Impact of Backhaul Subframe Misalignment on Uplink System Performance of LTE-Advanced Relay Networks

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Abstract*—Most work on relaying uplink assumes a strictly synchronized subframe partitioning between relay and access links among all eNBs. However, according to 3GPP guidelines eNBs can independently decide on different backhaul subframe configurations to adapt to, e.g. traffic variations, which then implies a backhaul subframe misalignment in the system. This configuration results in a new type of interference, referred to as relay-to-relay interference. In general, uplink interference characteristics will be significantly different compared to conventional fully synchronized configuration since the transmissions of relays and user equipments will interfere with each other. Accordingly, uplink power control parameters should be properly adjusted. In this work, we evaluate the impact of backhaul subframe misalignment on the uplink system performance of relay deployments within the LTE-Advanced framework considering 4 and 10-relay urban and suburban deployments. Besides, we investigate different inter-eNB coordination and subframe alignment scenarios. Comprehensive results show that a backhaul subframe misalignment can cause severe losses especially in cell coverage depending on the degree of coordination possible, and the availability of directional antennas at relays for backhauling. It is further shown that a proper power control optimization can cope with such performance degradations in urban deployments. As the cell-edge eNB-served user equipments are power limited in suburban deployments, the impact of power control optimization can be limited. Therefore, relay cell range extension is as well utilized in suburban deployments so that these user equipments are then served by relays. However, the performance degradation cannot be fully compensated by power control and cell range extension in suburban deployments, and thus a certain level of inter-eNB coordination is necessary.

Index Terms*—*LTE-Advanced, inband relay, power control, subframe configuration misalignment, cell range extension

I. INTRODUCTION

RELAYING is considered an integral part of 3rd Generation Partnership Project (3GPP) Long Term Evolution Release 10 and beyond (LTE-Advanced). The motive behind choosing relaying as an enhancement technology has been well elaborated in the literature. Namely, relay nodes (RNs) promise to increase the network capacity or to extend the cell coverage area [1][2]. Relaying is as well regarded a cost efficient technology [3].

A Type 1 RN is a layer 3 (L3) decode-and-forward RN which controls its own cell. The connection between RN and the core network is carried out through the donor evolved node B (eNB, aka DeNB) via a wireless backhaul link, whereas, user equipments (UEs) are served either by RNs on the access link or by the eNB on the direct link [4]. The RN utilizes the same frequency band on both the access and backhaul links, and thus these links are time-division multiplexed to prevent interference between them (half-duplex operation). However, transmissions on the direct and the access links can coexist (full frequency reuse).

One common assumption in the performance evaluation of relay deployments is that perfect inter-eNB synchronization is assumed and a network-wide subframe configuration is applied. Yet, the set of backhaul subframes can be independently configured by the eNBs to adapt to different network variations, e.g. different cell loads or traffic, which in turn causes a backhaul subframe misalignment in the network. In this configuration, a new type of interference, referred to as RN-to-RN interference, is introduced. Such interference occurs on the uplink (UL) when a relay link transmission of an RN interferes with an access link reception at another RN. Considering the small RN cell coverage area and thus the relatively close-by deployment of RNs, RN-to-RN interference can have severe effects on the system performance. Besides, as transmissions of RNs and UEs will interfere with each other, the UL interference characteristics will be significantly different [5][6]. This is due to different link characteristics such as antenna gain and propagation loss causing different transmit power levels of UEs and RNs. Hence, there is an urge to investigate the impact of the backhaul subframe misalignment and associated optimization strategies.

The impact of backhaul subframe misalignment in UL has not been adequately addressed in the literature. In a recent paper, [7], the impact of a backhaul subframe misalignment scheme on the system performance of 4-RN deployments is presented. Therein, however, two neighboring RNs within a cell are configured with partially misaligned backhaul subframes and this configuration is kept the same in the whole network. Moreover, although it is mentioned that in a 10-RN deployment the interference imposed by RNs increases, the impact on the system performance is not provided. Besides, power control (PC) parameters are not adjusted in case of misalignment yielding a suboptimum system performance.

