Cross-Link Interference Suppression By Orthogonal Projector For 5G Dynamic TDD URLLC Systems

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Abstract—Dynamic time division duplexing (TDD) is envisioned as a vital transmission technology of the 5G new radio (NR) due to its reciprocal propagation characteristics. However, the potential cross-link interference (CLI) imposes a fundamental limitation against the feasibility of the ultra-reliable and low latency communications (URLLC) in dynamic-TDD systems. In this work, we propose a near-optimal and complexity-efficient CLI suppression scheme using orthogonal spatial projection, while the signaling overhead is limited to B-bit, over the back-haul links. Compared to the state-of-the-art dynamic-TDD studies, proposed solution offers a significant improvement of the URLLC outage latency, e.g., $\sim -199\%$ reduction, while boosting the achievable capacity per the URLLC packet by $\sim +156\%$.

Index Terms — URLLC; Cross link interference; TDD; 5G.

I. INTRODUCTION

Ultra-reliable and low-latency communication (URLLC) is the major service class of the 5G new radio (NR) [1]. URLLC denotes short and stochastic packet transmissions with extreme reliability and radio latency bounds, i.e., couple of milli-seconds with a success probability of 99.999\% [2]. Furthermore, the global regulatory bodies have envisioned early 5G deployments over the 3.5 GHz spectrum due to its abundant available unpaired bands. Accordingly, dynamic time division duplexing (TDD) has become of a great significance early 5G deployments over the 3.5 GHz spectrum due to its reciprocal propagation characteristics. However, the URLLC reliability and latency targets are further challenging to achieve in dynamic TDD systems [2] due to: (a) the switching time between the downlink (DL) and uplink (UL) sub-frames, and (b) the potential inter-cell cross-link interference (CLI) between neighboring BSs of different directional transmissions [4]. That is, the DL-to-UL CLI (BS-BS) and UL-to-DL CLI (user-equipment to user-equipment (UE-UE)). The former is tackled by the flexible frame design of the 5G-NR, where variable transmission time intervals (TTIs) and a scalable sub-carrier spacing (SCS) are supported [1]. Thus, the DL and UL switching delay can be slot-dependent, i.e., $\ll 1$ ms. Although, the latter issue, especially the BS-BS CLI due to the power imbalance between the DL and UL transmissions, remains a critical issue against practical implementation of the dynamic TDD macro systems.

As part of the long-term evolution, i.e., 4G, standards, advanced linear interference rejection combining (IRC) transceivers [5] are adopted to suppress the inter-cell interference sub-space from that is of the useful signal. Although, within dense macro deployments, there exist multiple dominant and sparse BS-BS CLI interferers, degrading the IRC decoding performance due to the linear interference averaging.

Accordingly, optimal BS-BS CLI cancellation [6] is discussed within 3GPP, where inter-cell full-packet exchange is assumed. Moreover, coordinated dynamic scheduling and beam-forming [7, 8] are proposed to counteract the CLI by globalizing the BS scheduling decisions. Furthermore, joint beam-forming schemes are suggested [9, 10] in order to control the inflicted inter-cell CLI in the spatial domain. On another side, opportunistic CLI pre-avoidance [4, 11, 12] schemes have been introduced based on ordered signal-to-interference-noise-ratio (SINR) lists and a sliding radio frame configuration (RFC) code-book design, respectively.

In this paper, we propose a high-performance and low-complexity BS-BS CLI suppression algorithm (CSA) for 5G-NR dynamic TDD macro systems. The proposed scheme utilizes a linear estimation of an orthonormal sub-space projector to reliably suppress the BS-BS CLI on-the-fly, while it combines a hybrid radio frame design, cyclic-offset based frame code-book, and dual-objective dynamic user scheduling to opportunistically pre-avoid the UE-UE CLI occurrence. Compared to state-of-the-art dynamic-TDD studies, the proposed scheme offers a significant enhancement of the URLLC UL and DL outage latency, while improving the ergodic capacity, approaching the optimal CLI-free case. However, the proposed scheme neither requires periodic user CLI measurements nor significant signaling overhead. Particularly, the contribution aspects of this paper are as follows:

- Unlike the standard linear IRC receiver, we utilize a newly proposed inter-BS exchange of the user DL spatial signatures to manipulate the estimated interference co-variance. Hence, we introduce an enhanced formulation of the standard IRC receiver, where the BS-BS CLI spatial span is regularized on-the-fly, leading the IRC receiver be further directive to the user effective channel.
- The proposed solution requires a modest inter-BS signaling overhead.
- The proposed enhanced IRC receiver provides $\sim 199\%$ gain of the achievable URLLC outage latency, compared to state-of-the-art relevant IRC literature.

