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INSIDER THREAT OF INFORMATION SYSTEMS SECURITY COMPLIANCE IN LIBYAN HIGHER EDUCATION INSTITUTIONS (SYSTEMATIC REVIEW)

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ABSTRACT

The deployment of a millimetre wave over a short path is one of the keys to enabling technologies for the next generation of wireless communication systems. Path loss (PL) is the most important parameter to indicate the performance of the mm-wave wireless channel. However, the accuracy and efficiency of each model are limited to characterise path loss for an environment that is different in terms of weather conditions and geographical arrangement from that for which they have been designed. This paper analysed path loss for accurate signal estimation in Malaysia based on outdoor microcellular at 38 GHz on a 300 m path length. The impact of rain attenuation on path loss, path loss exponent (PLE), and shadow fading (SF) have been investigated. This paper also presents two-channel models utilised for simulations in terms of the outdoor Large-Scale Path Loss, the statistical spatial channel model NYUSIM (version 2) developed in 2019 by New York University (NYU) and the 3rd Generation Partnership Project (3GPP) TR 38.900 Release 14 channel mode. Even though the CI and 3GPP models are accurate and suitable in the area where the measurement campaign was carried out in the temperate climate and must need modification for different regions, such as tropical climate. The underestimation can be interpreted because of the difference in AF's attenuation factors (pressure, humidity, temperature, rain rate) calculated by the CI model in the NYUSIM simulations and the attenuation factor (AF) obtained from measurement data. The NYUSIM channel model better estimated the measured data of path loss compared with 3GPP. Thus, the CI model is suitable for outdoor environments.

Keywords: Information systems security compliance, Libyan higher education institutions Protection motivation theory, Theory of planned behavior

Introduction

The protection of information systems against unauthorized access to or modification of information is considered as the key issue on the information systems of originations [1]. Information security aims to enhance access controls, which prevent unauthorized personnel from entering or accessing a system. Additionally, its one of the vital l aspects which can Protect information no matter where that information is, i.e. in transit (such as in an email) or a storage area. Information security accts as the detection and remediation of security breaches, as well as documenting those events [] . It relies on five major elements: confidentiality, integrity, availability, authenticity, and non-repudiation[]. While the recognition of the potential dangers of information security is increasing in developed countries, in regions like

Libya in North Africa, the level of protection for this information is insufficient. (Asker & Tamtam.,2023).

Researches reveal that unintentional security incidents from insiders often occur, which could cause great devastation to information assets more than outsider attacks. In addition, researchers found that the majority of threats to information systems can be attributed to the weak experience and the awareness level of users of how to deal with internal and external security attacks on information assets (Asker & Tamtam.,2023 ; Parsons et al., 2014; Roy, 2010; Colwill, 2009).

To date, integrating Information Systems Security into Libyan Higher Education practices is still a slow and complex process, even after the Libyan revolution. Higher Education and universities accommodate ample amounts of confidential personal and educational information of international and national students, faculty and staff[5]. HEIs are increasingly using computers to manage significant academic and operational information.[6] still use the traditional style of education Information Systems Security. The researcher believes that there are prevalent barriers to the successful integration of Information Systems Security into Libyan Higher Education, including technological infrastructure, organizational support, employees' and IT professional attitudes, and technology skills.

Insider Threat Management for An Education Institution

In today's digital world, higher education institution HEI seeks to effectively securing their internal systems against security threats. This new reality means the institution has to protect against security threats from outside and inside. Today's organizations are creating more critical data than ever, which could be uploaded to the cloud, emailed outside the network or copied into a USB drive. Thus, HEI has to follow a defense depth strategy to protect against external attacks and insider threats without holding it back.

Therefore, it is substantial to consider the weather factors that affect .

Insider threat is a reality. Insiders commit fraud or steal sensitive information when motivated by money or revenge. Well-meaning employees can compromise the security of an organisation with their overzealousness in getting their job done. Every organisation has a varied mix of employees, consultants, management, partners and complex infrastructure and that makes handling insider threats a daunting challenge. With insider attacks, organisations face potential damage through loss of revenue, loss of reputation, loss of intellectual property or even loss of human life.

The insider threat problem is more elusive and perplexing than any other threat. Assessing the insider threat is the first step to determine the likelihood of any insider attack. Technical solutions do not suffice since insider threats are fundamentally a people issue. Therefore, a three-pronged approach - technological, behavioural and organisational assessment is essential in facilitating the prediction of insider threats and pre-empt any insider attack thus improving the organization’s security, survivability, and resiliency in light of insider threats[4].thus, Insider threat is a unique problem; it can never be eliminated. Although it has a generic pattern, every incident has special characteristics. No single clue is sufficient to predict a potential threat. Moreover, insider threats are unique to organisations in [3] extant opportunity-reducing techniques employed to mitigate insider threats have been evaluated . a theory of information security intelligence and examine the effects of managers' information security intelligence (MISI) on employees' procedural countermeasure awareness and information security policy (ISP) compliance intention has been proposed in [2]. Many information security incidents occur due to the negligence and unintentional behavior of internal employees resulting in a serious internal threat to the safety of organizational assets.[5]

Information security is a challenge facing Higher Education Institutions, as security breaches pose a serious threat (number / statistics) to sensitive information. CITED

Higher Education Institutions in Libya face security risks in relation to their information assets, which also stems from their own employees [7].

The increasing number (how musch /the number / %) of attack that has occurred in some of the HEIs shows that there are still in the model for Information Systems Security in Higher Education in Libya CITED

The lack of prior research models that can direct Higher Education Institutions in Libya with effective Information Systems Security, which is why the current research was conducted to provide a comprehensive framework that demonstrates the key factors that affect Information Systems Security

Thus, the research problem was the loss of confidentiality, integrity and availability of information in IS, case of some higher education institutions in Libya - Not enough resources are being invested in protecting information in higher educational institutions in Libya. []

According to the outcomes of a workshop for Faculty of Information Technology employees on information security in Libya on 06/26/2021, it has been reported that one of the reasons why IS security incidents and abuses continue to plague organisations is that organisational employees are the weakest link in ensuring IS security in according to the preliminary study – interview. They constitute an insider threat to their organisations in Libyan higher education institutions. The information systems security model has not been easy to understand because inconvenient methods cause security-related stress, leading to non-compliance. According to Elattresh et al., Managers in Libayn HEI did not evaluate employees' behaviors regularly, scale their awareness level, and provide training if needed until they adopted security-aware behaviors

The purpose of the present study will be to explore Information Systems Security in Higher Education in Libya with an emphasis on assessing the current security environment in higher education institutions based upon a conceptual model of Information Systems Security factors.

Recent studies of outdoor measurements have confirmed that carrier frequencies at 28 GHz and 38 GHz will work more effectively and reliably at a small cell size of around 200 m [15][4][16][17][2]. Throughout the literature, there is consistent evidence that full coverage can be achieved at cell radii (up to approximately 200 m for LOS and NLOS) links in dense urban environments.