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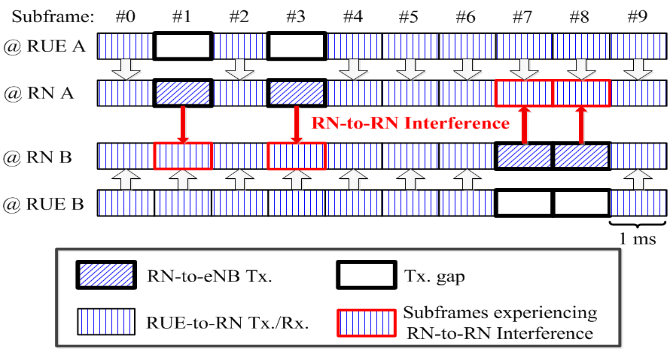

Figure 1. FDD UL LTE-Advanced frame structure for Type 1 RNs. Misalignment of backhaul subframes is depicted.

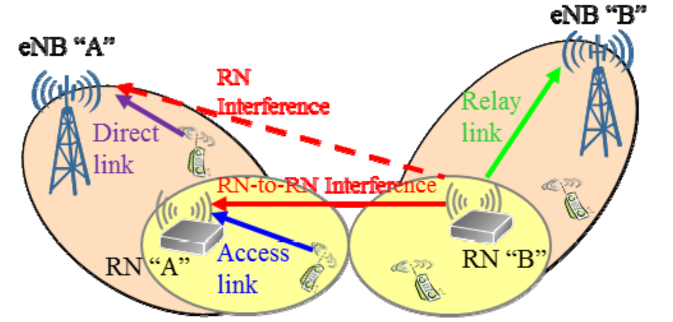

Figure 2. UL RN-to-RN interference due to backhaul subframe misalignment.

In this paper, we focus on the case where a system-wide backhaul subframe configuration is not possible. We investigate the impact of backhaul subframe misalignment on the system performance of relay deployments in scenarios with different degrees of inter-eNB coordination and subframe alignment capabilities. Thorough performance evaluation is carried out within the LTE-Advanced framework and the impacts of directional antennas (DAs), the number of deployed RNs and propagation conditions are demonstrated. PC parameters are optimized to cope with different interference characteristics imposed by the misalignment. In suburban deployments, relay cell range extension technique is also considered along with the power control optimization to enhance the performance of power limited cell-edge UEs.

The rest of the paper is organized as follows. Section II defines backhaul subframe misalignment and presents the associated RN-to-RN interference along with the inter-eNB coordination scenarios investigated in this study. In Section III, optimization strategies are outlined. The system model is given in Section IV. In Section V, detailed performance evaluation and analysis are carried out. Section VI concludes the paper.

II. Backhaul Subframe Misalignment and RN-to-RN Interference

A. Definition

An LTE frame spans in total 10 ms and comprises 10 subframes (aka transmission time intervals, TTIs). Given the full frequency reuse in LTE-Advanced networks, macro-UEs (MUEs) and relay-UEs (RUEs) are served simultaneously on the same frequency band and time slots by eNBs and RNs, respectively. Due to half-duplex operation, during the backhaul subframes for the relay link, RUEs are not scheduled, thus experiencing transmission gaps (Tx Gaps). Besides, we assume that backhaul subframes are assigned exclusively to RNs. Moreover, a maximum of six backhaul subframes can be semi-statically allocated for the relay link [4]. A backhaul subframe configuration is exemplified in Fig. 1, where two subframes are reserved for the relay links of RN 'A' and RN 'B' of which donor eNBs are, respectively, eNB 'A' and eNB 'B' as depicted in Fig. 2. The different backhaul subframe configurations shown can be attributed to the fact that the RNs are served by independent eNBs. Note that neighboring eNBs are not urged to align the access link – relay link resource split.

The misaligned backhaul subframe configurations lead to the case where, e.g. RN 'A' is serving its UEs on subframes 7 and 8, while RN 'B' is transmitting on its relay link to eNB 'B'. Hence, the relay link transmission of RN 'B' will interfere with the access link reception of RN 'A' as shown in Fig. 2 creating RN-to-RN interference. Note that the relay link transmission of RN 'A' on subframes 1 and 3 interferes as well with the access link reception of RN 'B' creating extra RN-to-RN interference at RN 'B'. In such a scenario, the RNs also interfere with the MUE transmission on the direct link (see RN Interference in Fig. 2).

