Dual Adaptive Modulation and Coding for Mitigating UE-UE Interference in Heterogeneous TDD Slot Configurations

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***Abstract*— The mobile communication system changes decade after decade. The next generation of mobile communication aims to provide users with better service experience and can be applied in various scenarios. When adjacent Transmission Reception Points (TRP) operate in different transmission directions in heterogeneous time-division duplexing (TDD) slot configurations for accommodating their diverse traffic load, additional Cross-Link Interference (CLI) happens. This will seriously degrade the transmission quality for nearby base stations or user equipments (UE). This paper proposed an approach on link adaptation to mitigate CLI. The mechanism proposed in this study will establish a Victim UE-Aggressor UE pair list through some UE-UE measurements. While transmission proceeds, the victim UE will feedback two channel quality indicators in two cases of sub-frames. One is without aggressor UE interference, and the other is with aggressor UE interference. Therefore, two modulations and coding selections (MCS) can be obtained through these two types of feedback. The proposed MCS adaptation method can possibly mitigate impact of CLI from aggressor UEs, reduce error rate, average packet delay and retransmission times, and improve system performance, such as downlink cell spectral efficiency as well as cell edge spectral efficiency.**

Keywords—Heterogeneous time slot configurations, UE-UE interference, adaptive MCS selection, victim-aggressor pairs, cell edge spectral efficiency.

I. Introduction

Radio spectrum is a very scarce and expensive resource. Especially time-division duplexing (TDD) is more flexible than frequency-division duplexing (FDD) in the current communication systems such as 3GPP Long Term Evolution (LTE) and 5G New Radio (NR). Where resource allocation of uplink (UL) and downlink (DL) can be varied in granularity of time slots in the same frequency band, and hence allows asymmetric traffic flows for uplink and downlink data transmission, easily fitting to use pattern at present. In the Time Division Long Term Evolution (TD-LTE) system, seven frame structures with different rates of DL/UL sub frames are defined according to unequal local traffic load of DL/UL.

The base station (BS) will choose one of the different TDD configurations based on its DL/UL traffic, probably resulting in the phenomenon of heterogeneous TDD slot configurations in nearby cells. Heterogeneous TDD slot configuration here means that there are at least two different TDD configurations for adjacent base stations in the system. In addition, when the UL and DL directions between adjacent base stations or UEs are different in the same time slot, serious Cross-Link Interference (CLI), i.e., BS-BS interference and UE-UE interference, will happen and deteriorate the transmission quality. BS-BS interference mainly affects the signal-to-interference-plus-noise ratio (SINR) of UL, especially for the case that the transmitting power of BS is large and even reaching nearby base stations. Reference [1] mentioned that there are several methods to mitigate CLI, for example, power control, scheduling coordination, and hybrid dynamic/static UL/DL resource assignment (hybrid TDD). Power control mainly decreases BS transmission power to mitigate BS-to-BS interference. Scheduling coordination uses scheduling scheme to avoid serious CLI. Hybrid TDD mainly focuses on changing frame format to mitigate CLI. Reference [2] restricts the transmit power of aggressor BSs to mitigate the BS-to-BS interference according to the UL SINR metric in victim BSs.

Meanwhile, UE-UE interference is particularly likely to occur at the cell edge, and UL transmission of UEs may seriously affect DL reception of nearby UEs. Identifying the interference sources and measuring how they affect is the first step to mitigate the problem. Reference [3] mentions that design principles of a simple probing signal and propose a practical and reliable solution for UE-to-UE interference measurement in a full duplex network. In [4], for the method of UE-UE interference measurement, Sounding Reference Signal-Reference Symbol Received Power (SRS-RSRP) or Received Signal Strength Indicator (RSSI) method is used for measurement. However, to our best knowledge, there are very few studies focusing on how to solve UE-UE interference. In order to mitigate the impact of CLI and use resources flexibly, we propose a method to mitigate CLI.

This paper mainly focuses on the mechanism of adaptive modulation and coding scheme selection to reduce the impact of CLI caused by UE-UE interference on overall system performance. We have observed the UE-UE interference in the NR/LTE system, and found that in most cases, the UL UE does not interfere too much with DL UE, but a small number of DL UEs do suffer from severe interference, which may cause degradation of communication quality. The reason is that UE-UE interference doesn't keep stable. Sometimes, the DL UE does not suffer from UE-UE interference and reports a good value of channel quality indicator (CQI). Later, the base station determines a proper modulation and coding schemes for the DL UE to use based on the reported good CQI value, but unfortunately UE-UE interference might occur this time, resulting in overestimation of modulation and coding scheme and increase of the block error rate and retransmissions.

The rest of this paper is organized as follows. In Section II, we present the system model and problem formulation, which explain the details of Heterogeneous TDD slot configurations. Section III describes Adaptive modulation and coding scheme (MCS) Selection for UE-UE Interference Mitigation and implementation. Section IV discusses Simulation Results and Discussion and Conclusions will be given in Section V.

