DownLink Resource Allocation for LTE-Advanced networks with Type1 Relay Nodes

Zhao ZhuYan [(1)], Wang Jian[(1)], Simone Redana[(2)], Bernhard Raaf[(2)]
[(1)] Nokia Siemens Networks Beijing, P.R. China, [(2)] Nokia Siemens Networks Munich, Germany
Email: [(1,2)] {zhuyan.zhao, jian.7.wang, simone.redana, bernhard.raaf}@nsn.com ,

Abstract— **Type1 in-band relaying is supported by Long Term Evolution Advanced (LTE-Advanced). Based on the frame structure defined in 3GPP LTE, a down link radio frame is partitioned into access and backhaul sub-frames. In the access sub-frames, the direct link and access link transmissions can take place simultaneously with full frequency reuse. In the backhaul sub-frames, the DeNB (Donor evolved Node B) allocates orthogonal resources for different DeNB->RN transmission as well as co-scheduled DeNB->UE transmissions. Macro UE scheduled during the backhaul sub-frames will avoid the interference from RN in downlink, enjoying improved SINR. However, this will decrease the efficiency of radio resource reuse, and potentially reduce cell throughput. In this paper, the performance of relay enhanced networks with partial macro UEs scheduled during the backhaul sub-frames is investigated through system level simulation. A simplified resource allocation algorithm (SRA) which aims to maximize the throughput of worst UEs in relay enhanced networks is proposed to calculate the resource allocation among DeNB->RN transmission, RN-UE transmissions, as well as DeNB->UE transmissions in backhaul sub-frames and access sub-frames. Average cell throughput gain and 5%-tile user throughput gain of proposed resource allocation algorithm (SRA) is compared with an exhaustive search algorithm.**

Keywords- LTE-Advanced; inband Relay; Relay deployment; Sscheduling; Resouce allocation .

I. INTRODCUTION

In 3GPP standardization, Type1 in-band relaying is supported by LTE-Advanced to improve cell coverage and throughput in cell border areas. The Type 1 relay node (RN) is viewed by the users equipments (UEs) as a full-functional eNB, hence the RN cells have their own physical cell ID and the RN transmits its own synchronization channels and reference symbols. The connection between RN and the core network is carried out through the DeNB via a wireless backhaul link. The link between the UE and its serving RN is referred as access link, while the link between a UE and its DeNB is referred as direct link. With in-band relay deployment, the same carrier is utilized for backhaul and access link transmission, and relays are assumed to operate in a half-duplex fashion, in which the backhaul transmissions are time-division multiplexed with access transmissions. Based on the frame structure defined in 3GPP LTE [1], a down link (DL) radio frame is further partitioned into access and backhaul sub-frames. In the access sub-frames, the direct link and access link transmissions can take place simultaneously with full frequency reuse. In the backhaul sub-frames, the DeNB allocates orthogonal resources for different DeNB->RN transmission as well as co-scheduled DeNB->UE transmissions. The access/backhaul allocation pattern repeats with a certain periodicity until it is changed by a higher layer configuration.

The resource allocation for relay-enhanced cellular systems has been widely studied [2-5]. In [2], a joint routing and scheduling resource allocation scheme is presented based on the assumption that the resources used among direct links and access links are orthogonal. At the same time, access and backhaul of relaying transmission occupy equally partitioned resources. In [3], an adaptive time domain resource partition is calculated based on proportional fair scheduling approach. The study assumes that radio resources are full-reused among direct links and access links in which the DeNB does not schedule macro UEs during the backhaul sub-frames. As RNs do not perform downlink transmission during the backhaul sub-frames, the SINR of the macro UEs scheduled in the backhaul sub-frames will be boosted, thus potentially improving the throughput, especially for the macro UEs located near the RN cell. However, scheduling too many macro UEs during the backhaul sub-frames will decrease the efficiency of radio resource reuse. DeNB should balance the gain and loss when selecting macro UEs scheduled during backhaul sub-frames and adapt the radio resource allocation to the number of co-scheduled macro UEs. In [4], a scheme for co-scheduling macro UEs and RNs is proposed for uplink.

