On Interference Coordination in Metropolitan Area Relay Networks

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Abstract: The radio resource management is crucial for the performance of a cellular network in general and for relay based deployments in particular. In this paper we study different interference coordination schemes for low cost relay networks in a metropolitan area with high user and traffic density, which we then evaluate in dynamic system simulations. Our results show that the performance of the relay network is very sensitive to the utilized interference coordination scheme. The difference in average user throughput between a very restrictive and the best scheme is about 300%. Thus, the results clearly indicate that the radio resource management should be flexible and no restrictive interference coordination is needed. Moreover we show that soft frequency reuse is a well suited interference coordination technique for relay networks that aim to provide outdoor to indoor coverage.

Keywords: Relay networks, Manhattan Grid, OFDMA, 4G, Scheduling, Soft Reuse, Soft Resource Partitioning.

1. Introduction

Next generation mobile communication networks aim to provide ubiquitous broadband radio coverage in a cost efficient manner. To fulfil this objective a high spectral efficiency is required and a frequency reuse of one is targeted. With its natural resistance to multi-path fading, its support of multiple-input multiple-output techniques [1] and higher order modulation Orthogonal Frequency Division Multiple Access (OFDMA) is a major candidate for fourth-generation air interfaces was also studied in the European research project WINNER [2].

Mobile users expect seamless coverage with a guaranteed Quality of Service (QoS) allowing a similar user experience than todays broadband internet connections. The consequence is a high spectrum demand of approximately 100MHz to allow high aggregate data rates of up to 1Gbit/s. For that reason, the world radio conference 2007 has allocated new spectrum in different frequency bands for future radio communication systems mainly beyond 3 GHz. The high carrier frequencies of these bands together with regulatory constraints on the transmission power will limit the range for broadband services. Thus, many small cells are required for contiguous coverage of areas with high traffic density. In [3] it was shown that relay based deployment concepts as part of multi-hop cellular networks provide the means to balance the capacity and increase the coverage area of a single BS.

The main motivation to deploy RNs is to decrease the overall network cost and the properties of the relay nodes (RN) have been chosen such, that a cost efficient deployment is possible.

The radio resource management is crucial for the performance of a cellular network in general and for a relay based deployment in particular. The interference in the network can for example be coordinated by frequency reuse. Recently soft frequency reuse a.k.a. soft-resource partitioning, and power planning has received increased attention, due to its ability to coordinate interference in wireless networks while allowing a reuse of one. The idea of SFR was first introduced in [4] and [5] in the context of capture division packet access. The use of half duplex relay nodes requires additionally coordination in the time domain, i.e. splitting the time slots (frames) into time slots where the relay is serving user terminals (UT) and time slots where the relay is communicating with the base station.

In this paper we study the impact of these different radio resource management options on the performance of a relay deployment by dynamic system simulations in a metropolitan area, represented by the well known Manhattan grid. We have chosen a metropolitan area test scenario, as it represents the densest population requiring the highest traffic density. Thus, metropolitan areas are the most interesting scenarios for fourth generation networks. Our results show that the performance of the relay network is very sensitive to the utilized interference coordination scheme. The difference in average user throughput between the worst (most restrictive) and the best scheme is about 300%. Thus, the results clearly indicate that the radio resource management should be flexible and no restrictive interference coordination is needed. Moreover, we show that soft frequency reuse is a well suited interference coordination technique for relay networks that aim to provide outdoor to indoor coverage. It increases the average user throughput by 14% compared to reuse one.

The remainder of this paper is organized as follows. In Section 2 we discuss different possibilities of interference coordination in a relay network and in Section 3 we present the metropolitan area test scenario and the simulation setup. Thereafter, we present in Section 4 the corresponding numerical results and we conclude with Section 5.

2. Radio Resource Management in Relay Networks

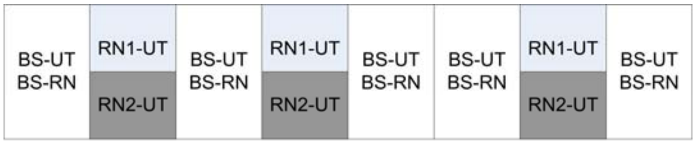
In this section we introduce different radio resource management (RRM) options in a relay network. As we will see later in the evaluation results, the RRM is crucial for the performance of a relay network but first we will introduce the main properties of the RN considered in this work, which follow the assumptions outlined in [6] and [7].