II. System Model And Problem Formulation

This section describes the system model, formulates the transmission quality under cross link interference in terms of signal-to-interference-plus-noise ratio, explains uplink power control strategy, and defines performance metrics used in this study.

A. CLI Scenario and Channel Model

Without loss of generality, we assume the geographic environment of Rural-eMBB which is defined in ITU-R M.2412 [5]. Our simulation is in a wrapped-around configuration of 19 sites, each of 3 BSs. The boresights of the Transmission Reception Points (TRP) antenna in each site are directed towards to 60, 180, and 300 degrees as shown in Fig. 1. Ten users in average per TRP are randomly and uniformly dropped throughout the geographical area, and hence there are a total of 570 UEs in this environment. More detailed environment assumption can be found in [5] [Table A.2.1-1].

We investigate the TDD based multi-input multi-output system (MIMO) and assume that three TRPs in the same site are with the same TDD slot configuration; i.e., the three TRPs of one site works in the same uplink/downlink direction in a sub-frame, which prevents back-to-back interference in the same site. However, when nearby sites are set with different TDD slot configurations, TRPs and their serving UE in these sites might suffer CLI. CLI is caused by simultaneous transmissions of downlink and uplink in the neighborhood. There are two kinds of CLI: BS-to-BS interference and UE-to-UE interference.

The channel model in our simulation and WiSE platform [6] follows the specification of the channel model in 3GPP TR38.901 [7], which specifies scenarios, antenna modeling, pathloss, light of sight probability, fast fading model, and finally channel coefficient generation for frequency from 0.5 to 100GHz.

B. Sites with Heterogeneous TDD Slot Configurations

Operator estimates the ratio of upcoming downlink/uplink traffic for each part of its service area and determines appropriate slot configurations for each site to satisfy its customers' need. Therefore, each site might be set to different TDD slot configurations because the traffic ratios in each part are not the same. Meanwhile, CLI may occur among certain slots under different configurations of nearby TRPs or cells.

We assume that 27 of the 57 cells use TDD configuration 0 based on traffic load, while the remaining 30 cells use TDD configuration 2, each with different colors as shown in Fig. 1. In this scenario, these two groups have different transmission directions in the certain sub-frames 3, 4, 8, and 9, and CLI hence happens. These sub-frames, which we named the CLI region, have cross link interference phenomenon and this interference occurs again and again for each configuration period, 10 slots here. Our study aims at mitigating influence of uplink UEs' transmission interfering nearby downlink UEs' reception at the same sub-frame, i.e., UE-UE CLI. BS-BS CLI is well studied and beyond our study [2].

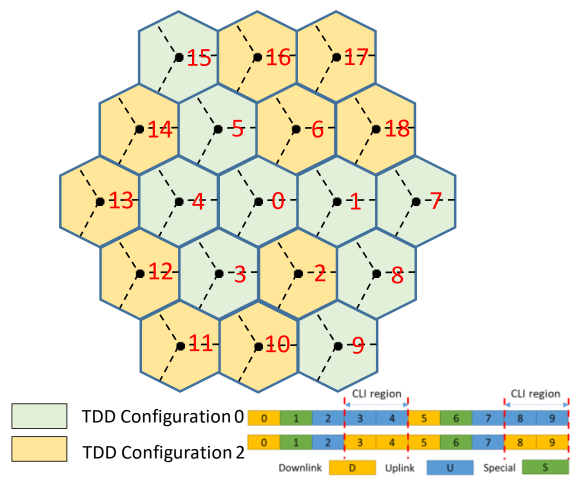

Fig. 1 Heterogeneous TDD slot configurations system.

C. Downlink SINR Formulation with/without CLI and Uplink Power Control

Before our discussion on downlink reception and UE-UE CLI influence, we first define several notations in Table I and formulate the ratio of SINR as follows. $\gamma_{i_n}^{DL}$ is the SINR of the i-th UE camping in the n-th DL cell without CLI interference (in non-CLI regions), which is expressed by

$$\gamma_{i_n}^{DL} = \frac{P_{i_n}^{DL}}{\sum_{k \in N, k \neq n} P_{i_n,k} + N_0} \quad (1)$$

where $P_{i_n}^{DL}$ is the received signal power at the i-th UE in the n-th cell, $P_{i_n,k}$ is the received interference power from the DL cell k, N_0 is white noise.

While taking CLI into consideration, the terms of UE interference power under all UL cells in CLI regions need to be added to (1), and $\gamma_{i_n}^{DLwithCLI}$ for CLI regions is obtained as follows

$$\gamma_{i_n}^{DLwithCLI} = \frac{P_{i_n}^{DL}}{(\sum_{m\in M}\sum_{j_m\in U_m} P_{i_n,j_m} + \sum_{\substack{k\in N-M\\ k\neq n}} P_{i_n,k}) + N_0} \quad (2)$$

where P_{i_n,j_m} is the received interference power from the j-th UE under the UL cell m.