Due to the complexity of the addressed problem herein and the 5G-NR system dynamics, the performance of the proposed solution is assessed using a highly-detailed system level simulator, with a high degree of realism. Following the
same simulation methodology in [4], these simulations are based on widely-accepted mathematical models and being validated against the latest 3GPP 5G-NR assumptions. The main functionalities of Layer 1 and 2 of the 5G-NR protocol stack are integrated including the hybrid automatic repeat request (HARQ) re-transmissions, 3D spatial channel modeling, adaptive modulation and coding.

The paper is organized as follows. Section II introduces the system model of this work. Section III presents the proposed solution while Section IV discusses the performance assessment metrics. Conclusions are drawn in Section V.

II. SYSTEM MODEL

We consider a synchronous dynamic-TDD 5G-NR network of a single cluster of $O$ BSs, each equipped with $N$ antennas. There are $K_{dl}$ and $K_{ul}$ uniformly-distributed DL and UL active UEs per BS, respectively, each with $M$ antennas. The URLLC stochastic FTP3 traffic model is assumed, with finite payload sizes of $f_{dl}$ and $f_{ul}$ bits, and Poisson arrival processes $\lambda_{dl}$ and $\lambda_{ul}$, in the DL and UL directions. Hence, the directional offered loads per BS are given by: $\Omega = f_{dl} \times \lambda_{dl}$ and $\Omega = f_{ul} \times \lambda_{ul}$, with $\Omega = \Omega_{dl} + \Omega_{ul}$ as the total load per cell.

We adopt the latest system assumptions of the 3GPP specifications for URLLC [2]. Hence, a 10 ms RFC is composed of 10 sub-frames, each is constructed of a scalable number of slots. Accordingly, we consider the dynamic 3GPP release-15 slot format design [13], with a flexible structure of the DL, UL and special symbols, respectively, as shown in Fig. 1. UEs are dynamically multiplexed by the orthogonal frequency division multiple access (OFDMA), with 30 KHz SCS and a physical resource block (PRB) of 12 consecutive SCs. Furthermore, a short TTI duration of 4-OFDM symbols is adopted.

Consider $\mathcal{B}_{dl}$, $\mathcal{B}_{ul}$, $\mathcal{K}_{dl}$ and $\mathcal{K}_{ul}$ as the sets of BSs and UEs with DL and UL transmissions, respectively. Thus, the DL signal at the $k^{th}$ BS, pre-coding vector of the the $k^{th}$ UE, and the transmitted data symbol of the $k^{th}$ UE, respectively. $G_{k,j} \in \mathbb{C}^{M \times M}$ implies the the cross-link channel between the $k^{th}$ and $j^{th}$ UEs, while $n_{dl,k}$ implies the additive white Gaussian noise. Similarly, the UL signal at the $k^{th}$ cell, $c_k \in \mathcal{B}_{ul}$ from $k \in \mathcal{K}_{ul}$, is expressed by

$$y_{c_k}^{dl} = \frac{H_{k,c_k}^{dl}}{\lambda_{dl}} + \sum_{j \in \mathcal{K}_{dl}} H_{k,j}^{dl} w_j s_j + \sum_{c_{dl} \in \mathcal{B}_{dl}} Q_{c_{dl},c_k} v_i s_i + n_{dl,k},$$

where $Q_{c_{dl},c_k} \in \mathbb{C}^{N \times N}$ is the cross-link BS-BS channel between the serving BSs of the $k^{th}$ and $i^{th}$ UEs, $c_k \in \mathcal{K}_{ul}$ and $i \in \mathcal{K}_{dl}$. Then, the post-receiver signal-to-interference ratio (SIR) in the DL $\gamma_{k}^{dl}$ and UL $\gamma_{k}^{ul}$ directions are given by,

$$\gamma_{k}^{dl} = \frac{\left\| (\mathbf{u}_k^*)^H H_{k,c_k}^{dl} \mathbf{v}_k \right\|^2}{\sum_{i \in \mathcal{K}_{dl}} \left\| (\mathbf{u}_k^*)^H H_{k,i}^{dl} \mathbf{v}_i \right\|^2 + \sum_{j \in \mathcal{K}_{ul}} \left\| (\mathbf{u}_k^*)^H G_{k,j} \mathbf{w}_j \right\|^2},$$