In this paper, we propose a simplified resource allocation algorithm (SRA) for in-band relay networks in downlink. The DeNB algorithm partially schedules macro UEs during the backhaul sub-frames and aims to maximize the throughput of worst UEs. The performance of relay enhanced networks when partially scheduling macro UEs during backhaul sub-frames is investigated through system level simulation. Average cell throughput gains and 5%-tile user throughput gains of proposed resource allocation algorithm (SRA) are then compared with an exhaustive search algorithm.

The rest of the paper is organized as follows. In Section II, the resource allocation algorithm of relay networks is presented. Thereafter, detailed performance evaluation and analysis are given in Section III. Section IV concludes the paper.

II. In-band Relay Downlink Resource Allocation

A. In-band Relay DL Resource Allocation Modeling

We consider LTE-Advanced relay with frequency division duplex (FDD) mode. A UE can be associated with at most one DeNB or RN according to the received downlink signal strength. In LTE the basic OFDMA resource allocation unit is called a resource block (RB), consisting of a constant number of subcarriers and OFDMA symbols. For the sake of simplicity, the resource allocation pattern is presented by the time domain resource partition. We name the link between a UE scheduled during backhaul sub-frames and its DeNB as BH-Direct link, and assume BH-Direct links take an orthogonal time domain resource in backhaul sub-frames. Figure 1 shows the radio resource allocation pattern model. The radio resources are split into 3 parts: the resources allocated to backhaul links in backhaul sub-frames, the resources allocated to BH-Direct links in backhaul sub-frames, and the resources allocated to access sub-frames which consist of direct and access links. The unified radio resources assigned to 3 parts are indicated with α, β and γ, respectively. In the paper, we relax the constraint that resource partition need to be an integer multiple of the number of RBs.

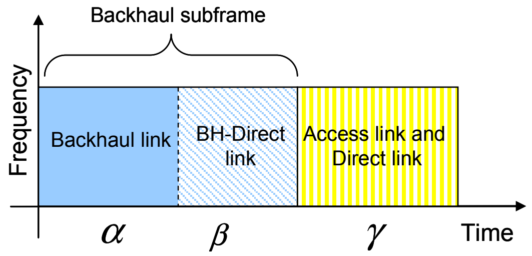

Figure 1: In-band relay DL resouce allocation pattern model

B. UE Throughput Derivation

In the study, we assume a Round Robin (RR) scheduler is used to assign resources to the DeNB served UEs and RN served UEs. The UE throughput in access link, BH-Direct link and direct link are calculated as follows.

1. DeNB->RN backhaul throughput

When multiple RNs are deployed in a DeNB cell, the resource shares among the backhaul links are proportional to the number of UEs served by RNs. In other words, a RN serving a larger number of relay UEs will get more resources on the backhaul link.

We assume the DeNB is serves M RNs. N_m is the number of UEs attached to RN m. K_1 is the number of UEs connected with RNs located in the DeNB cell.

$$K_1 = \sum_{m=1}^{M} N_m \tag{1}$$

The backhaul throughput of RN m is given as in (2). Considering backhaul throughput is equally assigned to the UEs of the RN m, then the average backhaul throughput assigned to user k of RN m is give as in (3)

$$TP_{eNB-RN}^{m} = \alpha \times \frac{N_m}{K_1} \times SE_{eNB-RN}^{m} \times BW \tag{2}$$

$$TP_{eNB-RN}^{m,k} = \alpha \times \frac{1}{K_1} \times SE_{eNB-RN}^{m} \times BW \tag{3}$$

Where, SE_{eNB-RN}^{m} is defined as the spectral efficiency on the backhaul link of RN m to its DeNB, and BW is system bandwidth.