Uplink transmission power of each UE is adjusted by an open-loop UL power control algorithm, which follows the specification [8] [9] to ensure that the power is received at the TRP with an appropriate level. The power control parameters used in our experiment, such as P_0 and α, are listed in the section of simulation results. Although the uplink power on UE is set by a deterministic formula, the UE-UE interference varies due to fast fading effect, diverse offered traffic, and dynamic scheduling. Uplink UEs at edge in CLI regions likely cause large interference to nearby downlink UEs due to this power control setting. Adaptive modulation and coding selection with CQI feedback originally performs well in case of no CLI situation. Without awareness of CLI regions, CQI feedback may misguide selection of modulation and coding due to alternation of CLI and normal regions.

TABLE I
NOTATIONS USED IN THIS STUDY

N	Set of cells
M	Set of UL cells in CLI region
i_n	The UE i in cell n
j_m	The UE j in UL cell m in CLI region
U_m	Set of UE in cell m
W	Bandwidth
P_{i_n,j_m}	Received interference power at i-th UE of cell n, come from j-th UE in UL cell m
$P_{i_n}^{DL}$	Received signal power of i-th UE in DL cell n
$P_{i_n,k}$	Received interference power at i-th UE of cell n, come from DL cell k
N_0	White noise
$\gamma_{i_n}^{DL}$	Signal to interference plus noise ratio (SINR) of DL UE i in cell n
$\gamma_{i_n}^{DLwithCLI}$	Signal to interference plus noise ratio (SINR) of DL UE i in cell n with CLI
$R_{i_n}^{DL}$	total received bits by DL UE i in cell n
$T_{i_n}^{DL}$	total time of UE i_n spends for DL transmission
$SE_{i_n}^{DL}$	DL user i_n spectral efficiency

D. Spectral Efficiency

Spectral efficiency, one of the important indicators of simulation results, is usually used to evaluate the system performance, and well defined in [5]. In addition, the cell edge UE spectral efficiency is defined as the 5-th percentile of the cumulative distribution function (CDF) of the user spectral efficiency. The DL user spectral efficiency $SE_{i_n}^{DL}$ is defined as

$$SE_{i_n}^{DL} = \frac{R_{i_n}^{DL}}{T_{i_n}^{DL} \times W} \quad (3)$$

where R_i^{DL} is the total received DL bits by UE i_n in cell n, W is bandwidth, $T_{i_n}^{DL}$ is the total time that UE i_n spends for DL transmission.

III. PROPOSED SCHEMES

By observing the distribution of UEs and their interaction of interference, we identify the subject and give the definition of the victim UEs and aggressor UEs in the first subsection. After that, we categorize four types of victim/aggressor UE pairs, and propose practical procedures to associate possible victim/aggressor UE pairs in the second and third subsections respectively, followed by a description of rough cost estimation in the fourth subsection. Finally, the MCS adaptation is explained in the final subsection, which we named dual track MCS adaptation.

A. Observation and definition

Without loss of generality, we assume a wrapped-around deployment of 19 sites, each with three sectors with heterogeneous time slot configurations to observe DL SINR distribution and phenomenon of CLI. We assume that 9 sites (27 cells) use TDD Configuration 0 and 10 sites (30 cells) use TDD Configuration 2 as shown in Fig. 1.

We will build our discussion of design principles and analysis based on the ratio of received signal power of the DL UE i_n to received interference power from its strongest interferer in CLI regions, which is called $SI_{UE2UE}R$.

$$SI_{UE2UE}R_{i_n} = \frac{P_{i_n}^{DL}}{\max_{m\in M, j_m\in U_m} P_{i_n,j_m}} \quad (4)$$

If $SI_{UE2UE}R$ is less than 1, i.e. 0 dB, we denote the DL UE as a victim UE. Then we define the victim UE set under the cell n as

$$\text{Victim}_n = \left\{ i_n \middle| \begin{array}{l} i_n \in U_n, \\ \text{SI}_{\text{UE2UE}}\text{R}_{i_n} < 1\,(0\,\text{dB}) \end{array} \right\} \quad (5)$$

and we denote the UL UE that causes the strongest interference to the DL UE i_n as its aggressor UE. Then we denote the aggressor UE as

$$\text{Aggressor}(i_n) = \underset{\substack{j_m \\ m \in M,\, j_m \in U_m}}{\text{argmax}}\ \text{P}_{i_n, j_m} \quad (6)$$

by our observation, the largest part of the interference power of the Victim UEs always comes from their corresponding UL UE with the strongest interference. Hence the victim and its strongest aggressor are our research subjects with neglecting other minor interferers. We can call the victim UE and its corresponding aggressor UE as a victim-aggressor pair, and denote all the Victim-Aggressor pairs in cell n as the set Victim-Aggressor pair list

$$\text{Victim-Aggressor Pair list} = \left\{ \langle i_n, \text{Aggressor}(i_n) \rangle \middle| \begin{array}{l} n \in N - M, \\ i_n \in \text{Victim}_n \end{array} \right\} \quad (7)$$

The SINR curve of DL UEs in the CLI region is shown in Fig. 2. By coloring those victim UE set in each cells as orange plots, the victims are shown to be heavily degraded due to its aggressor interfering and their plots fall on the long tail in the left part. Comparing to the case without CLI, these victim UEs' transmission quality can be greatly improved if we take some proper actions on them to reduce UE-UE interference.

