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Modelling on Impact of Building Obstruction for V2I Communication Link in Micro Cellular Environment

J S C Turner¹, ², Shahriman A B¹, ³, A Harun¹, ², ⁵, S A Z Murad², M N Isa², R C Ismail², D L Ndzi¹, M S M Hashim¹, ³, Z M Razlan¹, ³, W K Wan¹, ³, M F Ramli²

¹Motorsports Technology Research Unit (MoTECH), Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
²School of Microelectronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
³School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
⁴University of West of Scotland, UK
⁵Corresponding author: aziziharun@unimap.edu.my

Abstract. In vehicular communication, signal transmission in vehicle-to-infrastructure (V2I) mode typically takes place on highways, urban, suburban and rural environments. The presence of buildings in these environments poses a challenge to model path loss (PL) due to multiple propagation mechanisms such as diffractions and reflections. However, very little attention has been made to address building effects on the performance of V2I communication links in microcell environment. This paper investigates signal propagation characteristics caused by the impact of building under micro-cellular environment whereby the base station or road-side-unit (RSU) is usually located under the rooftop of building to allow communication between RSU and mobile station or on-board-unit (OBU) on the road. The goal of this paper is to validate and discuss available path loss models based on effect of building obstruction towards RSU-OBU links specifically in residential housing area. The channel measurements are conducted based on static line-of-sight (LOS) settings of a real-world environment at 2.4 GHz frequency band using IEEE 802.15.4 XBee S2C compliant device to measure its receive power. The results are demonstrated based on received signal strength indicator (RSSI) and root mean square error (RMSE). The attenuation profile is validated and compared with suitable path loss models to evaluate best fit and most compatible model based on our measurements data and environment. The analysis shows that several V2I path loss models and V2V channel models are applicable to be used as a reference to model in LOS microcell environment with building obstruction. The finding shows that PL Urban yields the best fit V2I path loss model in terms of RMSE when compared to our measurement campaign at 2.4 GHz.

1. Introduction
With the emergence of connected car technology in the automotive industries, vehicular communication studies nowadays has become one heavily researched topic in academia which targets the issues of reliability, connectivity and performance among vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication mode for safety applications. To this day, V2I and V2V safety-based application in connected autonomous vehicle (CAV) leverage on V2I and V2V communication with the purpose of extending driver’s horizon for early detection from hazardous situations [1] as...
well as to reduce or eliminate crashes via inter-CAV communication (V2I, V2V, V2P, V2N, etc.) [2].

The exchange of information and data transfer among road-side-units (RSUs) and on-board-units (OBUs) usually occurs between vehicles and surrounding infrastructure (traffic lights, base station, etc.). Furthermore, the basis of V2I communication consists of fixed infrastructure and RSUs that are typically installed along the highways, along the road and intersections [3]. Highway, straight lane and intersection are common places for modelling vehicular channels because these areas are one the most important parts for the implementation of V2I and V2V safety application through connected technology. However, very little effort has been made to characterize signal propagation at these respective places especially in microcell environment.

The radio propagation in V2I communication is greatly influenced by types of environments such as highways, suburban, rural areas. Existing objects, moving and stationary vehicles, building as well as vegetation affect the radio propagation in vehicular communication. In an urban environment, obstructions from the presence of buildings strongly affect radio propagation [4]. To ensure reliable and stable communication link can be sustained for efficient future deployments of road-side-units (RSUs), analyses on signal performance upon environments that are generally characterized by challenging propagation conditions is crucial. Moreover, the existence of static and moving objects in the vehicular communication environment has been confirmed to cause channel interference thus worsening the communication links, reliability of data transfer (internet access) between the vehicles and RSUs. Researchers in [5] and [6] demonstrated that signal propagation is strongly influenced by surrounding objects both static and dynamic in V2I communication via measurement studies. The delay spread measurements observed in [7] at four-way intersection and highways of urban NLOS scenarios showed an increase in number reflections as well as signal attenuation. A simulation study in [8] has adopted three elements of EM parameters such as brick, glass and metal which demonstrated major impact into V2I channel characterization at their respective environments (highways and railway stations).

