Macro Transmission Power Reduction for HetNet Co-Channel Deployments

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Abstract—**Enhanced Inter-Cell Interference Coordination (eICIC) techniques are targeted to improve the system and cell-edge throughput of Heterogeneous Networks (HetNets) in LTE-Advanced systems. In order to protect pico UEs from the strong macro interference, the macro eNB can either stop data transmission or simply reduce the transmission power during certain subframes. In this paper, we investigate the impact of reducing the transmission power in LTE HetNets. We evaluate the tradeoff among macro transmission power, cell load and system and cell-edge throughput, with bursty and non-bursty traffic. Moreover, we address some of the technical and standardization challenges related to having a time-varying transmission power. Based on the results, we provide guidance on how to best configure the network to achieve the full potential of the eICIC concept in dynamically changing environments.**

Index terms—**eICIC, heterogeneous network, Almost Blank Subframes, Low Power Almost Blank Subframes.**

I. INTRODUCTION

Heterogeneous Networks (HetNet) are being extensively discussed as a solution to increase the capacity of Long Term Evolution (LTE)-Advanced systems [1]. A HetNet [2] consists of a mix of macro-cells (called eNB in LTE) and low-power nodes such as pico-cells, femto-cells or relays, typically deployed in a relatively unplanned manner.

In co-channel HetNet deployments, interference problems may seriously degrade the performance of certain UEs. Enhanced Inter-Cell Interference Coordination (eICIC) techniques are strongly recommended to improve the system and cell-edge throughput [2]. Thus, the aggressor cell is prevented from transmitting on certain subframes, which the victim cell will use to schedule UEs severely affected by inter-layer interference. Particularly, in a multi-layer network with macro cells complemented by pico nodes, the macro eNB plays the role of the aggressor whereas pico-UEs in the cell-edge are the victim users. During the protected subframes, the macro layer can either stop data transmission or simply reduce the transmission power, scheduling strictly users in the vicinity of the macro eNB. These two options are referred to as ABS (Almost Blank Subframes) - or zero ABS - and LP-ABS (Low Power ABS), respectively. ABS was introduced in 3GPP Rel-10 (the first LTE-Advanced release) and its performance has been evaluated in previous work ([3]-[6]). In the case of LP-ABS, the introduction of a time-varying macro

transmission power entails further technical challenges that are still under discussion in 3GPP Rel-11. Naturally, the level of power reduction plays an important role. In any case, the effectiveness of the eICIC techniques is closely dependent on the optimal parameter setting.

Being a new feature open to debate at present, only 3GPP contributions are available in the literature (see e.g. [7][8][9][10]), covering just some of the aspects of LP-ABS. In this paper, we address the introduction of low power subframes in LTE HetNets. Based on extensive system level simulations with bursty and non-bursty traffic, we evaluate the tradeoff between macro transmission power, cell load and system and cell-edge throughput, and compare LP-ABS with ABS. The results provide guidelines on how to configure the network in dynamically changing environments. We investigate some of the technical and standardization aspects related to the introduction of the new topic, like extra required signaling and the impact of powering down on the eNB dynamic downlink power range and the Error Vector Magnitude (EVM) requirements.

The rest of the paper is organized as follows: Section II overviews the eICIC concept. Section III discusses operating eICIC with LP-ABS. In Section IV we evaluate the performance of LP-ABS vs. ABS in different scenarios, with bursty and non-bursty traffic. Section V addresses some of the technical and standardization challenges due to LP-ABS, like extra signaling support or the impact on the dynamic downlink power range and the EVM requirements. Finally, conclusion remarks are given in Section V.

II. EICIC FOR CO-CHANNEL DEPLOYMENTS

A HetNet deployment with macro and pico-eNBs on the same carrier is depicted in Figure 1. In a traditional macro-cell network, the cell offering the highest Reference Signal Received Power (RSRP) is selected as the serving eNB for the UE. However, applying this criterion to HetNets leads to a downlink imbalance problem: the coverage of the macro-cell is much larger than that of the pico-cell due to the difference in transmission power, resulting in a small number of UEs being served by the pico-eNBs. This imbalance can be corrected by expanding the range of the pico-cell. Thus a positive bias, denoted as Cell Range Extension (CRE) offset, is added to the RSRP measured from pico-eNBs, expanding the footprint of the pico layer and pushing more UEs into it.

