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CO-EXISTENCE AND INTERFERENCE INVESTIGATION BETWEEN LTE-TDD AND LTE-FDD UNDER THE FREQUENCY BAND BETWEEN 2500 TO 2690 MHZ FOR MALAYSIA

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A thesis submitted in
fulfillment of requirement of the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
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I hereby declare that this thesis entitled “Co-existence and interference investigation between LTE-TDD and LTE-FDD: A Solution for the frequency bands between 2500 to 2690 MHz” is the result of my own research except as cited in the references.

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For my beloved father, may his soul be embraced in the sacred bond of eternal life and rest in peace. For my beloved mother, my old good friend ever hopefully Allah keeps, saves and nurses her back to the her health

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ABSTRACT

The LTE-co-existence between FDD and TDD systems cannot be done, if the two systems are using an adjacent frequency band, and propagating in the same geographical area, because of a mutual interference that will initiate between the two systems. Consequently, the reason why the co-existence has been made for will not be achieved.

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 research, the co-existence is evaluated under wide range of separation distances between the FDD-eNodeBs and the TDD-eNodeBs, by applying wide range of ACIR offset for each considered distance between the eNodeBs of the two systems, the two power control parameters are performed, and two UEs distribution scenarios are considered as well.

The findings show that, the separation distance is a significant factor to mitigate the interference ratio, and to minimize the required ACIR offset, for the TLR to be acceptable and to recover the interference effect. In addition, the CeDS, MeDS, and EeDS respectively, the required ACIR offset are 130 dB, 60 dB, and 50 dB for the TDD uplink TLR to drop less than 5%. Meanwhile, 140 dB, 70 dB, and 65 dB of the ACIR are required for the uplink of the FDD, system which are considered quite beyond the acceptable ratio. On the other hand, the downlink of the FDD/TDD experiences high interference only in the case of CeDS, whereas, for TDD, 80 dB of the ACIR is required, meanwhile, 60 dB for the FDD case. The other interference scenario cases such as downlink of TDD/FDD considering FDD/TDD interference are acceptable.

ABSTRAK

LTE-kewujudan bersama antara FDD dan TDD sistem tidak boleh dilakukan, jika kedua-dua sistem sedang menggunakan jalur frekuensi yang bersebelahan, dan di kawasan geografi yang sama, kerana gangguan bersama akan dimulkan antara kedua-dua sistem. Oleh yang demikian salah satu, sebab mengapa kewujudan bersama tidak akan tercapai. Kajian ini dilaksanakan berdasarkan parameter yang realistik untuk membantu pereka rangkaian untuk membuat keputusan tentang peruntukan kekerapan dan rangkaian pergerakan yang terbaik untuk mencapai prestasi yang lebih tinggi di bawah kos yang paling rendah. Sepanjang kaglan ini, kewujudan bersama dinilai di bawah pelbagai jarak pemisahan antara FDD-eNodeBs dan TDD-eNodeBs, dengan mengaplikasikan pelbagai offset ACIR bagi mengimbangi setiap jarak di antara eNodeBs kedua-dua sistem, kawalan dua kuasa parameter yang dilakukan, dan dua senario pengedaran UEs adalah dipentingkan. Dapatan kajian menunjukkan bahawa, jarak pemesanan merupakan faktor uang signifikant untuk memidahan nisbah interference dan menguragkan offset ACIR supaya TLR boleh diterima dan menguragkan semula interference. Di samging itu CEDS, MEDS dan EeDS nilai ACIR offset adalah 130 dB, 60 dB, dan 50 dB manakala diperlukan untuk TDD uplink kerugian kendalian jatuh kurang daripada 5%, 140 dB, 70 dB, dan 65 dB ACIR adalah untuk kes uplink sistem FDD yang dianggap sebapin nisbah yang boleh diterima. Sementara itu, membandingkan dengan pautan turun daripada FDD/TDD, system ini didapati mempunyai inference tinggi pada tidak banyak dilaksanakan oleh uplink sistem TDD / FDD; untuk TDD manakala 80 dB ACIR diperlukan 60 dB ACIR untuk pautan turun FDD itu. Lain-lain scenario interference seperti pautan turun TDD/FDD menganggap FDD/TDD interference sebagai boleh terima.

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LIST OF ABBREVIATIONS

3GPP	–	Third Generation Partnership Project
ACI	–	Adjacent Channel Interference
ACIR	–	Adjacent Channel Interference Ratio
ACLR	–	Adjacent Channel Leakage power Ratio
ACS	–	Adjacent Channel Selectivity
BEMs	–	Bit Error Metrics
BWA	–	Broadband Wireless Access
CCI	–	Co-Channel Interference
CDMA	–	Code Division Multiple Access
CeDS	–	Co-located eNodeB deployment scenario
DQPSK	–	Differential Quadrature Phase Shift Keying
EDGE	–	Enhanced Data Rates for Global Evolution
eDSs	–	eNodeB Deployment Scenarios
EeDS	–	Edge-point eNodeB deployment scenario
eNodeBs	–	enhanced Node base station
EUDS	–	Edge UEs Distribution Scenario
EVM	–	Error Vector Metric
FDD	–	Frequency Division Duplex
GPRS	–	Generalized Packet Radio Service
GSM	–	Global Mobile system
HSDPA	–	High-Speed Downlink Packet Access
HSPA	–	High-Speed Packet Access

HSUPA	–	High-Speed Uplink Packet Access
ICI	–	Inter-Channel Interference
ICIC	–	Inter-Cell Interference Coordination
IMT-2000	–	International Mobile Telecommunication-2000
ITU	–	International Telecommunications Union
kbps	–	kilo-bit per second
LTE	–	Long Term Evolution
LTE-A	–	Long Term Evolution-Advanced
MCL	–	Minimum Coupling Loss
MCMC	–	Malaysian Commission and Multimedia Communications
MeDS	–	Mid-point eNodeB deployment scenario
MIMO	–	Multiple Input Multiple Output
NUDS	–	Normal UEs Distribution Deployment Scenario
OFDM	–	Orthogonal frequency division multiplexing
QAM	–	Quadrature Amplitude Modulation
QPSK	–	Quadrature Phase Shift Keying
RBs	–	resource blocks
Rel	–	Release
SMS	–	Short Messaging System
SRSP	–	Standard Radio System Plan
TDD	–	Time Division Duplex
TDMA	–	Time Division Multiple Access
TLR	–	Throughput Loss Ratio
UDSs	–	UEs Distribution Scenarios
UMTS	–	Universal Mobile Telecommunications System
VoD	–	video on demand
UE	–	User Equipment
SINR	–	Signal to Interference Noise Ratio

CHAPTER 1

INTRODUCTION

1.1 Preamble

The modern mobile communication systems is not only reserved for just voice and telephony services any more, it is supposed to offer applications such as email, Web browsing, message texting, streaming audio and video and many other beyond technologies which have aggressive usage of Internet and data packing. Therefore, the developing of those legacy technologies were very needful to provide higher data rates, and sufficient network capacity, which it is necessary to reduce the scarcities for those rich multimedia application as high as possible.