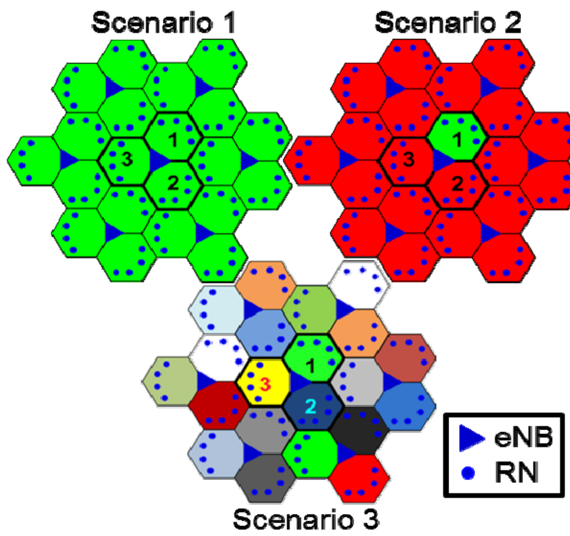

Figure 3. Considered inter-eNB coordination scenarios. Each color corresponds to a particular backhaul subframe configuration. One possible outcome is depicted for Scenario 3.

B. Inter-eNB Coordination Scenarios

In what follows, we present three main inter-eNB coordination scenarios (see Fig. 3) which imply different interference characteristics in the system.

Scenario 1. System-Wide Alignment: This scheme assumes coordination among all network eNBs, i.e. full coordination, to decide on the backhaul subframe configuration. This is performed in such a way that the same subframe configuration is used in all cells and hence, no RN-to-RN interference is experienced. Yet, such condition implies very low flexibility in terms of adapting to different system conditions. For instance, in case an eNB needs to reconfigure the backhaul subframe set for an RN, it has to coordinate this with all neighboring eNBs which in turn need to align the configurations of their RNs. Accordingly, being the common assumption in the literature, this scenario is taken as a benchmark for performance comparisons.

Scenario 2. Fixed Intra-cell Alignment: This scenario considers the case where the backhaul subframe configuration is the same for the RNs deployed in the midmost sector, while all other sectors have another misaligned configuration. This scenario is particularly studied to illustrate the bounds of the impact of such a misalignment.

Scenario 3. Random Intra-cell Alignment: In this scheme, the backhaul subframe configurations are the same for all RNs within a cell but can be different among different cells in the network. In particular, Scenario 3 depicts a practical case where the backhaul subframe configurations are *randomly* selected by eNBs for different cells.

III. Optimization Strategies and Joint Optimization

This section provides a brief overview of the utilized optimization strategies which are jointly applied in this study.

A. Optimization Strategies

1) UL Open-Loop PC: The main task of PC mechanisms is to compensate the long-term channel variations and to limit the amount of generated inter-cell interference [1]. In addition, the receiver dynamic range [1] of eNBs and RNs should be adjusted via PC. To fulfill these objectives, fractional PC (FPC) [1] is used for the Physical Uplink Shared Channel (PUSCH) to set the UE transmit power. Herein, FPC is also employed for the relay specific PUSCH (R-PUSCH). Accordingly, the transmit power of a node (UE or RN) that employs open-loop FPC, is given in dBm as:

$$P = \min\{P_{\max}, P_0 + 10 \cdot \log_{10} M + \alpha \cdot L\}. \qquad (1)$$

In this equation,

- $P_{\max}$ is the maximum allowed transmit power which has an upper limit of 23 dBm for UE power class 3 and 30 dBm for RN transmissions,
- P_0 is the power offset that can be set from -126 dBm to $P_{\max}$ with a step size of 1 dB,
- M is the number of physical resource blocks (PRBs) allocated to the node,
- α is a 3-bit cell-specific path loss compensation factor that can be set to 0.0 and from 0.4 to 1.0 with a step size of 0.1,
- L is the estimated downlink (DL) path loss at the node.

Herein, we present the case when $\alpha = 0.6$ in (1), i.e. the path loss is partially compensated such that the inter-cell interference is reduced. This scheme, in turn, increases the cell-center user performance at the cost of decreasing the cell-edge user performance. Furthermore, to prevent outage due to large inter-site-distance (ISD) in suburban scenarios, adaptive transmission bandwidth functionality (ATB) is utilized [1]. To be specific, power-limited UEs, which are typically cell-edge MUEs experiencing bad channel conditions, will not be assigned more resources than those they can afford, and the unused resources can be better utilized by other users resulting in more efficient bandwidth usage.

