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Performance Analysis of Intelligent Transport Systems (ITS) with Adaptive Transmission Scheme

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Abstract—**Various means of modern transports have already taken the initiative to incorporate computing and communication technology. This cross field area is coined as intelligent transportation systems (ITS). Transport systems of the future require fast and precise monitoring to ensure safety of such systems is guaranteed. Thus, the communication aspect demands seamless and minimal error whilst delivering vital data. However, the dynamic surroundings always post a challenge to wireless communications, taking account into a myriad of interference such as multipath fading, shadowing, dispersing and path loss. Furthermore, there is also case of mobility. In this paper, the performance of wireless communications with adaptive modulation and coding in vehicular scenarios were compared against rigid transmission techniques. Simulations were conducted over different mobility channel models against Signal-to-Noise ratio (SNR) to provide thorough analysis. Performance measure of Bit Error Rate (BER) and Packet Error Rate (PER) were used to provide understanding of the overall picture.**

Keywords-adaptive transmission schemes; intelligent transport systems; multipath fading

I. INTRODUCTION

Transportation has played an exceptional role in bridging distance for people. In modern times, the emphasis in quality and efficiency of transportation becomes even more apparent as the population increases at a fast rate. This requirement accelerates research in this field to achieve safer, cheaper, faster and more efficient transportation. In the same sense, modern connectivity methods have advanced so fast that the coverage of wireless networks in the city is almost overlapping each other. This is further proven with the constant rise in capacity for better communication services and better availability to the vast majority of people. The advancement in technology motivates the integration of computing into transportation to enable machine-to-machine communication. One of the objectives of Intelligent Transportation Systems (ITS) is to utilize technology to solve traffic problems. ITS highlights traffic surveillance, vehicle detection, vehicle classification, vehicle sensor networks and advanced traffic management system. Given the mobility nature of vehicles, difficulties are inevitable in realizing wireless communications to vehicles. These communications carry important information such as vehicle speed, driver state and traffic information. A wide range of applications and currently available technologies regarding ITS had been summarized in [1].

There are two types of vehicular communication modes: vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). V2V is further categorized into direct and indirect types where the former communicates directly to another vehicle and the latter uses a third party to pass the information on to another vehicle. Vehicular Ad-Hoc Networks (VANET) has also seen numerous developments and is an example of V2V application with many theoretical and practical research subjects [2]. Various efficient routing techniques can be applied in VANET to reduce latency and increase throughput [3].

First and foremost, to materialize the concept of ITS, vehicles must be equipped with sensor(s) to acquire information of the surrounding and it must be supported by a communication system for between vehicles and/or infrastructures. Currently, there are a variety of standard carriers dedicated for vehicular communications. Wireless Access in Vehicular Environments (WAVE) serves as a resource manager, physical and medium access control, gives security services, networking services, multichannel operations for V2V and V2I communication. Furthermore, dedicated Short Range Communications (DSRC) which is an extension from the IEEE 802.11 standard (newly identified as 802.11p) provides a suitable PHY and DLL interface for WAVE. Even the existing UMTS cellular network can provide good support with its added mobility advantage. On top of that, Millimetre wave (mmWave) has potential in short distance and high transfer speed vehicle communication applications [4]. Depending on the application, there might be a need to re-invent a new standard for a specific vehicular communications or the system can make use current deployments.

One fine example of ITS research contribution is California PATH [5]. They started conducting vehicle experiments in the late 1980s, namely its Lateral Control Test Vehicles and automated vehicle platoon control in highway situations. These systems require accurate data acquisition from sensors [6], reliable communication and, of course, impeccable control. After all, these research areas always have high safety benchmarks. They also made an impact by making long-term investments on Automatic Highway Systems (AHS).

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One key aspect of these transportation systems is that they deliver relevant information regarding passengers' safety and maximizing efficiency within minimum reaction time. All the infrastructure and vehicles must collaborate amongst each other to meet their collective objectives. Based on Fig. 1, an infrastructure with wide coverage sensing and up-to-date information of the road notifies the driver of any possible precautions at dangerous junctions. The system can also benefit via vehicles-to-vehicles communications, as emergency braking and unsafe proximity of nearby vehicles can update the driver. Vehicle communications related technologies also face challenges in standardization of the policies and protocols associated. Without careful planning, it may bring conflicts and irregularities. An extensive summary of all the recent projects with their objectives and scope is listed in [7].

