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Interference Coordination for 5G New Radio

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Abstract

The arrival of the 5G NR provides a unique opportunity for introducing new inter-cell interference coordination (ICIC) mechanisms. The objective is twofold: to better exploit the benefits of ICIC in coherence with the rest of radio resource management (RRM) principles in 5G, and to support new services and deployment scenarios. We propose several enhanced techniques. In the uplink, inter-cell coordination of the pilot sequence configuration mitigates the inter-cell interference problem of such pilots, which is especially severe for cell-edge users. In the downlink, coordinated small cell DTX aims at network interference control and energy consumption reduction, whereas inter-cell rank coordination can unleash the potential of advanced receivers with minimal control overhead. Besides, on-demand power boosting and coordinated muting can be tailored to meet URLLC requirements. The simulation results quantify the performance benefits of the different techniques under heterogeneous key performance indicators (KPIs). We also discuss the standardization effort required for having each of these techniques included in the 5G NR specifications.

Overall Inter-Cell Interference Coordination Design Principles for 5G New Radio

Co-channel inter-cell interference is known to be one of the limiting factors of cellular systems, and it has triggered numerous academic research studies and industrial standardization and implementation efforts in LTE/LTE-A. Standardized network-based inter-cell interference coordination (ICIC) schemes for LTE range from basic coordination to further enhanced ICIC, and more elaborate coordinated multi-point (CoMP) communication techniques [1–3]. The solutions for LTE were mainly designed to offer spectral efficiency benefits for data channel transmissions by applying various forms of inter-cell coordinated muting (or power adjustments) or interference randomization, while offering only limited benefits for control channel performance.

Fifth generation new radio (5G NR) [4, 5] is expected to experience a proliferation in the number of emerging use cases, categorized into three broad service groups [6]. Enhanced mobile broadband (eMBB), an evolution of today's broadband traffic, will still be a key driver, with a main key performance indicator (KPI) in the form of a target peak data rate of 20 Gb/s. Also, 5G opens the door to new use cases with heterogeneous requirements, like ultra-reliable low-latency communications (URLLC), where messages must be correctly decoded with very high probability (10^{-5} outage probability) and in a very short time (1 ms); and massive machine type communications (mMTC), catering to a large number (1 million devices/km2) of low-data rate, low-cost services. The first phase of the standardization process will primarily focus on the first two categories, namely eMBB and URLLC [4].

The set of radio features to support eMBB and URLLC is broad, and it can be categorized as follows: spectrum enhancements, with the use of licensed, lightly licensed, and unlicensed bands spanning microwave and millimeter wave frequencies; deployment enhancements, for instance in the form of ultra-dense networks with self-backhauling; and capacity enhancements, like non-orthogonal access, device-to-device and massive MIMO [7]. One important design principle in NR is to have a flexible and efficient use of radio resources and available spectrum [6]. As per the architecture, the latency requirements also pose new challenges for the backhaul, both in classical distributed cases and in emerging centralized RAN (C-RAN) [4], where a shared pool of centralized baseband resources serves a large number of remote radio heads. In this context, the ICIC framework evolution must go hand in hand with the new radio access.

In this article, we present a set of interference management advances for 5G NR. To fulfill the promise of a comprehensive and integrated network, 5G should move from a network-oriented to a service-oriented paradigm, where differentiated services with diverse KPIs can coexist on the same infrastructure. Moreover, ICIC design principles must exploit the new degrees of freedom that come with 5G NR, especially taking advantage of flexible physical-layer and medium access (MAC) design [5], as well as the richer architecture options [4]. In this light, we describe solutions to address major interference challenges. First, we consider the uplink (UL) inter-cell pilot (also known as the reference symbol) interference problem. Inter-cell pilot sequence coordination techniques are proposed, which improve the link performance because of enhanced channel estimation and coherent demodulation [8]. Another advantage of such techniques is their ability to support more users than the current LTE solutions. In the downlink (DL), we propose a scheme for joint interference control and energy efficiency in dense small cell scenarios [9] by means of enhanced methods for discontinuous transmissions at the cell level (cell discontinuous transmission DTX) based on fuzzy Q-learning [10]. We elaborate on the new

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opportunities that come from assuming multi-user multiple-input-multiple-output (MU-MIMO) and advanced interference-aware receivers as the baseline for 5G [11]. Building on the earlier work in [12], novel solutions for coordination of the maximum transmission rank between neighboring cells is also presented. Another proposal is to support the challenging reliability and delay requirements of URLLC through highly agile and fast coordination techniques, offering benefits for both control and the data channel performance [13].

