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Procedia Computer Science 52 (2015) 51 – 58

Procedia
Computer Science

The 6th International Conference on Ambient Systems, Networks and Technologies
(ANT 2015)

Doppler Shift Mitigation in a VANET using an IDDM approach

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Abstract

Vehicular Adhoc Networks (VANET) was created to facilitate and enable inter vehicular communication. One of the most challenging problems affecting the feasibility of VANET is the problem of high mobility of the nodes resulting in an induced Doppler Shift (DS) in the carrier frequency at the receiver end. The work presented in this paper proposes a solution to mitigate the effect of DS affecting the VANET environment. Based on the Direct Derivation Method (DDM) derived from the principle of communication theory, an Improved DDM (IDDM) concept, analysis and design is developed and explored. Several critical tests are performed and it was demonstrated that not only the IDDM response exhibits the BER threshold limit described by the IEEE 802.11 standard; the approach offers for the same SNR value, a throughput improvement of up to 66.66% and an improved BER response of more than 25% compared to the DDM and Constant (Cte).

Peer-review under responsibility of the Conference Program Chairs

Keywords: VANET; DSRC; V2V; MCS; Doppler Shift; Coherence Time; IEEE 802.11p.

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1. Introduction

Most cases of road accidents occur due to a lack of reception and/or the lack of perception of vital information pertaining to the condition of roads and their state on time. From the point of view of the driver, most accidents happen by surprise. Ideally, if the driver of a car is made aware of the state of road in good time, the ability to better utilise available information could alleviate problems that are associated with severe accidents on public roads. Due

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Peer-review under responsibility of the Conference Program Chairs
doi:10.1016/j.procs.2015.05.019

to the higher mobility that the nodes are subjected to in a Vehicular Network (VN), interoperability amongst mobiles of such networks presents numerous challenges. The higher mobility causes the quality of the radio channel to regularly fluctuate between slow and fast fading. The communication channel is therefore subjected to higher variability conditions which in turn proportionally affect the transmitted data drastically. In this type of environment, if a suitable mechanism for Doppler shift (DS) mitigation is not implemented, the success of a data transmission cannot be guaranteed especially if the relative mobility speed rises above 50 km/h. This is due to the fact that apart from the increased mobility of the nodes, the IEEE 802.11p PHY layer also makes use of Orthogonal Frequency Division Multiplexing (OFDM) which is very sensitive to DS [1]. In order to contribute to the success and implementation of VANETs, this paper proposes an IDDM approach which offers some robustness against the effect of DS in vehicular networks. Unlike most of the approaches proposed in literature, the particularity of this work is that a wide range of DS (50 to 1500 Hz) is also considered.

A number of related studies have been conducted in this area. A compensation technique that is applicable in both the frequency and the time domain for future orthogonal frequency division multiplex (OFDM) systems operating in ultra-high-speed mobile environments was proposed in [2]. Using the analytical descriptive approach, the intercarrier interference mechanism was quantitatively clarified. The Signal-to-Noise Ratio (SNR) degradation of an Orthogonal Frequency Division Multiplexing (OFDM) system caused by Doppler frequency shift, phase noise and the frequency offset of the local oscillator was analysed in [3]. The results of the analysis demonstrated that a Doppler frequency shift of the Radio Frequency carrier degrades the symbol timing, the subcarriers and the signal envelope by the same percentage. An investigation and analysis of the Doppler Effect (DE) over a wide range of Doppler Shift (DS) were conducted in [4]. The results from the analysis clearly demonstrated that sustainable communication links can be achieved by using an appropriate Modulation Code Scheme (MCS) selection with DS ranging from 1 to 1400Hz. A novel correlator based on a partial match filter (PMF) that is followed by an FFT and a maximum output selector to improve the Doppler tolerance for polyphase codes was proposed in [5]. The proposed scheme demonstrated that phase rotation resulting from Doppler frequency can be cancelled and the Doppler tolerance improved when the polyphase codes is detected. The study shows that Doppler loss can also be decreased significantly.

Similar to the work presented in this paper, a normalized empirical coherence time (NETC) metric based on modulation, packet duration, and the traditional coherence time was proposed in [6]. Using a frame length of up to 65 symbols, a line of sight propagation and a fixed SNR of 30 dB, it was shown that given a fixed channel with a particular coherence time, the NETC provides a more accurate bound compared to the traditional coherence time. This is because the NETC makes use of a limited maximum packet length, which results in a negligible throughput degradation. Although the NETC shows some improvements when compared to the traditional coherence time based systems, the derivation of the actual NETC is a complex process and requires an undefined parameter value to compute equation 13 which is used to estimate the NETC value. In general, not only the frame length is limited to 65 symbols, the NETC value computation and generation are very ambiguous.

