reason, after the choice of the rejected flow to try to route, a weight is given to each node with regard to its value of used band and to its position with respect to the couple source-destination of the flow under examination. In order to better assign the weight to each node three different classes of nodes have been adopted. The three classes are so divided:

- the first class consists of the destination node, the source node and all the nodes one hop away from source
- the second class groups, between the remaining relays, all those nodes which are situated on a portion of network described by a virtual circumference (or ellipse) built on the junction between source and destination
- the third class contains the rest of the nodes

Then it has been adopted a range of five different weights and they have been assigned, starting from the higher and diminishing more and more, to each nodes in this way:

- nodes of the first class with available resources lower than the required bandwidth of the rejected flow and lower than two times the required bandwidth if the node is the source one and the destination is not one hop away
- nodes of the second class with available resources lower than the required bandwidth of the rejected flow
- nodes of the first class with available resources upper than the required bandwidth of the rejected flow and upper than two times the required bandwidth if the node is the source one and the destination is not one hop away

- nodes of the second class with available resources lower than the required bandwidth of the rejected flow
- nodes of the third class

This division in five classes has been done to avoid that nodes which should be involved in the finding of the path for the rejected flow won't be too much loaded causing the well-known blocking effect. For example a great weight is given to the neighbours of the source, in fact, if one of these has a free band lower than the band required by the rejected flow we want to route, the path will never be found because this node can't receive the signal which all the neighbours receive, when the source transmits, because of "physical broadcast". For the same problem the source, when it isn't one hop away from destination, should be led to have at least two times the required bandwidth of available band because if a path is found this node will surely transmit and will surely receive back at least the signal of the next hop, thus with a high weight it's avoided to load too much this node reserving available network resources to try to find a route. In general terms the higher the risk of blocking effect for the new flow the higher the weight assigned to that node and the closer the position of node with respect to the couple source-destination the higher the weight assigned to that node. About how to establish which nodes are closer to the couple source-destination, if distance between this couple is quite low with respect to the range of coverage, a circumference is chosen with diameter equal to the that distance while, if distance is rather high, an ellipse is used with major axis equal to the distance.

9.1.4 Simulation Results

To evaluate the impact of these new features the new version of WiFR algorithm has been implemented into the event-driven network simulator ns-2 and some simulations have been conducted using two ray(ground reflection) channel, a provided bandwidth of 2 Mbit/sec, packets of 1Kbyte, a given traffic matrix with a number of sources which is the 20% of number of relays for random topologies and is equal to 16 for Manhattan topologies, Constant Bit Rate traffic sources with different random data rates. Simulations using the old version of WiFR algorithm have had favourable conditions. In fact, given the traffic matrix, routing has been defined trying 300 times to route the given connections picking them up in random order and maintaining the best attempts as final routing while for the new version only 30 attempts have been done selecting, every 10 simulations, the best attempt and running over this one the local search.

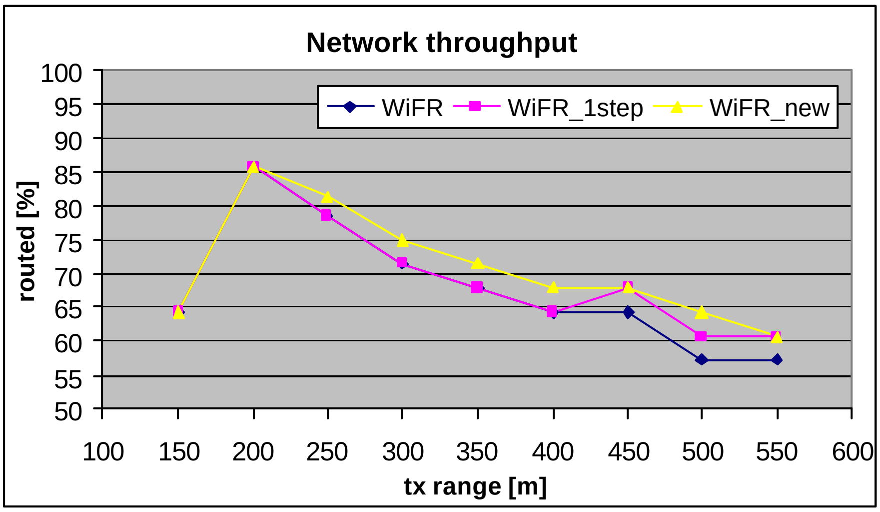

Figure 9-2: Random topologies, 90 relays, low traffic

Figure 9-2 shows throughput obtained in a FRN of 90 relays random deployed following a uniform distribution over a 1000m X 1000m area for various values of radio range below 600 meters which is the radio range under whom WiFR outperforms other algorithms [2].

With the only exception of the lowest values of radio range (where the connectivity is quite low), the new version of WiFR algorithm (WiFR_new) outperforms WiFR algorithm without modifications (WiFR). Throughput is increased on average of about 5% with peak of about 10% for particular radio range. The third line (WiFR_1step) represents network throughput obtained only with the first step of the modifications. Performances of such simulations are always at least equal to WiFR performances and the improvements are not considerable in relation with WiFR_new.

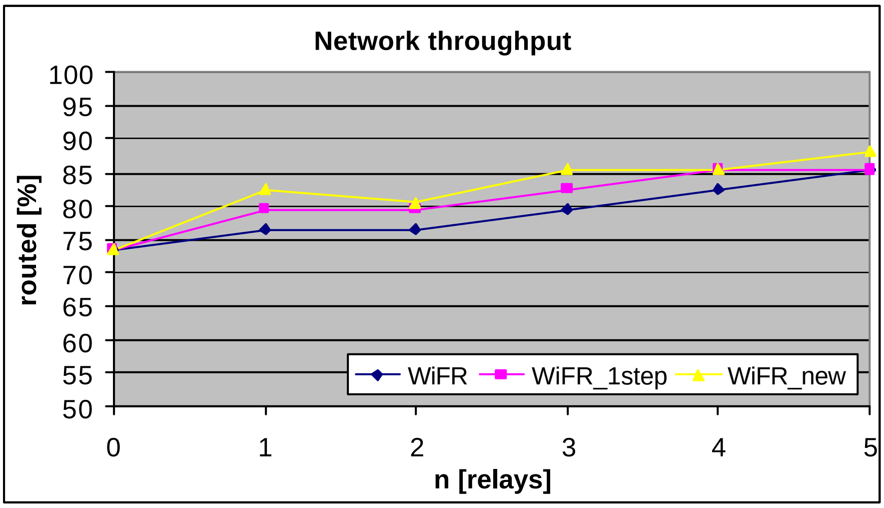

Figure 9-3: Manhattan topologies, medium traffic

Results shown in Figure 9-3 are obtained from simulations on Manhattan topology starting from a basic grid of 4x4 relays used as sources and/or destinations of the connections and adding a number n, from n=0 (basic grid) to n=5, of additional relays that has only the task of forwarding packets. Even for these simulations what said previously is confirmed; curves differ clearly from one another showing the two steps of the algorithm enhancement. In fact, starting from the reference curve obtained with old version of WiFR algorithm, a first improvement can be noticed with the modified path search (WiFR_1step) and a final enhancement is obtained with the new version of algorithm which consists of both the two steps.

9.1.5 Conclusions

From the set of simulations conducted to evaluate the impact of WiFR changes on FRN throughput, the following conclusions can be taken out.

