

Towards a Cross-Layer Based MAC for Smooth V2V and V2I Communications for Safety Applications in DSRC/WAVE Based Systems

Kazi Atiqur Rahman and Kemal E. Tepe

Abstract—The DSRC/WAVE system is standardized to disseminate safety critical information using IEEE 802.11p as a MAC protocol. Studies show that IEEE 802.11p does not address adverse effects of asymmetric radio link and mobility related problems in vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications. This paper presents a cross-layer (i.e. MAC and network) algorithm to address these problems for making the V2V and V2I communications efficient and reliable. The analysis shows that the proposed cross-layer algorithm removes contention in channel accessing and confirms a better channel utilization. The solution can be used to disseminate information up to three hops without using a routing protocol. This is particularly important for extending range of safety critical and emergency related messages in the vehicular network.

Keywords—IEEE 802.11p, cross-layer; cross-layer extended sliding frame reservation Aloha; mobile hidden station; asymmetric radio link; VANET; DSRC/WAVE systems; V2V; V2I.

I. INTRODUCTION

DSRC/WAVE system is designed for intelligent transport systems (ITS), and IEEE 802.11p is standardized for physical layer and MAC layer of short and medium range communications [1, 2]. This will provide communication and cooperation among vehicles for active safety and emergency applications. Because IEEE 802.11p’s medium access control (MAC) uses broadcast (i.e. no request-to-send (RTS)/clear-to-send (CTS)) as primary method for emergency and safety message dissemination [3], it does not have provisions to solve mobility related problems like mobile hidden station (MHS) [4] and asymmetric/unequal radio link (ARL) [5] either in vehicle to vehicle (V2V) or vehicle to infrastructure (V2I). MHS problem occurs when a station from outside of the channel reservation region enters to the reserved region and interferes with the reserved communication. In a two-way traffic, vehicles in one direction are MHSs to the vehicles moving in the other direction, which is practically experienced 50% of the time. MHS is illustrated in Figure 1, where Vehicle V4 is communicating with V5, and V6 is communicating with V7; and V4 and V6 are MHS to each other. Analysis presented in [4] shows that MHS significantly degrades performance of IEEE 802.11p up to 45%. An asymmetric radio link may occur for different reasons such as power limitation,

dynamic spectrum management, and applications specific requirements [6]. Figure 2 illustrates the ARL problem in a MANET scenario where an HS tolerant MAC protocol such as IEEE 802.11 MAC is considered. In Figure 2, Station R’s CTS message does not reach C, and C’s transmission can interfere with R’s reception because of C’s larger transmission range if C communicates with any other node. In other words, Station C is hidden because of R’s short transmission range. The concept illustrated in Figure 2 is applied in Figure 3, where IEEE 802.11p (i.e. no RTS/CTS) is considered as a MAC protocol. Since DSRC/WAVE system is designed to use different ranges for different services and applications, the ARL problem is inherent for V2V and V2I communications. For example, emergency vehicle alert message is considered to be transmitted in a range of 1000 meters (m), and safety critical short message transmission range varies from 100 m to 400 m. A scenario is provided in Figure 3 to illustrate ARLs in vehicular communications. DSRC has six service channels and one control channel (i.e. ch-178) [7]. According to DSRC channel allocation, emergency vehicle transmits ‘emergency vehicle approaching alert message’ through the control channel. This control channel is also used for safety critical messaging (i.e. collision warning, collision avoidance

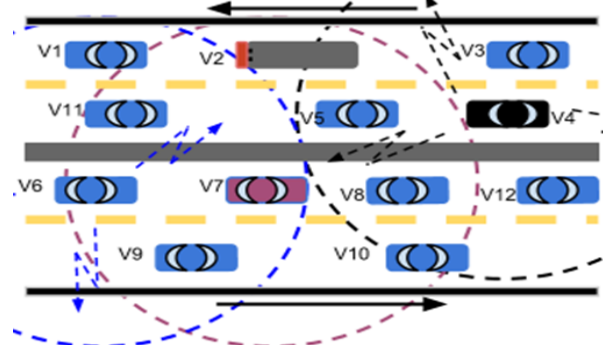


Fig. 1. Mobile hidden station scenario.