Although the Wireless Access in a Vehicular Environment (WAVE) standard was developed to enable Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication [7], most of the proposed works heavily rely of the V2I. V2I success depends on the availability and reliability of the other infrastructure network like GSM which in turn makes the deployment and implementation cost very expensive compared to V2V. The approach presented in this paper merely focus on V2V and V2I communication.

2. The IDDM Concept

From previous work performed in [8], it was shown that the Doppler Shift (DS) in frequency can be represented as

$$\Delta f = \pm\, (fc.V\cos\beta)/C \qquad (1)$$

where

Δf = change in frequency of the source seen at the receiver, fc= frequency of the source

V = speed difference between the source and transmitter, C = speed of light, β = angle of velocity vector

From the above expression, the change in frequency is maximal when β=0. OFDM symbols are very sensitive to this change. It was demonstrated in [3] that the Doppler shift affects the carrier frequency and the envelope by the same percentage. Based on the mathematical expressions derived in [8], it was also demonstrated that if the transmission duration (Td) period exceeds the coherence Time (Tc), the transmitted symbols will undergo a drastic change resulting in the interchanging of the real and the imaginary part of the signal. To cater for this problem, the DDM method approach as presented in [8] was developed. The DDM approach has shown some strength. However, it has some limitations in terms of throughput at higher relative mobile speed. The DDM approach was simulated using the communication system model developed in [4]. The said communication system components and subcomponents were well described and shown to be IEEE 802.11 conformant. The clarification and description of all components and subcomponents of this communication model are described in detail in [4]. From the work presented in [4], the channel model used was a combination of AWGN and a Raleigh channel model.

The AWGN degrades the signal by adding white Gaussian noise to a complex input signal. These added complex noise values are interrelated and Gaussian with zero-mean and noise variance. In a Raleigh fading channel, a transmitted signal is subject to fading caused by various factors that result from the mobile wireless environmental characteristics. Raleigh fading channels are useful models of real-world phenomena in wireless communication. For a realistic vehicular network environment, the DS is added to the above channels.

The DDM approach proved to be more resistant than the fixed conventional frame length (Cte) method in terms of the BER over the full SNR length of 0 to 30 dB. However, in terms of throughput, it only showed benefits for a lower and moderated DS. This was due to the fact that at higher DS the Tc is very small and the number of symbols to transmit is therefore minimal compared to Cte. For example, at 252 km/h the symMax of the DDM is about 25 symbols compared to the Cte of 100 symbols. In order to improve the throughput at higher speed, the number smyMax of the DDM needs to be longer. Looking at the DDM concept intuitively, if the DDM transmission duration (Td) is defined to be a multiple of Tc, then a different length of symMax can be evaluated based on Td. If the Signal throughput (St) is defined as: St= correctly received symMax/transmitted symMax, then several cases of using different Td size based on number of Tc can be explored to assess and determine the required Td value to be used for maximum St.

Case1: Td = 2Tc

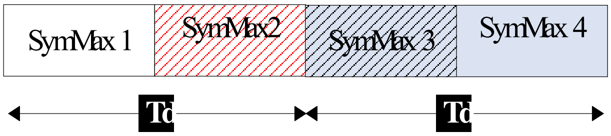

Figure 1: Case of transmitted data frame length= 2Tc

Figure 1 is made up of two frames differentiated in the white and light blue coloured blocks. Each frame lasts a duration period Td and is made of two SymMax. During each transmission period (Td), half of the frame will pass through without any alterations (in this case SymMax 1 and SymMax 4). Also, during the first Td, the first part of the frame (SymMax 1) is transmitted under the current Tc while the second part of the same frame (SymMax 2) is transmitted during the second Tc. Because SymMax 2 is affected by the second Tc, normally it would have passed through without any alterations if it was divided by the correction factor *j*. However, no correction is applied for the entire length of frame 1 (white colour). The correction is only applied to the second frame (light blue colour). As a result, SymMax 3 is affected because being under the current Tc, it is affected by the correction applied to the entire frame. SymMax 4 will pass without alteration because being under the second Tc it is affected by the second Tc. But since the correction factor was made for the full frame, the effect is purely cancelled. Looking at figure 1, it can be noticed that the signal throughput factor St= 2/4 =>0.50. As a result, for this case, the signal degradation is 50 %.