About simulations run with the only modified path search, the values of throughput obtained are generally included between the values obtained with the old and the new version of WiFR and even if the improvements are not so considerable the modified search routine is less complex and less heavy than the original one. Besides, as explained before, when for example scheduling problems occur, it's easier to re-compute the route because it's sufficient to delete the links which cause problems and to call again the routine. In this way paths already examined can't be selected again and a table which lists all the unavailable paths is no more necessary allowing to re-compute route more and more times.

About simulations conducted with the complete new version of WiFR algorithm, old WiFR is generally outperformed both in random topologies and in Manhattan topologies. It's to be noticed that the best results are obtained with a high number of relays because for a couple source-destination the number of paths available is higher and being the purpose of local search to shift flows from a path to another available if the choice of alternative paths is wide the new version of algorithm can be exploited at best (mainly in its second step). Besides a higher gain is achieved when the network is loaded with low/medium traffic, i.e. connection data rates up to 10/20% of the provided bandwidth, because with such data rates the network resources to free in order to route the rejected flow are lower than the resources to free if connections have higher data rates (high traffic).

9.2 Modes Conversion in Heterogeneous Relays

9.2.1 Functionality for Modes Conversion

Taking the $\mathrm{HERN}_{\mathrm{LN}}$ definition into account, this element would be always a "Decode & Forward" relay type since the communication between the two elements (BS and UT) that it has to hold, involve the use of some kind of mapping table for the conversion of protocols and some interworking mechanisms (congestion control) between the two physical layer modes used by each of the elements. So before forwarding the data, it is necessary to decode the data of the incoming mode, to do the conversion and to encode the data in the other mode. Assuming this operation and considering only the user plane functionality, Figure 9–4 illustrates the protocol architecture for a HERN connecting the F1 mode and other WINNER physical layer mode (A1) via the generic link layer, which is composed by the RLC-g and MAC-g sublayers. In fact, one of the initial ideas for partitioning certain layers in generic and specific parts was to facilitate, by means of the generic parts, the convergence of modes to be developed in WINNER system for covering different situations and scenarios.

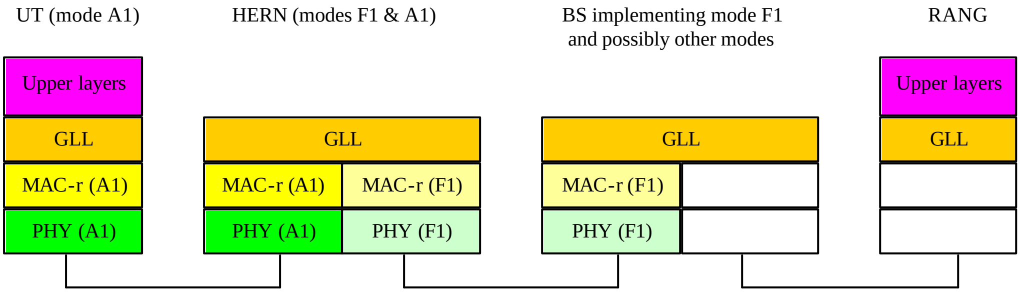

Figure 9–4: Exemplary protocol architecture for the user plane in a HERN deployment concept

Concerning the RRM in the context of heterogeneous relaying, the interworking could look like shown in Figure 9–5 where it is performed by the GLL on the user plane to forward the user data and the RRM. The RRM in this case will have some common (generic) functions depicted as RRM-g and some mode specific functions (RRM-rx). The RRM-g part is coordinating the resource demands between the two modes. The difference of the two links and therewith of the requirements for the two modes on both sides of the HERN can be described as follows:

- Hop 1 (BS-HERN):
    - No change in link quality (static and well known link conditions).
    - Point to point connection from HERN's point of view.
- Hop 2 (HERN – UTs):
    - Dynamic link conditions up to loss of connection.
    - Resource has to be shared by one or more connections.

This means for the HERN that on the one hand it has to distribute the resources between the UTs based on their demands and on the other hand it has to provide a mechanism to release resources on the first hop to achieve efficient resource utilization on both sides of the relay. Another possibility would be if the both hops of the relay share one radio resource. In this case a common MAC would be in charge of the shared medium access between both systems.

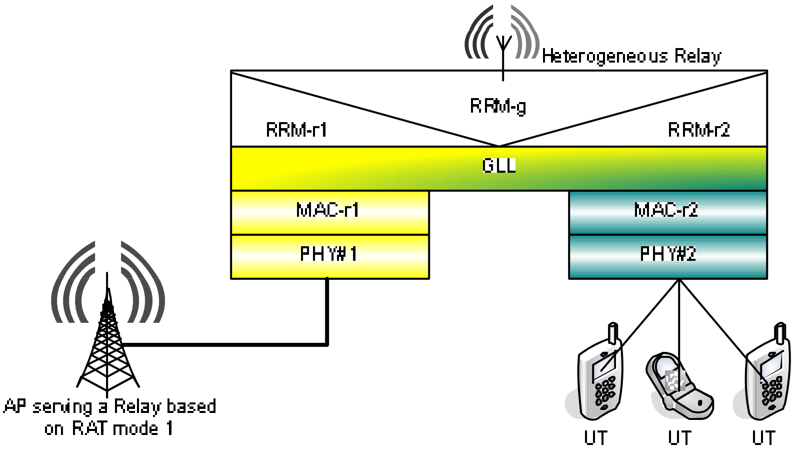

Figure 9–5: Possible protocol stack of heterogeneous relay node

9.2.2 Mapping of Protocol Functions to WINNER Multi-mode Architecture

The single radio access technology (RAT), to be developed in WINNER approach, is from the first contemplating the inclusion of different modes with the purpose of covering a wide range of situations and environments. Therefore it is foreseen that the concluding design of the different physical layer modes of WINNER, allow us an easy, efficient and seamless inter-working between for example the modes involved in a heterogeneous relay. As we have mentioned above, the most promising approach will be to implement the inter-working mechanism in the generic parts of the protocol. Moreover, a multi-mode protocol stack along with a unified interface towards upper layers may facilitate seamless inter-working between multiple modes and hide the heterogeneity of modes from upper layer protocols and functions.

In the presentation of protocol reference model proposed for WINNER and included in [2], it was outlined the multi-mode protocol architecture, which will facilitate coexistence of modes as for example in RNs connecting different modes (HERN). This will be a possible thanks to the modes convergence manager of a layer or stack. When two different modes are involved in the operation of a certain relay node, like in the case contemplated in the present deployment concept, the cross stack management will be performed by means of the Stack Modes Convergence Manager (Stack-MCM), which will control the management functionality in the respective protocol layers (N-layer-MCM), in a hierarchical manner.

Also from [2], in Figure 9–6 is shown an example of how to realize a multi-mode layer relay, allowing the bridging between the traffic flows in different modes for a particular layer (N-1). The different functionality of the layer is achieved through configuration by the (N)-MCM, that is the manager of modes convergence for layer N. In this example, the layer bridges mode 1 and mode 2 and does not provide services towards higher layers. This way, a heterogeneous relay node connecting two different physical layer modes can be efficiently implemented, because the functionality in the common part provides an inherent interface for the back-to-back interconnection of the different modes. Depending on the protocol layer where we desire to reach, we will have different levels of relay. So according as the needs we will have to deploy a more or less complex relay, and there will be to analyze for each case the most appropriate layer for inter-working. It should be noted that according as the complexity increase (implementing higher layers), the relay node becomes more intelligent and it will be able to optimize better the behaviour of the overall network deployment where it is included, but obviously the cost will be also higher. So it will be necessary for each particular case to achieve some kind of trade off between cost and implemented functionality.

