A NOVEL ADAPTIVE TIME GAP BASED CONGESTION CONTROL FOR VEHICULAR AD HOC NETWORK

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ABSTRACT

Despite the growing rates of vehicles on the roads and transported goods, transportation and traffic should become safer, cleaner and more efficient. Thus to ensure reliable and safe communication architecture within VANET, we propose in this context a cooperative and fully distributed congestion control approach, dedicated to operate within vehicular networks, integrated within the 802.11p underway standard, and based on time gap model. We present in this paper a cooperative and fully distributed congestion control approach, based on time gap, to adaptively control the PSM generation rate. Using the measured time gap of the neighbor vehicles in the same lane, the periodic safety message (PSM) generation rate is controlled in order to reduce the congestion, keeping the safety of the vehicles intact.

Keywords: time gap, congestion control, safety, VANET.

INTRODUCTION

Active safety technology is currently becoming a major area of research in the automotive industry. One of the big issues is of course which technology or safety area to concentrate on. There are countless possibilities, but the best choice would, of course, be the one which gives most in return when it comes to improved safety. Yet vehicular ad hoc networks can significantly increase passenger safety and comfort based on their active safety and advanced driver assistance systems. Rapid evolution of wireless communication technology has advanced the development cooperative systems use such as dedicated short-range communications (DSRC) to exchange information between vehicles and/or between vehicles and road infrastructure, conceiving what is termed as a vehicular communication network or a vehicular ad-hoc network (VANET). To enable the applications supported by the vehicular communication, a licensed free spectrum in the 5.9GHz band known as Dedicated Short Range Spectrum (DSRC) has been allocated [1].

In WAVE/DSRC stack, WAVE Short Message Protocol (WSMP) is a network layer protocol which provides communication services for the priority based short messages, called Beacons, which are mostly communicated over the control channel (CCH). Dissemination of information through beacon message in a VANET is termed as beaconing. The information inside a beacon may include vehicle’s address, location, speed, direction, event, or other information. These short messages are used to satisfy information requirements of the safety and no safety applications. In nonsafety applications, general transport awareness information within the network is disseminated through beacons. Each vehicle broadcasts a beacon message within its one hop to keep neighborhood awareness. In case of any emergency situation or an incident, for example, road blocks, landslide, construction sites, accidents, traffic jam, and so forth, similar beacon message (safety beacon message) may also be used to disseminate information about this specific event to warn drivers.

Based on severity of the incident, beacon messages may be assigned priorities and broadcasted accordingly. This type of beacon communication is used in vehicular networks to realize safety applications. In case of an incident or emergency situation the vehicle that encounters this event first or the vehicle that is involved in the incident triggers a safety beacon message to inform neighboring and the trailing vehicles about the incident to apply safety precautions proactively. Timely incident information dissemination to assure safety of passengers is the main objective of safety beacon messages. Therefore, the safety beacon message should be disseminated with minimum delay, packet loss, and congestion. The congestion and packet loss can be caused by the beacon broadcast storm, when a large number of vehicles broadcast the beacon message. This leads to improper information dissemination in the network. Since the same CCH is used by all vehicles, beaconing load may saturate the capacity of the channel. Therefore, channel congestion due to beaconing load should be avoided to minimize beacon collision and communication delay and improve channel access fairness and reception rate. Several beaconing schemes have been proposed in the literature and are classified into two main categories: periodic and adaptive. But most of them neglecting the road traffic situation and safety application requirements. Thus our research will based on to the safety of vehicles on the road by using safety time gap.

Time Gap metric is often used as a safety indicator for collision warnings in the transportation research. The earlier research had discovered that time-gap is indicated as the key factor for safety, and proper time-gap settings can lead to better performance and can compensate for in-vehicle distraction [2]. Time gap represents the actual time available for the following car to avoid a rear-end collision. Keeping a safe following distance from the leading vehicle is critical for mitigating rear-end crashes in vehicle following situation since it allows the following vehicle sufficient time to stop, and to stop gradually. Thus, in this paper the concept of time gap for following distance (TGFD) [3] will be applied in order to control congestion and improve utilization of channel in safety message dissemination.