1.2 Background of the study

Since the twenties of the last century, the communication system is started with analog telecommunications standards and continued until it was replaced by 2G digital telecommunications. The second-generation (2G) digital mobile communications systems were introduced in the early 1990s. Then the Global System Mobile standard has later been evolved into the Generalized Packet Radio Service (GPRS) to support a peak data rate of 171.2 kbps. The modulation scheme of the GPRS has evolved, whereas, new technology was called Enhanced Data Rates for Global Evolution (EDGE) (Mazur, Lindheimer, & Eriksson, 2001). The development kept increasing;

whereas, a new technology in North America used both TDMA and FDMA to compose which was called Code Division Multiple Access (CDMA) technology (Shi, 2007).

In North America, the Third Generation Partnership Project (3GPP) was the standardization body, which established technical specifications for 3G based systems on the evolution of CDMA technology and beyond. In 1997, 3GPP has started working on a standardization effort to meet goals specified by the International Telecommunications Union (ITU) and International Mobile Telecommunication-2000 (IMT-200) project. The goal of this project was the transition from a 2G TDMA-based GSM technology to a 3G wide-band CDMA-based technology called the Universal Mobile Telecommunications System (UMTS). The significant change is represented by the UMTS in mobile communications at that time. It was standardized in 2001 and dubbed Rel 4 of the 3GPP standards. As an upgrade to the UMTS system, the High-Speed Downlink Packet Access (HSDPA) was standardized in 2002 as Rel 5 of the 3GPP. High-Speed Uplink Packet Access (HSUPA) was standardized in 2004 as Rel 6, with a maximum data rate of 5.76 Mbps. Both of these standards, together known as High-Speed Packet Access (HSPA), were then upgraded to Rel 7 of the 3GPP standard known as HSPA+ or Multiple Input Multiple Output (MIMO) HSDPA. A rate of up to 84 Mbps using HSPA+ technology can be reached and was the first mobile standard to introduce a 2×2 MIMO technique.

With the mass-market expansion of smart-phones, tablets, notebooks, and laptop computers, users demand services and applications from mobile communication systems need more than 84 Mbps, therefore, the 3GPP introduced a new technology to meet the requirements for those devices which is dubbed as Long-Term Evolution Rel 8 (LTE Rel 8), it is commonly marketed as 4G LTE, a standard for wireless communication of high-speed data for mobile phones and data terminals (Dahlman, Parkvall, & Skold, 2013). It is based on the GSM/EDGE and UMTS/HSPA network technologies which can increase data rate up to 300 Mbps with scalable bandwidth from 1.4MHz up to 20 MHz. The Rel 8 LTE standard later evolved to LTE Rel 9 with minor modifications and then to Rel 10, also known as the LTE-Advanced (LTE-A) standard.

The LTE-A features can be represented as an improvements in spectral efficiency, peak data rates, and user experience relative to the LTE. With a maximum peak data rate of 1 Gbps, LTE-A has also been approved by the ITU as an IMT Advanced technology. The most challenges in the evaluation toward LTE-A is to achieve higher radio access data rates, providing sufficient coverage and capacity for the system, producing a wider scalable bandwidth, improving in the spectral efficiency, reduced operating costs, multi-antenna system, low latency, seamless integration with the Internet and existing mobile communication and enable highest possible cell edge user throughput. The mentioned targets represent obstructions for the present generation (LTE Rel 8) and it should be solved in order to move forward to the LTE-A (LTE Rel 10).

Table 1.1: Summary of mobile communication development (Zarrinkou, 2014)

Technology	Theoretical peak data rate (at low mobility)
GSM	9.6 kbps
CDMA	14.4k bps
GPRS	171.2 kbps
EDGE	437 kbps
CDMA-2000 (1xRTT)	307 kbps
WCDMA	1.92 Mbps
HSDPA (Rel 5)	14 Mbps
CDMA-2000 (1x-EV-DO)	3.1 Mbps
HSPA+ (Rel 6)	84 Mbps
LTE (Rel 8 and Rel 9)	300 Mbps
LTE-Advanced (Rel 10)	1 Gbps

The gap between user demands and network capacity is going bigger and bigger due to the continuous the development of smart phones and devises is unceasing with aggressive data applications are introduced to the market, because of that the mobile operators are being in a big predicament and face a huge competition with each other in order to provide a satisfactory network experience through for instance, higher data rate, lower latency and seamless connections to their users and at the same time is too hard for them to improve the network parameters, with reducing the network construction and operation costs besides the traditional revenue source of voice and SMS.

LTE as a mobile communications provides two different technologies Frequency Division Duplex (FDD) and Time Division Duplex (TDD) which use paired spectrum and unpaired spectrum respectively (Ghosh & Ratasuk, 2011). In order to meet the users demand that is mentioned before the mobile operators seek for achieving a full investment of the whole available spectrum for both TDD and FDD technologies.

The earliest LTE technology concept prefers the FDD technology to TDD, however nowadays TDD technology have a great demand as a complementary technology for the FDD in order to enhance capacity, coverage and end user throughput. Little by little, TDD has grown and became a key part of LTE and much popular than FDD technology. The modern mobile communication systems, use both technologies in which is dubbed as co-existence technology, which can gain additional free bandwidth for the existed system on accounting of keeping the progress with the user demand and offering a better peak data rate, balancing and shifting the load between them dynamically.

The operators across the world are looking to exploit the available spectrum for both earliest technology FDD and the new one TDD in order to meet the growing demand for network capacity. TDD is developed in order to provide extra capacity in parallel with existing FDD deployments. TDD is an equally viable and mature technology today as FDD.