Even though previous work has been done in the literature based on real measurements to predict outdoor path loss, most studies have been implemented in clear-sky conditions.

According to the author, few studies have considered rain attenuation impacts on path loss modelling [18], such as a wide-band measurement campaign conducted at 38 GHz at Urban (Campus) in Austin; during rain over short path lengths in the temperature areas. They have studied the effects of weather on the channel Additionally, in China [19], based on outdoor microcellular measurements at 26 and 32 GHz, they have implemented path loss modified by merging rain attenuation. A proposed dynamic rain model modifies the path loss models to see the difference between clear and rainy air concerning transceiver distances and rainfall intensities. Moreover, a dynamic rain cell model for a multi-user system is developed to investigate the total rain attenuation. However, in both studies, the rain rate was lower than 50mm/hence this study. There is little work on outdoor radio propagation models in mm-wave frequencies, particularly during rainy weather in tropical areas that experience a high probability of convective rainfall with large drop sizes compared to temperate regions of the world [11]. Hence the directional path loss, shadowing, and path loss exponent due to the impact of spread and randomness of rain attenuation over mm-wave propagation paths need to be investigated through measurements and extensive simulations in the tropical climate.

The use of mm-Wave in 5G and 6G wireless networks will solve the spectrum shortage in current 4G cellular communication systems that operate at frequencies below 6 GHz. However, latency, reliability, and availability are three aspects of reliable communication to enable broadband mobile outdoor applications by utilising millimetre-wave links [20]. Therefore, it's necessary to determine base stations' coverage potential in a real-world environment in a tropical area by assessing outage probability.

This paper analysed path loss for accurate signal estimation in Malaysia based on measurement at 38 GHz on a 300 m path length. The impact of rain attenuation on path loss PL characteristics, path loss exponent (PLE), and shadow fading (S.F) effect have been investigated in various T-R separation distances (extended from 1 m to 500 m). The diurnal effect on PL and the PLE has been predicted. Two-channel models are utilised for simulations in terms of the outdoor Large-Scale Path Loss, the statistical spatial channel model NYUSIM (version 2) developed in 2019 by New York University (NYU) and the 3rd Generation Partnership Project (3GPP) TR 38.900 Release 14 channel model. Rain attenuation impacts on path loss, path loss exponent, and shadow fading are analysed. Consequently, the contributions of this article can be summarized as follows:

- The effect of rain attenuation on large-scale channel characterisation at 38 GHz for 5G systems in tropical regions has been analysed and presented.
- Path loss at different distances has been estimated based on mean path loss and variance obtained by averaging the empirical measurements in dB values at 300m path length.
- The effect of diurnal variations on outdoor propagation path loss at 38 GHz has been analysed, and % of path loss exponent increase in the day-time has been determined
- A modification is proposed in the CI model to provide the most reasonable predictions of path loss for 5G links operating in the Malaysian tropical climate. The CI model has been modified by replacing the AF proposed in NYUSIM simulations with the attenuation factor introduced from the measured data at 38GHz, introducing a better representation of rain fade in a tropical climate.

1.2 Path Loss Model

Different path loss empirical models have been proposed and classified based on terrain, operating frequency range, mobile generation, and technologies. In recently published work, path loss models are mainly developed based on experimental data to fit a particular scenario or environment [21]. The received signal power decay rate variations with distance follow the free-space propagation law with a path-loss exponent of about 1.9 to 2.2. With directional antennas, the path loss when the boresights of the antennas are aligned is given by Equation (1) [22].

$$L_{LoS} = L_0 + 10n\frac{d}{d_0} + A_{gas} + A_{rain} \qquad (1)$$

where n is the path loss exponent, d is the distance between Tx -Rx, and L_0 is the path loss at the reference distance d_0. For a reference distance d_0 at 1 m, and assuming free-space propagation $FSPL\,(f, 1\,m) = 20log_{10}$ ($4\pi f \times 10^9/c$), Agas and A_{rain}, are attenuated by atmospheric gases and rain, which can be calculated from ITU-R P.676 [23-24]and ITU R P.530, respectively [25]

Among all available path loss models, the Stanford University Interim (SUI) alpha-beta-gamma (ABG), close-in (CI), and the floating-intercept (FI) models are the most popular, which can predict the RF cell size for the mm-wave bands [5][26][25]. Three parameters characterise the ABG model, shown in Equation (2), are α ,β and γ . The parameters α , slope, and intercept of a least-square linear regression best line fit the measurements. The additional parameter γ accounts for the different offsets estimated in various frequency bands.

$$PL_{[dB]} = \beta L_{[dB]} + 10.\gamma.\frac{F}{1Hz} + 10\alpha\frac{d}{1m} + \chi\sigma \qquad (2)$$

The CI model has better stability and accuracy with less complexity. Therefore, the channel developed by the University of New York named NYUSIM has implemented the Close-In model to establish the directional and omnidirectional path-loss models. In the CI model Expressed in (3), an arbitrary free–space reference distance, denoted by *d,* is first chosen to compute the free–space reference PL. Then, the path loss exponent (PLE), represented by *n,* is derived using a minimum mean square error estimate to fit the measurements best.

$$PLCI\,(f,d)\,[dB] = FSPL\,(f, 1\,m)\,[dB] + 10nlog10\,(d) + AT\,[dB] + \chi\sigma\,CI, where\ d \geq 1\,m \qquad (3)$$

$$FSPL\,[dB] = 32.4[dB] + 20log10(f) + 20\,log\,(d) \qquad (4)$$

This paper compares two popular channel models for next-generation wireless communications: the 3rd Generation Partnership Project (3GPP) TR 38.900 Release 14 channel model and the statistical spatial channel model NYUSIM developed by New York University (NYU). The two-channel models employ different modelling approaches in many aspects, such as the line-of-sight probability, path loss, and clustering methodology [5][20][26][25]. The focus will be on the outdoor Large-Scale Path Loss:

Large-Scale Path Loss (LSPL) in NYUSIM Channel Model
Large-Scale Path Loss (LSPLin the 3GPP Channel Model

1.3 LSPL In NYUSIM Channel Model

NYU WIRELESS has developed the statistical spatial channel model (SSCM) and validated it through measurements. It's one of the stochastic spatial channel models classified under the physical channel model. It was measured in several outdoor environments in rural macro-cell (RMa), urban macro-cell (UMa), and urban microcell (UMi), environments at frequencies from 28 to 73 GHz [16][5][6][25][28][29] [27]. The model is simple and requires less time with lower complexity. Moreover, NYU WIRELESS gives an actual performance of channel impulse responses similar in space and time. NYUSIM fits a wide range of operating frequencies up to 100 GHz with bandwidths from 500 MHz to 800 MHz continuous wave, multi-antenna systems and incorporates MIMO antenna arrays.

Furthermore, the atmospheric attenuation issues, such as the attenuation induced by rain, vapour, haze/fog dry air (containing oxygen), and foliage attenuation, are also addressed in the path loss modelling supported by NYUSIM software package version 1.6 released on December 15th, [24].

