MULTI-HOP PROPAGATION OF SAFETY MESSAGES FOR VEHICULAR AD-HOC NETWORKS

(ARAÇLAR ARASI AĞLAR İÇİN GÜVENLİK MESAJLARININ ÇOKLU-HOP GÖNDERİMİ)

by

Yavuz PEKŞEN, B.S.

Thesis

Submitted in Partial Fulfillment

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Table of Contents

List of Symbols

ACK	Acknowledgement (Packet)
AP	Access Point
ASTM	American Society for Testing and Material
C2C-CC	Car 2 Car Communication Consortium
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CTB	Clear To Broadcast
CTS	Clear To Send
CW	Contention Window
DCC	Decentralized Congestion Control
DCF	Distributed Coordination Function
DIFS	Distributed Inter-Frame Spacing
DSRC	Dedicated Short Range Communications
DSRC	Dedicated Short Range Communications
ETSI	European Telecommunications Standards Institute
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineering
ITS	Intelligent Transportation Systems
IVC	Inter-Vehicle Communications
LOS	Line Of Sight
MAC	Medium Access Control
MANET	Mobile Ad-Hoc Network
NAV	Network Allocation Vector
NLOS	Non Line Of Sight
NS-3	Network Simulator 3
OBU	On Board Unit
OFDM	Orthogonal Frequency-Division Multiplexing

PER	Packet Error Rate
PHY	Physical (Layer)
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
RTB	Request To Broadcast
RTS	Request To Send
SNR	Signal to Noise Ratio
SUMO	Simulation of Urban Mobility
TTL	Time To Live
V2I	Vehicle to Infrastructure
VANET	Vehicular Ad-Hoc Network
WAVE	Wireless Access in Vehicular Environments
WHO	World Health Organization
WLAN	Wireless Local Area Network

List of Figures

List of Tables

Abstract

VANET is a network type envisioned for the future of ITS application services to improve road safety and efficiency. The main objective of VANET is to provide a guaranteed communication environment in which high speed vehicles exchange information successfully in a region distributed from any central infrastructure. By the time being, existing ITS systems are not well known due to expensive deployments or being dependent on infrastructure but in VANET vehicle is able to communicate with each other and warn them before a dangerous situation occurs in the transmission range. In this thesis, a new MAC design is presented for the multi-hop propagation of safety messages. Furthermore, to understand the nature of vehicular environment and the behavior of vehicles, a prior work has been conducted. The proposed mechanism is based on the selection of relay node per hop utilizing discriminative vehicle physical and MAC layer quantities which then gives an access probability to vehicles in the directed range. This access probability tells vehicle how much slot unit will be deferred from the wireless medium.The first vehicle which ends the back off timer according to given probability will be qualified as candidate relay node. To verify the effectiveness of the MAC protocol design, computer based simulations have been conducted in NS-3. Scenarios and mobility trace of vehicles are imported from the urban mobility simulator SUMO. The results show that the protocol performs well even under poor channel quality in terms of packet delivery ratio and delay.

Résumé

Vanet est un type de réseau prévut pour l'avenir des services d'applications ITS afin d'améliorer la sécurité routiere et de développer leur éfficacité. L'objectif principal de VANET est de fournir un environnement de communication éfficace dans les véhicules à grande vitesse pouréchanger des informations avec succès dans une région sans infrastructure centrale. A l'heure qu'il est, les systèmes ITS existants ne sont pas encore bien connus en raison de leurs déploiements coûteux et leur dépendance d'une infrastructure. mais un véhicule ayant implémenté VANET est capable de communiquer avec les autres et de les avertir avant qu'une situation dangereuse ne se produit dans la zone de transmission. Dans cette thèse, un nouveau design MAC est présenté pour la propagation multi-hop des messages de sécurité. Par ailleurs, pour comprendre le comportement des véhicules et la nature de leur environnement, un travail a été réalisé préalablement. Le mécanisme proposé est basé sur la sélection de nœuds relais par hop qui selectionne des véhicules de façon discriminative en utilisant les couches physique et MAC qui lui donne des probabilités d'acces dans la zone de controle. La Probabilité d'accès annonce au véhicule combien d'unités de logement de temps seront retirés de l'espace réseau sans fil. D'apres les probabilités calculées, le premier véhicule qui a son compteur de retirement écoulé devient qualifié comme noeud de relai candidat. Pour verifier l'éfficacité de la conception du protocole MAC, des simulations virtuelles ont été menées avec NS-3. Les scénarios et la mobilité des véhicules sont importés du simulateur de la mobilité urbaine SUMO. Les résultats montrent que le protocole marche correctement même si la chaine disponible est de mauvaise qualité en termes de pourcentage d'acheminement de paquets et de retard.