It is worth highlighting that the proposed schemes are complementary, addressing different interference challenges but sharing the 5G NR philosophy of more dynamic coordination for a multi-service air interface. The details of the proposed mechanisms are presented in the next sections. The delay over the backhaul in the signaling exchange between base station (BS) nodes (through the so called Xn interface [4]) is a limiting factor in inter-cell coordination. In all cases, we strive for a generic design that is applicable both in distributed architectures with Xn interface as well as in C-RAN scenarios with a centralized controller. For the sake of conciseness, each downlink solution is tailored for a given service, although all UL and DL proposals are applicable to both eMBB and URLLC.

Uplink Inter-Cell Pilot Coordination

In UL, inter-cell pilot interference arises when the assigned uplink pilot sequences across multiple cells, which are non-orthogonal, are scheduled on the same time-frequency resources. The received pilots from a target user suffer from pilot interference coming from neighboring cells, resulting in poor channel estimation. This problem is especially severe for cell-edge users, as the power of the interfering pilots is comparable to that of desired pilots. It leads to errors in uplink coherent demodulation, and it is very detrimental in uplink multi-user MIMO scenarios that heavily rely on accurate channel knowledge to perform receive filtering. Additionally, in a calibrated time-division-duplex (TDD) system where channel reciprocity holds, the BS can acquire the channel knowledge necessary for downlink multi-user MIMO precoding via the uplink pilots sent by the users. In this case, pilot interference leads to erroneous channel knowledge, which affects the precoding quality and the downlink throughput.

In LTE-A, users across cells are assigned non-orthogonal yet distinguishable sequences. These sequences are cyclic extended Zadoff-Chu (ZC) sequences, which are spread over the subcarriers of interest. Cyclic-extension is necessary to maximize the number of distinguishable sequences. The available sequences in each cell are constructed by phase rotation of a root sequence identified by a root index, and are mutually orthogonal. The root sequences (and the corresponding root indices) across cells are different. Different root sequences or phase rotations thereof are not orthogonal, though they are distinguishable via their root indices.

Few solutions exist to mitigate inter-cell pilot interference via a distributed or centralized sequence assignment over the cells. A related work is [14], where the authors propose an assignment of ZC sequences in an Orthogonal Frequency Division Multiplexed (OFDM) system, such that the worst-case channel estimation mean square error (MSE) is minimized. However, a key assumption of [14] is that user pilots occupy all available subcarriers, which is not the case in a practical system, rendering the performed analysis inapplicable. Furthermore, the BSs treat pilot interference as noise, which is suboptimal at high uplink signal-to-noise ratios (SNRs) occurring in, for example, small cell scenarios. In such scenarios, a better approach would be the suppression of pilot interference at the BS to recover the desired pilots with as little interference as possible.

LTE-A can allow for pilot orthogonality among multiple cells: a BS assigns, from its pool of available orthogonal sequences, pilot sequences for users in neighboring cells. Such a solution is not scalable for many 5G applications, as the number of users a BS can serve within its cell decreases.

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One possibility to suppress the pilot interference in 5G NR and leave the number of served users within a cell unchanged can be realized by exchanging ZC root indices among BSs through the backhaul Xn interface. An alternative implementation is a centralized approach with a central controller sending the indices of all concerned BSs to each BS. Both implementations allow a given BS to construct the sequences used in neighboring cells and perform channel estimation, including not only the channel of the desired user but also that of users in neighboring cells [8]. The channel of the former is then estimated with some residual interference (due to the non-orthogonality of sequences across the cells), while the estimated channels of the latter can be dropped or used according to the desired application (e.g., CoMP beamforming or joint transmission rely on the knowledge of channels of users in neighboring cells). The channel estimation is performed in the time domain and exploits the fact that, in practical OFDM systems, the number of taps is (much) smaller than the number of subcarriers, which results in a reduced number of variables in the time domain (i.e., taps) that can be efficiently estimated. Going one step further, [8] proposes to optimize the choice of the used sequences such that the channel estimation MSE is further reduced. The gains of optimized sequence selection are mainly seen in the medium to high SNR regime where the non-orthogonality of used sequences becomes the limiting factor. Figure 1 shows the signaling steps necessary both for a centralized and a decentralized implementation. The first step consists of the signaling/exchange of sequence indices, while the second one involves informing the users within each cell of the chosen sequence within the respective cell.