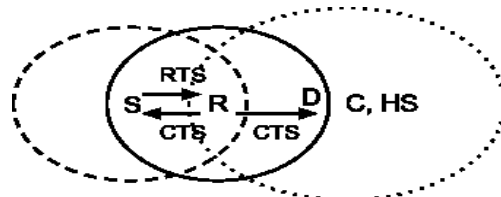


Fig. 2. Asymmetric radio link scenario.

Kazi Atiqur Rahman and Kemal E. Tepe are with WiCIP (Wireless Communication and Information Processing) Research Lab, University of Windsor, Windsor, Ontario, Canada, E-mail: {rahman1h, ktepe}@uwindsor.ca.

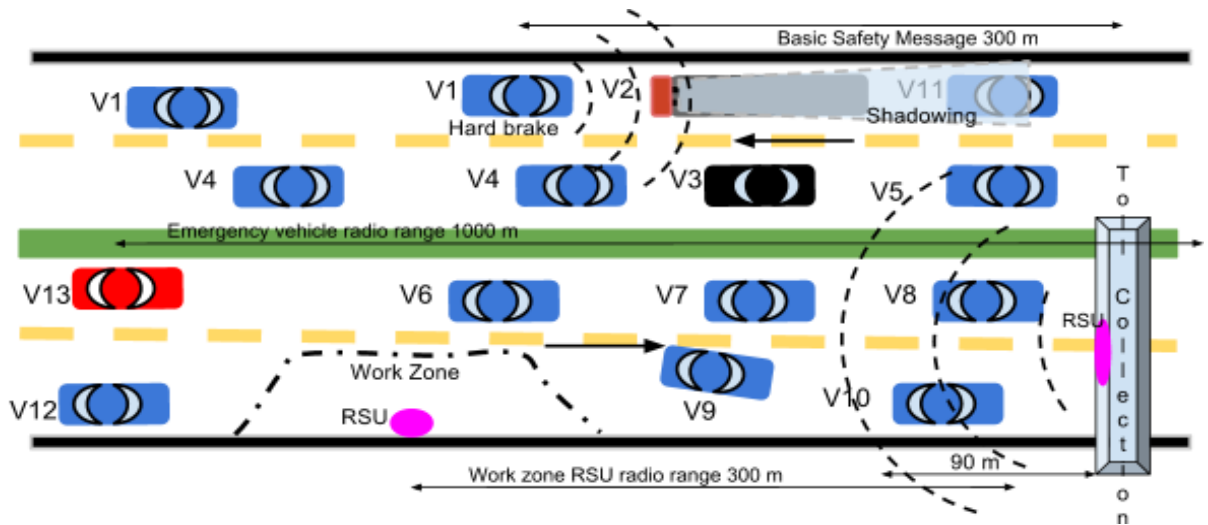


Fig. 3. Scenario - toll collection, work zone warning, shadowing effect etc.

warning.) with transmission range of about 300 m [7]. If different vehicles transmit different messages using the same channel, asymmetric radio link (ARL) problem arises. Some of these services using unequal ranges are visualized in Figure 3. For crowded highways, these problems are amplified along with another problem called DSRC channel congestion [8][9]. Although broadcast is robust enough to disseminate redundant information, it requires more bandwidth. That is why it is necessary to modify MAC to reduce DSRC channel congestion by limiting high volume of broadcast messages [8][9]. In this work we provide solutions to these problems.