Özet

VANET ; yolların güvenilirliğini ve etkinliğini geliştirecek olan ITS uygulama servislerinin geleceği için öngörülen bir ağ çeşididir. VANET' in ana hedefi, herhangi merkezi altyapıdan ayrık bir bölgede yüksek hızdaki araçların bilgiyi başarılı bir şekilde değiştirebilen garantili bir iletişim ortamı sağlamaktır. Şu ana kadar var olan ITS sistemleri pahalı yerleştirmeler ve altyapıya duyduğu bağlılıktan dolayı çok iyi bilinmemekteydi fakat VANET' de araç birbirleriyle iletişime geçebilmekte ve gönderim alanı içindeki diğer araçları muhtemel tehlike durumu oluşmadan önce uyarabilmektedir. Bu tezde, güvenlik mesajlarının çoklu-hop yayılımı için yeni bir ortam erişim dizaynı sunulmaktadır. Ek olarak, araçlara özgü ortamların doğasını ve araçların davranışını anlamak üzere ön çalışmalar yürütülmüştür. Önerilen mekanizma, yönlendirilmiş bölgedeki araçlara erişim olasılığı verecek ayrıştırıcı fiziksel ve ortam erişim kontrol katman özelliklerinden yararlanarak hop başına aktarıcı aracın seçimine dayalıdır. Erişim olasılığı araca kaç ünite adım kablosuz ortamdan çekileceğini söylemektedir. Verilen olasılıklara göre geri çekilme zamanlayıcısını sonlandıran ilk araç aday aktarıcı araç olarak nitelendirilecektir. Ortam erişim katman protokolü dizaynının etkinliğini kanıtlamak üzere, NS-3'te bilgisayar tabanlı simülasyonlar yürütülmüştür. Senaryolar ve araç hareket kabiliyeti şehir içi hareket simülatörü SUMO' dan alınmaktadır. Sonuçlar protokolün paket iletim oranı ve gecikme bakımından düşük kanal kalitesinde bile iyi çalıştığını göstermektedir.