In this work only pure “decode and forward” relays are considered. Decode and forward relays can take advantage of adaptive transmissions with different modulation and coding schemes, which is especially beneficial for “intelligent” deployments with a good link quality between BS and RN. Both RN and BS provide an identical interface towards user terminals (UT) and there is no necessity for the UT to distinguish between RN and BS and both are referred to as Radio Access Points (RAPs). The MCN is primarily designed and optimized for two hops (BS-RN-UT) in order to achieve a high performance in terms of throughput and delay and only two hop deployments are studied in our performance evaluation.

Results in [8] indicate that the cost of a RN should be about one half to one ninth of the cost of a BS to achieve a cost benefit by relays in a wide area scenario. The ratio depends very much on whether the evaluation is based on the minimum or average provided service level. Further results in [7] indicate that the cost ratio between micro BS and RN should be at least 1.5 for unequal traffic density in a wide area scenario and 3 in a metropolitan area scenario for relay deployments to be cheaper than BS only deployments.
In [9] the maximum output power and the complexity of the access point, like e.g. multiple antennas, were identified as the major network cost drivers. Hence, RN should have a low output power and a small number of antennas. Furthermore, small RNs that do not require shelter, cooling and backhaul connection reduce the site acquisition costs because they can for example be mounted on lamp posts. To further reduce the costs of the RNs, they are

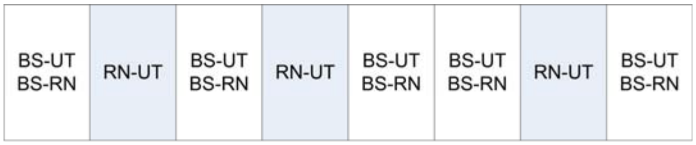
assumed to be half duplex. Finally, in-band relays do not require a wireless or wired backhaul connection and thus the operational expenditures (OPEX) can be further reduced compared to RN with an out-of-band backhaul. All of these aspects will enable the required cost ratio between micro BS and RN and they have also been taken into account when defining the test scenarios presented in Section 3.

Relay networks offer additional possibilities for radio resource management than traditional cellular networks deploying only BSs. Figure 1 illustrates different alternatives: in Figure 1(a) BS and RN do not serve user terminals UT at the same time and the RN are divided into two groups. Each group of RN uses half of the bandwidth resulting in a frequency reuse of two for the RN transmissions.



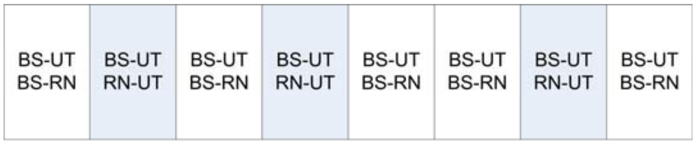
BS-UT BS-RN	RN1-UT RN2-UT	BS-UT BS-RN	RN1-UT RN2-UT	BS-UT BS-RN	BS-UT BS-RN	RN1-UT RN2-UT	BS-UT BS-RN

(a) Frequency reuse of two between two gorups of RNs.



BS-UT BS-RN	RN-UT	BS-UT BS-RN	RN-UT	BS-UT BS-RN	BS-UT BS-RN	RN-UT	BS-UT BS-RN

(b) BS and RN do not transmit at the same time.



BS-UT BS-RN	BS-UT RN-UT	BS-UT BS-RN	BS-UT RN-UT	BS-UT BS-RN	BS-UT BS-RN	BS-UT RN-UT	BS-UT BS-RN

(c) BS and RN serve UT at the same time.

Figure 1: Interference coordination options for the eight frames of the super frame.

In Figure 1(b) all RN use the whole bandwidth when serving UT. Thirdly, in Figure 1(c) BS and RN serve UT at the same time and over the whole bandwidth. Half duplex RN cannot transmit and receive at the same time. Thus, the amount of frames where the RN is receiving from the BS and the amount of frames where the RN is serving UT is an additional degree of freedom.

In addition to the aforementioned interference coordination schemes, we also study the use of directive antennas at the RN for interference coordination. One antenna points towards the BS and is used for BS-RN communication. The second antenna is pointing away from the BS and is used for RN-UT communication.

Further, we study the use of soft frequency reuse (SFR) for interference coordination in relay networks. The fundamental idea of SFR in an OFDMA system is to assign power masks in the time or the frequency domain to neighboring radio access points (RAP), i.e. BS and/or RN. Thus, SFR enables frequency reuse one and at the same time each RAP has high power resources with reduced interference available to schedule UT in the border area between RAPs. Figure 2 compares SFR and hard frequency reuse to a reuse of one.