From wireless communication aspects, propagation mechanism such as reflection, diffraction and scattering often influence radio wave and propagation signal over the cellular network [9]. These phenomena combined with existing obstacles (static and dynamic) from surrounding environments may successively affect vehicular communication. Moreover, a detailed study by the author in [10] implies that several methods used by various technologies in radio communication such as CS-CDMA are influenced by multiple access interference (MAI) especially in Rayleigh fading environment. Meaning that spectral efficiency based on TDMA and CS-CDMA in mobile cellular network environment is also influenced by MAI, thus affecting the performance of mobile radio system. Since the interoperability in vehicular communication system requires information to be broadcasted simultaneously over a channel, the aspects of communication link between both RSU-OBU under potential vehicular environment must be investigated and explored.

In the development of V2I communication systems, the issue that still remains to this day is the reliable communication between vehicles and infrastructural [11][12]. As such, characterizing V2I channel in a microcell environment [13] and roadways consisting of all three important elements that may undergo propagation mechanism is deemed necessary. The variety of factors in this environment poses a challenge to model V2I propagation channels. Therefore, critical measurement and further studies of under-explored environments are vital in this field of study. By taking details of the specific environment, objects, location and dimension accurately proper path loss models can be realized. In this paper, the impact of building obstruction in the microcell environment towards signal propagation is investigated and analyzed based on LOS condition with static scenario along the road in between rows of residential housing areas. In the following section, path loss models related to V2I and V2V channel models are described. Secondly, measurement campaign and data processing is demonstrated. Thirdly, results of RSSI, RMSE and LOS probability will be analyzed. Next, measurement data that are validated...
by comparing path loss models are discussed. Lastly, conclusion and future research work is drawn in the final section.

2. Path Loss Models

One of several deterministic radio propagation models that can be used to model path loss and compute received signal strength (RSS) is Free Space Path Loss Model (FSL) [14]. This model is usually considered when modelling free space radio wave propagation in a microcell environment. FSL model is described by equation (1) in [15]. The Two-ray ground reflection model which is presented by equation (5) in [15] is a widely used model to estimate path loss. This model is also described in [16] that suggests it considers ground reflection and direct path in LOS conditions. Log-Distance path loss (PDPL) model [17] given by equation (3) as well as Cheng Dual-slope model given by equation (4) in [15], respectively have been used in vehicular channel modeling. Ray tracing presented in equation (11) in [15] can also be used to model rural and highway scenarios since this model can predict single ground reflected ray path loss. The Log-Normal Shadowing model [18] is one of probabilistic radio propagation models used to predict RSSI and the distribution of received power shall follow log-normal. This model is also presented by equation (2) in [15]. Rice distribution is given by equation (8) in [15], is used to describe the multipath fading effects in LOS communication. Whereas, Rayleigh distribution given by equation (9) in [15] is used to describe the NLOS condition consisting of dense and scattered objects. Nakagami distribution such as Weibull as given by equation (9) in [15] have shown to provide a better fit on urban and highway environments which have been evaluated in both LOS and NLOS conditions by Cheng’s study as well as Sen and Matolak’ study [19].

2.1. LOS V2I and V2I Channel Model

Several path loss models concerning path loss estimation in V2I and V2V channel are described in [16]. Path Loss Urban (PL\textsubscript{urban}) model can be used to estimate urban areas with low rise building and uniform height given the base station height ranging from 0 to 10 meters. The path loss model is given by equation (1).

\[
PL\textsubscript{urban}(dB) = 40 \left(1 - (4 \times 10^{-3}H\textsubscript{RSU})\right) \log_{10}d - 18 \log_{10}H\textsubscript{RSU} + 21 \log_{10}f + 80\ [dB]
\] (1)

Where \(f\) is frequency in GHz, \(d\) is the distance between transmitting and receiving antennas in meters, \(H\textsubscript{RSU}\) is base station antenna height or RSU.