However, placing pico-cells within the coverage area of macro eNBs introduces several challenges in terms of
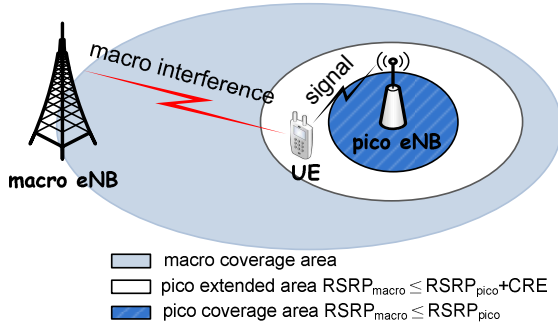
Figure 1. Baseline macro-pico heterogeneous network.

Figure 2. Simplified scheme of the power allocation for normal and protected subframes

interference management. The perceived Signal to Interference plus Noise Ratio (SINR) by pico-UEs in the extended area is poor, due to the stronger macro interference and lower signal strength from the serving pico-eNB. The macro base station can be configured to reduce the interference to victim pico-UEs by limiting its transmission during certain subframes [2]. The configured muting ratio will determine the periodicity of these special subframes in a time-domain basis. There are two options. In the first one, the so-called Almost Blank Subframes (ABS) or zero ABS, the macro layer stops data transmission during the muted frames. In the second case, referred to as Low Power Almost Blank Subframes (LP-ABS), the data channel transmission power is reduced.

III. LOW POWER ABS

(A) Definition

A cell having Low Power ABS reduces its data transmission power in the downlink. Thus, only users in the vicinity of the macro eNB are to be scheduled during the protected subframes. Compared to zero-power ABS, where no macro users are scheduled, the macro throughput performance is expected to increase with LP-ABS. This improvement comes necessarily at the expense of the pico layer. The pico user throughput will diminish since UEs in the extended area will suffer more severe interference from the macro cell. The tradeoff between both factors determines the optimal choice.

As it happens with ABS, the macro-eNB still has to transmit unchanged essential information required by the system for backward compatibility. Thus, the Common Reference Signals (CRS) as wells as other mandatory synchronization and paging channels, if these collide with the protected subframes, are transmitted at normal power. Figure 2 shows a simplified picture of the power allocation in normal and protected subframes. In normal subframes, it is possible to configure two different offsets between the CRS and the data, corresponding to symbols carrying CRS and not carrying CRS, respectively. During LP-ABS, the macro transmission power is reduced by a value of L dB, which is semi-statically configured for all LP-ABS, relative to normal subframe transmission. This essentially means that a victim UE experiencing interference from LP-ABS will be subject to relative high CRS interference as there is no power reduction for CRS. As recommended for ABS [3][11], pico-UEs should
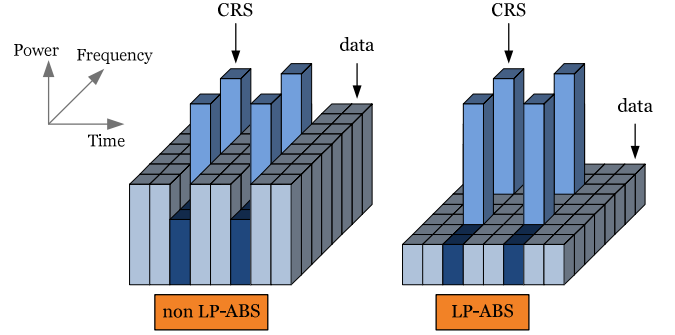
apply CRS Interference Cancellation (IC) during protected subframes in order to fully benefit from LP-ABS.

(B) Range Extension

With zero-power ABS, it has been found [6] that high CREs in the order of 12-16dB provide the optimal coverage. We discuss next that, in the case of LP-ABS, the range extension bias and the power reduction cannot be set independently. To that end, let us derive the SINR experienced by pico-UEs during normal and protected subframes. Pico-UEs in the basic coverage area of the cell connect to the pico independently of the CRE. Particularly, the users in the coverage border perceive the same signal level from the strongest interfering macro and the serving pico-eNB. If the total received interference plus noise is simplified by considering only the strongest interference component (which is for most users the most relevant contribution), then a rough approximation of the SINR of these users during normal subframes can be written:

$$SINR(dB) \approx RSRP_{pico} - RSRP_{macro} = 0 \qquad (1)$$

and it will be positive for pico-UEs in the coverage area. On the other hand, a pico-cell with a CRE = X dB means that UEs in the cell-edge will receive a macro RSRP X dB higher than that of the pico-cell. Besides, with LP-ABS the macro power is reduced by L dB. Thus, the SINR of these users during protected subframes yields:

$$SINR(dB) \approx RSRP_{pico} - RSRP_{macro\ LP-ABS} = L - X \qquad (2)$$

From (2) we can see that the CRE should not be larger than the power reduction the SINR of the pico users is to be kept positive. Higher CRE would reduce the reliability of the common/shared control channels.