2. *Relay UE throughput*:

The end-to-end (e2e) throughput of a relay UEs is defined as the minimum of the throughputs achieved on both the backhaul and the access link. The e2e throughput $TP_{eNB-RN-UE}^{k,m}$ of UE k attached to RN m is given as in (4)

$$TP_{eNB-RN-UE}^{k,m} = \min\left(\frac{\alpha \times SE_{eNB-RN}^{m} \times BW}{K_1}, \frac{\gamma}{N_m} \times SE_{RN-UE}^{k,m} \times BW \right) \tag{4}$$

Where, $SE_{RN-UE}^{k,m}$ is defined as the spectral efficiency on the access link of UE k to RN m.

3. *Macro UE throughput on BH-Direct Link*:

Let's denote with K_2 the number of macro UEs corresponding to the BH-Direct link. The throughput $TP_{eNB-UE-BH}^{k}$ of a UE k scheduled in BH-Direct link is given as in (5)

$$TP_{eNB-UE-BH}^{k} = \frac{\beta}{K_2} \times SE_{eNB-UE-BH}^{k} \times BW \tag{5}$$

4. *Macro UE throughput on Direct Link*:

Let's denote K_3 the number of macro UEs scheduled during access sub-frames. The throughput TP_{eNB-UE}^{k} of a UE k scheduled in direct link is given as in (6)

$$TP_{eNB-UE}^{k} = \frac{\gamma}{K_3} \times SE_{eNB-UE}^{k} \times BW \tag{6}$$

SE_{eNB-RN}^{m} , $SE_{RN-UE}^{k,m}$, $SE_{eNB-UE-BH}^{k}$ and SE_{eNB-UE}^{k} are calculated based on Shannon's capacity formula [6].

C. Resource allocation Optimization

We define the minimum UE throughput (throughput of worst UEs) of relay networks as $TP_{\min}$ then from (4) we obtain $TP_{\min}$ is less than the minimum throughput of relayed UEs :

$$TP_{\min} \le \alpha \times SE_{eNB-RN}^{*} \times BW \le TP_{eNB-RN-UE}^{k,m} \tag{7}$$

where $SE_{eNB-RN}^{*} = \min_{m}\left\{ SE_{eNB-RN}^{m} / K_1 \right\}, m = 1,\ldots,M$, and

$$TP_{\min} \le \gamma \times SE_{RN-UE}^{*} \times BW \le TP_{eNB-RN-UE}^{k,m} \tag{8}$$

where $SE^{*}_{RN-UE} = \min_{k,m}\left\{\frac{SE^{k,m}_{RN-UE}}{N_m}\right\} m = 1,...M; k = 1,..., N_m$.

Similar, from (7) and (8) we derive $\mathrm{TP}_{\min}$ is less than the minimum throughput of macro UEs:

$$TP_{\min} \le \beta \times SE^{*}_{eNB-UE-BH} \times BW \le TP^{k}_{eNB-UE-BH} \quad (9)$$

Where $SE^{*}_{eNB-UE-BH} = \min_{k}\left\{SE^{k}_{eNB-UE-BH} / K_2\right\}, k = 1,2..., K_2$, and

$$TP_{\min} \le \gamma \times SE^{*}_{eNB-UE} \times BW \le TP^{k}_{eNB-UE} \quad (10)$$

where $SE^{*}_{eNB-UE} = \min_{k}\left\{SE^{k}_{eNB-UE} / K_3\right\}, k = 1,2..., K_3$

From equations (7), (8), (9) and (10), the maximum $\mathrm{TP}_{\min}$ can be formulated as the following linear program:

Objective: maximum $\mathrm{TP}_{\min}$

Subject to:

$$\alpha \times SE^{*}_{eNB-RN} \times BW - TP_{\min} \ge 0 \quad (11)$$

$$\gamma \times SE^{*}_{RN-UE} \times BW - TP_{\min} \ge 0 \quad (12)$$

$$\beta \times SE^{*}_{eNB-UE-BH} \times BW - TP_{\min} \ge 0 \quad (13)$$

$$\gamma \times SE^{*}_{eNB-UE} \times BW - TP_{\min} \ge 0 \quad (14)$$

$$\alpha + \beta + \gamma = 1 \quad (15)$$

Let's define

$$SE^{*} = \min\left\{SE^{*}_{eNB-UE}, SE^{*}_{RN-UE}\right\}$$

then (12) and (14) can be simplified as:

$$\gamma \times SE^{*} - TP_{\min} \ge 0 \quad (16)$$

The maximum $\mathrm{TP}_{\min}$ is achieved when

$$\alpha \times SE^{*}_{eNB-RN} = \beta \times SE^{*}_{eNB-UE-BH} = \gamma \times SE^{*} \quad (17)$$