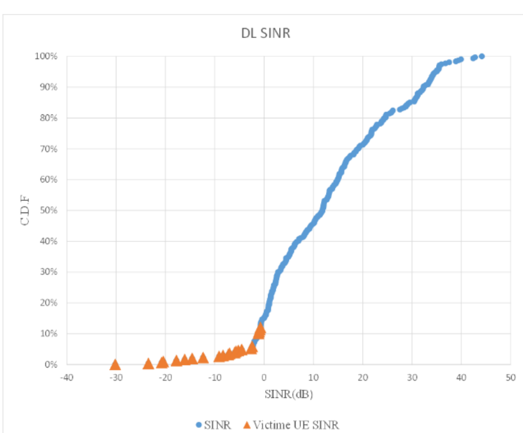

Fig. 2 DL SINR CDF with colored points of victim UEs.

B. Victim/Aggressor categorization

This study divides UE-UE interference into four types based on the distance range to their serving cells because we need to restrict the search range and sounding cost in the victim-aggressor pair identification process. These four types are shown in Fig. 3 and listed as follows.

(a) Both the victim UE and the aggressor UE are within a limited range (which we set to Inter-Site Distances (ISD) in this study) of their serving BS.

(b) The victim UE is within the limited range of its serving BS, but the aggressor UE is not.

(c) The aggressor UE is within the limited range of its serving BS, but the victim UE is not.

(d) Neither the victim UE nor the aggressor UE is within the limited range of their serving BS, which is a very rare case.

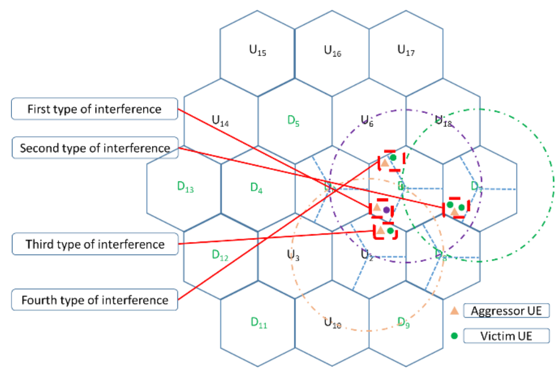

Fig. 3 Four types of UE-UE interference.

C. Victim/Aggressor identification

Initially the victim UE and aggressor UE are unknown in a real system except doing an exhaustive SRS-RSRP measurement [4] for each possible pairs, which costs hugely and takes a lot of time. We propose three methods to recognize victim-aggressor sets of the first three types of UE-UE interference cases respectively, and hence establish the Victim-Aggressor pair list for the whole system. The fourth type of UE-UE interference case is rare, and not easy to be identified by measurement, which is beyond our study. The three methods corresponding to the types of interference (a), (b), and (c) are described as follows.

1. Method One (for victims and aggressors both in range)

For the aforementioned UE-UE interference type (a), in which case the distance between the victim UE and its serving BS and, the distance between the aggressor UE and its serving BS are both within the limited range (assuming to be ISD in this study). It should be noted that the limited range is not required to be accurate and can be estimated by existing information such as the value of time advance or power level of each UE in uplink transmission. In this case, the serving cell of the aggressor UE is usually adjacent to the serving cell of the victim DL UE, which is illustrated as the four possible cells back-slash filled in Fig. 4, spanning the antenna transmission direction of the serving cell of the victim UE.

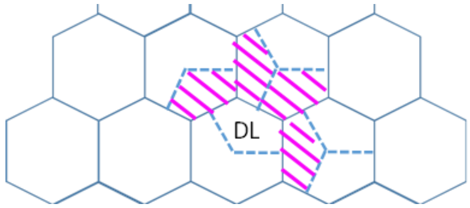

Fig. 4 The range of UL UEs which possibly affect those UEs in "DL" cell.