RELATED WORKS

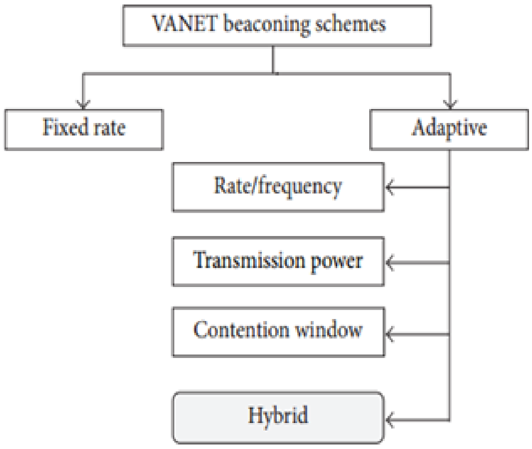

Figure-1. Classification of beaconing scheme of VANET.

Several beaconing schemes have been proposed in the literature. There are two main categories of beaconing schemes: fixed rate or periodic beaconing and adaptive periodic. The adaptive schemes are further classified into subcategories named transmission rate/frequency, transmission power, contention window size, or hybrid schemes that adapt any combination of beacon transmission characteristics mentioned above. Figure-1 shows the classification of beaconing techniques present in the literature. The periodic or fixed rate [4] beaconing approaches broadcast beacons at predefined intervals, usually Rtx =10beacons/s. However, the periodic beaconing approach congests the wireless channel and results in beacon loss, high delay, and improper information dissemination when VANET becomes dense due to dynamic topology. On the other hand, the low beacon rate minimizes the channel congestion and leads to inaccurate network information at vehicles. The routing decisions taken over this imprecise data will degrade performance of the routing protocol. In brief, fixed rate beaconing schemes are not suitable for VANETs to achieve information accuracy and prompt dissemination without compromising channel capacity. This issue has been resolved by adaptive beaconing schemes that adjust beacon rate or frequency, transmission power, or MAC contention window size, based on different network or channel parameters. Adaptive beaconing schemes use network conditions, traffic behavior, and/or wireless channel parameters that include a number of neighbors or 1-hope node density, beacon reception probability, beacon reception rate, distance between nodes, channel quality, channel busy ratio, and packet loss rate, to adjust the beacon rate, transmission power, contention window size, or any combination. In literature, there are many beaconing schemes that have been proposed for VANETs and the following is the brief overview of those schemes.

Adaptive transmission rate based beaconing schemes

Adaptive beaconing rate schemes tune beacon interval to adaptively increase or decrease beacon rate to cope congestion of the wireless link. It is evident that small beacon rate will alleviate link congestion at the cost of information accuracy. There are many schemes in literature that use different parameters to adapt beacon rate [5-18].

Adaptive transmission power based beaconing schemes

As stated earlier, the adaptive beacon rate algorithms may increase the freshness of information without congesting the channel in a sparse network scenario. However, it is difficult to achieve maximum network proximity awareness at constant transmission power in identical VANET scenario. Likewise, the link lifetime in VANET is unpredictable and limited due to high mobility and can be increased if a vehicle communicates at the higher transmission power. Hence, each vehicle requires adaptively regulating its transmission power subject to the network and channeling characteristics to avoid channel congestion and increase link lifetime. Transmission power adaption impacts the number of neighboring vehicles that are able to hear beacons sent by their neighbors. Low beacon transmission power would allow only the closest neighbors to hear/decode correctly the message. Conversely, high transmission power would increase the transmission range, allowing more neighbors to receive the message correctly and the number of nodes that are involved in interferences. However, adaptive power schemes may unfairly utilize the network channel due to the fixed beacon rate and highly dynamic topology. Researchers have proposed many adaptive beacon transmission power schemes [19-27].

Adaptive contention window size based beaconing schemes

There are few proposals that adaptively adjust the contention window size, CW, of MAC (as a sole control parameter) because in contention-based IEEE802.11p, adjusting CW greatly impact on the beacon collision. Increasing the CW reduces collision; however, it has negative effect on the transmission delay of beacons. The reason behind this phenomenon is the back-off algorithm. Back-off algorithm uniformly selects the back-off interval from [0, CW+1]. Initially, value of CW = CWmin and after each failed transmission attempt, value of CW is doubled. The failure detection in IEEE802.11p broadcast is difficult because it does not use any acknowledgment mechanism. However, adaption of CW may impact on network performance [28].

