Algorithms for Adaptive Radio Resource Management in Relay-Assisted LTE-A Networks

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***Abstract*—LTE-Advanced networking standard introduces fixed relays as one of the ways to support the ambitious performance requirements for next-generation network services. The relays are introduced to increase the available capacity or to extend the coverage of the network. Balancing the dynamic interference scenarios and the complex resource management in relay-assisted networks presents one of the key challenges for the further development of LTE-A. This paper introduces the challenge of adaptive resource management and identifies simple adaptive scheduling methods based on channel quality information. The paper then utilizes a comprehensive simulation tool to show clear throughput benefits of using adaptive resource management for either the cell edge users or users experiencing very good signal-to-interference ratio, depending on the system objective.**

I. Introduction

3GPP LTE-Advanced (LTE-A) introduces several new technical features which bring additional improvements in terms of coverage extension and/or increasing the capacity of the system. LTE-A enhances spectrum flexibility through carrier aggregation (CA) which gives the opportunity to use up to five components carriers. The release extends multi-antenna transmission where a maximum of 8 antenna ports is supported. For heterogeneous network deployments in terms of pico cells an additional feature to improve inter-cell interference coordination, as well as the support of relay nodes (RN) is introduced. Static relaying which can be used either for capacity or coverage extension is the focus of this paper. Several challenges have been identified to introduce the RNs to the LTE network [1]. They include maintaining backward compatibility and dealing with the higher dynamic of interference in the system. In addition it is important to design the scheduling of the available physical resources in the network which is the focus of this paper.

The RNs are classified according to their functionality. They have a wireless backhaul link (BL) which can be either deployed on co-channel (inband) or on dedicated channel (outband) [2]. An RN in its simplest mode has very little intelligence and just amplifies and forwards the received signal. This type of RN is defined as layer one RN. A layer two RN has at least the opportunity to decode and forward the signal to adapt modulation and coding schemes to the current channel quality. The radio resource control itself is controlled by the donor eNode-B (deNB) which serves the RN. Layer three RNs have full control of their radio resources and have the same functionality as an eNB. Within this study layer two RNs are used [3], [4]. The user equipment (UE) can be served via a direct link (deNB-UE) or via a two hop link which consists of the BL (deNB-RN) and the access link (RN-UE). In this context the advantage of a two-hop link is the split of direct links (DL) for UEs experiencing bad quality. A lower path loss (PL) on the access link (AL) is obtained since the distance to the serving RN is shorter than to the deNB. In addition the probability is increased to get line of sight conditions (LoS) for the AL. In case of a reuse factor of one the RNs as well as the eNBs have full access to the total system bandwidth.

However, to make use of that advantage in a scenario where inband BL is deployed it implies the need of excellent link quality to overcome the problem that there is usually a loss in time since the RN cannot receive and send simultaneously.

The 3GPP has defined the multicast broadcast single frequency network (MBSFN) subframe which is used for backhaul reception at the RN in [2]. As depicted in Fig.1 this special type of subframe gives the opportunity to transmit at first the physical downlink control channel (PDCCH) which is expected by each UE within each subframe and then switches to the reception mode where the RN can receive data from the deNB. During that time the UEs assigned to the RNs are not served with data. In the end of an MBSFN subframe the RN again switches back to sending mode. As mentioned

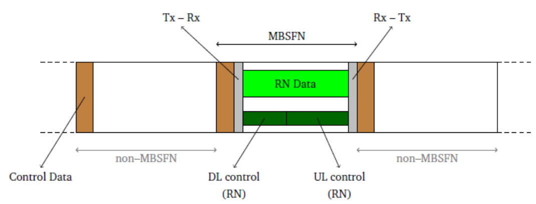

Figure 1. Use of MBSFN subframe structure to receive data at the RN

before, the used approach to serve the inband RNs is half-duplex, which brings a loss in time. Moreover there exist some additional constraints which are summarized as follows.