Before the actual SRS-RSRP measurement [4] to identify the possible victim-aggressor pairs, we can limit the number of UL UEs that need to send sounding reference signal (SRS) and the number of DL UEs that measure SRS because of above mentioned screening of ISD range and antenna-directional adjacency. Furthermore, only those UL UEs whose transmit power, in the four adjacent cells, are greater than the value (MaxUETxPower – AggressorThreshold) need to send SRS, and we denote these UL UEs in CLI regions as the sounding UE set for each DL cell d called P_d,

$$P_d = \left\{ j_m \middle| \begin{array}{l} m \in M, m \in \text{adjacent(d)}, j_m \in U_m, \\ \text{TxPower}_{j_m} > (\text{MaxUEPower(in dBm)} - 3\text{dB}), \\ \text{distance}(j_m, \text{BS}_{j_m}) < \text{ISD} \end{array} \right\} \quad (8)$$

where we empirically set the AggressorThreshold to 3 dB, adjacent(d) is the UL cells adjacent to the DL Cell d, BS_{j_m} is the serving BS of UE j_m, and distance(j_m, BS_{j_m}) is the distance between UE j_m and its serving BS_{j_m}. On the other hand, those UEs with the received power value less than the median of all DL UE received power values (about -57dBm in our experimental environment) need to measure SRS-RSRP, and we denote these DL UEs in cell d as the measuring UE set Q_d

$$Q_d = \left\{ i_d \middle| \begin{array}{l} i_d \in U_d, \text{distance}(i_d, \text{BS}_{i_d}) < \text{ISD} \\ P_{i_d}^{DL} < \text{median}(\{P_{i_n}^{DL} \mid n \in N, i_n \in U_n\}), \end{array} \right\} \quad (9)$$

For each DL cell d in CLI regions, the UEs in Q_d measure all the value of SRS-RSRP of UEs in P_d, derived from UE-specific SRS sounding and hence Victim-Aggressor pairs can be identified for each possible combinations among Q_d and P_d. Each UEs in Q_d reports the identity of its aggressor, who is the strongest interferer and the corresponding $SI_{UE2UE}R$ value is smaller than 1 (0 dB), to its serving cell d, and then the cell d forms the victim-aggressor pair list for our MCS adaptation scheme. To reduce measurement complexity, we select only those sounding and measuring UEs who satisfy the constraint of transmission and received power, and thus dominant pairs can be discovered. This is a tradeoff between measurement complexity and completeness of the pair list.

2. Method Two (victims in range but aggressors not)

The aforementioned UE-UE interference type (b) is the case when the distance between the victim UE and its serving BS is within the limited range (we set to ISD in this study), but the aggressor UE's is not. For this type of UE-UE interference, impact from the aggressor UE is not necessarily limited to the DL cells around the aggressor serving cell because the aggressor UE is not within the limit range. However, we conjecture that those UEs in the DL cell closest to the aggressor UE are the most likely to be affected. Those UEs served by the closest DL cell with the strongest signal strength and within the corresponding limited range are required to measure SRS from the aggressor UE to check whether they are victim UEs.

The UL UEs in the CLI region that needs to send SRS are those whose transmit power is greater than (Max Tx Power – AggressorThreshold) dBm (where we empirically set the AggressorThreshold equal to 1 dB here) and whose distance from their serving BS exceeds the limit range, and we denote these UL UEs as the sounding UE set called $P_{OutOfRange}$ in the system.

$$P_{OutOfRange} = \left\{ j_m \middle| \begin{array}{l} m \in M, j_m \in U_m, \\ \text{TxPower}_{j_m} > (\text{MaxUEPower(in dBm)} - 1\text{dB}), \\ \text{distance}(j_m, \text{BS}_{j_m}) > \text{ISD} \end{array} \right\} \quad (10)$$

For each UE j_m in $P_{OutOfRange}$, we assume the cell d is the nearest cell to it (in practice which can be found by comparing timing and strength of synchronization signals), and then the DL UEs belonging to Q_d need to measure SRS-RSRP from j_m.

Hence Victim-Aggressor pairs of type (b) can be identified for all possible combinations among Q_d and $P_{OutOfRange}$. Each UEs in Q_d reports the identity of its aggressor, who is the strongest interferer and the corresponding $SI_{UE2UE}R$ value is lower than 1 (0 dB), to its serving cell d, and then the cell d forms the victim-aggressor pair list for our MCS adaptation scheme.

3. Method Three (for aggressors in range but victims not)

For the aforementioned UE-UE interference type (c), that is, the distance between the aggressor UE and its serving cell BS is within the limited range (we set to ISD in this study), but the victim UE is not. Aggressors are not necessarily limited to the UL cell around the victim serving cell because the victim UE is not within the limited range of its serving cell. However, we conjecture that those UEs in the UL cell closest to the victim UE are suspect corresponding aggressors. Those UEs served by the closest UL cell and within the limited range are required to send SRS for checking whether they are aggressor UEs.