Most of the above congestion control schemes adaptively vary the transmission parameters of (periodic safety message) PSM to maximize the throughput and packet success rate while neglecting the road traffic situation and safety application requirements. In contrast to the above techniques, the proposed rate control algorithm adaptively varies the PSM generation rate according to the safety of vehicles on the road, hence

VOL. 10, NO. 20, NOVEMBER 2015 ISSN 1819-6608
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offering additional transmission capacity to other classes of traffic.

RESEARCH PROBLEMS

The efficient beacon broadcast mechanism is one of the challenging issues in VANETs because of the broadcast nature of IEEE802.11*p*and short-lived or time-constrained communication of the beacons [29]. The emergency situation information or status information of a vehicle must be timely updated at the neighboring vehicles to make sure the safety of passengers. In presence of beacon collision and channel congestion due to the dynamic nature of VANET, it is difficult to meet this feature of the beacon message. Therefore, the safety applications can easily be realized by controlling the congestion in the network. Periodic beacon messages are broadcasted at regular intervals or a constant rate (*R*tx), usually after every 0.1 s or *R*tx=10beacons/s, with constant transmission power, for example,*P*tx =20dBm, to announce the status of vehicle within its vicinity [30]. Vehicles collect sufficient neighborhood information by broadcasting periodic beacons to satisfy information requirements of the VANET applications, especially nonsafety applications. The precision of neighborhood information depends on *R*tx of beacon message. However the higher beacon *R*tx degrades the link performance and results in beaconloss. On the contrary, low*R*tx of a beacon message leads to imprecise neighborhood information at vehicles. This fairness between beacon load and information precision is still an open issue. Due to fast mobility of vehicles in the VANET, network density can abruptly change from sparse to dense or vice versa. Channel congestion is the problem of having unreliable communication performance because of heavy traffic load on the wireless channel. It is a major problem particularly for vehicular safety purposes because safety applications require frequent data exchange with low latency and high reliability. Since a wireless channel has limited capacity, heavy traffic load on the channel will cause channel congestion. Especially in dense traffic scenarios, channel congestion will cause high latency or packet loss and will make safety applications, such as cooperative collision avoidance (CCA). The safety applications in VANETs require exchange of various types of data traffic among road vehicles on the CCH within the CCH Interval. Depending on the type of application, the message generation could be periodic or event driven while the message transmission distance can be variable [31]. Among the safety information, single hop Periodic Safety Message (PSM) holds the highest share of the network load due to their periodic broadcast nature [32]. Due to the short CCH Interval, the traffic load generated by the periodic PSM could introduce large packet losses and higher channel busy percentage, thus reducing the safety of vehicles and the transmission opportunities of other types of traffic [4] [5]. As the number of non-safety applications and their WSA's grow, the control channel could further become congested. Therefore, congestion control policies which could reduce the channel utilization of the control channel without compromising the safety of the vehicles are required. In this paper, we present a congestion control algorithm which uses the time gap [3] of the vehicles to adaptively control the PSM generation rate

Adaptive time gap based congestion control

In this section, we explain the working of the proposed adaptive periodic safety message (PSM) congestion control algorithm. The goal of the paper is to work towards a congestion control policy which improves the channel utilization of the control channel while satisfying the safety requirements. To keep the scope of the paper limited, we keep the transmission power constant and only consider the packet generation rate control. Time-gap is defined as an adjustment of cars speed and keeps a pre-selected time-gap (gap divided by speed) between the lead vehicle and the driver's vehicle. To the best of our knowledge from extensive literature review done, no work ever existed using time-gap as based on congestion control algorithm.

