Interference Analysis for Mutual Coexistence between LTE TDD in Spatial and Time Domain

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Abstract —Traffic in a small cell has characteristics of burst and time varying, and it is advantageous to allocate TDD having a variable Downlink(DL) / Uplink(UL) traffic rate characteristic. However, existing standards have limitations on the utilization of DL and UL resources considering the instantaneous traffic situation of the cell. Therefore, 3rd Generation Partnership Project (3GPP) standardized TDD eIMT supporting dynamic configuration of DL/UL configuration of TDD cell. In this paper, based on the target scenario considered in TDD eIMTA Work item (WI), coexistence criterion information is obtained through interference analysis in multi-dimensional domain including time, space domain between LTE-TDD based mobile communication services. We also proposed a DL/UL configuration guideline for stable establishment of LTE-TDD service through calculation of acquisition available communication capacity.

Index Terms—Interference analysis, LTE-TDD, separation distance, LTE-TDD DL/UL configuration, event generation, iRSS & dRSS

I. Introduction

One of the future cell deployment scenarios for LTE systems is a heterogeneous network structure in which macro cells and small cells are mixed. In this case, since traffic of small cell has Bursty and time-varying characteristics, it is advantageous to allocate variable DL / UL traffic ratio which is characteristic of TDD. In the existing standard, it is possible to change the DL / UL configuration to be semi-static, but in actual LTE-TDD deployment, the same DL / UL configuration is set for cells of the same frequency at least in each region. This is to suppress the interference due to the signal transmitted from the base station to the base station when the DL / UL configuration between adjacent cells is different. Therefore, there is a limit to the utilization of DL and UL resources considering the instantaneous traffic situation of the cell only with the existing standard. In order to solve this problem, the 3GPP has standardized a specification for supporting the dynamic setting of the DL / UL configuration of the TDD cell under the title of "Further enhancements to LTE-TDD for DL / UL interference managements and traffic adaptation (TDD eIMTA)" [1]-[3]. The target scenario considered in the TDD eIMTA WI is shown in Fig. 1. A plurality of pico-cells that do not exist in the macrocell form a cluster, and pico-cells within one cluster are set to the same TDD DL / UL configuration. In addition, a plurality of pico-cells forming a cluster in an adjacent area can dynamically reset the TDD DL / UL configuration. In this paper, we analyze interference in time, space domain to verify the mutual coexistence with the terminal operating in the dynamic TDD DL/UL configuration.

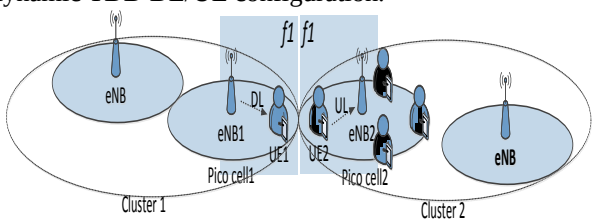

Fig. 1. TDD eIMTA scenario

II. Simulation Environment

In case of operating as a different link service by dynamic re-establishment of TDD DL / UL configuration in the adjacent region, the interference situation only in the TDD system can be observed as follows. In Fig. 2(A), The terminal of the pico-cell P1 receives the DL signal from the E-UTRAN Node B(eNB) and the terminal of the pico-cellt P2 transmits the UL signal to the eNB. At this time, the signal transmitted from the eNB of the pico-cell P1 acts as an interference to the UL transmission of the pico-cell P2, and interference between the eNB (or the base station) appears in this case. However, it is known that interference between eNBs (or base stations) can be neglected because interference can be mitigated by using a separate filter [4]. On the contrary, In Fig. 2(B) the terminal of the pico-cell P2 transmits the UL signal to the eNB and the terminal of the pico-cell P1 receive the DL signal form the base station. At this time, the signal transmitted from the terminal of the pico-cell P2 acts as an interference to the DL transmission of the pico-cell P1. In this case, it can be seen that interference occurs between the terminals. In the case of inter-terminal interference, they exist randomly, so that significant interference may occur when they are located close to each other. Therefore, in this paper, we consider the influence of inter-terminal interference according to the separation distance between adjacent two cells as shown in Fig. 2(B).

