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To cite this article: J S C Turner *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **557** 012056

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Effect of Roadways Plantation on Signal Propagation Analysis in Connected Autonomous Vehicle Communication

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Abstract. At present, the development of autonomous vehicle has altered the outlook of modern transportation worldwide. The state-of-the-art vehicular communication for transportation system is advancing, especially in vehicle to infrastructure (V2I) communication. An effective communication between vehicle and infrastructure has become a significant part of autonomous transportation criteria. The necessity for high quality of service communication inspire for good planning and preparation in communication process. Per se, this paper proposes vegetation attenuation models for advance planning of communication process between vehicle to infrastructure, defined mainly by plants, trees and vegetation along the roadways in Malaysia. The channel measurement performed in Universiti Malaysia Perlis test-bed having large tall trees and low shrubs along the routes resulted in several interesting results which would shape the planning of CAV communication. It is observed that communication close to low plantation or shrub requires high power consumption as the range is significantly reduced. It is also learned that certain types of plantations allows for different level of signal attenuation depending on the antenna heights. The research also found out that the attenuation profile follows strictly the log normal distribution and as such certain planning could be made to reshape the communication process to cater for this.

1. Introduction

A reliable, sustainable and robust communication network is a fundamental aspect of connected transportation system especially in connected autonomous vehicle program. Such fundamental is very critical in vehicle-to-vehicle as well as vehicle-to-infrastructure communication and data transmission. In vehicle-to-infrastructure communication, which is typically wireless and bi-directional, robust and reliable communication could be the deciding factor for accident avoidance and smooth transportation. With the advent of autonomous vehicle, roadways would soon become more sophisticated transportation alleys and as such communication with lane markings, road signs, and traffic lights would have to be properly managed.



To manage such complexity, strong communication foundation is required. Although there are several communication technologies available, such as WIMAX, Wi-Fi, LTE and DSRC, these technologies may not be able to support low latency, high accuracy and reliable data transmission required by Connected Vehicle Technology (CVT) applications. [1]. While Dedicated Short Range Communication (DSRC) provides low latency, fast network connectivity, various application of CVT may not be supportable [2]. In order to ascertain the communication and the reliable network connectivity, a thorough study has to be done to understand the factors affecting the V2I communication. One of the critical area of communication that require special attention is channel communication in V2i [1-2].

The concept of V2I communication and V2V communication is the latest advanced topic in autonomous connected vehicle field. The interaction of V2I uses wireless communication technologies which can provide wireless exchange of operational data between vehicles and highway infrastructure. These are intended to make driving safe, improve mobility, to reduce greenhouse gas and maintenance cost. V2I communication can be applied to all types of vehicle and road thus transforming them into smart-infrastructure. Each car can act as a moving sensor, this car can provide information to other car and infrastructure wirelessly, exchange information and many more. For example, cars can communicate with each other and alert drivers to roadside hazards ahead, wirelessly. It comprises a wireless network where automobiles send messages to each other with information about what they're doing. This data would include speed, location, and direction of travel, braking, and loss of stability. This interaction must require research in creations of algorithms for managing traffic, avoiding collisions and other vehicular tasks that use data exchanged between vehicles and infrastructure elements to perform calculations that can recognize high risk situations [3]. This result in warning and driver alerts through specific actions. For example, the ability for traffic signal systems to communicate information such as signal phase and timing (SPAT) to the vehicle in order to signal safety and warning to drivers. Most of V2I system are closely related and rely on V2V system which uses Intelligent Transportation System (ITS). These applications are usually based on roadside sensors and require observation on toll control or speed measurement and many more.

Several wireless technologies such as DSRC, LTE and VANET supports vehicular communication and prior studies suggested that most measurements in V2I communication use Wi-Fi such as WAVE or IEEE802.11p protocol, IEEE 802.11b, etc. as it can support both V2V and V2I communication. WiMAX is another recent technology that some researchers use to compare with Wi-Fi for evaluating the feasibility of vehicular network that focuses in V2I communication [4]. Apart from that, various research works related to protocol and security issues has been highlighted as one of challenges in vehicular communication due to large volume of information being access and exchanged in V2I communication [5]. However, it is also important to consider other sensing challenges such as source of blockage in communication path which include millimeter wave link, vehicles, pedestrians, static objects, trees and buildings. There are prior studies that have been disclosed regarding significant impact of trees, vegetation and antenna orientation as factors influencing the coverage areas [6]. As such, preliminary studies in areas where source of blockage in communication path is necessary. A good number of studies have been carried out on wireless sensor network architecture of vegetation and agriculture [6][7][8][9]. There many models being adapted and used for agricultural and vegetation and up to present, limited studies and lack of appropriate models is found in the studies of transportation environment with vegetation for CAV applications. This research looks into understanding the attenuation factors affecting such communication via channel measurement. Therefore, this paper evaluated a generic form of vegetation attenuation models, path loss and proposes appropriate parameters in the implementations of models for CAV communication.