Since time gap has been found to be an important safety metric which helps drivers to avoid collisions [35]. It provides an indication of the spacing between the vehicles depending on their speed. A higher time gap value indicates a safer road scenario [35, 36]. Based on the statistics [33, 34], this study assumes the value of $TGFD_{min}$ = 1s and $TGFD_{max}$ = 3s seconds has been found to provide sufficient safety margin to avoid collisions with the lead vehicle in an emergency condition. Time gap is an indicator which provides a measure to evaluate the safety of a given traffic situation. This is because of the earlier research had discovered that time-gap is indicated as the key factor for safety, and proper time-gap settings can lead to better performance and can compensate for in-vehicle distraction [2].

$$TGFD = T_b + T_p + T_d + (T_{ap_{vi}} - T_{ap_{vi+1}}) + T_{pr} + TG \quad (1)$$

Definition of Time Gap [3]

The TGFD leading vehicle is directly proportional to the safe driving distance on the road. To accurately estimate location of the vehicles, authors assume that position information is obtained through differential global positioning system (DGPS). The TGFD is taken as the minimum of time gap of leading (L_v) and following vehicles (F_v).

TIME GAP =min (TGFD L_v, TGFD F_v)

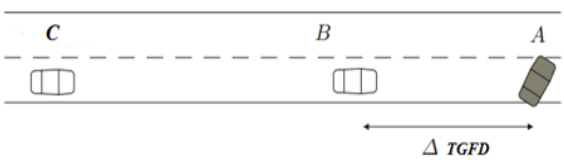

Figure-2. The road traffic scenario.

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Every vehicle sends its position information and current speed as a part of the PSM packet. Consider vehicle A in Figure-2 and the vehicles which can result in a collision with it. Vehicle B and vehicle C which are in the same lane can result in a head-on collision with vehicle A. The time gap provides a measure of the safe spacing between the vehicles in order to avoid collisions. If the time gap of the vehicles is greater than the safe time gap (1.5-3 seconds), the PSM generation rate can be reduced to adapt with the less likely collision traffic situation. As shown in Figure-2, every vehicle measures its own time gap and the time gap of the following vehicle to get an idea of the traffic situation. The PSM generation rate is controlled with the measured time gap using the graph in Figure-3. The PSM packets are generated with a maximum rate (Rmax) till a minimum time gap (TGFDmin). After the minimum time gap, the PSM generation rate is exponentially reduced till the maximum time gap (TGFDmax). After the maximum time gap, the PSM generation rate is fixed at a minimum rate (Rmin). The exponential curve is used for the rate control because the traffic situation becomes safer with the increasing time gap and hence, lower PSM generation rate can be selected. The measured time gap is taken as the minimum of the own time gap and the time gap of the following vehicle. The reason for taking the minimum of the two gaps can be explained as follows. For example, if the time gap measured by vehicle A is a large value and it adapts its rate based on this value, vehicle C will receive the PSM packets from vehicle A less often. However, the vehicle C may have a small time gap and would require a more often PSM packet reception from vehicle A. Therefore, every vehicle must consider the minimum of its own time gap and the time gap of the following vehicle for safety purposes.

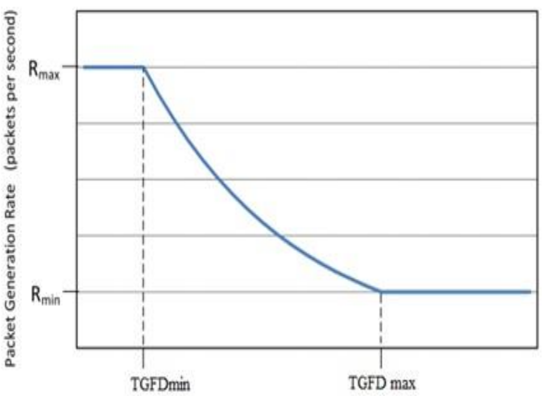
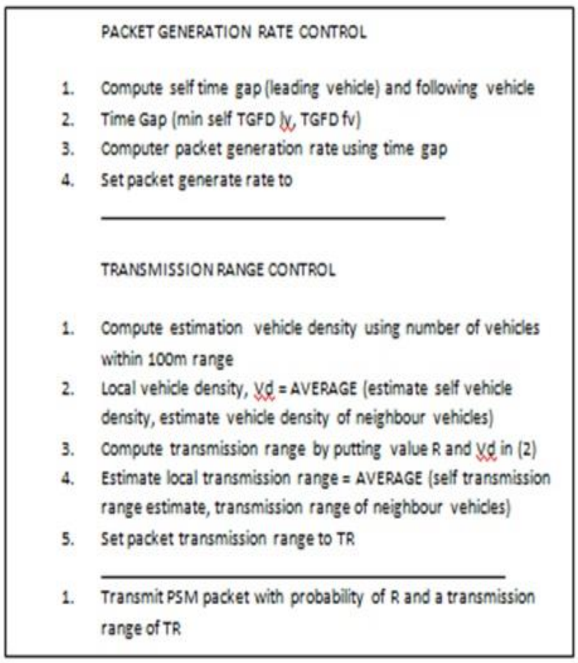


