Joint Interference Coordination and Spatial Resource Reuse

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Abstract **- Multihop cellular networks (MCNs) have drawn tremendous attention due to its high throughput and extensive coverage. Deploying relay nodes is foreseen a cost-efficient solution to combat the severe propagation loss at cell edge. However, relay cell coverage is limited by the low transmit power, limited antenna capabilities and wireless backhaul link bottleneck which may lead to load imbalances and hence low resource utilization efficiency. Further challenges in relay deployments are attributed to increased interference levels in the network compared with macro cell-only deployments, causing degradation of the user throughput. In this context, relay cell coverage expansion and interference coordination techniques are expected to improve the performance of relay deployments. In this study, we analyze the impact of the additional interference due to the relay node transmissions. Jointly with our previous study on cell expansion, spatial resource reuse from the graph-theoretical perspective. Next, our focus shifts to developing a simple but efficient radio resource management algorithm which enables the spatial resource reuse, the pricing- based radio resource management (PRRM) strategy. The PRRM performs spatial reuse for interference-free users operating in the high signal-to-interference-and-noise ratio (SINR) region, while guaranteeing the signal quality of interference-susceptible users usually located near the coverage boundary. By applying the PRRM, we evaluate the potential benefits of the spatial resource reuse.**

Keywords: Multi hop cellular networks, interference coordination, cell range extension, load balancing, LTE-Advanced, relay deployment

I. INTRODUCTION

The future wireless cellular networks, such as 3GPP advanced long term evolution (LTE-Advanced) and IEEE 802.16m systems, will adopt orthogonal frequency division multiple access (OFDMA) technology for multi hop cellular networks (MCNs). OFDMA is regarded as the most promising physical layer technology for the fourth generation (4G) wireless networks. New relay strategies and technologies are proposed to provide services with extended coverage and higher data rate.

The motive behind choosing relaying as an enhancement technology to current radio access networks is well known. Briefly, relay nodes (RNs) increase the network capacity or alternatively, extend the cell coverage area, and is as well regarded a cost efficient technology. RNs are characterized by compact physical characteristics, low power consumption and flexible deployment coming from the wireless backhaul link to the core network and loose installation guidelines with respect to radiation and planning regulation.

In line with the LTE framework, the relay cells are defined according to the received signal strength in the downlink (DL). Hence, the lower transmit power of an RN and limited antenna capabilities as well as the limited capacity of the wireless backhaul link will render a smaller RN coverage area, which may lead to load imbalances and degrade the system performance. In our previous study, relay cell range extension techniques are investigated within the framework of LTE-Advanced, where significant performance improvement has been observed. However, additional interference is introduced which needs further consideration. As the relay cell expands, more resources need to be scheduled on the access link, which means that both cell edge macro-UEs and cell edge relay-UEs will experience higher interference due to RN transmissions on access link. Thus, interference coordination between the macro cells and relay cells may be required to fully utilize the range extension capabilities.

II. INTERFERENCE COORDINATION

Relay deployments add to the macro cells separate cells which reuse the same set of resources. The impact of legacy inter-cell interference is already alleviated due to relaying deployment, since the legacy cell edge UEs are now served by RNs with higher received power. However, new types of interference appear by introducing RNs.

In AZ, the RS delivers data from the BS to the MS and frequency resource should be allocated to the RS. Three different sub bands are allocated to a BS and two RSs in each sector for mitigating intrasector interference among these stations.
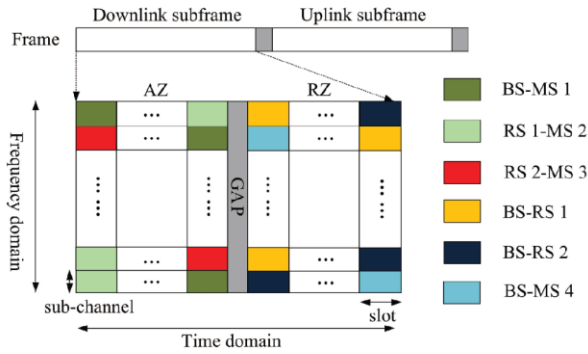
Fig. 1 TDD relay frame structure for MCNs

According to IEEE 802.16j/m specification, each time division duplex (TDD) frame consists of downlink and uplink sub frames. Each sub frame is subsequently divided into two time zones which are named as relay zone (RZ) and access zone (AZ), respectively. RZ is dedicated to the BS transmission toward both RSs and MSs, while AZ is dedicated to the reception of MSs from the BS or two RSs. Assuming each RS receives data for relaying in RZ at the current frame, it should be scheduled to transmit the data in AZ and empty its buffer at the next frame. In each sub frame, the frequency domain consists of sub channels and the time domain consists of slots. A slot in a sub channel is the minimum frequency-time resource unit. Fig. 1 shows TDD relay frame structure for MCNs.
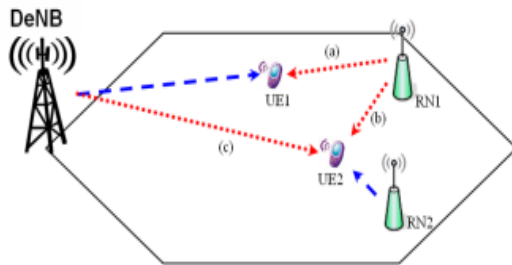

Fig. 2 Inter-cell interference in relay deployments.

