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On the Integration of Relaying in the WINNER MAC

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***Abstract*— This paper provides an overview about the relaying concept in the WINNER radio interface. The integration of relaying into the current WINNER MAC super-frame structure is shown. Further the problem of resource partitioning between Radio Access Points (RAP) which can be either Relay Nodes (RN) or Base Stations (BS) is addressed and the WINNER [1] solution for this challenge is presented. The resource partitioning problem will be further investigated. Different approaches on how to distribute the resource portioning information in the system will be discussed, namely the centrally controlled resource partitioning, the hierarchical resource partitioning and the distributed resource partitioning.**

***Index Terms*— WINNER, Relaying, multi-hop, MAC, resource partitioning**

INTRODUCTION

WHITHIN this paper we assume that the fourth-generation (4G) wireless broadband systems are at least to some extent cellular networks integrating Relay Nodes (RN) as fixed infrastructure elements [2][3][4]. Further we assume that such systems rely on a frame-based Medium Access Control (MAC) structure.

Under the assumption that the RN should appear towards the User Terminals (UT) like a BS it needs to create the same type of MAC frame as the BS. Therefore it requires a subset of the overall resources under its own control. We refer to the partitioning of radio resources between the infrastructure elements of the Radio Access Network (RAN) as resource partitioning. All RAPs have to be informed about the resource partitioning and have to inform their UTs about the subset of resources they are going to use. This information is required to enable a "microsleep" mode of the terminals during the periods where they do not have to expect any activity.

The resource partitioning has to cope with two parameters, the requested resources and the interference. For the implementation, the flexibility, the introduced delay and the required signaling have to be taken into account.

As shown in the literature [6] three types of RN applied in as fixed infrastructure elements can be distinguished:

1. RNs to extend the coverage range of a single BS
2. RNs to increase the coverage at the cell edge
3. RNs to cover otherwise shadowed areas

In the following it is assumes that not all UTs in the range of the RN are able to listen to the BS as well. Thus the RN has to send out its own broadcast channel (BCH) to broadcast cell information. In a fully synchronized system as assumed by WINNER these preambles are sent out by all RAPs at the same time on different sub-carriers in the frequency domain, as illustrated in Figure 1.

Relaying and the WINNER MAC Super Frame

The MAC layer design supports and enables several innovative features of the system concept, such as adaptive scheduling and fast link adaptation to exploit multi-user diversity, advanced spatial multiplexing/multiple access, fast retransmission also for delay sensitive flows, resource allocation in relay enhanced cells and constraint processing to support spectrum sharing between other networks and operators [7][8][9].

The WINNER MAC Super-frame

The WINNER MAC *super-frame* (SF) [10][7] as shown in Figure 1 is a time-frequency unit that contains pre-specified resources for all transport channels; Figure 1 illustrates its preliminary design for the TDD case. The super-frame is designed to

- include self-organized synchronization [11] of all involved base stations, relay nodes and user-terminals. This enables an improved spectral efficiency in two ways: It makes large guard-bands unnecessary and enables interference-avoidance scheduling between cells and relay nodes with fine granularity in time and frequency
- enable the resource partitioning to work efficiently in conjunction with inter-cell interference avoidance schemes. It is also designed for relay-enhanced cells, so that base stations and a set of relay nodes can share the total spectral resources efficiently.
- enable adaptive resource partitioning. On the super-frame time-scale, the resource partitioning can adapt to the traffic demand to/from different nodes in the REC over different transport channels

The Preamble

The WINNER relay node appears to the UTs as a BS. Therefore it has to provide the same preamble to its UTs. As WINNER assumes a fully synchronized system, all RAPs have to transmit their preamble at the same time. Thus the super-frame preamble is used by several adjacent RAPs in parallel using different frequency (sub-)carriers as shown in Figure 2. Please note that in a fully synchronized system like WINNER, also in case that no RNs are set up the BS would have to share the preamble as shown in Figure 2.

The preamble in its current version is split into an uplink (UL) and downlink (DL) synchronization slot, a random access channel (RAC) and the broadcast channel (BCH).

In the BCH relevant control information is broadcasted 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, to support advanced routing schemes, which are also studied in the WINNER context.