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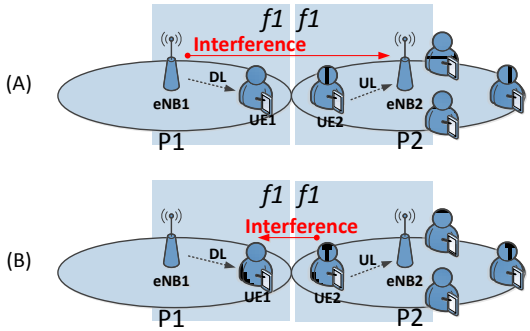

Fig. 2. Interference situation in case of different LTE-TDD configuration in the spatial domain

III. Interference Analysis

Fig. 3 shows the interference analysis process using the Monte Carlo algorithm, which is used as a standard interference analysis technique by the European commission. The diagram of interference analysis process is composed of Plug-in, Separation distance, event generation, Interference Received Signal Strength (iRSS) & Desired Received Signal Strength(dRSS) calculation, TDD DL/UL configuration, Interference calculation. Finally, we proposed TDD DL/UL configuration guideline satisfying the interference probability 5% standard value applied in European standardization organization and field test and the 20MHz LTE-TDD downlink target communication capacity(112Mbps) [5] shown in 3GPP TR 36.912. The processing for details about interference analysis is as follows.

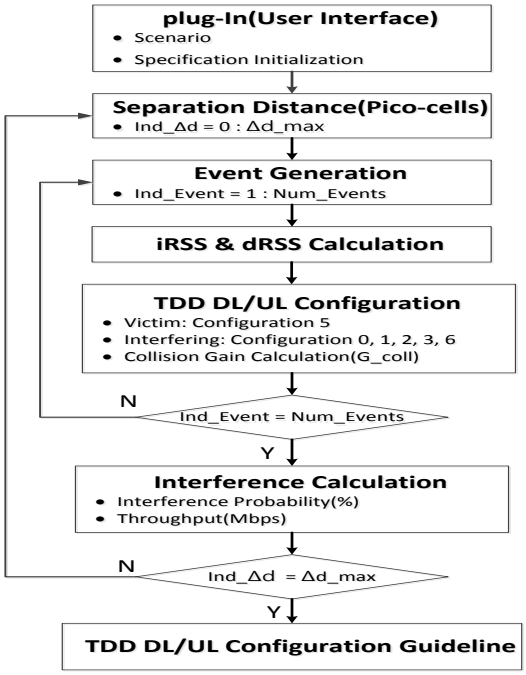

Fig. 3. Interference analysis processing based on the monte-carlo algorithm

A. Plug-in(User Interface)

The horizontal and vertical axes in Fig. 4 represent the interferer and interferer coordinates, respectively, and the blue Access Point(AP) and orange terminals on the left side of the drawing represent the target transmitter and receiver, respectively. At this time, the position of the orange terminal is fixed at a position having -110 dBm, -90 dBm, and -70 dBm receiving power from the blue AP. Also, a number of interfering transmitters in the pico-cell region of the interference receiver, indicated by the green AP, are randomly distributed [6].

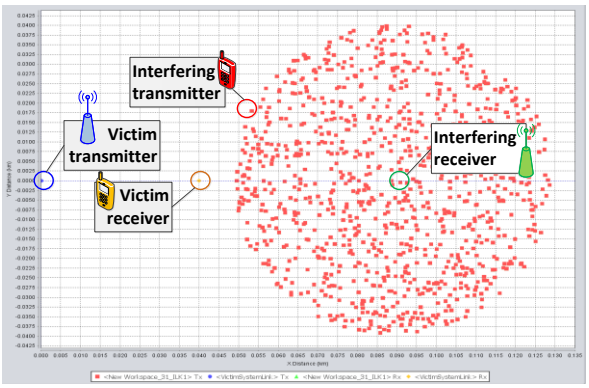

Fig. 4. PLUG-IN(User Interface)

The main system parameters of the interference sources and interferers defined in the simulation are shown in Table I based on the 3GPP standard [7], [8].