A study demonstrated in [13] suggests that ITU UMi and WINNER + UMi and 3GPP models are applicable to be applied in LOS conditions having low vegetation density. In their analyses, 3GPP and ITU models were proposed for fixed transmitter antenna height which in their case shows that 3GPP model gives the best fit in LOS condition. ITU-R P. 1411-5 [20] is a LOS path loss model pertaining to a base station being mounted below the rooftop level in an urban micro-, dense urban micro- and pico-cellular environment with distance of below 1 km [20]. The general equation for 3GPP is given by (2), ITU-UMi for LOS is given by (3) and ITU-R P. 1411-5 is given by (4), respectively.

\[
PL\textsubscript{LOS3GPP}(dB) = 41 + 20.9 \log_{10}(d)
\] (2)

\[
PL\textsubscript{LOSITU-UMi}(dB) = 22 \log_{10}(d) + 28 + 20 \log_{10}(f)
\] (3)

\[
PL\textsubscript{LOSITU-R}(dB) = \left|10 \log_{10} \left(\frac{\lambda}{2\pi d_{BP}}\right)\right| + 6 + 30 \log_{10}(d_{BP})
\] (4)

Where \(f\) is the frequency in GHz, \(d\) is the distance between transmitting and receiving antennas in meters, \(d_{BP}\) represents the breakpoint distance, \(d = 4 \left(\frac{(H_T-H_E)}{(H_T-H_E)}\right)^{\frac{1}{\lambda}}\) with \(H_T\) as the transmitter (base station) height, \(H_E\) is the receiver (mobile station) height and \(H_E\) is the effective road height.
With the existence of building facing each other along both sides of road, the Street Canyon (SC) ITU-R P.1411-10 [20] model can be applied in LOS and NLOS conditions if both the base and mobile stations are located below rooftop without taking account the antenna heights. The site-general model is given in equation (5), where $f$ is the frequency in GHz, $d$ is the distance between transmitting and receiving antennas in meters.

$$PL_{LOSITU-R-SC}(dB) = 10 \times 2.12 \log_{10}(d) + 29.2 + 10 \times 2.11 \log_{10}(f)$$ (5)

These existing path loss models will be used to evaluate our measurement data in microcell environment since V2I channel model is based on free-space loss model [16]. Furthermore, the path loss exponent, RMS delay, Doppler spread, PDP, DSD, LOS/NLOS probability are several parameters that were considered in characterizing signal propagation over paths with distance less than 1km which is affected mainly by buildings. These parameters were also used in measurements related to ITS application especially on road crossing, LOS, merging lanes, traffic congestion, in tunnel and on bridges [21]. In this paper, path loss model described earlier is concentrated on LOS conditions in accordance with our measurement campaign comprising LOS situation.

3. Measurement Campaign

The measurement campaign consists of three stages that involve configuring sensors and hardware equipment before deploying on the outdoor test-bed. Secondly, the important parameters such as distance, width of road and height of building of chosen location are recorded. Finally, channel measurement will be conducted as described in detail in the following subsections followed by observation analysis of signal propagation obtained during channel measurement.

3.1. Experimental Setup

The data collection and channel measurement are conducted using low mobility IEEE 802.15.4 XBEE S2C [18] wireless sensor nodes that operate at 2.4 GHz free licensed frequency band. A pair of sensor nodes as depicted in Figure 1 is used to represent the transmitter (RSU/base station) and receiver (OBU/mobile station). The receiver was programmed as a base station which was connected to the laptop running with XCTU software [22] that records RSSI values. Illustration of the experimental setup is shown in Figure 2 with $d$ as the distance between transmitting and receiving antennas in meters, $H_t$ and $H_r$ represents transmitting and receiving antenna heights in meters, respectively.

Figure 1. The illustration of Digi IEEE XBee 802.15.4 wireless sensor nodes.

Figure 2. Illustration of basic experimental setup for data collection.

A pair of transceivers was placed along the straight road between rows of residential buildings as depicted in satellite view shown in Figure 3 and Figure 4, respectively. Based on Figure 4, the transmitter...
marked as ‘Tx’ on the rooftop is in fixed condition whereas the receiver is placed at fixed point starting from 0 m and increment every 2 meters along the road to the far end of road at 80 m distance.

Figure 3. The satellite view of straight road at Taman Jejawi Utara street.  
Figure 4. The satellite view of the location of base station.

3.2. Location of Real-world Testbed
The measurement campaign was conducted on real-world testbed whereby this street is chosen as it fits the microcell environment for LOS condition testing marked with a red arrow as depicted in Figure 5. The details of each row of a single-storey building consisting of 12 blocks of houses collocated side by side with no gaps are illustrated in Figure 6.