While FDD uses paired spectrum, TDD uses unpaired spectrum (Refer to Chapter two, section 1.1). Therefore, it can provide flexible asymmetric uplink and downlink spectrum allocation to suit the market, whereas the most popular applications and thus the relative uplink/downlink loads can vary. For TDD, using the smart antenna technology provides ultra-high data rates and a superior user experience. Different from other technologies, TDD has gained global momentums based on several of its key advantages, for instance, the utilization of unpaired, affordable spectrum resource, and flexible uplink/downlink data rate.

TDD has drawn much attention within the industry, and became a promising candidate for the mobile broadband solution (Holma & Toskala, 2009). The development of TDD is still at its infancy and its prospect is yet to be proven by the markets over the coming years.

1.3 Problem statements

The requirements for utilizing the frequency bands between 2500 MHz to 2690 MHz and between 2300 MHz to 2400 MHz have been stated by the Standard Radio System Plan (SRSP) for the Broadband Wireless Access (BWA) systems in Malaysia (Commission, 2012) and (Commission, 2009), which it is called Malaysian Communications and Multimedia Commission (MCMC). It provides information about the minimum requirements for using the frequency band, technical characteristics of radio systems, frequency channeling, coordination initiatives in order to maximize the utilization, minimize interference and optimize the usage of the band. The frequency band between 2500 MHz to 2690 MHz is not only reversed for Malaysia, it is divided among Malaysia and its neighbor countries Brunei, and Singapore. According to the frequency allocation from the MCMC, the interference that may occur between Malaysia and its neighboring countries will be minimized if there is enough spatial separation between the systems which use adjacent frequency bands, but still the interference could be existed between Malaysia's operators or even between the systems which belong to same operator so long as the systems use adjacent frequency bands.

In the wireless communication generally the interference is incompletely avoidable, but at least it can be mitigated 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.

1.4 Aim

In order to achieve interference investigation for the co-existence between LTE-TDD and LTE-FDD for Malaysia under frequency band from 2500 to 2690 MHz.

1.5 Objectives

The objective of the research is to evaluate the amount of interference based on realistic parameters in order to help the network designer to make decisions about the best frequency allocation and network deployments so that higher performance under the lowest possible cost can be achieved. The purposes of the study can be summarized into four points:

1. To study the interference impact of the proposed frequency bands by the MCMC between Malaysia and its neighbor Singapore and Brunei.
2. To design interference modeling system for the co-existence between TDD and FDD.
3. To develop the MATLAB source code and simulate the designed interference modelling system.
4. To evaluate the impact of the interference at the co-existed Malaysia's systems considering different parameters.

1.6 Scope

The scope of the study is focused on the possible interference scenarios between the LTE-TDD and LTE-FDD generally on the data channel, under the allocated frequency band 2500 to 2690 MHz from MCMC for Malaysia considering its neighbor countries Singapore and Brunei. The defined environment area is chosen as micro-cell, urban area, and uncoordinated scenario. The investigation will be performed using MATLAB software.

1.7 Main contribution

There are two main contributions from this study; the first one can be concluded as, achieving investigation for the whole interference scenarios, between LTE-TDD and LTE-FDD, specifically for Malaysia under the frequency band between 2500 to 2690 MHz, which is divided among Malaysia and its neighboring countries Singapore and Brunei. Secondly, in specific, the impact of LTE-TDD on LTE-FDD has been investigated for China under the same frequency band, but in different frequency allocation. However, the impact of LTE-FDD on LTE-TDD has not been investigated before, which it is differing according to the essential difference between the characteristics of the TDD and FDD.

1.8 Thesis outline

The thesis contains of six chapters, the First Chapter is the introduction which is composed of preamble, study background, problem statements, objective, scope, aim, main contribution and finally the thesis outlines. Secondly, the literature review, which contains of details about the important system concepts, the previous related works, and summary of what have been done before is presented in Chapter 2. The Third Chapter is the methodology, which contains the algorithm of the system design and the mathematical modeling. Chapter 4 presentes an explanation for the MATLAB simulation source code. Data analysis and discussion are presented in Chapter 5, results are analyzed and discussed. Finally, Chapter 6 contains the conclusion and the recommendations for the future works as well.

CHAPTER 2

LITERATURE REVIEW

2.1. LTE transmission technology

There are many technologies has been introduced in the LTE, these technologies include the Orthogonal Frequency Division Multiplexing (OFDM), MIMO, turbo coding, dynamic link-adaptation techniques and two types of duplexing mode TDD and FDD. The difference in the characteristics between the two duplexing modes is the main reason of initiating many different interference scenarios. Therefore, only the duplexing modes are concerned in this study.

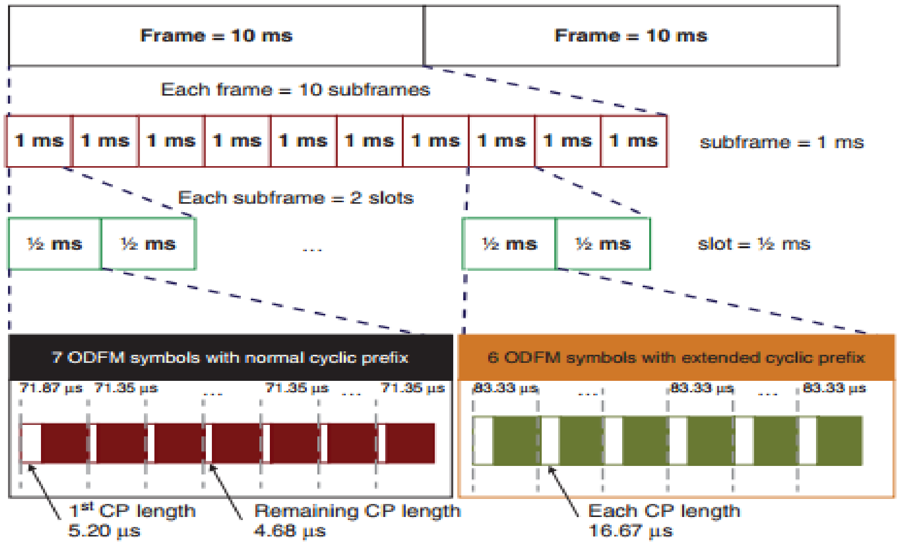

Figure 2.1: LTE time-domain structure
(Zarrinkoub, 2014)

In LTE, both the downlink and uplink transmissions are formed into radio frames with 10ms duration, the frame contains of 10 sequential sub-frames with equal durations, each frame consists of variant components depends on the type of duplexing mode and the amount of the bandwidth. The frame structure appears in Figure 2.1.