2) Relay Cell Range Extension: Due to low transmit power characteristc of RNs in DL, their coverage areas will be relatively small. In this context, cell range extension is primarily utilized to create a better load balance among the RN cells and macrocells. Relay cell range extension can tackle another issue, namely, some UEs will connect to the eNBs due to higher gains and transmission power as compared to RNs on the DL, though having lower path losses towards the latter. Such UEs will transmit on the UL at higher power levels to compensate the higher path losses to the eNB and hence, increase inter-cell interference levels in the network. Accordingly, after relay cell range extension is applied, these UEs will be served by RNs resulting in reduced inter-cell interference in the system. The considered relay cell range extension applies biasing during cell selection and handover decisions and eNB DL transmit power reduction techniques. As cell selection is done according to DL received power levels, both extension techniques have similar effect on the UL, which is lowering the cell selection threshold value in favor of the RNs. Therefore, they are collectivity referred to as the *effective biasing* (in the range of [0, 17] dB) on the UL. The performance of those techniques is presented in detail in [8][9][10]. Herein, we apply this strategy in suburban deployments in order to admit cell-edge MUEs to the RNs. These UEs are typically power limited due to large path-loss toward the serving eNB. Since the effect of PC optimization can be limited for these UEs, cell range extension can assist to mitigate the performance degradation due to backhaul subframe misalignment.

3) Resource Sharing: A proper resource sharing strategy is vital to attain the expected system performance enhancements through RN deployments [5][6]. We recall that for RUEs, the experienced end-to-end throughput (TP) depends on the qualities of both the access and relay links. In the considered hop-optimization model [5][6], a resource fair round robin scheduling is applied for all UEs. Plus, the resource shares of the RNs on the relay link are set to be proportional to the number of attached RUEs. The available capacity on the relay link is then distributed among RUEs utilizing max-min fairness. It is shown in [6] that this model achieves significant gain at low and mid TP regimes and high fairness in both RN cells and the system at the cost of a negligible decrease in cell capacity. Furthermore, the optimum number of backhaul subframes should be determined considering the above-mentioned resource sharing techniques.

B. Joint Optimization

The parameters of the aforementioned strategies, i.e. P_0 values on relay, access, and direct links, the number of backhaul subframes, should be jointly optimized to achieve the desired system performance enhancement. In addition, in suburban scenarios the optimum effective biasing value should be also obtained. Given the possible parameter ranges discussed before, tuning the parameters jointly is a challenging task. Therefore, we utilize Taguchi's method based on nearly

[1] The receiver dynamic range is defined as the difference in dB between the 5^{th}%-ile and 95^{th}%-ile of the cumulative distribution function (CDF) of the total received power.

orthogonal array (NOA) which is recently shown to be very effective in relay deployments [11][12]. Taguchi's method based on NOA significantly reduces the number of trial computations and complexity compared to a brute-force approach. Note that an NOA of 18 experiments and 9 levels is used herein. Furthermore, the optimization process is based on a target key performance indicator (KPI) based on UE TP cumulative distribution function (CDF). We utilize the following conventionally used KPIs.

- $\Gamma_{q\%}$: The q^{th}%-ile level of the UE TP CDF targets a certain level on the TP CDF, i.e.,

$$\Gamma_{q\%} = \mathrm{F}_s^{-1}(\frac{q}{100}), \quad (2)$$

  where F_s^{-1} (q/100) is the inverse of the CDF level at the q/100-quantile, called as q-percentile (%-ile). Accordingly, we have K1 ($\Gamma_{5\%}$) which shows the performance of the worst 5%-ile UEs and thus reflects the cell coverage, and K2 ($\Gamma_{50\%}$) which is the median UE TP.
- K3 (*Mean UE TP*): This metric reflects the average UE TP. Note that K3 can be dominated by cell-center UEs that are experiencing very high TP levels.

