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The Impact of LTE-FDD at the LTE-TDD for the Co-Existence under 2.6 GHz Band for Malaysia

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Abstract

For the co-existence scenario between LTE-FDD and LTE-TDD systems, if the two systems are using an adjacent frequency carrier, there will be a need for spatial separation between the eNodeBs of the two systems, otherwise the two systems will interfere each other. The study is implemented based on realistic parameters in order to help the network designer to make a decision about the best frequency allocation and network deployments in order to achieve higher performance under the lowest possible cost. Throughout this paper, the effect of the FDD system at the TDD is evaluated under wide range of ACIR and separation distances between the two systems eNodeBs as well. The results showed that, the recommended ACIR offset by the 3GPP is not enough for the LTE-TDD uplink throughput loss ratio to be acceptable, whereas 115 dB, 45 dB, and 35 dB of the ACIR is required for the throughput loss ratio in order to drop less than 5% for the co-located, Mid-point, and Edge-point eNodeBs deployment scenario respectively. Meanwhile, comparing to the uplink case, the downlink of the TDD system is much coherent; the recommended ACIR offset is only unacceptable for the co-located deployment case, whereas 50 dB of the ACIR is required for the system to drop less than 5%.

Keywords*: LTE-co-existence, interference, LTE-TDD, LTE-FDD, ACIR*

1. Introduction

According to the 3GPP standardization, the LTE system is meant to support high throughput and low latency, improved coverage in order to keep the path with the increasing global demand. Because of the scarcity of the spectrum resources, the solution is to propagate difference systems within the same geographical area. In [1], the frequency allocation for the LTE is divided into two main parts, unpaired spectrum and paired spectrum for TDD and FDD respectively, the unpaired spectrum uses only one frequency band for both uplink and downlink operations, whereas, the paired spectrum uses two separated frequency allocations for the uplink and downlink as it is explained in [2], each one of the paired and the unpaired frequency allocation has advantages and disadvantages in the term of average throughput, flexibility, and the efficiency of allocating the available frequency. The majority of LTE operators prefer using the paired spectrum (FDD) mode. However, nowadays the LTE-TDD is evolved and became a mature technology rather than just a complementary technology.

The Malaysian Standard Radio System Plan (SRSP) has specified the requirements for the LTE co-existence under the frequency bands between 2500 MHz and 2690 MHz in [3]. Whereas, in the near future, Malaysia is going to coexist LTE-TDD and LTE-FDD under thementioned frequency band which is not only reversed for Malaysia, it is divided among Malaysia and its neighbor countries Brunei, and Singapore. In the wireless communication systems, generally the interference is not completely avoidable, but at least it can bemitigated if it is firstly evaluated.

Before coexisting LTE-TDD and LTE-FDD systems, this study has to be performed based on the pre-agreed frequency allocation as a precautionary procedure. Otherwise, a mutual interference can probably be arisen between the two systems, which can damage the two systems' data and control channels as well. Therefore, the benefit of why the co-existence has been designed for in the first place cannot be gained.

As the ITU recommendations, the co-existence should be under adjacent frequency bands [4]. For this paper, the coexistence between LTE-TDD and LTE-FDD systems under the

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frequency band 2500-2690 MHz is going to be investigated; especially the impact of LTE-FDD at LTE-TDD will be presented for Malaysia.

The SRSP also provides the minimum requirements for sharing the frequency band between Malaysia and its neighbouring countries Singapore and Brunei, technical characteristics of radio systems, frequency channel, coordination initiatives in order to maximize the utilization, minimize interference and optimize the usage of the bandwidth.

Table 1 and Table 2 illustrate the worst case scenarios of frequency allocation for co-existing the TDD and FDD systems for Malaysia when considering its neighbouring countries Singapore and Bernie.

Table 1. The co-existence frequency allocation for downlink case

Country	FDD downlink MHz	TDD LTE MHz
Singapore	2624-2630	2606-2612
Brunei	2624-2630	2612-2618

Table 2. The frequency allocation for co-existence for uplink case

Country	FDD downlink MHz	TDD LTE MHz
Singapore	2564-2570	2606-2612
Brunei	2558-2564	2600-2606

In [5], it is recommended that the eNodeBs of FDD and TDD should not be placed together if the two of them are using the adjacent frequency carriers, because some of the physical data and control channels will experience severe adjacent channel interference. Consequently, it will be unable to be demodulated correctly.