Proof: assume the maximum $TP^{'}_{\min}$ is achieved when resource partition scheme is α' , β' , γ' , and $\alpha' \times SE^{*}_{eNB-RN} < \beta' \times SE^{*}_{eNB-UE-BH} = \gamma' \times SE^{*}$, according to (7) $TP^{'}_{\min} = \alpha' \times SE^{*}_{eNB-RN} \times BW$.

find $\Delta > 0$, $\alpha'' = \alpha' + \Delta$, $\beta'' = \beta' - \Delta$, and $\alpha'' \times SE^{*}_{eNB-RN} < \beta'' \times SE^{*}_{eNB-UE-BH}$.

Then, $TP^{''}_{\min} = \alpha'' \times SE^{*}_{eNB-RN} \times BW > TP^{'}_{\min}$, and $TP^{'}_{\min}$ is not the optimized solution. So (17) is proven.

According to (17), we have

$$\alpha = 1 \Big/ \left(1 + \frac{SE^{*}_{eNB-RN}}{SE^{*}_{eNB-UE-BH}} + \frac{SE^{*}_{eNB-RN}}{SE^{*}}\right) \quad (18)$$

$$\beta = 1 \Big/ \left(1 + \frac{SE^{*}_{eNB-UE-BH}}{SE^{*}_{eNB-RN}} + \frac{SE^{*}_{eNB-UE-BH}}{SE^{*}}\right) \quad (19)$$

$$\gamma = 1 \Big/ \left(1 + \frac{SE^{*}}{SE^{*}_{eNB-RN}} + \frac{SE^{*}}{SE^{*}_{eNB-UE-BH}}\right) \quad (20)$$

III. Performace Evaluation and Analysis

A static system level simulation developed in C++ has been used to evaluate the performance of the proposed radio resource allocation algorithm, which is referenced as SRA (simplified resource allocation algorithm).

3GPP urban (case1) scenario with inter-site distance of 500m has been considered. Each macro cell is configured with fixed 4 relay nodes deployed at the cell border as shown in Figure 2. Simulation parameters follow the parameter settings agreed in 3GPP [5] and are summarized in Table I. Only shadow fading is considered in the simulation but not fast fading.

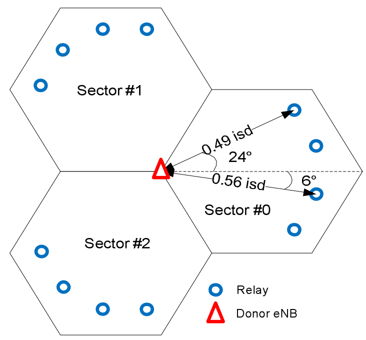

Figure 2: Relay nodes deployment (4RN/sectror)

TABLE I. Simulation Paramters

Parameters	Default
Carrier Frequency	2GHz
System Bandwidth	10MHz
System Layout	19 sites with 3 sectors
Inter-site distance	500 m
DeNB Transmit Power	46dBm
DeNB Antenna gain	14 dBi
UE Antenna gain	0 dBi
UE noise Figure	9 dB
RN Transmission power	30dBm
RN-eNB antenna gain	Directional antenna 7 dBi
RN-UE antenna gain	Omni directional antenna 5 dBi
RN noise figure	5dB

A. *Selection of Macro UEs Scheduled in Backhaul Sub-frames*

Since macro UEs scheduled during backhaul sub-frames will avoid interference from RNs in downlink, we define SINR gain Δ $SINR_k$ as the difference between the SINR experienced by the macro UE k with interference and without interference from the RNs. We assume the macro UEs with higher Δ SINR will be scheduled in backhaul sub-frames with higher priority.