2.1.1 Frequency division duplex (FDD)

The transmission and reception are performed using two frequencies (Downlink and Uplink bar). The transmitting and receiving of data occurs simultaneously using the two different carriers separately such as appear in Figure 2.2.

2.1.2 Time Division Duplexing (TDD)

TDD can be considered as a full duplex communication using a half-duplex communication mode, whereas the transmission and reception are done using one frequency band but in different time-slots, separated by a guard time. TDD mode has 7 different configurations for uplink and downlink; these configurations are dubbed as configurations 0 through 6, as it is shown in the following Figure 2.2.

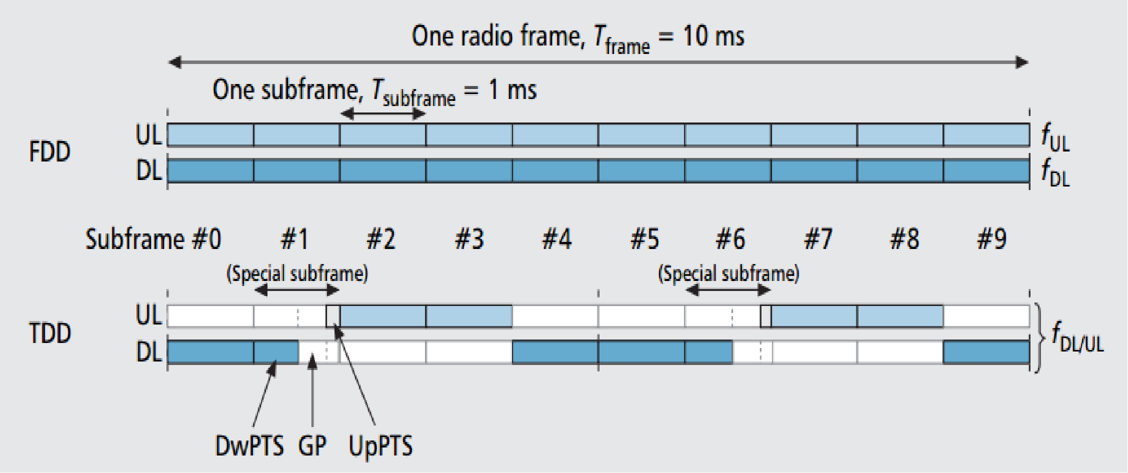

Figure 2.2: LTE frame structure

(Astely et al., 2009)

2.1.3 FDD vs. TDD

Table 2.1: LTE FDD vs LTE TDD technique.

TDD	FDD
Unpaired spectrum (not symmetrical).	Paired spectrum (symmetrical).
Can be relatively adjusted to the actual situation.	Fixed transmission technique.
Good for one direction application.	Good for the interactive application.
The guard period between the downlink and uplink transmissions is must.	No need to use guard periods between the downlink and uplink transmissions.
Relatively low system capacity.	Better system capacity.
Complementary technology.	Basic technology.

Both TDD and FDD are used in LTE. However, LTE-TDD is nowadays favored by a majority of implementations because of the unpaired spectrum, flexibility in choosing uplink to downlink data rate ratios, and the ability to exploit channel reciprocity. The FDD uses paired spectrum which provides two separated carrier frequencies, one for uplink and another for downlink. This is because of the both uplink and downlink transmission can occur simultaneously in the same time within a cell. Conversely, in the TDD frame the Uplink and Downlink transmission occurs reciprocally in different time slots. The frequency allocation is described in Table A.1 and Table A.2 (Refer to APPENDIX A) for FDD and TDD respectively (Networks, 2013) and (Inc, 2007).

2.2. Pathloss modeling

Generally, the air interface between User Equipment (UEs) and enhanced Node base station (eNodeBs) is considered as a wireless communication (Uitenbroek, 2000), which is not the same as the wire communication. The superiority of the wire communication appears clearly in the term of the received power and the amount of the losing in the path between the transmitter and the receiver. In (Anderson & Rappaport, 2004) and (Anderson et al., 2002), this loss between the transmitter and receiver is defined as the ratio of the effective transmitted power to the received power in the receiver and calculated as easiest form in the case of the free space loss, which means the absence of the terrestrial objects between the receiver and the transmitter, such as shown in Figure 2.3. Equation 2.1 in (Arunabha et al., 2010) represents the easiest form of calculating the received signal from the transmitter.

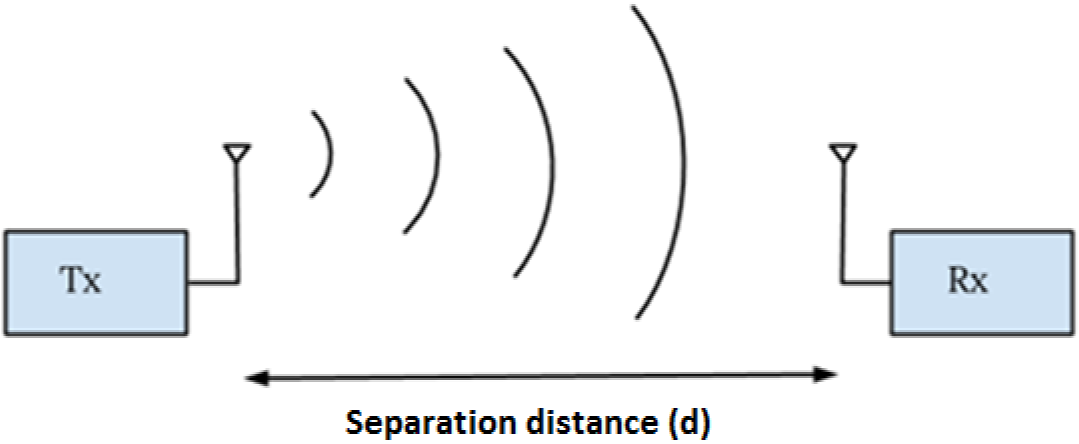

Figure 2.3: Free space pathloss.

$$P_r = P_t\left(\frac{\lambda^2 G_t\, G_r}{(4\pi d)^2}\right) \tag{2.1}$$

Whereas:

- G_t: The gain of the transmitter antenna.
- G_r: The gain of the receiver antenna.
- λ: The wavelength.
- d: The separated distance between the transmitter and receiver.
- P_t: The transmitted power.
- P_r: The received power.