Along with these KPIs, we propose KPI K4 which is defined as

- K4 ($\Gamma_{\mathrm{AM}}^{(w_1,w_2,\ldots,w_L)}$): This metric is the weighted arithmetic mean (AM) of the normalized $\Gamma_{q_j\%}$ values as defined in (2), for j=(1, 2,…,L). It is then given as

$$\Gamma_{\mathrm{AM}}^{(w_1,w_2,\ldots,w_L)} = \frac{\sum_{j=1}^{L} w_j \cdot \frac{\Gamma_{q_j\%}}{\kappa_{q_j\%}}}{\sum_{j=1}^{L} w_j}, \quad (3)$$

where $\kappa_{q_j\%}$ for j=(1, 2,…,L) are the normalization factors which correspond to q_j%-ile of the user TP CDF of the reference eNB-only deployment. This normalization is necessary to ensure a proper calculation of the weighted AM in relay deployments as the TP levels at different user TP CDF percentiles can be significantly different. Furthermore, this performance metric provides a high parametric flexibility through the selection of the weights and percentiles such that the priority of certain CDF percentiles can be increased by increasing the corresponding weights. As the cell coverage along with a more homogeneous user experience is the target of relay deployments, we focus on lower percentiles, i.e., we select (q_1, q_2, q_3) = (5, 25, 50)%-ile for the performance metric. Then, the performance metric reads as,

$$\Gamma_{\mathrm{AM}}^{(w_1,w_2,w_3)} = \frac{w_1 \cdot \frac{\Gamma_{5\%}}{\kappa_{5\%}} + w_2 \cdot \frac{\Gamma_{25\%}}{\kappa_{25\%}} + w_3 \cdot \frac{\Gamma_{50\%}}{\kappa_{50\%}}}{\sum_{j=1}^{3} w_j}. \quad (4)$$

Note that for a detailed analysis of this KPI, the interested readers are referred to [12].

IV. System Model

The simulated network is represented by a regular hexagonal cellular layout with 19 tri-sectored sites, i.e. 57 cells. RNs are regularly deployed at the sector border as exemplified in Fig. 3 (only 7 sites are shown for simplicity). Indoor users are assumed, where 25 uniformly distributed UEs are dropped per sector and the full buffer traffic model is applied. The rest of the simulation parameters follow the latest parameter settings agreed in 3GPP [4] (see Table I).

Relay site planning (alternative 1) is adopted [4]. Omni-directional antennas (ODAs) are considered for the access link transmission. Log-normal shadow fading is modeled for non-line-of-sight (non-LOS, NLOS) propagation conditions, while fast fading is not simulated. Besides, TP is computed from SINR via the Shannon approximation as described in [1].

TABLE I. Simulation Parameters

System Parameters	
Carrier Frequency	2 GHz
Bandwidth & The # of PRBs	10 MHz & 48 PRBs on all links
Highest MCS	64-QAM, R = 9/10
Penetration Loss	20 dB on eNB-UE and RN-UE links
Thermal Noise PSD	-174 dBm/Hz
SINR lower bound	-7 dB
Overhead in TP calculation	25% (due to control symbols and pilots)
eNB Parameters	
Transmit Power	46 dBm
Max Antenna Gain	14 dBi
Antenna Configuration	Tx-2, Rx-2
Noise Figure	5 dB
Antenna Pattern (Horizontal)	$A(\theta) = -\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 25$ dB
UE Parameters	
Max Transmit Power	23 dBm
Antenna Configuration	Tx-1, Rx-2
RN Parameters	
Max Transmit Power	30 dBm
Antenna Configuration	Tx-2, Rx-2
RN-eNB Max Antenna Gain	7 dBi
RN-UE Max Antenna Gain	5 dBi
Access Link Antenna Pattern	Omni-directional
Relay Link Antenna Pattern	Directional or omni-directional
Directional Antenna Pattern (Horizontal)	$A(\theta) = -\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 20$ dB
Noise Figure	5 dB
Channel Models	
Distance & Path Loss (PL)	R [km] & PL [dB]
Direct Link (eNB – UE) PL(LOS): 103.4 + 24.2log$_{10}$(R), PL(NLOS): 131.1 + 42.8log$_{10}$(R) **ISD 500m – Urban Model** Pr(LOS) = min(0.018 / R, 1) (1-exp(-R / 0.063))+exp(-R / 0.063) **ISD 1732m - Suburban Model** Pr(LOS) = exp(-(R - 0.01) / 0.2) **RN-RN Link & Access Link (RN – UE)** PL(LOS): 103.8 + 20.9log$_{10}$(R), PL(NLOS): 145.4 + 37.5log$_{10}$(R) **ISD 500m – Urban Model** Pr(LOS) = 0.5 – min (0.5, 5exp(-0.156/R)) + min (0.5, 5exp(-R/ 0.03)) **ISD 1732m - Suburban Model** Pr(LOS) = 0.5– min (0.5, 3exp(-0.3/R)) + min (0.5, 3exp(-R / 0.095)) **Relay Link (eNB – RN) {a & b account for the site planning gain}** PL(LOS): 100.7 + 23.5log$_{10}$(R), PL(NLOS): 125.2 + 36.3log$_{10}$(R)-b **ISD 500m – Urban Model** Pr (LOS) = 1-(1-(min(0.018./R,1)(1-exp(-R/0.072))+exp(-R/0.072)))^a **ISD 1732m - Suburban Model** Pr(LOS) = 1 - (1 - exp(-(R-0.01)/1.15))^a a=3 & b=5 towards donor eNB, whereas a=1 & b=0 towards other eNBs.	
Log-normal Shadowing	
Standard Deviation	8 dB (direct link), 10 dB (access link) 6 dB (relay link & RN-RN link)
De-correlation Distance	50 m
Correlation Factor	(0.5;1.0) between (sites; sectors)