Summing up, this procedure generalizes the idea of uplink CoMP data reception to pilot sequence reception. It can be implemented for ZC as well as other types of sequences (e.g., pseudo-noise sequences). It improves the channel estimation quality for non-CoMP applications and allows efficient CoMP operation without reducing the number of users that can be simultaneously assigned pilot sequences. As observed in [8], a careful choice of sequences can allow the achievable MSE to closely follow the interference-free MSE. In contrast to LTE solutions, keeping the number of users that can be served unchanged is especially important for eMBB and URLLC 5G services.

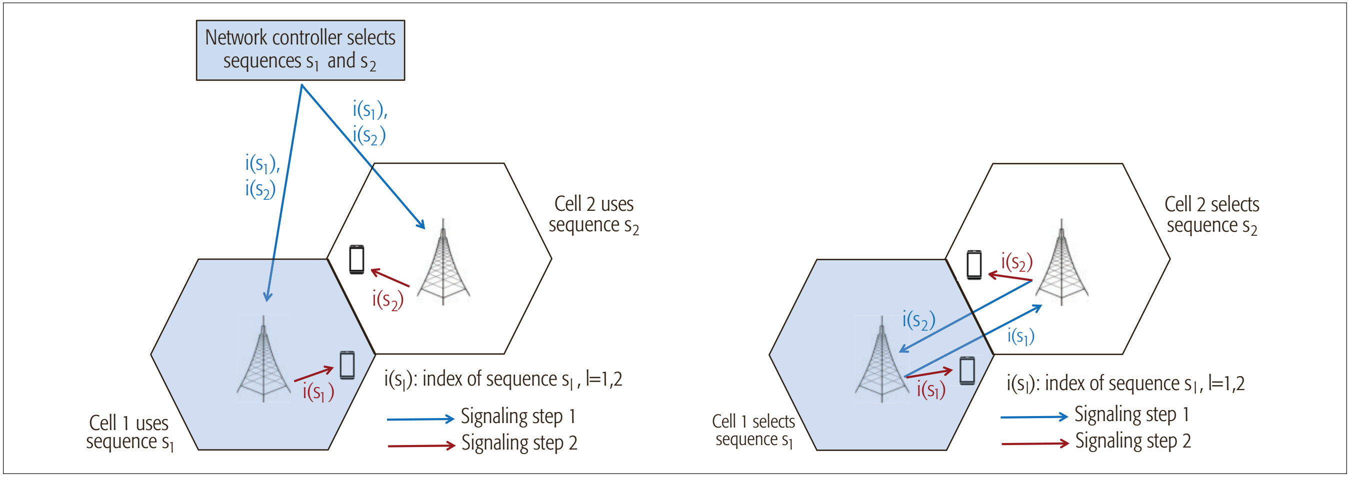

FIGURE 1. Signaling steps in a centralized or decentralized implementation of pilot sequence allocation.

Downlink Inter-Cell Interference Coordination

In the DL, the trend is toward more dynamic ICIC solutions, as already agreed in 3GPP for 5G NR [5], as well as addressing various network deployments (small cell and macro scenarios), key 5G technologies (dense small cell networks and MU-MIMO), and KPI requirements (spectral efficiency, energy, and reliability).

Downlink Inter-Cell Coordinated Small Cell DTX

Cell discontinuous transmission is an energy saving technology that adapts the cell activity to its instantaneous load. Within each frame, the cell DTX will instantaneously activate (deactivate) the cell components and the associated functionalities when the user data is present (absent) in the cell queue. Furthermore, it is possible to increase the period in which a cell switches off or mutes by maximizing the usage of the available frequency resources at each active TTI, that is, trading off latency for energy efficiency.

In dense small cell deployments, this approach comes with the challenge of orchestrating the network activity in order to limit simultaneous activation of nearby cells. First, the optimal selection of the subset of small cells to activate at each frame is a combinatorial problem, which is complex to solve. Second, dormant cells cannot exchange information and implement baseline ICIC solutions or CoMP schemes. Finally, a reliable solution needs to take into account the stochastic nature of both the traffic and the radio channel. Existing ICIC mechanisms are not designed to deal with multi-objective optimization problems, e.g., jointly reducing interference and energy consumption while satisfying traffic latency constraints.