$$\gamma_{k}^{ul} = \frac{\left\| (\mathbf{u}_k^*)^H H_{k,c_k}^{ul} \mathbf{w}_k \right\|^2}{\sum_{j \in \mathcal{K}_{ul}} \left\| (\mathbf{u}_k^*)^H H_{k,j}^{ul} \mathbf{w}_j \right\|^2 + \sum_{i \in \mathcal{K}_{dl}} \left\| (\mathbf{u}_k^*)^H Q_{c_{dl},c_k} v_i \right\|^2},$$

where $\| \cdot \|$ is the second-norm, $\mathbf{u}_k^* \in \mathbb{C}^{N/M \times 1}$, $\mathbf{X}^H$, $\mathbf{X} \in \mathbb{C}^{M \times 1}$ and $s_k$ are the zero-forcing pre-coding vector at the $c_k^{th}$ BS, pre-coding vector of the the $k^{th}$ UE, and the transmitted data symbol of the $k^{th}$ UE, respectively. $G_{k,j} \in \mathbb{C}^{M \times M}$ implies the the cross-link channel between the $k^{th}$ and $j^{th}$ UEs, while $n_{dl,k}$ implies the additive white Gaussian noise. Similarly, the UL signal at the $k^{th}$ cell, $c_k \in \mathcal{B}_{ul}$ from $k \in \mathcal{K}_{ul}$, is expressed by

$$y_{c_k}^{dl} = \frac{H_{k,c_k}^{dl}}{\lambda_{dl}} + \sum_{j \in \mathcal{K}_{dl}} H_{k,j}^{dl} w_j s_j + \sum_{c_{dl} \in \mathcal{B}_{dl}} Q_{c_{dl},c_k} v_i s_i + n_{dl,k},$$

where $Q_{c_{dl},c_k} \in \mathbb{C}^{N \times N}$ is the cross-link BS-BS channel between the serving BSs of the $k^{th}$ and $i^{th}$ UEs, $c_k \in \mathcal{K}_{ul}$ and $i \in \mathcal{K}_{dl}$. Then, the post-receiver signal-to-interference ratio (SIR) in the DL $\gamma_{k}^{dl}$ and UL $\gamma_{k}^{ul}$ directions are given by,
A. Link-direction adaptation

During each RFC update instance, each BS independently selects an RFC from the RFC code-book which best satisfies its individual link-direction selection criterion, with a respective DL-to-UL symbol ratio, i.e., $d_c : u_c$. We adopt the DL and UL buffered traffic size as the main criterion to select an RFC. The buffered traffic ratio $\mu_c(t)$ is defined as

$$\mu_c(t) = \frac{Z_c^d(t)}{Z_c^d(t) + Z_c^s(t)},$$

where $Z_c^d(t)$ and $Z_c^s(t)$ are the total buffered DL and UL traffic of the $c^{th}$ BS at the RFC update time $t$. For example, at the $c^{th}$ BS with $\mu_c(t) = 0.3$, the buffered UL traffic volume is $2.3x$ the buffered DL traffic, thus, BS consequently selects a slot format of DL:UL symbol ratio as $\sim 1:2:3$. The placement of the DL and UL symbols during a slot duration is set evenly to allow for multiple scattered DL and UL transmission opportunities. Accordingly, the achievable capacity $T$ of each cluster is given by

$$T = C \sum_{c=1}^C \min \left( u_c, u_c^{\text{opt}} \right) F^u_c + \min \left( d_c, d_c^{\text{opt}} \right) F^d_c,$$

where $F^u_c$ and $F^d_c$ represent the rate utility functions of the UL and DL directions, respectively. $u_c^{\text{opt}}$ and $d_c^{\text{opt}}$ are the optimal numbers of the UL and DL slots that should be adopted during the current RFC to perfectly match the current traffic variations. Thus, UL $\chi^u$ and DL $\chi^d$ symbol mismatch are inflicted due to the insufficient RFC quantization as

$$\chi^u = \left| u_c - u_c^{\text{opt}} \right|, \quad \chi^d = \left| d_c - d_c^{\text{opt}} \right|.$$  (7, 8)

To maximize capacity $T$, $u_c = u_c^{\text{opt}}$ and $d_c = d_c^{\text{opt}}$ should be always satisfied. Although, $u_c^{\text{opt}}$ and $d_c^{\text{opt}}$ may introduce severe BS-BS CLI which severely degrades the UL capacity.

