Reference Architecture for Relay-Based Mobile Broadband Systems

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***Abstract*— This paper presents a new mobile radio communication system architecture with an inherent support of layer 2 relays. The paper presents the layered architecture as well as the logical network nodes architecture and the mapping of layers on the respective logical network nodes for a 4G mobile broadband communication system. It is shown how radio resource management in a relay-supporting cellular radio access network may be performed and signalled in order to efficiently assign radio resources to the individual radio access points (RAPs) which can be either base stations (BS), that have a direct connection to the backhaul network or relay nodes (RN), that are connected wirelessly via the BS to the backhaul network.**

***Index Terms*— deployment concept; system architecture; multi-hop; relaying; WINNER; MAC; RRM**

I. Introduction

THE vision of a B3G radio communication system as followed by WINNER [1] allows for ubiquitous broadband radio access. The user should be enabled to get access to the Internet and all its services as he/she is used to it from today's company and broadband home networks. The WINNER vision is to provide one radio access technology which is able to be adapted flexibly to the different scenario needs, ranging from rural scenarios with low user densities, but probably higher terminal velocities to urban scenarios with high user densities but limited user mobility. This flexibility is enabled by a flexible protocol reference architecture as presented in [2][3].

The need for innovative relay based deployment concepts as inherent part of the WINNER system concept is motivated by the limited range of broadband radio interfaces as studied by WINNER. The range is limited due to high attenuation at carrier frequencies beyond 3.4 GHz[1], a limited transmission power (EIRP) owing to regulatory constraints and unfavourable radio propagation conditions, e.g., in densely populated areas. Conventional cellular radio network deployment concepts would require a high density of base stations to achieve sufficient radio coverage in such environments. As a consequence, cost without applying advanced deployment technologies might increase in terms of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

As shown in [4] relays can be deployed in different usage scenarios in order to

- increase the coverage range of a base station (BS)
- increase the capacity at the cell border
- cover otherwise shadowed areas

The main focus of the deployment concept is based on fixed relay nodes (FRN) as part of a cellular system. The advantage of fixed relays is that they can be connected to a fixed power supply and provide reliable coverage compared to solutions based on mobile terminals. The concept of fixed relays as infrastructure elements in cellular networks was first presented by Walke in [5].

In [6][7] relay implementations and traffic performance results have been presented for a relay based system based on an enhanced IEEE802.16 like system, showing the feasibility and benefits of a centrally controlled relay based system. The concept of relays has been proven for a decentrally controlled approach in the W-CHAMB system [8]. In WINNER the approach taken was to integrate relaying as inherent part of the system from the beginning. The assumptions and requirements for the design of the relay based system concept will be presented in the next section. Thereby a focus will be put on the technology requirements and constraints as foreseen for a broadband air interface as investigated by WINNER.

In the following section some basic assumptions about the considered relay-based system are provided based on the current research work as performed by WINNER. In Sec. III a layered system architecture as under investigation in WINNER is described. Thereby the different layers of the system architecture are introduced and mapped onto the logical nodes architecture. Sec. IV shows how information about the partitioning of radio resources may be distributed across the different nodes and layers of the system architecture. The important role of the MAC layer in the relay based WINNER system is described in Sec. V. In Sec. VI an overview of the system characteristics and how they could fit to potential deployment scenarios is provided. The paper concludes in Sec. VII.

II. Scenario Assumptions

The key technologies of the WINNER air interface are well summarised in [9]. From the physical layer perspective two modes of operation can be differentiated which are the half duplex FDD and the TDD mode.

For performance reasons the relays are built as decode and forward relays (see also [10]). This type of relay is able to take advantage out of improved link conditions between the BS and the RN or for inter RN connections, which is not the case for simple repeaters (amplify and forward relays).

