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Effect of Surface Attenuation on Signal Propagation Analysis in Connected Autonomous Vehicle Communication

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Abstract – *The advent of the autonomous vehicle has modified the landscape of modern transportation in the world. More sophisticated transportation requirement is emerging, notably in communication between vehicles to infrastructure. Robust and reliable communication infrastructure has become a crucial part of transportation criteria. The need for such a high quality of service communication drives for excellent preparation and planning in the communication process. As such, this research focuses on coming out with models to be used for advanced planning of communication processes between vehicles to infrastructure which is defined mainly by ground surfaces and objects around the roadways in Malaysia. Channel measurement around the testbed in Universiti Malaysia Perlis resulted in several interesting results that would shape the planning of CAV communication. It is observed that communication close to the ground requires high power consumption as the range is significantly reduced. It is also learned that certain ground surfaces allow for a 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 to this.*

Keywords: Connected Autonomous Vehicle (CAV), radio-wave propagation, Dedication Short Range Communication (DSRC), Received Signal Strength Indicator (RSSI)

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1.0 INTRODUCTION

A reliable, sustainable and robust communication network is a fundamental aspect of the connected transportation system, especially in connected autonomous vehicle program. Such fundamental is very critical in vehicle-to-vehicle (V2V) as well as vehicle-to-infrastructure (V2I) communication and data transmission. In V2I 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 the autonomous vehicle, roadways would soon become a more sophisticated transportation alley and as such communication with lane markings, road signs, and traffic lights would have to be properly managed.

To manage such complexity, a 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 (Dey et al., 2016). While Dedication Short Range Communication (DSRC) provides low latency, fast network connectivity, various application of CVT may not be supportable (Dar et al., 2010). In order to ascertain the communication and reliable network connectivity, a thorough study has to be done to understand the factors affecting the V2I communication. One of the critical areas of communication that require special attention is channel communication in V2I (Dar et al., 2010; Dey et al., 2016). This research looks into understanding the attenuation factors affecting such communication via channel measurement.

2.0 EXPERIMENTAL SETUP AND METHODOLOGY

Channel measurement has been used extensively to provide a comprehensive understanding of the surrounding area of interest for communication planning purposes. Many works have been performed in the infrastructure deployment planning as well as in the agricultural field. Authors in Harun et al. (2011), Ndzi et al. (2012), Harun et al. (2013), and Turner et al. (2014) have been performing such studies in the agricultural field specifically for sensor deployment and monitoring system execution. In this study, a good understanding of signal propagation in roadways is essential for establishing a reliable communication standard. For the radio-wave propagation in 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.

For the radio-wave propagation through the foliage medium, there is an additional (excess) loss on the propagation components such as direct wave and reflected waves. One of the well-known empirical models to be used for such propagation is Weissberger's modified exponential decay model represented by equation (2) and it is applicable where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates (Harun et al., 2011). 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,

$$L_W(dB) = \begin{cases} 1.33 \times f^{0.284}\, d^{0.588} & 14m < x \leq 400m \\ 0.45 \times f^{0.284} d_f, & 0m \leq d_f < 14m \end{cases} \quad (2)$$

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

Harun et al. (2012) had shown that WSN channel can be modelled using a log-normal model. The log-normal model is described by (3),

$$P_r(d) = P_{r_0} - 10\alpha log_{10}(d) + X_\sigma \quad (3)$$

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 Xσ represents a Gaussian random variable with zero mean and standard deviation of σ dB.

2.1 Measurement Location and Equipment

The measurement has been conducted at Universiti Malaysia Perlis's AAM-approved circuit as depicted in Figure 1. The circuit has been designated as a testbed for all research concerning autonomous vehicles as well as connected autonomous vehicle program.