B. Proposed BS-BS CSA

During the inter-BS CLI slots within an RFC, the DL-aggressor BSs signal adjacent victim UL BSs with a DL precoder map over the Xn-interface. Such on-demand signaling denotes a vector of the DL sub-band pre-coding matrix indices (PMIs), which will be used during the next slot by the scheduled DL users. For instance, with 10 MHz bandwidth, i.e., 50 PRBs, 4 antenna port setup, i.e., 4-bit PMI, 3 BS-BS CLI slots, 8-PRB sub-bands, the size of the DL precoder map $\mathcal{O}$ can be calculated as:

$$\mathcal{O} = 3 \times \left( \frac{50}{8} \times \left( \log_2 \left( \frac{50}{8} \right) + 4 \right) \right) \approx 124 \text{ bits per } 10 \text{ ms.}$$

Accordingly, the victim UL BSs seek to identify the strongest $N - 1$ sub-band BS-BS interferers as

$$A_{b_d,b_d}^l = \left\| Q_{b_d,b_d}^l v_{b_d}^l \right\|^2, \quad b_d \in \mathcal{B}_d, \quad b_d \in \mathcal{B}_d, l \in L.$$  (10)

where $Q_{b_d,b_d}^l$ is the BS-BS channel between the $b_d^l$th and $b_d^l$th BSs over the $l^{th}$ sub-band, with $L$ as the number of DL aggressor sub-bands. $v_{b_d}^l$ implies the DL precoder of the scheduled user over the $b_d^l$th sub-band at time $t$. Finally, for each UL transmission during the current BS-BS CLI slot, UL BSs calculate the average UL interference covariance matrix $\mathcal{A} \in \mathbb{C}^{N \times N}$.

$$\mathcal{A} = \left[ \begin{array}{cccc} \beta_{1,1} & \cdots & \beta_{1,N} \\ \vdots & \ddots & \vdots \\ \beta_{N,1} & \cdots & \beta_{N,N} \end{array} \right].$$

The UL BSs accordingly estimate an orthonormal projector subspace $\mathcal{A}^\perp \in \mathbb{C}^{N \times N}$ by the orthogonal projection, as

$$\mathcal{A}^\perp = \mathcal{A} \left( \mathcal{A}^T \mathcal{A} \right)^{-1} \mathcal{A}^T,$$

where $(\cdot)^{-1}$ and $(\cdot)^T$ are the inverse and transpose operations. Finally, for each UL transmission during the current BS-BS CLI slot, UL BSs calculate the average UL interference covariance matrix $\mathcal{R}_k^\perp \in \mathbb{C}^{N \times N}$, in order to construct the LMMSE-IRC receiver matrix for decoding, expressed as

$$\mathcal{R}_k^\perp = \mathcal{A}_k^\perp \times \left( \mathcal{E}_k^\perp \right)^H.$$  (17)

Such interference estimate is highly sparse in the spatial domain due to the BS-BS CLI summation, leading to a degraded linear-IRC decoding performance. Thus, prior to decoding, the UL BSs spatially project the interference column vectors of $\mathcal{R}_k^\perp$, onto the projector sub-space basis as

$$r_{i,\rho}^\perp = \text{proj}_{\mathcal{A}^\perp} \left( r_{i,\rho}^\perp \right) = \frac{1}{\left\| a_{\rho} \right\|} \times a_{\rho}, \quad \forall \rho = 1, 2, \ldots, N.$$  (18)
Table I

| Parameter                      | Value                                      |
|--------------------------------|--------------------------------------------|
| Environment                   | 3GPP-UMA, one cluster, 21 cells            |
| UL/DL channel bandwidth       | 10 MHz, SCS = 30 KHz, TDD                  |
| TDD mode                      | Synchronized                               |
| Antenna setup                 | N = 4, M = 4                               |
| UL power control              | α = 1, P0 = −103 dBm                      |
| Link adaptation               | Adaptive modulation and coding             |
| HARQ configuration            | Asynchronous, Chase Combining             |
| Processing times              | PDSCH : 4.5-OFDM symbols, PUSCH : 5.5-OFDM symbols |
| TTI configuration             | 4-OFDM symbols                             |
| Traffic model                 | FTP3                                        |
| DL/UL scheduling              | Proportional fair                          |
| DL/UL receiver                | LMMSE-IRC                                  |
| Pattern update periodicity    | Slot duration                              |
| Transport layer setup         | UDP, MTU = 1500 Bytes                     |
| User scheduler                | Proportional fair                          |