The radio resources are organised in an OFDMA manner, which means they can be assigned portions of time and frequency. Due to the frequency adaptive scheduling approach

[1]Please note that WINNER also takes frequencies below 3.4 GHz into account

[11] the smallest time frequency unit is defined as one chunk. The radio resources are further subdivided into MAC super-frames (SF) as shown in an example configuration in Figure 4. The MAC SF consists of a preamble and a number of MAC frames [16].

All stations in the system are fully synchronised [13]. All broadcast preambles will be transmitted at the same point in time. Thereby the idea is that the WINNER RN is acting toward its UTs like a "normal" BS. Consequently the RN has to show BS behaviour during the preamble phase.

Due to the impact on the radio resource management the WINNER system will be optimised for the two hop case, but without restricting the number of hops to two. The current main working assumption is a centrally controlled RRM.

With respect to the different characteristics and requirements of the different deployment scenarios the physical deployment of RAPs can take place either above or below rooftop.

III. System Architecture

This section is divided into two sub-sections. The first sub-section shows the layered system architecture which structures the functionalities of the proposed communication system, while the second sub-section shows how these system layers are represented in the different logical nodes of the network architecture.

A. *The WINNER Layered System Architecture*

The WINNER system architecture is layered in order to define concise system parts in form of hierarchical layers as suggested by the ISO/OSI reference model [14]. The layered approach is used to clearly define the interface structure and the protocols required to support telecommunication services [15]. Another advantage of the layered approach is to separate the radio interface functions as transmission dependent and transmission independent. Figure 1 shows a layered system architecture as currently under investigation in WINNER, which is well serving the needs of a 4G radio system. It comprises four layers namely the Radio Resource Control (RRC) Layer (located on ISO/OSI layer 3), the Radio Link Control (RLC) Layer and the Medium Access Control (MAC) Layer (both on ISO/OSI layer 2) and the Physical (PHY) layer (ISO/OSI layer 1). The upper layers are currently split into user and control plane. While the architecture reminds of the 3G architecture, the layers with its functionalities might differ strongly from 3G, which is especially true for MAC, RLC and RRC as shown in some examples in Sec.IV and Sec.V. In addition to the radio layers a stack and protocol management on the management plane is introduced, which is explained in more detail below.

1) *Management Plane*

The protocol management can be differentiated into two different groups of management tasks, Layer Management and Stack Management tasks.

a) *Layer Management Tasks*

According to a chosen set of parameters and algorithms, the functionality of a protocol layer is composed from generic, system-specific and system-Mode-specific Functional Units as proposed in [3]. Composition in this context means to instantiate, parameterize and interconnect the appropriate set of functions i.e., select behaviour and / or set parameters of individual protocol functions. More advanced tasks include changes of the configuration at runtime, and context transfer. Context transfer involves either the preservation of internal protocol states to be reused after a configuration change or the translation of internal protocol states into corresponding states after a configuration change, if possible.

b) *Stack Management Tasks*

The stack management is envisaged to handle the overall stack configuration. Triggering configuration inside layers by instructing Layer Managers accordingly and handling of parameters that have to be jointly set/optimised across different layers are among the tasks of the stack management. In the case of operation of multiple modes, the stack management may also control their operation, i.e., the coexistence of and the switching between modes.

As RN are part of the access technology they mainly comprise the transmission dependent layers, i.e. PHY, MAC and depending on the final solution also RLC and RRC, as will be shown in the next section.

B. *Logical Nodes Architecture*

For communication systems which support user and terminal mobility the logical deployment of protocol termination points and the related functions and services is important. This deployment is described by means of logical network nodes where a Logical Network Node (LN) is defined by the service (or group of services) it provides towards other nodes (the provided service access points) and the service (or group of services) it requires from other nodes.

Identical Logical Nodes terminate an identical set of protocols and provide/require the same group of services (i.e. identical service access points). One physical network node can comprise one or several LNs and it can have different logical network node configurations in different physical deployment concepts.

Figure 2 shows the current status of the WINNER logical nodes architecture based on the architecture found in [16]. It consists of two central network nodes which are the Radio Access Network Gateway (RANG) and the Access Control Server (ACS) and the three nodes communicating via the WINNER air interface, which are the BS, the RN and the UT.