1 Introduction

Recent advances in wireless communication technology have created a new way to accessing information at different and distributed locations from centralized area. More information brings with wider range of diversity and functionality in the use of sectors. One of the most probable and applicable sectors is the transportation due to high number of vehicles and free movement of these vehicles in a structured way. Transportation systems are basically designed to transport vehicles from one place to another regardless of the distance. Providing and preserving safety of drivers are the main concern of the transportation systems during travel time. Comfortable driving experience, ease of accessing information related with traffic and all other advantages are less prior than safety. It is aimed that smart devices which are error free would take the responsibility of delivering safe driving from human. ITS continues collecting these smart devices that have been developed and manufactured so far under its own structure. The goal of the transportation systems is to implement applications that are derived from all possible use case scenarios. There are tons of possible scenarios with the combination of free movements of vehicles and the surrounding environment. Crucial scenarios are being defined by communities by picking them among the all possible scenarios. Nevertheless, it is quite early to anticipate that the systems would be fully functional on roads for now. However, it seems to be the one of the best solutions by utilizing these systems that alleviate the negative effect of the predefined use cases at the moment. Leveraging the idea of wireless technology in vehicular environment has attracted researchers since 1980 (Kawashima, 1990). It also kept the topic current by communities. Despite all, developments have progressed slowly and not been sufficient enough at that times. Last decade, works presented in transportation systems have been accelerated along with the 802.11 WLAN and developments in hardware solutions. In 1999, U.S Federal Communication Commission has allocated 75Mhz of bandwidth to be used by DSRC in the 5.9Ghz frequency band (ASTM, 2003). DSRC is a short range communication type which is considered for automotive use and defined as the set of protocols and standards. In the middle of 2003, ASTM and IEEE organizations have approved DSRC (Jiang et al., 2006) for the development of ITS. After the activation of DSRC, wireless communication capabilities are aimed to cover typically within 1000m for transportation applications at highways (Biswas et al., 2006). International governments allocated 5.8/5.9Ghz and 700Mhz at Japan (Hartenstein and Laberteaux, 2008). Initiatives from governments have encouraged organizations to launch new national or international projects. C2C-CC started the project NOW (Torrent-Moreno et al., 2008) in 2004, and announced the latter project named COMeSafety (Bossom, 2008) which includes the major communication architecture in Europe. In Japan, internet-its (Izumi, 2002) project has been conducted. FleetNet (Enkelmann, 2003), CARNET (Morris et al., 2000) and CARTALK (Reichardt et al., 2002) are other significant projects related with vehicular communication. From another perspective, the necessity to transportation system is growing larger over time. Geographical extension of cities lead transportation networks to grow as well. It also becomes harder to manage and maintain the road network. Furthermore, it brings with the infrastructure for safety of drivers and traffic management which implies extra cost for governments. Even though delivering safety to drivers is one the main concerns of the transportation systems, drivers are exposed to hazardous events. According to WHO, 1.27 million people died as a result of road traffic collision in 2004 (World Health Organization, 2009). Besides, this recent survey showed a 1 :20 ratio between deaths and severe injuries. It was estimated that 25.4 million people would be injured if the number of deaths was the same as in 2004. For this reason, a new approach is required and should be integrated into the systems. Car manufacturers have started selling their products with on-board electronic devices such as camera and radar to meet these requirements. Mobile communication is regarded as a more promising and broader solution to improve road safety and traffic management in vehicular environments. Furthermore, passengers can spend their time efficiently during travel time using various types of non-safety application ranging from web browsing to accessing entertainment contents.

2 The Goal Of Thesis

Delivering safety message to all vehicles in a short time is an open and challenging problem in VANET literature. In this thesis, we introduce a novel multi-hop MAC protocol, named ATP that is designed to select a single relay node per hop for the purpose of disseminating the safety message to vehicles further away from the danger zone. We further improve ATP in terms of reliability and channel availability and propose a second protocol H-ATP. Although H-ATP performs better than ATP and traditional RTS/CTS handshake mechanism in the simulations, the original approach is derived from ATP. Besides, the examination and simulation results of ATP help us to understand the characteristics of vehicular environment in a more accurate way. We observe the performance of ATP, H-ATP and RTS/CTS mechanisms through two simulation works. In the first one, we utilize from SUMO tool to obtain realistic vehicle movements by defining a set of parameters such as vehicle density, road pattern and traffic scenario. In the second part, we import them and obtain the packet related results from the network simulator NS-3.

3 Outline

The rest of thesis is organized as follows. In Section 2, we present an overview of VANET and 802.11p protocol. Section 3 reviews the related works on the design of MAC proposed for safety packet dissemination in inter vehicle communication. In section 4, the design of back-off procedure and two protocols that are derived from this procedure are presented. In section 5, we give technical details about the metrics and parameters used and discuss the results of the protocol from simulation studies that have been performed by realistic vehicular mobility (SUMO) and network tool (NS-3). Section 6 summarizes and concludes the thesis.

