An MCS adaptation technique for doppler effect in IEEE 802.11p vehicular networks.

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Computer Science 19 (2013) 570 – 577

Procedia
Computer Science

The 4th International Conference on Ambient Systems, Networks and Technologies (ANT 2013)

An MCS adaptation technique for Doppler Effect in IEEE 802.11p Vehicular networks

E. A Feukeu, K Djouani, A Kurien

F'SATI, Tshwane University of Technology, Private Bag x680, Pretoria 0001

Abstract

In a vehicular network, all mobile nodes in communication are affected by Doppler Effect (DE) caused by the mobility of node. DE contributes considerably to the channel degradation in a Vehicular Ad-hoc Network (VANET). In this paper, a novel Modulation Code Scheme (MCS) adaptation technique to combat DE is presented. This method called Automatic Doppler Shift Adaptation (ADSA) is a new way of optimizing the transmission system medium based on extensive simulation. The performance evaluation of the ADSA method is explored and compared to the Binary Phase Shift Keying (BPSK) with rate 1/2. Some published works have shown that a higher DE can only be combated using BPSK rate 1/2. However, results from simulations clearly demonstrate that the ADSA method outperforms BPSK rate 1/2 MCS under various channel condition in terms of Bit Error Rate (BER), and data rate which results in improved throughput.

Selection and peer-review under responsibility of Elhadi M. Shakshuki

Keywords: WAVE, DSRC,OFDM, Doppler Effect, MCS

1. Introduction

Every year, traffic related accidents cause a lot of loss in capital and property all over the world. For instance, in USA in 2003 alone, traffic related accidents accounted for $230 billion in damaged property, 2,889,000 nonfatal injuries and 42,643 deaths. Some or most of these accidents could have been prevented if reliable implementation of safety message exchange based communication was established between moving vehicles [1]. One of the measures to enhance the safety issue on a public road motivated the creation of the Wireless Access in Vehicular Environment (WAVE) standard [2]. The WAVE or

* E.A Feukeu Tel.: +27 835743136;
E-mail address:feukeu@gmail.com.

Selection and peer-review under responsibility of Elhadi M. Shakshuki
doi:10.1016/j.procs.2013.06.076

Dedicated Short- Range Communication (DSRC) supports vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) based communication. The primary goal of this standard is to enable collision prevention application through the dissemination and exchange of short messages from mobiles involved in communication. However like any new system, this standard come in with embedded new challenges. WAVE relies on the IEEE 802. 11a Orthogonal Frequency Division Multiplexing (OFDM) mechanism to achieve data rates of up to 27 Mbps as specified in table 2. IEEE 802.11p being one of the components of the WAVE standard is designed to handle all operations related to Medium Access Control (MAC) and Physical (PHY) layer. Due to high speed imposed by V2V, V2I network and the high sensitivity of the OFDM symbols to Doppler Shift (DS), one of the major challenges of the WAVE standard is the problem posed by Doppler Effect (DE).

This paper focuses on a development, analysis and performance exploration of an ADSA method to combat DE in a vehicular network under various channel condition. Some works have already been published in this area. In [3], a new and effective Doppler Effect compensation scheme for OFDM systems based on constellation estimation is presented. The approach makes use of analytical descriptions that quantitatively clarify the mechanism of inter-carrier interferences. In [4], it is shown that the Doppler frequency shift affects the frequencies of the RF carrier, subcarriers, envelope, and symbol timing by the same percentage in an OFDM signal or any other modulated signals. The study also analyses the Signal to Noise Ratio (SNR) degradation of an OFDM system due to Doppler frequency shift, frequency offset of the local oscillators, and phase noise. In [5], to implement Doppler compensation, a new hybrid polyphase code set combined with a single frequency pulse is proposed to enable Orthogonal Netted Radar Systems (ONRS) to have good resilience to Doppler shifts. The author in [6] considers a novel technique for the measurement and correction of the Doppler shift (frequency offset) in a received QPSK signal in which the Doppler shift may be very high, the signal/noise ratio very low, and the receiver has no prior knowledge of the received data symbols. In [7], a new methodology using BPSK and QPSK is proposed to reduce the effect of Doppler shift impact ranging from 0 to 500 Hz. The said method uses an adaptive algorithm that adjusts MCS according to DS. Theoretically speaking and to the best of our knowledge, up to now, no comprehensive formulae which can be used to eradicate the drawback of the DE over a wide range of DS exist. This absence of direct formulation has made DE to become a challenging problem for the wireless network.

