Path Loss Analysis Considering Doppler Shift Effect on Cellular Communication for Connected Car Application at Rural Area

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Abstract. In this paper, the study on path loss of cellular communication is conducted by experiment and simulation on three different communication modules at rural area. This three-communication module will have different carrier frequency to determine the effect of doppler shift to communication path loss of moving vehicle. To enhance the accuracy of these studies, both simulation and experiment output will be compared. Simulation studies will be based on proposed modified path loss model. For the experimental portion, the Path Loss will be determined based on two things: the measured received power on communication modules antenna and transmit power from base station. From this experiment, the best selection of communication module by considering the fading effect from doppler shift is selected to be used in connected car.

1. Introduction

Connected car technology ought to be a keystone of revolutionizing in the automotive area. The use of wireless communication technologies on vehicle is the key to connecting vehicle to become one important part in Intelligent Transportation System (ITS) [1]. From basic information such as location of the car and now the vehicle engine performance itself can be monitored. Due to rapid advancement of electronic system for vehicle engine, previously every vehicle using only one Engine Control Unit (ECU) but now several control unit systems have been developed to control every part in vehicle by sharing the information each other’s [2]. In the 1990s, with the introduction of 802.11 wireless communication standard, ECU not only communicates within the internal vehicle system, it can also share information between different vehicles [3]. This technology made the connected car system can be achieve to support the ITS.

According to Kleberger et al. [2011], “the connected car consists of three domains: the vehicle itself, consisting of the in-vehicle network and the ECUs, the portal at the automotive company, and the communication link between them” [4]. The studies in this paper is focusing on communication link between vehicle and database to ensure the reliability of the information sharing through cellular network system. As suggested by Junyeong et al. [2014], it is important to provide better communication link quality due to increasing of vehicle speed and data packet size [5]. To overcomes the poor communication link during vehicle moving in urban area road, experiment on path loss and handover delay of cellular communication is made in this paper.
2. Existing Studies
There are few proposed solutions to provide better quality of communication. As suggested by Jyothi et al. [2014], it’s better to use Global System for Mobile communications (GSM) SIM900A rather than Bluetooth and Zigbee communication system for advance mobile communication [6]. Before the communication module is implemented on connected car, two main parameters need to be analysed: as path loss and doppler shift effect [7]. Yet, despite there are many existed models for analysing the path loss model but not all of it can be compatible to be used in certain unique environment [8]. For instance, Shooting and Bouncing Rays (SBR) method in Ray tracing path loss model was used by Amornthipparat et al. [2008] to study non-Line of Sight (NLOS) path loss in street cell environment [9]. Similarly, there have been studies on path loss between transmitter and receiver at urban and suburban environment [10]. However, so far there are only few researches that consider the influence of doppler effect in the path loss.

3. Methodology
In this paper, we are comparing path loss that happen on three different communication modules that have different frequency carrier by analysing the measured path loss data. Additionally, the tuned free space path loss model is used for the simulation. As for the experiment, we need to complete three phases of development and analyses in order to find suitable communication module that can be implemented in connected car system.

3.1 Communication Node Development.
Communication node hardware has been developed with three devices that are Arduino Uno, GSM modem and GPS. For GSM, three different models (with separate band and coverage) have been selected to test their communication performance; SIM900, SIM800L and SIM5360E. Note that SIM900 and SIM800L are using 2G signal for their communication coverage. In this experiment, SIM900 was using 1800MHz as the system band. Alternatively, for SIM800L and 900MHz, they were set as network band by using the AT+CBAND AT command. Lastly, SIM5360E was set to using UMTS 2100MHz as network band due to the modem 3G coverage capability. The experiment setup for these three GSM modems can be referred in Figure 1. Each communication node will perform the AT+CSQ AT command to obtain the communication modem Received Signal Strength Indicator (RSSI) which determines the received power in the GSM Antenna and perform ping request to test the latency of communication link. In this communication node GPS GY-NEO6MV2 has been used to get a latitude and longitude of the vehicle in deciding the distance between vehicle location and base station. At the end, these three GSM modems have sent all the data to webserver at www.000webhost.com.

![Figure 1. SIM900 Communication node](image-url)

In this communication node GPS GY-NEO6MV2 was used to get a latitude and longitude of the vehicle in deciding the distance between vehicle location and base station.
3.2 Webserver deployment
For recording, the data collected from the communication node. Webserver was deployed at www.000webhost.com by using Hypertext Preprocessor (PHP) and My Structured Query Language (MySQL) algorithm. This webserver used to store longitude, latitude, RSSI and vehicle speed data as displayed in Figure 2.