4 Vehicular Ad-Hoc Network (VANET)

Mobile nodes need a distributed network structure to exchange information with each other via vehicle-to-vehicle and vehicle-to-infrastructure communications. Conventional MANET types such as sensor and mesh networks unfortunately are not suitable to IVC systems due to high mobility of vehicles especially on highways, dynamic road topologies and hostile channel conditions of the surrounding environment. Thus, a new and robust communication platform is needed for the successful implementation of ITS safety applications. The idea of VANET has been leveraged by the recent advances in wireless communication technology as a special kind of MANET. By definition, the term ad-hoc represents the case which a node can receive or send information to other neighbor vehicles in the communication range without requiring a central station to employ coordination function 802.11 DCF in any time. There must be at least two vehicles to form a decentralized network but they have to carry a WLAN capable on-board devices to exchange information among themselves. Thus, vehicles act as mobile nodes in the surrounding environment. Communications among and between vehicles are divided into two main categories depending on the environment and infrastructure support.

4.1 Vehicle to Vehicle (V2V) Communication

V2V communication enables vehicle owing WLAN capable OBU to send safety or non safety messages to targeted vehicles. Likewise, the vehicle can receive other messages from their neighbors. Messages especially safety ones are assumed to be transmitted by broadcast communication type. Thus, vehicles do not need to know the identification information of other vehicles before sending its packet in IVC systems. V2V is an important communication type of VANETs due to interoperability between each WLAN capable vehicles. It is not required to deploy high cost infrastructure for the dissemination of information to mobile nodes. Figure 4.1 depicts a simplified and typical scenario to

V2V communication.

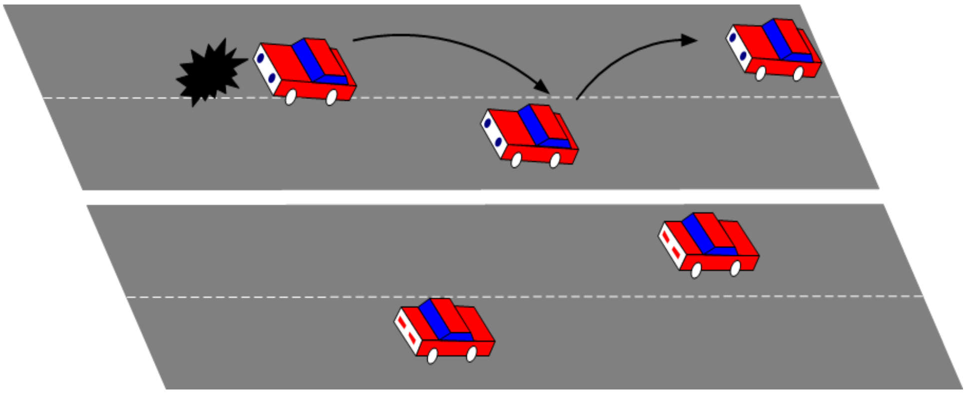

FIGURE 4.1 – Sample Scenario for the V2V Communication

Assume that the network connectivity is established along with the communication range of vehicles. There are two types of use cases (single and multi-hop) in delivering messages to targeted vehicles which will be explained in next sections. The driver of vehicle A experiences an entity in front of the vehicle while driving and mechanics in it are dramatically changed due to behavior of driver toward to the situation such as hard braking or rapid lane changing by maneuvering. High alteration in the vehicular mechanic triggers a new action which is the generation of safety packet. Other electronic safety device modules are very helpful at informing driver before interacting directly to a dangerous situation. As a result, dangerous situation is categorized from various application structures. Vehicle autonomously generates safety message and transforms it into packet with the header. Since wireless communication is assumed to be used cooperatively by vehicles, vehicle A needs to inform the existence of an obstacle by broadcasting its packet to one-hop neighbors. Neighbor nodes in the behind of vehicle A are in critical situation so that vehicle A should ensure that all vehicles has received the safety packet successfully in one or multiple transmission attempts. It is quite the concern of application and the underlying network protocols which the OBU uses. But more importantly, message should be propagated to the areas beyond of the communication coverage of vehicle A since it is probable that other vehicles moving at the far behind of vehicle A have an accident due to obstacle. Hence, the safety message is forwarded by vehicle B and C cooperatively. The requirements of application defines how far the message should be propagated along the roadway. Well known applications for V2V communication are Pre-Post Crash Warning, Blind Spot Warning, Cooperative Collision Warning, Highway - Intersection Merge Assistant.