The remainder of this paper is organized as follows: A brief review of the IEEE 802.11p protocol is presented in section 2. The system model development and MCS derivation is presented in section 3. In section 4, simulation for model validation is presented. Finally, the conclusion is presented in section 5.

2. A Brief Review of IEEE 802.11p protocol

The OFDM protocol used in IEEE 802.11p is specifically made for the DSRC message type and will more commonly use 10MHz bandwidth. The basic parameters for this OFDM channel are shown in table 1 [8]. From this channel's parameter specification, four modulation techniques are available for use on a subcarrier, each of which corresponds to a different number of bits encoded per subcarrier symbol [8]. Eight combinations of modulation code rates and Forward Error Correction (FEC) coding rates applicable to IEEE 802.11p are also shown in table 2. It is observed from this table that the data rate for IEEE 802.11p vary from the lowest modulation code (BPSK Rate 1/2) of 3Mbps to 27 Mbps which corresponds to the highest modulation code (64-QAM Rate 3/4). It must also be noted that this maximum can only be reached during channel free interference with very low Doppler shift. However, this type of channel condition is seldom available in a vehicular network. A vehicular network is very versatile and is an environment that that changes very fast. Due to its nature, mobiles in these networks are mostly in movement at all times. Speed imposed by the node of this network introduces a Doppler shift in their carrier frequency. A novel method to combat the alteration in frequency introduced by the Doppler shift is presented in the next section.

Table 1: Basic OFDM Parameter of IEEE 802.11p

Parameter	**Value**
Number of data subcarriers	48
Number of pilot subcarriers	4
Total number of subcarriers	52
Subcarrier frequency spacing	156.25 KHz
Guard interval (GI)	1.6 µsec
Symbol interval (including GI)	8 µsec

Table 2: Modulation Code Scheme of IEEE 802.11p

Modulation	Coded Bit Rate (Mbps)	Coding Rate	Data Rate (Mbps)	Data Bit per OFDM Symbol
BPSK	6	1/2	3	24
BPSK	6	3/4	4.5	36
QPSK	12	1/2	6	48
QPSK	12	3/4	9	72
16-QAM	24	1/2	12	96
16-QAM	24	3/4	18	144
64-QAM	36	2/3	24	192
64-QAM	36	3/4	27	216

3. System Development and MCSs Derivation

The particularity of this method is that of the MCS selection concept on which the future selection has no relationship with the present or neither the previous state. Naturally, the choice of any MCS at a given SNR range is very seldom and random. This can be explained by the fact that wireless environment behaviour is not accurately predictable and random. In the case of vehicular network, a White Gaussian Noise (AWGN) and Rayleigh channel added to Doppler Effect are considered. The combination of these three components increases the analytical complexity of the system. In order to analyse this system fairly, the ADSA method is considered as an appropriate technique in the sense that a solution can be found based on simulation. The ADSA method can be applied to any system for variable selection in which the choice of the selection of the parameters cannot be found directly from analytical derivation. This method aims to select optimal parameters based on intense simulation of a set of parameters on which the system response output is more than one variable meeting the minimum selection criterion. The optimal parameter is then chosen based on how good is any other output variable components compared to the rest that meet the minimum criterion. The concept of the ADSA method can be summarized as follows:

1. Simulate the system model taking into consideration all available MCS. Repeat this simulation several times (at least twenty times) and average the response.
2. Observe the system output and select all MCS which tends to be much closer to the maximum allowable limit at any given DS value.
3. Derive the MCS reference model from the selected MCS obtained in 2 and store them for future use.
4. Test the reference model against any stronger or robust MCS of the corresponding SNR value to assess its performances.