In the LTE frequency division duplex (FDD) downlink frame structure several subframes are not configurable as MBSFN subframes since they transport system relevant information such as physical broadcast channel (PBCH) (1st subframe) or primary and secondary synchronization signal

(P/S-SS) (5th, 6th and 10th subframe). In addition the MBSFN subframe has a periodicity of 8 milliseconds (ms) while the LTE frame structure is defined with a periodicity of 10ms. In principle each RN could be configured in sending or receiving mode at different times. The set number of MBSFN subframes can be updated every 40ms via PBCH to react on e.g. a changing traffic demand of the RN [5]. This results in a higher dynamic of interference than in a system without RN extension and introduces additional challenges to cope with, such as faster channel feedback outdate in FDD DL [1].

Basic scheduling procedures, such as round robin (RR) or proportional fair (PF) scheduling methods in eNB only networks have been extensively studied, e.g. [6]. As well in RN aided LTE networks, modified radio resource management (RRM) procedures are investigated and analyzed, e.g. [7], [8]. In this paper several definitions of a weighting factor which prioritizes the RNs to be scheduled are introduced. The influence of these different approaches on the network performance is shown. The evaluation of different approaches is done based on the results of system level simulations (SLS) in terms of wideband average signal to interference plus noise ratio (wSINR) and UE throughput.

The paper is organized as follows. The system model is described in Section II. In Section III the modified scheduling schemes are defined, followed by Section IV which presents assumptions and results of the SLS. Section V concludes the paper.

II. System Model

A. Network Layout

In Fig. 2 the used RN extended LTE-A network with 19 hexagonal cell sites and 3 sectors per site is shown. In each

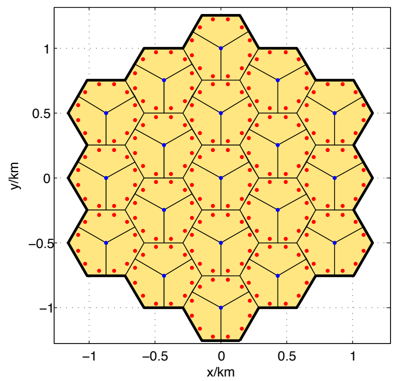

Figure 2. Network Layout,19 eNBs, 3 Sectors/Site, 4 RNs per Sector

sector 4 RN are placed near the cell edge with planning gain based on [9]. Each cell sector is equipped with a directional antenna with a 3dB horizontal beam width of 70°. The receiving antenna of the RN has a directional antenna with a 3dB horizontal beam width of 40°. Transmitting antennas of the RN and the receiving antenna of the UEs are omni directional. A uniformly UE distribution is considered. The assignment of UEs is done based on the reference signal received power (RSRP). Then an estimation is done considering the worst case wSINR for all UEs where all RNs are transmitting. The possible DLs are compared to the AL of the two-hop link. Out of the wSINR a supportable rate (SR) is derived based on a Shannon bound approximated curve [10]. If all SR are known initially, the BL and the AL of the two hop link, are compared with each other. The minimum of both values is than compared with the SR of the DL. Therefore the UEs will only be served on the physical resource blocks (PRB) of the RN if the quality is better than on the DL.

B. Dynamic Interference, Scheduling and Buffer

The available system bandwidth is separated in PRBs, which can be assigned to UEs every ms by the scheduler. The RNs have the same available system bandwidth as the deNB. The interference situation can change rapidly by switching RNs from receiving into sending mode in different subframes than in the neighboring sites or sectors. Even if the same subframes are configured as MBSFN, the amount of transmitted PRBs could be different and thus interference will be more dynamic in frequency and time than in homogeneous networks. The scheduling can be shifted from a fair resource distribution, which would be a RR approach without considering the channel quality, to a max-min scheduler where the UEs with the best link quality get all the resources. A PF scheduler prioritizes the UEs with good quality conditions while also serving UEs with worse channel quality.