Forwarding of User Data

The user data received either from the UT (UL) or the BS or a previous RN (DL) has to be forwarded by the RN. Thereby all DL communication takes place during the DL phases and all UL data is transmitted during the UL Phases. This means that the RN is inactive for its UTs while communicating with

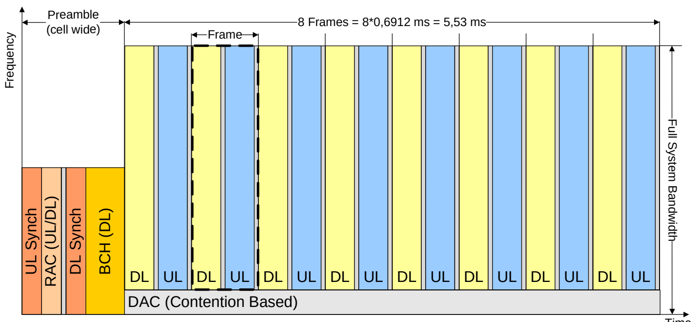

Figure 1: WINNER MAC Superframe (TDD) [7]

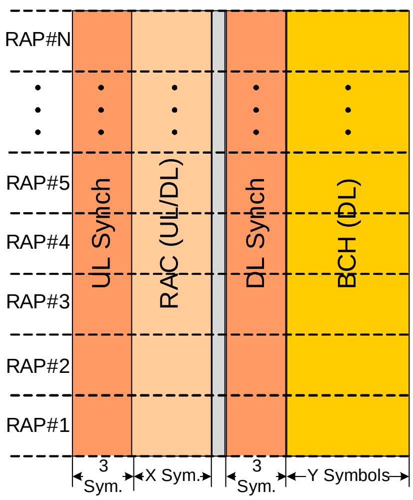

Figure 2: Parallel usage of Super-frame Preamble on the example of TDD

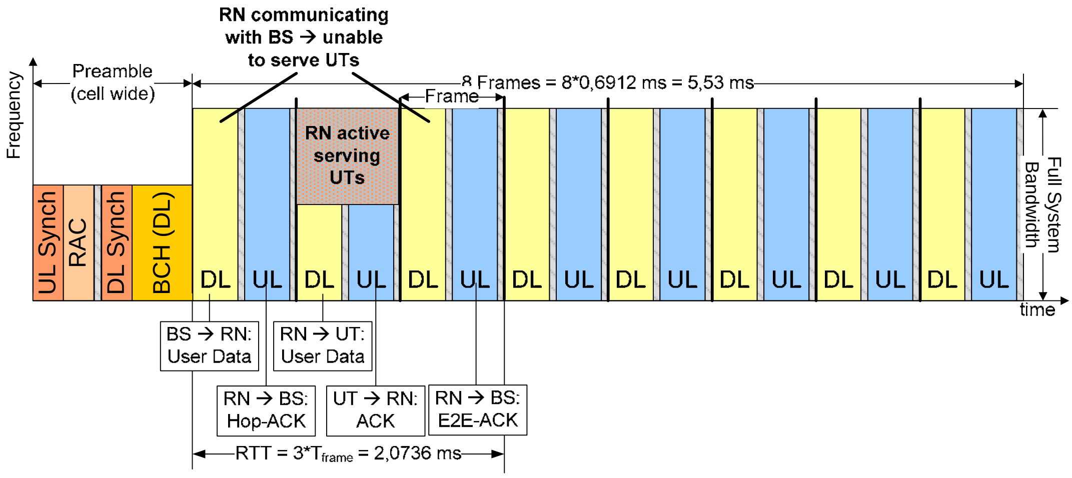

Figure 3: Downlink RTT example

the BS as it has to receive data itself, unless the RN is equipped with two transceivers. As shown in Figure 3 the Round Trip Time (RTT) of a two-hop connection in the optimistic case is the duration of three MAC frames (2,0736ms in the current reference parameterization). Figure 3 also shows the assumed two level ARQ with an inner ARQ (Hop-ARQ) and an outer end-to-end (E2E) ARQ [12].

To forward the data the RN is assumed to be equipped with own buffers. Intelligent flow control mechanisms should be able to restrict the buffer size at the RN. The RN is shaping the UL in its cell itself, while it can rely on pre-shaped data coming from the BS.