The study in [6] also concludes that, for the co-existence between the LTE-TDD and LTE-FDD in adjacent frequency band the interference should be taken into a real consideration to insure the quality of the data transmission and to achieve the goal of why the coexistence has been made for in the first place.

In general, the interference issue has been investigated many times before, and there are also proposed solutions such as in [7]. However, throughout this work, more specifically, the study evaluated the FDD system interfereing signals which affect the TDD system. Therefore, the user operator can evaluate the system damage ratio. Consequently they will be able to make a decisionabout the eNodeB distribution scenario, the best frequency allocation, and a proper interference mitigation mechanism.

The ACIR is Adjacent Channel to Interference Ratio, from [8] report the ACIR can be defined as the ratio of the total power transmitted from a source (eNodeB or UE) to the total interference power affecting a victim receiver (eNodeB or UE), resulting from both transmitter and receiver imperfections the ACIR is calculated using the following equation:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \quad (1)$$

whereas the ACLR is the Adjacent Channel leakage power ratio, it is a ratio of the transmitted power to the power measured after a receiver filter in the adjacent RF channel, and ACS stands for Adjacent Channel Selectivity, it is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel frequency.

Across this paper, section 2 is going to cover the SINR theory, and the system modelling. Section 3 will be focused into simulation result and the analyses, while section 4 will discuss the simulation results. Eventually section 5, includes the conclusions and recommendations.

2. The System Modeling

The Figure 1 shows the scenario of the FDD uplink and FDD downlink system is interfering the TDD uplink system, as well the Figure 2 shows the scenario of the FDD uplink and FDD downlink system is interfering the TDD downlink system.

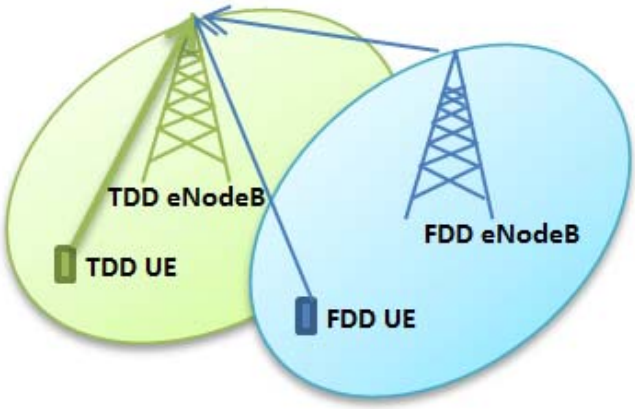

Figure 1. The interference of the TDD uplink and downlink at the FDD uplink

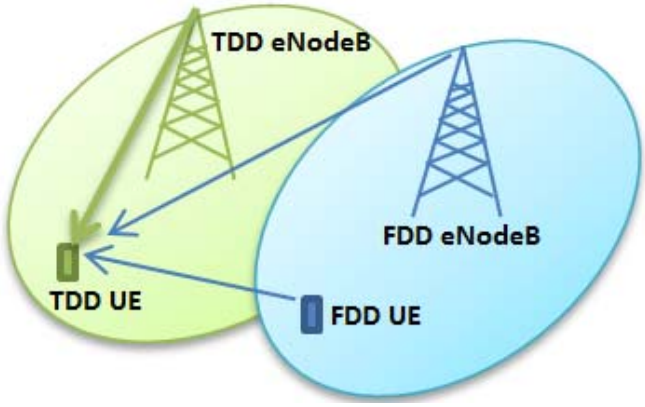

Figure 2. The interference of the TDD uplink and downlink at the FDD downlink

2.1. SINR

According to [9] the performance of the wireless cellular can be evaluated based on the received signal compared to the interference and noise (SINR), which can be calculated using Eq. 2. The throughput of the system significantly can be degraded because of two type of interference. Firstly, the Co-Channel Interference (CCI), which means the combination of the interference signals from the UEs or eNodeBs those belong to the same system. Secondly, the Inter Channel Interference (ICI), which means the combination of the interference signals from the UEs or eNodeBs those belong to the other system within the same propagation area.

$$SINR = \frac{S}{CCI + ICI + N_t} \quad (2)$$

Whereas S is the received signal, and N is the noise.