IV. LP-ABS EVALUATION

The performance of the eICIC is closely related to the adjustment of all the parameters involved, i.e., CRE and muting ratio. With the introduction of LP-ABS a new parameter, the power reduction L, comes into play. In this Section we evaluate the performance achieved by LP-ABS and compare it with zero ABS in different scenarios. As performance indicators, we use the 5%-ile (cell-edge) and

Table I: Summary of simulation assumptions

| Parameter	Setting
Network Layout	500m macro-layer inter-site distance with 4 pico-eNBs per macro-cell
Cell layout	7 macro-sites (21 macro-cells), wrap around
Total number of UEs in the network	630
UE placement	2/3 UEs inside the hotspots; the remaining UEs are uniformly distributed within the macro-cell area
Transmit power	Macro-eNB: 46dBm; pico-eNB: 30dBm
Sub-frame duration	1ms (11 data plus 3 control symbols)
Modulation and coding schemes	QPSK (1/5 to ¾), 16QAM (2/5 to 5/6) and 64QAM (3/5 to 9/10)
1st transmission BLER	10%
HARQ modelling	Ideal chase combining with maximum 4 transmissions
Bandwidth	10MHz at 2GHz frequency
Antenna system	2x2 with rank adaptation and interference rejection combining
Traffic model	Full buffer, finite buffer
eNB packet scheduling	Proportional Fair (PF)
CRS IC	CRS macro interference is perfectly cancelled [11]

Figure 3. 5%-ile vs 50%-ile experience user throughput with ABS and LP-ABS and different CRE offsets

Figure 4. Macro and pico 5%-ile performance for ABS and LP-ABS

50%-ile (median) UE throughput, i.e.,the UE throughput (both macro and pico UE) obtained at the 5% and 50% points of the Cumulative Distribution Function curve. A network layout with co-channel deployment of macro and pico-eNBs as defined in [12] is simulated. The network topology consists of a standard hexagonal grid of three-sector macro-eNBs, complemented with a set of low power pico-eNBs with omni-directional antennas. A quasi-dynamic system level simulator is used, including explicit modelling of major Radio Resource Management (RRM) algorithms such as packet scheduling, Hybrid Automatic Repeat Request (HARQ), link adaptation, 2x2 closed loop MIMO with precoding and rank adaptation [13]. For scenarios with eICIC enabled, we assume a perfectly synchronized network. According to 3GPP simulation guidelines, one pico-eNB is deployed in each hotspot, and the hotspots have approximately the same amount of UEs. UEs are assumed to support separate reporting of CSI for zero or LP-ABS and normal subframes. The main simulation parameters are summarized in Table I.