Within the study a modified RR as well as modified PF scheduling approaches are considered. Therein the well known metrics are extended by a weighting factor which prioritizes RNs to get data when they are able to receive during MBSFN subframes. Hence, it is not a full buffer, fully loaded system for the AL. Limited by an introduced buffer scheme at the RN the data is scheduled based on the common schemes at the RN. The maximum configurable number of 6 MBSFN subframes within a radio frame is used. The RNs are only transmitting during non-MBSFN subframes. For each UE the SINR on its scheduled PRBs is calculated. MBSFN subframes are configured synchronous to prevent even higher dynamics in interference. This is done to have less influencing variables on the results, therefore having a better impression of the scheduler's behavior and on the influence of the different weighting factors.

An additional challenging problem is to handle the channel estimation feedback in such dynamic systems [1] which will be investigated in the future (see Section V).

III. Adapted Basic Scheduling Schemes by Different Types of Weighting Factors

A. Weighted Round Robin Scheduler

The common round robin approach is defined by,

$$m_{\text{PRB}}(u) = \left\lfloor \frac{p_{\text{RR}}(u)}{\sum_{i=1}^{U} p_{\text{RR}}(i)} \cdot \text{PRB}_{\text{total}} \right\rfloor, \qquad (1)$$

where the number m of PRB which will be assigned to the user u is defined as the priority p_{RR} of the user which is divided by the sum of the total number of priorities of the assigned users, multiplied with the maximum number of available PRB_{total}. The priority factor p_{RR} can be defined as one which results in a common round robin approach. This is done by,

$$p_{\text{RR}}(u) = 1, \qquad \forall\, u \in U; \tag{2}$$

where the same priority p_{RR} for user u of all users U is given.

To prioritize the RN at the deNB,

$$\begin{aligned} & p_{\text{mRR}}(u) = 1 \cdot w_{\text{RR}}(u), \\ & w_{\text{RR}}(u) = \begin{cases} 1 & \text{for UE}_{\text{eNB}} \\ w(rn) & \text{for RN} \end{cases} \quad \text{with } w(rn) = U_{\text{served}}, \end{aligned} \tag{3}$$

is used. Here the weighting factor w is given. If the user u is defined as an RN the number of UEs assigned to the RN (U_{served}) equals the weighting factor $w(rn)$. In all other cases w_{RR} is defined as one.

B. Weighted Proportional Fair Scheduler 1

As a basis for the second alternative in this study the common PF scheduling approach is given by,

$$p_{\text{PF1}}(u, \text{PRB}) = w_{\text{PF1}}(u) \cdot \frac{\text{SR}(u)}{\sum_t \text{THR}(u,t)^{\alpha}}, \tag{4}$$

The priority is calculated for each user u on each available PRB based on Eq. 4 where the SR of each user u is calculated as explained in Section II. The exponent α is defined as the fairness factor and set to one to keep proportional fairness.

As an example, if α would be set to zero a max-min scheduling approach would be used which can be seen as unfair since all the resources would be always assigned to users with the best SR.

The weighting factor w_{PF1} is calculated in the same manner as for the modified approach in Eq. 3. The throughput THR of each user u at every time t is calculated by,

$$\text{THR}(u,t) = \beta \cdot \text{THR}(u, t-1) + (1-\beta) \cdot \text{d}(u,t), \tag{5}$$

The first term is defined as the previous user throughput already transmitted. The second term d is defined as the instantaneous throughput transmitted in the latest time instance. The factor β is defined as the forgetting factor which influences the priority based on a weighting of past transmitted data.

As an example, if β would be defined as one only the initial transmitted throughput would influence the metric, thus it would result in a max-min scheduling approach. During this study the forgetting factor β is set to 0.97.

This approach does not take into account the link quality which will be introduced due to the following.