The DL UEs in the CLI region that needs to measure SRS are those whose received signal power is less than the median of all DL UE received signal power and whose distance from their serving BS exceeds the limit range, and we denote these DL UEs as the measuring UE set called $Q_{\text{OutOfRange}}$ in the system.

$$Q_{\text{OutOfRange}} = \left\{ i_{\text{d}} \left| \begin{array}{l} \text{d} \in N - M, i_{\text{d}} \in U_{\text{d}}, \\ P_{i_{\text{d}}}^{DL} < \text{median}(\{P_{i_n}^{DL} \mid n \in N, i_n \in U_n\}), \\ \text{distance}(i_{\text{d}}, \text{BS}_{i_{\text{d}}}) > \text{ISD} \end{array} \right. \right\} \quad (11)$$

For each UE i_{d} in $Q_{\text{OutOfRange}}$, we assume the cell m is the nearest UL cell with the strongest signal strength to it, and then the UL UEs belonging to P_m need to send SRS-RSRP to i_{d}.

Hence Victim-Aggressor pairs of this type can be identified for all possible combinations among $Q_{\text{OutOfRange}}$ and P_m. Each UEs in $Q_{\text{OutOfRange}}$ reports the identity of its aggressor, who is the strongest interferer and the corresponding $\text{SI}_{\text{UE2UE}}\text{R}$ value is less than 1 (0 dB), to its serving cell, and then the cell forms the victim-aggressor pair list for our MCS adaptation scheme.

Major part of the victim UEs (about 50% under the constraints we set) can be recognized by these methods and recorded into the list of Victim-Aggressor pairs.

D. Measurement Cost estimation

In Table II we roughly estimate measurement cost. It includes the total number of UEs transmitting SRS, the total number of UEs to measure SRS, and the actual number of recognized Aggressor UEs and Victim UE in measurement, which are observed in one of our simulations.

The number of UL UE signals to be measured by one DL UEs is roughly 4 to 16 for the method one because the DL UEs need to measure SRS from UL UEs of one to four UL cells in the vicinity. Meanwhile, by our observation in one of simulations, the 10 UL UEs selected in the method two are distributed in six cells, and the 11 DL UEs selected in the method three are distributed in seven cells. After taking the average number of UEs measuring SRS per DL cell and transmitting SRS per UL cell into consideration respectively, the number of UEs measuring SRS in the method two and the number of UL UEs transmitting SRS in the method three hence can be estimated, and the total measurement cost of three methods can be derived as in Table II.

TABLE II
MEASUREMENT COST ESTIMATION

	UL	DL
Number of UEs in CLI regions	262	307
Number of cells in CLI regions	27	30
Method One		
Number of UEs transmitting SRS with defined constraints	106	
Average number of UEs transmitting SRS per UL Cell	3.925926	
Number of UEs who measure SRS with defined constraints		143
Average number of UEs who measure per DL Cell		4.766667
Number of UL UEs measured by each DL UEs		4 to 16 UEs
Method Two		
Number of UEs whose distance to serving cell over 500 meters and whose TxPower over 22 dBm	10	
Number of cells whose UEs need to measure SRS		6
Number of UEs who need to measure SRS with defined constraints		6*5=30
The actual number of Aggressor UEs after measurement	5	
Method Three		
Number of UEs whose distance to serving cell over 500 meters and whose RxPower less than median		11
Number of cells whose UEs need to transmit SRS	7	
Number of UL UEs transmitting SRS with defined constraints	7*4=28	
The actual number of Victim UEs after measurement and $\text{SI}_{\text{UE2UE}}\text{R} < 0$		2
Total		
Number of UEs transmitting SRS/Number of UEs who measure SRS	106+10+28 =144	143+30+11 =184

E. Dual-track CQI feedback and MCS adaptation

Before description of the dual track notion, a heterogeneous slot configuration for example is shown in Fig. 5, which is also used in our discussion and simulation, and CLI might happen in certain sub-frames, called CLI region, such as sub-frame 3, 4, 8, and 9. According to our observations, in most cases, UE-UE interference is mainly caused by aggressor UEs. System performance can be improved if these cases of CLI can be properly handled.

In downlink transmissions of the LTE system, the UE measures channel quality, and then reports the channel quality indicator (CQI) to the base station. The base station determines a proper modulation and coding, which may satisfy certain block error rate, such as 0.1, to be used by the UE for following transmissions, based on the CQI value the UE reports earlier. However, if MCS selection is performed in this way, it might cause an anomaly in the case of CLI. For an example in Fig. 5, the UE measures channel quality in sub-frame 0 and reports its CQI, where the UE doesn't suffer interference from the aggressor UE. After a feedback delay, supposing a four-slot length, DL transmission in sub-frame 4 of TDD configuration 2 uses the MCS determined by the previously measured CQI of sub-frame 0, and encounters interference from the aggressor UE. The transmission with the overestimated MCS may be corrupted. On the other hand, when the UE measurement encounters interference from the aggressor UE in CLI region, such as sub-frame 3, the subsequent transmission with this underestimated MCS in non-CLI region, such as sub-frame 7, impossibly encounters interference from the aggressor UE, and thus missing out a chance to boost transmission performance.