Reinforcement learning solutions provide an efficient framework to learn an optimal activation strategy by interacting with stochastic environments [9]. We design a fuzzy Q-learning based cell DTX controller that uses its decisions in the previous time slot to estimate the interference level experienced by the active small cells. In addition, the controller observes the queued data pending for transmission per cell, the expected capacity, and the requirements of the active services to decide whether to activate a small cell.

The sketch of the architecture and the detailed signaling exchange required by the scheme are shown in Figs. 2a and 2b, respectively. Notice that the pictured solutions here utilize the enhanced support for different architectures and functional splits that comes with 5G NR [4]. In those examples, the aggregation node buffers the data related to nearby small cells while the orchestration functions are deployed at the network controller. Additionally, the measurements related to the radio access network capacity can be forwarded to the controller node during the small cell activation. Radio resource management (RRM) and lower-layer functions are implemented locally at the transmission points; thus, the controller and the small cells do not need to continuously exchange messages through the backhaul. On the contrary, a fully distributed architecture requires coordination across nearby small cells, which in turn increases the small cell (and the backhaul) energy consumption. In the same way, implementing centralized scheduling or coordinated beamforming schemes at the network controller 1) increases network complexity; 2) needs regular transmission of channel quality indicators (CQIs) over the backhaul link; and 3) is affected by the backhaul latency and capacity constraints. In any case, the proposed solution with reinforcement learning manages the small cell activity to limit network energy consumption without reducing the system quality of service (QoS).

Downlink Inter-Cell Rank Adaptation

In a MIMO setting, the downlink serving rank (or number of transmission streams) plays a major role in the interference suppression levels of interference rejection combining (IRC) receivers. This is because significant interference suppression is only possible when the number of desired data streams and dominant interference streams are collectively fewer than the receiver dimension, i.e., the number of receive antennas. Traditionally, rank selection at each user is essentially performed in a selfish manner independently per link, without taking into account the interference caused by such selections. For 5G NR, an inter-cell rank coordination mechanism can improve the network and the cell-edge user throughput by coordinating the generated inter-cell interference from the aggressor cell.

Consider a MU-MIMO TDD system. The

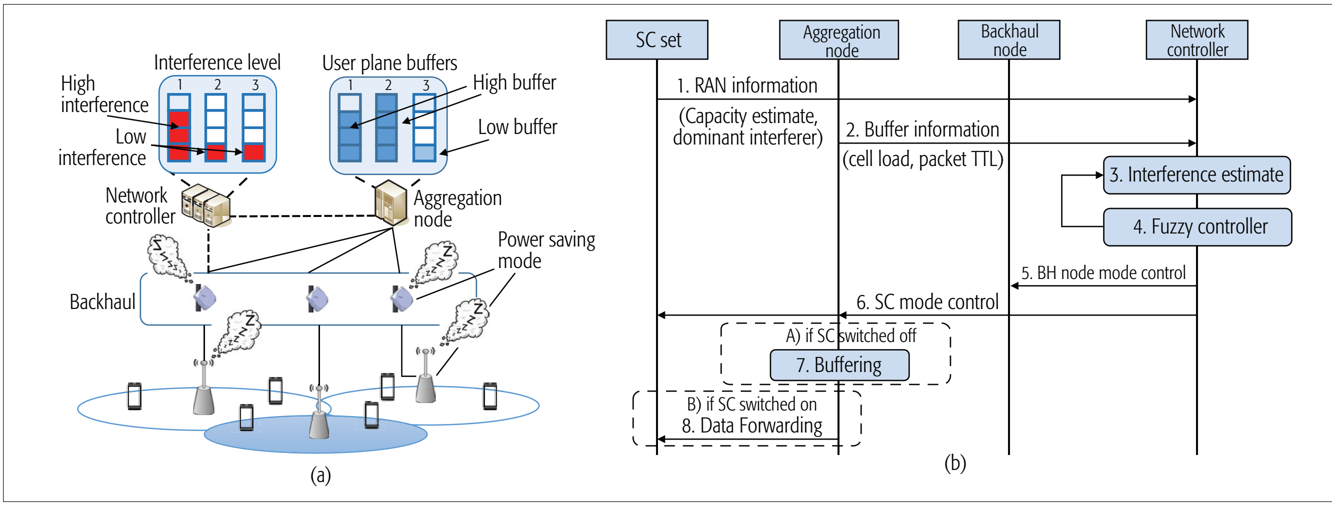

FIGURE 2. Downlink inter-cell coordinated small cell DTX: a) sketch of the architecture; b) signaling exchange.

available resources are divided into time-frequency slots, with the smallest unit being a physical resource block (PRB), corresponding to the duration of a single time transmission interval (TTI) over a single frequency channel. The transmission toward a desired UE from its serving BS generates interference toward out-of-cell interfered receivers. A cell-edge user scheduled on a given set of PRBs in a neighboring cell is most likely to be affected by the transmission on the same PRBs, and hence requires interference coordination. Studies have shown that coordinating the transmission rank can help improve the performance of interference suppressing receivers, such as the IRC [11].