In this paper, we introduce a cross-layer design (CLD) approach by using network layer information in extended sliding frame reservation Aloha (ESFRA) [10]. This CLD approach mechanisms solve the MHS, ARL and congestion problems. The proposed protocol, called cross-layer ESFRA (CESFRA), manages channel access as well as it disseminates safety critical information up to the third hop neighboring stations without any routing protocol. For example, in case of collision avoidance alert messaging, the DSRC/WAVE systems disseminate safety information only one hop (i.e. 300 meters), whereas CESFRA manages to disseminate the information up to the third hop (i.e. 900 meters).

Following section explains the cross-layer design approach. Then cross-layer behavior of CESFRA and its effectiveness in DSRC/WAVE systems are analyzed in Section III. The paper is concluded in Section IV.

II. CROSS-LAYER EXTENDED SLIDING FRAME RESERVATION ALOHA MAC PROTOCOL

CESFRA is based on ESFRA, which has been proposed in [10] to solve MHS in V2V communications. Since some of the principles of CESFRA are similar to ESFRA, ESFRA is explained first.

A. Mechanism of ESFRA

ESFRA is based on the principle of R-Aloha, where the channel time is divided into frames, and frames are divided into N time slots. All the mobile stations are considered to be synchronized with a global synchronization scheme like

timing in global positioning system (GPS). If a station has packets to send, it senses the channel at the beginning of each slot, transmits the packet if an idle slot is found, and reserves the same slot in the subsequent frames. A sliding frame (SF) control mechanism is applied in ESFRA to disseminate this reservation information to neighbor nodes. For any station, a sliding frame is defined as the preceding N slots including its current slot. Each station in the network records the status of the slots of its sliding frame, and makes a small look up table called frame information (FI). Each transmitting station broadcasts its updated FI at the end of its packet transmission as shown in Figure 4(a). FIs in ESFRA contain the status information of a slot that specifies whether this slot reserved by any other node as BUSY-1 (B1), BUSY-2 (B2) or FREE (F) as shown in Figure 4(a). If a station discovers that another station is using a slot for transmission, it does not use this slot, which is recorded as B1 in this station's FI. If a station discovers any slot with status B1 in any of its received FIs, it does not use this slot, and the slot is recorded as B2 in its own FI. If a station discovers any slot with status B2 in any of its received FIs, it does not use this slot, and the slot is recorded as FREE in its own FI.

B. CESFRA and Its Information Dissemination Mechanism

According to ESFRA [10], any mobile station located at most three hops away from the sender is aware of the respective communication. This property of ESFRA can be used to disseminate the application data up to three hops. Thus, ESFRA with some modifications can be used as a cross-layer (i.e. MAC and application layer) protocol to disseminate information to extended neighborhood. Applications like collision warning and avoidance, advance association between vehicles and road side units (RSUs), and communication between two RSUs up to three hops away can directly be performed using CESFRA without using a routing protocol. The FI in ESFRA is enhanced to contain cross-layer information (CI) in the frame as illustrated in Figure 4(b).

Unlike ESFRA, a CI is a complete packet to transmit which contains a number of fields equal to the number of slots in a frame. Every field has two parts e.g. control information and upper-layer information (UI). Slot statuses,

slot numbers etc. are control information, and on the other hand vehicle ID, BSMs, collision information etc. are UIs. So, any network layer information included along with the control information is also passed up to three hops in VANET without any routing support. For multi-hop information dissemination, the emergency message generating vehicle puts the message into its own CI. Every vehicle who receives this CI copies the message in its own CI and transmits.