Figure-3. PSM generation rate at different time gap.

For the multi-hop traffic, a distance based wait time scheme is used to adaptively select the rebroadcast nodes, and retransmissions to overcome multi-path fading in this paper [37, 38]. The multi-hop message could be accident warning information initiated by a vehicle located next to the emergency location. Every vehicle which receives the multi-hop packet initiates a wait timer based on the distance from the transmitter node using the following equation:

Wait time = Tmax (1- (d/R) (2)

Where Tmax is the maximum wait time of the timer, d is the distance between the transmitter and receiver and R is the transmission range. According to (2), the wait timer of the furthest vehicle expires first and it rebroadcasts the multi-hop packet. All vehicles receiving the duplicate of the multi-hop packet from the message propagation direction, cancel their rebroadcast. If a vehicle does not receive a duplicate packet within a retransmission wait time (Tretx), it retransmits the multi-hop packet. The numbers of retransmissions are set to 3. The value of Tmax and Tretx are taken as 5ms in the simulations. The multi-hop rebroadcast packets queued in the SCH Interval are stored and transmitted in the next CCH Interval.


PACKET GENERATION RATE CONTROL

1. Compute self time gap (leading vehicle) and following vehicle
2. Time Gap (min self TGFD lv, TGFD fv)
3. Computer packet generation rate using time gap
4. Set packet generate rate to

TRANSMISSION RANGE CONTROL

1. Compute estimation vehicle density using number of vehicles within 100m range
2. Local vehicle density, Vd = AVERAGE (estimate self vehicle density, estimate vehicle density of neighbour vehicles)
3. Compute transmission range by putting value R and Vd in (2)
4. Estimate local transmission range = AVERAGE (self transmission range estimate, transmission range of neighbour vehicles)
5. Set packet transmission range to TR

1. Transmit PSM packet with probability of R and a transmission range of TR

Figure-4. Packet generation algorithm by using TGFD.

Simulation

The multi-channel operation defined in the IEEE 1609.4 was implemented in NS2 to generate PSM packets uniformly within the CCH Interval. The PSM packets which could not be transmitted during the CCH Interval were dropped as fresh PSM packets were sent in the next CCH Interval. The simulation scenario is a highway with a road length of 5 km and 3 lanes per direction. The vehicular traffic model used in the simulation uses an exponential distribution of inter vehicle spacing at low vehicle density (60 vehicles/km) and a normal distribution of inter-vehicle spacing at medium and high vehicle densities (120 vehicles/km and 180 vehicles/km) [39]. The simulations are performed at three mean vehicle speeds of low (40 km/h), medium (70 km/h) and high (100 km/h). The speed of each vehicle is normally distributed with a

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standard deviation of 10% of the mean vehicle speed. The transmission range of the vehicles is fixed to 300m. The performance metrics used in this paper are packet success rate, packet generation rate, channel busy percentage, end to end delay, warning notification time of multi-hop traffic and number of transmissions required for multi-hop packet propagation within the intended road section. The channel busy percentage is defined as the percentage of CCH Interval the vehicle sensed the channel as busy due to receiving power greater than the carrier sense threshold. The warning notification time of the multi-hop packet is defined as the time required for all the vehicles within the intended road section to get notified of the emergency. Each simulation was run for 300 seconds for a number of seed values. The results were averaged over all the simulations. For the proposed adaptive rate control algorithm, we select Rmin as 1 packet/second whereas Rmax is set to the maximum PSM generation rate for cooperative awareness (10 packets/second) [31]. The TGFDmin used in the simulations is equal to 1.5 seconds which is the safety time gap required for collision avoidance [35,36]. The TGFDmax is set to 10 seconds.