Figure 5. Satellite view of real-world testbed in microcellular environment representing LOS situation between transmitting and receiving antennas (Tx-Rx)

Figure 6. Detail illustration of real-world measurement campaign setup in accordance to Figure 5
Based on Figure 6, the building faces one another at the opposite side along the road. There were several vehicles consisting of cars, MPVs and a van parked along the street. A few mango trees were present on the side of the street. The maximum length of the road, \( L_d = 80 \) m, with width, \( W = 12 \) m. The height of building rooftop, \( H_t \) where the base station is mounted on is \( 3.0 \) m height. The Rx height, \( H_r = 1.5 \) m will be mounted above the ground representing the height of car roof or mobile station. Both rows of buildings are in uniform height, \( H_b \) having rooftop height ranging from \( 3 \) m to \( 5 \) m. The forefront rooftop is between \( 3 \) m to \( 4 \) m whereas the middle rooftop forming a triangle-like shape is between \( 4 \) m to \( 5 \) m height. The width of the building, \( W_b = 6 \) m whereas the length, \( L_b = 21 \) m.

### 3.3. Data collection methods

The channel measurement was performed at night time, with no traffic, pedestrian on the road as depicted in Figure 7 and Figure 8. Before conducting channel measurement, the 1st Fresnel Zone \([18][23]\) is calculated based on the current antenna heights described earlier to estimate the permissible obstruction allowed in the vicinity of the experimental setup. Furthermore, the spectrum analyzer is also performed to test the RF noise level as depicted of each channel so that during configuration and data collection the worst noise channel can be avoided. For this measurement, channel 19 configured for both transmitter and receiver respectively. With these steps, optimum radio performance can be achieved during data collection because unnecessary interference caused by nearby objects have been avoided. During data collection, the transmission power is set to highest dBm whereas data rate is set to 250 kbps. The packet rate is set to 1 second per packet with receiver’s sensitivity of -95 dBm. For this scenario, the measurements were carried out over path length of 80 m distance. During channel measurement, signal was transmitted for 2 minutes at each point between distance, \( d = d_1, d_2,...,d_n \) starting at 0 m up to 80 m distance which ended at Building 12 of both rows (see Figure 6). Data were collected at every 2 m distance interval and repeated two times. The data requirement such as building structure, building heights and vegetation information as described in Figure 6 are parallel in accordance with Annex 1 ITU-R P.1411-10 Tables 1 and 3, which suggested that this physical operating environment is under residential and microcell category. The location accuracy is set to high resolution in the order of 1 to 2 m during data collection.

![Figure 7. Measurement campaign taking place during night time with base station running channel measurement.](image1)

![Figure 8. Measurement campaign taking place with static setting on the road.](image2)

### 3.4. Channel Measurement Analysis

Figure 9 shows the attenuation profile of signal transmission caused by the impact of building wall of Row 1 and Row 2, between Building 1 to Building 12 (see Fig. 6) in a residential street of Taman Jejawi Utara, Arau. This scenario is applied to LOS situation as signal travels along the road over path from Tx-Rx. The result of attenuation based on antenna height setting for base station, \( Tx = 3.0 \) m and mobile station, \( Rx = 1.5 \) m over 80 m path is depicted in Figure 9. Based on Figure 9 (a), the signal slightly decreases as it propagates along the road consisting of one mango trees and a car parked close to Building 1 of Row 2 within the first 10 m distance. In the first 10 m distance, the signal is observed to...
decrease from -41.44 dBm to -45.06 dBm at distance interval of 1 m. At 2 m distance, signal increases to -43.3 dBm and continues to decrease to -46 dBm at 4 m distance. At this distance, a 5 m tall mango tree is present at the corner of the street. From distance 4 m up to 10 m, signal is observed to increase and then decrease gradually. Along the distance, a car is present at the corner of the street. A significant drop is observed at 11 m up to 18 m distance from -49 dBm to -58.3 dBm. Based on ITU-R P.1411-10 standard, this is the effect of corner loss which is resulted when gaps or alleys between buildings exist. In this scenario, the buildings of Row 1 and Row 2 are collocated side by side with no alleys. However, most of the building have porch installed with rooftops. Only several buildings have a partial rooftop that covers the porch. Building 2, 4, 5, 9 of Row 1 and Building 3 of Row 2 have partial rooftop at the porch which created gaps between the buildings. Based on Figure 9 (b), the corner region is observed from distance 11 m up to 18 m where Building 2, 4, 5 of Row 1 and Building 3 of Row 2 is located. This phenomenon follows the typical trend for propagation that occurs along street canyon at low antenna height if the frequency is ranging from 2-38 GHz [20].