Table I: LTE-TDD Interference Analysis Parameters

Parameters	eNB	UE
Cell radius(cluster/pico)	50m/40m	
Frequency	3.412MHz	
Channel model	ITU-R P 526-2	
Bandwidth	20MHz	
Antenna height/gain	10m/5dBi	1.5m/0dBi
Output power	24dBm	23dBm
Noise floor	-165dBm	
Sensitivity	-171dBm	
I/N	-6dB	
Required S/(I+N)	0.5dB	
Max number of UEs	10	

B. Separation Distance(Pico-cell)

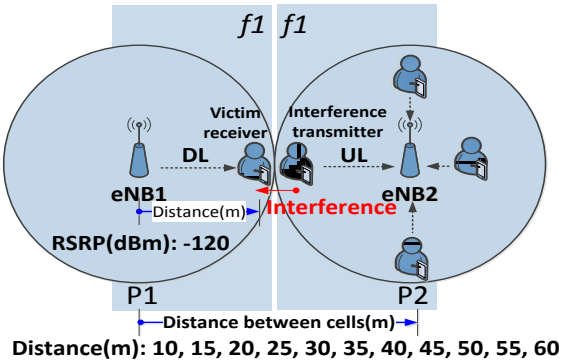

Fig. 5. Interference analysis scenario in the spatial domain

In Fig. 5, interference probabilities are checked according to the separation distance(from 10m to 60m at 5m interval) between the interferer terminals performing

UL transmission with a transmission power of 23dBm in the neighboring pico-cell 2 region and the terminal receiving the DL signal in the adjacent pico-cell 1 region.

C. Event Generation & iRSS, dRSS Calculation

In this step, iRSS and dRSS, which are input to the victim receiver through repetitive simulation during N events according to separation distance, propagation environment, antenna gain, interferer receiver sensitivity, etc. can be calculated in the following way [8]. dRSS is the received power from the eNB1 to the victim receiver, and it is defined by the following in (1).

$$dRSS = P_{wt} + g_{wt\to vr}(f_{vr}) + PL_{wt\to vr}(f_{vr}) + g_{vr\to wt}(f_{vr}) \quad (1)$$

Table II shows the respective parameters included in (1).

TABLE II: DEFINE DRSS FORMULA PARAMETERS

P_{wt}	Wanted transmitter power (dBm)
$g_{wt\to vr}$	Wanted transmitter antenna gain (dBi)
$PL_{wt\to vr}$	Pathloss (dB) (Wanted transmitter to Victim receiver)
$g_{vr\to wt}$	Victim receiver antenna gain (dBi)

iRSS is the received power from the interfering transmitter to the victim receiver, and it is defined by the following in (2).

$$\mathrm{iRSS} = \mathrm{f}(\mathrm{emission}_{\mathrm{it}}, \mathrm{g}_{\mathrm{it}\to\mathrm{vr}}, \mathrm{PL}_{\mathrm{it}\to\mathrm{vr}}, \mathrm{g}_{\mathrm{vr}\to\mathrm{it}}) = 10\log\left(\sum_{\mathrm{i}=1}^{\mathrm{n}} 10^{\frac{\mathrm{iRSS}_{\mathrm{unwanted}}}{10}}\right) \quad (2)$$

In (2), $\mathrm{iRSS}_{\mathrm{unwanted}}$ denotes the received signal from the interfering transmitter that flows into the i-th victim receiver among the n events, and it is defined by the following in (3).

$$\mathrm{iRSS}_{\mathrm{unwanted,i}} = (\mathrm{emission}_{\mathrm{it}}(\mathrm{f}_{\mathrm{it}}, \mathrm{f}_{\mathrm{vr}}) + \mathrm{g}_{\mathrm{it}\to\mathrm{vr}} - \mathrm{PL}_{\mathrm{it}\to\mathrm{vr}} + \mathrm{g}_{\mathrm{vr}\to\mathrm{it}}) \quad (3)$$

In (3), $\mathrm{emission}_{\mathrm{it}}(\mathrm{f}_{\mathrm{it}}, \mathrm{f}_{\mathrm{vr}})$ denotes the unwanted emission mask function applied to the transmitter according to the center frequency change of the interferer. Table III shows the respective parameters included in (2), (3)