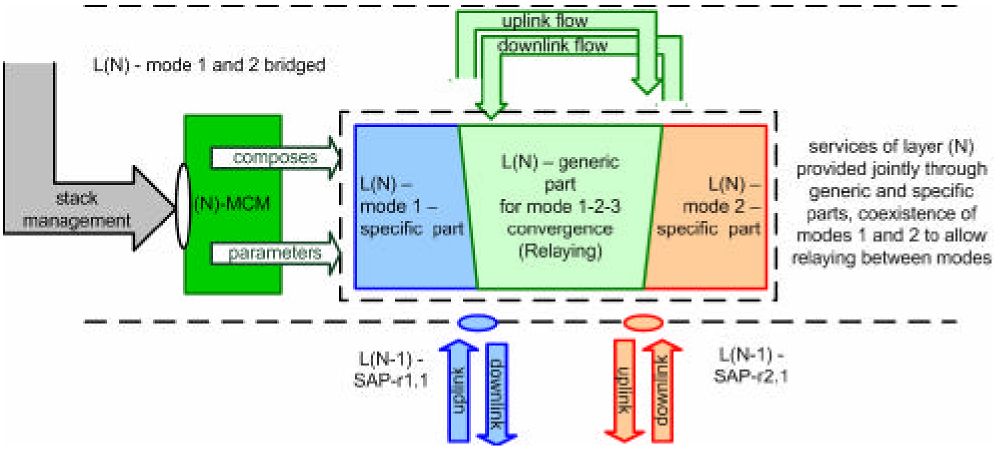

Figure 9–6: Implementation of a multi-mode layer (N) relay. The common or generic part enables the bridging between layer (N-1) traffic flows in different modes

9.3 Mobile relay – based Deployment Concepts

9.3.1 Mobile Relay Deployment Concepts – Related Technologies

Technologies related to the three MR-based DCs have already been proposed in other fora e.g. 3GPP. These have been highlighted in Section 5. In this Section we provide a more detailed elaboration.

9.3.1.1 Mobile Positioning

Mobile positioning is regarded as a fundamental "building block" of current and short/long term cellular systems and as a major enabler for those networks. The calculation of the location of a terminal (user) can be considered very important information because it can be used for a number of occasions

- Provision of services and applications to users e.g. emergency services
- Enhancements of algorithms for better and efficient use of network resources e.g. handover based location [16]

A number of positioning techniques have been considered for current and future systems like Cell Id, OTDOA, RTT, A-GPS etc. [17] All these techniques have a number of advantages and disadvantages effectively trading complexity Vs accuracy. For instance, Cell Id is very inaccurate (just positions the UT within the serving cell). However, it is very simple to implement. Thus, it is not possible to select one technique that can have a "smooth operation" across all cases/environments. Factors like NLOS, fading, indoors coverage, hearability, mobility etc degrade the performance of those techniques. Those factors are even more "important" when the BS-UT distance is high. If we could reduce this distance, the above factors would impact much less the accuracy of those techniques. Thus, relays could be used to address this issue and overcome those limitations. The coverage of fixed/mobile relays is expected to be substantially smaller compared to those of a BS, with all the advantages this has. Thus, mobile relays could be used as an enabler under the following two approaches.

- No-time domain (i.e. mobile relays assumed stationary at the ToD of the measurement): A UT can be positioned with the serving cell being the MR or with combined measurements of the MR and the BS. For instance, in the case of Cell Id the MR can be positioned in a circle of 50-100m (coverage of the MR) compared to the circle of 100 to 1000m (coverage area of the BS).
- In the time domain i.e. MR is used to take multiple measurements in different positions. The MR can effectively "mimic" multiple BSs in the absence of a minimum 3 BSs for positioning a UT with high accuracy. This is very applicable in cases of either isolated or two cells or when the UT cannot "listen" to its surrounding BS (due to the hearability problem). In those cases the only techniques are Cell Id/RTT. However, with this approach multiple RTT and OTDOA measurements can be taken. Additionally, due to the smaller UT-MR distances we expect to have LOS conditions, better channel conditions thus higher accuracy.

This is a similar approach to what has been proposed in 3GPP as the Positioning Elements (PE) technique. [17] Effectively the use of fixed elements, in a CDMA-based network, which can mimic the CPICH transmissions of additional BSs and thus, enhance the accuracy.

9.3.1.2 MBMS

As part of the 3GPP Release6 of the specifications the MBMS concept is being introduced. [18] Effectively, this is a way of providing initially-unicast services over broadcast RABs/RBs for more efficient use of network resources. For instance, in order to avoid maintaining e.g. 50 dedicated links (DPDCH/DPCCH) with 50 UTs in a cell, we switch to a broadcast/multicast mode and we Tx only in one common DL channel. Although issues like power control might have some implications, the whole implementation of MBMS makes a much more effective use of resources and also reduces other problems e.g. multi-user interference/ near far effect. The importance of MBMS is expected to increase for future systems as it has been highlighted in several for a e.g. within 3GPP Long Term Evolution. [19]. The reason for identification this in this section is that MBMS could potentially be applicable for fixed or mobile relays. By building MRs Type I/II to support only MBMS, we simplify very much their functionalities. For instance, we don't need to consider any UL signalling (provided no UL is introduced for future proposals of MBMS) nor there is any need for dedicated links between UT-MR, only one link that of the BS-MR. In that sense, a number of complex functionalities like power control are only performed between the BS-MR.

9.3.1.3 ODMA

ODMA (Opportunity Driven Multiple Access) is a concept which was introduced in 3GPP, as part of the initial proposals for Rel99. The main idea is that of using a terminal to support out-of-coverage terminals. [14]. This proposal is very similar to the Type III MRs. Of course that proposal was quite simpler to what is proposed under the mobile relaying concept. This idea was not taken forward due to the complexity of that proposal in such an early stage of 3GPP. However, as an initial concept it was quite interesting and it is a concept that can be seen now under a different perspective that of the mobile relaying concept Type III, now that this technology is more mature after solving any technical problems. Although the Type III concept stretches a lot the UE functionalities, it is anticipated that simpler solutions can be supported without implementing quasi-BS functionalities at (preferably) high end terminals e.g. routing/forwarding of packets to other UEs. As it has been pointed out, probably the bottle neck is this technology is the actual user acceptance and anything that will make users unhappy should be taken care of.