Analytically, the ADSA method can also be presented as follows:

If M is considered as the MCS vector in which
$M=\{m_1, m_2 \,.\,.\,.\,.\,.\; m_8\}$

where m_1 = MCS1 = BPSK rate 1/2 and m_8 = MCS8 = 64-QAM rate 3/4.
Consider D to be a DS vector in which

$D=\{D_{1n}, D_{2n} \ldots\ldots D_{Maxn}\}$

in which for D_{1n}, if n=1 then D_{1n}=1 Hz and D_{2n} = 2 Hz else if n=50 then D_{1n}=50 Hz and D_{2n}=100 Hz and so forth. Let S be the SNR vector, in which,

$S=\{s_{1n}, s_{2n} \ldots\ldots s_{Maxn}\}$

where for s_{1n}, if n=1 then s_{1n}=1 dB and s_{2n}=2 dB else if n=5 then s_{1n}=5 dB and s_{2n}=10 dB and so forth. Then for a given SNR level (s_{xn}), the optimal MCS (Mop) can be selected as :

$Mop = m_x$ if at m_x, the $BER_x \leq BER_{th}$
and $BER_x \leq BER_{MR}$

where $BER_{th} = 10^{-3}$ stands for a threshold defined by the standard, x stands for any value comprise between 1 and 8 in case of MCS and comprise between 1 and maximum value in case SNR, and MR stand for the rest of all other MCS at a given SNRx level.

The ADSA method can be classified as a heuristic technique in which the development and simulation are purely mathematical and theory based. The idea is to develop a method which will minimize the BER under a given channel condition. By minimizing the BER, the transmission efficiency of the system will therefore be improved. The approach presented here was developed using the system, setup and validation model proposed in [9]. In [9], the ADSA method was used under good channel condition (SNR=30 dB).

In this work, the approach is extended to explore the benefit brought by this method under various channel conditions in a vehicular network. This method consists of simulating a model of the wireless communication channel over a wide range of Doppler Shift (DS) [0,1500Hz]. During the simulation, each MCS from table 1 is employed several times and averaged over the number of tests to form an approximation of the average MCS response. For SNR =5 dB, the results from the simulations are presented in Figure 1 to 3. Figure 1 presents the response obtained from all MCS used under different DS values.