The proposed inter-cell rank coordination aims at limiting the maximum rank of an aggressor, thus providing a guarantee on the experienced interference. To further limit the complexity of the scheme, only the strongest interferer, known as the dominant interferer (DI), of the victim UE is considered in the coordination. The victim UE reports the DI physical cell id together with a measure of the dominant to interference ratio (DIR), defined as the ratio between the DI power to the rest of interference and noise power in the network. As happens with the interference, the DIR can change very fast in fractional load scenarios [15], and therefore the LTE-A measures of received signal power are not sufficient.

The proposed coordination mechanism involves the following steps, as illustrated in Fig. 3:

1) The UEs report the DIR and the CQI to the serving BS. The serving BS determines whether the DIR is above a certain pre-specified threshold, and rank coordination is only invoked for those UEs with a strong DI. The UEs selected for rank coordination are then grouped according to the DI, to avoid conflicting coordination requests from the same BS.

2) The serving BS decides what will be the maximum transmission rank for each of the UEs in each group, along with the interference rank it would like to have. The signal to interference and noise (SINR) ratio is used for the decision. The ranks are chosen based on the estimated post IRC SINR.[1] The proposed rank coordination mechanism is not bound to any specific rank adaptation algorithm, though interference-aware rank adaptation algorithms such as those presented in [12] are best suited for such applications.

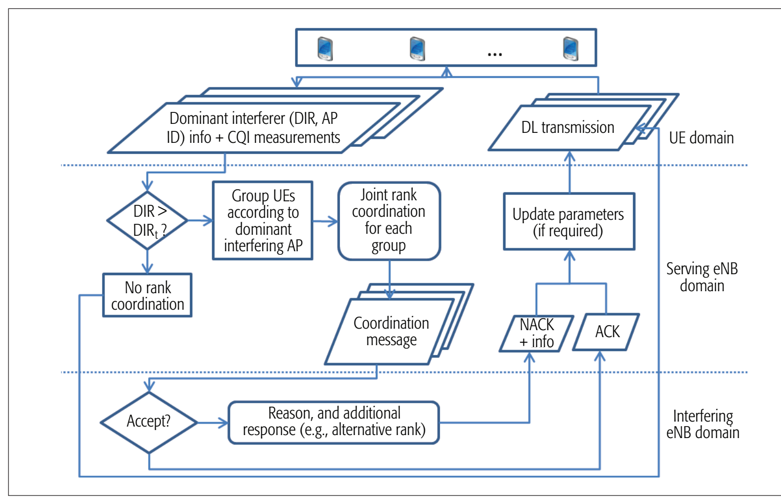

FIGURE 3. Flowchart of Message Flow with multiple UEs.

3) The serving BS sends the desired rank message to the respective interfering BS. The desired rank message is indicated as the maximum allowable transmission rank for a given set of PRBs. These messages can be per single PRB, or several PRBs can be grouped into a single desired rank and priority level. The granularity provides a trade-off among performance, overhead and complexity.

4) The serving BS updates its transmission parameters according to the feedback message from the interfering BS. Such updates can include re-scheduling the users, re-adjusting the transmission parameters, or re-adapting the transmission rank with respect to the feedback message. The 5G TTI is expected to be shorter than the current 1 ms of LTE [5]. The rank coordination could occur over a longer time basis (in the range of 5-10 ms), therefore suitable for heavy payload traffic spanning over multiple TTIs. For random intermittent traffic with small payload, the interference rank can be pre-coordinated to cater to such bursty but critical payloads.

The algorithm in Fig. 3 is applicable to both distributed and C-RAN architectures, taking advantage of the flexible architecture options that come with 5G NR [4]. Naturally, when having a centralized unit, the scheme simplifies since there is no

[1] The post IRC SINR is the criterion for eMBB services. For URLLC, the probability of satisfying a target SINR can be used instead.

need for coordination messages among BSs. It is also worth highlighting that the proposed rank coordination can be applied in macro cellular settings, as well as small cell deployment scenarios.