with $a_1$ and $\tilde{r}_k^{ul}$ are the column vectors of the projector subspace $A^{1}_k$ and the updated interference covariance matrix $\tilde{R}^{ul}_k$. Hence, the spatial span of $R^{ul}_k$ is regularized by suppressing the sparse $N − 1$ BS-BS CLI strongest aggressors, i.e., removing the second summation of eq. (16). Finally, the UL LMMSE-IRC receiver matrix is then designed as

$$u_k^{ul} = \left( H_{c_k,k}^H w_k \left( H_{c_k,k}^H w_k^H + \tilde{R}^{ul}_k \right)^{-1} H_{c_k,k}^H w_k \right) H^{ul}_{c_k,k} w_k$$ (19)

Therefore, the UL decoder becomes highly directive towards the span of the direct effective channel, and outside the subspace spanned by the principal BS-BS CLI basis, leading to a significant improvement of the URLLC UL performance.

IV. SIMULATION RESULTS

We adopt extensive system-level simulations to evaluate the performance of the proposed BS-BS CSA, where the major 3GPP 5G-NR assumptions for URLLC [4] are followed, and as listed in Table I. A $8 \times 2$ antenna setup along with 10 MHz bandwidth of 30 KHz SCS are configured, while the DL transmission power is set to 40 dBm. The offered DL traffic is set to 2x times the UL traffic. During each TTI, BSs dynamically schedule active UEs using the proportional fair (PF) criterion. The achievable SC SINRs are combined using the exponential SNR mapping [15] in order to estimate an effective SINR level. Accordingly, fully dynamic modulation and coding selection (MCS) and Chase combining HARQ re-transmissions are utilized. Pending HARQ re-transmissions are always prioritized over new transmissions during the first available DL/UL slot transmission opportunity. We assess the performance of the proposed solution against the state-of-the-art dynamic-TDD studies as follows:

CLI-free TDD (CF-TDD) [6]: a fully dynamic TDD setup, where BSs independently select the RFCs that best meet their individual traffic demands; however, with the assumption of a perfect UE-UE and BS-BS CLI cancellation. We consider

such optimal; although, theoretical baseline, as the reference case.

Non-coordinated TDD (NC-TDD): a fully dynamic TDD is assumed; however, neither inter-BS coordination nor UE-UE and BS-BS CLI cancellation are supported. Herein, BSs achieve the maximum dynamic-TDD adaptation; though, with potentially severe BS-BS and UE-UE CLI, respectively.

Coordinated-RFC TDD (CRFC-TDD) [4]: a hybrid frame design along with a cyclic-offset-based RFC code-book are constructed to reliably pre-avoid the UE-UE CLI. That is, UEs with the worst radio conditions, are preemptively scheduled during certain CLI-free slots, i.e., static slots within all RFCs. Hence, CRFC-TDD boosts the cell-edge capacity; though, performance is highly limited by the more critical BS-BS CLI.

We first evaluate the performance of the proposed scheme in terms of the URLLC outage latency. That is, the achievable

 Fig. 3. BS-BS CSA: UL latency performance.

 Fig. 4. BS-BS CSA: DL latency performance.
URLLC radio latency at $10^{-5}$ outage probability. It implies the one-way radio latency from the moment a packet arrives at transmitter until it has been successfully decoded at the receiver end, including the standard BS and UE processing delays, dynamic user scheduling delay, and the HARQ retransmission buffering delay, respectively. Thus, Fig. 3 and 4 depict the complementary cumulative distribution function (CCDF) of the UL and DL URLLC latency, respectively, under various offered load levels for the proposed CSA, NC-TDD, and the hypothetical; though, optimal, interference-free (I-free) case, where we assume a perfect inter-cell interference cancellation, including the same-link and cross-link interference. As clearly shown, the proposed CSA scheme offers a decent URLLC outage latency due to the enhanced suppression of the principal BS-BS CLI interferers. The degraded outage latency under the high offered load region is attributed to the inflicted queuing delay due to the dynamic user scheduling, and the increasing same-link inter-cell interference. The NC-TDD with the standard IRC receiver design clearly inflicts a significant degradation of the achievable URLLC latency due to the severe BS-BS CLI.