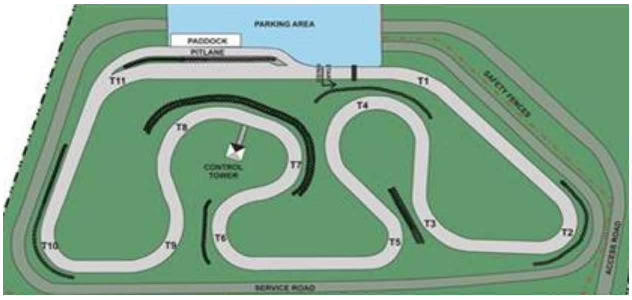

Figure 1: Universiti Malaysia Perlis (UniMAP) Circuit

It is very imperative to simulate Malaysian roadways in conducting this research especially in mimicking the ground surfaces around Malaysian roadways. Various surfaces around this circuit have been identified for data collection. Grass field such that depicted in Figure 2 has been chosen to represent ordinary grass fields normally found along Malaysian roads. Another important field to be measured is soil surface which is very prevalent around the roadways in Malaysia. Figure 2 also shows a similar soil surface used in this research data collection. The gravel filled field as depicted in Figure 3 is also another surface attenuation factor to be considered in this research.

Figure 2: Grass field for data collection (left); soil surface used in data collection (right)

Figure 3: Gravel filled field used in data collection

Data collection was performed using wireless nodes with multiple antenna heights adjusted along a metal pole. The nodes operate at 2.4 GHz frequency with an antenna gain of 3 dB. The receiver sensitivity is at -95 dBm. The specification of the node is given in Table 1.

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 85º 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

2.2 Experiment Design

The measurement is performed by moving the receiver along the specified paths while fixing the location of the transmitter. Received Signal Strength Indicator (RSSI) values are collected and recorded. The illustration of the methodology is shown in Figure 4. As the receiver’s antenna moves along the designated path, the RSSI value is measured and recorded. The further the antenna separation the lower the value recorded and as the value reached the receiver’s sensitivity, the measurement is concluded. The measurement is then repeated with different antenna heights.

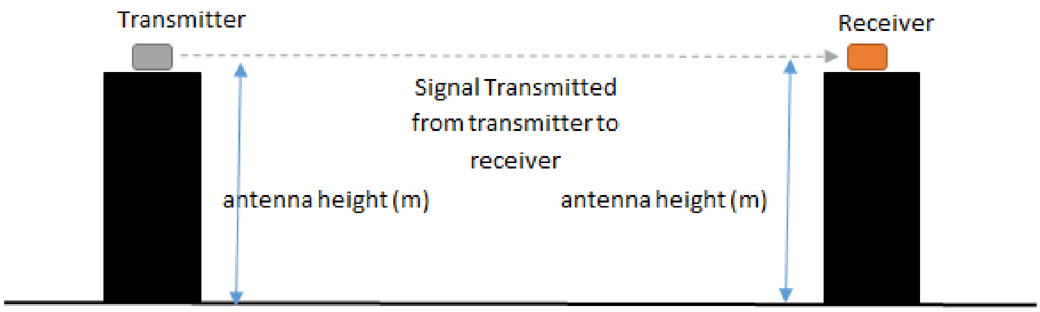

Figure 4: Nodes measurement setup

3.0 RESULTS AND DISCUSSION

The first measurement was performed on a plot of the field with open bare soil. The plot is around 50 m in length and almost very flat. Measurement was also carried out over the path length of 0 m to 50 m with a 1-meter increment at a time. Figure 5 shows the result of the measurement.