V. PERFORMANCE EVALUATION AND ANALYSIS

We have investigated 4-RN and 10-RN deployments in 3GPP urban (Case 1) and suburban (Case 3) scenarios with ISDs of 500 m and 1732 m, respectively. The eNB-only deployment with round robin scheduler and the relay deployment considering Scenario 1 are taken as references for performance comparisons. The PC parameters of the eNB-only deployments are as provided in [1]. Accordingly, for eNB-only deployment in urban scenario FPC (α=0.6) with P_0=-55 dBm (cell capacity-oriented setting) is applied while FPC (α=0.6) with P_0=-63 dBm (trade-off setting) is applied in suburban scenario. The optimized PC parameters for Scenario 1 are as in [1] for FPC (α=0.6).

A. Urban Scenario

1) Impact of DAs at RNs

One major advantage of RNs is the expected low cost. Yet, upgrading RNs with extra components, such as DAs, may bring notable gain in system performance. Thus, we investigate the impact of the availability of DAs for backhauling on the relay link. Utilizing a DA, which is pointing toward the serving eNB, decreases the interference imposed by RNs at access nodes which are not aligned with the main lobe of the antenna.

Fig. 4 illustrates the TP performance of the considered scenarios relative to eNB-only deployment when the PC parameters found in Scenario 1 are also applied in Scenarios 2 and 3. When DAs are installed at RNs, for both 4 and 10-RN deployments, the backhaul subframe misalignment does not cause performance degradation relative to Scenario 1. On the contrary, for 4-RN deployment, the performance at 5%-ile UE TP increases thanks to reduced total inter-cell interference on the direct link reception. That is, when DAs are available at RNs, the RN interference (see Fig. 2) in case of backhaul subframe misalignment is lower than the MUE interference in case of full alignment (Scenario 1). Furthermore, when ODAs are installed at RNs, for 4-RN deployment a similar performance is observed. On the other hand, for 10-RN a significant performance degradation is seen at 5%-ile UE TP relative to Scenario 1. This is mainly due to the larger number of subframes which are subject to RN interference.

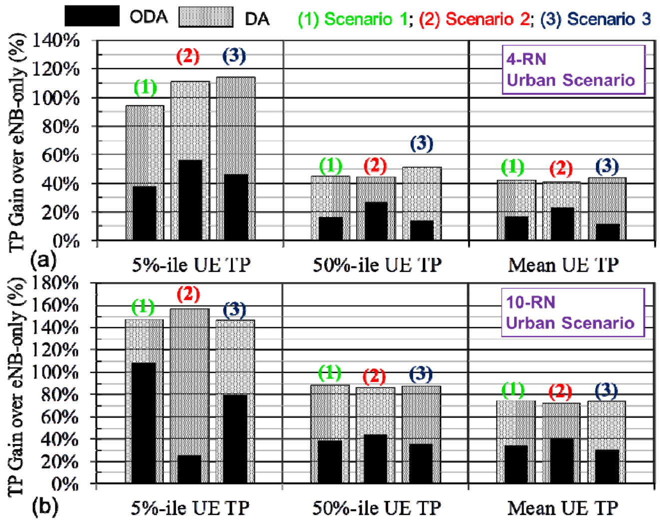

Figure 4. TP gain over eNB-only considering ODA and DA for backhauling; 4 RNs (a) and 10 RNs (b), Case 1.