DeNB can set a SINR gain threshold to schedule a proper number of macro UEs during backhaul sub-frames. When a UE's Δ SINR is higher than the threshold, it will be scheduled during backhaul sub-frames, otherwise during access-sub-frames. In the scenario that the macro cell is configured with 4 RNs, 33% of UEs are connected with RNs and 67% of UEs are connected with the DeNB. Figure 3 shows the cumulative probability density distribution (CDF) of Δ SINR of macro UEs. From the figure, 29%, 20%, 14% and 10% of macro UEs have Δ SINR larger than 1dB, 2dB, 3dB and 4dB. These are 19.6%13.4%, 9.48%, and 6.81% of all UEs (Macro UEs and Relay UEs).

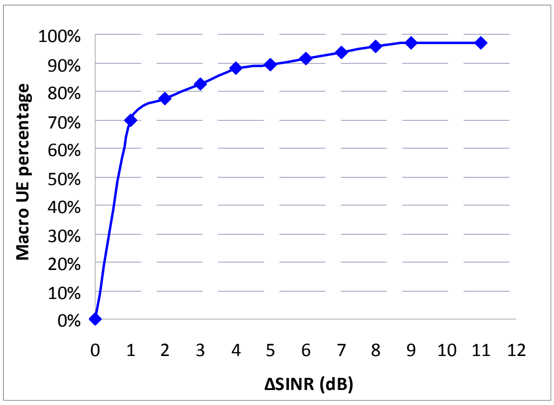

Figure 3: CDF of macro UE reative SINR (RN=4)

B. *Impact of Scheduling Macro UEs in Backhaul Sub-frames*

Table II shows the average cell throughput and 5%-tile UE throughput performance for the relay enhanced networks with and without macro UEs scheduled during backhaul sub-frames. The average cell throughput and 5%-tile UE throughput gain is relative to no RN (Macro only) scenario.

Table II (a) shows the resource allocation and related performance of the relay enhanced networks without macro UEs scheduled during backhaul sub-frames. As no macro UE is scheduled during backhaul sub-frames, β=0. We calculate γ and α by using an exhaustive search method. The search precision is 0.1, and search rang of γ is 0.6–0.9. Among the search results, resource allocation scheme of γ=0.8 and α=0.2 that provide the maximum 5% tile UE throughput is selected according to the principle of maximizing the throughput of worst UEs.

Table II (b)-(e) show the resource allocation and related performance of the relay enhanced networks with macro UEs scheduled during backhaul sub-frames. DeNB sets ΔSINR threshold as 1dB, 2dB, 3dB and 4dB. The simulation results with resource allocation calculated by using SRA and an exhaustive search resource allocation method (ESRA) are presented. To reduce the complexity of ESRA, we fixed γ as 0.6 or 0.7, and then search the fraction of β in backhaul sub-frames, which is β/(1-γ). The search precision is 0.1, and the search rang is 0.1-0.4. For example, when γ is 0.6 and the fraction of β is 0.1, β and α are calculated as 0.04 and 0.36, respectively. From the search results the resource allocation scheme that provides the maximum 5% tile UE throughput is selected. For instance, in Table II (b), resource allocation scheme of γ=0.6, α=0.24 and β=0.16 is selected to get the maximum 5% tile UE throughput which is 0.238Mbps.

From Table II (b)-(e), the resource allocation α, β and γ calculated by SRA and ESRA are generally aligned. The difference is due to the coarse search precision used in ESRA. When SRA is used, as ΔSINR increases from 1dB to 4dB, β is reduced from 0.25 to 0.06 because the ratio of UEs scheduled in backhaul sub-frames reduced from 19.4% to 6.81%. At the same time, α is in the range of 0.23–0.25 because relay UE number is almost in each scenario. It means that SRA can adaptively calculate resource allocate scheme with the change of user numbers.