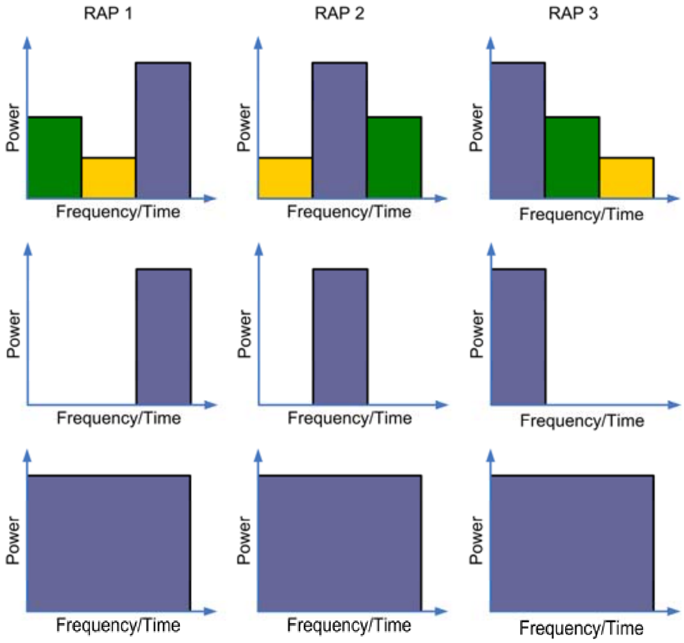


Figure 2 Soft Frequency Reuse vs. Hard Frequency Reuse vs. Reuse one.

3. Metropolitan Area Test Scenario

The metropolitan area test scenario is an urban microcellular scenario using the time division duplex (TDD) WINNER physical layer mode and 100 MHz bandwidth at 3.95 GHz. A detailed description of the WINNER system parameters can be found in [10]. In the metropolitan area test scenario, a two-dimensional regular grid of streets and buildings is considered, the so-called Manhattan grid. The test scenario with the BS and RN locations, and the assigned power masks to the RN in the SFR case, is presented in Figure 3. Both the BSs and the RNs are deployed below rooftop and with a single antenna per BS sector and RN. The maximum transmit power for both BS sectors are set to 37dBm and for the RN to 30dBm. The RNs are equipped with a single omni-directional antenna or with two directional antennas, one pointing towards the BS and one pointing away from the BS, which is used to serve the UT. Even though the RN is equipped with two antennas, only one receiver and transmitter chain is required, because the RN is operating in half duplex. The corresponding channel and path-loss models for all links are B1 LOS for nodes in the same street and B1 non-LOS for nodes in different streets. They are specified in [11].

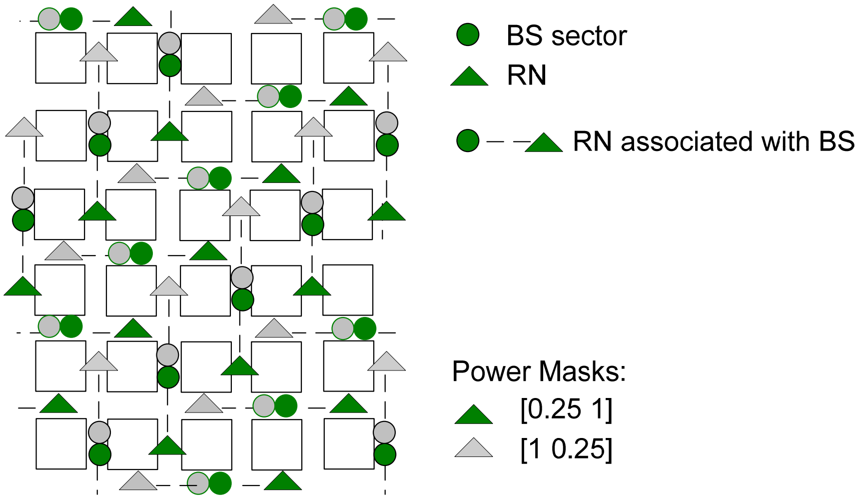


Figure 3 Relay deployment pattern with assigned power masks for RN in the center cells.