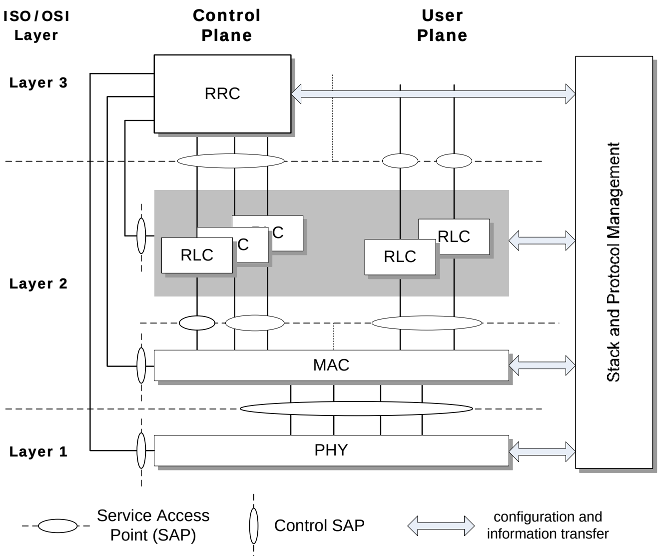

Figure 1: Layered System Architecture

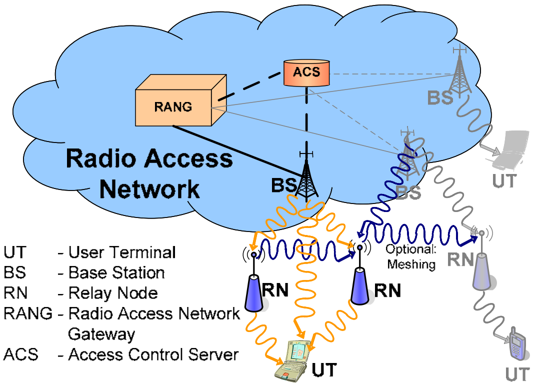

Figure 2: Logical Network Nodes Architecture

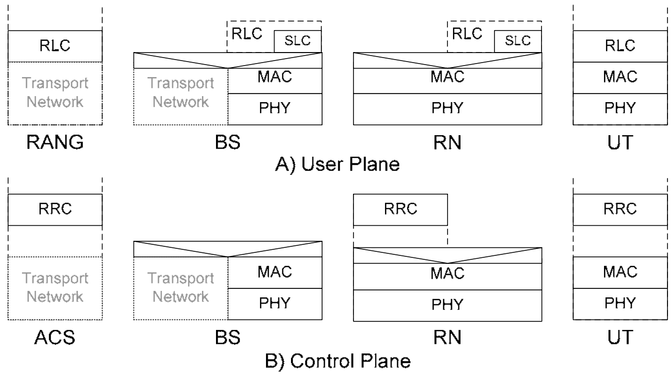

Figure 3: Mapping of layers on Logical Nodes

Optional RNs can connect to more than one REC or RNs of the same tier (and same REC) in a mesh mode.

Figure 3 shows how the mapping of the different layers of the system architecture onto the different logical nodes for both the user- and the control plane could look like in a centrally organised system layout. The Service Level Controller (SLC) [17] which performs the traffic shaping is envisaged to be part of the RLC and the only RLC function that might be needed at the RN on the user plane. In case of the RN the SLC is required only for shaping the uplink traffic from the UTs to the RN as on the first hop, both UL and DL traffic will be shaped by the SLC of the BS or the RANG. The forwarding of user data at the RN will be performed by the MAC. The mapping could change, e.g., if the RNs and BS are designed in a more self-organising manner. The presented layer mapping as shown in Figure 3 should only be seen as example for a more centrally organised deployment concept.