2) Optimization considering ODAs at RNs

As installing DAs at RNs can effectively tackle the issues that may arise due to backhaul subframe misalignment, we focus on the case with ODAs. A joint optimization of PC parameters is applied as discussed in Section III.B where K4=$\Gamma_{\mathrm{AM}}^{(1,1,1)}$. The TP gains of Scenario 3 relative to Scenario 1 are depicted in Fig. 5 and the optimized PC parameters are provided in Table II. Further, the results pertaining to Scenarios 2 and 3 without optimization are also depicted, i.e. the results from Section V.A.1 for comparison. It can be seen that using different KPIs, various trade-offs can be attained. Moreover, if K4 is utilized, the performance can be enhanced at all considered TP levels for both 4 and 10-RN deployments. In addition, it is shown that the performance degradation due to backhaul subframe misalignment can be fully alleviated by the joint optimization using K4 in 10-RN deployment. Therefore, inter-eNB coordination is not necessary in urban deployments provided that a proper joint optimization is performed.

B. Suburban Scenario

1) Impact of DAs at RNs

Similar to urban deployment, the impact of the availability of DA is investigated first. In Fig. 6, the results are depicted for 4 and 10-RN deployments. It is observed that when DAs are installed at RNs the performances of different scenarios are comparable. It is worth noting that Scenario 3 is the main focus as it reflects a practical case. However, when ODAs at RNs are considered, significant performance degradation is observed at

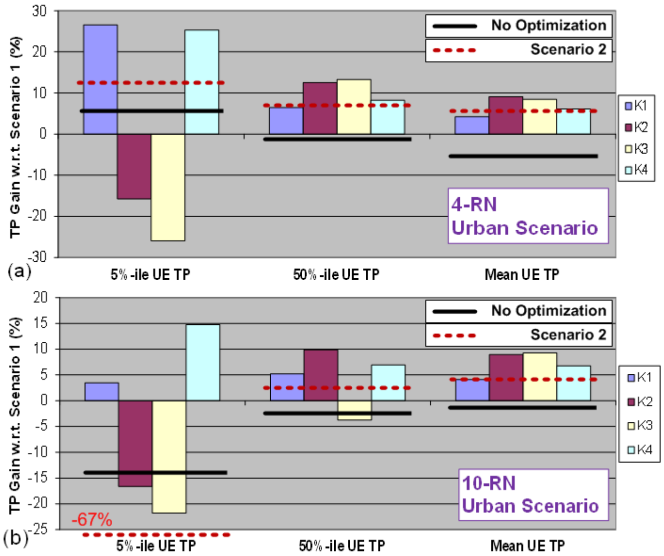

Figure 5. TP gains of Scenario 3 over Scenario 1 considering ODA for backhauling and joint optimization; 4 RNs (a) and 10 RNs (b), Case 1.

TABLE II OPTIMIZED PARAMETERS FOR SCENARIO 3, CASE 1

Scenario	KPI	Number of Backhaul Subframes	P_0 [dBm]		
			MUE	RUE	RN
4 RNs	K1	3	-56	-70	-67
	K2	3	-45	-64	-57
	K3	4	-44	-64	-60
	K4	3	-53	-69	-65
10 RNs	K1	5	-50	-66	-65
	K2	4	-43	-65	-53
	K3	3	-43	-69	-56
	K4	4	-51	-68	-60

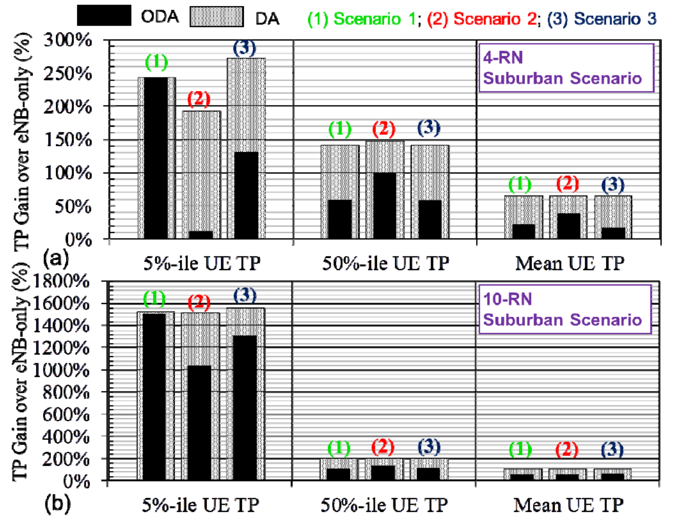

Figure 6. TP gain over eNB-only considering ODA and DA for backhauling; 4 RNs (a) and 10 RNs (b), Case 3.