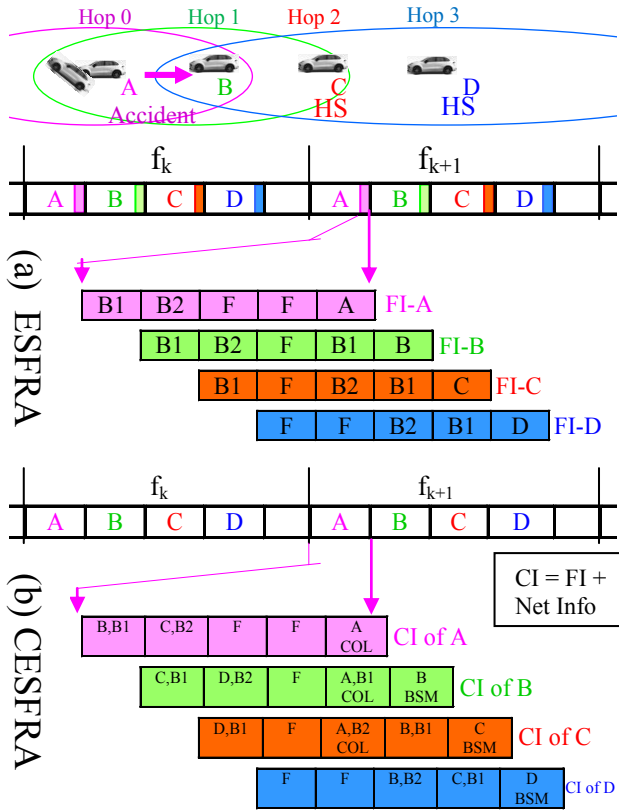


Fig. 4. ESFRA and CESFRA protocol structures.

Figure 4(b) illustrates an accident avoidance scenario using CESFRA. It also shows the snapshots of CIs transmitted by vehicles. Vehicle A in the highway scenario in Figure 4 generates hard brake message by avoiding an accident, and this message should be reached at Vehicles B, C and D. Each vehicle reserves one slot for transmitting its own CI. In this example scenario, every CI contains slot reservation information (i.e. slot status (B1 or B2 or F) and vehicle IDs (A, B, C or D)) and upper layer information (i.e. collision information or BSM). After collision detection A includes the accident information (i.e. col) into its own CI (i.e. CI of A). Whenever B receives CI of A, it changes A's slot reservation status to B1 in its own CI, and copies the accident information. Vehicle B applies all other rules of ESFRA to include slot statuses of all other received CIs into CI of B. After receiving CI of B, Vehicle C changes A's slot reservation status to B2 in its own CI, and copies the accident information. Vehicle D gets the accident information from C's CI. In this way, the accident information reaches the 3rd hop.

III. ANALYSIS OF CESFRA IN DSRC/WAVE SYSTEMS

CESFRA MAC is simulated and compared with IEEE 802.11p MAC to reveal effects of MHS and ARL problems in V2V and V2I communications. The cross-layer behavior of CESFRA is also justified in simulated highway scenario.

A. Simulation Results: Comparison of CESFRA MAC and IEEE 802.11p MAC

CESFRA MAC and IEEE 802.11p MAC are compared in V2V and V2I communications. Both protocols are simulated in OMNeT++ with MiXiM modeling framework. The IEEE 802.11p physical layer available in MiXiM is used as the physical layer in both protocols. Two separate simulations are performed to reveal the impact of the MHS and ARL problems. A highway scenario, where ten high speed (30 meter/second) mobile stations are moving from opposite direction, is created to reveal the adverse effect of the MHS problem in this simulation. The other simulation uses ten stations with different transmission ranges (i.e. 300 meters and 150 meters) to create the ARL problem. These protocols are also analyzed using discrete time Markov chain (DTMC) in [10]. The results with Markov modeling are taken from [10].