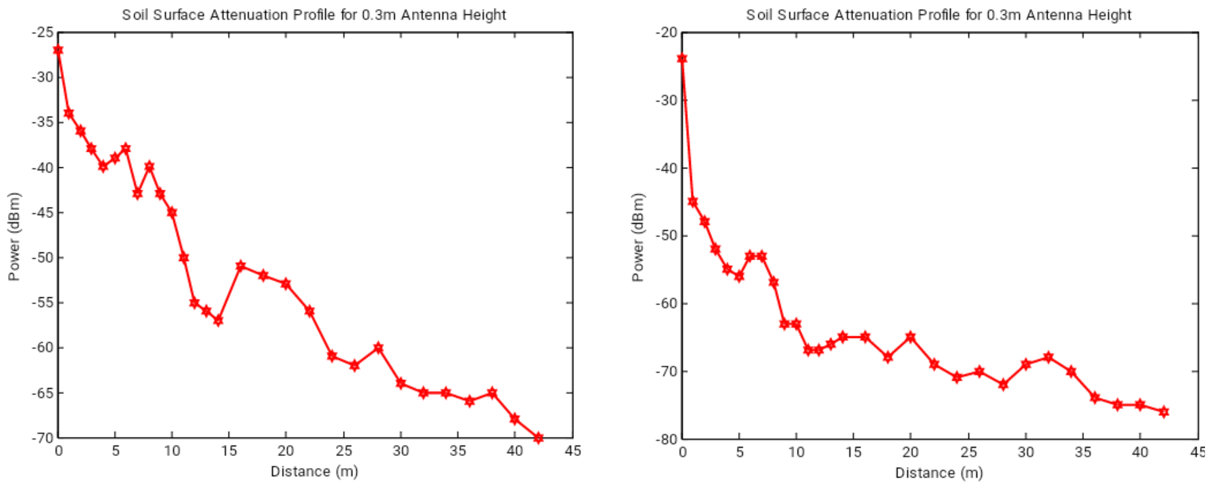

Figure 5: Soil attenuation profile for antenna height 1.3 m (left); soil attenuation profile for antenna height 0.3 m (right)

As the signal propagates along the soil path, it is observed that a significant drop happened after 7 m distance for 0.3 m antenna height which brought the signal power to -68 dBm. Low antenna height (almost on the ground) limited the propagation path thus ground reflection and scattering took effect earlier. The difference in power loss is almost 10 dB compared to antenna height at 1.3 m. The range of the propagation for 1.3 m antenna height is extended further compared to 0.3 m antenna height which shows almost -77 dBm reading at 40 m distance while for 1.3 m antenna height, the signal power is at -67 dBm for the same range.

The second experiment was performed at a gravel filled plot which has a range of about 60 m. Figure 6 shows the result of the measurement of the gravel path. As the signal propagates along the gravel path, power drops significantly for both antenna heights although 1.3 m antenna height recorded extensive power drop compared to that of 0.3 m. This is mainly due to the size of gravels initiated high level of scattering and causing signals diverted in various ways and many find the way back to the receiver's end at various 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 1.3 m antenna height is insignificant which is at 2 dB from 10 m to 25 m distance while the drop for 1.3 m antenna height grows significantly from the same range which is at 12 dB. Furthermore, the range recorded by 1.3 m antenna height is significantly higher since it is observable that the power level is at -80 dBm at 55 m and -88 dBm for 0.3 m antenna height at the same range.