Introducing a new scheme for the signaling of allocated resources as presented in [15] should enable the reduction of the overhead especially in the communication between BS and RNs and between successive deployed RNs. This holds true as well for all other kinds of signaling needed in conjunction with resource partitioning which need for is discussed in the following section.

Resource Partitioning within the WINNER System

The re-partitioning of radio resources within the WINNER system takes place on different levels distinguished by their dynamics as shown in Figure 4 [8]. On the long timescale the resources are partitioned between different operators, also referred to as resource sharing. Resource sharing is assumed to take place on a timescale ranging form several super-frames up to a few times per day. On the same long timescale the switching point between UL and DL is (re-)scheduled. On the medium timescale, i.e. per super-frame, the resources are partitioned between the RAPs, i.e. each RAP gets assigned a part of the time frequency space resources to serve its own UTs and depending on the resource partitioning scheme also the following RNs. The partitioning between scheduled resources and the contention-based Direct Access (transport) Channel (DAC) resources is also performed on the medium timescale. Resources assigned on dynamics below one super-frame are referred to as short timescale resource partitioning. The resource allocation to UTs and the partitioning between frequency adaptive and non frequency adaptive chunks is done on the short timescale dynamic.

This paper will concentrate on the resource partitioning between RAPs on the medium timescale, which is briefly referred to as resource partitioning in the following.

The minimum granularity for the partitioning is assumed to be one frame (out of eight) on the time-axis and one chunk on the frequency axis. The reason why no further partitioning in the time-domain seems useful is that the in-band signaling of the current resource allocation inside the frame is felt to become unacceptably complicated otherwise. Therefore this information would ideally be broadcasted at a fixed point in time, which makes it very complicated to subdivide the frame in the time-domain to be controlled by different nodes, see Figure 5. Therefore the currently preferred solution is to partition resources inside one frame in the frequency domain only, which still provides a sufficiently

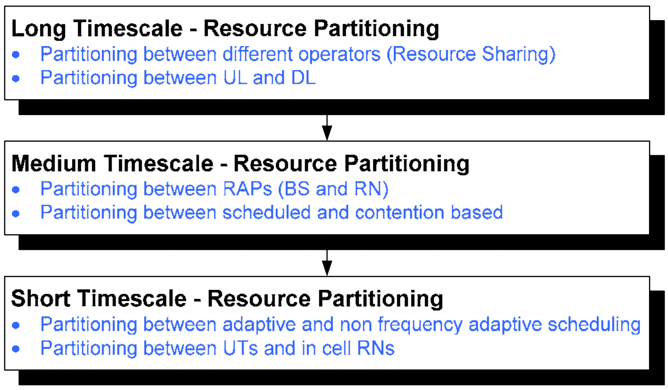

Figure 4: Resource Partitioning Timescales

high level of granularity.

The number of hops is an important design parameter in relay-based systems. The current assumption in WINNER is to optimize for two hops without ruling out the option to be flexible in number of hops, e.g. to allow meshing.

It is possible to organize the resource partitioning in a centralized, hierarchical as well as in a distributed fashion. These options are treated in more detail in the following:

Centrally Controlled Resource Partitioning

The logical nodes architecture as currently under investigation in WINNER provides with the Access Control Server (ACS) a central network instance that can control one or more base stations and relay nodes [8][9].

In the centrally controlled approach the ACS as central network instance is distributing the resource partitioning information to all RAPs under its control. For a relay based system this information is conveyed in two steps as shown in Figure 6. In the first step the ACS is sending a Radio Resource Control (RRC) message via a point to multipoint connection to all RNs under its control. The RRC messages can be protected by error recovery services (ARQ) of the lower layers (RLC).In the second step the resource partitioning information is broadcasted to the UTs using the BCH of the RAPs. The RRC can be located in ACS in case of the BS or in the RN itself.

Consequently the ACS as central instance has control over all RNs and the BS. Thus, the BS as central node of a REC has no control of the RNs within its REC. The ACS can maintain a central knowledge base collecting, e.g., SINR information from all RAPs. The collected information can be used for optimized interference avoidance strategies. Interference information within the REC as well as across REC borders can be taken into account.