In the logical node set-up presented in Figure 3 the RN might need RRC layer functionality for two reasons. On the one hand a peer entity is needed to communicate with RRC on the network side, providing the respective measurement data gained from MAC/PHY. On the other hand the RRC might be needed to send further RRC messages to the next tier of relays in case of RAN deployments with more than two hops.

In Figure 3 the presentation of the RRC layer in the left part of the RN protocol stack denotes that it has a peer –to-peer communication with the RRC at the ACS, but not with the RRC at the UT. Thus the RRC at the UT is communicating with the ACS's RRC as well. This is in line with the idea that the data forwarding is completely handled on MAC level, which means the user data is not delivered to a higher layer.

IV. Radio Resource Partitioning

A. *Definition*

As stated in Sec. II the RNs should provide the same air interface as the BSs. From the UT perspective they are identical Radio Access Points (RAPs). If the RNs are in the interfering range of other RAPs they need to know about the radio resources that they can handle autonomously. Therefore the radio resources have to be distributed between the different RAPs firstly. After the resource partitioning has been performed and signalled, the second stage of the resource allocation process is then the scheduling of radio resources between the connected UTs by each serving RAP, which is further referred to as resource scheduling. For the sake of completeness it should be mentioned that another (hierarchically higher) level of resource partitioning has to be assumed which is the partitioning of resources between WINNER and other systems (if necessary) and the partitioning between RAPs of different operators. In the following the term resource partitioning will be used to denote the resource partitioning between different RAPs of one operator.

B. *Distribution of Resource Partitioning Information*

In general, this partitioning can be performed either in a hierarchical or in a centralized way. In the hierarchical version, e.g., the RRC protocol in the ACS would dedicate parts of the resources to the use at the BSs and their first tier of RNs. A RN in the first tier could then perform the sub-partitioning for the second tier on its own and so on.

In the centralized partitioning variant, the RRC instance in the ACS responsible for the partitioning would have the complete control over all of the Relay-Enhanced Cells (RECs) it governs.

It is worth noting that in the case of a two-hop system (for which the first optimization will be performed as we recall), the two solutions do not differ at all. In the following, we will therefore assume a centralized resource partitioning. It is further assumed that the centralised resource partitioning is performed by the ACS which is able to control several BS and connected RNs and can distribute the radio resources in a coordinated way allowing for interference avoidance between neighbouring RAPs, which can belong to the same or different RECs.

Figure 4 shows how the resource partitioning information is distributed to all nodes in the REC. The RN receives the resource partitioning information for the next MAC SF from the ACS as control packet in the MAC frame from the BS. The RN has to decode the resource partitioning information and inform its UTs about the resources it will use in the next SF using the next Broadcast Channel (BCH). The next describes in detail how the MAC performs the distribution of the relevant information. The resource partitioning allows assigning resources to groups of RNs (denoted as RN_A, RN_B, etc in Figure 4) which comprise RNs that are spatially separated from each other [16]. Thereby a group can comprise one RN, sub-set RNs or all RNs of a REC.

V. The MAC in a Relay Based System

The current design of the WINNER MAC SF [12] starts with the downlink preamble control transmission´, which is followed by n_f MAC frames, that are partitioned in a downlink

(DL) and uplink (UL) phase (see Figure 4). The downlink preamble contains the BCH. The BCH contains a control message that specifies the resources used by the RAP within this super-frame as shown in Figure 4. Adjacent BS and RN should use orthogonal time-frequency sets within this timeslot for their downlink preamble control transmission, to avoid mutual interference and to enable reception of multiple RAP's BCHs by the UTs.

In the BCH relevant control information is broadcast to the UTs, which include:

- cell information (e.g. RAP ID, operator code etc.),
- description of the subset of overall resources used by the respective RAP in the coming MAC frames of the MAC super-frame
- UL/DL switching point settings
- In addition it might be necessary to transmit information about the number of hops and the link quality of the multi-hop route towards the BS

Thus after having successfully received the BCH the UT knows that it has received and decoded the correct BCH based on the RAP ID. Further the UT knows which of the n_f MAC frames (and sub carriers) it has to receive and decode in the upcoming MAC frames. This information allows the UT to stay idle in the other MAC frames to save battery power.