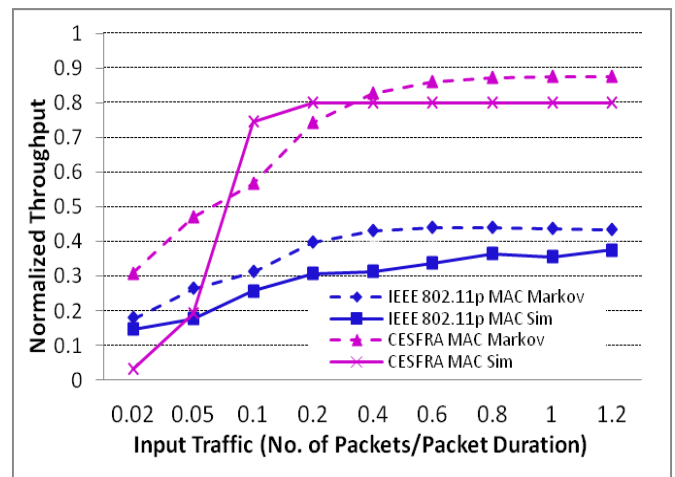


Fig. 5. Comparison of throughputs considering the effect of the MHS problem.

Figure 5 illustrates the normalized throughputs obtained from the Markov analysis and simulation considering the effect of the MHS problem. In case of simulation, the normalized throughput is defined as a fraction of the maximum channel capacity. In Markov analysis, the normalized throughput is defined as the probability that the channel remains in the transmission state. In both cases, the inherent meaning of throughput is the probability of successful transmission. Input traffic is used as the variable of the analysis, and it is defined as the total number of incoming packets per packet duration. The simulation results show that CESFRA MAC provides about forty percent more throughput when the input traffic is 0.8. The Markov analysis in Figure 5 also shows similar difference between the two protocols. Although the normalized throughput obtained from the Markov analysis is higher than that of from the simulation for both protocols, the behavior of the throughput curves from the simulation results follow similar trends that of obtained from the analytical result for the

respective protocol. For IEEE 802.11p MAC, the throughput obtained from the Markov analysis is about eight percent higher than the throughput obtained from the simulation for input traffic greater than 0.05. Same behavior is observed in the discrepancy of the analytical and simulation results for CESFRA MAC with input traffic higher than 0.4 and less than 0.07. The reasons behind this discrepancy are the assumptions made while Markov modeling, such as the radio channel is assumed lossless, the behavior of the physical layer is assumed ideal, and the propagation delay is assumed negligible.

Figure 6 illustrates that CESFRA MAC successfully transmits about 19000 packets in each simulation after input traffic 0.1, whereas IEEE 802.11p MAC reaches its maximum transmission of about 8000 packets per simulation at input traffic 1. Provided that the simulation time is fifty second for every input traffic. CESFRA MAC performs more than fifty percent successful packet transmission. The results in Figures 5 and 6 show that CESFRA MAC outperforms IEEE 802.11p by solving the MHS problem. As MHSs are situated 3 hops apart from the sender, CESFRA MAC manages to send the MAC control information up to the 3rd hop to make MHSs aware of the communication, whereas IEEE 802.11p MAC manages to pass MAC control information up to the 2nd hop.

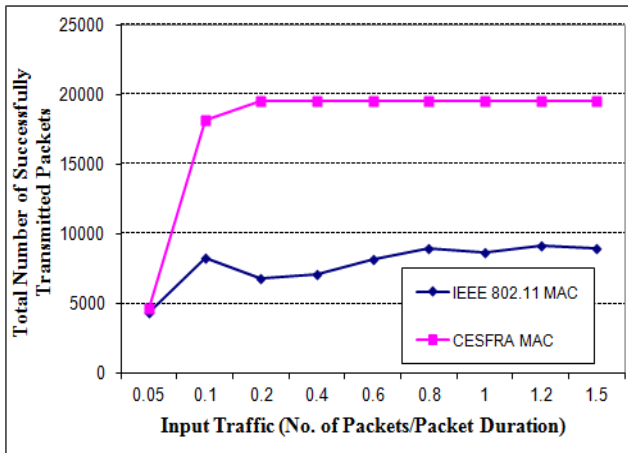


Fig. 6: Total number of successfully transmitted packets considering the effect of the MHS problem.