The subsequent contents of the paper are arranged as follows. Section II introduces the various challenges faced by wireless vehicular communications. Section III provides an insight into adaptive modulation and coding schemes. Section IV covers the V2V models used to conduct simulations and in section V the results of the simulations are displayed and discussed. Finally section VI concludes the paper.

II. Radio Communications Systems in Vehicular Context

Wireless communications in vehicles' context are complex because of a few reasons. The places that vehicles travel have radio reflective surfaces (buildings and/or vehicles in cities) which will cause path diversity. Different standard of communications will have different set of environment obstacles. Moreover, vehicles are constantly moving at different speeds, resulting in variation of signal transmission.

A. Multipath Effects

In the simplest case, a communication link without obstacles in between the transmitter and receiver are said to have Line of Sight (LOS). But if the communication link is presented with a nearby radio reflective object, there is a possibility of multipath interference if two rays travel in different paths and they arrive at different time. This may cause destructive interference or InterSymbol Interference (ISI). It is also found that vehicles close to buildings will experience diffraction of rays [8], which is one of the examples of precaution that should be noted.

Multipath can be solved by extending the period of each transmitted symbol. If its duration sufficiently long, the symbols will not interfere with the subsequent symbols arriving from another path. This is demonstrated in Orthogonal Frequency Division Multiplexing (OFDM) where it is more resistant to multipath effects compared to single carrier wave because of the introduction of longer symbols in multiple carriers orthogonal to each other.

B. Fading Effects

Fading happens due to multipath propagation from several paths, resulting in a conjoining of signals from different paths with different timings, gain and delay. In other words, the receiver receives a combination of various copies of distorted original signals. Fig. 2 illustrates a simple case of multipath fading. Collectively, the channel impulse model can be described as:

$$h_c(t) = \sum_{k=0}^{K-1} \alpha_k \delta(t - \tau_k) \quad (1)$$

where α_k , k and τ_k is k[th] complex path gain, number of paths and k[th] path delay respectively. Small scale fading are monitored in spatial scales, almost one of half wavelength whereas, for VHF or higher there is large scale fading which occurs in scale of more wavelengths. Large scale fading is also called shadowing. Rayleigh Fading and Rician Fading are often used to characterize small scale fading. Rayleigh does not take account into LOS path gain. In contrast, Rician considers LOS path gain.

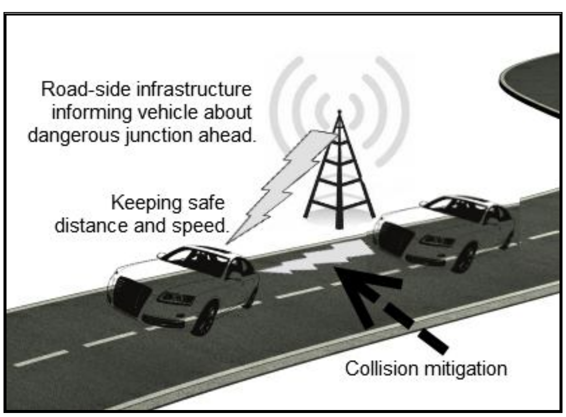

Figure 1. Example of a scenario of ITS solutions with V2V and V2I wireless communications.

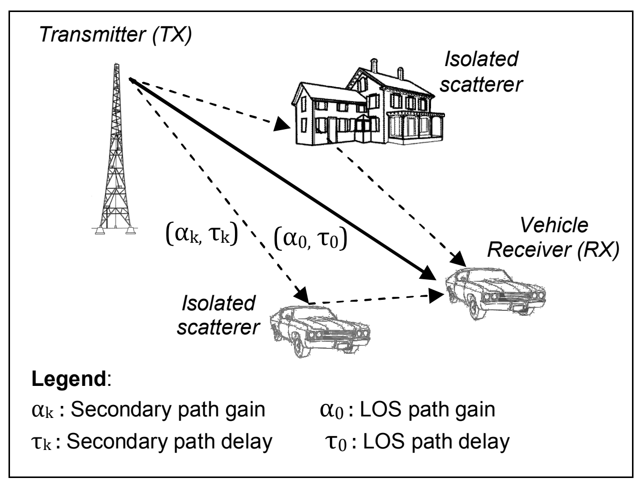

Figure 2. Multi-path propagation model.