![Figure 2](image_url) Data collection table for communication node.

3.3 Analysis on measure and simulation path loss of communication that correlate to distance and vehicle speed.
For the analysis on communication link performance, the experiment only using one method; measuring path loss based on RSSI data in each types of communication module. This communication module tested by moving the vehicle along the rural area as shown in Figure 3. Three different velocity has been used in this test; 60km/h, 90km/h and 120km/h.

![Figure 3](image_url) Jalan Arau-Changlun rural area beside paddy field road.

The distance between vehicle and base station along the road was determined by referring to the Open Signal App as illustrated in Figure 4 that contains base station location information.
As for the simulation, the Tuned Free Space Path Loss model proposed as modified path loss model calculation. This model was suggested by Hong et al. as modified path loss model to simulate the experiment for high velocity moving communication node and considering doppler shift effect [11]. Doppler shift is a fading path loss effect that happens due to moving communication node. Based on this experiment, the received signal may have a Doppler shift of,

\[ f_D = \frac{v \cos \theta}{\lambda} \]  

(1)

associated with it, where \( \theta \) is the arrival angle of the received signal relative to the direction of motion, \( v \) is the receiver velocity, and

\[ \lambda = \frac{c}{f_e} \]  

(2)

is the signal wavelength (\( c = 299\,792\,458 \, m/s \) is the speed of light) and \( f_e \) is a frequency band of signal). The geometry associated with the Doppler shift is shown in Figure 5.
The Doppler shift results from the fact that transmitter or receiver movement over a short time interval \(\Delta t\) causes a slight change in distance

\[
\Delta d = v \Delta t \cos \theta
\]  

(3)

that the transmitted signal needs to travel to the receiver. The phase change due to this path length difference is

\[
\Delta \varphi = \frac{2 \pi v \Delta t \cos \theta}{\lambda}
\]  

(4)

The Doppler frequency is then obtained from the relationship between signal frequency and phase:

\[
f_D = \frac{1}{2 \pi} \frac{\Delta \varphi}{\Delta t} = v \cos \theta / \lambda
\]  

(5)

This doppler shift \(f_d\) parameter was calculated based on three different frequency carrier from communication module. Arrived angle, \(\theta\) and distance, \(\Delta d\) was measured based on the GPS data and OpenSignal Apps information.

Next, this doppler shift parameter was employed in calculating path loss in Tuned Free-Space path model using the following formula:

\[
L = K_1 \times \log_{10}(f_d) + K_2 \times \log_{10}(d) + K_3 + 32.45 + 20 \times \log_{10}(d) + 20 \times \log_{10}(f)
\]  

(6)

Where \(L\) is a path loss result that obtain from Tuned Free-Space model by using \(K_1, K_2\) and \(K_3\) that is median of optimum values minimum error between tuned path loss model and measured data obtained from Hong et al. analysis result on signal measurement at rural area. The value of \(K_1 = 5.0, K_2 = 19.2\) and \(K_3 = 9.0\).
4. Result

Figure 6. Path Loss vs Distance measurement data for three different communication modules with vehicle speed at A=60KmH, B=90KmH and C=120KmH
Figure 7. Path Loss vs Distance Tuned Free-Space path loss model data for three different communication modules with vehicle speed at A=60KmH, B=90KmH and C=120KmH

The results above are referring to the 3rd Generation Partnership Project (3GPP) in Technical Specification Group Radio Access Network, Evolved Universal Terrestrial Radio Access (E-UTRA) and Base Station (BS) radio transmission and reception (Release 15) that stated, the standard transmitting power for macro cellular communication base station is 46dBm. The result on Figure 6, where the path loss data are generated based on measuring RSSI from communication module and transmitting power from base station. It is showed the differences in path loss that happen in communication link will increasing if the frequency is increase. Whereas, in Figure 7 showed that the calculated data chart from the trend of path loss is just same with measuring data.
5. Conclusion
In this paper, the propagation path loss effect on communication link of connected car was investigated by considering doppler effect. From the experiment conducted, result shown that SIM800 is the most suitable, because of the low frequency from the SIM 800 communication module. This showed that the lower the frequency band, the better communication link in the signal propagation aspect. However, further study are needed to enhance the understanding of the communication link in urban or suburban area, before any conclusions can be made. Therefore, data from this study can be applied to network technologies specializing in connected car communication systems with another part, such as signal encoding algorithm and network technology.

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