Case2: Td=3Tc

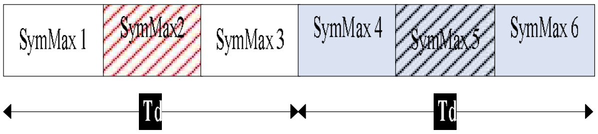

Figure 2: Case of transmitted data frame length= 3Tc

Figure 2 is made of two frames differentiated by the white and light blue colours. Each frame lasts a duration period Td and is made of three SymMax. During each transmission period (Td), 2/3 of the frame will pass through without any alterations (in this case SymMax 1, SymMax 3, SymMax 4 and SymMax 6). In addition, during the first Td, the second part of the frame (SymMax 2) is transmitted under the second Tc and is therefore affected since no correction was applied to frame 1 (white blocks). The first and the third part of the frame 1 (SymMax 1 and SymMax 3) will pass through without any alterations because based on the DS derivation concept, if no correction is applied, then only even numbered Tc frames are affected drastically. The correction is only applied to the second frame 2 (light blue blocks). As a result, SymMax 5 is affected because being under the even numbered Tc, it is affected by the correction applied on the entire frame 2. SymMax 4 and SymMax 6 will pass without any alterations because being under the even numbered Tc of frame 2, the correction was applied and the degradation effect is simply cancelled. Normally, SymMax 4 and SymMax 6 would have been affected if the correction factor was not made for the full frame 2. SymMax 5 is affected because not being an even numbered Tc, it is a victim of the correction factor applied in frame 2. Looking at figure 2 it can be noticed that the signal throughput factor St= 4/6 =>0.666 which is 66.66%. As a result, for this case, the signal degradation is about 33 %.

Case 3: Td=5 Tc

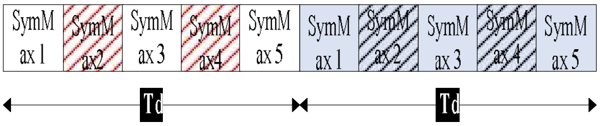

Figure 3: Case of transmitted data frame length= 5Tc

The application of the same concept in figure 3 gives a signal throughput factor St=6/10=> which is 60% resulting in signal degradation of 40%. Based on the above three cases, it can be seen that a maximum ratio can only be achieved if Td=3Tc. So if the new frame length is set to Td = 3Tc then a throughput improvement of about 66% can be achieved compared to the previous DDM. It can also be noted that this is valid for a long frame transmission under a variable speed. The Improved DDM (IDDM) is then defined as being DDM where Td=3Tc.

3. Simulation and Analysis

The simulation analysis is divided into two parts. The first part deals with DS problem analysis and identification. This component clarified the problem posed by DS and explains why it is important to develop effective strategies to cater for the DS effect under higher speed mobility. The second part called Model Development deals with BER analysis of the IDDM compared to the DDM and Cte.

3.1. DS Problem Analysis

The scenario presented in the simulations is that of two vehicles moving in a straight line in the opposite or in the same direction. It is assumed that both mobiles are equipped with a GPS. In this work, apart from the OFDM parameters described in [8]; the following were also used:

Carrier frequency: 5.85e9
Delay spread: 3e-6
Symbol duration: 8e-6;
OFDM sub-carrier: 48
Pilot: [1 1 1 1 1 1 1 1 1 1 1 1 1 1 111];
frame length of Cte: 3000 symbols;
frame length of DDM and IDDM: 6000 symbols;

Relative speed: 25 to 250 km/h
ChannelType: 'Rayleigh'
InputSamplePeriod: 2.0000e-007
DopplerSpectrum: [1x1 doppler.jakes]
MaxDopplerShift: 1500
NormalizePathGains: 1
PathGains: -0.7422 + 0.9787i

It should be noted that the Cte (constant) used has a fixed frame length with fixed number of symbols along all simulations to demonstrate that a long data frame cannot be successfully transmitted over a VANET environment if a specific strategy is not adopted. Using the above parameters, Cte was computed using BPSK and QPSK rate 3/4 with variable speed of 25 to 100 km/h. Simulation results for the case of BPSK is presented in figure 3.