---

**Figure 9.** Attenuation profile for (a) 3.0 m x 1.5 m antenna height over 80 m distance for LOS scenario and (b) illustration of corner region

The signal increases to – 54.5 dBm at 20 m distance before decreasing abruptly to – 62.4 dBm over the path of 8 m distance when reaching 28 m distance. The signal experience a significant drop due to the presence of vehicles parked at both sides of the street between Building 4, 5 and 6. Trees and vegetation were present at that particular location. Radio propagation that occurs along the path below 1 km is usually affected by surrounding buildings and the presence of trees instead of ground elevation as suggested in ITU-R P.1411-10. Moreover, the effect of scattering and diffraction is likely caused by the presence of buildings, trees and vegetation rather than diffraction over the rooftops because the antenna height is located at below rooftop level. In this scenario, the presence of buildings, trees and vehicles may have contributed to signal loss which does not increase in a monotonic manner. In other words, the signal attenuation appears fluctuated while descending that explains this propagation characteristic may be dependent on the corner loss instead. At 30 m distance, the signal increases to -57.9 dBm and continue to decrease over 4 m distance. At 36 to 40 m distance, the signal is observed to have fluctuated in an ascending manner before descending gradually over the distance of 56 m. This incident is due to multipath fading that occurs when signal propagates along path of Building 7, 8 and 9 where a number of vehicles are parked along the street. Significant drop is observed starting at 58 m up to 70 m distance when the signal travels over Building 9, 10, and 11. The signal decreases abruptly from – 71.2 dBm at 60 m to – 84.8 dBm at 64 m distance. At this location, there are four vehicles parked under rooftop of Building 10 of Row 2 with two cars parked along the street. During data collection, the cars were parked very close to the receiver which was mounted at 1.5 m above the ground. The cars were parked in high density having a similar height to the receiver. The effect of large metal objects such as cars has proven to induce significant power loss to signal propagation [15], thus the presence of cars may have caused obstruction to the 1st Fresnel Zone and cause signal to experience drastic loss. At the opposite row,
Building 9 has partial rooftop whereas Building 10 has no rooftop. The effect of corner loss that existed between Building 9 and 10 of Row 1 may also contribute to signal loss. As the signal travels through Building 11 and 12 of both rows, the signal gradually increases from –70.4 dBm to -68.5 dBm from 70 m to 80 m distance. At this location, there are no vehicles parked along the street and only one mango tree exists at the end of the road.

4. Results and Discussion
The result of signal attenuation profile was modelled with probabilistic and deterministic basic radio propagation model as well as path loss model for V2I and V2V channel in vehicular environment. Figure 10 shows the comparison of several basic radio propagation models over free space which is applicable to evaluate V2I channel as V2I path loss is predicated on free space loss.

![Figure 10](image-url)

**Figure 10.** Path Loss Modelling of LOS Building Obstruction in Microcell Environment using (a) Basic Radio Propagation Models (b) LOS Path Loss Models for V2I and V2V Channel in Vehicle Environment

Based on Figure 10 (a), the attenuation profile for LOS building obstruction was modeled with Log-normal, Log-Distance and Cheng dual-slope. It can be observed that the attenuation profile follows log-normal distribution with an RMSE value of 11.849. Modeling Log-Distance path loss model shows larger RMSE of 27.495 whereas, Cheng dual-slope gives RMSE of 26.392 slightly smaller than Log-Distance. Both Cheng Dual Slope and Log-Distance show a small difference in RMSE because Cheng Dual Slope is an extension and improved version of Log-Distance path loss model. In Figure 10 (b), the attenuation profile for LOS building obstruction is also modelled and compared with existing V2I path loss and V2V channel model to validate the best fit model applied to this specific measurement data and environment. Based on Figure 10 (b), Path Loss (PL) Urban and PL 3GPP yield smaller RMSE compared to Log-Distance and Dual Slope.