In the current NYUSIM software package version, 2.0 can generate various channel parameters using MATLAB code. In addition, significant channel modelling components such as human blockage, spatial consistency, and outdoor-to-indoor (O2I) penetration loss have also been implemented in NYUSIM 2.0 [29]

The Close-In (CI) model has been implemented in NYUSIM. For both omnidirectional and directional antennas, the PLE has been estimated to be 2 and 3.2 for UMi LOS and NLOS scenarios, respectively. [5-6-16-21-24-28-29-30]. The close-in model is famous for a single frequency to predict signal strength for cellular systems—the CI model accounts for the frequency dependence of path loss using a 1 m close-in. The LOS path losses roughly follow the free space reference distance based on Friis' law formula and can be expressed at least for the points with distances < 100 m [31]. Frii's free space path loss (FSPL) can be described as:

$$FSPL\ [dB] = 32.4[dB] + 20log10(f)\ 20\ log\ (d) \qquad (5)$$

This is particularly valuable when comparing propagation measurements over different mm-wave frequencies. The most significant difference in propagation path loss at mm-wave frequencies is in the first meter of propagation. The close-in model for urban areas is given as follows:

$$PL^{CI}\ (f,d)\ [dB] = FSPL\ (f,1\ m)\ [dB]\ +\ 10nlog10\ (d)\ + AT\ [dB]\ + \chi\sigma\ CI, where\ d\ \geq\ 1\ m \qquad (6)$$

Where the carrier frequency is represented as *f* in GHz, the distance is *d in meters*. The path loss exponent (PLE) is n, the attenuation term induced by the atmosphere is denoted as AT, α is the scattering coefficient, and the attenuation represents dB/m for frequencies ranging from 1 GHz to 100 GHz [16-5-6-21-24] χσ CI represents the shadow factor in dB. The lognormal shadowing model has been used to model any arbitrary link without considering antenna characteristics. The AT is the atmospheric attenuation which is given by:

$$AT\ [dB] = \alpha[dB/m]\ \times d[m] \qquad (7)$$

where α is the attenuation factor in dB/m for the frequency range of 1 GHz to 100 GHz, caused by atmospheric gases, fog, rain, snow and haze [24-6-5-29].

The path loss exponent n can be calculated as follows:

$$n = \frac{RS - \alpha[dB/m] \times d[m] - \ \chi\sigma\ CI}{10loglog\ (d)} \qquad (8)$$

and $$\chi CI\sigma = PLCI\ (f,d)\ [dB]\ -\ FSPL\ (f,1\ m)\ [dB]\ -\ 10nlog10(d) -\ AT\ [dB]$$ (9)

R_S, is the average measured received signal, and α is the attenuation.

The CI model is employed in NYUSIM, and the PLE estimated for both omnidirectional and directional antennas are 2 and 3.2 for UMi LOS and NLOS scenarios, respectively. [16][5][6][25][28][29] [27]. The 1-m CI model used in NYUSIM has the same mathematical form as the existing ABG model but has fewer parameters with much easier analysis and better accuracy over a wide range of microwave and mm-wave spectra, scenarios, and distances [5-6-21-25]. With a deterministic 1 m "close-in" free space reference term to provide a standard and stable definition of "path loss exponent" across all different parties, scenarios, and frequencies) (3GPP SSCM model)

In the [16] report, the close-in model characterises the large-scale signal fluctuations depending on the surrounding environment imposed by large obstructing objects, which causes an additional loss in the wireless channel. Hence, the net of received signal strength at the same distance is a random variable that depends from place to place and from time to time because of the different scattering. Therefore, only a single parameter, the PLE, needs to be determined through optimisation to minimise the model error of mean loss over distance in the CI path loss model. More suitable for calculating path loss of values at greater distances from 200 m up to 400 m, the close-in free space model is less sensitive to perturbations in data [21]. The path loss models discussed above are based on omnidirectional path loss.

Generally, directional path loss models cannot be obtained by simply adding directional antenna gains into the omnidirectional path loss model. This is because all paths/directions do not contribute to the directional path loss due to the spatial filtering of directional antennas [21].

Rain attenuation greatly influences the ultra-reliability requirements for outdoor environments in the 5G communication system. Therefore, it can be highlighted that rain attenuation is one of the principal components in modelling path loss for determining the 5G cell size and coverage in a tropical climate. [5-6-24] shows that the CI model with a 1-m reference distance is suitable for outdoor environments. Same as those reported in [21]. The CI propagation model is better for modelling the propagation environment at a shorter distance (less than 500m). Moreover, the CI propagation model considers atmospheric attenuation issues, such as the attenuation induced by rain, vapour, haze/fog dry air (containing oxygen), and foliage attenuation. Thus, the current study focused more on the CI propagation model.

1.4 LSPL In3GPP Model

The third-generation partnership program (3GPP) has proposed a "3GPP channel model" for frequencies up to 100 GHz. The model covers various scenarios like UMi street canyon, UMa, RMa, and indoor office. The model features include support of large bandwidth up to 10% of the centre frequency but no larger than 2 GHz, mobility of one end of the link, spatial consistency, large antenna arrays and modelling of blockage and oxygen attenuation phenomena" [30]. 3GPP Umi is the standard of the 3GPP urban micro (UMi) path loss model. Two types of large-scale path loss models have emerged in 3GPP: a single-parameter close-in free space reference distance (CI) model and a three-parameter alpha-beta-gamma (ABG) model [5-6-21-24]. Two parameters facilitate a higher degree of freedom in calculation and analysis.

The ABG PL model is given as follows:

$$PL^{ABG}\,(f,d)[dB] = 10\alpha log10\,(d) + \beta\ + 10\gamma log10\,(f) + \ \chi\sigma\ ABG$$
(10)

where α captures how the PL increase as the transmit-receive distance (in meters) increases, ß is a floating offset value in dB, γ attempts to capture the PL variation over the frequency *f* in GHz, and χσ ABG is the SF term with standard deviation in dB

In the UMi LOS scenario, the CI path loss model is utilised for d3D smaller than the breakpoint distance d′ BP. After the breakpoint distance, a new term involving the BS and UE heights is added to the CI model, where the BS height is set to 10 m, and the UE height ranges from 1.5 m to 22.5 m and is given by:

$$PL_1 = 32.4 + 21(\,d_{3D}) + 20(\,f_c) \qquad (11)$$

Table1 represent the used abbreviations

Notation	Definitions
P_{Rx} [dBm]	The desired power at the receive
P_{Tx} [dBm]	The transmit power
$G_{TX}a$	Transmitting antenna gain
$G_{RX}a$	Receiver antenna gain
$PL\ [dB]$	The propagation loss
$FSPL\ [dB$	The loss of free space
Ar	Attenuation due to rain
Aa	Attenuation due to atmospheric gases
FM [dB]	Fade margin
$P_{Rx}th$	Receiver sensitivity threshold
$\underline{PL}$	Mean value of the measured path loss at 300 m
d_i	Distance between the Tx and the Rx
σ	Standard deviation about the mean
ψ	The standard deviation of shadow fading
$prob(\%)$	Percentage of time
ψ	The standard deviation of shadow fading
γ	Threshold value of path loss
ρ	Reliability