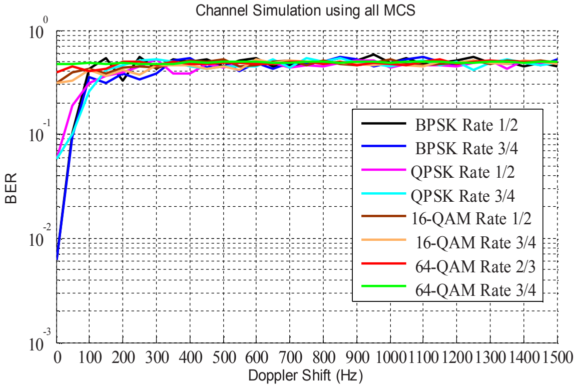

Figure1: Channel Simulation using all MCS

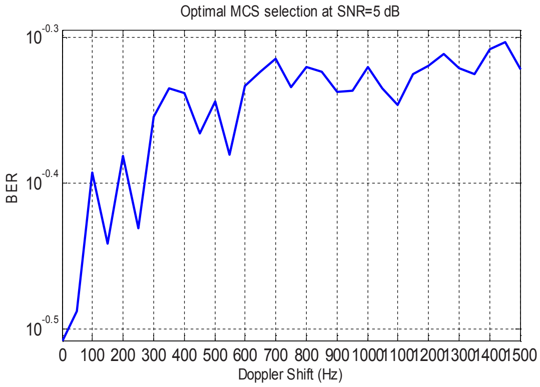

Figure 2: Channel response under Optimal MCS

Based on the desirable and acceptable levels defined by the IEEE and according to IEEE 802.11a standard [7], the acceptable probability of bit error should be less than or equal to 10e-5. This can be expressed as a percentage of BER of 10e-3 [10]. Based on this figure, it can be seen that there is no one specific MCS that can perform over the entire DS range under the required acceptable BER level. However it can be observed that if a composition of MCS is selected wisely optimum performances can be achieved. Under optimal MCS selection, the response of the system will be that depicted in Figure 2. This figure is obtained by choosing among all selected MCS any MCS with minimum BER at a given DS value. For instance, looking at the curves from Figure 1, it can be observed that for DS values that range between 200 Hz and 300 Hz, a BPSK-rate of 3/4 is the ideal choice. At this stage, MCS values obtained from Figure 2 are saving into a table so that these values can be used in future. Due to a large number to be presented in the table and to ease the visibility, a curve representing these values is depicted in Figure 3.

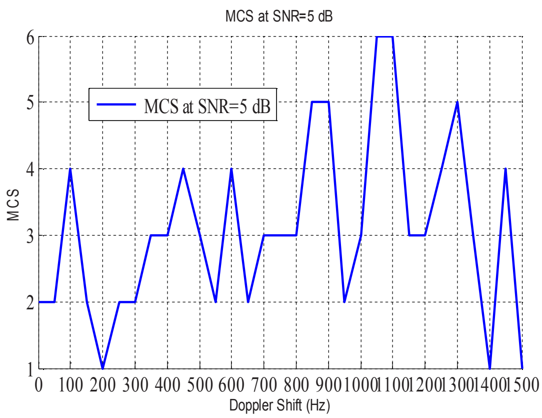

Figure 3: Derived MCS for Optimal selection

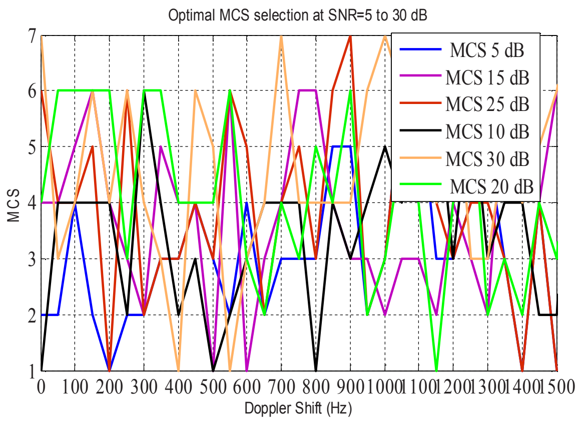

Figure 4: Derived optimal MCS for SNR=5 to 30 dB

Looking at both Figure 1 and 2, the choice of several MCS presented in Figure 3 is justified by the fact that no single MCS could withstand the DS over the entire variation length. Therefore to form a robust system, the only alternative left was to make use of a combination of MCS. Based on the theory described by the ADSA method, the optimal MCS selection derived from Figure 1 was obtained and presented in Figure 3. To explore the consistency of the developed technique, this work was extended for SNR value of 10, 15, 20, 25 and 30 dB. Results of the equivalent selected optimum MCS are presented in Figure 4 and table 3.

Table 3: SNR vs DS for SNR=5 to 30 dB.

SNR (dB)	Doppler Shift (Hz)																														
	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
5	2	2	4	2	1	2	2	3	3	4	3	2	4	2	3	3	3	5	5	2	3	6	6	3	3	4	5	3	1	4	1
10	1	4	4	4	4	2	6	4	2	3	1	2	3	4	4	4	1	4	3	4	5	4	5	6	3	6	3	4	4	2	2
15	4	4	5	6	4	3	2	5	4	4	1	6	1	3	4	6	6	4	3	3	2	3	3	2	4	3	2	6	5	4	6
20	4	6	6	6	6	3	6	6	4	4	4	6	3	2	4	3	5	4	6	2	3	5	4	1	4	6	2	3	2	4	3
25	6	4	4	5	1	6	2	3	3	4	3	6	5	2	4	5	3	6	7	2	3	6	6	4	3	4	4	3	1	4	1
30	7	3	4	6	4	6	4	3	1	6	5	1	3	4	7	4	4	4	4	6	7	6	6	4	7	3	3	5	4	5	6