The study considered two UEs deployment scenarios, whereas the TDD UEs will randomly be distributed overall the TDD eNodeBs, which is called the normal distribution. The second distribution is called the edge distribution, whereas, the TDD UEs is only located at the edge of the TDD eNodeB.

2.2. The Mathematical Modelling

From the simulation process in Figure 3, at the first of all, the TDD eNodeBs and FDD eNodeBs are considered installed at the same place which means the separation distance between them is zero meters. Secondly, each time the TDD eNodeBs is going to be moved by 20 meters, the shifting will continue till the TDD eNodeBs becomes at the edge of the FDD eNodeBs which mean the distance between them is 3000 meters (the radius of the eNodeBs). For each shifting process a range of -50 dB up to 150 dB of ACIR offset will be applied considering an increment of 5 dB per each step. The previous processes will be repeated for each power control parameters sets and both UEs distribution scenarios, the other simulation parameters is in the Table 4 from the 3GPP in [10].

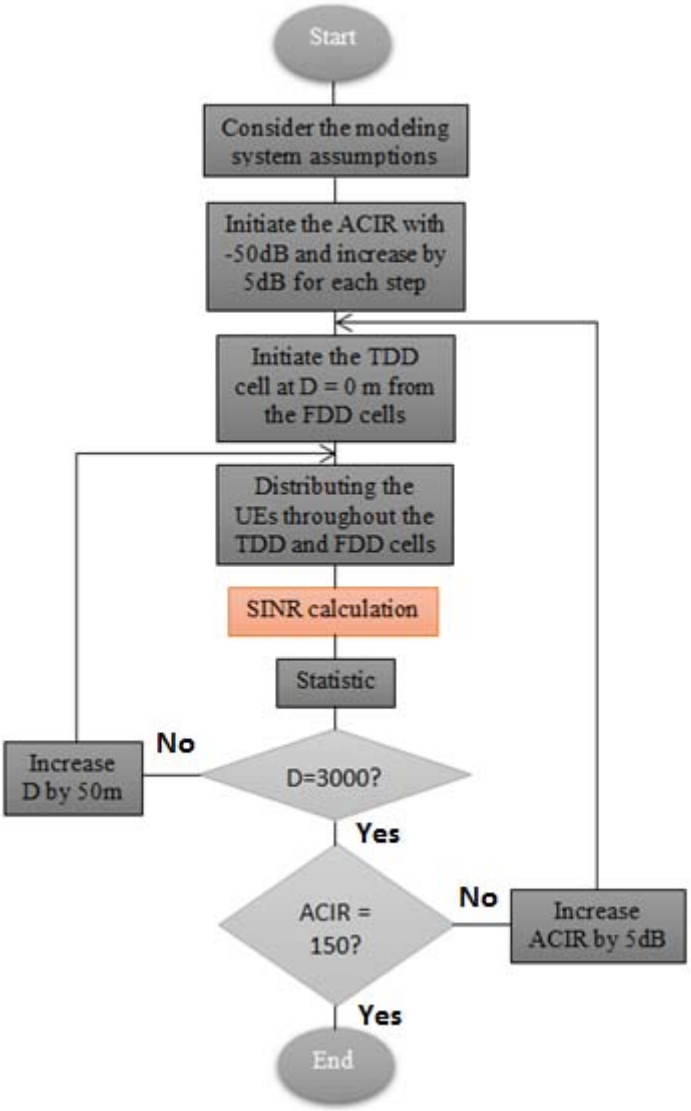

Figure 3. The general simulation algorithm

For the wireless system the propagated signal is affected by the environment parameters [8], the effect of these parameters are differently modelled in equations depending on the type of the nature of the transmitter, the receiver, and the propagation parameters, these equations are called pathloss models equation.

The Eq. 3 is pathloss model for the free space loss from [11]:

$$PL_{eNodeB-eNodeB} = -10log_{10}\left(\frac{\lambda}{4\pi R}\right)^2 - 10log_{10}(\frac{d}{R})^2 \quad (3)$$

Whereas, n is number of the specific eNodeB, on is number of the other eNodeB, λis the wavelength, R is the distance between the eNodeBs number (n) and the other eNodeB number (on), d is the average separation between the row of the buildings.