Unfortunately, the transmission environment is not always clear as Figure 2.4. There are many other types of pathloss that can degrade the received signal, such as shadowing which is considered as a random variable, based on temporary obstacles between the transmitter and receiver in a predetermined range of values (Rahnema, 2008), and the fading which means receiving many versions of the same signal in different times because of the reflection from the around terrestrial objects. All the mentioned parameters are included in the calculation of the path loss between UEs-to-eNodeBs and UEs-to-UEs such as appears in Figure 2.3.

Generally from (SMG, 1997), the transmission loss can be calculated using Equation 2.2 as a summation of the free space loss L_{fs}, the diffraction loss from rooftop to the street, L_{rts}, and the reduction due to multiple screen diffraction past rows of buildings, L_{msd}. These three parameters differ according to the environment and the situation of transmitter and receivers antenna, which provides many different models:

$$L\left(d\right) = L_{fs} + L_{rts} + L_{msd} \tag{2.2}$$

For calculating the path loss, there are many empirical models that have been developed for many scenarios depending on the nature of the propagation area, the type of eNodeB itself for a certain range of the transmission frequency, the distance between the transmitter and the receiver and many other parameters.

An investigation is done in (Khan, Eng, & Kamboh, 2012) to evaluate the performance of different path loss models in various environments to determine the signal strength by considering many heights of the receiver antenna under 2.4 GHz frequency band. A set of seven path loss models are tested and the result are listed in Table 2.3 COST-231 HATA, ECC-33, SUI, HATA, COST-231 WI, HATA and Ericsson models, under the assumption parameters which are listed in Table 2.2 The results recommended that, the antenna heights and environments should be taken into consideration for the path loss estimation and performance differentiation, in terms of signal strength compared to the free space pathloss.

Table 2.2: The pathloss modeling assumptions

(Khan *et al*., 2012)

Parameters	The value
Environment	Urban, suburban and rural.
Operation frequency	2.4 GHz.
Distance between source and destination	Maximum 10 km.
Shadowing correction	9 dB for rural, and 10 dB for suburban and urban.
Building to building distance	60 m.
Average building height	20 m.
Street width	30 m.
Street orientation angle	400 for urban and suburban.

Table 2.3: The percentage of the models pathloss compared to free space pathloss (Khan *et al*., 2012)

Model	Antenna heights		
	6m	9m	12m
COST-231 WI (urban)	22.2%	-	-
HATA (urban)	-	20.31%	12.36%
COST-231 HATA (urban)	40.16%	38.25%	36.79%
SUI (suburban)	12.47%	11.08%	-
Ericson	56.54%	55.55%	12.57%
COST-231 WI (rural)	12.57%	12.57%	12.57%
SUI (rural)	28.24%	-	-
COST-231 HATA (rural)	-	22.41%	14.39%
Ericson	77%	-	-

2.3. Transmitter and receiver required characteristics

2.3.1 Adjacent Channel Leakage power Ratio (ACLR)

Mainly because of transmitter non-linearity, the spectrum mask from transmitter will leak into adjacent channels. Therefore this is a very important system parameter, since it is essential for the co-existence performance of systems on adjacent channels. The ACLR is a ratio of the transmitted power to the power measured after a receiver filter in the adjacent RF channel. Both the transmitted power and the received power are measured within a filter response that is nominally rectangular, with a noise power bandwidth equal to the chip rate (Specification, Radio, & Network, 2009).

2.3.2 Adjacent Channel Selectivity (ACS)

The receiver will have additional interference from the adjacent channel, since the receiver filter cannot be ideal, i.e. not “nominally rectangular” as proposed in the definition of ACLR. The filter will have side lobes in the adjacent channel, causing the power from the main lobe of the transmitted interference source to affect receiver performance. The ACS is known as Adjacent Channel Selectivity is a measure of a receiver’s ability to receive a signal at its assigned channel frequency, in the presence of a modulated signal in the adjacent channel. The ACS is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel frequency (Specification, Radio, & Network, 2009).

2.3.3 Adjacent Channel Interference power Ratio (ACIR)

The ratio of the total power transmitted from a source (eNodeB or UE) to the total interference power affecting a victim receiver, resulting from both transmitter and receiver imperfections (Pike, 1999). From the above two definitions, it is clear that the ACIR (total interference between adjacent channels) solely depends on the ACLR and ACS performance. The relationship between them is described Equation 2.3:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \tag{2.3}$$

In the uplink, the limiting design factor is the UE transmitter, which will dominate the uplink interference. The reason is that ACLR-UE << ACS-eNodeB, which implies that uplink ACIR ≈ ACLR-UE. Thus, in an uplink simulation, it is essentially the UE’s ACLR performance that is simulated. In the downlink, the limiting design factor is the UE receiver, which will dominate the downlink interference. The reason is that ACS-UE << ACLR-eNodeB, which implies that downlink ACIR ≈ ACS-UE. Therefore the downlink simulation will thus essentially be a simulation of UE-ACS performance.

2.4. Previous related research work

A coexistence studies is provided in the work (Huang, Tan, Wei, Fang, & Zheng, 2011), where the study is focused in the band of 2.6GHz under many deployed scenario. The paper is analyzing the interference problems of BS to BS, BS to UE and UE to BS, except UE to UE which is assumed less important to be analyzed. The evaluation is based on the term of throughput loss for the edge and the closed users, considering distances of 0, 144, and 288m between the two eNodeBs. When eNodeB affects the uplink for another eNodeB, the results showed that, the requisite values of ACIR are 86.9 dB, 81.6 dB and 80 dB for the users those who are much closer to its eNodeBs and 87 dB, 81.9 dB and 80.6 dB for the edge users. When UEs affect the uplink of UEs belong to the other system, the requisite ACIR value are 19.4 dB, 23.2 dB and 24.4 dB for power control parameter set 1, and 18.4 dB, 21.3 dB and 23 dB for power control parameter set 2 (Refer to **Table 3.4 In CHAPTER 3**), it is noticed that, the preference PC2 to PC1 in terms of the throughput loss below than 5%. The requisite ACIR value are 19.4 dB, 23.2 dB and 24.4 dB when using the control parameters set 1, 18.4 dB, 21.3 dB and 23 dB when use the control parameters set 2. Besides that, when the eNodeBs affect the downlink of the users for the other system, ACIR values of 38.7 dB, 41.3 dB and 47.7 dB are requested to achieve throughput loss below than 5%. The study concludes that, for the co-existence between the TDD and FDD in adjacent frequency band the interference between eNodeBs should be taken into a real consideration to insure the quality of the data transmission and achieve the goal of the coexistence in the first place.