The 5%-tile UE throughput gains of relay enhanced networks without and with scheduled macro UEs in backhaul sub-frames are given in the Figure 4. When ΔSINR is 1dB, with macro UE scheduled during backhaul sub-frames, the 5%-tile UE throughput gain is 26.5%, which is increased 7.5% compared to the scenario without macro UE scheduled during backhaul sub-frames. As the ΔSINR increases from 1dB to 4dB, the 5%-tile UE throughput gain is almost identical. It means even only a small number of macro UE is scheduled in the backhaul sub-frames, the 5%-tile UE throughput can be improved. From Figure 5, we can see SRA always shows higher 5%-tile UE throughput than ESRA. The average cell throughput gains of relay enhanced networks without and with scheduled macro UEs in backhaul sub-frames are given in Figure 5. When ΔSINR is 1dB, with macro UE scheduled during backhaul sub-frames, the average cell throughput gain is 27.7%, which is increased 7.8% compared to without macro UE scheduled during backhaul sub-frames scenario. As the ΔSINR increases from 1dB to 4dB, the average cell throughput gain is reduced from 27.3% to 25.3%, because less macro UE are scheduled during backhaul sub-frames. When ΔSINR=1dB or 2dB, we can see ESRA shows higher average cell throughput than SRA. But considering the objective is to maximize the worst UE throughput, such resource allocation scheme reduces the 5% tile UE throughput.

IV. CONCLUSION

The resource allocation among the different links in relay deployment is crucial to guarantee the overall system performance of the network. A simplified resource allocation algorithm has been proposed to optimize the resource allocation considering macro UEs scheduled in backhaul sub-frames. The simulation results show that allowing the DeNB to schedule macro UEs in backhaul sub-frames can improve both capacity and coverage. In the case that DeNB is deployed with 4 RNs, compared to baseline resource allocation method in which no macro UEs are scheduled in backhaul sub-frames. When 29% of macro UEs (UEs with ΔSINR >1B) are scheduled in backhaul sub-frames, the 5%-ile UE throughput and average UE throughput are improved by 7.5% and 7.8% respectively. In LTE-A networks, UEs report buffer status and measurement reports to the DeNB. The DeNB is then able to schedule the macro UEs with serious RN interference in backhaul sub-frames, and adjust the resource allocation among the links according to the proposed algorithm based on existing LTE-A signaling architecture.

TABLE II. AVERAGE CELL THROUGHPUT AND 5%-TILE UE THROUGHPUT PERFORMANCE

(a) RN=4, no macro UE scheduled in backhaul sub-frames

	Resource Allocation			Average aggregate throughput per cell		5%-tile UE throughput	
	AC	BH subframe		Value (Mbps)	Gains	Value (Mbps)	Gains
	γ	α	β				
RN=0	1	0	0	21.67		0.194	
RN=4	0.9	0.1	0	24.43	12.7%	0.204	5.1%
	0.8	0.2	0	25.99	19.9%	0.231	19.0%
	0.7	0.3	0	26.85	23.9%	0.221	13.9%
	0.6	0.4	0	26.63	22.9%	0.194	-0.1%

(b)RN=4, ΔSINR=1dB

ESRA	0.6	0.36	0.04	28.28	30.5%	0.083	-57.2%
		0.32	0.08	28.63	32.1%	0.163	-16.0%
		0.28	0.12	28.6	32.0%	0.225	15.9%
		0.24	0.16	27.92	28.8%	0.238	22.6%
SRA	0.51	0.24	0.25	27.68	27.7%	0.246	26.5%

(c) RN=4, ΔSINR=2dB

ESRA	0.6	0.36	0.04	27.79	28.2%	0.147	24.4%
		0.32	0.08	27.85	28.5%	0.212	9.1%
		0.28	0.12	27.83	28.4%	0.242	24.4%
		0.24	0.16	27.28	25.9%	0.241	24.1%
SRA	0.63	0.23	0.14	27.59	27.3%	0.243	25.0%