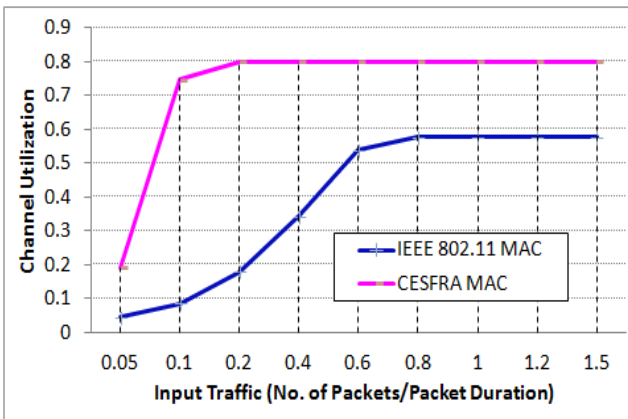


Fig. 7: Effect of ARL problem on channel utilization.

Figure 7 shows that CESFRA MAC reaches the maximum channel utilization at input traffic 0.2 while IEEE 802.11p MAC at input traffic 0.8. The channel utilization of IEEE 802.11p MAC is 58 percent in networks with ARLs. Normally the channel utilization of IEEE 802.11p MAC is about 80 percent at full load if ARL or MHS problems are not considered [4]. As there is no MHS in this simulation scenario, only ARL problem is responsible for this 22 percent reduction of channel utilization. As CESFRA MAC solves ARL problem, it provides about 80 percent channel utilization.

B. Justification of the Cross-layer Behavior of CESFRA in Some Example Safety Critical Scenario

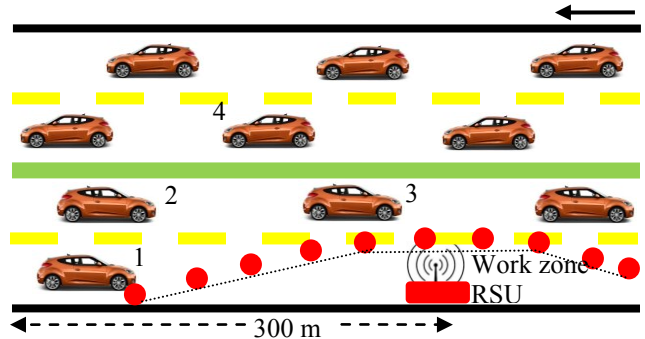


Fig. 8. Work zone warning RSU in a highway scenario.

1) Safety Critical Scenario - Work Zone Warning

According to DSRC/WAVE specification, the work zone RSU is transmitting the 'work zone alert' message in 300 m as shown in Figure 8. So, Vehicle 1 gets approximately 300 m to change lane which may not be sufficient for high traffic scenario. On the other hand, CESFRA manages to disseminate work zone messages approximately 900 m, which provides a secure and reliable lane change facility.

2) Safety Critical Scenario - Toll Collection

CESFRA improves the quality of service of the toll collection. How much time an RSU gets to collect the toll from a vehicle depends on the number of vehicles within its 90 meter range. CESFRA associates a vehicle with the toll collection RSU at least 3 hops ahead (i.e. 270m = 90m X 3 hops). So, CESFRA makes toll collection procedure smooth and reliable.

3) Safety Critical Scenario - Other Services

The on-board unit (OBU) collects safety critical information from the messages broadcast by surrounding vehicles, and warns the driver if a collision is likely. The control channel with a transmission range of 300 m is used for this kind of messaging.

An example scenario is presented in Figure 9. If Vehicle V8 is stopped suddenly for any reason (i.e. a blockade on the road, snow, a collision already happened etc.), the vehicles within 300 meter of V8 is supposed to get the message from V8, and they will either try to change lane or stop. In a high speed and high traffic scenario, in most of the cases failure to change lane or stop within 300 meter will cause disastrous back to back collision. CESFRA solves this problem disseminating this collision avoidance information up to 900

meter without any routing. CESFRA is compared with DSRC/WAVE specification with respect to some safety applications as shown in Table I.