Table II holds a comparison of the URLLC radio latency in ms, for all schemes under evaluation at different offered traffic loads per BS. To reflect the URLLC reliability targets, the URLLC outage latency at the $10^{-5}$ outage probability level is evaluated. The CF-TDD clearly provides the best URLLC outage latency performance due to the absolute absence of the UE-UE and BS-BS CLI. The NC-TDD and CRFC-TDD schemes fail to offer a decent URLLC DL and UL outage latency, mainly due to the severe and unhandled BS-BS CLI. Under high offered loads, their respective outage latency increases dramatically due to the inflicted UL re-transmissions.

The proposed BS-BS CSA offers a significant improvement of the URLLC DL and UL outage latency, clearly approaching the optimal CF-TDD under all offered loads; however, with a significantly reduced control overhead size. Due to the sufficient BS-BS CLI suppression, the proposed solution guarantees faster UL transmissions without several HARQ retransmissions, leaving more time and resources for DL traffic.

These conclusions are confirmed by examining the empirical CDF (ECDF) of the buffered traffic ratio $\mu$ as in eq. (5), and shown by Fig. 5. The lower $\mu$, the higher the buffered UL traffic in the scheduling queues. Herein, we introduce a hypothetical case, where the system is only noise-limited, i.e., inter-cell same-link and cross-link interference is assumed to be perfectly suppressed (I-free case as depicted by Fig. 3 and 4). This case provides a fairer buffer ratio, i.e., $\mu = 0.5$ at the 50 percentile since all DL and UL payloads get successfully decoded from the first time. The NC-TDD and CRFC-TDD offer an extremely low $\mu$, i.e., $\mu = 0.15$ and 0.2 at the 50 percentile. That is, the buffered UL traffic is 5.6x and 4x times the buffered DL traffic, respectively.

### Table II

| Offered load | CF-TDD | NC-TDD | CRFC-TDD | Proposed BS-BS CSA |
|--------------|--------|--------|----------|--------------------|
|              | DL     | UL     | DL       | UL                |
| 4 Mbps       | 7.15   | 14.16  | 8.47     | 105.34            |
|              | 0.0%   | 0.0%   | +16.9%   | +150.8%           |
|              | 4.01   | 15.17  | 106.3    | 606.3             |
|              | 0.0%   | 0.0%   | +198%    | +199%             |
|              | 11.01  | 16.29  | 183.90   | 125.40            |
|              | 0.0%   | 0.0%   | +199.4%  | +199.6%           |
|              | 17.28  | 18.23  | 12490    | 25610             |
|              | 0.0%   | 0.0%   | +199.4%  | +199.7%           |
| 5 Mbps       | 8.14   | 15.17  | 106.3    | 606.3             |
|              | 0.0%   | 0.0%   | +198%    | +199%             |
|              | 11.01  | 16.29  | 183.90   | 125.40            |
|              | 0.0%   | 0.0%   | +199.4%  | +199.6%           |
|              | 17.28  | 18.23  | 12490    | 25610             |
| 6 Mbps       | 7.15   | 14.16  | 8.47     | 105.34            |
|              | 0.0%   | 0.0%   | +16.9%   | +150.8%           |
|              | 4.01   | 15.17  | 106.3    | 606.3             |
|              | 0.0%   | 0.0%   | +198%    | +199%             |
|              | 11.01  | 16.29  | 183.90   | 125.40            |
|              | 0.0%   | 0.0%   | +199.4%  | +199.6%           |
| 7 Mbps       | 17.28  | 18.23  | 12490    | 25610             |
|              | 0.0%   | 0.0%   | +199.4%  | +199.7%           |

Fig. 5. BS-BS CSA: traffic buffering performance.

Fig. 6. BS-BS CSA: UL interference performance.
industry and academia, the proposed algorithm offers a significant improvement of the URLLC outage latency performance and the ergodic capacity accordingly, while greatly minimizing the control signaling overhead space to B-bit.

The main insights brought by this paper are as follows: (a) achieving the URLLC outage targets in dynamic TDD systems are highly challenged because of the switching delay among the DL and UL transmission opportunities, and the resultant CLI. (b) the 5G new radio introduces a flexible slot format design, which in turn minimizes the DL/UL switching delay to less than a single millisecond. (c) however, within macro deployments, the BS-BS CLI dominates the URLLC outage performance due to the higher power DL interfering transmissions, (d) thus, inter-cell CLI coordination techniques become vital in order to reap the benefits the flexible TDD systems, and (e) proposed solution demonstrates a near-optimal BS-BS CLI suppression capability while preserving the transmission flexibility of the dynamic TDD technology, and with a limited signaling overhead size.

VI. ACKNOWLEDGMENTS

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