The pathloss between the UEs and eNodeBs can be calculated using the Eq. 4 in [10].

$$\begin{aligned} PL_{eNodeB_{UE}} &= 161.40 - 7.1log_{10}(W) - 7.5log_{10}(h) \\ &- \left(24.37 - 3.7\left(\frac{h}{h_{eNodeB}}\right)^2\right)log_{10}(h_{eNodeB}) \\ &+ \left(43.422 - 3.1log_{10}(h_{eNodeB})\right)\left(log_{10}(d_{UE_{eNodeB}}) - 3\right) \\ &+ 20log_{10}(f_c) + \left(3.2\left(log_{10}(11.75h_{UE})\right)^2 - 4.97\right) \end{aligned} \quad (4)$$

Whereas, W is street width, h is average height of buildings, f_c is the transmission frequency, h_{eNodeB} the highest of the eNodeB, $d_{eNodeB\text{-}UE}$ the distance between the UE and eNodeB in meters, h_{UE} the highest of the UE.

The pathloss between the UE-UE can be calculated using Eq.5 in [12].

$$\begin{aligned} PL_{UE\_UE} = &-20log_{10}\left(\frac{\lambda}{2\sqrt{2}\pi d_{UE_{UE}}}\right) - 10log_{10}\left(\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\theta} - \frac{1}{2\pi+\theta}\right)^2\right) \\ &- 10log_{10}\left(\left(\frac{b}{2\pi d_{UE_{UE}}}\right)^2 + \frac{\lambda}{\sqrt{\left(\Delta h_m{}^2 + b^2\right)}}\left(\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\phi} - \frac{1}{2\pi+\phi}\right)^2\right)\right. \end{aligned} \quad (5)$$

Whereas, Δh_b is the height difference between the eNodeB antenna and the mean building rooftop height, b is the average separation between rows of buildings, Δh_m is the difference between the mean building height and the mobile antenna height, x is the horizontal distance between the UE and the diffracting edges, h is the average height of building, h_m is the height of UE, h_b height of eNodeB.

The transmitted power of eNodeB number (n) per UE number (u) is fixed it can be calculated using the Eq.6.

$$\begin{aligned} &PL^{UE(u)}_{eNodeB(n)} = P^{max}_{eNodeB(n)} * \frac{R}{M} \\ &M = R * U \end{aligned} \quad (6)$$

Whereas, R is the number of RB per UE, U means number of the active UEs, M is the number of the all available RBs in each cell, the maximum transmitted power from the eNodeB number (n).

The UE transmission power to the eNodeB can be calculated using the following equation:

$$P_t = P_{max} * \min\left(1, \max\left(R_{min}, \left(\frac{CL}{CL_{x-ile}}\right)^{\gamma}\right)\right) \quad (7)$$

Whereas, P_t is the transmitted power in dB, P_{max} is the maximum allowed transmitted power of the UE, R_{min} is the minimum reduction value which prevents the UE in the good channel condition not to transmit at very low power, CL is the coupling loss that can be calculated by the equation bellow.

CL = max {path loss - G_Tx - G_Rx, MCL}.

MCL is the minimum coupling loss, $CL_{x\text{-}ile}$ is percentage of UEs which have the highest coupling loss, and consequently they will transmit at $P_{max,}$ and finally γ is a balancing factor

between UEs with bad channel conditions to the UEs with the good channel conditions it is ranged as 0<γ<=1. The TABLE II includes the power control parameters γ and $CL_{x\text{-}ile}$ which are recommended by 3GPP technical report in [9].

Table 3. Power control algorithm parameter sets

Parameter set	Gamma (γ)	$CL_{x\text{-}ile}$ 5 MHz bandwidth
Set 1	1	112
Set 2	0,8	129

Thereby, the received signal (S) from the UEs at the eNodeB can be calculated using the equation bellow:

$$S = P_t - PL \tag{8}$$

Due to the full orthogonally of the LTE system, there will not be interference with the UEs those belong to the same cell, the interference only comes from the other adjacent cells that are using the same RBs of the specific UE, the uplink co-channel interference can be calculated using the Eq.9, and the downlink interference can be calculated using the Eq.10.

$$CCI_U(u,n) = \sum_{m=1,m\neq n}^{N} (P_t(u,n) * PL_{eNodeB-UE}(u,n)) \tag{9}$$

$$CCI_D(u,n) = \sum_{m=1,n\neq m}^{N} (P_{eNodeB(n)}^{UE(u)} * PL_{eNodeB-UE}(u,n)) \tag{10}$$