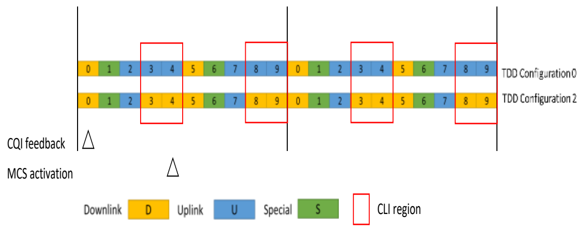

Fig. 5 Aggressor UE interferes with Victim UE in heterogeneous TDD system.

Therefore, we apply two CQI feedback tracks to solve this problem. That is, to distinguish the CQI feedback into two tracks, one for non-CLI regions and the other for CLI regions. The MCS estimation is also correspondingly divided into two tracks. When the aggressor UE interferes in CLI regions, the CQI will be measured. After the feedback delay, supposing six sub-frames here, the MCS will be estimated according to the measured CQI and activated in the following sub-frames in CLI regions. The moments of CQI measurement and corresponding MCS activation are shown in Fig. 6, the patterns below the sub-frame represents the moment of CQI measurement, after six sub-frames feedback delay, the MCS will be estimated according to the previously measured CQI and activated in the follow sub-frames.

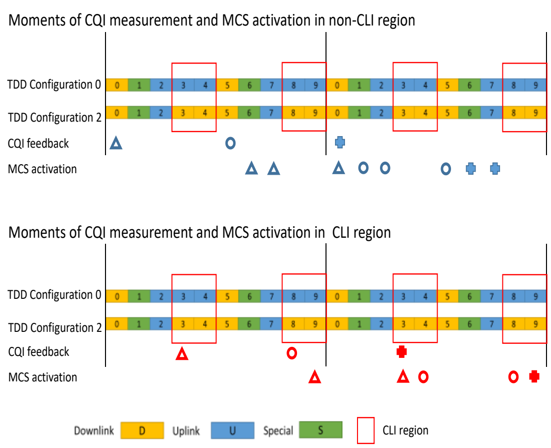

Fig. 6 Dual tracks of CQI feedback mechanism.

IV. Simulation Result

To validate and accurately assess the adaptive MCS selection schemes under heterogeneous TDD configurations, WiSE simulator [6] is used to evaluate performance of the outdoor scenario used in 3GPP calibration campaigns. The simulated parameters are shown in Table III.

Table III
Simulation Assumption

Parameters	Values or assumptions
Carrier frequency	4 GHz
ISD	500 m
BS antenna height	25 m
UE antenna height	1.5 m
System bandwidth	20MHz (100PRBs)
Max Tx Power	TRP : 49 dBm UE: 23 dBm
Percentage of high loss and low loss building type	100% low loss
UE antenna elements	(M, N, P, Mg, Ng)=(1,1,2,1,1) $(d_H、d_V)$=(0.5, N/A)λ 0°, 90° polarization
TRP antenna elements	(M, N, P, Mg, Ng)=(8,8,2,1,1) $(d_H、d_V)$=(0.5, 0.8)λ +45°, -45° polarization
UE distribution	10 users per macro TRP, 20% indoor and 80% outdoor
UE speeds of interest	3 km/h for indoor and 30 km/h for outdoor
BS noise figure	5 dB
UE noise figure	9 dB
Thermal noise level	-174 dBm/Hz
Traffic Model	FTP model 1, file size=0.25 Mbytes, downlink λ=6.4 arrivals/sec/cell, uplink λ=9.6 arrivals/sec/cell
Max DL/UL Rank number	1
Feedback delay	6 sub-frames
MCS	Max 256QAM
Scheduler	Round Robin
UE density	10 UEs per TRP
UL Power control	$(P_0, \alpha) = (-106\text{dBm}, 1)$
Channel model	Channel model B
Channel estimation	Ideal

Three methods for adapting MCS to be evaluated are the baseline and two adaptive modulation schemes. The method Baseline is the original MCS selection method implemented in WiSE, which is not aware of CLI regions and based on periodical CQI feedbacks. Two adaptive modulation schemes are the proposed two tracks MCS selection method, called DualTrackMCS and a modified MCS selection method, which always uses a lower MCS for all sub-frames in all CLI regions, called CLI-degradedMCS, where the lower MCS used in CLI regions is estimated based on the received interference power from the aggressor UE in the identification process and recent received signal strength.

Fig. 7 shows differences of MCS statistics in CLI regions and non-CLI regions of DualTrackMCS. Proportion of low order MCS in CLI regions is higher than that in non-CLI regions.

Fig. 8 compares few representative victim cases in one of simulations, including two victim UEs with lower $SI_{UE2UE}R$ values and two victim UEs with higher values, for following case analysis. These UE numbers are 127,169,216,222, and their $SI_{UE2UE}R$ values are -30.2 dB, -8.3 dB, -14.4 dB, -5.4 dB, respectively.

Observing the error rate in Baseline in Fig. 8, the descending order of error rates of four UEs is UE216, UE127, UE222, and UE169. The order of the number of retransmissions is the same, which means that the number of retransmissions is positively related to the error rate. Besides, the UEs with low $SI_{UE2UE}R$ values usually have higher error rates, such as UE216 and UE127.