TABLE III: DEFINE IRSS FORMULA PARAMETERS

$g_{it\to vr}$	Interfering transmitter antenna gain (dBi)
$PL_{it\to vr}$	Pathloss (dB) (Interfering transmitter to Victim receiver)
$g_{vr\to it}$	Victim receiver antenna gain (dBi)

D. TDD DL/UL Configuration

Interference, which has the greatest influence on the performance of the system in the time domain, is interference between neighboring cells, and the interference situation is determined according to which DL / UL structure is used for each service. In contrast to LTE-FDD, which transmits data every 10ms, LTE-TDD transmits and receives data in a reverse manner and has a protection time to prevent interference. The guard time has a guard time when changing DL / UL transmission direction once every 5ms or once per 10ms according to DL / UL structure, It is divided into Fixed sub-frame and Flexible sub-frame based on the protection time. The fixed sub-frame means a sub-frame in which the transmission direction of the DL / UL does not change or a sub-frame in which there is no change in the interference situation due to the DL / UL switching. Fig 6. In this paper, we assume the interference situation caused by the signal transmitted from the base station to the base station or from the terminal to the terminal when the DL / UL configuration between adjacent cells is different. The terminal of the pico-cell A receives the DL signal of the base station at 0, 3, 4, 5, 6, 7, 8 and 9 positions constituted by a total of 8ms sub-frames and the terminal of the pico-cell B transmits the UL signal to the base station at 3, 4, 7, and 8 positions constituted by a total of 4ms sub-frames. At this time, the signal transmitted from the pico-cell B terminal acts as an interference to the DL signal of the pico-cell A, and it can be confirmed that the DL and the UL are overlapped in the flexible sub-frames 3, 4, 7, and 8. In order to compare the interference environment generated in different DL and UL structures in this way, Table IV shows the five different environments in this paper.

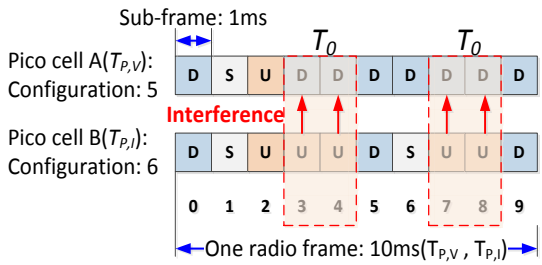

Fig. 6. Interference situation in case of different LTE-TDD configuration

TABLE IV: INTERFERENCE SITUATION IN CASE OF DIFFERENT LTE-TDD CONFIGURATION

Scenario	Pico-cell A	Pico-cell B
1	TDD configuration 5 (DL:UL=9:1)	TDD configuration 0 (DL:UL=2:3)
2		TDD configuration 1 (DL:UL=3:2)
3		TDD configuration 2 (DL:UL=4:1)
4		TDD configuration 3 (DL:UL=7:3)
5		TDD configuration 6 (DL:UL=5:5)

In this simulation, it is assumed that the Victim receiver operates as a downlink service and the interference transmitter operates as an uplink. That is, considering the inter-terminal interference, the collision factor due to the reverse link service between the victim receiver and the interference transmitter is defined by the following in (4) [9].

$$\mathrm{G_c} = 10\log\left(\frac{\mathrm{T_0}}{\mathrm{T_{P,V}}}\right) \quad (4)$$

Table V shows the respective parameters included in (4)

TABLE V: DEFINE COLLISION VALUE FORMULA PARAMETERS

$T_{P,V}$	Victim downlink sub-frame
$T_{P,I}$	Interfering uplink sub-frame
T_0	Overlap(Victim and Interfering)

E. Interference Calculation

Through the statistical data of the average value of dRSS and iRSS generated during N events and the collision value(G_c) according to TDD configuration, interference probability and throughput are calculated. The interference ratio is determined through the ratio between the reference interference protection ratio($C/(I+N)_{target}$) and the dRSS and iRSS inputted to the interference receiver. The following in (5) and (6) show the basic formulas for judging the occurrence of interference, respectively. in (5), If the ratio of dRSS to iRSS is larger than the interference protection ratio($C/(I+N)_{target}$), it is judged that interference does not occur, in case of the ratio of dRSS and iRSS is smaller than the interference protection ratio, It is determined that interference occurs