The ICI is divided into four types:

1- The received signals at the eNodeB from the UEs which belong to the other system:

$$ICI_{UU}(u,n) = \sum_{on=1}^{N} \sum_{ou=1}^{N} P_t(ou,on) * PL_{eNodeB-UE}^{-1}(ou,n) * ACIR^{-1} \tag{11}$$

2- The received signal at the UE from the UEs which belong to the other system:

$$ICI_{UD}(u,n) = \sum_{on=1}^{N} \sum_{ou=1}^{N} P_t(ou,on) * PL_{UE-UE}^{-1}(on,ou,n,ou) * ACIR^{-1} \tag{12}$$

3- The received signal at the eNodeB from the eNodeBs which belong to the other system:

$$ICI_{DU}(u,n) = \sum_{on=1}^{N} \sum_{ou=1}^{N} P_{t_{eNodeB(on)}}^{UE(ou)} * PL_{eNodeB-eNodeB}^{-1}(on,ou) * ACIR^{-1} \tag{13}$$

4- The received signal at the UE from the eNodeBs which belong to the other system:

$$ICI_{UU}(u,n) = \sum_{on=1}^{N} \sum_{ou=1}^{N} P_{t_{eNodeB(on)}}^{UE(ou)} * PL_{eNodeB-UE}^{-1}(on,ou) * ACIR^{-1} \tag{14}$$

Whereas, ACIR is the attenuation factor which degrade the effect of the interference.

3. Simulation and Result

The interference evaluation mechanism is performed according to the system throughput loss; the results are plotted as 3-D figures. Whereas, the z-axis represents the percentage of the throughput loss, the x-axis represents the considered separation distance between the TDD eNodeBs and the FDD eNodeBs, and eventually the y-axis for the applied ACIR value for each power control sets and UEs distribution scenario.

Table 4. The propagation environment assumed parameter

Parameter	Assumption (common)
Environment	Macro cell, Urban area, Uncoordinated deployment
Carrier frequency	2500-2690 MHz.
Cellular layout	Hexagonal grid, 19 cell sites, 57 sectors with eNodeB in the corner of the cell.
eNodeBs centre to centre distance (R)	6000m
Building to building distance (d)	80m
The Height of the eNodeB	30m
The width of the streets	20m
The height of the UE	1.5m
eNodeB antenna gain (include feeder loss)	15 dBi
eNodeB antenna height	30 m
log-normal fade shadow	10 dB
MCL (including antenna gain)	70 dB
white noise power density	-174 dBm/Hz
eNodeB noisefigure	5 dB
UE noisefigure	9 dB
system bandwidth	5 MHz
eNodeB max Tx power	61 dBm
UE max Tx power	23 dBm
UE min Tx power	-40 dBm
R_{min}	-64dB
number of active UEs	3 UEs per site for downlink case 1 UE per site for uplink

Among the whole range of the separation distance between the TDD eNodeBs and the FDD eNodeBs, three eNodeBDeployments Scenarios (eDSs) are investigated in details in term of the separation distance between the FDD eNodeBs and the TDD eNodeBs, firstly the Co-located eDS (CeDS), which means the separation distance is zero meter. Secondly, at the separation distance of 1500 meters, this represents the Mid-point eDS (MeDS). Finally, at the separation distance of 3000 which means the eNodeBs of the two systems are located at the edge of each other which it is called Edge eDS (EeDS) such as in the Fig.4 for the sub-figures (a), (b), and (c) respectively.

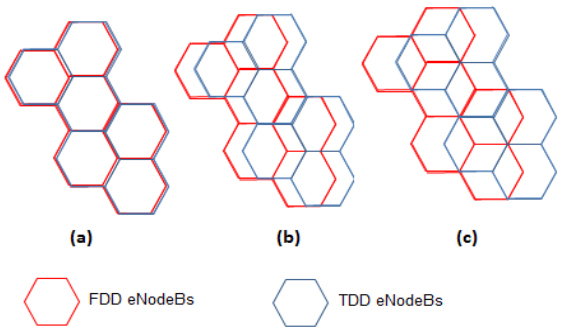

Figure 4. The eNodeBs deployment scenarios

The study has also included the User Equipment distribution scenario as one of main parameters, where they are, the Edge User Equipment distribution scenario (EUDS) and Normal User Equipment distribution scenario (NUDS), such as recommended in [13], whereas the cell-edge user equipment throughput is considered one of the main challenging indicator of LTE-A to fulfil International Telecommunication Union – Radio communication Sector (ITU-R).