Performance analysis

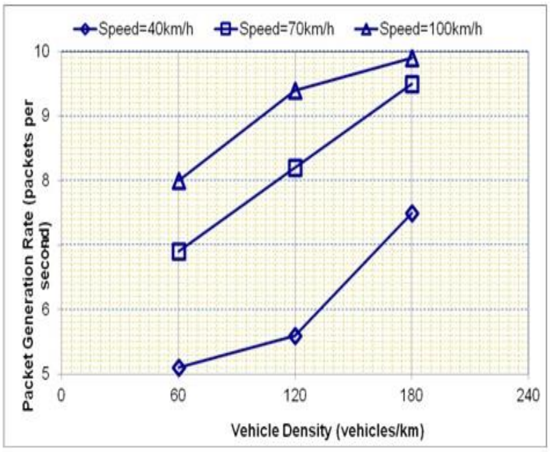

Figure-5. PSM generation rate at different speeds and vehicle densities.

The result in Figure-5 shows the PSM generation rate at different speeds and vehicle densities. As the average vehicle speed is increased at a vehicle density, the time gap is reduced and PSM generation rate is increased. Similarly, as the vehicle density is increased, the average spacing between vehicles decreases resulting in a lower time gap and hence, a higher PSM generation rate. The vehicle speed decreases with the vehicle density according to the traffic flow theory [39].Therefore, at a high vehicle density such as 180 vehicles/km, the vehicles would be operating at a lower speed where the proposed rate control algorithm results in reduced packet generation rate.

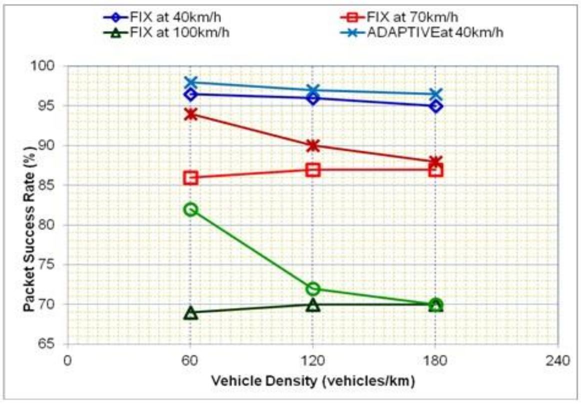

Figure-6. The packet success rate of the proposed adaptive rate control algorithm (Adaptive) which is compared with the standard IEEE 802.11p protocol using a fixed PSM generation rate of 10 packets/second.

Figure-6 shows the packet success rate of the proposed adaptive rate control algorithm (Adaptive) within a safety distance of 100m which is compared with the standard IEEE 802.11p protocol using a fixed PSM generation rate of 10 packets/second. The proposed rate control algorithm improves the delivery rate of the basic safety messages. At a lower vehicle density, the packet success rate for the adaptive rate control algorithm is slightly higher than the fixed rate technique. However, at a higher vehicle density of 120 vehicles/km, the packet success rate for the rate control algorithm is 1-10% higher than the fixed rate transmission (FIX) technique at different speeds. The performance improvement results from the reduced PSM generation rate without compromising the safety of the vehicles. As the speed of the vehicles increases, the packet success rate for the rate control algorithm slightly reduces due to a higher PSM generation rate. However, the packet success rate still remains higher than the fixed rate PSM transmission scheme, hence offering better road safety for vehicles.

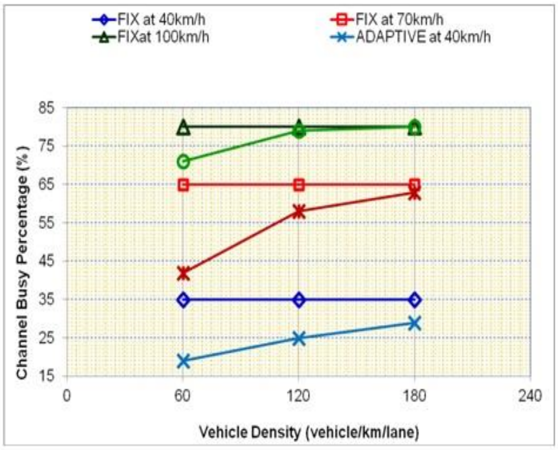

Figure-7. The channel busy percentage of the proposed adaptive rate control algorithm (Adaptive) compared with the fixed rate transmission (Fix) scheme.