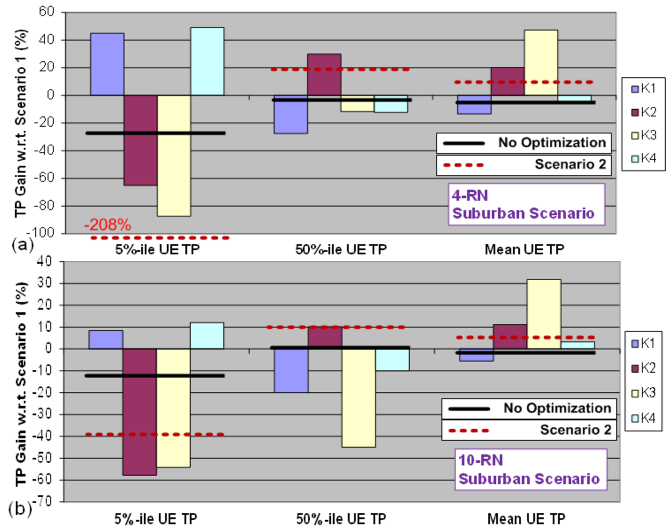

Figure 7. TP gains of Scenario 3 over Scenario 1 considering ODA for backhauling and joint optimization; 4 RNs (a) and 10 RNs (b), Case 3.

5%-ile UE TP for both 4 and 10-RN deployments relative to Scenario 1. This is due to cell-edge MUEs which are impacted by RN interference. It is worth noting that these MUEs mainly contribute to the low TP regime, and since installing DAs at RNs only improves the performance of RUEs, it does not increase 5%-ile UE TP in Scenario 1.

2) Optimization considering ODAs at RNs

A joint optimization of PC parameters and relay cell extension is performed where K4= $\Gamma_{\mathrm{AM}}^{(2,1,2)}$ (see Table III). Since installing DAs at RNs mainly resolve the issues due to backhaul subframe misalignment, the case with ODAs at RNs is further elaborated. The TP gains of Scenario 3 are shown in Fig. 7 for 4 and 10-RN deployments relative to Scenario 1.

It is observed that beside various trade-offs via different KPIs, the joint optimization with K4 can alleviate the detrimental impact of RN interference at 5%-ile UE TP; however, performance degradation is still observed at 50%-ile UE TP. Consequently, to fully eliminate such performance degradation a certain level of inter-eNB coordination is necessary in suburban deployments.

TABLE III OPTIMIZED PARAMETERS FOR SCENARIO 3, CASE 3

Scenario	KPI	Effective Biasing [dB]	Number of Backhaul Subframes	P_0 [dBm]		
				MUE	RUE	RN
4 RNs	K1	-16	2	-64	-69	-65
	K2	-3	6	-58	-63	-62
	K3	-17	5	-53	-66	-64
	K4	-15	3	-64	-72	-67
10 RNs	K1	-14	4	-64	-76	-59
	K2	-6	6	-57	-65	-53
	K3	-17	3	-52	-60	-59
	K4	-11	5	-62	-73	-60

VI. CONCLUSION

Most work on relaying assumes a system-wide backhaul subframe alignment, and the practical case of a misalignment is not addressed adequately. In this paper, we have thoroughly analyzed the impact of backhaul subframe misalignment within the framework of LTE-Advanced Type 1 relay networks considering both urban and suburban models along with 4 and 10-RN deployments. It is shown that if DAs are available for backhauling, misalignment does not degrade system performance. However, if ODAs are installed for backhauling, the misalignment causes severe performance degradation at low TP regime in suburban and 10-RN urban deployments. Nevertheless, the proposed joint optimization copes with such degradation in urban deployment and thus inter-eNB coordination is not necessary. In suburban deployments, the joint optimization tackles the degradation at low TP regime at the cost of performance decrease at mid TP regime. Therefore, to fully alleviate the negative impact, a certain level of inter-eNB coordination is necessary in suburban deployments.

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