This paper is organized as follows; in section 2 describes vegetation models and parameters used in path loss and received power calculations. Section 3 presents measurement location, setup and device that were used. Section 4 presents experimental designs and followed by results and discussions in section 5. Conclusions are drawn in Section 6.

2. Background

Channel measurement has been used extensively to provide comprehensive understanding of the surrounding area of interest for communication planning purpose. Many works has been performed in the infrastructure deployment planning as well as in the agricultural field. Authors in [7-11] have been performing such studies in agricultural field specifically for sensor deployment and monitoring system execution. Nevertheless, there has not been much work done in the area of road transport planning especially concerning the deployment of autonomous vehicle. In this study, a good understanding of signal propagation in roadways is essential for establishing reliable communication standard.

For the radio-wave propagation is free space, the path loss (L) can be predicted using the free space loss (FSL) equation,

$$L_{FSL}(\text{dB}) = -27.56 + 20 \log_{10}(f) + 20 \log_{10}(d) \quad (1)$$

Where f is the frequency in MHz, d is the distance between the isotropic transmitting and receiving antennas in meters.

The 1st Fresnel Zone [12-14] is known to be the most to affect the performance of wireless network as obstacle in this zone can create out of phase signal from 0 to 90 degrees, thus it is important to estimate the maximum radius of 1st Fresnel Zone before conducting channel measurements on the test-bed. The radius, r of Fresnel Zone at the greatest distance is at the center (B) of line-of-sight (LOS) between the transmitting and receiving antennas as depicted in Figure 1. According to authors in [13] and [14], the maximum allowable obstruction height must be within 60% of clear Fresnel Zone for optimum radio performance. The 1st Fresnel Zone can be calculated using the general equation as in (2). In equation (2), n is the n^{th} Fresnel Zone radius in meter, d_1 is the distance of point B (center) from the transmitter (T_x) in meter, d_2 is the distance of B from the receiver (R_x) in meter and λ is the wavelength of the signal in meters as in (3).

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \quad (2)$$

$$\lambda = \frac{c}{f} d_1 = d_2 \quad (3)$$

where, c is the speed of light in vacuum ($3 \times 10^8 \text{ ms}^{-1}$), $(d_1 + d_2)$ is the total distance (D) in meter and f is the signal frequency in Hertz. Based on Figure 1, the (r) at its maximum distance and the allowable height for obstruction can be calculated using (4) and (5), respectively.

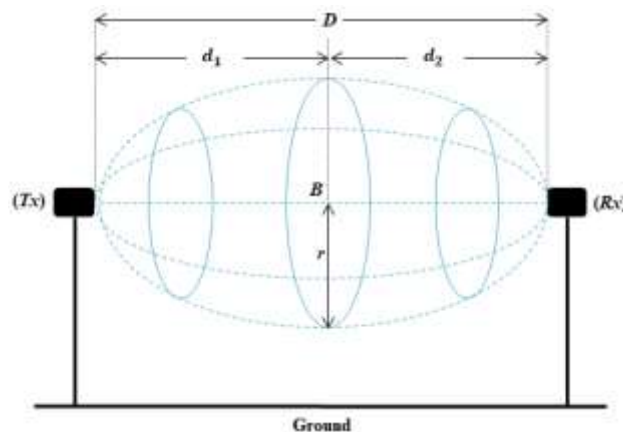


Figure 1. The 3D Ellipsoid of the 1st Fresnel Zone

$$R = 8.657 \sqrt{\frac{D(km)}{F(GHz)}} \quad (4)$$

$$R = 8.657 \sqrt{\frac{0.6D}{F}} \quad (5)$$

where, R is the Fresnel Zone Clearance Radius in meter, D is the total distance in kilometers and F is the frequency transmitted in gigahertz.

Signal reflections, diffractions and scattering from medium and surfaces impact propagation in mobile communication system [12]. As such, the reflection from the ground and surface from surrounding objects must be taken into account by considering the ground-bounce reflection and the surface roughness [13]. The ground-bounce reflection generates a mirror-like or specular signal reflection with an angle of incidence, θ_{inc} equals to the angle of departure, θ_{dep} or ($\phi_1 = \phi_2$) as in (6), where the signal is reflected on a smooth and flat surface as in Figure 2 [12]. Hence, knowing both T_x (transmitter) and R_x (receiver) height, distance d_1 and d_2 can be determined. In Figure 2, H_t and H_r is the transmitting and receiving antennas height, respectively, d is the total distance between the transmitting and receiving antennas and d_{slant} is the total distance of direct wave (slant range) as in (7) and (8), respectively. It is also understood that the received signal can be determined by summing the direct reflected wave at the receiver whereas the magnitude and phase of reflected signal can be determined by ground's reflection coefficient. The reflection coefficient is denoted by rho ($\rho = -1$) with smooth surface and small angle incidence.