Looking at this table, it can be observed that except for value of DS less than 50 Hz, no logical relation can be observed from current choice MCS to the next one. This is one of the reasons why the derivation of an analytical model is complex. But based on the ADSA method, table 3 represents the selected of optimal MCS obtained from simulation. In this table, for a given DS and SNR values, a corresponding optimal MCS can be directly derived. Based on the demonstrated strength of BPSK rate 1/2 described in various literatures in the sense of robustness against channel fluctuations, and also based on the result obtained when combating DE of some published work, the ADSA method is compared against the BPSK rate 1/2 in the next part of this paper.

4. Model Simulation

To assess the performances of the developed model, the basic OFDM parameters described in table 1 were used. This system was implemented and simulated in MATLAB. Using DS and SNR values described in table 3, the following additional parameters were used:

Frame size = 1000 bytes, Number of frame = 50, Channel model = AWGN + Raleigh,
Training symbol size= 3 bytes, Carrier frequency= 5.85 GHz, Maximum transmission range = 1000 m.

It is to be noted that the DS variation from 0 to 1500 Hz is equivalent to a mobile speed variation from 0 to 250 km/h or to a relative speeds variation of mobiles from 0 to 125 km/h. Using the above setup, several simulations were performed for each SNR level. For SNR = 5 and 10 dB, figures 5 and 6 were obtained.

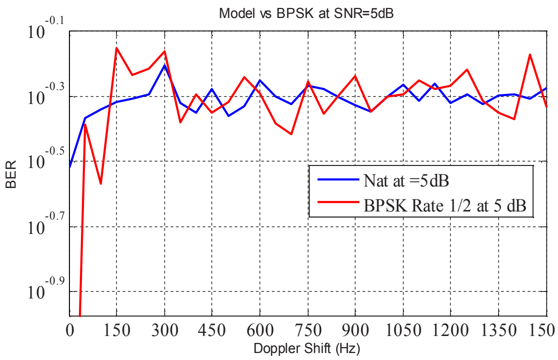

Figure 5: ADSA vs BPSK rate 1/2 at SNR= 5 dB.

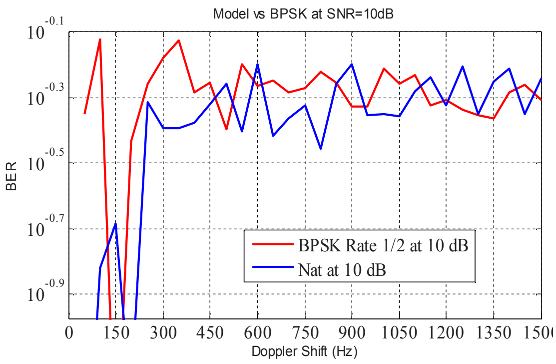

Figure 6: ADSA vs BPSK rate 1/2 at SNR= 10 dB.

In all figures, Nat represents the ADSA method and BPSK rate 1/2 will be interpreted as MCS1. From figure 5, it can be observed that for DS value less than 150 Hz, MCS1 performed better. At DS values greater than 150 and up to 300 Hz, ADSA performed better. From DS of 350 Hz upward, both techniques offer comparable performance in terms of BER. From figure 6, a clear dominance of the ADSA method over MCS1 can be observed up to 800 Hz. From 800Hz upwards, the performances of both techniques are comparable in terms of BER.

Figures 7 and 8 represent the results obtained from simulations scenarios where the SNR was set to 15 and 20 dB. In figure 7, a clear dominance of the ADSA method can be observed up to 450 Hz limit at which both techniques become comparable in term of BER.