Downlink On-Demand Power Boost and Coordinated Muting

The SINR outage is a relevant metric for URLLC in 5G NR, and it can be improved with two well known principles, namely power boost of the desired signal and muting or blanking of the interfering signal. The flexible physical-layer design for 5G NR [5], and especially the novel frame structure design, opens the door for revisiting those principles. First, more dynamic schemes with fast reactions are needed. Second, the in-resource physical layer control signaling that follows the corresponding data transmission for each individual user signaling is an enabler for new ICIC solutions, offering equal gains in control and data channels [6].

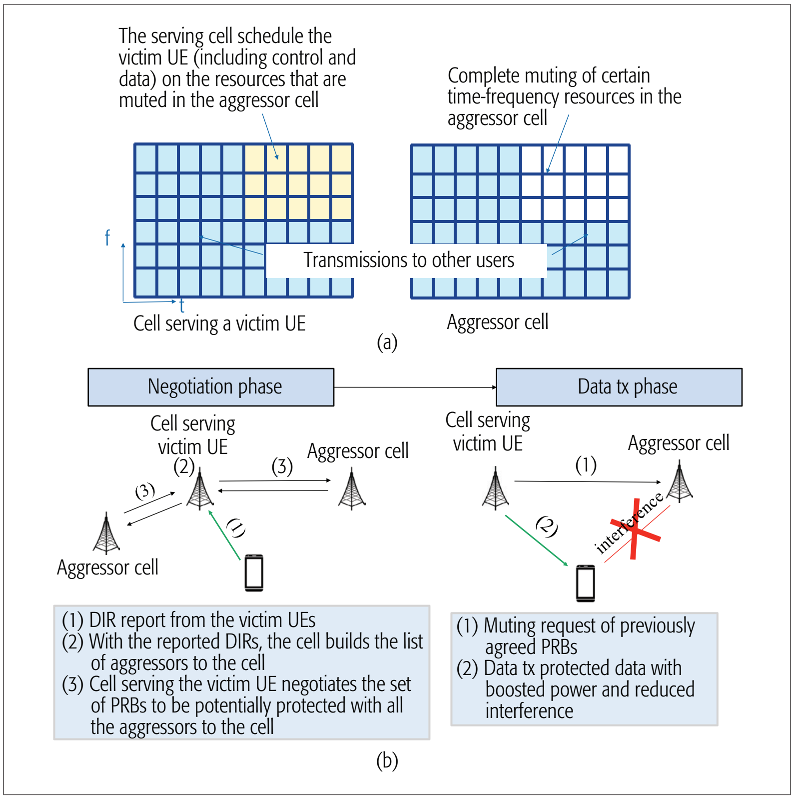

FIGURE 4. On-demand power boost and interference muting: a) main principle; b) UE reporting and inter-cell coordination during the negotiation phase (slow basis) and the data transmission phase (fast basis).

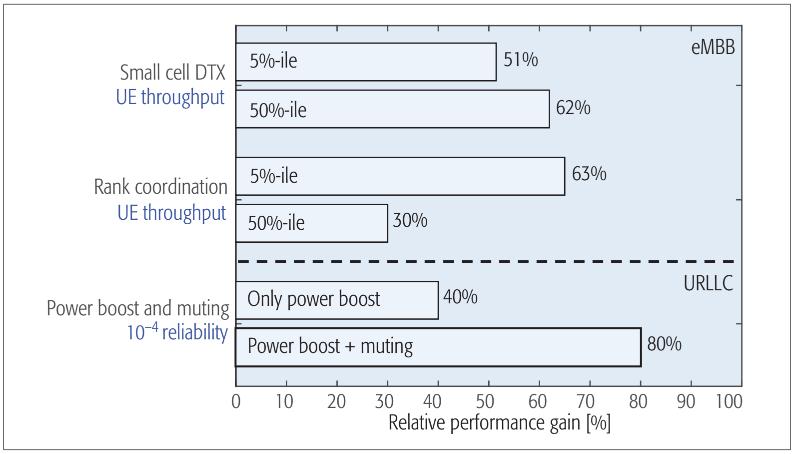

FIGURE 5. Relative performance gains of the three proposed DL ICIC mechanisms. For the small DTX and the rank coordination, the UE throughput gain in 5%-ile and 50%-ile is plotted. The relative gain with power boost only and with combined power boost and cell muting is shown in terms of delay reduction for a 10-4 reliability, with a first transmission target BLER of 1%.