(d) RN=4, ΔSINR=3dB

ESRA	0.7	0.27	0.03	28.58	31.9%	0.179	-7.8%
		0.24	0.06	27.28	25.9%	0.224	15.4%
		0.21	0.09	27.14	25.2%	0.239	23.2%
		0.18	0.12	26.53	22.4%	0.237	22.0%
SRA	0.68	0.24	0.08	27.45	26.7%	0.245	26.0%

(e) RN=4, ΔSINR=4dB

ESRA	0.7	0.27	0.03	27.28	25.9%	0.211	8.6%
		0.24	0.06	26.82	23.8%	0.233	19.9%
		0.21	0.09	26.38	21.7%	0.237	22.2%
		0.18	0.12	26.2	20.9%	0.234	20.7%
SRA	0.69	0.25	0.06	27.15	25.3%	0.244	25.7%

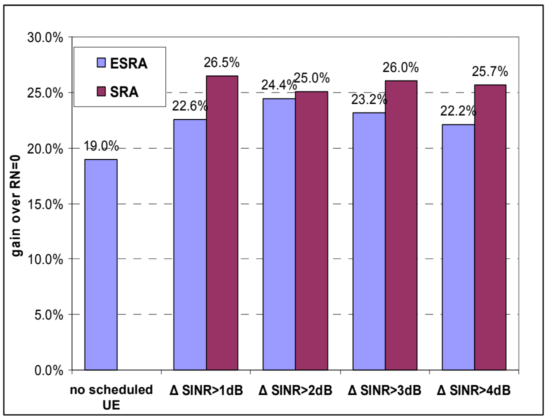

Figure 4: 5%-ile UE throhgput gain (RN=4) when macro UEs are scheduled in backhaul sub-frames.

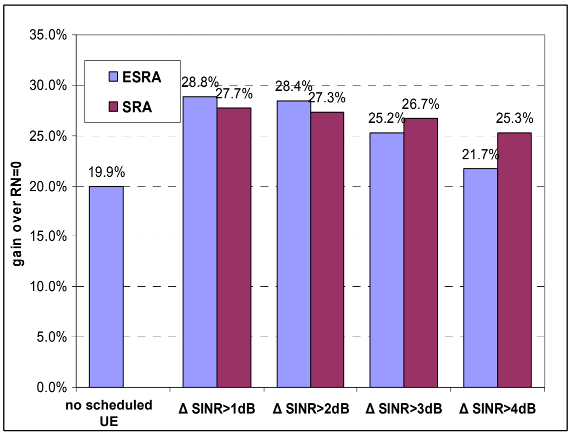

Figure 5: Average cell throughput gain (RN=4) when macro UEs are scheduled in backhaul sub-frames.

REFERENCES

[1] A. Bou Saleh, S. Redana, et al., "On the Coverage Extension and Capacity Enhancement of Inband Relay Deployments inLTE-Advanced Networks," Journal of Electrical and Computer Engineering, vol. 2010, no. 894846, pp. 1–12, 2010.

[2] M. Salem, A. Adinoyi, H.Yanikomeroglu, et al, "A Fair Radio Resource Allocation Scheme for Ubiquitous High-data-rate Coverage in OFDMA based Cellular Relay Networks," in Proc. GLOBECOM 2009, Honolulu,HI, Dec. 2009

[3] Zhangchao Ma, Wei Xiang, Hang Long, and Wenbo Wang, "Proportional Fair Resource Partition for LTE-Advanced Networks with Type I Relay Nodes," IEEE ICC, 2011.

[4] O. Bulakci, A. Bou Saleh, et al., "Flexible Backhaul Resource Sharing and Uplink Power Control Optimization in LTE-Advanced Relay Networks", Proc. IEEE Veh. Tech.Conf., Sep 2011.

[5] 3GPP TR 36.814, "Further Advancements for E-UTRA, Physical Layer Aspects, (Release 9)", v. 9.0.0, March 2010.

[6] P. Mogensen, W. Na et al. LTE capacity compared to the Shannon bound, in Proceedings of the 65th IEEE Vehicular Technology Conference (VTC '07), pp. 1234–1238, Dublin, Ireland, April 2007.