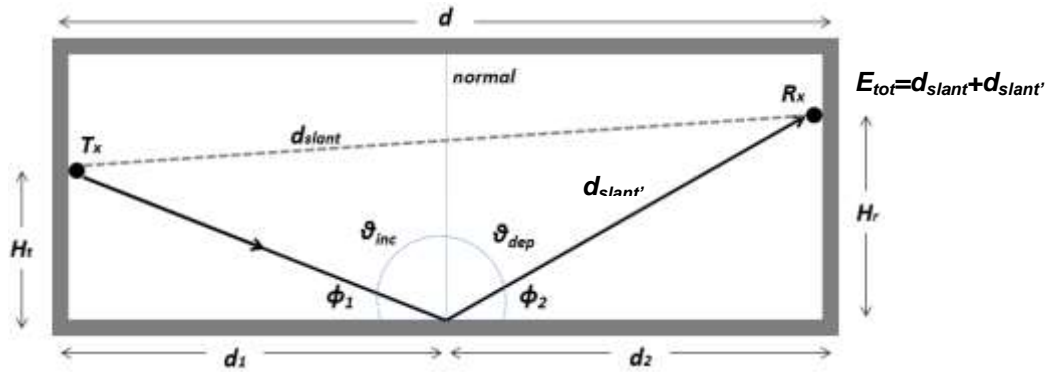


Figure 2. Two-ray ground reflection model [10][12]

$$\phi_1 = \tan^{-1}\left(\frac{H_t}{d_1}\right), \phi_2 = \tan^{-1}\left(\frac{H_r}{d_2}\right) \quad (6)$$

$$d = d_1 + d_2 \quad (7)$$

$$d_{slant} = \sqrt{d_2 + (H_t - H_r)^2} \quad (8)$$

Figure 2 shows the signal reflection on smooth and flat surface and this model is commonly known for predicting large-scale signal strength over distance in kilometres for mobile radio system and line of sight in urban environment. This model considers both direct path and ground reflected propagation path between the transmitter and receiver. It is also a widely used model in wireless sensor network when vegetation is present with antenna measurement at significant height and outside the vegetation. In addition, based on Figure 2, the received power, P_r at a distance d from the transmitter for Two-ray ground bounce model can be calculated using equation (9). Where P_t is the transmitted power in dB,

G_t is the transmitter antenna gain, G_r is the receiver antenna gain, d is (T_x - R_x) separation distance in meters. Antenna gain, G can be calculated using equation (10) and the (11).

$$P_r = P_t G_t G_r \frac{H_t^2 H_r^2}{d^4} \quad (9)$$

$$G = \frac{4\pi A_e}{\lambda^2} \quad (10)$$

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c} \quad (11)$$

Where A_e is the effective aperture which is related to physical size of antenna, f is the carrier frequency in Hertz, ω_c is carrier frequency in radius per sec and c is speed of light in meters per second. At large values of d the received power and path loss is independent of frequency. Path loss for Two-ray model with antenna gain is in equation (12).

$$PL(dB) = 40\log d - (10\log G_t + 10\log G_r + 20\log H_t + 20\log H_r) \quad (12)$$

At small d , an addition of equations must be used to compute the total E-field using equation (13). $E_{tot}(d, t)$ is the total electric field, E_0 is the free space E-field in units of V/m, at a reference distance d_0 from the transmitter and d_{slant} and $d_{slant'}$ represents the two propagating waves arriving at receiver which is the direct wave and the reflected wave that travel at distance d_{slant} and $d_{slant'}$, respectively as shown in Figure 2.

$$E_{tot}(d, t) = \frac{E_0 d_0}{d_{slant}} \cos\left(\omega_c \left(t - \frac{d_{slant}}{c}\right)\right) + (-1) \frac{E_0 d_0}{d_{slant'}} \cos\left(\omega_c \left(t - \frac{d_{slant'}}{c}\right)\right) \quad (13)$$

Another method of determining the ground reflection is by taking the surface roughness into consideration. The Rayleigh criterion [13], H_R can be used to quantify the flatness of the surface depending on the terrain variations (Δ_h) as in (14), where d is the distance between transmitting and receiving antennas, λ is the wavelength (in meters), H_t is the transmitting antenna height and H_r is the receiving antenna height. The terrain variations can cause signal to experience 90 degree phase shift at the reflection point [13]. That is, if the surface is having roughness which is almost negligible ($\Delta_h < H_R$), then the surface can be considered as smooth and reflection may occur. With severe roughness ($\Delta_h > H_R$) the surface will experience scattering instead.

$$H_R = \frac{\lambda d}{8(H_r + H_t)} \quad (14)$$

In addition, there a number of models that provides prediction of excess attenuation due to existence of vegetation. One of them is Non-zero Gradient (NZG) model. Proposed by Seville and Craig, this model is used for frequencies above 5GHz and currently under ITU-R recommendation [18-19][24]. The NZG model is given by equation (15) where R_0 is the initial gradient, R_∞ is final gradient of attenuation curve, k is the offset of the final gradient and d is the vegetation depth in meters [18]. The extension of this model that takes into account the antenna beam width and frequency is given by equation (16), where W is the maximum effective coupling width between the transmitting and receiving antennas that lies between vegetation medium (largest measured vegetation depth), f is the signal frequency in GHz and a, b, c, k, R_0 and R_∞ are constants given in [19].