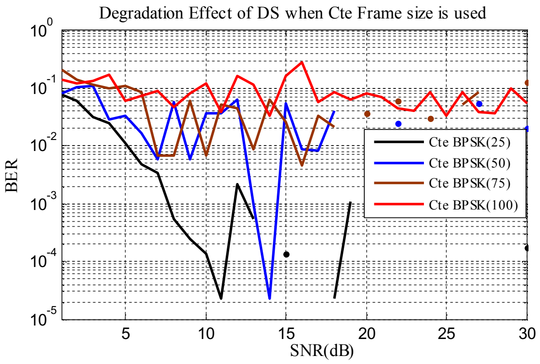

Figure 3: DE on Cte at 25 to 100 Km/h

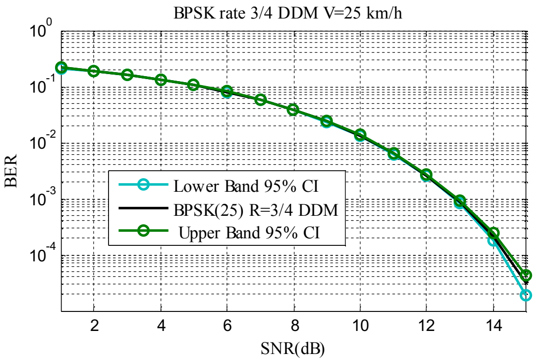

Figure 4: DDM at 25 Km/h with 95% CI

The results depicted in figure 3, shows that there is no need to compensate for DS when the relative mobile speed is at 25 km/h. This is justified by the fact the Cte BPSK (25) response crosses the BER of 10e-3 around 8 dB. As long as a BER performance is less than 10e-3, the candidate MCS is considered valid and competent for any wireless transmission [9]. Looking at Cte BPSK (50), it can be observed that although this curve crosses the acceptable BER limit around 13 dB, it does not stay within the range for long. The interpretation of this type of behaviour explains that this candidate could sometimes meet the acceptable BER response but without any guaranty. A remarkable observation of the Cte BPSK (75) and Cte BPSK (100) show that when the relative speed crosses 75 km/h, it becomes very difficult or almost impossible to achieve an acceptable BER of 10e-3. This is justified by the fact that the BER response at 75 and 100 km/h fluctuates above 10e-2. With this response level, no acceptable wireless communication can be achieved [10]. A general analysis and observation of figure 3 clearly demonstrates the problem caused by higher mobility of the communication nodes resulting in a poor and unacceptable communication system. Based on these experiments, it can be said that unlike in a fixed WLAN, if an effective strategy to cater for DS is not implemented, then any attempt to transmit data under VANET is almost impossible.

To justify the accuracy of the results presented in this work, all simulation tests were performed with 95% confidence interval (CI). Figure 4, depicts the performance result when considering a BPSK rate 3/4 using the DDM technique at a speed of 25 km/h with 95% CI band. Looking at figure 4, it can be observed that the discrepancy between the actual curve (BPSK (25) R=3/4 DDM) and the sidebands is very minimal. This minimum difference indicates that as long as two adjacent curves are spaced with the interval greater than this difference, they will be considered as two valid and distinct curves.

3.2. Model Evaluation

In general, the simulation of the IDDM test helps to understand whether it was necessary to develop IDDM and also to see if the IDDM would pass the threshold BER test as described by the IEEE 802.11 standard. In fact the required BER threshold for a possible communication in a wireless environment should be around the BER of 10e-3 [10]. One main advantage of the IDDM compared to DDM is that using the same concept, no correction factor is used. The other reason is that taking into account the 66.66% throughput improvement of IDDM compared to the DDM, the IDDM design and development is worthy. To evaluate and justify the work presented in the paper, the IDDM response is compared against DDM and the Cte. The performance exploration of the proposed IDDM technique is presented in the next paragraph of this paper.

In order to create a model for the practical environment simulations, some simulations were performed to probe the effectiveness of the proposed approach first to see if the BER response is below an acceptable level and secondly, to verify the performance of the IDDM against DDM and Cte. These results are depicted in figures 5 to 8. It should be noted that a wide range of relative speeds (50 to 250 km/h) was considered in the simulations to cater for all possible communication scenarios. This is justified by the fact that the maximum allowable speed on South African highways is 120 km/h. If two vehicles driving at the speed of 120 km/h each are moving in the opposite direction, then the maximum relative speed will be 240 km/h. However, if they are moving toward each other, the relative speed will tend toward zero. The concept of Doppler Effect demonstrated that when mobile are moving toward each other, the relative speed decreases. When mobiles meet at the intersection, the relative speed is closer to zero and when they are moving in opposite directions, the relative speed increases. Therefore, a speed range of 25 to 250 km/h will cater for any communication scenario.