9.3.1.4 Moving Networks

The idea of moving networks has been presented in previous deliverables. [2] Effectively the starting point was coverage of groups of users with the same mobility e.g. in trains. The idea was to deploy MRs on top of trains which would relay AP information to the area in the train. This initial idea could be stretched to other usage cases e.g. ships, buses, although the special characteristics of each case/scenario should be taken into account. As a technology it is quite interesting and lately in the UK operators and train providers were keen in pursuing such ideas. However, due to the relative "limited"/special business cases, it should be aimed to extend this concept by adding other usage cases/scenarios so that a fully economically feasible business case can be set. Of course, technical problems e.g. handover, should be taken care of. Another interesting point is that the idea of moving network was lately introduced by a means of a WI in 3GPP. Specifically in 3GPP SA WG1, document number S2-050008 introduces the idea of moving networks. [13]

9.3.1.5 Repeaters

In 3GPP, as part of Rel99, the concept of repeaters was introduced. [20]. The rational behind that was the provision of better coverage for cellular systems. In Europe, repeaters are currently used mostly within cells, to provide better coverage in shadowed areas, whereas in the USA they target extending the cells borders. Whatever the case, they tend to address coverage issues. What has been accepted in Rel99 is very simple repeaters (relays) which just receive, amplify and transmit the signal. They do not perform any base band signal processing and as such they are very simple network elements. Of course they don't provide any "sophisticated" functionalities, but that actually follows the rational of those networks elements to provide better "added value" (i.e. coverage) in 3G networks with reduced cost. Thus, what we see is that the issue of fixed relays has been introduced in 3GPP. So the question to ask is if a more "advanced mobile repeater" could be addressed within WINNER as a future extension of the currently-to-be-deployed repeaters. Could a mobile repeater be implemented or is it very much depended on topology-related issues. If by some modifications those can be overcome, would that be a feasible solution?

9.3.1.6 Vehicular Networks

As presented in the WWRF#11, in the automotive industry there are projects which are targeting vehicular communication. [21] They target systems mostly designed for automotive exchange of information, e.g. traffic information and also they target more mesh networks i.e. antennas fitted on all vehicles. Although different to the Type II concept, some commonalities can be found in the area of mobility, routing/forwarding, especially if we assume a two-hop, "hierarchical" type vehicular network. Thus, it would be interesting to investigate those two networks and see what commonalities (if any) there are in a possible merging/Interworking /overlapping of those systems. For instance, mobile relays Type II-based network could be seen as a higher layer (in the architecture) of this mesh-level network for automotive industry.

9.3.2 Power Control

As we saw in the previous sections, MRs Type I/II could be used either as simple elements to support only broadcast/multicast services or they could incorporate almost-full BS functionalities. However, what ever the use, some basic issues need to be addressed. One of them is power control/allocation of Tx power levels for the basic PHY channels i.e. CPICH and broadcast/common channels. If we assume a UMTS-like system, a MR should define its Tx power levels for the CPICH so that its coverage is defined. Although there are variations, due to e.g. the breathing effect, in general the power of CPICH is assumed to be constant, and in the UMTS case 10% of the total power. The initial assumption is that MRs will be transmitting in fixed power. However, this is bound to cause problems. Effectively, the MR will either be transmitting either in too low or too high a power. Thus, either it will induce interference, based of course on the multiple access technique employed or it will not provide adequate coverage. The aspect of fixed power was investigated in [2] [66] where the main findings are that the MR can offer high gains in terms of received power levels at the UE even at relatively low distances from the BS. However, the curves of the deltaPr follow a "Gaussian-like"/non uniform pattern, which in the end might not be desirable. Thus, in this section two possible solutions will be presented.

Based on the first approach the Tx power levels for common channels are based on some predefined patterns, which can be communicated once in the MR and can be calculated "in advance" by an RRM algorithm based on specific information e.g. type of relay, trajectory, deployment parameters, needs to cover etc. These patterns should be such that will cancel this "Gaussian-like" pattern of the curves as shown in [2] [21]. The patterns considered are shown in Figure 9-7. The points define the 9 different points of the MR movement on the horizontal axis. (The model followed is included in [21]. What is portrayed in Figure 9-7 are all the values for 4 patterns, with a step of (step=max-min/4). For instance, for the first pattern the Tx power levels are (90,80,70,60,50,60,70,80,90).

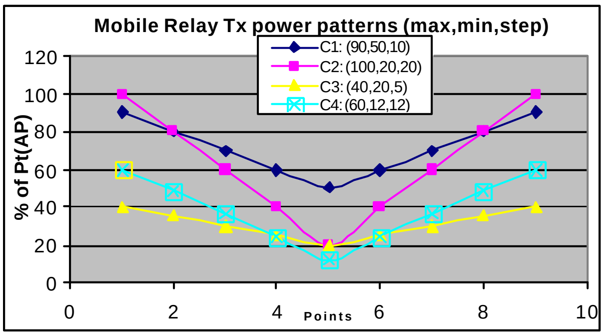

Figure 9-7: Power patterns for pattern-based scheme

In Figure 9-8 we present the values of the deltaPr for the pattern-based Tx power levels where we assume a simple scenario of the MR moving on the horizontal axis.

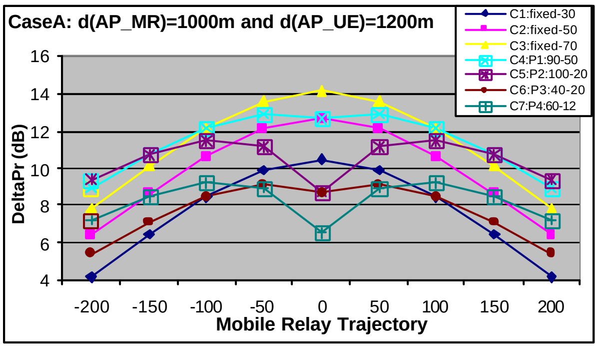

Figure 9-8: Results for pattern-based Tx power levels

Seven cases are considered, three of fixed power (30/50/70% of the total power of BS is allocated in the MR) and 4 with the pattern-based Tx power levels. What we see, by comparing also the results in [2][21], is that more uniform power levels at the UE are experienced.

Even with this scheme though, it is possible due to some unexpected events e.g. change of route for a MR fitted on a bus, that in the end those patterns do not correspond to the required values. Additionally, if we see Case7, still this pattern provides a hollow for the y=0 position of the MR which might not be desirable. This means that a more dynamic algorithm must be in place which will calculate the Tx requirements for the MR taking into account a number of parameters like position, needs to cover and some offline information on the Tx requirements for each of the positions within a cell (based on pre-dimensioning/cell planning), map those with the location of the MR and signal these in frequent time intervals to the MR. Effectively the above RRM algorithm will calculate on a dynamic way the Tx power levels for of the MR and will signal them on a continues basis. The relevant results are shown in Figure 9-9. An additional case (Case 8) to those portrayed in Figure 9-8 is shown, that of the "tailor-made pattern". Thus, based on the above we see that by selecting values from each of those patterns and effectively presenting a more "tailor-made" pattern we can even have more uniform values. For instance, if we “merge” case 4 and case 5, effectively taking the first two values from case 4 and the next 3 values from case 5, we can have a variable pattern which will give us more uniform gain.

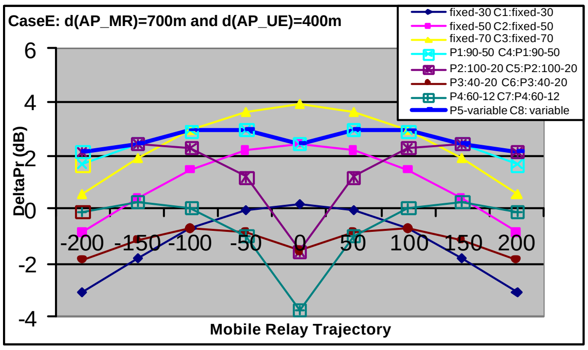

Figure 9-9: Results for variable pattern-based scheme

This second approach is more accurate. However, there is the price of increased MR-AP signalling. So, a trade off between signalling Vs accuracy has to be made. For instance, we expect that the second proposal should be in place when large variations are expected e.g. mid of day, whereas the first could be applicable for more simple cases e.g. early in the morning. In general, the RRM algorithm should be able to support al three proposals (fixed, pattern based, variable pattern-based) and based on the information available on each case, MR type, trajectory, ToD, needs to cover, traffic, number of UE etc will decide which scheme to apply. The goal is to provide a dynamic system that can adapt to all needs and available resources. A more detailed description is included in [22].