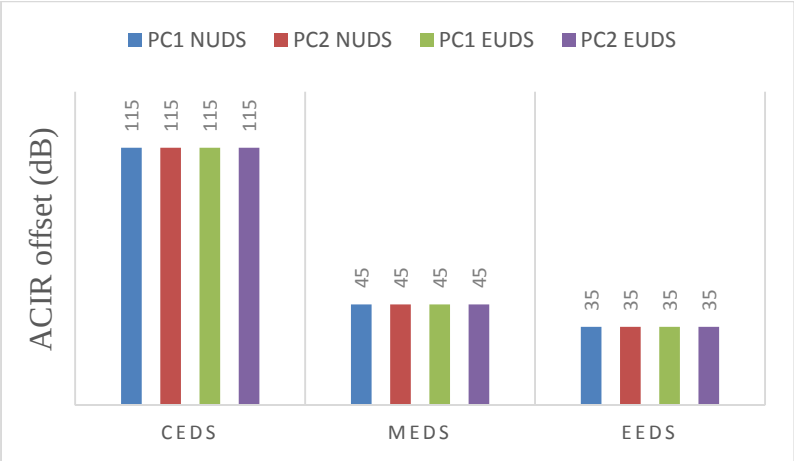

Figure 5. The throughput loss of the TDD uplink system

The TDD uplink throughput loss ratio (TLR) is illustrated in the Figure 5 for the Normal UEs Distribution Scenario (NUDS) and Edge UEs Distribution Scenario (EUDS) respectively, when the system is interfered by the uplink and downlink of the FDD system. The results showed that, the TLR is almost the same for two power control parameters (set1 and set 2)and for the two cases of UEs Distribution Scenarios (UDSs) because of the narrow transmission channel (only 5 MHz). It is also showed that the FDD system interferences the uplink of the TDD system pretty badly, specifically at the CeDS, whereas 115 dB of ACIR is required for the system throughput loss to drop less than 5% considering the two UEs distribution. Meanwhile, the required ACIR is only 45 and 35 dB for the cases MeDS and EeDS. Less than all, the edge-point eNodeBs deployment achieved the lowest ACIR offset to achieve less than 5% of the throughput loss as offset of 50 dB for the two case of UDSs.

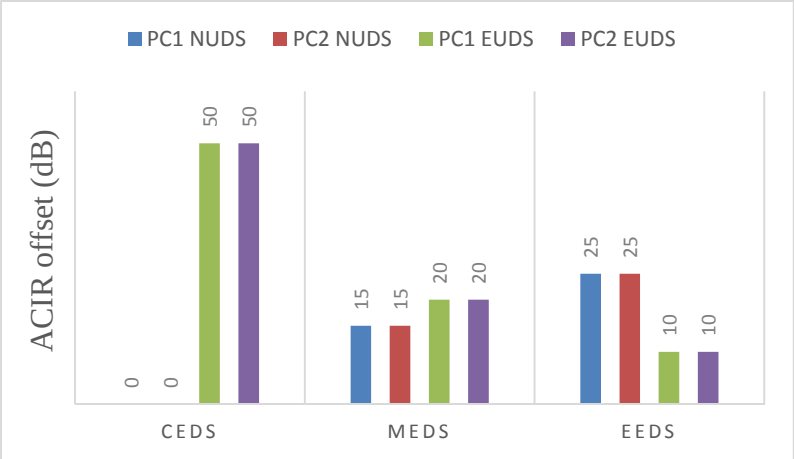

Figure 6. The throughput loss of the TDD downlink system

FROM the Figure 6 it clearly appears that, the TDD downlink is less affected by the FDD system compared to the uplink region of the system. Whereas, the worst case scenario is recorded at the CeDS, whereas 50 dB is required to achieve throughput loss ratio of less than 5% considering the for the EUDS whilst a 0 dB of the ACIR is required for the case of the NUDS. For the MeDS, the ACIR ratio minimized to 20 dB for the EUDS, meanwhile the value increased for the NUDS by 15 dB. Following the same manner for the EUDS, the ACIR kept minimizing for the EUDSwhereas it reatched only 10 dB. As well, the the ACIR ratio kept increasing till it became 25 dB for the NUDS.