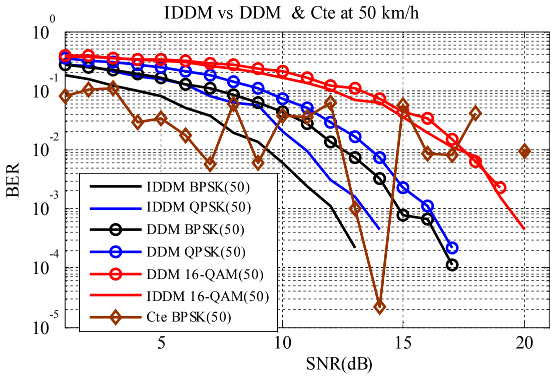

Figure 5: IDDM vs DDM and Cte at 50 Km/h

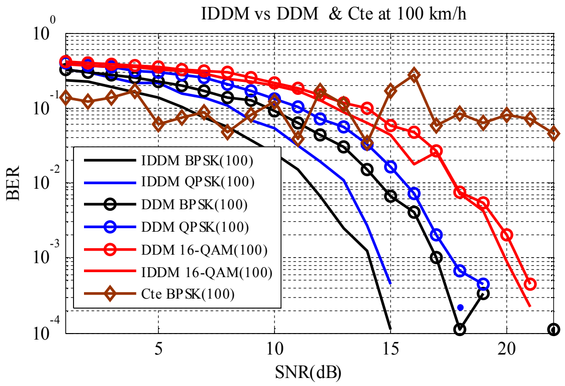

Figure 6: IDDM vs DDM and Cte at 100 Km/h

The analysis of figure 5 to 8 show that in any figure, IDDM and DDM offer better BER compared to Cte. Looking at the IDDM in comparison to DDM, it can be observed that both BPSK and QPSK of the IDDM outperform the BPSK of DDM. It can also be noted that when BPSK or QPSK is used, for any given equivalent MCS, the IDDM approach offers more than 25% improvement in terms of BER response compared to DDM. This improvement can be observed from figure 5 to 8. Simulation results also reveal that the response of the 16-QAM of both IDDM and DDM is very similar. This similarity can also be observed in almost all figures. However, in all figure the IDDM offers more than 100% improvement compared to Cte. To derive the MCS which is suitable for the particular channel condition, the MCS that performs best is selected for any given SNR range. Taking the case of figure 5, based on the required BER limit, it can be observed that no possible communication can be achieved for a SNR less than 12 dB. However, from 13 to 14 dB, the best MCS in terms of BER is the BPSK. From 15 to 19 dB, QPSK is the best candidate as it offers comparable strength to BPSK MCSs. From 20 to 30 dB, taking into consideration the confidence interval band, it can be seen that any MCS is a potential candidate. In this case the backoff state and the transmission success rate are used to select a corresponding MCS. At the particular SNR (20 to 30 dB), the channel response behaviour resembles that of conventional MANET used in IEEE 802.11 where the strongest MCS is the BPSK in case of high channel interference. Based on this concept, while transmitting between 20 and 30 dB, the first choice will be the BPSK, the second choice will be QPSK followed by the 16-QAM. The choice of moving from lower MCS to the next higher MCS is possible only after successful transmission. In case of unsuccessful transmission, the system will automatically move from the current MCS to the next lower MCS. To summarise figure 5, BPSK= [13 14], QPSK= [15 20] and all= [21 30].

Figure 6 clearly shows that at a relative speed of 100 km/h, no possible communication can be achieved with Cte since Cte BPSK (100) is no longer able to cross the 10e-3 BER response level. This is why the development of DDM and IDDM become so important because as the relative speed rises, the Cte losses its robustness whereas the IDDM and DDM continue to show more resilience to the degradation caused by the DS. Considering figure 6 the system response is summarised as: no communication is possible for SNR less than 14 dB, BPSK and QPSK = [15 20] and 16-QAM= [21 30].

Looking at figure 7, it can be observed that the IDDM response is well above both the DDM and Cte responses and the prescribed threshold. It can also be observed in these figures that no possible communication is sustainable for a SNR less than 16 dB. In this figure, the MCS selection in the range of 24 to 30 dB is therefore subject to the same concept as explained in figure 5 and 6. The selected MCSs are: BPSK = [16 18], QPSK = [19 23], and any MCS = [24 30].