4.2 Vehicle to Infrastructure(V2I) Communication

In V2V communication, there should be at least two nodes for wireless communication in the shared medium. However, one vehicle is sufficient to establish network connectivity in which later the vehicle processes the incoming safety or non-safety information in V2I communications. V2I environments allow vehicles to communicate with RSUs which are likely deployed to higher locations that have LOS in the given region. In contrast, V2V communication may suffer from obstacles such as trucks and high buildings according to geographic locations and spatio-temporal entities while a transmission is ongoing. It implies that NLOS occurs between two nodes. Eventually message reception is failed by signal attenuation or absorption. However, it would not be problem for V2I communications. In this way, V2I communications perform better than V2V communications as well as other advantages. The connectivity is more stable due to non-mobility of road side units and vehicles around the area are given a higher chance of receiving information with high bandwidth resource compared to V2I communication. Figure 4.2 shows an exemplary scenario which is likely to occur on a typical straight roads.

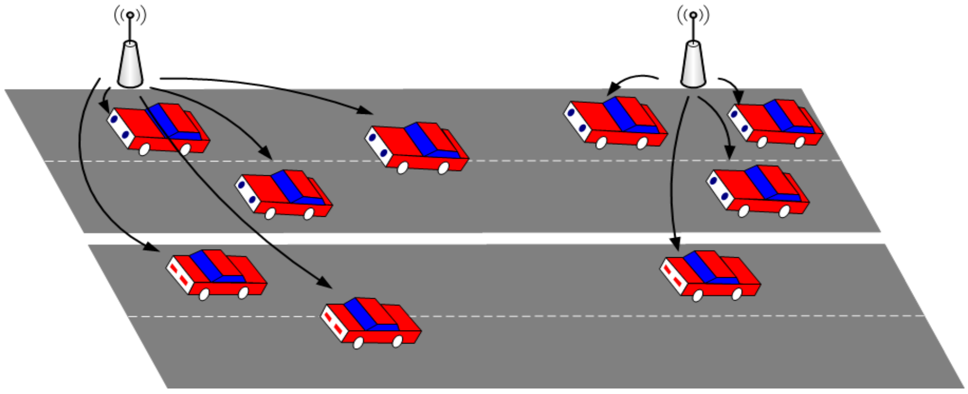

FIGURE 4.2 – Sample Scenario for the V2I Communication

When vehicle C enters into the communication range of RSU R, it disseminates the messages whose life time is not ended yet to RSU R as well as to other mobile neighbors due to broadcast nature. Messages which passed their life time means that the events correlated with them are assumed to be present no longer and vehicles which have not received these messages would be not interested in processing the corresponding information. A RSU manages the timing of its network and the behavior of the neighboring nodes which are interconnected with more reliable link. Therefore, it can be said that they can act as APs along with the aforementioned advantages of RSUs. This concept quite differs the local networks they manage from ad-hoc behavior of VANETs but they form a wireless network area which has no connection to internet. Another prominent advantage of RSUs is the capability of allocating near-unlimited resource in terms of data storage and power. After RSU receives messages from vehicle A, it stores these message to be used by other vehicles such as vehicle C passing through RSU. Vehicle C receives traffic congestion information, changes its route by using detour and eventually prevents from waiting in the congested area. Such examples may be derived with many use cases that can be happening around vehicles. However, deploying RSU and setting up vehicle-to-infrastructure is a challenging task due to the cost of sub components and the high number of available locations but benefiting from V2I communication in specific zones determined by the traffic related statistics is an efficient way to reduce the number of accidents or reroute vehicles passing along the way. Several applications for V2I communication are Blind Merge Warning, Left Turn Assistance, Traffic Signal Violation Warning, Post Crash Warning.