Another coexistence study is provided in the paper (Motorola Solutions, Inc., Dubai, 2013) by Muhannad Aulama using band 7 for FDD and band 38 for TDD. The evaluation is performed based on inter system interference affection in terms of capacity and performance as a function of guard band, the antenna coupling loss between the eNodeBs, and the antenna spacing between the UEs. The study is performed for two combination TDD-TDD coexistence, and FDD-TDD coexistence scenarios considering three different guard bands of 0 MHz, 5 MHz, and 10 MHz in order to determine the minimum frequency guard bands, eNodeBs coupling loss, and UE antenna isolation as well. For the term of eNodeBs coupling loss, in the real world the eNodeBs is installed corresponding to non-co-sited antennas with 10m separation which means Minimum Coupling Loss MCL of value 33 dB, non-co-sited with 100 m separation with MCL value of 53 dB, and co-located vertically with value of MCL equal to 70 dB such as in Figure. 2.4. The three values of 80 dB, 60 dB and 40 dB, corresponding to 100-meter, 10-meter, and 1-meter are considered to UEs antenna spacing. This study performs four type of interference schemes which include eNodeB-eNodeB, UE-UE, UE-eNodeB, and eNodeB-UE apart of (Huang, Tan, Wei, Fang, & Zheng, 2011) and (Liu, Zhong, Wang, Lan, & Harada, 2013) which perform only BS to BS, BS to UE and UE interference schemes.

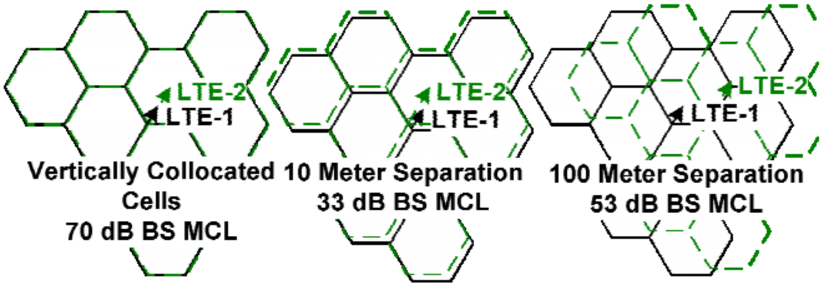

Figure 2.4: The three cell layouts (Motorola Solutions, Inc., Dubai, 2013).

Generally, this study evaluates the throughput degradation that occurs as a result of the co-location LTE systems. For the FDD-TDD case, it is observed that the guard band of 0 MHz does not provide a good isolation for both FDD uplink and downlink, while a guard band of 5 MHz provides a good isolation for the MCL value of 70 and above for FDD uplink, and 60 and more for the FDD downlink, meanwhile 10 MHz guard band is enough for 100m spaced antenna setup for uplink, and it is required at least 60 dB value of MCL for the UE spacing of 10 meters in the downlink case. The author mentioned two cases for the TDD-TDD coexistence is investigated, the results showed there is no interference for the completely synchronized duty cycle, but for the unsynchronized case with 20% duty cycle shift between the interfering system, at least a guard band of 5 MHz can provide a good isolation with the MCL higher than 53 dB, meanwhile 10 MHz provides sufficient isolation for all antenna deployment setup. 5 MHz can provide an acceptable isolation for the UE-UE with MCL value of 80 dB and as well 60 dB for 10 MHz guard band. The study concluded that, the best guard band is 10 MHz for TDD-TDD coexistence at all eNodeBs MCL values, and also for FDD-TDD coexistence with MCL values higher than 53 dB to provides good isolation at the eNodeBs, a guard band of 0 dB is considered as an acceptable isolation regardless of BS MCL values. Therefore, it is recommended that, not to use 0 MHz as a guard band in LTE frequency planning.

A coexistence investigation between two LTE macrocells has been performed in the paper (Lan & Harada, 2013) such as shown in Figure. 2.5. In addition there are two methods for power allocation-based are proposed for eNodeB-to-eNodeB interference, whereas, the only different between them is the initial transmission power setting. A previous study on (Motorola Solutions, Inc., Dubai, 2013) recommends 10 MHz guard band, however this study showed higher spectrum efficiency and even a better performance when the guard band is equal to or narrower than 10 MHz. Specifically, the study focused on a power allocation solution for co-located coexistence scenario between two macrocells in order to reduce the interference based on adjusting the transmission power theory of the aggressor eNodeB. According to the results, the throughput loss will be less than 5% using the proposed methods. In addition, the result showed that, 87 dB of ACIR is required for the 5% average throughput loss in the coordinated case, which is considered much higher than the scheduled eNodeB RF characteristics where the ACLR is 45 dB and ACS is 42.3 dB. It is concluded that, if there are two operators using adjacent frequency bands in the same geographical area, the transmission power decreasing is a one way to avoid a severe Adjacent Channel Interference ACI. It is observed, that method 1 allows the aggressor much lower transmission power compared to method 2. A 30% and 40% of performance loss is suppressed when considering guard band of 0 MHz guard band compared to 5 MHz and 10 MHz guard bands respectively. Generally, the first method is appropriated in the case of two different operators meanwhile the second one for the case of one operator owns the two LTE networks whereas some information can be shared between them.

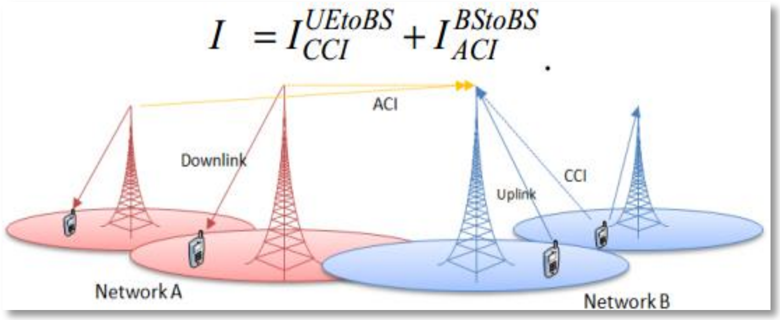

Figure 2.5: eNodeB-to-eNodeB interference scenario (Lan & Harada, 2013).