C. Weighted Proportional Fair Scheduler 2

As a second alternative for the weighted PF scheduling a different weighting factor is defined by,

$$w_{\text{PF}}(rn) = \begin{cases} w_{\text{PF1}}(rn) \cdot w_{\text{PF2}}(rn) & \text{if } w_{\text{PF2}}(rn) > 1, \\ w_{\text{PF1}}(rn) & \text{if } w_{\text{PF2}}(rn) \le 1, \end{cases} \tag{6}$$

and

$$\begin{aligned} w_{\text{PF2}}(rn) &= \sum_i^{U_{\text{served}}} \left(\frac{\text{SR}_{\text{AL}}(i)}{\text{SR}_{\text{BH}}(rn)} \cdot \frac{\text{SR}_{\text{AL}}(i)}{\sum_j^{U_{\text{served}}} \text{SR}_{\text{AL}}(j)} \right) \\ &= \sum_i^{U_{\text{served}}} \left(\frac{\text{SR}_{\text{AL}}(i)^2}{\text{SR}_{\text{BH}}(rn) \cdot \sum_j^{U_{\text{served}}} \text{SR}_{\text{AL}}(j)} \right), \end{aligned} \tag{7}$$

Where w_{PF} is the weighting factor for the RNs. w_{PF1} is the factor given by the number of users as in Eq. 4 and w_{PF2} is the factor introduced by comparing the SR of access and backhaul links given in Eq. 7.

A ratio between access (SR_{AL}) and backhaul (SR_{BH}) links is calculated. If the AL has a better quality than the BH link, w_{PF2} is larger than one and thus more resources should be spent to serve the RN than in the previous approach in Section III-B. The ratio between AL and BH link is multiplied by the ratio between the quality of the AL and the sum of all ALs of the RN which reflects the importance of the link among all connected users (U_{served}) to the RN. The resulting product of multiplying the two ratios in sum over all served users is defined as w_{PF2}.

D. Weighted Proportional Fair Scheduler 3

As described in Section I it is of greatest importance to provide excellent link conditions for the BH link because of the loss in time by using inband RNs. The proposed weighting factor in Section III-C might remain as the number of users, since the BH is not worse in many cases compared to the AL. For that reason, another alternative is defined. This approach relates the AL and BH links by comparing the theoretical amount of data that each link can provide given by an initial resource distribution. If the RN receives less data than the users demand, the weighting factor increases the scheduling priority of the RN. If the UEs do not require as much data as the BL can offer the weighting factor is less than unity to allow other RNs or UEs at eNBs to receive more data. Based on the SR a proportional distribution is done in order to determine the amount of PRBs per UE. As given by,

$$d(u) = \text{PRB}_{\text{AS}}(u) \cdot \text{SR}(u) \cdot \text{BW}_{\text{PRB}} \cdot T_{\text{SF}}. \tag{8}$$

The assigned resources per UE, $PRB_{AS}(u)$ are multiplied with the SR, the BW of a PRB and the duration of a subframe T_{SF} to calculate the amount of data which has to be transmitted for a single UE. Finally the ratio between access d_{AL} and backhaul d_{BH} data, respectively is calculated to obtain the weighting factor for RNs as described by,

$$w_{\text{PF3}}(rn) = \frac{\sum_i^{U_{\text{served}}} d_{\text{AL}}(i)}{d_{\text{BH}}(rn)}. \tag{9}$$

IV. System Level Simulation Assumptions and Results

In Tab. I the most important simulation settings are summarized which follow [9].

In Fig. 3-5 the simulation results are depicted for all approaches as cumulative distribution functions (CDF). On the

Table I
SYSTEM LEVEL SIMULATION PARAMETERS

Parameter	Value
Cellular Layout	Hexagonal grid, 19 sites, 3 sectors per site
Inter Site Distance	500m (3GPP case 1)
Carrier Frequency	2GHz
System Bandwidth	10MHz, DL
eNB TxPower	46dBm
eNB antenna pattern	3GPP 3D Ant. Model with 14dBi max. gain
RN Tx Power	30dBm
RN Tx antenna pattern	Omni directional with 10dBi gain
RN Rx antenna pattern	Directional with 40° beam width and max. gain of 7dBi
No. of MBSFN subframes	6
Propagation Model	Distance dependent model according to [9]
Number of RN per sector	4
RN location	Cell edge with planning gain (alternative 2) according to [9]
UE distribution	Uniform distribution
Avg. no. of UEs / sector	20
Scheduler	modified RR, modified PF
Transmission scheme	SIMO based on [10]
Traffic Model	Full buffer @ eNB, limited buffer @ RN
Control Channel Overhead	3 symbols for DL CCHs per subframe plus demodulation of reference symbols