In relay cell range extension techniques are performed by introducing a bias to cell selection and handover thresholds along with a reduction in DeNB transmission power, resulting in significant performance improvement.

SINR of a macro-UE will decrease due to DeNB power reduction, unless the UE is handed-over to relay cells. In this sense the RN-to-macro-UE interference coordination can reduce the SINR losses of the macro-UEs due to cell expansion. In addition, this does not affect the relay-UE throughput performance, since the relay link is mostly the bottleneck and resources at an RN are mostly not fully utilized. For the relay-UEs on the other hand, DeNB power reduction reduces as well their interference level since the

DeNB-relay interference level is automatically lowered. That is, the weight or the significance of the second term in the denominator of , which is the RN-to-macro UE interference, becomes relatively greater. It is therefore of importance to mitigate interferences coming from the RNs for the critical UEs jointly with cell range extension techniques.

Denoting N_i and I_i as thermal noise and sum interference level from other cells observed at the receiver of the ith user respectively, The signal-to-interference-plus-noise-ratio (SINR) can be expressed as in for macro-UEs and as in for relay-UEs, where M is the number of RNs, and PDeNB, i and PRN, ,ij are the received signal strengths at UE i from the DeNB and RN j,

III. PERFORMANCE EVALUATION

Comprehensive system level simulations were performed according to the latest 3GPP LTE-Advanced specifications. Results are provided for both urban (Case 1) and suburban (Case 3) scenarios with inter-site-distances (ISDs) of 500 m and 1732 m, respectively. The deployment is considered as a reference to determine the performance gains of interference coordination when relay cell expansion is applied. The evaluation concentrates on optimizing the best 5%-ile cumulative distribution function (CDF) throughput level, which reflects the cell edge user performance. Furthermore, other key performance indicators (KPIs) such as 50% performance and cell average throughput are also considered.
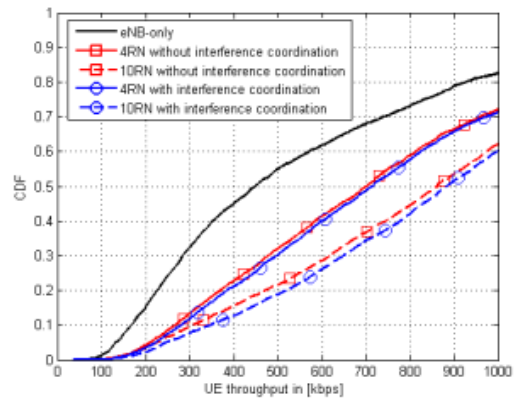

Fig 3 Urban scenarios without cell expansion.

In Fig. 3, the DL throughput CDF plots for urban scenarios with and without interference coordination are shown. With the coordination scheme, overall performance gains are achieved, where more improvements are observed in the 10- RN deployment because there are more interfering sources that are coordinated in this case.

It is worth noting that relay-UEs, which are limited by the relay link throughput, do not benefit from interference coordination. However, the interference coordination scheme

still improves the access link SINR and hence reduces the number of resources required on the access link, given the relay link bottleneck, consequently reducing the interference imposed on the macro-UEs. In addition, simulations in suburban models show only marginal gains in the 4-RN deployment, since it is not the co-channel interference but the received power levels which limit the system performance in coverage-limited suburban scenarios.

CONCLUSION

In LTE-Advanced networks, performance of the relay deployments depends strongly on addressing different radio resource management challenges, like cell load imbalances, resource allocation, and interference management. In addition, the relay cell edges rather than the traditional macro cell edges turn to be the critical areas especially when considering relay cell expansion. In this paper, we have investigated inter-cell interference jointly with relay cell expansion techniques. An interference coordination scheme based on prioritized scheduling has been applied on top of relay cell expansion techniques to further improve the system performance. The prioritized scheduling exploits the fact that the access links are not fully loaded due to the wireless backhaul link bottleneck. Comprehensive system level simulations have been carried out to evaluate the downlink performance of 3GGP LTE-Advanced Type 1 relay deployments. Results show that the interference coordination further improves the system performance in urban deployments. On the other hand, only modest gains are observed in the suburban scenarios, in which the low received power levels of the UEs limit the cell expansion and the effect of interference coordination. Besides, the presented scheme can be realized based on the ICIC procedures specified for LTE in the early release and hence no impact on the standard is expected.

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