A drawback of the centralized approach might be the signaling overhead, as the resource partitioning information has to be conveyed twice to the RNs and to the UTs. In

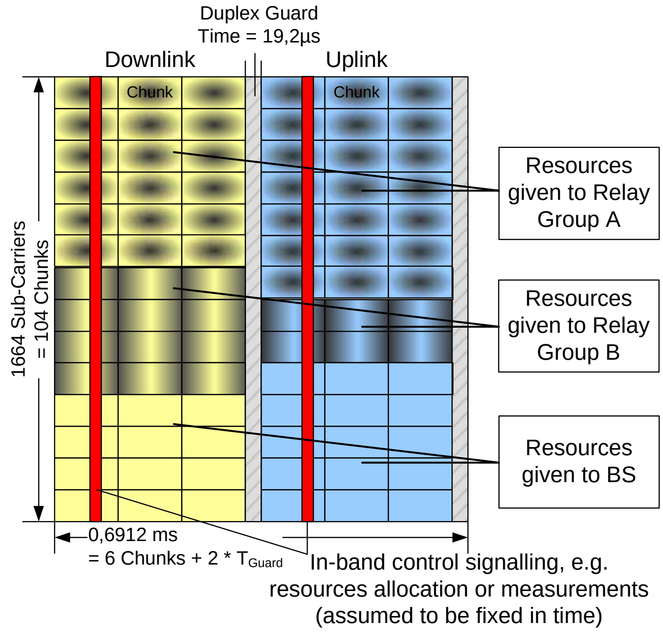

Figure 5: Granularity of resource partitioning

a multi-hop (>2) system the resource partitioning information has also to be conveyed over all hops of the network.

In the following the centrally organized resource partitioning will be investigated in more detail.

Timing Constraints

The decision on how to partition the resources between the RAPs should be based on most up to date data from the RAPs. This data includes interference measurements as well as resource request coming from the RAPs. To ensure that the resource partitioning is based on recent data the resource partitioning information should be transmitted as late as possible in the super-frame. The position of the resource partitioning information in the super-frame is constricted by the ARQ and the number of hops and vice versa.

The resources in the super-frame will be repartitioned each super-frame based on data collected during the previous super-frame or even before. On the UL the resource requests from the UTs need at minimum two MAC frames ($2*T_{Frame} = 1{,}3824ms$) from the source to the ACS (UT – RN – BS/ACS).

If the resource partitioning information is protected by ARQ at least one MAC frame is

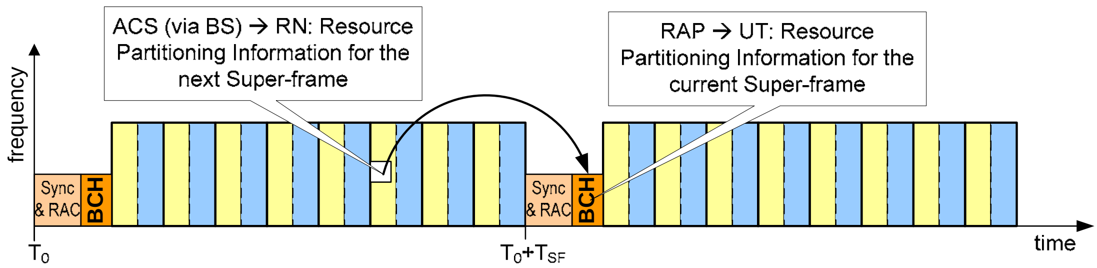

Figure 6: Conveying of Resource Partitioning information in centralized approach

required to retransmit the resource partitioning information. Thus the resource partitioning information should not be sent in the last frame of the super-frame. Under the assumption that the RN is able to respond with an (N)ACK message in the same frame (UL) it has received the resource partitioning information (DL) at least one frame for retransmission should be offered.

Hop Restrictions

The number of hops is especially crucial in the centrally controlled resource partitioning as all information, i.e. the resource requests and the resource partitioning information, have to be conveyed over all hops. This has also impact on the ARQ protection as well as on the number of hops itself.

With the constraint that the resource partitioning should be conveyed within one super-frame the number of hops is limited by the number of MAC frame within one super-frame. In the example parameterization with 8 frames per super-frame ($n_f = 8$) a relay chain with eight tiers of relay nodes could be established, which is from the current perspective more than sufficient. Of course no ARQ feedback could realized with eight relay tiers.