$$Atten = R_\infty d + k \left(1 - \exp\left(-\frac{R_0 - R_\infty}{k} d\right)\right) \quad (15)$$

$$A = \frac{R_{\infty}}{f^a W^b} d + \frac{k}{W^c} \left(1 - \exp \left(- \frac{(R_0 - R_{\infty}) W^c}{k} d \right) \right) \quad (16)$$

Modified Exponential Decay (MED) model is another vegetation model that was proposed by Weissberger and the modified version is in CCIR recommendations [20]. This model is known to be very simple but does not include the measurement of propagation mechanisms but can be used for radio-wave propagation through the foliage medium. A more simplified and generalized form of MED vegetation model is given by equation (17) [6].

$$P_r(dB) = X f^Y d^Z \quad (17)$$

Where f is the frequency in megahertz (MHz), d is the vegetation depth in meters and X , Y and Z are the model parameters.

Weissberger's model [7] represented by equation (18) and it is applicable where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates. It is applicable in the situations where the propagation is likely to occur through a grove of trees rather than by diffraction over the canopy top, and is given by

$$L_W(dB) = \begin{cases} 1.33 \times f^{0.284} d^{0.588} & 14m < x \leq 400m \\ 0.45 \times f^{0.284} d_f & 0m \leq d_f < 14m \end{cases} \quad (18)$$

Where f is the frequency in GHz, and d_f is the foliage depth in meters.

Other modified vegetation models under MED models are such as ITU-R model [24][25], COST235 model [21][25] and FITU-R model [23][25] as in equation (19), (20) and (21), respectively. For these models, f represents its frequency in megahertz (MHz) and d represents vegetation depth in meter (m) based on Annex 1 in ITU-R recommendation [24]. ITU-R model is applicable for distance below 400 meters and its X and Y parameters can be changed for improvement in the model to find the best fit [19]. In other models such as COST235 and FITU-R model, they consider more specific geometry measurements with given parameters for in-leaf and out-of-leaf conditions.

$$L_{ITU-R}(dB) = 0.2 \times f^{0.3} d^{0.6} \quad (d < 400) \quad (19)$$

$$L_{COST}(dB) = \begin{cases} 26.6 \times f^{-0.2} d^{0.5} & \text{out - of - leaf} \\ 15.6 \times f^{-0.009} d^{0.26} & \text{in - leaf} \end{cases} \quad (20)$$

$$L_{FITU-R}(dB) = \begin{cases} 0.37 \times f^{0.18} d^{0.59} & \text{out - of - leaf} \\ 0.39 \times f^{0.39} d^{0.25} & \text{in - leaf} \end{cases} \quad (21)$$

Moreover, Harun et al. have also shown that WSN channel can be modeled using a log-normal model. The log-normal model is described by (22) [9]

$$P_r(d) = P_{r_0} - 10\alpha \log_{10}(d) + X_{\sigma} \quad (22)$$

Where $P_r(d)$ is the received power (in dBm) at a distance d (in meters) from the transmitter, P_{r_0} is the signal strength at 1 m antenna separation, α is the path loss exponent and X_{σ} represents a Gaussian random variable with zero mean and standard deviation of σ dB.

3. Measurement Location and Equipment

The measurement has been conducted on Universiti Malaysia Perlis campus route highlighted in yellow line as depicted in Figure 3. This route is chosen because there are two types plantations planted on each roadside along the route highlighted in yellow. Tall trees with thick leaves and trunk are located on the left lane while low plantation or shrubs are located on the right lane.

It is very crucial to simulate Malaysia roadways with existing plantations in conducting this research especially as Malaysia roadways in the Northern state mostly have heavy plantations along the roadside, highways, streets, etc. This particular route has been identified for data collection to represent similar existence of plantations around Malaysia roadways. Shrub in Figure 4 has been chosen to represent low plantations normally found along Malaysian road.



Figure 3. Universiti Malaysia Perlis campus route. The route highlighted in yellow has tall trees and shrub along the roadside.



Figure 4. Shrub or low plantations in a row along the roadside.



Figure 5. Tall trees with thick leaves and trunks in a row along the roadside.

Another important field to be measured is trees which is very prevalent around the roadways in Malaysia. Figure 5 shows tall trees with thick leaves and trunk. The trees represent similar plantations that can be found along roadsides, highways and streets of urban areas in Malaysia. Thus, this type of plantation is used in this research for data collection.