The proposed on-demand power boost and coordinated muting [13] works as follows. On one hand, the power of a contiguous block of PRBs carrying both control scheduling information and corresponding data transmissions is boosted at the cell serving the victim UE. The power in the rest of the band should accordingly be de-boosted to keep a constant nominal power. Furthermore, the maximum value of allowed power boosting relative to the nominal value must be properly designed to limit the dynamic range and the error vector magnitude (EVM) requirements. On the other hand, the same contiguous block of PRBs is muted in the aggressor cell, allowing the neighboring cell to transmit both control channel scheduling information and data channel on those protected resources with enhanced signal and reduced interference. This principle is illustrated in Fig. 4a.

One of the key points of the concept is being "on-demand," that is, activated only when needed. This implies deciding whether a UE has to be protected or not. The decision should take into account the potential performance benefit for the victim UE and the resource sacrifice for the muted cells. Similar to rank coordination, the complexity of this scheme is limited by coordinating only with the DI. The input for the decision includes information of the traffic requirements and the signal and interference conditions in the network. For the latter, each cell keeps a list of the DIs to the served critical users, sorted from the strongest to the weakest. The length of said list is *N*, which is known by all cells in the network and may depend on the traffic requirements or the system bandwidth, among others. In any case, *N* is not expected to be high when we account uniquely for the DIs. Moreover, the muting is applied only if the DI signal strength is close enough to the desired signal strength and considerably outstanding as compared to the rest of the interferers and the system noise. Under these circumstances, the gain for the victim UE justifies the loss in available radio transmission resources for the rest of the network. The total amount of PRBs is then divided into *N*+1 PRB regions, such that it is always possible to negotiate an orthogonal set of PRBs among interfering cells (to avoid overlapping in the protected resources).

Cells need to agree on the set of muted (and boosted) resources and its activation. In a centralized architecture, a central entity keeps track of available information in terms of received signal and interference to the UEs in the network, and can rapidly take network-wise muting decisions. In distributed architectures, the coordination is divided into two phases that work at different time-scales. The idea is illustrated in Fig. 4b. By default, all cells use all the PRBs. The negotiation phase takes place on a slower basis, with the goal of deciding the set of PRBs to be potentially (i.e., if needed) protected. With agreement on the protected resources set-up, the cell serving the victim UE will ask the aggressor

Scheme	Dir	Primary services	Backhauling	Standardization effort	
Inter-cell coordination of uplink pilot RS sequences	UL	eMBB and URLLC	No strict latency requirements	Xn signaling of sequences indices in a centralized or distributed fashion • In a centralized implementation, a central controller signals to a group of cells/base stations the sequence indices to be used in each cell of that group •In a distributed implementation, the concerned base stations exchange the sequence indices among each other	There are no special requirements to the UE
Inter-cell coordinated small cell DTX	DL	eMBB and URLLC	Low latency for fast coordination	• In a distributed implementation, Xn shares the output of the DTX controller. • At time t, the DTX controller at each small cell takes its decision based on the information received at t-1 by nearby small cells.	• As part of the CSI, the UE reports the DIR to have information of the strongest aggressor. • This information can be updated on low frequency wrt the DTX coordination
Inter-cell coordinated rank adaptation	DL	eMBB and URLLC	Low latency for very fast coordination	• In a distributed implementation, Xn negotiation of the rank limitation among the cell serving a victim UE and the aggressor cells. • The rank message indicates the maximum transmission rank for a given (set of) PRBs that the aggressor cell is recommended to use	As part of the CSI, the UE reports the DIR to have information of the strongest aggressor
On-demand power boost and cell muting	DL	eMBB and URLLC	Low latency for very fast coordination	The coordination in a distributed implementation is divided into two phases: • Xn negotiation of the protected PRBs works in a slower basis, and implies one cell serving a victim UE to negotiate with the list of relevant aggressors the set of PRBs that can be potentially protected • Xn activation of the muting works in a fast basis, and implies the cell sending the protected data to ask the aggressor cell to mute	• As part of the CSI, the UE reports the DIR to have information of the strongest aggressor • The UE can periodically report measurements of the signal and interference under given hypotheses, to reinforce the link adaptation procedures with dynamic network interference coordination

TABLE 1. Overview of proposed ICIC mechanisms.

cell to mute during the transmission phase, happening every time a vulnerable packet arrives. This process is much faster since the specific PRBs have already been configured.