Methodology

A short path link operating at 38GHz horizontal polarisation was monitored for one year. The link was set up between the Wireless Communication Research Lab (WCRL) and the Celcom Tower at the UTM Skudai campus in Malaysia, the distance of which is close to 300 metres. Table 2 describes the physical parameters for the link. Three types of data were collected. These are one-minute integration time rainfall rate (mm/h) and received signal level (RSL, dBm) data and path loss have been measured simultaneously, and satisfactory data availability of 98.6% was achieved for reliable statistical results. The measurements were taken for 139 rainy events of this particular year for 6,341 rainy minutes, including Malaysia's Monsoon seasons. The measured rain rate and corresponding received signal strength is presented over fixed Tx and Rx antenna height to analyse the effects of weather on the channel at 38 GHz for one year. The rain attenuation data was extracted from the received signal level, and statistical analysis was performed. The Received Signal Levels (RSL) dynamic range was 36.3 dB (varies from -25.3 dBm to -61.6 dBm). The measurements were conducted in typical LOS at approximately 18m antenna height, and any barriers did not block the experimental radio path. These data have been processed to plot a continuous rain rate and attenuation curves.

2.1 Rain Attenuation Measurements

All data of the measured received signal level PRX [dBm] considering rain attenuation was prepared in Microsoft Excel and then transferred into MATLAB for computing and plotting of attenuation factor. An average value of rain rate of 125 mm/h is found at 0.01% of the time and the corresponding rain attenuation is more than 15 dB at 38 GHz. The rain attenuation in (dB) along LOS, a 300m link with horizontally polarized, was extracted by the difference between the RSL during clear sky conditions and the RSL during rain. It does not include free-space path loss as follows:

RSL during clear sky -RSL during rainy conditions [dB] (12)

The rain attenuation has been predicted at different path lengths (100m to 500m) at 38 GHz by utilising the Budalal model proposed in [41] as shown in Figure 1, which will benefit to consider attenuation factor for path loss analysis in the next section.

2.2 Path loss calculation

The method and tools used to analyse and obtain path loss, shadowing, and path loss exponent are also presented. Measured rain attenuation was entered into two-channel models, namely: the 3rd Generation Partnership Project (3GPP) TR 38.900 Release 14 channel model and the statistical spatial channel model NYUSIM (version 2) developed in 2019 by New York University (NYU). Equation (1) has been utilised to predict mean path loss with known T-R distance for the outdoor environment, which can be computed from the link budget allocated by [32-33-34-24-21]. A step-by-step methodology and systematic approach for the analysis of path loss in this paper's implementation are as follows:

Step1: All data was organised in Microsoft Excel and then placed into MATLAB for analysis and plotting. Figure 2. Represents the research flow chart to estimate path loss from the measured data.

Step 2: Analyse the pathloss phenomenon in rainy air at 38 GHz over 300m path length statistically by utilising the measured received signal level as shown in Figures 3 and 4. The free-space propagation loss, atmospheric gasses, shadowing, and rain attenuation at different % of the time have been included in path loss calculations.

Step 3: New findings are reported primarily average path losses, the maximum amount of PL during the day (average rain rate 120mm/h, 31°-32° c) compared to the measurements taken at night (30 mm/h, 22°-24°c).

Step 4: The PL model vs probability at a further distance has been predicted

Step 5: Extract the path loss parameters from measured data by comparing them with two path loss models (3GPP) TR 38.900 Release 14 channel model and the NYUSIM (version 2)

Step 6: Comparison between predicted models with estimated PL from measured data

Step 7: Recommendation for the best PL model at mm-wave over a short path

Step8: Modify the CI model in the NYUSIM by considering attenuation factors measured at 38GHz.

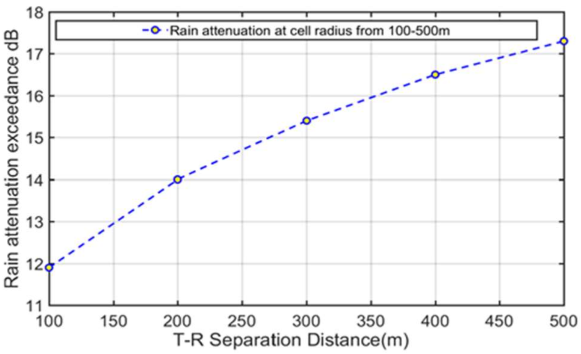

Figure 1 Rain attenuation prediction at 38GHz and path length <1km.

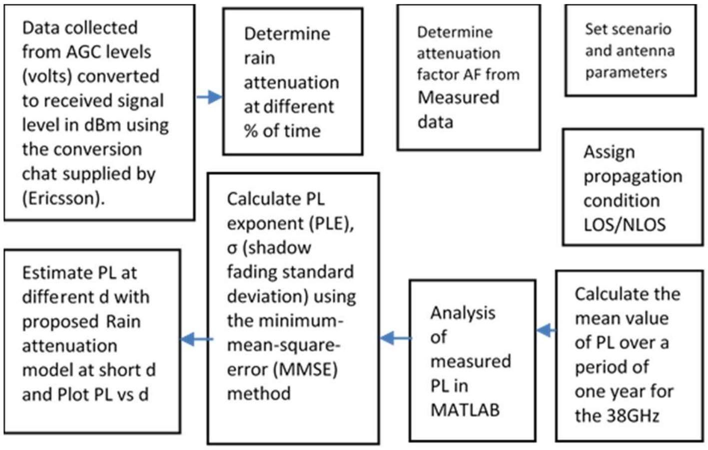

Figure 2. Research flow chart to estimate Path loss from the measured data

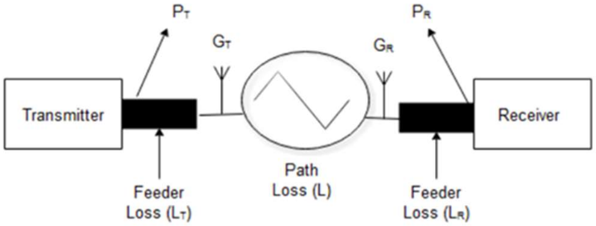

Figure 3. Pathloss phenomenon in clear air 38 GHz

The details of path loss parameters analysis have been described thoroughly in the next section. Thus:

$$PRX\ [dBm] = PTX\ [dBm] + GTXa\ [dBi] + GRXa\ [dBi] - PL_m\ [dB] \qquad (13)$$

Thus:

$$PL_m\ [dB] = PTX\ [dBm] + GTXa\ [dBi] + GRXa\ [dBi] - PRX\ [dBm] \qquad (14)$$

For a communication link with TX power Pt, the TX antenna gain GTXa, and RX antenna gain GRXa, the received power PRX [dBm] where 〖PL〗_m [dB]denotes the large-scale path loss component.