Data collection was performed using XBEE S2C wireless sensor nodes as the receiver and transmitter. The illustration of the methodology is shown in Figure 6. The transmitter and receiver are placed on top of metal pole that can be adjusted for multiple antenna heights. In this experiment, the data collection is focused on trees and shrub plantation areas along the roadside with antenna height of 0.3 meter and 1.3 meter, respectively. The software used for programming the wireless nodes is XCTU Software [16]. The receiver was programmed as remote while the transmitter was programmed as local or as base station which is connected to the laptop running with XCTU Software. The nodes operated at 2.4 GHz frequency band with 3 dB antenna gain [15]. The receiver sensitivity is at -95 dBm and the rest of node's specification is as given in Table 1.

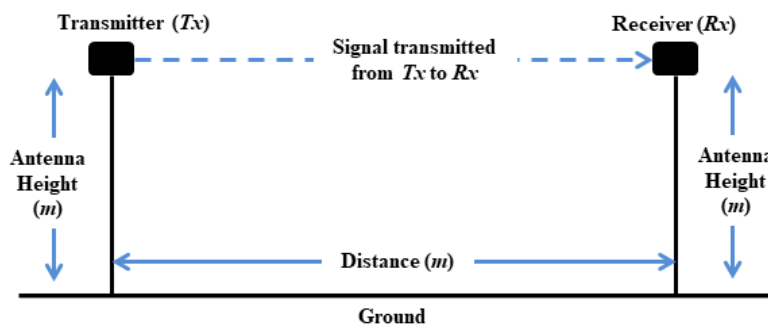


Figure 6. Transmitter and receiver measurement setup

Table 1. XBEE S2C specification used in data collection.

Specification	Xbee Series 2
Performance	
Indoor/urban Range	up to 133 ft. (40 m)
Transmit Power Output	2mW (+3dBm)
RF data Rate	250,000 bps
Serial interface data rate	1200 - 230400 bps (non-standard baud rates also supported)
Receiver sensitivity	-95 dBm (1% packet error rate)
Power Requirement	
Supply Voltage	2.8 – 3.4 V
Operating current	40mA (@ 3.3 V)
Power down current	< 1 uA @ 25oC ISM
General	
Operating Frequency Band	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)
Operating temperature	-40 to 85° C
Antenna options	Integrated whip, Chip, RPSMA, or U. FL Connector
Networking and security	
Supported network topologies	Point-to-Point, Point-to-Multipoint, Peer-to-Peer & Mesh
Number of channels	16 Direct sequence channels
Addressing options	Pan ID and Addresses, Cluster IDs and Endpoints

4. Experimental Design

The measurement for both plantations was performed by placing the transmitter (T_x) at fixed location. The receiver (R_x) was placed at every 1 meter distance (d) increment from the transmitter along the plantation as depicted in Figure 7 and Figure 8, respectively. The measurement geometry for tree is in

line of trees while shrub is into vegetation. Received Signal Strength Indicator (RSSI) values are collected and recorded. Since data collection is focused on plantations along the roadside, the measurements were collected during no traffic condition. In other words, there were no vehicles passing by the road during data collection to ensure stable measurements. The measurement was taken with increment 1 meter until the value recorded has reached its receiver's sensitivity for both shrub and trees. At each plantation, the measurement was taken with 2 different antenna heights, 0.3 meter and 1.3 meter respectively. The measurement was taken for two minutes at each point and is repeated for two times and averaged. The recorded values were concluded and presented. In this experiment, the maximum distance for data collection that can be achieved is 45 meters and 63 meters, respectively.

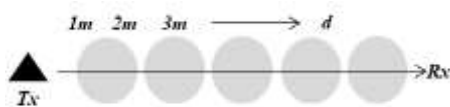


Figure 7. Measurement geometry for trees (line of tree)

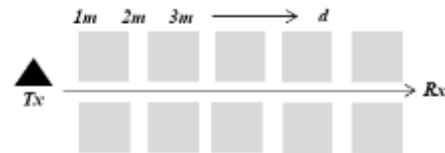


Figure 8. Measurement geometry for shrub (into vegetation)

5. Results and Discussions

First measurement was performed along the roadside area with shrub plantations. The lane with shrub plantation consisted of thick leaves, was planted and grew in a row along the roadside about 45 meters length. Measurement was also carried out over the path length of 0 meter to 45 meters with 1 meter increment at a time. Figure 9 and Figure 10 shows the result of the measurement.

As signal propagates along shrub path, it is observed that significant drop happened after 6 m distance for 0.3 m antenna height which brought the signal power from -51 dBm to -91 dBm. Low antenna height (almost on the ground) limited the propagation path thus ground reflection and scattering took effect earlier. The different in power loss for the first 3 m distance is 33 dB compared to antenna height at 1.3 m which is 28 dB. The range of the propagation for 1.3 m antenna height is extended further compared to 0.3 m antenna height which shows almost -91 dBm reading at 28 m distance while for 1.3 m antenna height, the signal power is at -77 dBm for the same range.