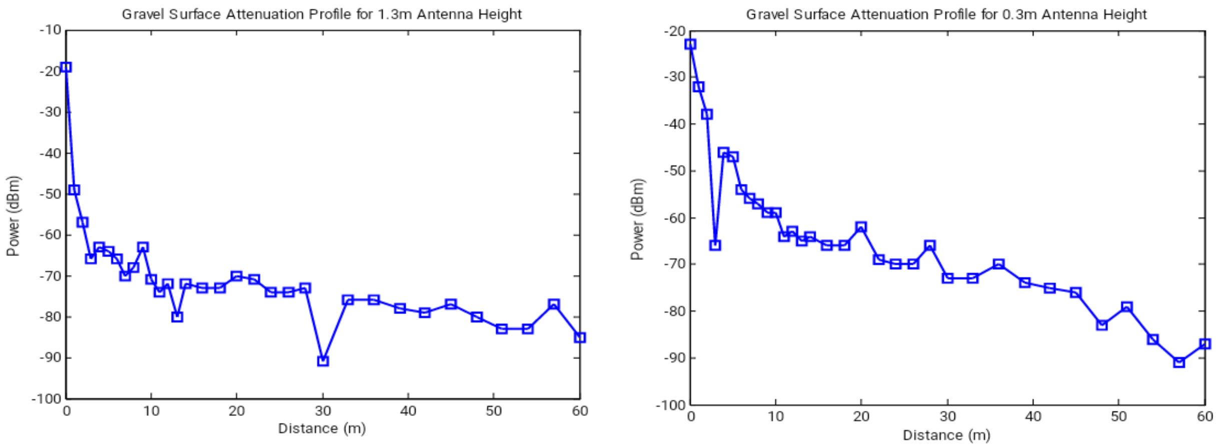

Figure 6: Gravel attenuation profile for antenna height 1.3 m (left); gravel attenuation profile for antenna height 0.3 m (right)

Measurement was also carried out for the grass field to understand the effect of the surface on the attenuation profile. The field chosen for this experiment is about 100 m length and grasses are quite thin at this time of the year. Figure 7 shows the result of the measurement.

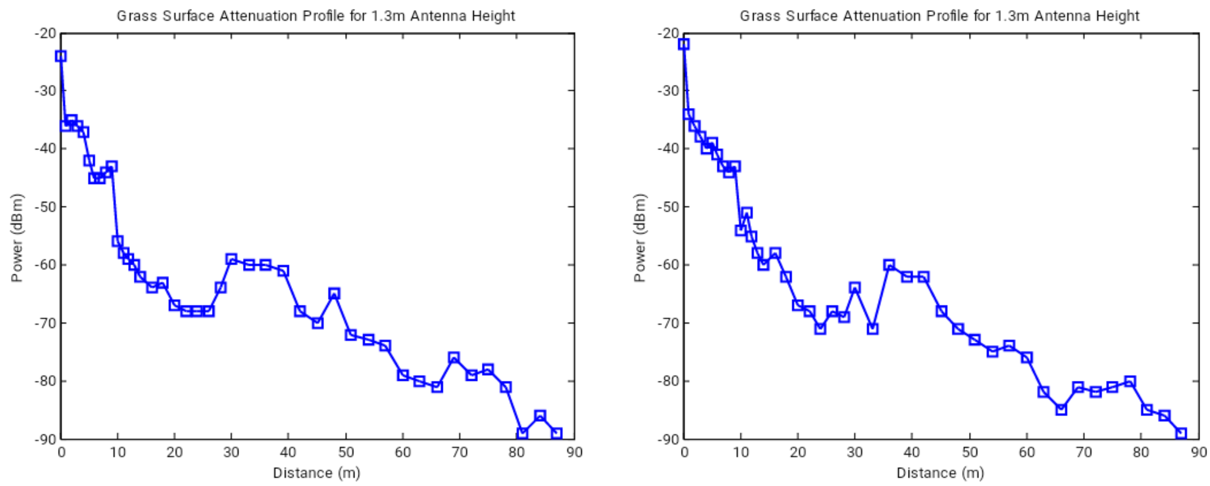

Figure 7: Grass attenuation profile for antenna height 1.3 m (left); grass attenuation profile for antenna height 0.3 m (right)

As the signal propagates along the grass field, it is observed that there is no significant difference found in signal power depreciation for both 1.3 m and 0.3 m antenna heights. Nevertheless, small differences found at multiple distances such as at 20 m range where 1.3 m antenna height recorded -70 dBm power while 0.3 m antenna height recorded about -72 dBm readings. Another one found at 65 m range where the power measurement difference is about 5 dB between both antenna heights in which 1.3 m antenna height recorded higher signal power measurement. The absence of a significant difference for this grass is mainly due to the minimal scattering produced by thin grass and as such the signal propagation follows almost the Free Space Loss (FSL) attenuation model.