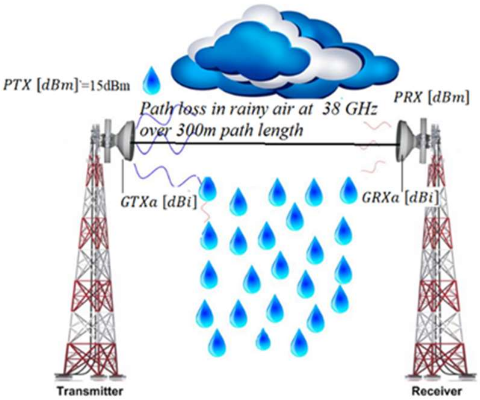

Figure 4 Pathloss phenomenon in rainy air at 38 GHz over 300m path length

Table 2. Summary of links parameters for the 38 GHz

Link physical	Parameters
Frequency Band	38GHz
Polarisation	HP
Antenna Gain	44.9 dBi
Maximum Tx Power	15 dBm
Link length	300m
System bandwidth	28 MHz
Tx height	18.6m
Rx Antennas height	17.3m
Sensitivity	-61.6 dB

Path Loss Calculation from Measured PRX [dBm]

The mean path loss with known T-R distance for the outdoor environment can be computed from the link budget by obtaining measured received signal level PRX [dBm], transmit signal level PTX [dBm] and all gains from Equation (1) and (2) as allocated by [23-3-34]. In this regard, the PRX [dBm] measured continuously (power concentrated in a particular direction) for one year on a fixed short-rang mm-wave link at 38 GHz has been used to investigate the path loss phenomenon shown in Figure 4. The result is illustrated in Table 4 and Figure 5. Equation 14 predicts the path loss (path loss incorporating atmospheric attenuation). Thus, the attenuation factor as a function (frequency, pressure, humidity, temperature, and rain rate) has been considered, as shown in Figure 5. However, actual path loss values fluctuate about the mean in practical applications.

Additionally, the total path loss 〖PL〗 _m [dB] can be estimated for urban microcellular (the maximum radius of a microcell is 200 meters) from the measured data in Malaysia by utilising Equation (15) [35].

$$PL\,[dB] = FSPL\,[dB] + Ar + Ag + Aw + LT + LR \tag{15}$$

where FSPL is the free space path loss, LT has transmitted system power loss, LR is a receiver system power loss, AW is wet antenna loss, which is considered for outdoor units. In this experiment, the antennas are covered by radomes and shaded by a wooden box to prevent wetness attenuation during measurement to achieve accurate rain effects on the propagation path only. AG is the median attenuation due to atmospheric gases. Ar is rain attenuation with rain 0.01% exceedance and all loss in (dB). The FSPL at 38GHz was mathematically calculated using Equation (1). The power loss at transmitting and receiver systems can be ignored compared to the free space path loss at 38 GHz, 113.58dB for 300 m path length.

The path loss depends on the carrier frequency, path length, location of the link, the average path loss exponent n, and the distance between the transmitter and receiver. The effects of oxygen and water vapour were already considered at 38 GHz and ignored for frequencies lower than 30GHz, vapour attenuation is about 0.08691 dB/km, and oxygen attenuation is 0.03563 dB, as stated in the recommendation of ITU-R 676-10 standard. Therefore, their impacts on the mm-wave links are minimal compared to rain, especially at the mm-wave frequency range [3][33].

Path Loss Estimation at Different Distances

It is more common to determine the mean value of path loss and variance based on averaging the empirical measurements' dB in practice. The reasons behind this concept are the literature shows that obtaining observed averages based on dB path loss measurements leads to a minor estimation error [20]. In previous work in Malaysia and China, the most considerable distance between the transceiver was 141 m [37][20].

Based on the mean value of the measured path loss at 300 m by Equation (16) (the mean value of _PL (300m)is 132.36dB), the path loss has been predicted at various distances (ranging from 1 to 500m) between the transmitter and receiver.

$$\underline{PL}\,(300m) = \frac{1}{N}\sum_{i=1}^{N} \quad PL(i) \qquad (16)$$

$$PL(d_i) = \underline{PL}\,(300m) - \big(20log_{10}(300) - (A_{0.01\%(300)}\ \big) + 20log_{10}\frac{(d_i\,)}{d_0} + A_{0.01\%(d_i)}$$

(17)

d_i is the distance between the Tx and the Rx where d_i≥ d_0 and _PL (300m) is the mean value of path loss at 300M, N is the number of measured points, and the PLE is assumed to be =2. Figure 5 presents the result.

The modelling technique used to describe the 38 GHz LOS data is known as the close-in, assuming that the links had the exact specification represented in Table 2 and the same environment. Additionally, the clear air close-in model is modified as described in (17) by merging the proposed model in [38-41] for rain fade prediction over short paths to consider the attenuation factor at different d over short paths (range from 1 to 500 m). Figure 5 presented a comparison of path loss in dB, between rainy days and no rain event, in Malaysia versus the logarithm of distance in m at a frequency of 38 GHz.

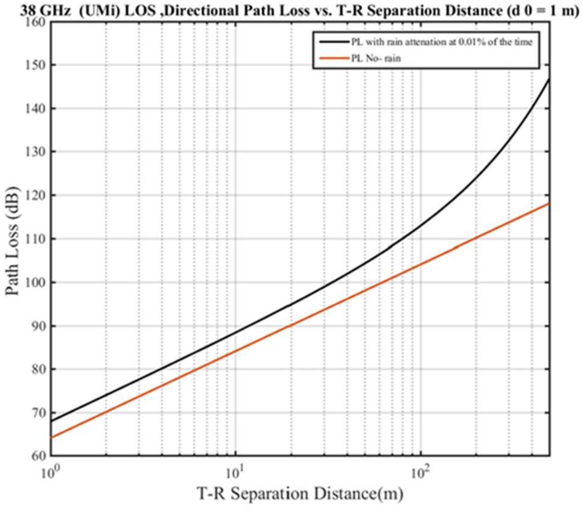

Figure 5. Comparison of path loss in dB, between rainy days and no rain event, in Malaysia versus the logarithm of distance in m at a frequency of 38 GHz

Figure 5 shows that the path loss grows fast in the first 35 meters, from 64 dB to about 95 dB. After that, the path loss increases slowly and reaches about 110 dB at 200 meters. On the other hand, the path loss with rain attenuation (0.01% exceedance) grows faster.

The deviation between PL with and without rain has increased dramatically after 200m. we can justify that, as recommended by [16], the attenuation factors can be ignored at path lengths shorter than 200m in temperate regions. Of course, the situation will worsen during tropical rain events, even at short communication paths. Thus, 200m is considered a path loss behaviour's transferring point. It finally reaches about 128dB at 200 meters, considering the rain. It's noted that the path loss is more significant during rain than in free space by approximately 18 dB at 300m.