The error recovery by means of ARQ can be on two levels in case of more than two hops as described in the second section of this paper. The RTT of the outer ARQ would restrict the number of RNs in a row to four ($=n_f/2$), if the possibility to convey the resource partitioning information up to the last tier is maintained. If only an inner ARQ (Hop-ARQ) is assumed the number of hops would be restricted to $n_f-1=7$ under the assumption that it is enough to preserve one MAC frame for a potential retransmission and not more than one retransmission is required.

The described extreme scenarios for more than two hops are taking into account that the resource partitioning information is older than one super-frame. If one sticks to the constraint that the information has to be gathered and transmitted within one super-frame the result would be a restriction to four ($n_f/2$) tier of relay (results in 5 hops).

Under the constraint that the resource partitioning should be based on information not older than one super-frame, the number of hops is limited to 3 ($(n_f/2)/2=2$ tiers of RNs) with e2e ARQ and 4 ($(n_f/2)-1=3$ tiers of RNs) with sole hop-ARQ.

Please note that in this exemplary calculations the processing time, e.g. for the evaluation of CRC checksums or to calculate an efficient partitioning of resources has been neglected. It should also be mentioned that it might not be necessary to restrict the transmission to one MAC super-frame, which would allow a much higher number of relays.

Hierarchical Controlled Resource Partitioning

In the hierarchical approach a RAP assigns a part of it's owns resources for the next tier of RNs. Consequently the BS gets assigned the resources for the whole Relay Enhanced Cells (REC), i.e. the RAPs are hierarchically organized with the BS on the highest level. In general the distribution of the resource partitioning information remains as shown in Figure 6, but in opposite to the centrally controlled resource partitioning the BS or the previous tier of RN is now the source of the resource partitioning information for the next super-frame. In the hierarchical controlled resource partitioning each RAP has to claim resources for its own use and the hierarchical lower RNs.

Obviously hop-ARQ is enough to protect the resource partitioning information as the information will be calculated individually for each hop.

Compared to the pure centralized approach the hierarchical concept provides a higher flexibility and dynamic to react on local resource requests. A RAP can assign resources to the next tier of RNs on a short term basis, e.g. to solve higher QoS demands. Flows with less critical QoS demands can be delayed until additional resources have been assigned.

In the hierarchical approach the interference avoidance mechanisms do not have the chance to control all RAPs of the network. Thus, a centrally controlled interference avoidance function can only avoid intra REC interference. Also the computational complexity at the RAPs is increased as they have to calculate the resource partitioning individually.

A combination of centralized and hierarchical organization is possible. Thereby, primary RAPs get assigned the resources from the central network element (ACS). The primary RNs can further assign parts of "their" resource to secondary RNs in their range, e.g. to cover otherwise shadowed areas or to increase the coverage at the cell border.

The hierarchical controlled resource partitioning is especially important for a special type of RNs where the BS (or RN) can be heard by all UTs in its REC [14]. In this case the BS is able to broadcast the resource partitioning information for the whole (sub-)REC in the BCH. This method is very efficient due to short RTT for the resource partitioning information, but seems to be a rather rare case.

Distributed Resource Partitioning

In the distributed resource partitioning each RAP agrees with the neighboring RAPs on resource partitioning. The advantage of distributed resource partitioning is the short information flows, i.e. a flexible hop number is possible without any constraints. Further all RAPs can be self-organized.

The drawback compared to the centralized approach is that the information which can be taken into account, e.g. to allow for optimized interference avoidance are limited.

In [13] a system which supports distributed resource partitioning is presented. But in opposite to WINNER the system is based on fixed time-frequency channels, which can be reserved by means of contention.

Conclusions

The paper presented a detailed overview about the relaying capabilities of the WINNER system. Different possibilities of resource partitioning have been discussed in the paper. The most detailed solution is the centrally controlled radio resource management, where the highest amount of interference avoidance might be possible. On the other hand a high degree of self-organization is desired for flexible deployment concepts with low maintenance, which could be provided by a distributed solution.

The discussion on the pros and cons of the different approaches build the basis for the decision on which scheme to use in the final WINNER system. In which a mixed scheme composed out of two of more presented approaches is possible.

Although WINNER is currently providing a fully synchronized system, it is worth mentioning that the shown relay integration is suitable for partly synchronized or asynchronous networks as well.

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