A comparison between the three surface medium of propagation has been done and the result is displayed in Figure 8. From the graph on the left, it is observed that at 1.3 m antenna height the separation between the three ground surface is very obvious and gravel surface seemed to be the one causing highest attenuation, followed by grass and finally the soil surface. As such, for any communication exchange, the effect of these three ground surfaces could be quantified and the profile is sufficient to provide an understanding of the effect. For 0.3 m antenna height, however, the separation is less obvious and it seemed as though the effect is almost similar for all three ground surfaces. Nevertheless, the grass surface seemed to be the less attenuated among all three ground surfaces.

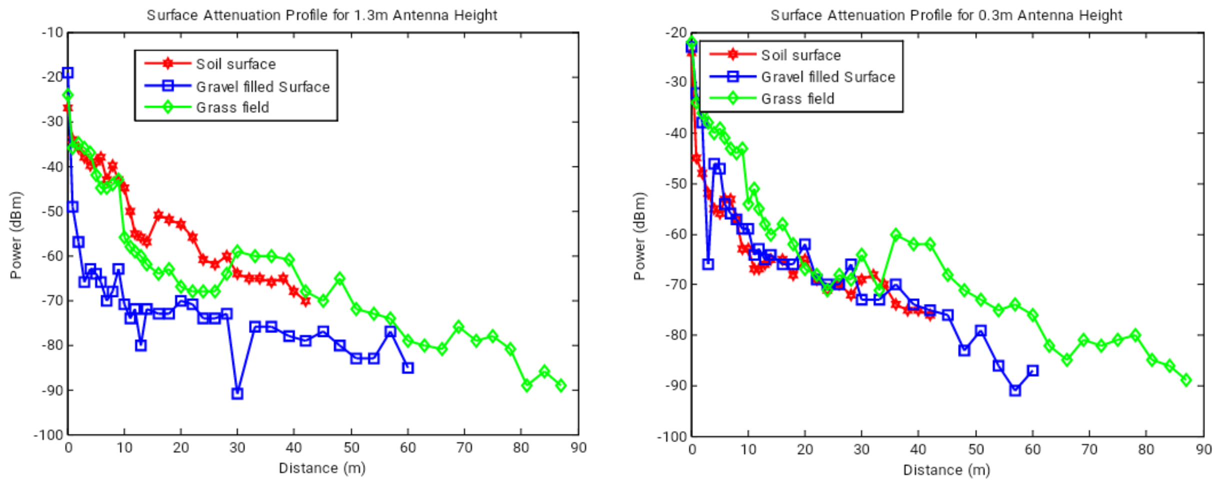

Figure 8: Ground surface attenuation profile for antenna height 1.3 m (left); ground surface attenuation profile for antenna height 0.3 m (right)

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

Figure 9 (left) shows the modeling for soil surface at 1.3 m antenna height while Figure 9 (right) shows the modeling for 0.3 m antenna height. Based on the model, the soil signal profile at 1.3 m antenna height is following log-normal distribution with RMSE of 3.86. Modeling against Weissberger's attenuation model gives RMSE of 12.57. Soil signal modeling at 0.3 m antenna height follows log-normal distribution as well with RMSE 2.39. The gravel surface was also modelled with log-normal and Weissberger's models and both 1.3 m and 0.3 m antenna heights show the error close to log-normal distribution at 3.9 and 4.93 respectively as shown in Figure 10. Grass surface modeling for 1.3 m and 0.3 m antenna heights also yield the same result where the profile follows log-normal distribution with RMSE at 5.22 and 4.88 respectively as in Figure 11.