1) Rayleigh Fading Distribution

Rayleigh is a special case of fading where there is no dominant LOS component. In that case, the Received Signal Strength (RSS), phase and angle of arrival (AOA) will experience variations. There are events of deep fades which will cause sudden outage in the communication link via drop in RSS. When the vehicles travel around, occasionally it will cause deep fade over time, this is called fast fading. Fast fading will still cause destructive interference although there are no ISI because of the low gain in deep fades. The Probability Density Function (PDF) of Rayleigh model is characterised as [9]:

$$p(r) = \begin{cases} \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) & (0 \le r) \\ 0 & (r < 0) \end{cases} \quad (2)$$

where σ represents RMS value of RSS, and σ^2 is time-average power of received signal.

Instantaneous power is obtained for determining SNR value by squared amplitude, r2. The Cumulative Density Function (CDF) in [9] defines the threshold R that must not be crossed.

$$P(R) = P(r \le R) = \int_0^R p(r)dr = 1 - e^{-\frac{R^2}{2\sigma^2}} \quad (3)$$

2) Rician Fading Distribution

In the case of existing line of sight component, the distribution is no longer Rayleigh but Rician as one dominant path shadows the other paths in terms of power. In the event of Rician fading random multipath components arriving at different paths are superimposed on a stationary dominant LOS signal. Rician distribution has a Rician factor, *K* (4), which is the ratio of the dominant LOS component over the dispersive components.

$$K(dB) = 10\log\left(\frac{A^2}{2\sigma^2}\right) \quad (dB) \quad (4)$$

Rician distribution is given by (5), where *A* is the amplitude of the dominant component, σ represents RMS value of voltage, and σ^2 is time-average power of received signal. $I_0(.)$ is the zero order Bessel function of the first kind. As $A \rightarrow 0$ and $K \rightarrow -\infty$, Rician distribution shifts to a Rayleigh distribution.

$$p(r) = \begin{cases} \frac{r}{\sigma^2}\exp\left(-\frac{(r^2 + A^2)}{2\sigma^2}\right) I_0 \frac{A_r}{\sigma^2} & (A \ge 0, r \ge 0) \\ 0 & (r < 0) \end{cases} \quad (5)$$

Before testing wireless communication systems in simulations, the value of *K* and the set of channel characteristics must be obtain statistically or deterministically. In a simulation viewpoint, there must be a balance between quantitative and complexity. If a model is rigorously and thoroughly described, its complexity is high. If that is the case, its potential might not be fully utilized because analysis and computer simulations might take a substantial amount of time.

3) Interference

The vast number of wireless networks and its dense deployments at present bring huge diversity to the wireless spectrum. The reason is of some researches aim to utilize the already congested channel efficiently [10].

These heterogeneous networks will be congested in due time since majority of the wireless communications standards for transportation are assigned in unlicensed bands e.g. Industrial, Scientific and Medical (ISM) band. This could trigger interference between adjacent wireless devices.

III. ADAPTIVE MODULATION SCHEME

Signal fading and path loss in wireless communications are common time varying challenges. Rapid changes in the environment can cause a variety of unwanted channel gains and interference. In the vehicular sense, these problems can affect the channel link substantially. For instance, urban terrain is filled with reflective surfaces which will cause the transmitting wave to travel two separate paths. Both waves arrive at the receiver at a different time, hence causing destruction interference of the intended wave. Such multipath fading effects results in errors at the receiver end.

The persistence of wireless channel challenges is increased with mobility. Vehicles travelling at wide range of speeds can also cause channel interference characteristics to change, this effect is called fast multipath fading. Adaptive modulation and coding (AMC) is found to perform fading compensation [11]. Adaptive modulation also aims to increase spectral efficiency of wireless communications while taking account into current channel conditions so to maintain transmission quality. As shown in Fig. 3, Adaptive modulation is paired with a channel estimator which estimates Channel State Information (CSI) by statistical techniques or by training symbols provided periodically by the transmitter. Using CSI feedback, the transmitter has a clear idea of what are the channel conditions. AMC can then adjust transmit parameters such as transmit power, modulation scheme or code rate. AMC allows the communication link to maximize spectral efficiency whenever possible. Compared to fixed transmission systems which assume the worst case channel conditions, the spectrum is wasted. In this paper an adaptive transmission technique with channel estimation [12] is implemented in top of wireless communication for vehicular application.