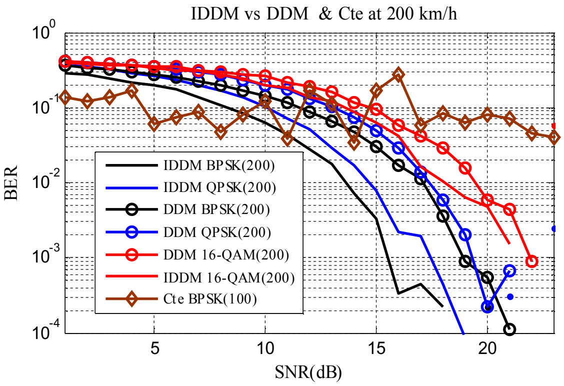

Figure 7: IDDM vs DDM and Cte at 200 km/h

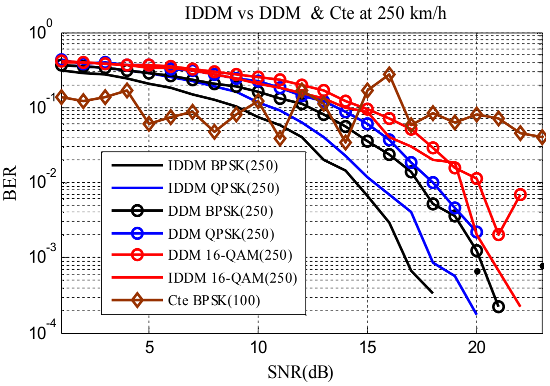

Figure 8: IDDM vs DDM and Cte at 250 Km/h

Analysis and observations from figure 8 show that effective communication can be achieved only for BER greater than 17dB. In this figure, IDDM also performed well above both the DDM, Cte response and the BER threshold. In terms of MCSs candidate, the analysis of figure 8 with respective relative velocity of 250 km/h is given as: BPSK and QPSK = [18 23], and all = [24 30]. To summarise the above simulations, table 1 was computed to present the optimal MCSs which could be used in future to ensure successful transmission when the IDDM concept is employed.

Table 2: Derived MCS table

Relative speed (km/h)	SNR (dB)																	
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
50	2	2	4	4	4	4	4	4	x	x	x	x	x	x	x	x	x	x
100			4	4	4	4	4	4	x	x	x	x	x	x	x	x	x	x
200				2	2	2	4	4	4	4	4	x	x	x	x	x	x	x
250						4	4	4	4	4	4	x	x	x	x	x	x	x

To ease the reading in table 1, the MCSs used were described using numbers defined as: BPSK = 2, QPSK= 4, 16-QAM = 6 and any (all) MCS= x. It is should also be noted that each entry of the table displays the maximum achievable MCS for a given channel condition. For instance, a MCS of 4 in the table means that BPSK and QPSK can be used with a maximum achievable MCS being QPSK rate 3/4. It can also be observed that MCS 7 and 8 are completely absent from the table. This is because 64-QAM is very weak once the communication channel is affected by the DS. This table will be of great importance if the system performance will only be based on BER metric evaluations. Based on the results obtained from different simulations, it can be concluded that the IDDM has some potential in terms of BER response over the DDM and Cte. However, further exploration for consistency in terms of channel throughput and system efficiency is required. In reality the BER test takes into consideration the number of bit errors in a given frame only. On the other hand, the channel throughput and the system efficiency take into consideration the number of frames passing through the channel without a single bit error. In order to consider all other practical aspects of the vehicular network characteristics, a channel throughput and system efficiency computation and analysis are also necessary.

4. Conclusion

This work demonstrated that unlike in a fixed WLAN, if an effective strategy to cater for DS is not implemented, then any attempt to transmit data under VANET is almost impossible. To cater for the above mentioned problem, the study developed an Improved DDM (IDDM) technique and tested it against DDM and Cte. The IDDM proved to offer for the same SNR value and improved BER response of more than 25% and 100% compared to the DDM and Cte respectively. It is to be noted that although the figures only show the result in terms of BER, the performance in term of throughput and efficiency of IDDM can also be demonstrated. This work also demonstrated that not only does the IDDM prove to offer higher performance compared to DDM, it achieves these results without any correction factor which can be translated into lower implementation complexity. The other particularity of this work is that a wide range of DS (50 to 1500 Hz) is considered.

Future work will consider deriving MCSs for all relative speeds and thereafter testing the IDDM approach consistency against other rate adaptation candidates in term of efficiency, throughput and transmission rate

Acknowledgement

This work was supported by Tshwane University of Technology/French South African Institute of Technology and National Research Foundation (NRF) via the scholarship program of Research and Innovation Support and Advancement (RISA).

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