$$\mathrm{dRSS/iRSS}_{trial} > C/(I+N)_{target} : \ Good\ event \quad (5)$$

$$\mathrm{dRSS/iRSS}_{trial} < C/(I+N)_{target} : \ Interference \quad (6)$$

In (7) represents the probability probability formula that can be calculated when the interference judgment process is performed N times as described above. In (7), N_{all} denotes the number of events used for the simulation, and N_{good} denotes the number of cases where the interference protection ratio is larger than that in (5). That is, when the probability that interference does not occur is (N_{good}/N_{all}), the probability of occurrence of interference ($P_{interference}$) is equal to 1 minus the probability that no interference occurs.

$$P_{interference} = 1 - (N_{good}/N_{all}) \quad (7)$$

IV. SIMULATION RESULT OF INTERFERENCE ANALYSIS

Fig. 7, Fig. 8 shows the interference probability and the channel capacity according to the inter-cell separation distances and the dynamic TDD configuration when the received signal strength of the victim receiver is -120dBm. In simulation result, when the separation distance is 10m, the interference probability is highest and the communication capacity is lowest. Because, when a terminal randomly distributed in an adjacent cell region transmits a UL signal at a power of 23dBm at a cell boundary, the iRSS value generated during N events has a value higher than the received signal strength of -120dBm, so that the ratio of dRSS and iRSS values is greater than the interference protection ratio. Therefore, since the probability of communication among the total number of events is small, the interference probability is increases. In addition, if the separation distance is increases, the value of iRSS flowing into the victim receiver will gradually decrease due to the path loss depending on the distance. As a result, it is confirmed that all dynamic TDD configuration satisfies the interference probability within 5% at the separation distance of 50m. In case of the communication capacity, it can be confirmed that it is gradually increased in contrary to the interference probability, and it can be confirmed that satisfies the communication capacity (112Mbps) standard at the separation distance of 45m. Fig. 9, Fig. 10 shows the interference probability and the channel capacity according to the inter-cell separation distances and the dynamic TDD configuration when the received signal strength of the victim receiver is -90dBm. As a result, it is confirmed that all dynamic TDD configuration satisfies the interference probability within 5% and the communication capacity standard at the separation distance of 35m. Fig. 11, Fig. 12 shows the interference probability and the channel capacity according to the inter-cell separation distances and the dynamic TDD configuration when the received signal strength of the victim receiver is -70dBm. As a result, it is confirmed that all dynamic TDD configuration satisfies the interference probability within 5% and the communication capacity standard at the separation distance of 25m.

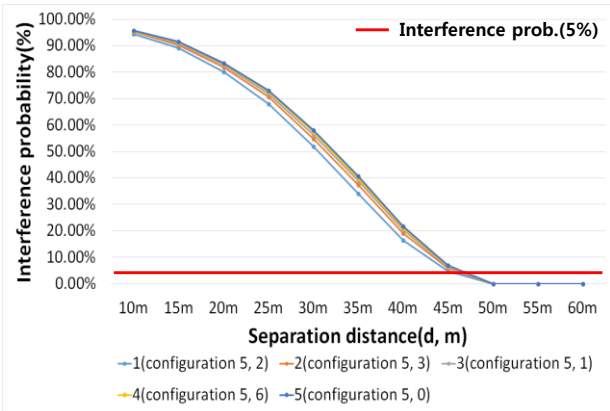

Fig. 7. (RSRP: -120dBm) Interference probability according to the distance and dynamic LTE-TDD configuration

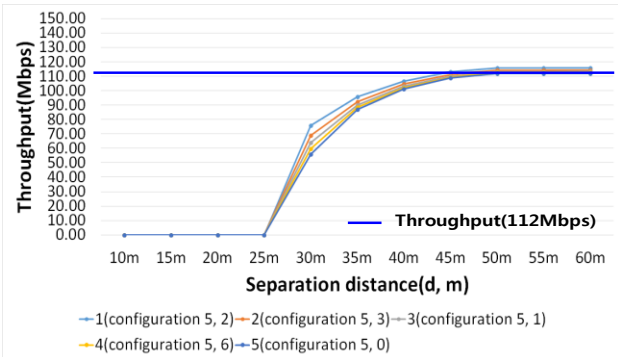

Fig. 8. (RSRP: -120dBm) Communication capacity according to the distance and dynamic LTE-TDD configuration