The simulation tool is a dynamic event driven simulator that simulates UL and DL directions simultaneously with OFDMA symbol resolution with an Exponential Effective SINR Mapping (EESM) link to system mapping [12]. The most important simulation parameters can be found in Table I. Similar to [13] we use a two stage scheduling process. A time domain scheduler guarantees fairness between the users. It selects the 6 users with the lowest average throughput in the last 200ms. The frequency domain scheduler uses the proportional fair criteria to improve the spectral efficiency. The user throughput statistics have been collected every 400ms.

Table 1 Selected simulation parameters in addition to the parameters specified in [10].

Parameter	Value
RN Tx power	30dBm
RN antenna gain (non-directional case)	7dBi (omni)
RN antenna gain (directional case)	14dBi (75deg beamwidth)
Initial RAP Selection	Received Signal Strength
Handover	Hard Handover
Handover margin	3dB
Network synchronization	Fully synchronized
Traffic Model	Full Buffer
Simulation Time	70s
Call arrival process	Poisson arrivals (4500 during simulations)
Max. number of active UT	1500

To avoid edge effects the simulation results are only obtained from 4 monitored cells in the center. One tier of cells (21 cells) around these center cells is fully modeled, including user mobility, handovers, scheduling, etc. The rest of the cells are modeled as interfering RAP, i. e. the user traffic and the scheduling are not modeled but they are included in the interference calculation. The UTs are randomly placed and move only in areas served by the active cells at a pedestrian speed of 3km/h. We present selected simulation parameters, that are not specified in [10], in Table 1. In the SFR case we subdivide the available OFDMA resource units (chunks) in the frequency domain into equal sized groups and assign a power level P = {1, 0.25} to each group. The power levels have not been optimized for any particular scenario but we believe they are reasonable choices.

4. Numerical Results

4.1 Outdoor Scenario

Table 2 compares the impact of the different interference coordination schemes in Section 2 on the performance of the relay deployment presented in Section 3 for outdoor users located in the streets. We start from a scenario with the most restrictive interference coordination, i.e. BS and RN do not serve UT at the same time and the RN use a frequency reuse of two (Hard mask). The RN marked in green in Figure 3 use half of the bandwidth and the RN marked in gray use the other half. This is the reference scenario and the impact of the other radio RRM schemes will be presented as relative increase or decrease in average user throughput of the users served by the monitored cell for at least 75% of the session time.

Table 2Performance Impact on the average User Throughput of different RRM Options.

RRM option	Relative Average UT throughput
Reuse two in frequency domain	1
Reuse one in frequency domain	1.38
Directive Antenna at RN	1.67
BS and RN serve UT at the same time	2.30
Optimal amount of frames where the RN serves UT	3.00
Soft Frequency Reuse	2.98

Figure 4 compares the SINR of the received packets for the relay deployment for the different RRM schemes. The solid blue curve, having the highest SINR, represents the reference scheme, with a reuse of two between the two groups of RN. The RNs serve their UT in three out of eight frames. The SINR of the received packets is clearly higher for the relay deployment with the reference scheme. For example, compared to the case where BS and RN transmit at the same time, the median SINR is 22dB higher and the difference increases even further for the higher parts of the CDF. Nevertheless, the SINR distribution also indicates that the performance of the relay deployment could be increased by a less restrictive interference coordination to allow more parallel transmissions while decreasing the SINR to a tolerable value.

Allowing all RNs to use the whole bandwidth increases the average user throughput already by 38%. The RNs are only one block away from the BS in the test scenario in Figure 3. Thus, the UTs between the BS and the RN can easily be served by the BS. Therefore, we study the performance impact of using directive antennas at the RN pointing away from the BS to serve the UTs instead of omnidirectional antennas. This increases for example the 10%-ile of the SINR CDF by 2dB. However it requires the use of a second antenna for the BS-RN communication but this small increase in hardware cost is outweighed by the increase in average user throughput of almost 20%.

Next, we allow both the BS and the RN to serve its UT at the same time. This results in a further increase of 38% in average user throughput.