The additional information on the hop numbers and link quality is necessary to allow the UT to choose the best possible RAP in the case that it can listen to more than one. In some cases it might be more appropriate to connect to the BS (or a RN closer to the BS), even though the SINR of the RN is stronger than the one received from the BS, e.g. due to delay constraints, or due to the fact that the overall throughput over the multi-hop link is less than the one received directly from the BS (or next RN).

The range of the safe reception of the BCH message places an upper bound on the size of the cell. Thereby two types of RNs can be distinguished:

RN Type I has a serving area that is spatially partly or completely orthogonal to the BS serving area. UTs connected to *RN Type I* might not be able to hear the BS therewith the BS' BCH. *RN Type I* has to transmit its own BCH to be visible for all UTs in its serving area (cell). Thus *RN Type I* has the full control about its cell, which means it is transmitting a full BCH including the BCH. *RN Type I* serves to bring the high capacity of the BS into a larger area and serve to cover otherwise shadowed areas [4].

RN Type II has a serving area that is completely inside the BS' serving area. All UTs served by *RN Type II* can also hear the BS BCH. *RN Type II* is not transmitting an own BCH. The BS can transmit one BCH for the whole cell. The BCH would be decoded by the RNs as well as by the UTs. The information in the BCH information serves allows for both the UTs and the RNs to decode the required resource partitioning information. *RN Type II* serve for capacity optimisation and power minimisation as they allow shorter distances to UT with higher PHY modes and lower transmit power [4].

RN Type II would be less complex than *RN Type I* and the control information would be less delayed. The *RN Type II* is able to listen to the BS on first DL as the BCH is send by the BS, but on the other hand it cannot serve its UTs without implementing an additional transceiver turn around time. *RN Type I* on the other hand is much more flexible than *RN Type II* as it could also serve for the purpose of capacity optimisation and it has to be proven what dynamic in resource partitioning is required in the real world that cannot be fulfilled by *RN Type I*.

VI. Flexible Deployment

Within this section an exemplary mapping of the system architecture on different possible deployment scenarios is described. It can be shown that the developed system concept is easily adaptable to the different scenario needs. Thereby three categories of scenarios can be basically distinguished from the deployment point of view, the local area scenarios, the metropolitan area scenarios and the wide area scenarios.

Looking at the coverage of local area scenarios which means a physical deployment of single cells, which could also be relay enhanced cells, e.g. to overcome wall attenuation in the indoor area, the physical nodes architecture would most likely contain a physical BS which comprises simple versions