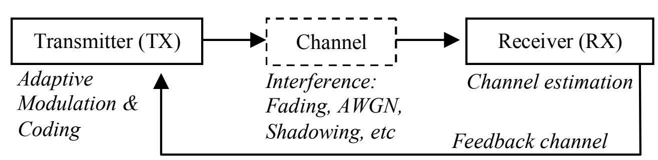

Figure 3. AMC system model.

IV. EMPIRICAL CHANNEL MODELS FOR VEHICLE-TO-VEHICLE (V2V) SITUATIONS

Physical layer channel modelling is essential in designing and evaluating communication systems. These models which will characterise the environment can assist in testing various communication schemes at the protocol stack. Hence, it can provide a convenient platform for the task of computing simulations. V2V scenarios often exhibit a greater magnitude of complexity in the channel compared to the simple channel models with underlying assumptions. Thus, this step's goal is to obtain the key channel statistical parameters and examine the effect of that model on various transmission schemes in vehicular communications.

Investigations in vehicular communications have gained significant momentum due to computing advancement of small and high performance dedicated systems. These systems strive to provide safety, awareness and comfort for vehicle passengers and pedestrians. Understanding the degree of impairments caused by the channel is imperative as even the best adaptive communication system can possibly face degrades in link quality when severe fading is present.

There are many scenarios that can be represented. Capture work in urban settings with the antenna inside or outside the car is found in [13]. The authors also included open spaces and highways with low and high density of traffic. Others study suitability of mmWave in various settings [14], where it uses directional antennas to overcome the strong propagation loss of mmWave. However, the directivity causes difficulty in maintaining the link. A doubly selective wireless propagation model is derived for V2V and V2I situations [15]. The authors produced three V2V models and three V2I models in tandem with IEEE 802.11p WAVE in metropolitan areas. This paper, in the subsequent section will be dedicated to covering only V2V models from [9].

A. *Channel Model Settings*

From the V2V models in [15], a tapped delay line structure is used for the channel simulation. Each tap process has the possibility of Rician fading, Rayleigh fading and Doppler spread. Table I describes the parameters of the developed models. The distance between transmitter (TX) and receiver (RX), the number of takes to obtain the model and average PER obtained when emulated over WAVE/DSRC. Every "take" lasts for approximately 9.6 seconds of recorded data.

B. *Scenario Descriptions*

1) *V2V Expressway Oncoming*

Figure 4. Freeway scenario with both oncoming vehicles.

The authors in [15] tried to synchronize both vehicles on a highway without a middle wall. Both vehicles are approximately accelerated to 105 km/h. Traffic during the "takes" are average as shown in Fig. 4.

2) *V2V Urban Canyon Oncoming*

Figure 5. Urban canyon.

Traffic during this capture Fig. 5 is congested and therefore hard to find the right time to adjust to desired settings. This was done at the speed of 32 km/h to 48 km/h.

3) *V2V Expressway Same Direction with Wall*

Figure 6. Freeway with a wall dividing opposite traffic lanes.

The authors measured data across various locations with expressways and a wall as a divider between opposite lane directions. During capture, all that needs to match is the timing when both vehicles are in the 300-400 m vicinity of each other.

V. RESULTS & DISCUSSION

Adaptive transmission scheme performs well compared to fixed modulation scheme. In fig. 7, it is observed that in fading conditions (Maximum Doppler 200Hz and Rayleigh Fading) Adaptive scheme is able to maintain its BER performance in slowly increasing favourable SNR conditions. However, a fixed transmission scheme (QPSK) with an average channel capacity of 4 bits per channel use, is unable to overcome fading effects as the BER performance indicates an approximate average error rate of 50 %. This undesirable performance is caused by a lack of adaptive capabilities. Note that however, the bit rate changes according to channel condition. This means there is a balance of maintaining error rate and channel capacity.