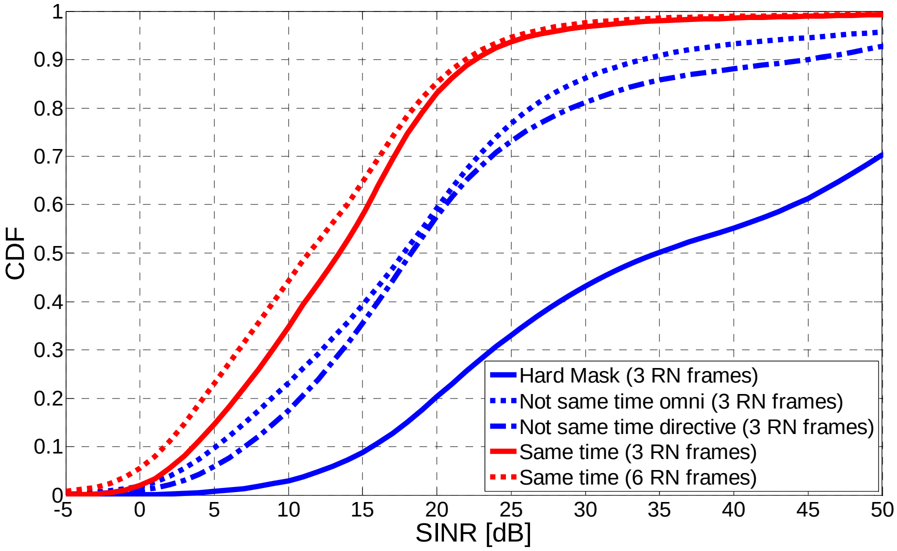


Figure 4 SINR of received packets CDF comparison of the relay deployment with different interference coordination options

In all the previous scenarios the RN was serving its UT in 3 out of 8 frames. Due to the lower transmit power of the RNs it was assumed that the RN would serve less UT and thus it served its UT in less than half of the frames. However the BS-RN link quality is much better than the average RN-UT link quality. Especially when BS and RN serve UT at the same time the interference situation is challenging and it is beneficial, if the RN can serve its UT in more than 3 frames. Therefore we varied the number of frames where the RN is allowed to serve its UTs up to 6 frames. The best result was achieved when the RN can serve its UTs in six out of eight frames, i.e. two frames are sufficient for the BS-RN communication. The number of frames is kept constant during the whole simulation and the same number is used within the whole network.

Selecting the optimal number of frames for RN transmission improves the user throughput by an additional 30%. This indicates that next to interference coordination in the frequency domain, the performance of relay deployments depends very much on the proper balance between the resources spent on the first hop between BS and RN and on the second hop between RN and UT. It is for further studies, if the performance of the relay deployment can be improved by allowing the RNs to transmit in different frames in different relay enhanced cells. Soft frequency reuse cannot further increase the average user throughput in the outdoor scenario.

The higher SINR of more restrictive RRM options could also be exploited by multi-stream transmission using MIMO techniques such as per-antenna rate control. However, the dense deployment of radio access points (RAP) assures a LOS or obstructed LOS connection of the UT to the serving RAP and the multi-stream support of the resulting MIMO channel will not be very good. In any case, we do not expect that the use of MIMO could increase the average user throughput by 300% which would be required to outperform the best performing RRM scheme studied in this paper.

4.2 Indoor Scenario

In addition to outdoor users, we simulated the same scenario but with only indoor users. The results for the first RRM schemes were similar than in the outdoor case. However, for indoor users, soft frequency reuse provides a 14% increase in average throughput compared to reuse one. This can be explained by the quality of the different links. The outdoor to indoor penetration loss is 13dB to 28dB depending on the angle with which the signal enters the building. Thus, the link quality to the indoor UT is much worse than the link quality of the BS-RN link. For the soft frequency reuse case we utilized a slightly modified version of the phased scheduler [7] that aims to schedule high SINR links at low power mask areas and low SINR links at high power mask areas. Thus, most of the BS-RN communication takes place at low power mask areas and the BS can serve UT with reduced interference in the high power mask areas.

5. Conclusions

In this paper we studied different RRM schemes for relay networks in a metropolitan area with high user and traffic density. Different interference coordination options were introduced and their impact on the average user throughput was investigated.

The results clearly indicate that no restrictive interference coordination is needed and a frequency reuse of one should be targeted. Overly restrictive interference coordination schemes can lead to significant performance degradation, e.g. the average user throughput of the most restrictive interference coordination scheme was only one third of the user throughput of the best performing scheme.

Interference coordination based on soft frequency reuse is very well suitable for relay deployments that provide outdoor to indoor coverage. It can exploit the significantly higher link quality of the BS-RN link quality compared to the BS-UT and RN-UT link and the average user throughput increases by 14% compared to reuse one. However, no improvement is obtained through soft frequency reuse in the pure outdoor scenario.

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