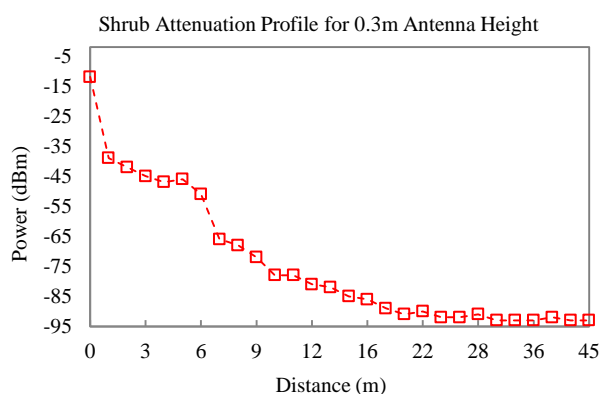


Figure 9. Shrub attenuation profile for antenna height 0.3 m

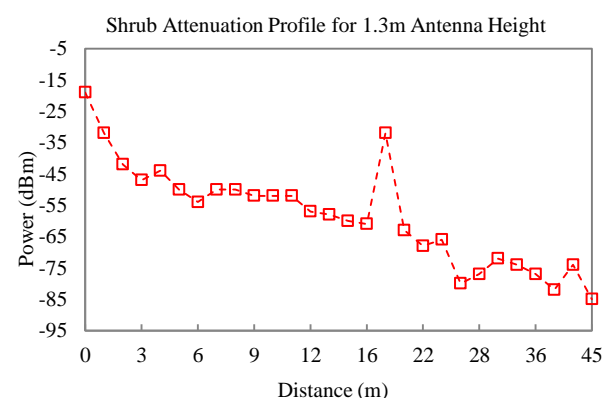


Figure 10. Shrub attenuation profile for antenna height 1.3 m

Second experiment was performed at tall trees path which has a range of about 63 m in length. Figure 11 and Figure 12 shows the result from the measurement for roadside with tall trees. As signal propagates along tall trees, power drops significantly for both antenna heights although 0.3 m antenna

height recorded extensive power drop compared to that of 1.3 m. This is mainly due to the existence of trees with trunks and leaves that initiated high level of scattering. This phenomena cause signals to diverted in various ways and many find the way back to receiver's end at multiple times due to delays variation as the signal propagates in the Fresnel Zone. Nevertheless, as the distance increases, the difference in signal drops for both antenna heights become more incoherent. It is observed that the drop for 0.3 m antenna height is significant which is at 19 dB from 10 m to 25 m distance while the drop for 1.3 m antenna height grows significantly for the same range which is at 29 dB. Moreover, significant fluctuations in signal can be observed starting at 8 m up to 60 m for 0.3 m antenna height and at 12 m up to 60 m for 1.3 m antenna heights. The presence the trees in between have affected the Fresnel Zones that cause multipath fading in signal propagation. The trees having larger dimension in wavelength compared to the signal has caused the signal to bend around the trees, absorbed or reflected towards each other. Hence, signal combines both constructively and destructively which results in random fluctuations.

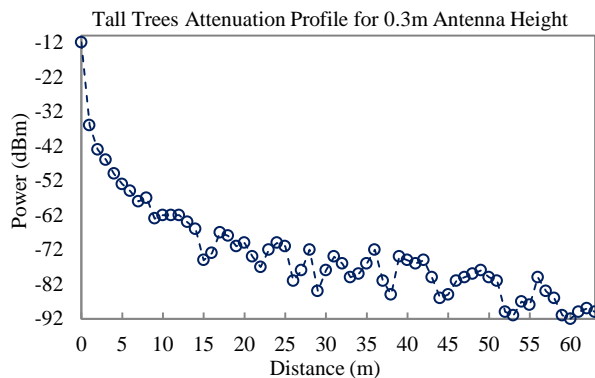


Figure 11. Tall trees attenuation profile for antenna height 0.3 m

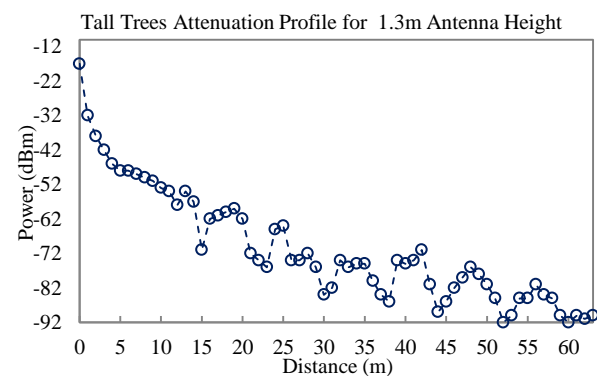


Figure 12. Tall trees attenuation profile for antenna height 1.3 m

A comparison between the two surface medium of propagation has been done and the result is as shown in Figure 13 and Figure 14. Based on Figure 9, it is observed that at 0.3 m antenna height the difference between two plantations is very obvious and shrub seemed to be the one causing higher attenuation compared to trees. For 1.3 m antenna height however, the separation is less obvious and it seemed as though the effect is almost similar for both plantations.