In Figure 3 we show the results of the simulations with full buffer traffic, i.e., full load conditions. The 5%-ile vs. the 50%-ile user throughput is plot for different power reductions (zero-power ABS and LP-ABS with L=12dB, 9dB, 6dB) and different CRE (from 0dB to 14dB). Following the recommendations in Section III, L equals the maximum CRE in each case (and no limitation for ABS). The muting ratio is 4/8 both for ABS and LP-ABS. It has been found that this is the optimal ratio for both options in the considered scenario. For small values of CRE, LP-ABS outperforms ABS both in coverage and median. However, ABS provides slightly higher performance in 5%-ile and 50%-ile when it is configured with a high value of CRE (12-14dB). Moreover, it is observed in LP-ABS that both the 5%-ile and the 50%-ile achieve the maximum with the maximum allowed CRE. It has been checked with simulations that higher values of CRE lead to degradation in the coverage performance. On view of Figure 3, the change between LP-ABS and ABS is recommended to be at a CRE of 8-10dB. Notice that the selection of the CRE offset is also closely related to the offloading ratio, so that the
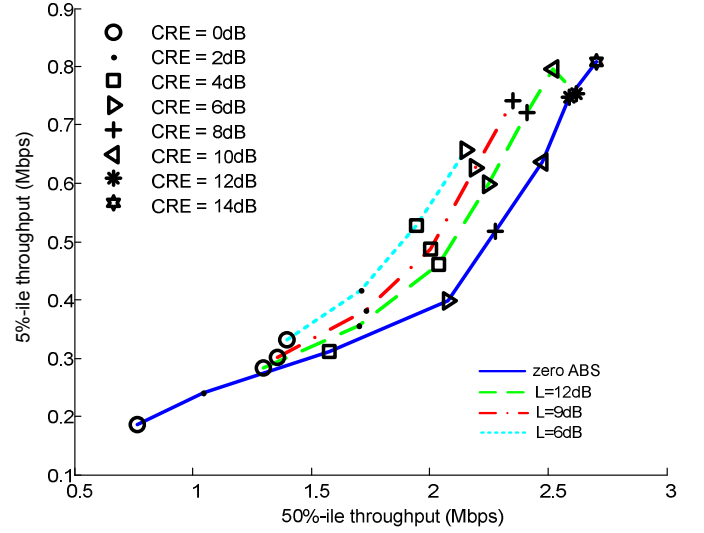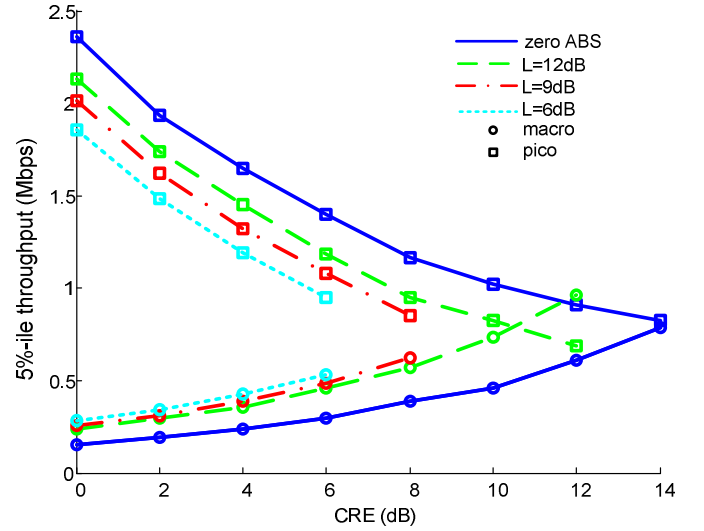
ratio of UEs offloaded to the pico-layer increases with the CRE value. In Figure 4, the 5%-ile user throughput is shown separately for the macro (circles) and pico (squares) layer. As expected, macro performance improves with LP-ABS and pico performance diminishes due to higher interference suffered specially by users in the cell-edge. It is worth noting that the level of power reduction (from 6dB to 12dB) for a given CRE does not change much the macro layer but it impacts significantly the pico-performance. Thus, it could be concluded that small values of L dB are sufficient to reach the maximum performance of LP-ABS. However, larger power reductions make it possible the application of larger CRE offsets and the consequent improvement of macro performance thanks to higher pico offloading ratios.

The influence of the system load in the performance of LP-ABS is investigated in Figure 5. We show the results with dynamic traffic model with Poisson call arrival, assuming a finite payload for each call. Once the payload has been successfully delivered to the UE, the call is terminated. It is observed in the Figure how the optimal eICIC configuration
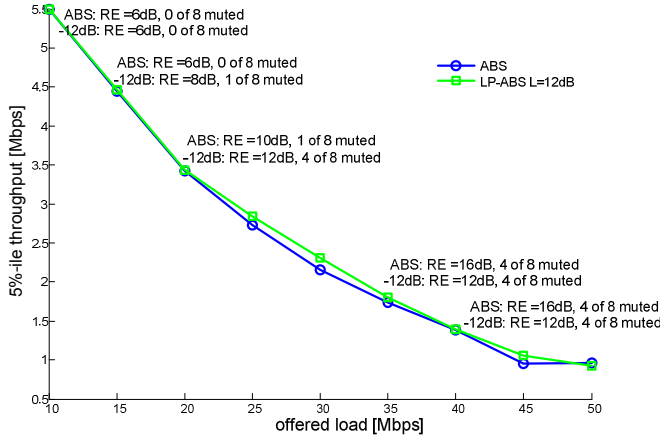
Figure 5. Optimal 5%-ile vs. offered load