4.3 Single-hop Broadcast

The idea is to exchange information in one hop communication range. Single-hop operation is illustrated with the following process. A vehicle queries a message or needs to inform a status related with itself and originates the corresponding packet. Many of the safety applications in ITS are based on single-hop communication. Consider the case where a vehicle does not have any external device sensing the surrounding environment but WLAN device. Once the vehicle is about to collide with another front-vehicle due to sudden maneuver resulting from stargazing or sudden appearance of object, periodic exchange of status information which we call it beacon messaging will the prevent possible accident. Likewise, sudden slowing of the vehicle will be dangerous for the back-vehicles. Likewise, the operation follows the same procedure mentioned above.

4.4 Multi-hop Broadcast

Multi-hop dissemination techniques play a crucial role in delivering entertainment, traffic management and especially safety critical messages. Unlike single-hop, in multi-hop, vehicle who originates the encapsulated packet and adds other useful parameter values according to protocol used by the protocol layer into header. The main goal is to disseminate the packet beyond the communication range of the packet originator under the provision of the corresponding application service. In this case, other vehicles are included for cooperative multi-hop dissemination. Many protocols conduct studies on solving the problem of selecting the best candidate for relaying the packet to further distances. It implies that it is not only the responsibility of a single node which is originator but also all others to relay packet.

4.5 802.11p and WAVE

With the emergence of DSRC technology and definition of a set of related standardizations, working groups such as IEEE 1609 has started working on WAVE structure comprising a set of services under the support of DSRC (1609, 2006). These services are ;

1. Resource Manager
2. Security and Management
3. Networking
4. Multi Channel Operations

and their relationship between each other is depicted in Figure 4.3.