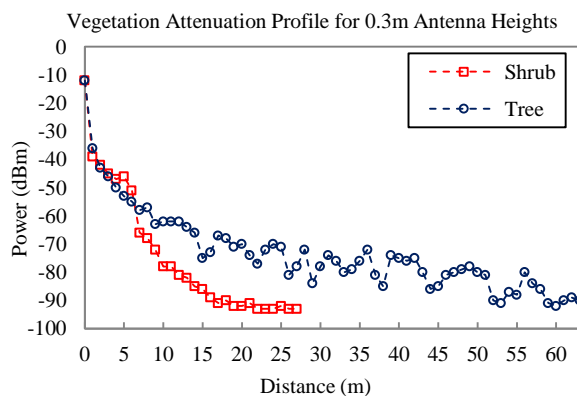


Figure 13. Vegetation attenuation profile for antenna height 0.3 m

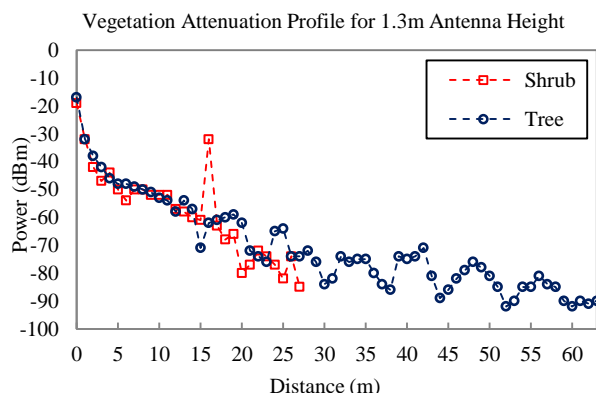


Figure 14. Vegetation attenuation profile for antenna height 1.3 m

In order to understand further the attenuation factor and effect of these plantations on signal propagation, a modelling was done for each of the profiles and the results are in the following figures.

Graphs in Figure 15, Figure 16, Figure 17 and Figure 18 describe the distribution of data for both shrub and trees attenuation profiles using log normal distribution, NZG [18], Weissberger's Model [20], COST235 [21] (Out-of-Leaf), ITU-R [22] and Fitted ITU-R (FITU-R) [23] models. The RMSE [17] values for vegetation attenuation models are as shown in Table 2. Figure 15 shows the modelling for shrub at 0.3 m antenna height while Figure 16 shows the modelling for 1.3 m antenna height. Based on the models, shrub signal profile at 0.3 m antenna height is following log normal distribution with RMSE of 8.40. Modelling against COST235 (out-of-leaf) attenuation model gives RMSE of 36.87 while ITU-R model, NZG model and Weissberger's model give RMSE of 39.59, 33.23 and 40.76, respectively. Shrub signal modelling at 1.3 m antenna height follows log normal distribution as well with RMSE 9.05. Modelling shrub signal at 1.3 m antenna height against COST235 (out-of-leaf) attenuation model gives RMSE of 20.88 while ITU-R model, NZG model and Weissberger's model give RMSE of 23.29, 17.88 and 24.43, respectively. Line of tree was also modelled with log normal, COST235, ITU-R, NZG, and Weissberger's model. Based on the attenuation profile, both 0.3 m and 1.3 m antenna heights show the error close to log normal distribution at 6.43 and 4.87 respectively as shown in Figure 17 and Figure 18. Tree modelling for 0.3 m and 1.3 m antenna height yield similar result where the profile follows log normal distribution. RMSE for other attenuation models such as COST235 in-leaf and both FITU-R for both in-leaf and out-of-leaf were also calculated as stated in Table 2. Based on Table 2, COST235 model shows smallest RMSE value for both shrub and tree at 0.3 m and 1.3 m antenna height, respectively. Shrub attenuation profile at 1.3 m antenna height gives smallest RMSE value as compared to other vegetation attenuation models. NZG model gives the smallest RMSE value which is 17.88, followed by COST235 (In-Leaf) model with RMSE value of 20.26, COST235 (Out-of-Leaf) model with RMSE value of 20.88, ITU-R model with RMSE value of 23.29, Weissberger's model with RMSE value of 24.43 and FITU-R model with RMSE value of 24.55.