The summary of RMSE [24] values for all path loss models are given in Table 1. Based on Table 1, Log-Normal yields the smallest RMSE value followed by PL Urban (12.502) and PL 3GPP (15.633) models. The RMSE is larger with Cheng Dual Slope followed by Log-Distance model. Street Canyon and ITU-UMi path loss models were also modelled and the RMSE was calculated. However, these models were not included in Figure 10 (b) because both models show an almost similar profile with RMSE value close to PL 3GPP. PL Street Canyon ITU-R P.1411-10 gives RMSE of 15.767 whereas PL ITU-UMi gives 15.778. It can be observed that PL Urban given by equation (1) in Section 2.1 shows that this model follows the free space loss normal distribution under microcell environment at 2.4 GHz frequency band when compared to our measurement data. This indicates that PL Urban yields better RMS errors when modelling propagation loss within this environment at 3.0 m x 1.5 m antenna height. However, based on this PL model, it was designed to specifically evaluate urban areas consisting
uniform height structures at a carrier frequency of 5.9 GHz. Although it can be used to validate V2I and V2V channel models in the microcellular environment consisting of similar building structures, an accurate site-specific model is still required to meet the specified operating frequency on this respective environment at 2.4 GHz carrier frequency.

### Table 1. Root Mean Square Errors Path Loss Models for LOS Building Obstruction at 3.0 m x 1.5 m antenna height in Microcell Environment

<table>
<thead>
<tr>
<th>Path Loss Models</th>
<th>RMSE (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log-Normal</td>
<td>11.849</td>
</tr>
<tr>
<td>Log-Distance</td>
<td>27.495</td>
</tr>
<tr>
<td>Cheng Dual Slope</td>
<td>26.392</td>
</tr>
<tr>
<td><strong>PL Urban</strong></td>
<td><strong>12.502</strong></td>
</tr>
<tr>
<td>PL 3GPP</td>
<td>15.633</td>
</tr>
<tr>
<td>PL ITU-R Street Canyon</td>
<td>15.767</td>
</tr>
<tr>
<td>PL ITU-UMi</td>
<td>15.778</td>
</tr>
</tbody>
</table>

Furthermore, it can be observed that attenuation profile of Log-Distance and Cheng Dual Slope follows Log-normal distribution which implies that V2I model is predicated on free space loss model [16]. Cheng Dual slope is an extended version of Log-Distance that considers breakpoint distance in the formula and suitable for vehicular channel modelling. V2I and V2V channel models that also include breakpoint distance are PL ITU-R Street Canyon (ITU-R P.1411-10) and PL ITU-UMi under LOS condition. Moreover, the measurement data and theoretical prediction shown in Figure 10 has a good agreement with the two-slope regression fit concept. H. L. Bertoni suggested that during channel measurement on a typical straight road, the LOS path may consist of two regions which can be differentiated by its breakpoint distance [25]. The two regions namely near and far region shall experience drastic fluctuation in signal power will after the breakpoint due to ripple effect of a travelling wave by the Fresnel Zone clearance [18] wave-front that has been blocked in the second region.

The breakpoint distance is one of the important factors when evaluating propagation loss characteristics under microcell environment. Breakpoint distance given in equation (6) can be used to determine the size of microcell, provide a more precise fitting to the measurement data as well as for the purpose of achieving accurate prediction formula [26][27].

\[
D_{bp} = K_{bp} \frac{H_t H_r}{\lambda}
\]  

Where \(D_{bp}\) is breakpoint distance, \(K_{bp}\) is the breakpoint coefficient, \(\lambda\) is radio wavelength, \(H_t\) and \(H_r\) is transmitting and receiving antenna height, respectively. Following this, site-general model for two slope and single breakpoint given by Recommendation ITU-R P.1411-10 in equation (7) [20] is applicable for LOS situation along a straight path consisting of transmitting and receiving antenna heights below rooftop level.

\[
L(d, f) = 10 \alpha \log_{10}(d) + \beta + 10 \gamma \log_{10}(f)
\]  

DB

Where, \(d\) is distance between transmitting and receiving antenna in meters between 5-660 m, \(f\) is operating frequency between 0.8-73 GHz, \(\beta\) is offset value given by 29.2, \(\gamma\) is coefficient of frequency
dependence given by 2.11, and a distance-dependent path loss coefficient, $\alpha$ is related to basic transmission loss can be defined in equation (8) [26] for short and long distance, respectively.