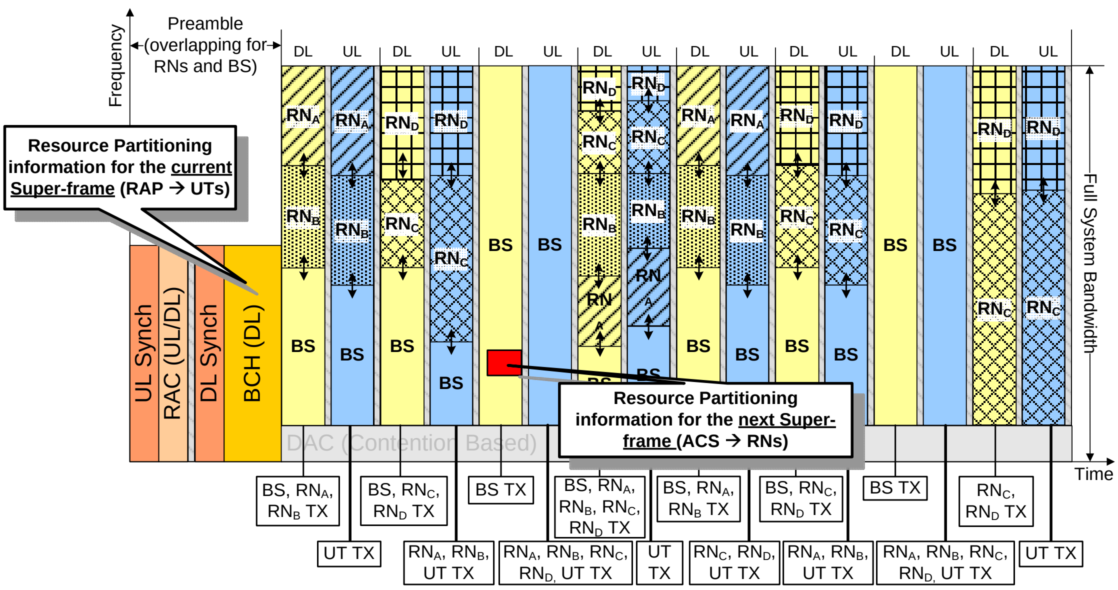

Figure 4: Distribution of Resource Partitioning information in the WINNER MAC Super-frame (Example)

of the logical nodes ACS, RANG and BS as no direct interaction with other BS is needed.

In a local area scenario relays would be mainly used to cover areas which are otherwise shadowed from the BS or suffer from high pathloss due to obstacles. The RRM functions could be rather simple as the user will have low mobility and only little or no co-channel interference is expected. With respect to the missing interference the functions for radio resource control could be simplified as, e.g. no sharing of radio resources between nodes of different RECs is required.

In metropolitan area scenarios a more ubiquitous coverage is required which has to be seen from two perspectives. On the one hand a lot of users with low mobility and the need for high data rates are expected. Such scenarios will most likely be covered by deploying the RN and BS antennas below rooftop in order to allow LOS connections. RNs can be used to enlarge the coverage area and capacity of a BS and to cover areas, like side alley which otherwise would have been shadowed from the BS by buildings and other obstacles. This scenario would be multi-cellular. Thus the BS is likely to comprise only the BS logical node with the respective WINNER and transport network protocols. The RANG and ACS would then be placed as central nodes serving several BS and RNs inside the RAN to allow for efficient mobility support and radio resource management between the cells. Indoor coverage might be realised by mounting relays on windows, receiving data from outdoor BS, while serving the users in the building

A second type of metropolitan area scenario could cover a smaller number of users that are going to use the WINNER system in a more mobile scenario travelling with speeds up to 70 km/h. In this case larger cell sizes would be required. Thus the positioning of BS and RN antennas above rooftop seems to be the better solution, which allows the placement of relays mainly to increase the range of one BS. LOS connection between the BS and RN is envisioned for also for this scenario. Further relays can be used to improve indoor coverage. The physical nodes might look as described for the first Metropolitan area scenario.

Wide area scenarios are seen as rural scenarios with low user density but partly high mobility. In this case also large cell ranges are envisaged with antennas above roof top. Indoor coverage could be realised by heterogeneous relays again. Here also Type II relays as described in Section V could be used to increase the capacity in outer cell regions. Specific solutions have to be designed for moving networks.

VII. CONCLUSIONS

The presented system architecture is providing the required means for flexible deployment concepts which is needed to allow ubiquitous radio access in different deployment scenarios. The flexibility is on the one hand ensured by means of the protocol reference architecture (not in the scope of this paper, see [2][3]) while on the other hand the developed logical nodes architecture provides the flexibility to design physical network nodes according to the specific scenario needs.

With the centrally organised radio resource partitioning a solution has been shown that allows the integration of relay nodes into the system while maintaining the possibility of central interference avoidance strategies. The presented MAC protocols allow keeping the user terminals as simple as in a conventional single hop solution. Thereby the floor is still open for alternative solutions, e.g. supporting more distributed and therewith self-organising system layouts.

The mapping on different deployment scenarios underlines the flexibility of the presented system architecture.

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