Estimation of Pathloss Exponent During Rain Events

The path-loss exponent has been widely investigated and modelled without considering the rain. A few research works have computed the value of PLE with concurrent rain attenuation in temperate regions with very low rain intensity compared to tropical climates. During rain events, the path-loss exponent will be changed. In this case, the attenuation factor model will include an exceptional path loss exponent n_s. Hence the path loss exponent n_s can be calculated from Equation (18) by utilising the CI model with considering the attenuation factor (AF) as given in Equation (3)

$$n_{s(rain)} = (PL\_dB - FSPL\ (f, 1\ m)[dB])/(10log\ (d/d0\ )) \qquad (18)$$

Shadow fading standard deviation (dB) can be expressed as (Sun et al.,2016):

$$\chi CI\sigma = PL^{CI}\ (f, d)[dB] - FSPL\ (f, 1\ m)[dB] - 10n_{s(rain)}log10(d) - AT\ [dB] \qquad (19)$$

Where $PL._{dB}$he averages measured path loss, $FSPL\ (f, 1\ m)\ free\ space\ path\ loss,$ α is the attenuation factor corresponding to weather conditions in Malaysia. The average value of path loss exponent from measured data was 2.79, estimated from the CI model Concerning the 1m reference distance, this value of n characterises how fast the path loss increases within 300m in rainy weather, as shown in Table 4.

The value of PLE obtained from the minimum mean square error fit to measurements was n= 3.007. Hence, the path loss varies as a function of rain attenuation at a fixed Tx to R_X separation distance is obvious.

The standard deviation about the mean value is:

$$\sigma^2 = \frac{(MMSE)}{i} \qquad (20)$$

From the calculation, is σ =5.224dB

The analysis shows that the path loss models' parameters are changed with rain fade.

Estimation of Shadow Fading (SF) from measured PRX [dBm]data

A model of random variations of the received power (due to the random attenuation) at a given distance for mm-wave systems is also needed. The most common model for this additional attenuation is lognormal shadowing. In this model, the ratio of transmit-to-receive power ψ = Pt/(Pr) is assumed random with a lognormal distribution given by [42-43]

$$PL(\psi) = \frac{\xi}{\sqrt{2\pi\sigma_{\psi dB}}} exp\ exp\left[-\frac{\left(10\ log_{10}\psi - \mu_{\psi dB}\right)^2}{2\sigma^2_{\psi dB}}\right], \psi > 0 \qquad (21)$$

Table 3. For Path loss (PL_m) Derived from Measured ($PRX\ [dBm]$) at 38GHz link

Hour	Minute	Rainfall mm	RRmm/h	AGC volts	PRX [dBm]	Rain attenuation
14	11	2	120	2.11	35.46	-35.46

14	12	2	120	1.94	-42.53	-42.53
14	13	3.5	210	1.82	-47.28	-47.28
14	14	3	180	1.57	-57.01	-57.01
14	15	4.5	270	1.46	-61.60	-61.60
14	16	3	180	1.79	-48.23	-48.23
14	17	3	180	1.86	-45.67	-45.67
14	18	3.5	210	1.72	-51.28	-51.28
14	19	3	180	1.94	-42.58	-42.58
14	20	1.5	90	2.06	-37.61	-37.61
14	21	1.5	90	2.05	-37.91	-37.91
14	22	1.5	90	2.06	-37.60	-37.60
14	23	2	120	2.06	-37.54	-37.54
14	24	2	120	2.07	-37.23	-37.23
14	25	2	120	2.04	-38.22	-38.22
14	26	1.5	90	2.11	-35.61	-35.61
14	27	1	60	2.17	-33.10	-33.10
14	28	1	60	2.14	-34.47	-34.47
14	29	1	60	2.14	-34.51	-34.51
14	30	1	60	2.24	-30.51	-30.51
14	31	0.5	30	2.28	-28.66	-28.66
14	33	0.5	30	2.29	-28.39	-28.39
14	35	0.5	30	2.28	-28.94	-28.94
14	37	0.5	30	2.32	-27.09	-27.09
15	26	0.5	30	2.39	-24.24	-24.24

Table 4. The estimated value of PLE extracted from measured PRX [dBm] by utilising Equation (14) with considering rain attenuation

$PRX\ [dBm]$	Rain attenuation dB	Path loss dB	Path loss exponent
-35.46	9.96	139.46	3.05
-42.53	17.03	146.53	3.33
-47.28	21.78	151.28	3.52
-57.01	31.51	161.01	3.92
-61.60	36.1	165.60	4.10
-48.23	22.73	152.23	3.56
-45.67	20.17	149.67	3.46
-51.28	25.78	155.28	3.68
-42.58	17.08	146.58	3.33
-37.61	12.11	141.61	3.13
-37.23	11.73	141.23	3.12
-38.22	12.72	142.22	3.16
-35.61	10.11	139.61	3.05
-33.10	7.6	137.10	2.95

-34.47	*8.97*	*138.47*	*3.01*
-30.51	*5.01*	*134.51*	*2.85*
-28.66	*3.16*	*132.66*	*2.77*
-28.39	*2.89*	*132.39*	*2.76*
-28.94	*3.44*	*132.94*	*2.78*
-27.09	*1.59*	*131.09*	*2.71*
-24.24	*0*	*128.24*	*2.59*

Diurnal Effect on Path Loss Observed in Malaysia

The received signal power PRX dBm is very sensitive to atmospheric conditions, such as temperature, humidity, and rain (Hosseini et al.,2016). Hence, this section exploits this mm-wave band for diurnal variations in attenuation. A total number of 127620 values of PRX dBm were recorded during different weather events, including rain and clear sky, to present the results of a fixed millimetre short rang link (less than 1km) propagation investigated at 38GHz. In addition, the results for 300 m have been presented to get insight into diurnal variations of weather and their impact on channel performance. The results show a decreasing trend of PRX dBm concerning rain intensity in the location. Consequently, Malaysia's diurnal path loss is probably due to the inhomogeneous rain rate distribution along the short communication path. This will result in a corresponding degradation in the PLE values. Figure 6 shows the impact of attenuation factors (temperature and humidity, and rainfall variation on channel quality over the 38 GHz band by representing the path loss variation with time. It is observed that the channel quality varies noticeably during the day.

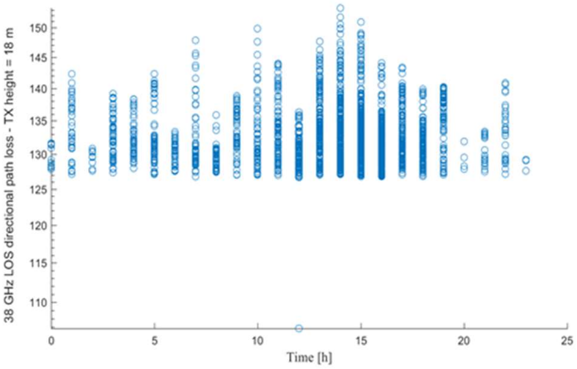

Figure 6. Diurnal path loss variation measured at 38 GHz for 300 m path.