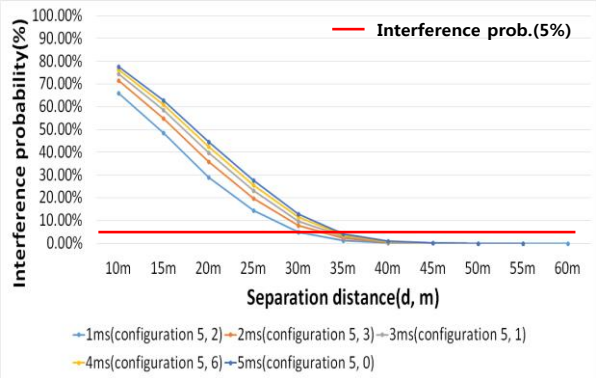

Fig. 9. (RSRP: -90dBm) Interference probability according to the distance and dynamic LTE-TDD configuration

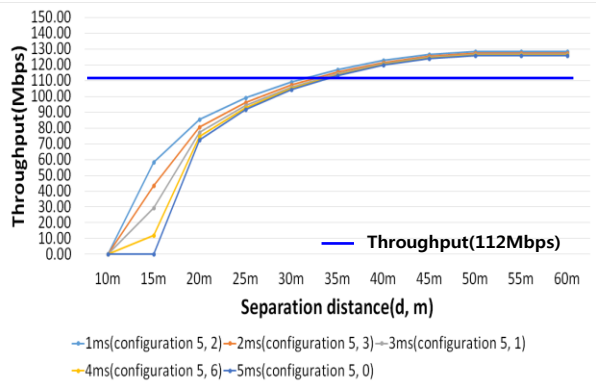

Fig. 10. (RSRP: -90dBm) Communication capacity according to the distance and dynamic LTE-TDD configuration

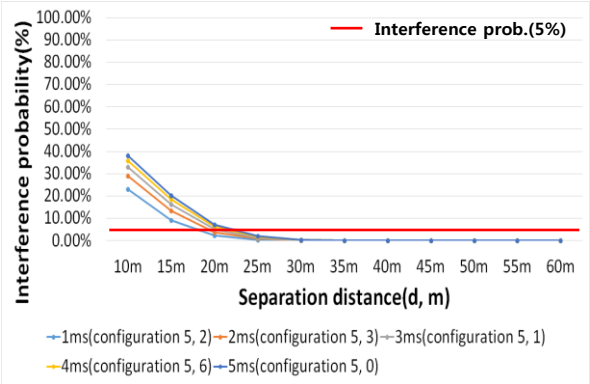

Fig. 11. (RSRP: -70dBm) Interference probability according to the distance and dynamic LTE-TDD configuration

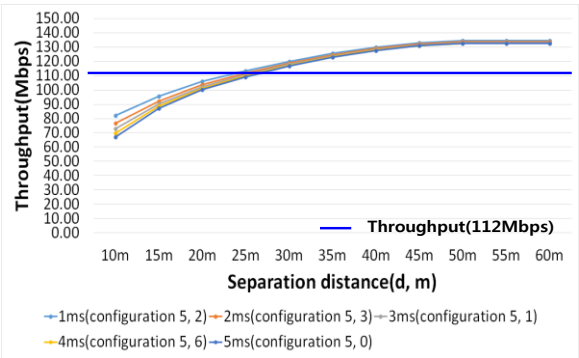

Fig. 12. (RSRP: -70dBm) Communication capacity according to the distance and dynamic LTE-TDD configuration

V. Conclusion

In this paper, we describe the eIMTA standard supporting the dynamic configuration of TDD DL/UL and it was performed the interference analysis in the space, time domain in case of the reverse link service among the operation scenarios considered in 3GPP Release-12 WI. Through the results, we were obtained the coexistence criterion information of the Multi-dimensional domain including time, space domain between mobile communication services based on LTE-TDD and we also proposed the DL/UL configuration guideline for stable establishment of LTE-TDD service through calculation of acquisition available communication capacity.

Acknowledgment

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