varies with the offered traffic load. We plot the achieved 5%-ile user throughput for the optimal eICIC parameter setting (muting ratio and CRE) for an offered traffic load varying from 10Mbps to 50Mbps, for zero-power ABS and LP-ABS with a power reduction of 12dB. It can be observed that the optimal coverage of ABS and LP-ABS is very close for all values of traffic load. Moreover, the eICIC configuration should adapt to the load conditions: when the cell load is low, there is marginal gain from applying eICIC and the muting is not needed; as the offered low increases, both the macro and the pico layer start having higher probability of transmitting and causing interference. Thus, higher CRE and muting ratios are needed, converging to the optimal values of full buffer for high values of load. Besides, this convergence is quicker for LP-ABS due to the higher interference suffered by pico-UEs (see e.g. the case with offered load = 20Mbps: zero-ABS uses CRE = 10dB and 1/8 muting ratio, while LP-ABS is optimized with CRE = 12dB and muting ratio = 4/8).

We can conclude that from a performance point of view the introduction of LP-ABS mode in Rel-11 brings additional flexibility for optimizing the system under different conditions, enabling second order optimizations. Nonetheless, reducing the macro transmission power also has a *cost* in terms of additional complexity and standardization, as detailed in next Section.

V. STANDARDIZATION IMPACT

In this Section we discuss some of the aspects related to the standardization impact of introducing LP-ABS in LTE specifications.

(A) eNB-2-UE and X2 Signalling Support

As it has been shown in Section IV, the eICIC configuration that optimizes the overall system performance varies with the load of the system and, therefore, with the time. Depending on the network conditions, the macro layer may choose between LP-ABS and ABS and, in the case of LP-ABS, the level of power reduction. The introduction of low power subframes may likely call for additional information exchange to fully support the new feature. Moreover, efficient use of LP-ABS may also benefit from additional information exchange

between macro and pico, as compared to what is already standardized in Rel. 10 for the X2 interface. For example, it is required that macro-UEs can be informed whenever there is a new ABS or LP-ABS pattern taken into use. Recall that Rel. 10 already includes exchange of information such as ABS information, ABS status, and Invoke over the X2 to facilitate coordinated adjustment of ABS muting patterns ([14]). With the introduction of LP-ABS, it could be beneficial to also inform of the LP-ABS power reduction when sending ABS information. Secondly, as the pico eNB is in the best position to judge if higher or lower LP-ABS power reduction would be needed, it could be beneficial to also allow the pico to suggest values for the LP-ABS power reduction to the macro.

Finally, the UE also needs to know the power offset between the data channel and CRS. In Rel. 10 specification, UE specific power offsets between CRS and the data channel are semi-statically configured and valid for all subframes. In case of macro-cells with LP-ABS, different power offsets are used for different subframe patterns. Thus, two different offsets shall be signaled to the UE: one for normal subframes and one for LP-ABS.

(B) Dynamic Downlink Power Range

In LTE, the Resource Element (RE) power control dynamic range is the difference between the power of an RE and the average RE power for a base station at maximum output power [15]. The minimum requirement of RE Power control dynamic range is defined in Table II.

Table II: RE Power Control Dynamic Range

Modulation scheme used on the RE	RE power control dynamic range (dB)	
	(down)	(up)
QPSK (PDCCH)	-6	+4
QPSK (PDSCH)	-6	+3
16QAM (PDSCH)	-3	+3
64QAM (PDSCH)	0	0

On the other hand, the Error Vector Magnitude (EVM) is a measure of the difference between the ideal symbols and the measured symbols after the equalization [15].

In order to minimize the standardization impact and according to Table II, the maximum power reduction with current LTE specifications would be -6dB using QPSK, 3dB for 16QAM and 0dB for 64QAM. Thus, a power reduction of L=6dB would be possible without significant specification changes only if the modulation is constrained to QPSK during the protected frames. Without these constraints, the introduction of LP-ABS leads to a significant increase in the dynamic range of RE power within an OFDM symbol. For example, for a power reduction of 9dB the lower dynamic ranges in Table II would have to be set to -9dB for all modulation schemes. In addition, a larger dynamic range yields degradation in the EVM so that the support of high power reductions will be achieved at the expense of better EVM requirements[1]. More details can be found in [16].