9.4 Cooperative Relaying

9.4.1 Cooperative Connectivity Models

9.4.1.1 Introduction

Recent findings in the literature have shown that the performance of wireless relaying networks can be increased through the application of distributed spatial diversity techniques that rely on the mesh connectivity between wireless user terminals. Each of the proposed distributed spatial diversity techniques places different requirements on system resources used to achieve this mesh connectivity. Therefore, system resource constraints that limit the terminal connectivity constrain the distributed spatial diversity techniques that can be applied. This section considers the connectivity impact of a number of important system resource constraints.

This section extends the previous work with the incorporation of explicit separation between common channel combination and orthogonal channel combination, system connectivity models for arbitrary numbers (K) or channels available, and system connectivity model combinatorial equations.

9.4.1.2 System Resource Constraints

The system resource constraints are described in this section. Options for each constraint are introduced along with their connectivity impact. Connectivity impact is defined in comparison to a fully connected system with links between all terminals. Table 9-1 summarizes the considered system resource constraints and corresponding constraint options.

Table 9-1 System resource constraint options

System Resource Constraint	Constraint Options
Number of Channels Available (NCA) This constraint defines the number of orthogonal relaying channels available for the transmission of a signal between a single source-destination pair. The half-duplex nature of wireless terminal hardware requires that each relay transmit and receive with different channels, implying a minimum of two orthogonal channels. Use of more than two orthogonal channels increases the system cost since more bandwidth is necessary to	N Channels Available (NCA): There are N orthogonal channels available, where N is the number of transmitters. There is no connectivity impact.
	K Channels Available (KCA): There are K orthogonal channels available, where 2 < K < N. The connectivity impact is that receivers may only be connected to transmitters on the opposite K-1 channels. A special case is when K equals the number of relay levels in the network.

achieve a given rate of transmission for each source-destination pair.	2 Channels Available (2CA): There are two orthogonal channels available. The connectivity impact is that receivers may only be connected to transmitters on the opposite channel (an odd number of hops away).
Relay Common Channel Combination (RCC) This constraint defines the ability of relay terminals to diversity combine incident signals from multiple preceding terminals on a single common channel. Use of relay common channel diversity combination increases the system cost since common channel combination hardware is required for relayed signals. Relay common channel combination can be achieved in practice using techniques such as orthogonal space-time coding and delay diversity.	Relay Common Channel Combination (RCC): Relays are able to diversity combine incident signals from multiple preceding terminals on a single common channel. There is no connectivity impact.
	No Relay Common Channel Combination (NRCC): Relays are not able to diversity combine incident signals from multiple preceding terminals on a single common channel. The connectivity impact is that relays may only be connected to one transmitter on each channel.
Destination Common Channel Combination (DCC) This constraint defines the ability of destination terminals to diversity combine incident signals from multiple preceding terminals on a single common channel. Use of destination diversity combination increases the system cost since common channel combination hardware is required for received signals. Destination common channel combination can be achieved in practice using techniques such as orthogonal space-time coding and delay diversity.	Destination Common Channel Combination (DCC): Destinations are able to diversity combine incident signals from multiple preceding terminals on a single common channel. There is no connectivity impact.
	No Destination Common Channel Combination (NDCC): Destinations are not able to diversity combine incident signals from multiple preceding terminals on a single common channel. The connectivity impact is that destinations may only be connected to one transmitter on each channel.
Relay Orthogonal Channel Combination (ROC) This constraint defines the ability of relay terminals to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. Use of relay orthogonal channel diversity combination increases the system cost since orthogonal channel combination hardware is required for relayed signals. Relay orthogonal channel combination can be achieved in practice using traditional combination techniques.	Relay Orthogonal Channel Combination (ROC): Relays are able to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. There is no connectivity impact.
	No Relay Orthogonal Channel Combination (NROC): Relays are not able to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. The connectivity impact is that relays may only be connected to a subset of transmitters on a single common channel.
Destination Orthogonal Channel Combination (DOC) This constraint defines the ability of destination terminals to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. Use of destination diversity combination increases the system cost since orthogonal channel combination hardware is required for received signals. Destination orthogonal channel combination can be achieved in practice using traditional combination techniques.	Destination Orthogonal Channel Combination (DOC): Destinations are able to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. There is no connectivity impact.
	No Destination Orthogonal Channel Combination (NDOC): Destinations are not able to diversity combine incident signals from multiple preceding terminals on different orthogonal channels. The connectivity impact is that destinations may only be connected to a subset of transmitters on a single common channel.
Multiple Channel Transmission (MCT) This constraint defines the ability of transmitters to concurrently transmit on multiple orthogonal channels. Use of multiple channel transmission increases the system cost since more complex multiple channel transmission hardware is required.	Multiple Channel Transmission (MCT): Transmitters are able to concurrently transmit on multiple orthogonal channels. There is no connectivity impact.
	Single Channel Transmission (SCT): Transmitters are not able to concurrently transmit on multiple orthogonal channels. The connectivity impact is that transmitters may only be connected to a subset of receivers that use one common channel.
Interhop Interference Cancellation (IC) This constraint defines the ability of receivers to cancel the effects of interhop interference created by the retransmission of signals on the same channel at different hops along a multihop transmission path. Use of interhop interference cancellation increases the system cost since more complex equalization hardware is required for received signals.	Interhop Interference Cancellation (IC): Receivers are able to cancel the effects of interhop interference. There is no connectivity constraint.
	No Interhop Interference Cancellation (NIC): Receivers are not able to cancel the effects of interhop interference. The connectivity impact is that networks with K channels available (KCA) have a maximum hop depth of K.

9.4.1.3 System Connectivity Models

The possible system resource constraint combinations are analyzed in this section and a set of resultant system connectivity models is derived from the combinations. The system connectivity models can be fully classified according to three parameters: the connectivity of the relays, the connectivity of the destination, and the maximum hop depth of the network. The following terminology is used when classifying the achievable connectivity of the resultant system connectivity models:

- *Single Relay (1R):* Each relay can be connected to one previous transmitter.
- *Common Channel Relay (CR):* Each relay can be connected to the subset of previous transmitters on a single common channel.
- *K Channel Relay (KR):* Each relay can be connected to one previous transmitter on each of the K-1 orthogonal channels that it does not transmit on.

- *Non-Identical Relay (NR):* Each relay can be connected to all previous transmitters that do not transmit or receive on an identical subset of orthogonal channels.
- *Full Relay (FR):* Each relay can be connected to all previous transmitters.
- *Single Destination (1D):* The destination can be connected to one previous transmitter.
- *Common Channel Destination (CD):* The destination can be connected to the subset of previous transmitters on a single common channel.
- *K Channel Destination (KD):* The destination can be connected to one previous transmitter on each of the K orthogonal channels.
- *Non-Identical Destination (ND):* The destination can be connected to all previous transmitters that do not receive on an identical subset of orthogonal channels.
- *Full Destination (FD):* The destination can be connected to all previous transmitters.
- *K Hop (KH):* The network has a maximum hop depth equal to K, where there are K channels available.
- *Full Hop (FH):* The network has a maximum hop depth equal to the number of transmitters.