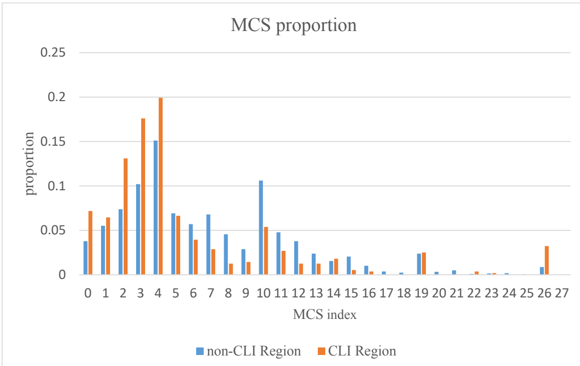

Fig. 7 MCS poportion of Dual Track MCS.

Our proposed scheme tries to conservatively adapt MCS during interference of aggressor UEs to reduce the number of retransmissions, for example UE 216, 127, and 169. Reduction of retransmissions is much obvious especially for those UE with low $SI_{UE2UE}R$ values and higher error rates, such as UE216 and UE127. However, this adapting may also increase the chance of being interfered by the aggressor UE due to increase of transmission slots of the UE caused by lowering the MCS index, resulting in an increase in the number of retransmission times instead, such as UE222.

Intuitively, decrease of retransmission times reduces average packet delay. We take UE169 with a moderate $SI_{UE2UE}R$ as an example. The DualTrackMCS case of UE169 has the least number of retransmission times among the three, and also the shortest packet delay. Meanwhile, the Baseline case has the most retransmission times, and also the longest average packet delay time. Unexpectedly, for the UE127 with a poor $SI_{UE2UE}R$ value, the CLI-degradedMCS case has the longest average packet delay and its number of retransmissions is the least among the three; when the baseline of UE127 has the most retransmission times, it has the shortest average packet delay. This is because the hybrid automatic repeat request (HARQ) mechanism prioritizes resource allocation of UEs with failed transmissions, and then the remained resources are allocated to UEs with backlog data, which may also include the failed UE. This UE might get more resources than others and hence reduce average packet delay. UE216 also has a similar situation. We define the average packet delay time in this paper as the average time of UE sends a packet.

From the perspective of DL cell spectral efficiency, the number of retransmission times of UE216 with DualTrackMCS is the least among the three methods, and its DL cell spectral efficiency is the highest. In the other hand, the CLI-degradedMCS of UE216 has the most retransmission times, and the DL cell spectral efficiency is the worst. This verified the abovementioned phenomenon where the UE with poor $SI_{UE2UE}R$ and failed transmissions is prioritized to get more resources to retransmit the packet, resulting in decrease in the DL cell spectral efficiency value. UE127 also encounters this similar situation. Although the case of UE-UE interference does not prevail, few cases with poor transmission quality still may downgrade the whole cell performance.

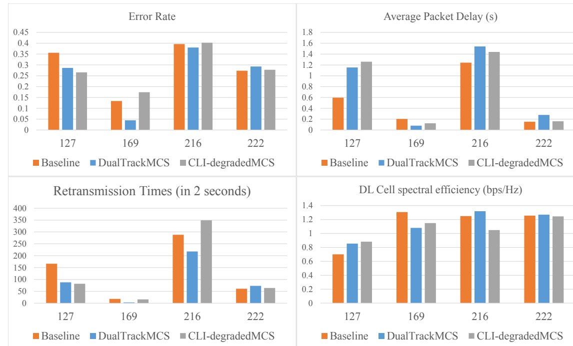

Fig. 8 Four Metrics of Four UE representative cases with three schemes.

Table IV shows the average DL cell spectral efficiency slightly differs because heavy UE-UE CLI does not prevail in the whole system, and the DL cell edge spectral efficiency of DualTrackMCS is the best one because the proposed DualTrackMCS effectively improves transmission of victim UEs who is usually those located under the 5-percentile of SINR CDF curves. The CLI-degradedMCS also improves but less than the DualTrackMCS because the CLI-degradedMCS may underestimate MCS when there is no interference from the aggressor UE.

Table IV
DL CELL SPECTRAL EFFICIENCY

	DL Cell Edge Spectral Efficiency (bps/Hz)	Average DL Cell Spectral Efficiency (bps/Hz)
Baseline	0.005471	0.811054
DualTrackMCS	0.013645	0.848461
CLI-degradedMCS	0.009796	0.827011

V. CONCLUSIONS

In this paper, we propose the methods to establish victim/aggressor UE pairs, and then use the dual track MCS adaptation to resist UE-UE CLI. By numerical results of our study, we discover that reducing retransmissions increases DL cell spectral efficiency. In addition, the proposed dual track MCS adaptation can effectively improve DL cell edge spectral efficiency.

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