left side the wSINR and on the right side the UE throughput are shown. Fig. 3 gives results for the UEs which are served by the macro via the DL. Fig. 4 illustrates the results for the UEs which have been served by the RNs and finally the overall performance is depicted in Fig. 5. In addition it is worth to mention that in all scenarios approx. 50 per cent of all UEs are served by RNs and the other half through DL connection. The black curve in all CDFs is always defined as the reference scenario where no RNs are deployed in the system. Focussing on the overall results we can observe that there is a gain for all schemes compared to the reference in terms of wSINR and UE throughput. In the following the different approaches are compared with each other and obtained effects are described.

A. UEs served through direct link (UE@MBS)

In Fig. 3 the effect of selecting the best link, in terms of SR, to serve the UEs is clearly seen on the wSINR results, where for all the proposed schedulers the UEs' SINR conditions are better than the reference case (MBS only). Only those UEs, whose best serving option is the DL, remain connected to the MBS shifting low wSINR users to the RNs. Hence, improving the SINR. The differences between schedulers are caused by changes in the interference, due to different RNs transmitting. Additionally, the obtained throughput indicates the performance of each scheduler. The best throughput for UEs connected directly to the MBS is obtained when applying the basic RRS, since these UEs are scheduled in every TTI with the same amount of resources as RNs (in the case RNs are in receiving mode). When the weighting factors are applied, in order to transmit more data to the RNs, the macro UEs' performance is reduced. Therefore, the PFS-3 throughput result is almost the same as the reference scenario in despite of the wSINR improvement. There is no significant difference between PFS-1 and PFS-2 because of the seldom appearance of cases where the ALs are better than the backhaul, as a result of the site planning.

B. UEs served through RNs (UE@RN)

In Fig. 4 a deviation in wSINR compared to the reference scenario can be observed. The interference experienced by this user group is higher than in a macro only case, since all the RNs are transmitting simultaneously (assuming they have data to forward). Therefore, the wSINR can be even worse than in a macro only case. However, in situations where the interference is not significant, higher SINR values than for macro UEs are possible as a result of the shorter separation distances between UEs and the RNs.

If no weighting factor is applied in order to prioritize the data transmission to the RNs, UEs connected via a two hop link are not scheduled often enough due to the time division scheme applied to manage the RNs. Thus, the UE throughput of the basic RRS is worse than the reference scenario. Otherwise, when applying weighting factors, the throughput is significantly improved, especially for UEs with very good wSINRs (over the 90th percentile). That is the case of the PFS schemes. A higher impact can be seen of the schedulers at low throughputs (5th percentile) in comparison to the DL users. As mentioned for the wSINR, RN users suffer higher interference and the majority of them is expected to be mainly localized in that part of the throughput CDF.

C. Overall served UEs (UE@MBS+RN)

Fig. 5 summarizes the results for all UEs (direct and two hop links). Three regions can be observed at the throughput CDF: from 0 to 60th percentile, there is a higher influence of the RN users; therefore, schedulers which provide more data to the RNs (PFS-1 and PFS-2) have the best performance. In the case of PFS-3, the amount of remaining resources to be used by the macro UEs is too low, counteracting the benefit of the weighting factor in the overall system. From 60th to 95th percentile, the higher influence of the macro UEs can be seen by taking into account the best result provided by the basic RR scheduler, which benefits the most these users. Finally, from 95th to 100th percentile, UEs with the best wSINR are represented. As mentioned before, those UEs are served through the RNs and are better served when providing enough data, which is possible by using the PFS-3 alternative. Finally it can be seen that the used metrics can either improve the capacity (avg. gain) or the coverage (5 percentile).