The phrase previous transmitter denotes any transmitter that is earlier along the transmission path (at a lower hop depth) than the candidate receiver. The connectivity equations allow the resultant achievable connectivity to be calculated directly from the system resource constraints.

Connectivity Equations for Models with KCA: The connectivity equations for system connectivity models with K channels available are:

```
zR: if (NRCC& NROC)z = 1
    else if(NRCC& ROC)z = K
    else if(RCC& NROC& SCT)z = C
    else if(RCC&(ROC| MCT))z = N
yD: if (NDCC& NDOC)y = 1
    else if(NDCC& DOC)y=K
    else if(DCC& NDOC& SCT)y = C
    else if(DCC&(DOC| MCT))y = F
xH: if (IC)x = F
    else if(NIC)x =K
```

Connectivity Equations for Models with 2CA: The connectivity equations for system connectivity models with 2 channels available are:

```
zR: if (NRCC| NIC)z = 1
    else if(RCC & SCT & IC)z = C
    else if(RCC & MCT & IC)z = N
yD: if (NDCC& NDOC)y = 1
    else if(NDCC& DOC)y=2
    else if(DCC & NDOC & SCT) y = C
    else if(DCC & NDOC & MCT & IC) y = N
    else if(DCC &((DOC| NIC)& MCT))y = F
xH: if (IC)x = F
    else if(NIC)x=2
```

Connectivity Equations for Models with NCA: The connectivity equations for system connectivity models with N channels available are:

```
zR: if(ROC|(RCC& MCT))z = F
    else z = 1
yD: if(DOC|(DCC& MCT))y = F
    else y = 1
xH: x = F
```

9.4.1.4 Minimum Cost Constraint Sets

The sets of constraints that result in each system connectivity model while minimized the system cost (the minimum cost constraint set) are derived in this section. Figure 9-10 (a), (b), and (c) respectively summarize the minimum cost constraint sets for the system connectivity models with K, 2, and N channels available.

The minimum connectivity constraints sets for each model are derived using the following implicit ordering, with increasing system cost, of the system resource constraints:

1. Destination Orthogonal Channel Combination: Orthogonal channel combination hardware is required on the destination.
2. Destination Common Channel Combination: Common channel combination hardware is required on the destination. The incremental system cost is considered to be greater than destination orthogonal channel combination because it involves more complex non-classical combination hardware.
3. Relay Orthogonal Channel Combination: Orthogonal channel combination hardware is required on every relay. The incremental system cost is considered to be greater than destination common channel combination because it involves combination hardware on every relay instead of combination hardware only on the destination.
4. Inter-hop Interference Cancellation: Inter-symbol interference equalization hardware is required on every relay. The incremental system cost is considered to be greater than relay orthogonal channel combination because it involves more complex equalization hardware.
5. Relay Common Channel Combination: Common channel combination hardware is required on every relay. The incremental system cost is considered to be greater than inter-hop interference cancellation because it involves leveraging the feed-forward part of the inter-hop interference for diversity combination.
6. Multiple Channel Transmission: Multiple channel transmission hardware is required on transmitters. The incremental system cost is considered to be greater than relay common channel combination because it involves each transmitter generating comparatively more power and interference within the network.
7. K Channels Available: K orthogonal channels are available. The incremental system cost is considered to be greater than multiple channel transmission because it involves K-2 more channels being provided within the network for every active source-destination pair.

- N Channels Available: N orthogonal channels are available. The incremental system cost is considered to be greater than K channel available because it involves N-K more channels being provided within the network for every active source-destination pair.

Model	Minimum Cost Constraint Set
1R1DKH	{KCA, NRCC, NDCC, NROC, NDOC, SCT, NIC}
1R1DFH	{KCA, NRCC, NDCC, NROC, NDOC, SCT, IC}
1RKDKH	{KCA, NRCC, NDCC, NROC, DOC, SCT, NIC}
1RKDFH	{KCA, NRCC, NDOC, NROC, DOC, SCT, IC}
1RCDKH	{KCA, NRCC, DCC, NROC, NDOC, SCT, NIC}
1RCDFH	{KCA, NRCC, DCC, NROC, NDOC, SCT, IC}
1RFDKH	{KCA, NRCC, DCC, NROC, DOC, SCT, NIC}
1RFDFH	{KCA, NRCC, DCC, NROC, DOC, SCT, IC}
KR1DKH	{KCA, NRCC, NDCC, ROC, NDOC, SCT, NIC}
KR1DFH	{KCA, NRCC, NDCC, ROC, NDOC, SCT, IC}
KRKDKH	{KCA, NRCC, NDCC, ROC, DOC, SCT, NIC}
KRKDFH	{KCA, NRCC, NDCC, ROC, DOC, SCT, IC}
KRCDKH	{KCA, NRCC, DCC, ROC, NDOC, SCT, NIC}
KRCDFH	{KCA, NRCC, DCC, ROC, NDOC, SCT, IC}
KRFDKH	{KCA, NRCC, DCC, ROC, DOC, SCT, NIC}
KRFDFH	{KCA, NRCC, DCC, ROC, DOC, SCT, IC}
CR1DKH	{KCA, RCC, NDCC, NROC, NDOC, SCT, NIC}
CR1DFH	{KCA, RCC, NDCC, NROC, NDOC, SCT, IC}
CRKDKH	{KCA, RCC, NDCC, NROC, DOC, SCT, NIC}
CRKDFH	{KCA, RCC, NDCC, NROC, DOC, SCT, IC}
CRCDKH	{KCA, RCC, DCC, NROC, NDOC, SCT, NIC}
CRCDFH	{KCA, RCC, DCC, NROC, NDOC, SCT, IC}
CRFDKH	{KCA, RCC, DCC, NROC, DOC, SCT, NIC}
CRFDFH	{KCA, RCC, DCC, NROC, DOC, SCT, IC}
NR1DKH	{KCA, RCC, NDCC, ROC, NDOC, SCT, NIC}
NR1DFH	{KCA, RCC, NDCC, ROC, NDOC, SCT, IC}
NRKDKH	{KCA, RCC, NDCC, ROC, DOC, SCT, NIC}
NRKDFH	{KCA, RCC, NDCC, ROC, DOC, SCT, IC}
NRCDKH	{KCA, RCC, DCC, ROC, NDOC, SCT, NIC}
NRCDFH	{KCA, RCC, DCC, ROC, NDOC, SCT, IC}
NRFDKH	{KCA, RCC, DCC, ROC, DOC, SCT, NIC}
NRFDFH	{KCA, RCC, DCC, ROC, DOC, SCT, IC}