$$L_{pp} = \begin{cases} 
10\alpha_1 \log(d), & d < D_{bp} \\
10(\alpha_1 + \alpha_2) \log(d), & x < D_{bp}
\end{cases}$$  \hspace{1cm} (8)

The propagation loss exponent $\alpha_1$ represents distance, $d$ smaller than breakpoint distance, $D_{bp}$. For distance, $d$ larger than breakpoint distance, $D_{bp}$ the propagation exponent becomes $\alpha_1 + \alpha_2$. In this case, the propagation exponent $\alpha_1 = 1.97$ given that breakpoint coefficient, $K_{bp} = 4$ [25] and distance, $d < D_{bp}$. This regression analysis can be used to evaluate the best breakpoint coefficient based on RMSE by varying $K_{bp}$ values with respect to each $D_{bp}$ for this environment. As such, using this approach comparison between predicted and measured propagation losses with minimal RMS errors is possible.

Applying Slope-intercept model before the breakpoint for measurements approaching 2 km distance of LOS on flat terrain given in equation (9) [28] and equation (10) [25] for beyond the breakpoint respectively will give a similar form of equation prior to PL Urban given in equation (1). According to H.L. Bertoni, both equation (9) and (10) support the measurements in constructing LOS path loss model for microcells with condition that $D_{bp}$ must be smaller than $E_{tot}$ distance bearing low frequency or frequency independent. $E_{tot}$ distance based on Figure 2 in [18] represents the horizontal separation by Two-ray model [25] consisting of rays $r_1$ and $r_2$ from $d_{slant}$ and $d_{slant}'$, prior to antenna mounted above the ground in a typical UHF and microwave frequency environment.

$$PL = 81.1 + 39.4 \log(f) - 0.1 \log(H_t) + (15.8 - 5.7 \log(H_t)) \log(d), d < D_{bp}$$  \hspace{1cm} (9)

$$PL = 48.4 + 47.5(f) + 25.3 \log(H_T) + (31.2 + 13.9 \log(H_t)) (\log(d) - \log(D_{bp})), d > D_{bp}$$  \hspace{1cm} (10)

Where, $f$ represents frequency in gigahertz, $d$ is distance in kilometers and $H_t$ is base station antenna height or the transmitter height in meter. Based on our measurement, $D_{bp} = 144$ m larger than distance, $d$ hence a new variable of slope intercept model can be define to fit the measurement data in this environment as given by equation (11).

$$PL_{proposed}(dB) = 43.3(1 - 1.38 \log_{10}(H_t)) \log_{10}(d) - 1.73 \log_{10}(H_t) + 20 \log(f) + 90$$  \hspace{1cm} (11)

Where, $H_t$ represents the base station which in our case is the transmitter antenna height in meters and $f$ is carrier frequency of 2.4 gigahertz. Comparing this proposed path loss model in the measurement data, yields slightly better RMS error (11.616). In future work, this proposed path loss model will function as a benchmark and assist in defining accurate V2I path loss model in situ.

5. Conclusion

In this paper, the propagation loss characteristics under LOS have been evaluated in a conventional way using received power and RMSE. The measurement data is then validated with available propagation models such as Free-space loss, log-distance, log-normal shadowing including V2I and V2I channel models. The regression analysis has been discussed in terms of distance characteristics. Two-ray model and detailed regression analysis in aspects of distance, antenna heights and frequency dependence will be continued in the future. Hence, the first phase objective regarding channelling effect study over LOS in the microcell environment has been demonstrated. Several parameters such as multiple antenna height and road width will be continued. Moreover, non-line of sight (NLOS) channel measurement in microcell environment will also be included in in future work. With this finding, the applicability of appropriate and standard path loss models may provide a benchmark for modeling V2I channel in vehicular environment. Since the real world data collection is very challenging due to various factors,
the validity of data analysis must be compared to prediction (vehicular channel, path loss models) based on the existing propagation models, through approximation analysis (RMSE) and validation models to demonstrate the efficiency of obtained measurements. In simulation, some scenarios require high computational complexity such as high traffic density. To simulate certain scenario such as high density vehicle, it will require very high complexity and cost. Thus, data collection and measurement on real-world environment is still necessary and important to model path loss which can provide far less complex parameters.

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