4. Discussion

The 3GPP in [14] recommended the minimum ACIR offset in Table 5, whereas, it should be taken into a real consideration. According to the simulation results the table content concluded the results in the Figure 7 and Figure 8 for the uplink and downlink of the TDD system throughput loss at the of the TDD system respectively.

Table 5. The minimum recommended ACIR offset.

The Link	ACIR Offset
eNodeB -> UE	32.7
eNodeB -> eNodeB	41.2
UE -> eNodeB	29.8
UE -> UE	28.2

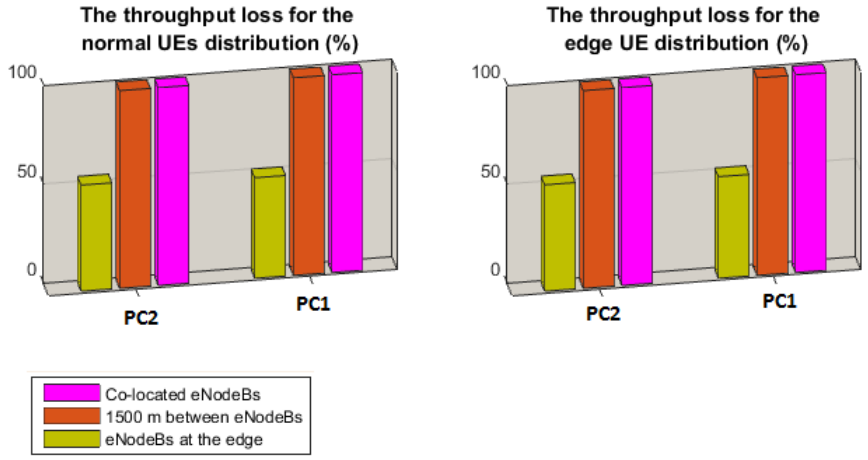

Figure 7. The expected throughput loss for the TDD uplink case

The Figure 9 explain the severity of the FDD uplink and downlink interference at the uplink of the TDD system, it can be conclude that, 100% of the uplink throughput will be lost for the CeDS and MeDS, except for the EeDS, whereas the throughput loss ratio in only 50% which it stills quite beyond the acceptable range.

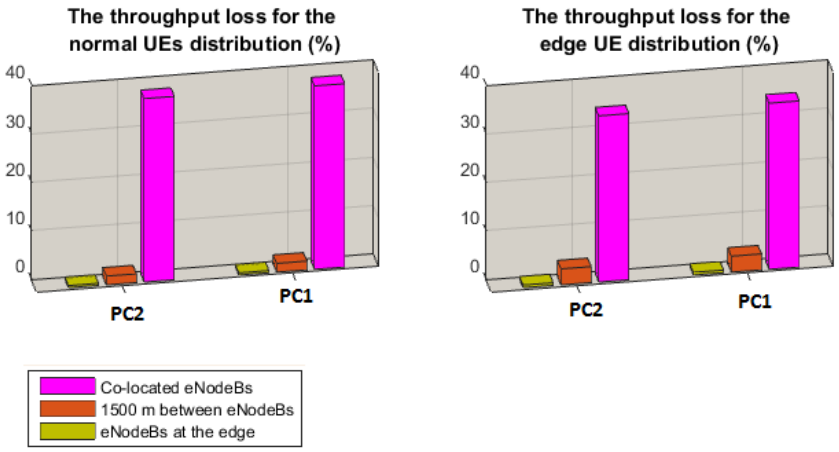

Figure 8. The expected throughput loss for the TDD downlink case

From the Figure 8, it is obvious that the downlink of the TDD system is not quietly affected by the FDD system compared to the uplink case, whereas the throughput loss ratio is only unacceptable for the CeDS case, meanwhile for the other two eDSs the throughput loss will remain less than 5%.

5. Conclusion

The co-existence between LTE-FDD and LTE-TDD systems cannot be done, so long as systems are using an adjacent frequency carrier, and propagating in the same geographical area, the impossibility because of the uplink of the TDD system will suffer a sever interference when considering the lowest recommended ACIR offset. The result also showed that, a little different between the two power control parameters, this different because of the narrow considered transmission channel. For the system to work properly, the study suggests an enough spatial separation and ACIR offset should be considered, on the other hand an interference mitigation mechanism should be considered as well.

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