(a) Minimum Cost Constraint Sets for KCA

Model	Minimum Cost Constraint Set
1R1D2H	{2CA, NRCC, NDCC, NROC, NDOC, SCT, NIC}
1R1DFH	{2CA, NRCC, NDCC, NROC, NDOC, SCT, IC}
1R2D2H	{2CA, NRCC, NDCC, NROC, DOC, SCT, NIC}
1R2DFH	{2CA, NRCC, NDOC, NROC, DOC, SCT, IC}
1RCD2H	{2CA, NRCC, DCC, NROC, NDOC, SCT, NIC}
1RCDFH	{2CA, NRCC, DCC, NROC, NDOC, SCT, IC}
1RNDFH	{2CA, NRCC, DCC, NROC, NDOC, MCT, IC}
1RFD2H	{2CA, NRCC, DCC, NROC, DOC, SCT, NIC}
1RFDFH	{2CA, NRCC, DCC, NROC, DOC, SCT, IC}
CR1DFH	{2CA, RCC, NDCC, NROC, NDOC, SCT, IC}
CR2DFH	{2CA, RCC, NDCC, NROC, DOC, SCT, IC}
CRCDFH	{2CA, RCC, DCC, NROC, NDOC, SCT, IC}
CRFDFH	{2CA, RCC, DCC, NROC, DOC, SCT, IC}
NR1DFH	{2CA, RCC, NDCC, NROC, NDOC, MCT, IC}
NR2DFH	{2CA, RCC, NDCC, NROC, DOC, MCT, IC}
NRNDFH	{2CA, RCC, DCC, NROC, NDOC, MCT, IC}
NRFDFH	{2CA, RCC, DCC, NROC, DOC, MCT, IC}

(b) Minimum Cost Constraint Sets for 2CA

Model	Minimum Cost Constraint Set
1R1DFH	{NCA, NRCC, NDCC, NROC, NDOC, SCT, NIC}
1RFDFH	{NCA, NRCC, NDCC, NROC, DOC, SCT, NIC}
FR1DFH	{NCA, NRCC, NDCC, ROC, NDOC, SCT, NIC}
FRFDFH	{NCA, NRCC, NDCC, ROC, DOC, SCT, NIC}

(c) Minimum Cost Constraint Sets for NCA

Figure 9-10: Minimum cost constraint sets for (a) KCA, (b) 2CA, and (c) NCA

9.4.1.5 System Connectivity Model Transitions

The transitions between system connectivity models with respect to the lifting of system resource constraints are shown in this section. The boxes with ‘KH/FH’ represent two system connectivity models with different maximum hop depths. Transitions between ‘KH’ and ‘FH’ system connectivity models correspond to the IC system resource constraint being lifted. The boxes with only ‘FH’ indicate that the corresponding ‘KH’ system connectivity model does not exist for the given number of available channels. Transitions are in the direction of decreased system resource constraints. Transitions that decrease system resource constraints without improving the system connectivity are not shown, nor are transitions that do not follow the minimum cost constraint sets. Figure 9-11 shows the transitions when there are K channels available for various constraint changes. The system connectivity models derived when there are K channels available are the most general set.

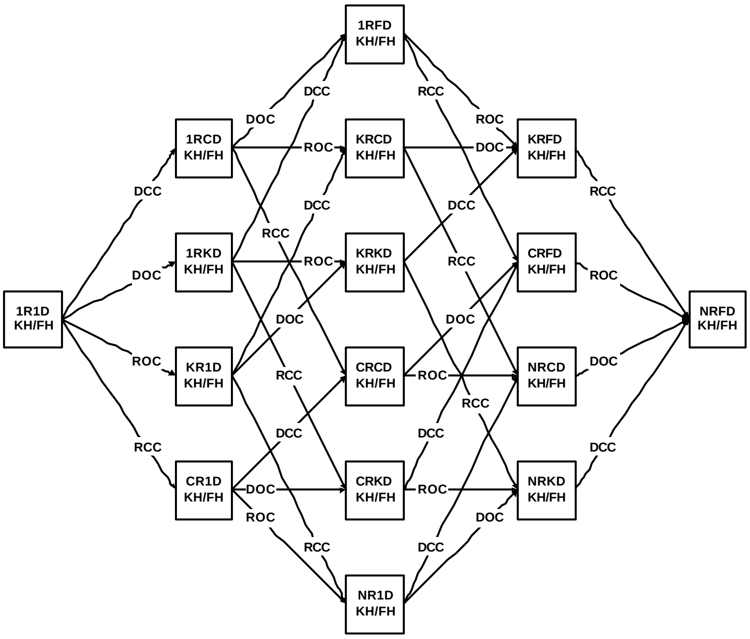

Figure 9-11: System connectivity model transitions for KCA

Figure 9-12 shows the transitions when there are 2 channels available for various constraint changes. The system connectivity models derived when there are 2 channels available are a subset of the models derived when there are K channels available, with the reduction resulting from additional system connectivity constraints and intersection between models.

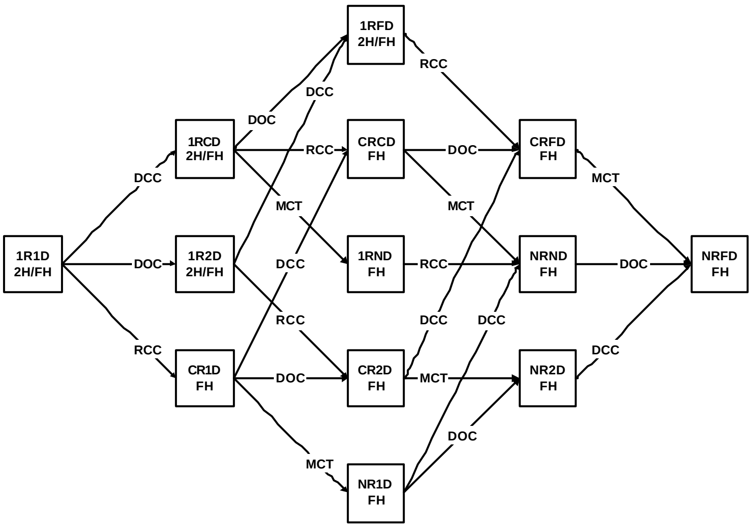

Figure 9-12: System connectivity model transitions for 2CA

Figure 9-13 shows the transitions when there are N channels available for various constraint changes. The majority of system connectivity models result from constraint combinations with less than N channels available. Only the system connectivity models with full relay connectivity, FR1DFH and FRFDFH, are exclusive to constraint combinations with N channels available. The possible system connectivity models are much more diverse when there are less than N channels available.

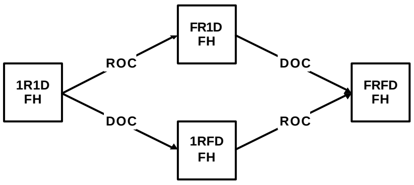

Figure 9-13: System connectivity model transitions for NCA

9.4.2 Connectivity Models in the Literature

Table 9-2 shows the mapping of the system connectivity models to the various distributed spatial diversity techniques presented in the literature, indicating the connectivity model, literature reference, cooperative technique, and assumed channel allocation. This mapping highlights that the literature published so far has only started to explore the many possible cooperative connectivity models.