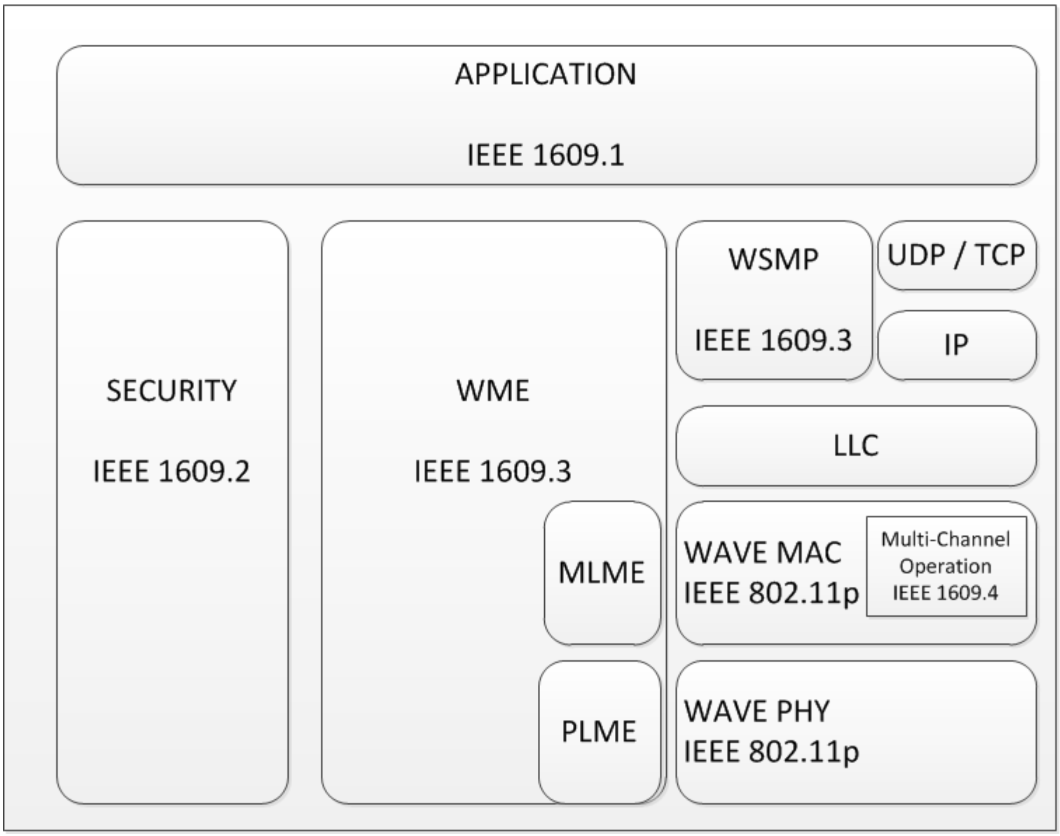

FIGURE 4.3 – The structure of WAVE

As previously mentioned, DSRC technology has been devised by making adjustments to 802.11a for an environment where the network is established and broken in a very short amount of time due to high mobility of vehicles. An international standard, 802.11p (802.11p/D3.0, 2007) is a draft amendment to the 802.11 WLAN protocol to be used by IEEE devices for ITS applications in vehicular environments including V2V and V2I communications. It is used to connect WAVE mode services to DSRC standardizations. Upper MAC extension of WAVE is defined by Multi Channel Operations. WAVE has one control and six service channel as presented in Figure 4.4.

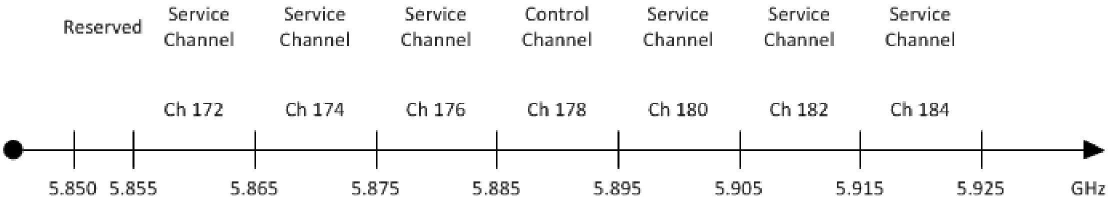

FIGURE 4.4 – Channel Allocation in USA

Being compatible with DSRC standardizations, WAVE divides 70Mhz overall bandwidth into 10Mhz channels sequentially. PHY layer of 802.11p adopts OFDM transmission technique. Therefore, integrating 10Mhz bandwidth with OFDM, each channel offers 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbps data rates. 802.11p task group has recently worked on draft 11 which has been closed with 99% affirmative votes in 2010 (802.11p, 802.11p).

4.6 ETSI

ETSI specifies the European profile standard for communications in the 5GHz band (ETSI, 2009). The presented work is based on IEEE 802.11 and developments at 802.11p. Frequency spectrum is shared among 3 channels according to the usage type ;

- ITS-G5A : contains CCH, SCH1 and SCH2 with 30 MHz bandwidth dedicated to safety related applications (5.875-5.905 MHz)
- ITS-G5B : contains SCH3 and SCH4 for non-safety applications (5.855-8.875 MHz)
- ITS-G5C : other ITS applications (5.470-5.725 MHz)

ITS-G5 stations operate outside the context of a BSS. Even though data and header frames of ETSI are compliant to IEEE 802.11 several 802.11 services such as timer synchronization and access control are excluded from the specification set. Unlike 1609.4, stations do not need to synchronize their timers in a given interval to operate on multi-channel. To mantain network stability, throughput efficiency and fair resource allocation, ETSI introduces DCC mechanism which monitors the channel and manages the packet transmission (ETSI, 2012). There are 3 states in DCC. According to current state and parameters set in the upper layers, DCC routes the packet to the corresponding queue.

5 Characteristics of VANET

Many studies have focused on the research problems in MANET. Although VANET shares the same characteristics such as movement and self-organization of nodes with MANET, it is different in some ways which challenges the operation capability. Therefore, these unique characteristics must be investigated in detail to understand the negative and positive implications of vehicular networks. In the following, we explain the most prominent factors that differ VANET from MANET in addition to ad-hoc general problems.

5.1 High Mobility

Drivers determine their speed dynamically with respect to type and availability of roads and other reasons such as weather condition and sudden maneuver. While several of them prefer to travel with low speeds, the others reach or even pass the limit of the supported speed. Although High mobility seems to be an advantage from vehicle perspective, it has negative effects in VANET due the degree of high relative speeds between vehicles. