EMPIRICAL STAIRWELL PROPAGATION MODELS FOR LONG TERM
EVOLUTION APPLICATIONS

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To my dearest parents, siblings, beloved wife and precious children, whose presence have been a constant enlightenment in my life
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ABSTRACT

This thesis presents investigation of path loss, $PL$, and shadowing, $X_\sigma$, of signal wave along and about multi floor stairways that have dog-leg stairwell configuration. The objective is to develop frequency-dependent empirical propagation models that could approximate $PL$ and $X_\sigma$ for two conditions. The first condition is when both transmitter, $Tx$, and receiver, $Rx$, are within the stairwell structure. The second condition is when either one of the $Tx$ or $Rx$ is inside adjacent rooms to the stairwells. Attention was also drawn towards the influence of stair flights and floor height to attenuation of signal wave as it propagates within the stairwell. Analysing the impact of the aforementioned structures within the stairwell, signal wave propagating between stairwell and adjacent in-building space as well as developing frequency-dependant empirical propagation model are research areas which have yet to be covered by previous propagation studies pertaining to multi floor stairway. Frequencies of interest, $f$, ranged from 0.7 GHz up to 2.5 GHz that cover various long term evolution (LTE) and public safety communication bands. Research works involved measurement campaign in four different multi-floor buildings inside Universiti Teknologi Malaysia’s campus. $PL$’s relations with separation distance between $Tx$ and $Rx$, $d$, and $f$ were formulated with auxiliary site-specific terms added to improve two proposed empirical propagation models. It was found that for signal wave propagation where both $Tx$ and $Rx$ were within the stairwell, placing $Rx$ at elevated or lower than $Tx$ does not influence significantly recorded $PL$ data. However, for propagation between stairwell and adjacent rooms, placing $Rx$ at elevated or lower than $Tx$ may influence significantly recorded $PL$ data. Suitable measurement campaign planning was arranged in the light of this finding. The proposed models were then examined and compared with ITU-R, COST and WINNER II indoor empirical propagation models. From measurement in dedicated testing sites, it was demonstrated that the proposed models have the smallest computed mean, $\mu_R$, relative to the other standard models. The largest $\mu_R$ was -2.96 dB with a 3.34 dB standard deviation, $\sigma_R$. On the other hand, results from COST, ITU-R and WINNER II models demonstrated lower precision in all inspected settings, with the largest $\mu_R$ being 8.06 dB, 7.71 dB and 15.98 dB respectively and their $\sigma_R$ being 3.79 dB, 6.82 dB and 9.40 dB accordingly. The results suggest that the proposed $PL$ models, which considered the impact of building structures within and about the stairwell could provide higher $PL$ prediction’s accuracy for wireless communication planning pertaining to the stairwell environment, particularly for public safety responders.
ABSTRAK

Tesis ini mempersembahkan pemeriksaan terhadap kehilangan laluan, \( PL \), dan pemudaran bayang, \( X_\sigma \), gelombang isyarat di dalam dan sekitar tangga yang mempunyai konfigurasi separuh pusingan. Objektif penyelidikan ini adalah untuk menghasilkan model perambatan gelombang secara empirik yang bersandarkan frekuensi dan mampu meramal \( PL \) dan \( X_\sigma \) bagi dua keadaan. Keadaan pertama adalah ketika kedua-dua pemancar, \( Tx \), dan penerima, \( Rx \), berada di dalam struktur tangga. Manakala keadaan kedua pula adalah ketika salah satunya berada di dalam bilik-bilik bersebelahan dengan tangga. Tumpuan penyelidikan turut diberikan kepada kajian kesan deretan anak tangga dan ketinggian tingkat bangunan terhadap tahap pelemahan isyarat gelombang yang merambat di dalam struktur tangga. Analisis impak daripada struktur-struktur binaan tangga yang dinyatakan, kesan perambatan gelombang di antara tangga dan ruang dalam bangunan di sekitar tangga serta pembentukan model empirik perambatan gelombang yang bersandarkan frekuensi merupakan bidang kajian yang masih belum diterokai untuk kerja penyelidikan perambatan gelombang berkaitan tangga dalam bangunan bertingkat. Julat frekuensi, \( f \), yang ditumpukan dalam penyelidikan ini adalah antara 0.7 GHz sehingga 2.5 GHz yang meliputi beberapa julat khusus untuk aplikasi evolusi jangka panjang (LTE) dan sistem telekomunikasi untuk tujuan keselamatan awam. Kerja-kerja pengukuran dilakukan untuk persekitaran tangga di dalam empat bangunan berbeza di kampus Universiti Teknologi Malaysia. Hubungan \( PL \) dengan jarak di antara \( Tx \) dan \( Rx \), \( d \), serta \( f \) kemudiannya diformulasikan. Beberapa terma tambahan ditambah pada formulasi yang telah dibentuk untuk menambahbaik dua model perambatan gelombang yang dikemukakan hasil analisis dalam penyelidikan ini. Bagi perambatan gelombang ketika \( Tx \) dan \( Rx \) berada dalam struktur tangga, didapati kedudukan \( Rx \) berada lebih tinggi atau rendah berbanding \( Tx \) tidak mempengaruhi secara signifikan data \( PL \) yang diperolehi. Namun, bagi perambatan gelombang di antara tangga dan bilik-bilik bersebelahan, kedudukan \( Rx \) yang berada lebih tinggi dari \( Tx \) boleh mengakibatkan data \( PL \) berbeza dengan ketara berbanding dengan keadaan kedudukan \( Rx \) lebih rendah dari \( Tx \). Oleh itu, kemen pengukuran disesuaikan mengambil kira penemeuan ini. Model-model perambatan gelombang yang dikemukakan kemudiannya diuji dan dibandingkan dengan model-model perambatan gelombang dalam bangunan ITU-R, COST dan WINNER II. Daripada penelitian yang dijalankan, dua model yang dikemukakan mempunyai min, \( \mu_R \), terkecil berbanding model-model rujukan lain. \( \mu_R \) terbesar yang telah dikira adalah -2.96 dB dengan sisihan piawai, \( \sigma_R \), 3.34 dB. Pengiraan berdasarkan model COST, ITU-R dan WINNER II pula menghasilkan kejitaan yang lebih rendah bagi setiap pengujian yang dibuat, dengan \( \mu_R \) terbesar boleh mencapai sehingga 8.06 dB, 7.71 dB dan 15.98 dB dengan \( \sigma_R \) sebesar 3.79 dB, 6.82 dB and 9.40 dB bagi ketiga-tiga model tersebut. Keputusan ini menunjukkan model-model \( PL \) dikemukakan yang telah mengambil kira impak struktur binaan di dalam dan sekitar tangga mampu meramal \( PL \) dengan lebih baik bagi perancangan sistem komunikasi wayarles persekitaran tangga, khasnya bagi kegunaan para petugas keselamatan awam.
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LIST OF SYMBOLS

\( PL \) - Path Loss
\( \Gamma \) - The Fresnel reflection coefficient
\( \theta_i \) - Incident angles
\( \theta_r \) - Reflection angles
\( E_i \) - Incident wave
\( E_r \) - Reflection wave
\( E_t \) - Transmitted wave
\( H_i \) - Incident wave magnetic field polarization
\( H_r \) - Reflection wave magnetic field polarization
\( \varepsilon \) - Permittivity
\( \mu \) - Permeability
\( \sigma \) - Conductance
\( \varepsilon_r \) - Relative permittivity
\( f \) - Operating frequency
\( \Gamma_v \) - Vertical E-field
\( \Gamma_h \) - Horizontal E-field
\( \eta \) - Intrinsic impedance of the mediums
\( \theta_B \) - Brewster angle
\( \lambda \) - Operating frequency’s wavelength
$h_c$ - Critical height
$h$ - Protuberance’s height
$ho_s$ - Scattering loss factor
$\sigma_h$ - Mean height
$I_0$ - Zero-order of the first kind Bessel function
$T_x$ - Transmitter
$R_x$ - Receiver
$v$ - Diffraction parameter
$d_1$ - Actual earth-plane distance from transmitter to the edge causing diffraction
$d_2$ - Actual earth-plane distance from receiver to the edge causing diffraction
$d_1'$ - Modified earth-plane distance from transmitter to the edge causing diffraction
$d_2'$ - Modified earth-plane distance from receiver to the edge causing diffraction
$L_F$ - Free space loss
$P_T$ - Transmitted signal power
$P_R$ - Received signal power
$G_B$ - Base station antenna’s gain
$G_M$ - Mobile antenna’s gain
$d$ - Distance between the transmitter’s antenna and receiver’s antenna
$L_{ex}$ - Excess loss
$L$ - Total Loss
$d_0$ - Close-in reference distance
$d_f$ - Fraunhofer distance
\( \hat{n} \) - Path loss exponent
\( \hat{R} \) - Residuals
\( X_\sigma \) - Shadowing model
\( \sigma_R \) - Standard deviation
\( \mu_R \) - Normal distributed variable
\( PL_{FS} \) - Free space loss
\( \alpha \) - Attenuation coefficient
\( k_f \) - Amount of floors
\( L_f \) - Floor loss
\( b \) - Non-linearity of \( PL \) increment with increasing floor
\( k_{wi} \) - Quantity of wall
\( L_{wi} \) - Type of wall
\( A \) - Fitting parameter
\( B \) - Intercept
\( C \) - Path loss frequency dependency
\( f_c \) - System frequency
\( X \) - Site-specific term related to the type of wall
\( FL \) - Floor Loss
\( N \) - Distance power loss coefficient
\( n \) - Number of floors
\( P_{tx} \) - Transmitted Power
\( G_{Tx} \) - Transmitted power of signal generator
\( G_{Rx} \) - Antenna gain at Rx-end
\( P_{Rx} \) - Received signal strength
\( \hat{S} \) - Total summation of the square of \( \hat{R} \)
\( \hat{\beta}_0 \) - Intercept of the graph line
\( \hat{\beta}_1 \) - Slope of the graph line
\( \hat{c} \) - Added constant term to power law expression
\( a & b \) - Constant terms in nonlinear regression expression
\( \hat{n} \) - Number of samples
\( \hat{X} \) - Mean of the samples
\( t_{crit} \) - Total number of samples
\( S \) - Standard deviation of the samples
\( \bar{\bar{f}} \) - Optimum value
\( n_{mp} \) - Total measurement point
\( PL_p \) - Path Loss predicted
\( PL_m \) - Path Loss Measured
\( X_\sigma \) - Impact of shadowing
\( \mu_R \) - Mean Error
\( \sigma_R \) - Standard deviation
\( f(\tilde{R}) \) - Probability Density Function curve
\( \sigma_X \) - Dispersion of variable population
\( \mu_X \) - Mean of variable population
\( \hat{Z} \) - Maximum probability value that \( X_\sigma \) increases average PL
\( \hat{T} \) - A specific event in which the value 1 is yielded when it is true and 0 when it is false
\( F(\tilde{R}) \) - Normally-fitted Cumulative Distribution Function curve
\( \hat{F}_R(\tilde{R}) \) - Empirical Cumulative Distribution Function curve
\( \bar{n} \) - Number of \( \tilde{R} \) variables
\( PL_{d0} \) - Path loss at difference distance
\( \hat{n}_{\text{LOS}} \) - Path loss exponent for Line Of Sight

\( S1, ..., S6 \) - Stair flights 1 to 6

\( FPF_{1\text{-floor}} \) - One floor penetration factor

\( FPF_{2\text{-floors}} \) - Two floor penetration factor

\( E_{\text{factor}} \) - Even-numbered stair flight correctional factor

\( H_{\text{factor}} \) - High stair flight correctional factor

\( \ddot{a}, ..., \ddot{d} \) - Site-specific constant terms

\( \hat{f}(R) \) - Inverse- Cumulative Distribution Function curve

\( \hat{n}_{\text{closed range}} \) - Path loss exponent for closed range

\( AF \) - Attenuation based on number of separation floors

\( SW \) - Attenuation based on number of separation wall

\( n_w \) - Number of wall
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<td>IAN</td>
<td>Incident Area Network</td>
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<tr>
<td>4G</td>
<td>Fourth-Generation</td>
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<td>CDF</td>
<td>Cumulative Distribution Function</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<td>COST</td>
<td>Cooperation in the field of Scientific and Technical Research</td>
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<td>FAF</td>
<td>Floor Attenuation Factor</td>
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<td>FDTD</td>
<td>Finite Difference Time Domain</td>
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<td>FPF</td>
<td>Floor Penetration Factor</td>
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<td>GRG</td>
<td>Generalized Reduced Gradient</td>
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<td>IAN</td>
<td>Incident Area Network</td>
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<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>ITU-R</td>
<td>ITU’s Radiocommunication Sector</td>
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<td>LOS</td>
<td>Line Of Sight</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>MIMO</td>
<td>Multiple-Input-Multiple-Output</td>
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<tr>
<td>PDF</td>
<td>Probability Density Function</td>
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<tr>
<td>QoS</td>
<td>Quality of Service</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>TCFN</td>
<td>Temporary Cognitive Femtocell Network</td>
</tr>
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<td>UTM</td>
<td>Universiti Teknologi Malaysia</td>
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<td>WAF</td>
<td>Wall Attenuation Factor</td>
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CHAPTER 1

INTRODUCTION

1.1 Background

The success of public safety personnel’s operations depend heavily on the ability of these personnel to communicate in the most effective manner. Critical information would need to be relayed among these personnel and to other associated parties that are involve in the emergency response. Growing investment towards improving the standards and capability of public safety communication technologies reflects the acknowledgement from public towards the need to equip public safety personnel with the finest telecommunication system and resources (Doumi et al., 2013). Many improvements to available communication technologies used for emergency response have been proposed in order to accelerate warning ability in the face of disaster and also assists in decision making in the disaster relief operations.

Among the most critical part of public safety communication is the one utilized by first responders who are present and actively engage in operations at emergency or disaster site. Contemporary emergency-response communication especially for first responders heavily depend on terrestrial cellular infrastructure. Unprecedented emergency events, either man-made or natural occurrence, could
lead to the cease of operation or inadequate service by terrestrial infrastructures due to damage or interrupted electricity supplies to those infrastructures. Thus, back-up telecommunication system has to be in place if such a disaster’s aftermath happens (Portmann and Pirzada, 2008).

To improve the aforementioned limitations, deployment of incident area network (IAN) that could widen and improve radio frequency (RF) coverage has been studied and in the process to be made available. The IAN network can be set-up temporarily in an *ad-hoc* manner. IAN’s areas of interests include all known environments where wireless signal strength reception need to be boosted up or the covered vicinity has to be extended (Gentile *et al.*, 2012).

The establishment of Long Term Evolution (LTE) and LTE-Advanced broadband technologies are expected to supplement variety of IAN requirements. Since these networks will be widely deployed, regulators, public community and manufacturers have begun cooperating towards realizing a common standard so less costly equipments can be used in facilitating LTE application for public safety use (Doumi *et al.*, 2013). The use of carrier aggregation (CA) technology that is supported by LTE-Advanced system (Pedersen *et al.*, 2013) means that first responders could also take advantage of large data or files transfer for effective emergency response (Al-Hourani and Kandeepan, 2013). Therefore, investigating frequency range covering from below 1 GHz until beyond 2 GHz (Yan *et al.*, 2013) that have been allocated for LTE or LTE-Advanced applications should be important to strengthen the know-how in implementing LTE- assisted IAN.

In a high rise where the number of floors is considerably large, the availability of reliable telecommunication means for emergency responders inside stairway is crucial. These responders commonly use the stair when attending to emergency cases that take place in a multi floor building due to safety reason. Thus, radio propagation along the stairway need to be carefully characterize in
order to ensure communication link between emergency responders is not susceptible to interference due to the stair setting (Lim et al., 2009). Given that the stair structure is heavily made up of reinforced concrete (Ashraf et al., 2010), radio frequency penetration from outside sources is typically minimized (Aerts et al., 2013). Thus, the use of repeaters or relays to extend coverage should be expected (Craighead, 2009). Small cell LTE relays could play important roles in filling up the gap towards enhancing public safety communication coverage for this crucial segment of a multi floor building (Al-Hourani and Kandeepan, 2013).

An IAN that is set up to provide reliable wireless coverage for stairways in a tall high rise would require a significant number of relays. Relays may need to be placed within the stair itself (Souryal et al., 2008) as well as in nearby indoor locations (Liu et al., 2014). The planning stage of establishing the relay-assisted IAN is very critical. Deploying too many relays can cause conflict in the network due to packet loss and time delay (Rafaei et al., 2008). On the other hand, insufficient number of relays would results in poor coverage (Liu et al., 2014). Modelling signal attenuation or popularly known as path loss, PL, as a function of separation distance between transmitter-receiver link could help by providing early PL prediction and act as a tool to demonstrate best practices when setting up the wireless network (Valcarce and Zhang, 2010).

1.2 Problem Statement

Investigation on wireless signal wave propagation along the stairway at different operating frequency ranges had been carried out by Yang and Wu (2001), Teh and Chuah (2005) and Lim et al. (2009). The research works, nevertheless, were based on ray-tracing deterministic approaches that are computationally intensive and require prolonged time-period to complete. Additionally, the laborious tasks require the use of software with complex
computational capabilities. A much simpler and easily implemented technique to estimate signal wave’s attenuation is via empirical PL model (Valcarce and Zhang, 2010). Empirical PL models for the stairway environment were presented by Yu et al. (2014), Lim et al. (2014) and Wang et al. (2014) but only covered operating frequency for 2.4 GHz and higher frequency ranges.

To the author’s knowledge, no existing stairway’s empirical PL models for spectrum range below 2 GHz have been proposed and available in the literature despite various bands in the mentioned range have been stipulated for public safety purpose (Matolak et al., 2013). Therefore, developing comprehensive empirical PL model that comprise of frequency spectrum below 2 GHz is necessity to assist stairway’s IAN planning since unprecedented emergency events may require the IAN to be adaptive and operates in more than one frequency (Rafaei et al., 2008).

For better characterisation of signal wave attenuation inside multi floor buildings, a mathematical term is commonly introduced in empirical PL formulation to signify losses incurred as signal wave penetrates into different floors (Sarkar et al., 2003). The proposed stairway’s empirical PL models by Yu et al. (2014), Lim et al. (2014) and Wang et al. (2014) had not considered the floor attenuation factor, which limits practical application of the models given the ambiguity on the maximum floors that the models can still be considered befitting. Hence, a different independent analysis need to be carried out to identify the floor attenuation factor for better stairway’s PL prediction.

It is also important to note that attenuation of signal wave as it penetrates nearby floors could be influenced by building’s floor height. Investigation to demonstrate the dependency of signal wave losses to floor height can improve indoor PL model (EUR., 1999). Emergency responders may encounter different high rises with floor height variations and need unique strategies to deploy IAN’s relays based on the different heights. Investigation on the effect of floor height to
floor attenuation is thus essential and must be looked into in order to warrant that proposed $PL$ model for the stairway setting could be fine-tuned with respect to diverse building floor height. At present, no study has been carried out to characterise the effect.

Aforementioned studies on signal wave propagation were also limited to propagation along the stairway structure and did not consider neighbouring indoor setting. IANs for stairway coverage are in fact expected to include adjacent in-building space where emergency responders demand seamless connectivity beyond the stairway to support reliable communication in their emergency operations (Souryal et al., 2008). Signal wave’s propagation through the stairway into nearby multi floor sections may have traits that can be distinguished from propagation in conventional indoor settings (Austin et al., 2011). Modelling the setting would facilitate future IAN implementation through an optimized deployment strategy (Liu et al., 2014).

1.3 Objectives

The aim of this research was to develop empirical propagation models with respect to the stair environment based on measured $PL$ along and about stairways residing in multi floor buildings. This aim was meant to support and further enrich literature on LTE application for public safety communication. Thus, objectives that were included in this research study are as follows.

1. To characterise $PL$ and the shadowing phenomena for propagation within the stairway as well as between the stairway and adjacent indoor settings.
2. To conduct the characterisation of PL and shadowing at different operating frequencies within the spectrum allocated for LTE.

3. To develop frequency-dependent empirical propagation models for the investigated scenarios based on the characterisation of PL and shadowing conducted.

4. To validate the empirical propagation models with measurement results and make comparison to available indoor empirical propagation models.

1.4 Scopes of Work and Research Limitation

In order to ensure the research study’s significance, the most popular and generally constructed stairway arrangement in multi floor buildings will be investigated. Follows, are the scopes of work decided for this research study.

1. The study of PL and shadowing focused on signal wave propagation within and about reinforced concrete dog-leg stairway environment.

2. The study of PL and shadowing between stairway and nearby setting would be limited to neighbouring rooms adjacent to the stairway.

3. Empirical PL measurement carried out at five narrow band frequencies namely 0.7 GHz, 0.9 GHz, 1.8 GHz, 2.1 GHz and 2.5 GHz.

4. Measurement carried out at four different student residential and faculty buildings inside Universiti Teknologi Malaysia’s (UTM) campus with diverse floor height.
Measurement carried out in the presence of sporadic and small number of moving stair occupants.

1.5 Research Contributions

This research work focused on modelling $PL$ empirically with respect to the dog-leg stairwell, which is the most common stair configuration found in modern buildings. The proposed $PL$ models have been validated and are shown to compute closer prediction-to-measured $PL$ values relative to several indoor $PL$ models that are usually set as benchmark when assessing indoor signal wave attenuation (Zyoud et al., 2013). Spectral range covered by the proposed frequency-dependant $PL$ models envelop bands that have been dedicated for public safety communications (Matolak et al., 2013) as well as Long Term Evolution (LTE) fourth-generation (4G) wireless technology (Yan et al., 2013). The proposed models could therefore be used as reference works for not only public safety communication but also the planning of LTE indoor small cells for frequencies within the range where wireless coverage associated to multi floor stairwell is concerned (Lim et al., 2014). Follows are the contributions pertaining to indoor empirical propagation modelling presented from this research study.

1. The reference measurement campaign setup for transmitter, $Tx$, and receiver, $Rx$, positioning at two examined scenarios, namely when both $Tx$ and $Rx$ are within the stairwell structure as well as when either one is located outside and adjacent to the stairwell structure. Another related contribution for the latter scenario include the identification of region where different locations of receiver, $Rx$, but with approximately similar $d$ could nonetheless resulted in considerable differences in terms of $PL$ values due to their relative position to $Tx$. The observation was reflected in the proposed model.
2. The development of the first frequency-dependant PL and shadowing models, covering a nearly 2 GHz wide spectrum ranging from 0.7 GHz up to 2.5 GHz for within the stairwell scenario.

3. The description of floor loss and stair flight impact to wireless signal wave attenuation that have never been included in preceding works on stairwell’s empirical PL models. Results from examining signal wave attenuation when penetrating different floors had in addition revealed the influence of floor height variations to PL. These observations have been weighed in to develop a more accurate empirical PL model for propagation along the stairwell scenario.

4. The development of the first frequency-dependant PL model for stairwell and nearby in-building setting covering spectrum ranging from 0.9 GHz up to 2.5 GHz. Experimental works and analysis on PL for stairwell and adjacent rooms in this research work have produced frequency-dependent PL model that is more precise for the examined scenario relative to standard indoor empirical models.

1.6 Thesis Layout

The next five chapters in this thesis cover the fundamentals along with research activities involved in the development of propagation models along and about the multi floor stairwell for LTE frequency spectrum plus the inferences drawn from the study.

The second chapter is the literature review. This chapter provides review on recent developments of public safety communication along with technologies that have been proposed to enhance the communication system. Next, studies
carried out by researchers on wireless signal wave propagation along the stairway are described. Topics on wireless propagation and the stairway structure are then explained. The chapter subsequently presents the fundamentals of statistical analysis employed in this investigation work.

The third chapter is on methodology. This chapter illuminates the flow of research study by explaining procedures of research activities that have taken place. The activities include pilot study, measurement campaign, and using certain techniques to analyse collected data for the development of propagation model.

Chapter four is on results and discussions for propagation along the stairway. In this chapter, results and analysis based on recorded $PL$ data for the stated scenario are presented in order to demonstrate related $PL$ and shadowing models as well as their validation.

Chapter five is on results and discussions for propagation between stairway and adjacent rooms. Results and discussions are explained in similar style as the presentation in chapter four.

Chapter six is the conclusion. This chapter discusses the inference drawn from this research study, justify the significance of the research work and give suggestions on future development based on the findings.
REFERENCES


International Telecommunication Union Recommendations (2001). *Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900MHz to 100GHz.* I. T. U. R.


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1. Empirical models: Empirical models are usually extracted from channel measurements conducted at some typical places. They are extracted by fitting the measurement data with some simplified mathematical formulas or distribution functions. The widely used empirical models for indoor environments include, for instance, the one-slope model, wall and floor factor models, COST231 multi-wall model and linear attenuation model etc. 2. Stochastic models: Stochastic models are usually used to model the random aspects of radio channels with random variables, e.g. fading characteristics of radio channels. From the application scenarios' perspective, we have indoor radio propagation models and outdoor radio propagation models. Many propagation models were proposed for this purpose. Most of these models are for macro and micro cellular networks. Small cell which is known as femtocell has been launched for future networks and it is wildly deployed by the mobile operators around the world. The available propagation models' accuracy is at question when applied to femtocell design and engineering. @inproceedings{Zyoud2013ComparisonOE, title={Comparison of empirical indoor propagation models for 4G wireless networks at 2.6 GHz}, author={Alhareth Zyoud and Jalel Chebil and Mohamed Hadi Habaebi and Md. Rafiqul Islam and Akram M. Zeki}, year={2013} }. Empirical stairwell propagation models for long term evolution applications. Omar I. Abdul Aziz. 2016.