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[1] Current EVM requirements are 17.5% for QPSK, 12.5% for 16QAM and 8% for 64QAM.
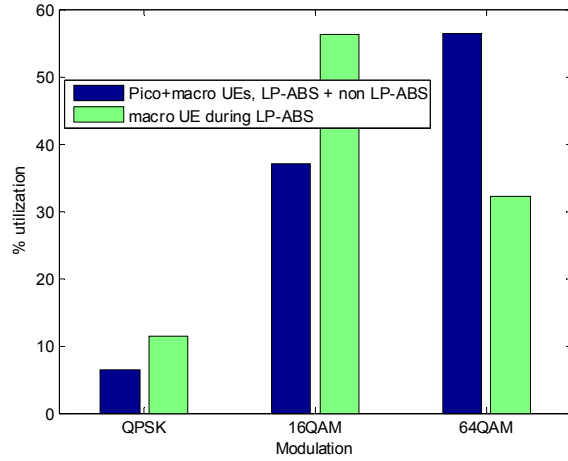
Figure 6. Modulation use

The question that arises here is which modulations are used during protected subframes. As the transmission power is reduced, the macro layer is expected to reduce the modulation order in a natural way. However, we can see in Figure 6 that high order modulations are often used. In the Figure, it is shown the modulation use for a power reduction of 6dB, CRE = 0dB and a LP-ABS ratio of 50%. The blue bar includes the whole transmission (including protected and non- protected subframes) and all users, while the green bar plots only macro UEs and low power subframes. As expected, the modulation order decreases when the transmission power is reduced, but we still have some 88% of 16QAM and 64QAM. As discussed before, the impact of introducing LP-ABS in the specification could be minimized if the modulation order is limited to QPSK during low power subframes. If so and on view of the results of Figure 6, a perceptible degradation in macro performance is expected. This performance degradation is shown in Figure 7, where the 5%-ile and 50%-ile user throughput are plot for CRE from 0 to 6dB and L=6dB, with and without modulation constraint. The 5%-ile is not affected by the constraint, since these users are not scheduled during LP-ABS. However, a loss of ~13% is found in the median user compared to the case of not-constrained LP-ABS.

VI. CONCLUSION

LP-ABS is a potential new feature within 3GPP Rel. 11 eICIC techniques. The introduction of the LP-ABS mode brings additional flexibility for optimizing the system under different conditions, enabling second order optimizations. But LP-ABS also has a *cost* in terms of additional signaling and standardization changes. From a performance point of view, we have provided guidelines on the optimal network configuration to achieve the full potential of the eICIC concept in dynamically changing environments. Results show that LP-ABS provides better results than zero ABS for small CRE offsets. Regarding the muting ratio, it is recommended to be increased with the load of the network. In terms of standardization effort, it can be minimized by limiting the modulation scheme and the maximum power reduction, with the consequent performance degradation. Otherwise, the dynamic downlink power range and EVM requirements will be significantly affected by the power reduction.
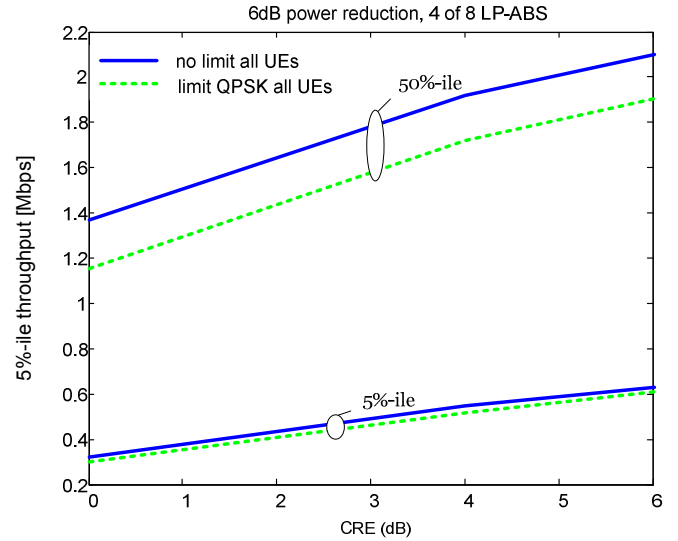

Figure 7. 5%-ile and 50%-ile experience user throughput with modulation constraint

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