The work by author (Liu et al., 2013) agreed that, the coexistence research for LTE systems is strongly required, when the LTE-TDD and LTE-FDD system propagated in the same geographical area and adjacent frequency band, in such case the transmitted data can suffer a severe interference that can damage the data in the both coexisted systems. This research focused throughout the previous coexistence studies was generally on the throughput loss for the overall data channel. However, the feature of this study is, evaluating performance of control channels (CCHs) in the typical coexistence scenario not only data channel, because the quality of CCHs is significantly limited the performance of communication systems. As it is anticipated, the performance of uplink CCHs of the victim system is significantly degraded in the co-location case. It is recommended that, the required value of the ACIR is 41.2 dB in order to prevent the effect of the ACI which is generated by the eNodeBs of collocated LTE system at the uplink of CCHs of the victim LTE system, but in the uncoordinated deployment scenario the ACIR between eNodeBs should be 59.8 dB even the target received power is set to the maximum value.

Throughout the work by author (Zheng et al., 2009), the interference problem and its solution is investigated including the two power control sets, system bandwidths and occupied frequency bands. Beside that the newest LTE technologies are investigated adopting beam-forming technology or (ICIC) mechanism. Therefore, under current LTE Radio Frequency (RF), this study ensures that, two LTE systems can be coexisted considering these advanced techniques. Alike to (Lan & Harada, 2013), if more attention on transmission design is paid, this can significantly reduce the interference on narrow-band system. This study showed that, when locate an LTE system at the edge of other LTE system base stations. The edge user of the second system will transmit at higher power in order to ensure their link qualities, which causes severe interference to the second system. Therefore, the necessary ACIR is to avoid the interference should not be less than 24.3 dB, whereas it is only 18.3 dB when the two systems co-sited in the same place. In the case of the LTE uplink interferes the uplink of another system, also the results ensures the preference of PC1 than set 2 in the term of the required ACIR. The study concluded that, when the beam-forming technology was adopted, the requisite ACIR value decreases by 20 dB. After applying the beam forming the result showed that, when the two systems is shifted by D=433 m, this results in the interference will be less compared to co-site situation, which can show the benefit of performing this technology. The result is also indicted that, the requisite ACIR value will be decreased by 10 dB when apply inter-cell interference coordination mechanism.

Another importance of the interference analysis is also recommended by Wei, Jie and Zhong in (Wei, Zhong, Liu, & Fu, 2014). In this work the control channels interference such as Figure 2.6 is investigated from UE to physical control channels between the FDD and TDD under frequency band of 2500MHz to 2690MHz. The results ensure that, if the FDD and TDD-eNodeBs are co-located using adjacent frequency bands, the physical control channels may not be demodulated properly. The interference severity of physical control channels is investigated under wide range of ACIR offset values. The results show the preference of PC2 compared to set 1 in the term of the required ACIR, and the severity of Co-channel Interference CCI is much higher compared to ACI, because of the transmission power of the UE is much less than that of the eNodeBs.

Author (Lan & Harada, 2012) paper investigated the interference problem of macro-cell/micro-cells and macro-cell/pico-cells, in LTE networks. The focus was on analyzing the ACI of the cells, under different duplex modes TDD/FDD and FDD/TDD, using adjacent frequency bands (2500 to 2690 MHz). Based on the results, it is found that, the coexistence is not possible in some scenarios of two LTE systems using the mentioned radio frequency if the throughput is considered important. The main motivation behind this study is, to see the possibility of deploying small cells with low-transmission power eNodeBs with macro-cell network in the adjacent frequency band, and also determining the uplink capacity of FDD macro-cell network as a result of the ACI from eNodeBs and UEs of TDD micro/Pico system.

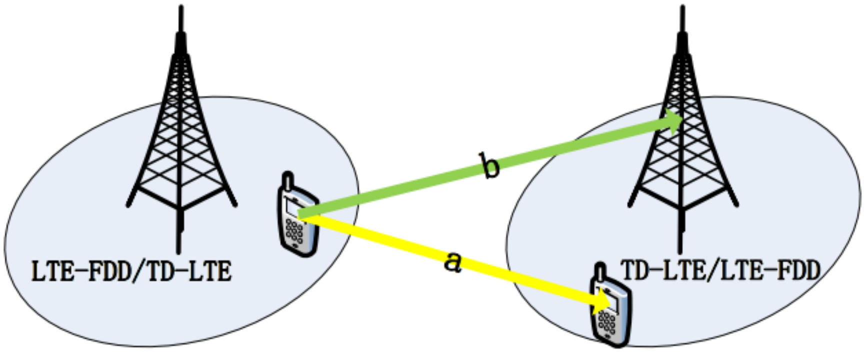

Figure 2.6: Interference to uplink and downlink control channels (Wei, Zhong, Liu, & Fu, 2014).

This study concluded that, in order to keep the throughput loss of the FDD uplink smaller than 5% when affected by the downlink of TDD-downlink, at least about 77 dB and 50 dB ACIR are needed for Macro\micro-cell and Macro\pico-cells coexistences respectively. A 37 dB and 17 dB is required for Macro\micro-cell and Macro\pico-cells when considering the effect of TDD uplink at the FDD uplink. When the FDD downlink is interfered by TDD downlink the required ACIR values are 35 dB and 42 dB for Macro\micro-cell and Macro\pico-cells coexistence respectively. According to the transmission power of the TDD pico-cells; its impact at the FDD downlink is much smaller compared to the impact of the TDD micro-cell.

A simple mathematical model is mapped in (Liu, Zhong, Wang, Lan, & Harada, 2013b) to show the effect of the control channel performance on data channel under the effect of the adjacent channel interference (ACI) on the control channels. It is found that, the severe interference occurs from the downlink of the co-located LTE eNodeB at the uplink of the victim LTE system. It is noticed that, the control channel are located more closed to the transmission band of the interfering system, thereby, the received interference by the CCHs is more serious. The main reason of the study is to propose a mapping from the CCHs performance to the system throughput. There are four type of interference considered by the author:

1. TDD/FDD downlink to FDD/TDD downlink.
2. TDD/FDD downlink to FDD/TDD uplink.
3. TDD/FDD uplink to FDD/TDD downlink.
4. TDD/FDD uplink to FDD/TDD uplink.