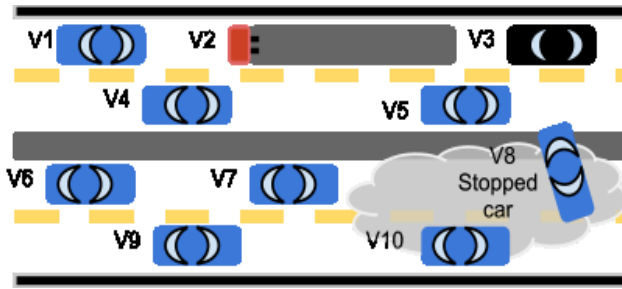


Figure 9: Cooperative collision warning with CESFRA.

TABLE I. COMPARISON OF DSRC/WAVE AND CESFRA WITH RESPECT TO SAFETY CRITICAL INFORMATION DISSEMINATION DISTANCE IN DIFFERENT SAFETY SCENARIOS.

Safety scenario	DSRC/WAVE (meters)	CESFRA (meters)
Toll collection (V2I)	30~90	> 600
Work zone warning (V2I)	300	900
Collision warning/avoidance (V2V)	300	900
Any V2I communication	300	900
Any V2V communication	300	900

IV. CONCLUSION

A cross-layer based MAC algorithm, called CESFRA, is presented to disseminate the network layer information up to three hop neighborhood. The proposed protocol resolves contention for channel access effectively and reduces

collisions due to HS, MHS, and ARL problems successfully. With these improvements, CESFRA provide DSRC/WAVE to achieve its objectives in safety and emergency communication scenarios.

REFERENCES

- [1] D. Jiang, and L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments", Proc. of IEEE VTC, Pages 2036-2040, Singapore, May 2008.
- [2] "Wireless Access in Vehicular Environment (WAVE)" in Standard 802.11, Specific Requirements, IEEE Std. 802.11p/D1.0, Feb. 2006.
- [3] K.A. Hafeez, L. Zhao, B. Ma, and J.W. Mark, "Performance Analysis and Enhancement of the DSRC for VANET's Safety Applications", IEEE Transactions on Vehicular Technology, Vol. 62, No. 7, September 2013.
- [4] K.A. Rahman, N. Jaber, and K.E. Tepe, "Markov Analysis of the Mobile Hidden Station Problem in MANET", Proc. of the 7th IWCMC, Istanbul, Turkey, 05-08 July 2011.
- [5] K.A. Rahman, and K.E. Tepe, "Analyzing Extended Sliding Frame Reservation-Aloha MAC Protocol against Asymmetric Radio Link Problem in MANET/VANET", Proc. of the IWCMC, Cagliari, Sardinia, Italy, July 2013.
- [6] G. Wang, D. Turgut, L. Bölöni, Y. Ji, D. C. Marinescu, "A MAC layer protocol for wireless networks with asymmetric links", Elsevier Ad Hoc Networks Journal, Volume 6, Issue 3, Pages 424-440, ISSN 1570-8705, May 2008.
- [7] "SAE J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary" and "DSRC Implementation Guide", SAE International, 16 February, 2010.
- [8] Y. P. Fallah, C.-L. Huang, R. Sengupta, and H. Krishnan, "Analysis of Information Dissemination in Vehicular Ad-Hoc Networks With Application to Cooperative Vehicle Safety Systems ", IEEE Transactions on Vehicular Technology, Vol. 60, Issue 1, January 2011.
- [9] W. Alasmary, and W. Zhuang, "Mobility Impact in IEEE 802.11p Infrastructureless Vehicular Networks", Elsevier Journal of Ad Hoc Networks, Vol. 10, Issue 2, Pages 222-230, March 2012.
- [10] K.A. Rahman, and K.E. Tepe, "Extended Sliding Frame R-Aloha: Medium Access Control (MAC) Protocol for Mobile Networks", Elsevier Ad Hoc Networks Journal, Vol 10, Issue 6, Pages 1017-1027, August 2012.