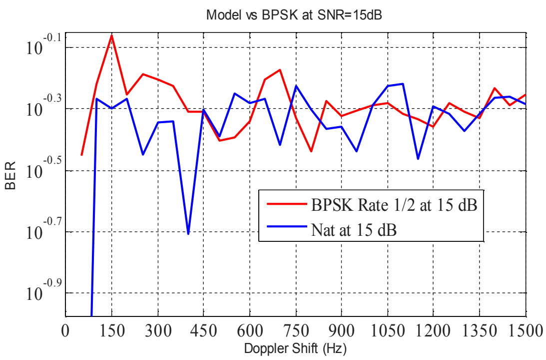

Figure 7: ADSA vs BPSK rate 1/2 at SNR= 15 dB.

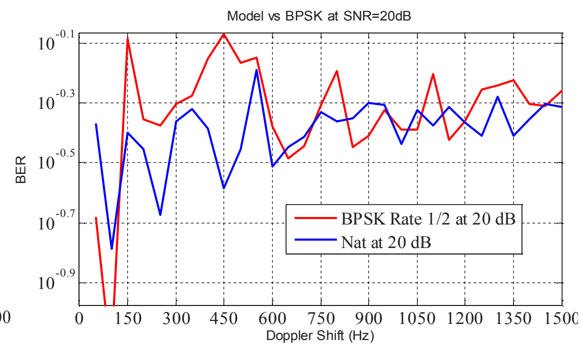

Figure 8: ADSA vs BPSK rate 1/2 at SNR= 20 dB.

In figure 8, it can be observed that for DS value less than 150 Hz, the MCS1 performance is above the ADSA method. But from 150Hz up to 750 Hz, the ADSA method is above MCS1. From 750 Hz upwards, a close look at the ADSA method shows that it is within the required BER limit level specified by the standard. It can also be noticed that at the exception of frequency ranging around 550 Hz, the ADSA method overall performance is clear.

Simulation results for SNR level of 25 and 30 dB are presented in figures 9 and 10. A clear performance domination of the ADSA method can be observed in Figure 9. Not only did the ADSA method perform better than MCS1, but also performed within the required specified BER limit level.

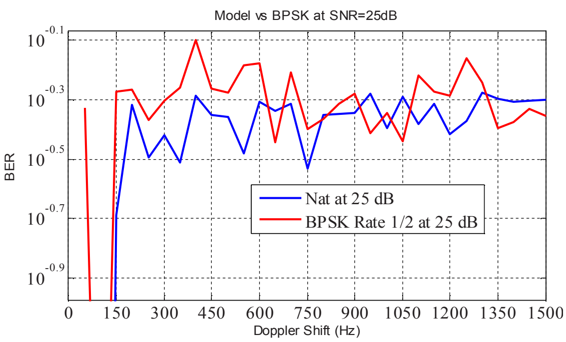

Figure 9: ADSA vs BPSK rate 1/2 at SNR= 25 dB.

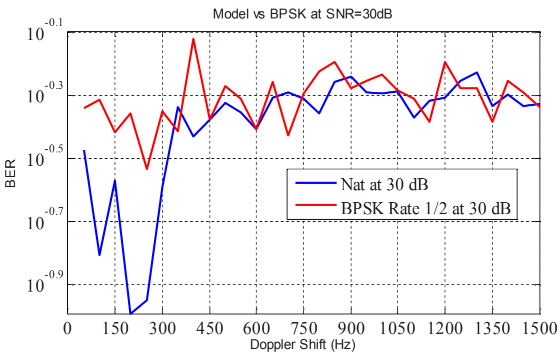

Figure 10: ADSA vs BPSK rate 1/2 at SNR= 30 dB.

Observations from figure 10 shows that the ADSA method outperformed the MCS1 over a full variation range of the DS. Although it did not performed under the specified BER limit level at certain points, its robustness over the MCS1 is still observed.