VOL. 10, NO. 20, NOVEMBER 2015 ISSN 1819-6608
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Figure-7 shows the rate control algorithm reduces the channel busy percentage up to 40%, 15% and 8% at vehicle speeds of 40 km/h, 70 km/h and 100 km/h respectively for a vehicle density of 120 vehicles/km. The channel busy percentage for the rate control algorithm increases with the vehicle density and vehicle speed due to a lower time gap. However, the channel busy percentage still remains lower than the fixed rate PSM transmission scheme, thus offering additional capacity to other traffic sources. The results show that at lower speeds significant channel capacity can be used for other applications using the rate control algorithm.

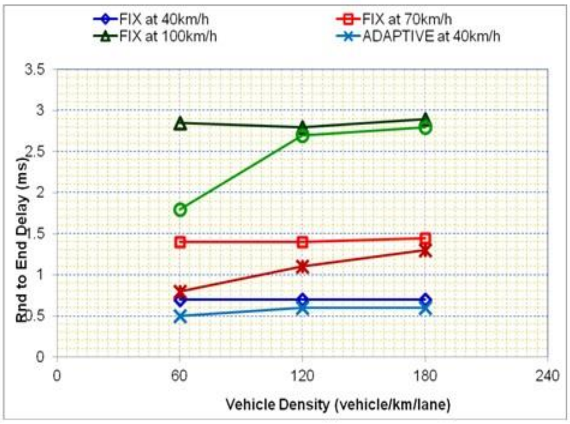

Figure-8. The end to end delay for the PSM packets.

Figure-8 Shows that due to a lower channel busy percentage, the end to end delay of the proposed adaptive rate control algorithm is lower than the fixed rate transmission at different values of vehicle density and vehicle speeds

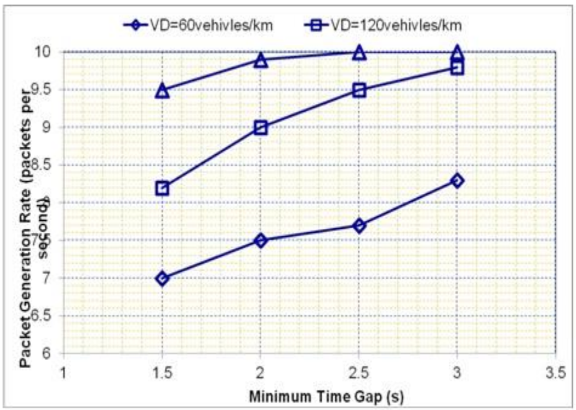

Figure-9. The PSM generation rate of the proposed adaptive rate control algorithm for different minimum time gap (TGFDmin) values.

Figure-9 shows that the PSM generation rate is increased as TGFDmin is increased. A lower minimum time gap may improve the channel busy percentage due to a lower PSM generation rate, however the safety is compromised. Therefore, the minimum time gap provides a tradeoff between the channel busy percentage and the road traffic safety feature

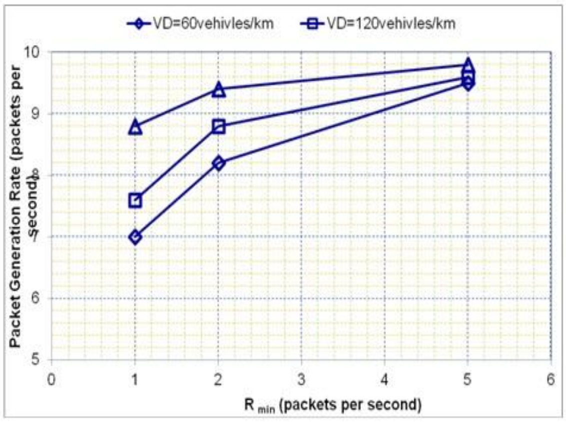

Figure-10. PSM generation rate of the proposed adaptive rate control algorithm for different minimum rate (Rmin) values..