Table 9-2 Mapping of literature to system connectivity models

Model	**Ref**	**Cooperative Technique**	**# Chnls**
1R1D2H	[38]	2-hop multi-hop without diversity	2CA
1R1D2H	[39]	Conventional 2-hop relaying	2CA
1R1DFH	[38]	Multi-hop without diversity	2CA
1R1DFH	[40]	Relay channel	NCA
1R1DFH	[41]	Multi-hop cooperation	NCA
1R2D2H	[38]	2-hop multi-hop diversity	2CA
1R2D2H	[42]	Cooperative diversity	2CA
1R2D2H	[43]	Cooperative diversity	2CA
1R2D2H	[44]	User cooperation diversity	2CA
1R2D2H	[45]	Cooperative diversity	2CA
1R2D2H	[46]	Cooperative diversity	2CA
1R2D2H	[47]	Cooperative protocols I, II, and III	2CA
1RKDKH	[41]	Multi-hop, multi-branch cooperation	NCA
1RKDKH	[48]	Non-interfering multi-path transmission	NCA
1RCD2H	[49]	Parallel relay network	NCA

1RCD2H	[50]	Virtual antenna array	2CA
1RCDKH	[48]	Interfering multi-path transmission	KCA
1RFD2H	[41]	Multi-branch cooperation	NCA
1RFD2H	[51]	Non-orthogonal amplify and forward	2CA
1RFD2H	[51]	Dynamic decoded and forward	2CA
1RFD2H	[52][53]	Distributed Alamouti system	2CA
1RFD2H	[54]	Repetition-based cooperative diversity	NCA
1RFD2H	[54]	Space-time-coded cooperative diversity	2CA
1RFD2H	[55]	2-hop cooperative relaying	2CA
KRKDFH	[56]	Two-level leapfrog scheme with K=2	KCA
KRKDFH	[39]	Cascaded (K-1)-hop cooperative diversity	KCA
KRFDFH	[57]	C(m) cooperative diversity where K=m+1	NCA
CRKDKH	[48]	AF-MIMO Tunnel	KCA
CRCDKH	[58]	Cooperative broadcasting	KCA
CRCDKH	[59]	Distributed MIMO Multi-hop System	KCA
FRFDFH	[38]	Multi-hop diversity	NCA
FRFDFH	[39]	Full cooperative relaying	NCA
FRFDFH	[57]	C(N-1) cooperative diversity where K=N	NCA
FRFDFH	[60]	Decode / compress and forward	2CA

10. Annex III: Acronyms

3GPP	3rd Generation Partnership Project
AC	Admission Control
ACK	ACKnowledgment
ACS	Access Control Server
AE$_{WX}$	WINNER Access Equipment for Mode X
A-GPS	Asisted GPS
AMC	Adaptive Modulation and Coding
AN	Ambient Networks
AP	Access Point
AQM	Active Queue Management
AR	Access Router
ARQ	Automatic Repeat reQuest
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
BTS	Base Transceiver Station
BW	BandWidth
CC	Central Controller
CCK	Complementary Code Keying
CCPCH	Common Control Physical Channel
CDMA	Code-Division Multiple Access
CFP	Contention Free Period
CMR	Cooperative Mobile Relaying
CPICH	Common PIlot CHannel
CRC	Cyclic Redundancy Check
CSI	Channel State Information
CSMA/CA	Carrier-Sense Multiple Access/Collision Avoidance
CS$_{W}$	WINNER Connection Service
CQI	Channel Quality Indicator
DC	Deployment Concept
DCF	Distributed Coordination Function
DIFS	Distributed Inter-Frame Space
DL	Downlink
DPDCH/DPCCH	Dedicated Physical Data/Control CHannel
DS-CDMA	Direct Sequence Code Division Multiple Access
DSSS	Direct Sequence Spread Spectrum
EDCA	Enhanced Distributed Channel Access
FBRN	Fixed Bridging Relay Node
FCS	Fast Cell Selection
FDD	Frequency Division Duplex

FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FHSS	Frequency Hopping Spread Spectrum
FoM	Figures of Merit
FPLRN	Fixed Physical Layer Relay Node
FRRN	Fixed Routing Relay Node
FRN	Fixed Relay Node
GLL	Generic Link Layer
GPSR	Greedy Perimeter Stateless Routing
HARQ	Hybrid Automatic Repeat reQuest
HCF	Hybrid Coordination Function
HERN	HEterogeneous Relay Node
HORN	HOmogeneous Relay Node
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HS-PDSCH	High Speed Physical Downlink Shared Channel
IBSS	Independent Basic Service Set
IFFT	Inverse FFT
IMDR	Induced Multi-user Diversity Relaying
IP	Internet Protocol
L{x}	Layer x=1,2,3
L2T	Layer 2 Tunnel
LAN	Local Area Network
LLC	Logical Link Control
LOS	Line of Sight
LUT	Look-Up Table
MAC	Medium Access Control
MAC-g	Generic Medium Access Control
MAC-r	Mode-Specific Medium Access Control
MAN	Metropolitan Area Network
MANET	Mobile Ad-hoc NETwork
MBMS	Multimedia Broadcast / Multicast Services
MBRN	Mobile Bridging Relay Node
MCM	Modes Convergence Manager
MH	Multi-Hop
MIMO	Multiple-Input Multiple-Output
MMPD	Multi-Mode Path Diversity
MPLRN	Mobile Physical Layer Relay Node
MR	Mobile Relay
MRA	Multi-Radio Access
MRC	Maximum Ratio Combining
MRN	Mobile Relay Node
MRRN	Mobile Routing Relay Node

MUD	Multi-User Detection
NACK	Negative ACKnowledgement
NLOS	None LOS
ODMA	Opportunity Driven Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OTDOA	Observed Time Difference Of Arrival
P2P	Peer-to-Peer
PCF	Point Coordination Function
PDPC	Packet Discard Prevention Counter
PDU	Protocol Data Unit
PE	Positioning Elements
PER	Packet Error Rate
PHY	Physical Layer
PLM	Physical Layer Mode
PmP	Point-to-multi-Point
PS	Packet Switch
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality-of-Service
QPSK	Quadrature Phase Shif Keying
Relx	Release{x} (x=99,4,5,6)
RAB	Radio Access Bearer
RAN	Radio Access Network
RANG	Radio Access Network Gateway
RAP	Radio Access Point
RAT	Radio Access Technology
RB	Radio Bearer
REC	Relay Enhanced Cell
RED	Random Early Detection
RLC	Radio Link Control
RN	Relay Node
RNC	Radio Network Controller
RRC	Radio Resource Control
RRC-g	Generic Radio Resource Control
RRC-r	Mode-Specific Radio Resource Control
RRM	Radio Resource Management
RS	Resource Controller
RTT	Round Trip Time
SA	Services and Architecture
SAP	Service Access Point
SAR	Specific Absorption Rate
SDM	Space Division Multiplexing
SDMA	Space Division Multiple Access

SDU	Service Data Unit
SH	Single-Hop
SIFS	Short Inter-Frame Space
SIR	Signal-to-Interference Ratio
SLC	Service Level Controller
SINR	Signal-to-Interference Noise Ratio
SNR	Signal-to-Noise Ratio
SS	Secondary Station
STTD	Space-Time Transmit Diversity
SUD	Single-User Detection
ToD	Time of Day
TDD	Time Division Duplex
TDMA	Time-Division Multiple Access
TFR	Temporarily Fixed Relay
TNL	Transport Network Layer
TTI	Transmission Time Internal
Tx/Rx	Transmit / Receive
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UT	User Terminal
UTRA	Universal Terrestrial Radio Access
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access
WiFR	Wireless Fixed Relays Routing
WINNER	WWI New Radio IP
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WSE	Weighted Spectral Efficiency
WWRF	Wireless World Research Forum
WWI	Wireless World Initiative

11. Annex IV: References

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