Performance Evaluation of Downlink Interference Coordination

We briefly present and discuss the performance of the three proposed downlink enhancements. For more details of the performance, we refer the reader to [10–13]. The relative performance gains are shown in Fig. 5. The KPIs are different for each case: user throughput for the small cell DTX and the inter-cell rank coordination, tailored for eMBB; and reliability for the on-demand power boost and cell muting, tailored for URLLC. The scenario comprises 19 tri-sectorized macro cells in a hexagonal grid, with MxM MIMO and 10 MHz bandwidth. For the small cell DTX, there are also four small cells per sector.

A classical DTX optimized only for energy saving and without interference management serves as the baseline for the small cell DTX scenario. There are 30 users requiring near-real time video traffic. We can see that the proposed solution outperforms the reference case in both the 5th percentile (5 percent-ile) and 50th percentile (50 percent-ile) by more than 50 percent. The baseline cell DTX with data buffering, due to the uncoordinated small cell activation and transmission, results in high packet error rate (PER), which, depending on the type of service, may lead to mismatch the QoS constraints. This issue can be solved by the proposed scheme, which results in a large improvement in terms of PER at the cost of a limited additional complexity and without affecting energy consumption.

As per the inter-cell rank coordination, the technique is compared against non-coordinated schemes. The traffic is full buffer. We use 8x8 MIMO, IRC receiver and a DIR threshold value of 5 dB. The KPI of interest is the UE throughput. It is shown that gains as high as 65 percent in the outage (5 percent-ile) and around 30 percent for the 50 percent-ile UE throughput are achieved with the proposed rank coordination. Overall, the scheme results in a fairer performance where significant outage throughput gains are obtained at the expense of minimal control overhead.

Finally, for on-demand power boost and cell muting, the analyzed KPI is the delay reduction for a 10^{-4} reliability target, and we evaluate the case with only power boost and with power boost and cell muting for a 2×2 MIMO. The traffic is a mix of UEs with sensitive information to be protected in the form of small packets of 32 bytes and a first transmission block error rate (BLER) target of 1 percent, and background full buffer traffic to emulate eMBB with no special delay or reliability requirements. The delay of the protected data is reduced as much as 40 percent compared to having no power boost, and up to 80 percent when inter-cell muting is simultaneously activated. Although not shown, very high gains are also observed in the tail of the distribution, such that the maximum experienced delay is significantly reduced.

The performance gains show clear benefits of network coordination with limited complexity and standardization effort. In all cases, we have strived for a generic design that is applicable both in distributed architectures as well as in scenarios with a centralized controller performing network-wise optimizations.

Summary

The arrival of new services and requirements for future 5G NR calls for a revision of inter-cell interference coordination mechanisms. In this article, we identify and address major interference challenges in the uplink and the downlink. Although the four proposed schemes address different interference challenges, they are compatible and they all build toward 5G NR, being highly dynamic, flexible, and multi-service capable. The proposed solutions utilize the enhanced flexibility and new options that come with 5G NR design. In the uplink, inter-cell pilot interference is mitigated with proper coordination of the pilot sequences. In the downlink, coordinated small cell discontinuous transmission aims at improving network energy consumption while maintaining high throughput performance, whereas inter-cell rank coordination can play a major role in scenarios with advanced interference-aware receivers. Also, on-demand power boosting and coordinated muting is tailored to meet URLLC requirements. The performance gains show clear benefits of network coordination with limited complexity and standardization effort. In all cases, we have strived for a generic design that is applicable both in distributed architectures as well as in scenarios with a centralized controller performing network-wise optimizations.

Finally, an overview of the four studied network-based ICIC mechanisms is shown in Table I. As already mentioned, the DL solutions are customized in this article for a given service, as emphasized in the Table, although they are all applicable to eMBB and URLLC. Regarding the standardization effort to have these techniques supported in future 5G specifications, the requirements are categorized into inter-cell coordination through the Xn interface and requirements to the UE in terms of measurements. For the former, such coordination includes the exchange of information related to traffic, load, rank, protected resources, and sequence indices, and can happen on a slower or faster basis. For the UE requirements, we discussed in this article the potential of new UE measurements and reports related to the DI.

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