V. CONCLUSION AND FUTURE WORK

This paper shows simulation results for a RN enhanced LTE network. It defines and analyzes different approaches of how RNs can be scheduled at the MBS, taking into account the usage of MBSFN subframes. It can be seen that the definition of how to prioritize the RNs in the scheduling process is important. The goal could be a capacity extension or a coverage improvement for the system. Five possible metrics are compared and the results show either a coverage improvement or a capacity extension. It could also be observed

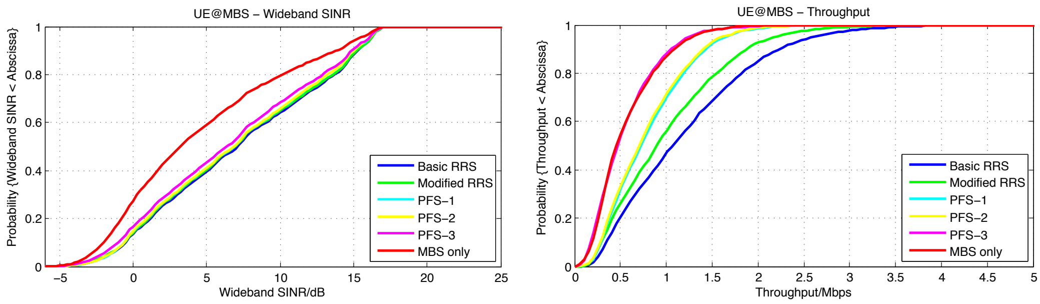

Figure 3. SLS Results for UEs served by MBS

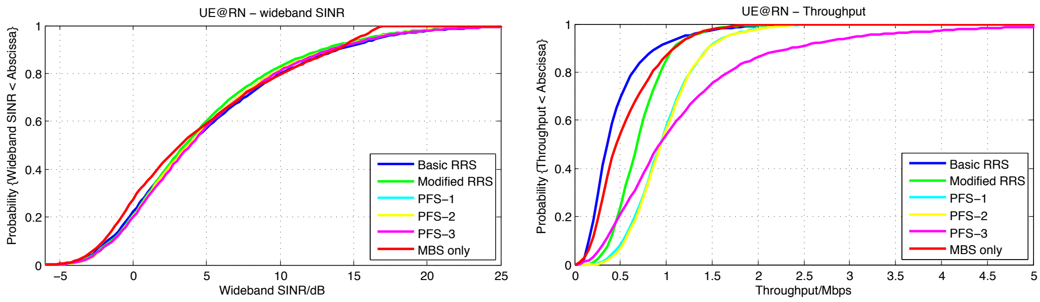

Figure 4. SLS Results for UEs served by RNs

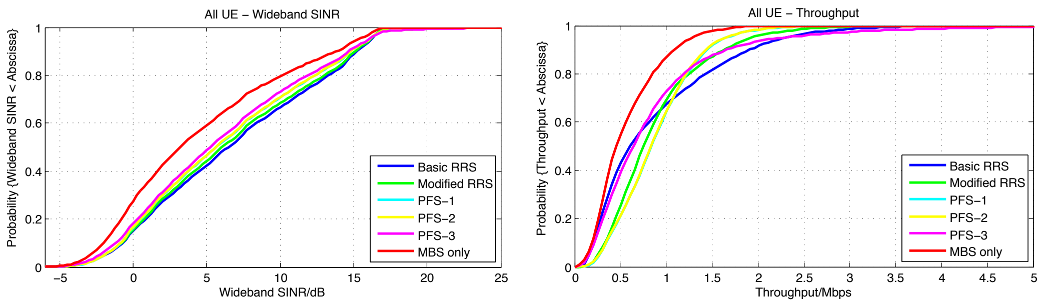

Figure 5. SLS Results for all UEs served by MBS and RNs

that the wideband SINR conditions of the users are influenced by the different scheduling approaches.

The next step will be to introduce a MIMO system with a frequency selective channel model and channel feedback information, considering [11]. Based on that a deeper analysis can be done of how to handle a fast outdate of the channel estimation feedback information in such a system with high dynamic of interference which needs to be investigated further, as recommended in [1], [12].

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