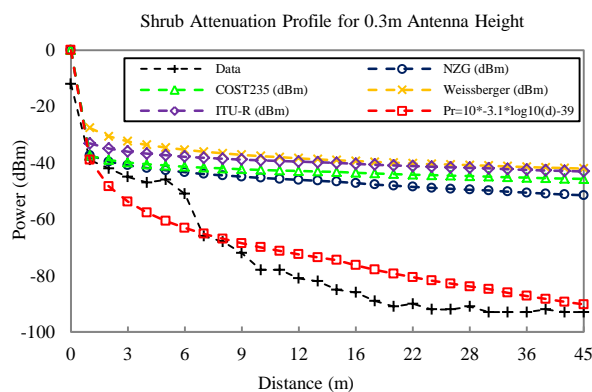


Figure 15. Shrub attenuation profile modeling for antenna height 0.3 m

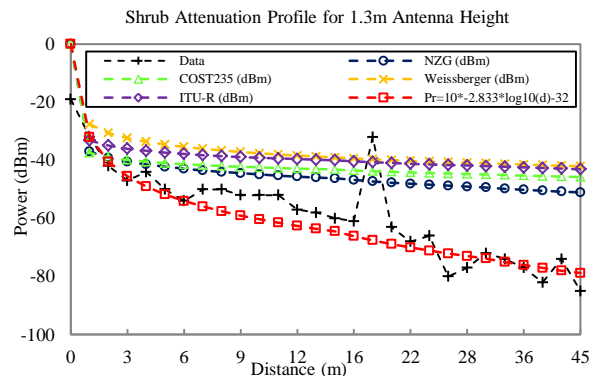


Figure 16. Shrub attenuation profile modeling for antenna height 1.3 m

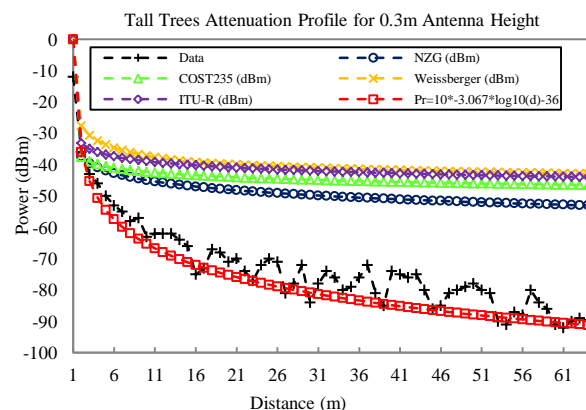


Figure 17. Trees attenuation profile modeling for

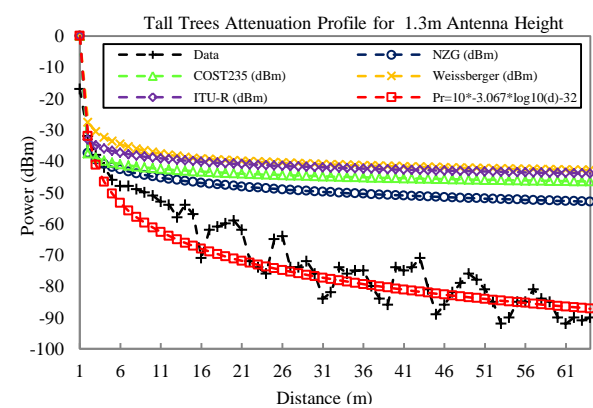


Figure 18. Trees attenuation profile modeling for

antenna height 0.3 m

antenna height 1.3 m

Table 2. RMSE of Vegetation Attenuation Models at Roadside Area

Antenna Height (m)		RMSE (dB)							
						In-Leaf	Out-of-Leaf	In-Leaf	Out-of-Leaf
		$VL_{Weissb.}$	VL_{ITU-R}	VL_{NZG}	$VL_{COST235}$				
Shrub	1.3	24.43	23.29	17.88	20.26	20.88		45.52	24.55
	0.3	40.76	39.59	33.23	35.99	36.87		62.49	40.95
Tree	1.3	41.57	40.54	32.01	37.85	37.92		66.73	42.08
	0.3	41.19	40.16	31.62	37.48	37.54		66.36	41.70

6. Conclusion

Vehicle-to-Infrastructure communication is very crucial in implementing a robust and reliable CAV program. In order for such communication to be established, proper study and planning need to be performed taking into consideration the environment in and around roadways in Malaysia. By looking into the test bed for potential CAV deployment in Universiti Malaysia Perlis, a few types of roadside plantations were identified as key contributor to wireless signal attenuation affecting the communication. Shrub and tall trees with trunk and thick leaves are always available along the urban and rural road transport environment in Malaysia. As such identifying the signal attenuation factor for these plantations would certainly be an important task in this work. Based on the studies performed, this research identified that for low plantation such as shrub, the difference in power loss is almost 33 dB compared to antenna height at 1.3 m which is 28 dB throughout the studied path. As for trees a more significant difference found for both 0.3 m and 1.3 m antenna heights as signal tends to fluctuates throughout the path. Comparing both shrub and trees signal profile, it is observed that at 0.3 m antenna height the separation between both plantations. It is very obvious shrub seemed to be the one causing highest attenuation at 0.3 m antenna height compared to shrub at 1.3 m and trees for similar antenna heights. For 1.3 m antenna height however, the separation is less obvious and it seemed that the effect is almost similar for both plantations. Thus, for any communication exchange the effect of these plantations along the roadside could be quantified and the profile could be sufficient to provide understanding of the effect. Signal profile modeling shows that both shrub and trees profile at both antenna heights follows log normal distribution and none follows Weissberger's distribution. For a reliable communication between vehicle-to- infrastructure to be established, all these models and results have to be properly incorporated into the planning and execution.

7. References

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