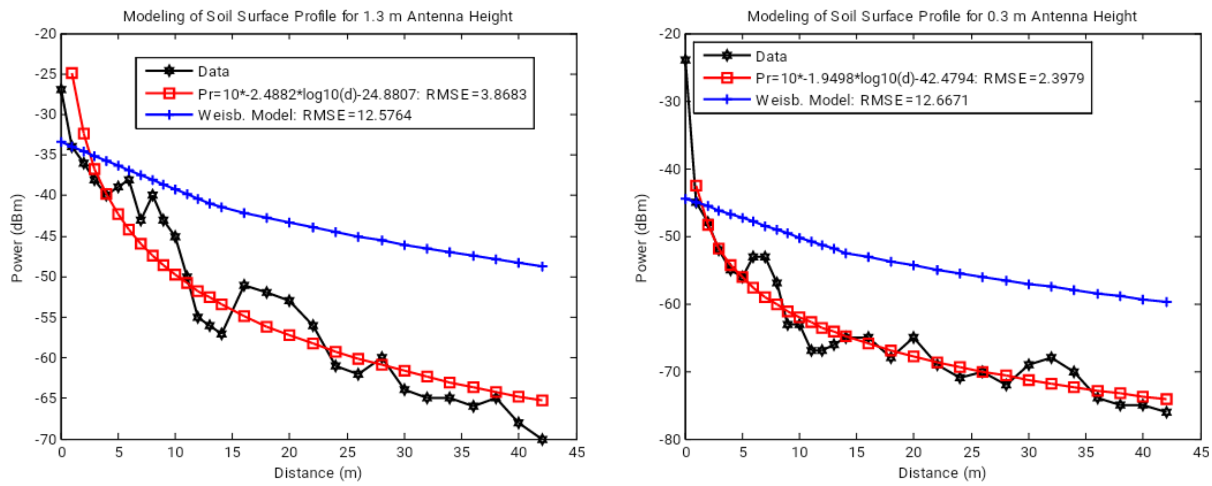

Figure 9: Soil surface attenuation profile modeling for antenna height 1.3 m (left); soil surface attenuation profile modeling for antenna height 0.3 m (right)

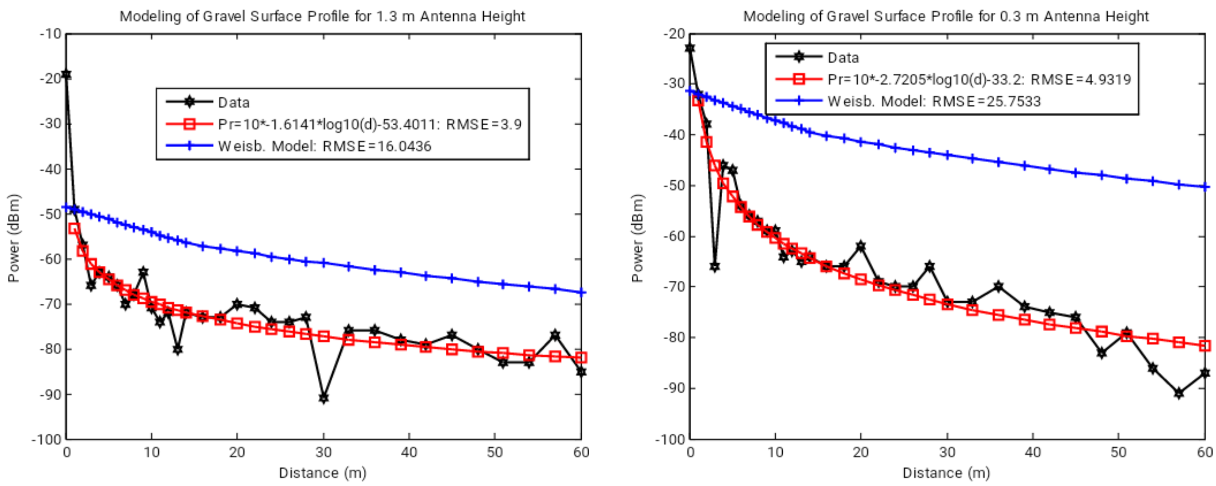

Figure 10: Gravel surface attenuation profile modeling for antenna height 1.3 m (left); gravel surface attenuation profile modeling for antenna height 0.3 m (right)