In summary, it can be observed that for SNR level of 10 dB and higher, the performance of the ADSA method was proved and demonstrated. At SNR value of 20 dB and above, a clear dominance of the ADSA method was also confirmed from figures 8 to 10. It can also be observed from figures 8 to 10 that, the ADSA method performed within the acceptable level of the specified BER limit. It is very important to highlight the fact that based on the selected optimal MCSs presented in Table 3, the ADSA method has clear performance benefits over the MCS1 for all SNR level which is demonstrated in all figures in terms of BER, data rate and throughput. This is justified by the fact that instead of using BPSK Rate 1/2 in all cases when the DE increases, higher MCS are been used by the developed model. Results from these simulations also emphasize on the fact that under good channel conditions, MCS1 (BPSK rate 1/2) is not the only best MCS to choose when combating DE.

5. Conclusion

This paper presented a novel method called ADSA to combat DE in vehicular networks. Specifications of MCS used during the development of the method were presented in table 1 and 2. The method description, development motivation and tests were presented in section 3. Section 3, explained the concept and clarified how this proposed technique can be applied to other systems in which direct analytical solution are complex or not readily available. In section 4, several tests are performed to explore the effectiveness of the proposed method. In a WLAN environment, BPSK is well known as been the most robust MCS capable to withstand high channel perturbation and interferences. Analysis from the work performed in this paper shows that under vehicular network conditions, the robustness of the BPSK does not longer stand for the channel condition where the SNR is 10 dB and above. Results from various simulations clearly demonstrated that the developed method outperforms the BPSK rate 1/2. It should be highlighted that not only it is shown that the proposed method is proved in terms of BER, it has also more enhanced throughput due to the fact that the reference MCS model make use of higher MCSs. The strength of the proposed technique can also be confirmed by observing figures 8 to 10. The advantage of this method is that it is straight forward and less complex in terms of implementation. The inconvenience of the ADSA method is that it is time consuming.

Future work will consider computing and deriving the model for all values of SNRs in order to have a complete reference model.

Acknowledgements

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).

References

[1] National Center for Statistics and Analysis, "Traffic Safety facts 2003," Report DoT HS 809 767, Nat'l. Highway Traffic Safety Admin.,U.S.DoT, Washington.DC,2004

[2] U.S. Department of transportation., 2006. *Vehicle Safety Communications ProjectVFinal Report*. U.S.: Rep. DOT HS 810 591 Nat. Highway Traffic Safety Admin.

[3] Lee. B.S, "Doppler effect compensation scheme based on constellation estimation for OFDM system", ELECTRONICS LETTERS 3rd January 2008 Vol. 44 No. 1.

[4] Fuqin. X and Monty. A, "The Effect of Doppler Frequency Shift, Frequency Offset of the Local Oscillators, and Phase Noise on the Performance of Coherent OFDM Receivers," National Aeronautics and Space Administration Washington, DC 20546–0001.

[5] Zhao Zhao; Xiang-quan Shi; , "Doppler compensation for orthogonal netted radar systems," *Signal Processing, 2008. ICSP 2008. 9th International Conference on* , vol., no., pp.2246-2249, 26-29 Oct. 2008

[6] Clark, A.P. & Aftelak, A.; "Doppler-shift correction via correlation for a received QPSK signal," Communications, Speech and Vision, IEE Proceedings I , vol.137, no.6, pp.387-394, Dec. 1990

[7] Khaldoun. A, Utayba. M and Nizar. A, " Doppler Shift Impact On Vehicular Ad-hoc Network", Canadian Journal on Multimedia and Wireless Networks, Vol. 2, No. 3, August 2011

[8] Kenney, J.B., "Dedicated Short-Range Communications (DSRC) Standards in the United States," *Proceedings of the IEEE* , vol.99, no.7, pp.1162-1182, July 2011

[9] Feukeu.E.A, Djouani.K & Kurien.A.., "Doppler Effect Analysis and Modulation Code Derivation", The 7th International Symposium on Intelligent Systems Techniques for Ad hoc and Wireless Sensor Networks (IST-AWSN), Niagara Falls,Ontario,Canada, August 2012.

[10] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Std. 802.11, 2007.