The result in Figure-10 shows the PSM generation rate of the rate control algorithm reduces to a minimum rate (Rmin) after the maximum time gap is reached. From Figure-2, as Rmin is increased, the graph becomes less steep resulting in selection of higher packet generation rate. Therefore, we can see from the simulation results in Figure-10 that as Rmin is increased, the packet generation rate is also increased. As a result, Rmin provides a tradeoff between channel busy percentage and the safety awareness packet frequency.

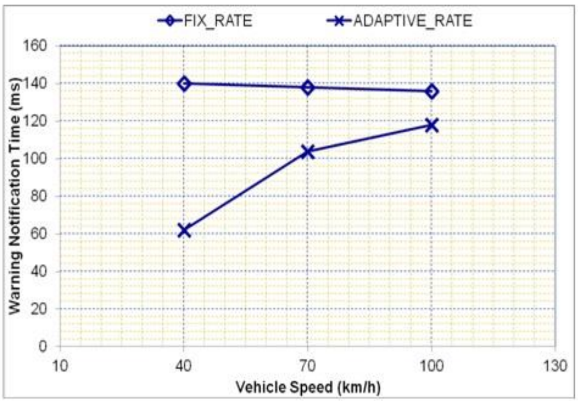

Figure-11. The warning notification time of the multi-hop packet when using a fixed rate transmission as compared to the adaptive rate transmission

The result in Figure-11 shows the warning notification time of the multi-hop packet when using a fixed rate transmission as compared to the adaptive rate transmission at a vehicle density of 120 vehicles/km. The result shows that the adaptive rate control algorithm improves the warning notification time of the multi-hop emergency message by 55%, 24% and 16% at vehicle speeds of 40 km/h, 70 km/h and 100 km/h . The adaptive rate control algorithm improves the channel utilization of the control channel without compromising the safety of the vehicles, thus providing space for the other type of traffic.

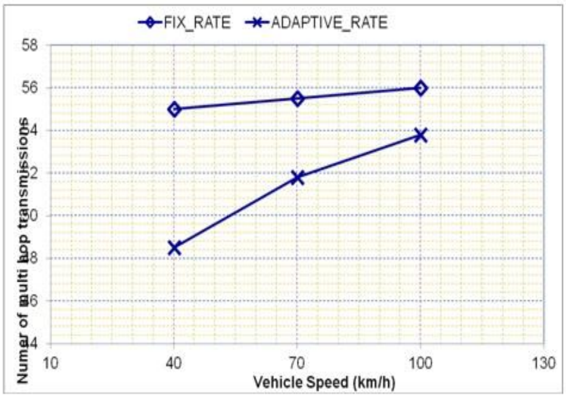

Figure-12. Total number of transmissions required to propagate a multihop packet within 2 km road section.

From Figure-12, Due to a lower channel busy percentage, we can see that the adaptive rate control algorithm requires a lower number of transmissions for multi-hop message propagation.

CONCLUSIONS

Appropriate congestion control mechanisms are essential to provide efficient operation of a network. Ensuring congestion control within vehicular ad hoc networks faces special challenges, due to the specificities of such environment (High mobility of nodes, high rate of topology changes, high variability in nodes density and neighborhood configuration, broadcast/geocast communication nature, etc.). In this context, we present in this paper a cooperative and fully distributed congestion control approach, based on time gap, TGFD [3] to adaptively control the PSM generation rate. Using the measured time gap of the neighbor vehicles in the same lane, the PSM generation rate is controlled in order to reduce the congestion, keeping the safety of the vehicles intact. Every vehicle maintains the maximum packet generation rate below the safe time gap and exponentially reduces the packet generation rate as the measured time gap of vehicles increases. The simulation results show that the proposed algorithm could significantly reduce the channel utilization, thus offering more transmission opportunities to other classes of traffic. Also, the proposed rate control algorithm enhances the road safety due to a higher PSM delivery rate. The simulation results also verify that the rate control algorithm improves the warning notification time and transmission overhead of the multi-hop traffic.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Universiti Sains Malaysia (USM) for supporting this work under USM Short term Grant Scheme No. 304/PKOMP/6313023.

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