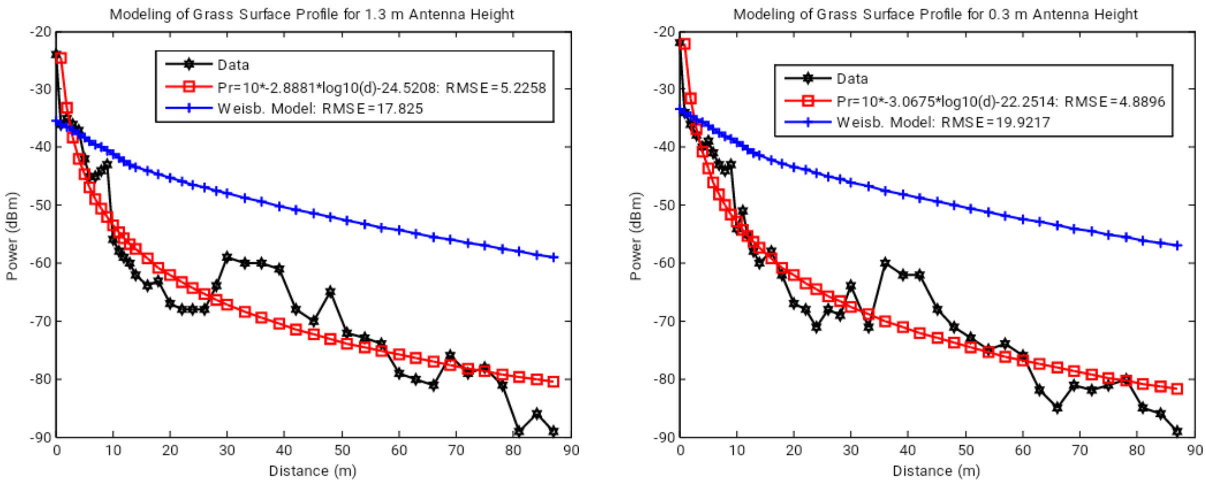

Figure 11: Grass surface attenuation profile modeling for antenna height 1.3 m (left); grass surface attenuation profile modeling for antenna height 0.3 m (right)

4.0 CONCLUSION

V2I communication is very crucial in implementing a robust and reliable Connected Autonomous Vehicle (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 testbed for potential CAV deployment in Universiti Malaysia Perlis, a few types of ground surfaces were identified as a key contributor to wireless signal attenuation affecting the communication.

Soil surface, gravel-filled surface and grass surface are the prevalent ground surfaces making up the road transport environment in Malaysia. As such identifying the signal attenuation factor for these surfaces would certainly be an important task in this work. Based on the studies performed, this research identified that for soil surface, the difference in power loss is almost 10 dB compared to antenna height at 1.3 m throughout the studied path. The range of the propagation for 1.3 m antenna height is extended further compared to 0.3 m antenna height which shows almost -77 dBm reading at 40 m distance while for 1.3 m antenna height, the signal power is at -67 dBm for the same range. Measurement on gravel surface shows that the signal drop for 1.3 m antenna height is insignificant which is at 2 dB from 10 m to 25 m distance while the drop for 1.3 m antenna height grows significantly from the same range which is at 12 dB. It is also found out that the power level is at -80 dBm at 55 m and -88 dBm for 0.3 m antenna height at the same range. As for grass surface measurement, there is no significant difference found in signal power depreciation for both 1.3 m and 0.3 m antenna heights. Nevertheless, small differences found at multiple distances such as at 20 m range where 1.3 m antenna height recorded -70 dBm power while 0.3 m antenna height recorded about -72 dBm readings.

Comparing all the three surfaces signal profile, it is observed that at 1.3 m antenna height the separation between the three ground surfaces is very obvious and gravel surface seemed to be the one causing highest attenuation, followed by grass and finally the soil surface. As such, for any communication exchange, the effect of these three ground surfaces could be quantified and the profile is sufficient to provide an understanding of the effect. For 0.3 m antenna height, however, the separation is less obvious and it seemed that the effect is almost similar for all three ground surfaces. Signal profile modeling shows that all the surface profile at both antenna heights follows log-normal distribution and none follows Weissberger's distribution. For reliable communication between V2I to be established, all these models and results have to be properly incorporated into the planning and execution.

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