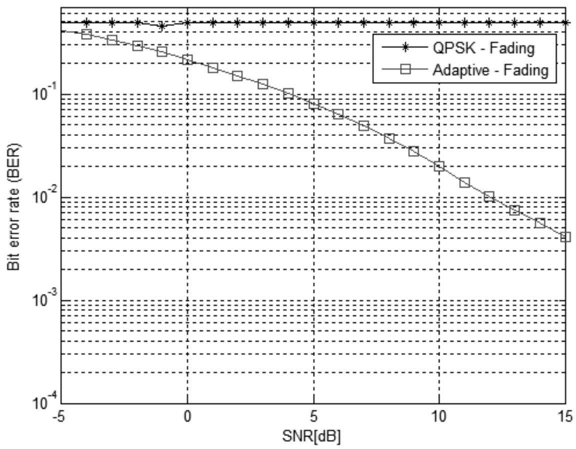

Figure 7. Comparing between transmission with QPSK and Adaptive Scheme over fading channel.

Simulation results for V2V situations include all three V2V channel models provided in [9]. In this category, the 3 scenarios, expressway oncoming, expressway oncoming same direction with wall and urban canyon are compared against each other. Firstly, the PER of three channel models are evaluated with adaptive transmission scheme in Fig. 8. The performance of adaptive transmission scheme on the expressway oncoming and urban canyon model are quite similar, whereby both reaches a minimal PER of 21 % and 25 %. In the case of channel SNR quality of 10 dB and below, both experiences same rate of improvement in PER. Besides that, channel model of expressway same direction with wall exhibits the best PER performance. At approximately 5 dB onwards, the PER is mostly 0 %.

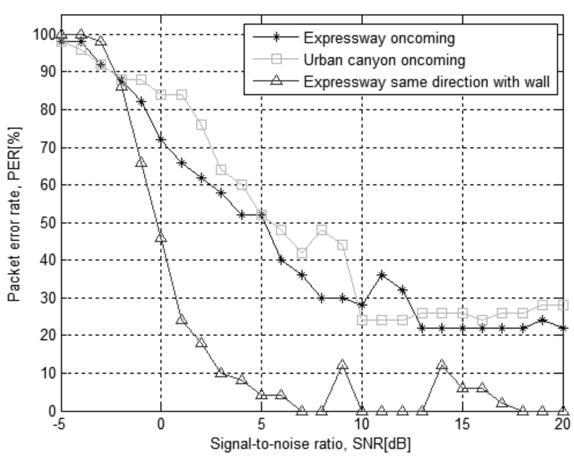

Figure 8. PER in percentage against different channel models.

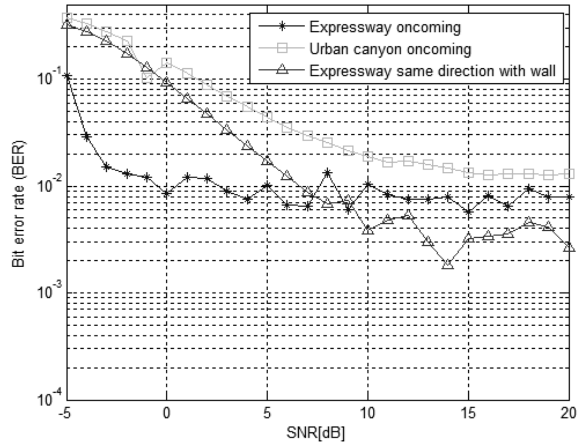

Figure 9. BER performance against different channel models.

BER performance for three channel models performed quite similarly in Fig. 9. Expressway oncoming has the most uniform BER at 10^{-2}, but expressway oncoming direction with wall achieves the best BER performance among the three models.

VI. CONCLUSION

This paper has tested an adaptive transmission scheme which thrives in fading and noisy wireless environment compared to a fixed modulation scheme. Utilizing some mobility channel models it is also proven the wireless communication scheme also performs fairly at average speeds on the freeway. However, there is still room for wireless transmissions to improve in fading conditions. To achieve that, more testing must be conducted so that the adversities in wireless environments can be well understood. As future work, more diverse and variety of V2V and V2I measurements of channel models should be done to cover more extensive cases.

TABLE I. MODELS USED IN SIMULATIONS

V2V scenario	Distance between Rx and Tx (m)	No. of takes used in model	Average PER result (%)
Expressway Oncoming	300-400	4	5.6
Urban Canyon Oncoming	100	2	4.4
Expressway -same direction with wall	300-400	21	1.9

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