The probability of the correction detection for the CCHs is considered as base for the model. For the downlink 5% is considered, it is noticed that 32.7 dB value of ACIR is required in order to achieve 0.5% of different for the system throughput with and without CCH. For the victim edge UEs the difference reached up to 4%. It is noticed that, the throughput loss is lower in PC set 1 compared to PC set 2. For the uplink throughput loss in order to drop less than 5% , 85 dB of ACIR is required when the ACI comes from the downlink. When the interference comes from uplink, the ACI is very smaller compared to the ACI which comes from downlink, for both PC set 1 and 2 the throughput loss drop less than 2.5% when the ACIR reaches 0 dB for the downlink and 30 dB for the uplink throughput loss case.

An experimental study is proposed in the paper (Cano-Pons, Chareau, & Fortuny-Guasch, 2012) by European Commission. The adjacent channel interference is evaluated to determine the impact of 5MHz channel bandwidth of LTE-TDD on 5MHz channel for UMTS-FDD and LTE-FDD uplink using 1920 MHz frequency band for the channel. The transmission signal for both victim and interference system is generated using vector signal generators, and a real-time spectrum analyzer is used as a receiver for the signals. The Error Vector Metric (EVM) is used to evaluate the amount of the interference and Differential Quadrature Phase Shift Key (DQPSK) and Quadrature Phase Shift Key (QPSK) are considered as a modulation schemes are for UMTS-FDD and LTE-FDD respectively. The study concluded that, the effects of the interference that is caused by the downlink of LTE-TDD at the adjacent channel of the UMTS-FDD uplink is very low compared to the uplink of LTE FDD. It can be concluded from this study that Bit Error Metrics BEMs currently set for UMTS appears to be invalid for LTE-TDD and need to be revised.

2.5. Summary of the previous related works

Table 2.4: Summary of the related works.

No	Author	Interference scenario case	The required ACIR value	Research specification	Frequency Band
1.	Liu, Yinshan and Zhong (2013)	Downlink affects uplink	41.2 coordinated case 59.8 uncoordinated case	Physical data channel	2.6GHz China
2.	Huang, Biao and Tan (2011)	Downlink affects uplink For (0, 144, 288) m between the eNodeBs	86.9 dB, 81.6 dB 80 dB For the close UEs 87 dB, 81.9 dB 80.6 dB For the edge UEs	Physical data channel	2.6GHz China
3.	Lan, Yang and Harada, Atsushi (2013)	Downlink affects uplink	87 dB Uncoordinated case	Physical data channel	2.6GHz China
4.	Lan, Yang and Harada, Atsushi (2013)	Downlink affects uplink	77 dB micro-cell 50 dB pico-cells	Physical control channels	2.6GHz China
5.	Huang, Biao and Tan (2011)	Downlink affects Downlink For (0, 144, 288) m between the eNodeBs	38.7 dB, 41.3 dB, 47.7 dB	Physical data channel	2.6GHz China
6.	Huang, Biao and Tan (2011)	uplink affects uplink For (0, 144, 288) m separation	I9.4 dB, 23.2 dB, and 24.4 dB (PC1) I8.4 dB, 21.3 dB, And 23 dB (PC2)	Physical data channel	2.6GHz China
7.	Liu, Yinshan and Zhong (2013)	uplink affects uplink	30 dB	Physical data channel	2GHz China
8.	Zheng, Ruiming and Zhang (2009)	uplink affects uplink	24.3 dB	Physical data channel	2GHz China
9.	Lan, Yang and Harada, Atsushi (2013)	TDD downlink affects FDD uplink	85 dB	Physical control channels	2.6GHz China
10.	Lan, Yang and Harada, Atsushi (2013)	TDD uplink affects FDD uplink	37 dB micro-cell 17 dB pico-cells	Physical control channels	2.6GHz China
11.	Lan, Yang and Harada, Atsushi (2013)	TDD downlink affects FDD downlink	35 dB micro-cell 42 dB pico-cells	Physical control channels	2.6GHz China

Table 2.4 contains summarization of the previous related works, for the co-existence under the same frequency allocation for Malaysia (2.6GHz) except the works No. 7 and No. 8 which have done under the frequency band 2GHz, some researches have done generally at the physical data channel except the cases No. 4, No. 9, No. 10, and No. 11. The reset of the researches are more closely related to this research, however, a different frequency allocation and some other network parameters are specifically considered to investigate the co-existence successful possibility for Malaysia.

2.6. Research contribution

Table 2.5: Research study Contribution for the co-existence in Malaysia

Interference scenario case	The required ACIR offset	Research specification	Frequency Band
TDD uplink affects FDD uplink	Not-specified yet	Physical data channel	2.6GHz Malaysia
TDD uplink affects FDD downlink	Not-specified yet	Physical data channel	2.6GHz Malaysia
TDD downlink affects FDD uplink	Not-specified yet	Physical data channel	2.6GHz Malaysia
TDD downlink affects FDD downlink	Not-specified yet	Physical data channel	2.6GHz Malaysia
FDD uplink and downlink affects TDD uplink	Not-specified yet	Physical data channel	2.6GHz Malaysia
FDD uplink and downlink affects FDD downlink	Not-specified yet	Physical data channel	2.6GHz Malaysia

Table 2.5 specifies the considered interference scenarios in the first column, the research specification area in the third column, and the frequency band for the study in the last column. In addition, the table is bridging the gap and summarizing the research contribution, whereas, the second column which is titled as "The required ACIR offset", would display the obtained values after the simulation process.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Preamble

This study is based on 3GPP analysis in (Specification, Radio, & Network, 2014), and the simulation is based on snapshots where UEs are randomly placed in a predefined deployment scenario. The transmitted power of UE and eNodeB are simulated by applying algorithms for scheduling, and power control. The aggregation of the interference between the co-existed radio systems can be evaluated throughout the methodology that is going to be explained, which supports accurate results for the whole expected interference scenarios in the proposed system. In this research, only realistic parameters are going to be used in the simulation in order to provide realistic results.

3.2. The type of potential Interferences

According to the previous related works, and specifically in (Qingyu, et al, 2000), the coexistence study is performed in order to quantify the effect of the probable mutual interference between the two coexisted systems. The LTE-FDD has effects on the LTE-TDD, and the LTE-TDD also has effects on the LTE-FDD system in return so long as they are adjacently allocated to each other.