The analysis of rain fade characteristics shows that the received signal envelope fades out (significant drop) more during the day than night-time because of the high probability of a rain event. The outdoor night-time rain attenuation measurements (30mm/h, 22°-24°c) have been compared with day-time measures in intense rainy weather (average rain rate 125mm/h, 31°-32° c). In all one-year measurement data, the PLE value in the LOS environment is approximately 9.41% higher during the day than the night as shown in Table 3.4. The Detailed Configuration for NYUSIM Simulation was observed that severe path loss is most likely to occur between 14:00 and to15:00. Less path loss was noticed during the hours from [00:00, 08:00], and [20:00- 24:00] due to rain events are relatively rare in those times compared to the

[12:00, 16:00] and [16:00, 20:00] intervals. It can be justified that, during rain, the number of significant multipath components increased, and received power decreased. The increase of PLE is interpreted by the high probability of rain fade occurrence, which causes a decrease in SNIR at the receiver antenna. It is noticeable from Figure 6 that the same Tx to Rx separation distance in these measurements has different path losses because the surrounding environment and rain intensities are different. Thus, the averaging of PL is 132.36dB.

Table 5. The PLE values in extreme rainy weather for LOS outdoor measurements at 38 GHz in Malaysia

Parameter	value
Frequency	38GHz
Scenario	LOS
Environment	rain
Tx antenna height	18m
Rx antenna height	17.3m
PLE, average rain rate 120mm/h day time	2.79
PLE, average rain rate 30mm/h night time	2.55
% Of PLE increase in the day-time	9.41%

Since the worst-case scenario is to investigate the attenuation due to rain has been considered. According to the analysis in the previous chapter, the rain attenuation was as high as 25.78 dB at 38 GHz with a rain rate of 210 mm/h. The highest attenuation value was recorded during the worst month, "October", and the worst hour (2 to 3 pm). It was justified by the work presented by [44-45]. In this regard, the measured path loss value at this rain event was around 155.28 dB. Therefore, even though PLE is considered a tool to predict path loss, it can increase the prediction error variance between measured and estimated results

Comparison Between Estimated Path Loss from Measured Data with Those Predicted by Models

Overestimation or underestimation of path loss (PL) may occur if the appropriate model is not chosen for a scenario. The PL models were developed to predict coverage area over the mm-wave band for 5G networks and have been utilised [26]. Thus, the comparison between large-scale PL estimated from measured data and predicted PL using the theoretical PL models is analysed in this section. The parameters of two popular PL models recommended for the next-generation channel model: the (3GPP) TR 38.900 Release 14 channel model and the NYUSIM, have been utilised in our analysis and observation. The detailed configuration for NYUSIM simulations is illustrated in Table (6). The comparison of the free-space path loss model, CI, and 3GPP PL models with PL estimated from measured data at 38 GHz for the UMi LOS environment is shown in Figure 6.

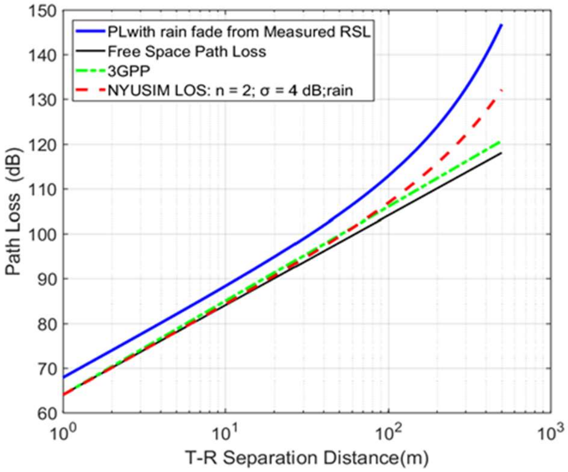

Figure7. comparison of free-space, CI, and 3GPP path loss models with path loss estimated from measured data at 38 GHz for the UMi LOS environment

A few key observations can be obtained from Figure 7. First, the CI model better fits the PL estimated from the measured data than 3GPP. This observation agreed with the [46][24] results. Furthermore, [24] developments show that the CI model with a 1-m reference distance is suitable for outdoor environments. Secondly, it has been noted that the CI and 3GPP models had a very similar performance when T-R distances varied between 1 and ~ 100 m. The path loss in dB attenuated by the atmospheric factors in dB/m has been generated according to NYUSIM. The difference between path loss calculated from the CI model and path loss estimated from measured data was 10.24 dB.

As shown in Figure 6, starting from around 100 m separation distance and above, there is a divergence between CI, 3GPP models, and PL estimated from measured data due to the attenuation rate per distance increases compared to short-distance transmission. On the other hand, a considerable variation has been observed in CI and 3GPP model performance when the path length increased by more than a ~ 200 m distance. Furthermore, it is also shown that the 3GPP model underpredicts path loss when the receiver is far from the transmitter. Finally, it can be concluded that the close-in (CI) model parameters have a more considerable change with different rainfall intensities than the 3GPP model.

Table 6 The Detailed Configuration for NYUSIM Simulations

Input Channel Parameters	Value(s)
The carrier frequency in GHz (0.5-100 GHz)	38 GHz
RF bandwidth in MHz (0-1000 MHz)	800 MHz
The operating scenario can be UMi, UMa or RMa	UMi
The operating environment can be LOS or NLOS	LOS
Minimum and maximum T-R separation distance	100-500 m
Base station height in meters (10-150 m)	15 dBm
Transmit power in dBm	(0-50 dBm)
Tx antenna height	18.6m
Rx antenna height	17.3m
Barometric Pressure in mbar (1e-^{5} to 1013.25 mbar)	1010.00
Humidity in % (0-100%)	85%

The temperature in degrees Celsius	28°C
Rain rate in mm/hr (0-150 mm/hr)	125mm/hr
Polarisation (Co-Pol or X-Pol)	Co-Pol
Transmit - Receive array type (ULA or URA)	ULA
Number of transmit antenna elements (1-128)	1
Number of receive antenna elements (1-64)	1
Tx, Rx antenna Gain	24dBi
Transmit and Receive antenna spacing in wavelengths	0.5
Receive antenna azimuth HPBW in degrees (7-360°	TX = 10;
Receive antenna elevation HPBW in degrees (7-45°	
Antenna types	Directional

Even though the CI and 3GPP models are accurate and suitable in the area where the measurement campaign was carried out in the temperate climate and must need modification for different regions, such as tropical climate.

The underestimation can be interpreted because of the difference in AF's attenuation factors (frequency, pressure, humidity, temperature, rain rate) calculated by the CI model in the NYUSIM simulations and the attenuation factor (AF) obtained from measurement data. It's worth mentioning that NYUSIM's and 3GPP's main codes consider ITU-R P.530-17, which has been used to calculate rain-induced attenuation. Therefore, the model is more suitable for temperate regions and may not be accurate for the tropics. These models can accurately predict rain fade in the temperate area and are not accurate with large raindrops during intense tropical rain events of 125 mm/hr.

Modification Of CI Model

A modification is proposed in the CI model to provide the most reasonable predictions of path loss for 5G links operating in the Malaysian tropical climate. The CI model has been modified by replacing the AF proposed in NYUSIM simulations with the attenuation factor introduced from the measured data at 38GHz, introducing a better representation of rain fade in a tropical climate. The path loss in dB/m attenuated by the atmospheric factors is predicted and presented in Figure 8. The dark blue line illustrated the rain attenuation as a function of distance obtained from the proposed model in [41]. It's observed that the PL line's trend follows the trend of the rain attenuation at a distance ≥ 100m. These observations have been reported in [46]. The modified CI model better estimates path loss by considering attenuation factors that become more influential parameters in the tropical environment. Another interesting relationship observed from the results is that the AF values are correlated to the rain rate mm/h in tropical climates.

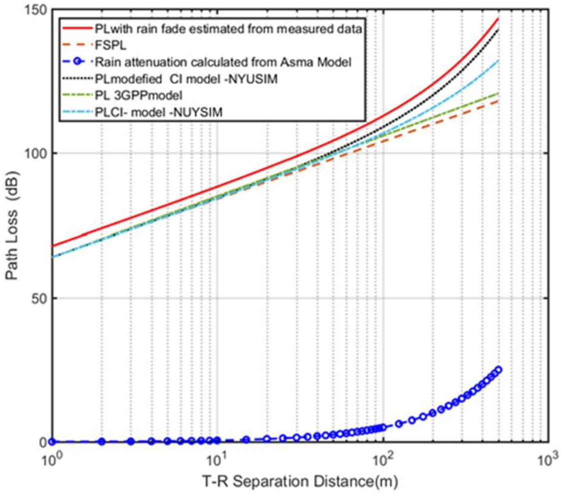

Figure 8 Compares the path loss predicted by Close-In, modified CI and 3GPP models with that estimated from measured data.

Multiple regression for predictive analysis of path loss has been used to fit the measured PL in the outdoor environment by considering the rain attenuation; the fit line formula provided as:

$$y = 11.976 \, ln \, ln \, (x) \; + 64.048 \qquad (22)$$

Where y is path loss in dB, x is the distance in (m)

It is noted that the parameters of the CI model ($n_{(rain)}$, σ) is calculated by performing a linear regression line fit into the PL estimated from measured data. Which represents the modified PLE and SF variables after merging the rain fade [17]. First, 64 .048 dB value is close to the free-space path loss at d_0=1 m $20 \, log_{10}(4\pi d/\lambda)$ at 38 GHz, this path loss is approximately 64 dB. Also, the term $11.976 \, ln \, ln \, (x)$ in Equation (22) represents $27.58log_{10}(d)$ where 27.58 =$10n_{(rain)}$ It gives a path loss exponent of 2.58 in the LOS conditions. It is shown that there exists a linear relationship between the mean value of measured path loss, including rain attenuation at PL(*d*) and the logarithmic value of distance, and Equation (22) can be written as follows:

$$PL(d, f, A0.01\%) = FSPL \; (f, 1 \; m) \; [dB] \; + 27.58log_{10}(d) \qquad (23)$$

where 27.58 =$10n_{(rain)}$

Without considering antenna height impact on path loss, the empirical values of CI model parameters at 38GHz have been determined by [24,5,4] compared with PL in a tropical climate in UMi and LOS scenario with consideration of rain attenuation as presented in Table 8.

Adjusted R-squared is a statistical factor measure of how close the data are to the fitted regression line. The Coefficient of determination, known as the adjusted R-squared factor, has been used to present the model with better performance, as shown in Table 7. It is observed that path loss calculated using the modified CI model (Adjusted R-squared=0.85) is closer to the path loss estimated from measured data. The higher the adjusted R-squared, the better the model fits and gives a complete description [47].

Table 7. adjusted R-squared

mode	3GPP model	NUYSIM	Modified CI model
Adjusted R-squared	0.68	0.79	0.85

Table 8 Comparison of the PL according to NYUSIM model: In UMi and LOS scenario for the parameters of at 38GHz (temperate areas and tropical)

NYUSIM: In UMi and LOS scenario	*d* (m)	PLE	σ dB
Tempter regions	70-930	1.9 to 2	3.5 to 4
Tropical regions	300	2.586 to 3	4.98 to 5.22

From the results, it's clear that the modified CI model gives a better estimation of path loss by considering attenuation factors in the tropical environment

It's clear that even though the path length at tropical 300m, only the PLE and σ dB are highly affected by rain attenuation compared with measurements that have been done at the same frequency in the temperate areas at a path length teched 930m. To evaluate the agreement of measured results at d=300m with simulated/calculated ones, average deviation error, ADE as presented in Equation (24) is used [48].

$$ADE = \sqrt{\sum_{i=0}^{nk} \frac{\left|PL_{simu/calcu}\,[dB]-P\ \ _{m}\,[dB]\right|^{2}}{k}} \qquad (24)$$

The calculated ADE values also suggest that the CI model in the NYUSIM simulations can give better performance than the 3GPP model in tropical-zone propagation. The 3GPP, CI model, and modified CI give an ADE of 12.34 dB,7.8 dB, and 2.89 dB, respectively, compared to the path loss estimated from measured data. This work shows NYUSIM is more accurate for realistic simulations than 3GPP in outdoor environments. The CI propagation model performs better for modelling the propagation environment at any shorter distance. In contrast to the 3GPP model that relied on many legacies sub-6 GHz results, NYUSIM emphasises a more physical basis and builds upon massive amounts of real measured data at mm-wave frequencies [16][5] [52-54][50]; [49-51] [27]. Standard deviations, σ, which represent the signal variation (e.g., caused by shadowing) around the general signal trend with rain fade, are significantly higher by calculating the average difference between predicted mean path loss using (23) and the local path loss the corresponding location.

The proposed modified model can be used in the Malaysian tropical climate or any other environment with similar characteristics [55].

Conclusion

In this paper, large-scale propagation characteristics of the outdoor environments have been investigated using 38GHz measurements for 300 m paths considering rain attenuation in tropical climates. Parameters used in modelling the path loss for LOS with clear skies and rains have been derived from the measured data. The path loss predicted by the CI path loss model and the 3GPP model for the same 38 GHz with 300 m path length was compared to the measurement data. The diurnal effect on path loss observed in Malaysia has also been investigated. The outdoor night-time rain attenuation measurements (30mm/h, 22°-24°c) are compared with day-time measures in intense rainy weather (average rain rate 120mm/h, 31°-32° c). In a one-year measurement, the PLE value in the LOS environment is approximately

9.41% higher during the day than the night. The parameters of the two most recommended channel models for next-generation wireless systems: the 3rd Generation Partnership Project (3GPP) TR 38.900 Release 14 channel model and the statistical spatial channel model NYUSIM developed by New York University (NYU) have been analysed based on measurement. A significant discrepancy is observed between the prediction by CI and 3GPP models and measurements. The variation becomes higher for the separation distance is longer than 70 m. It is observed that the path loss calculated using the CI model is closer to the path loss estimated from measured data.

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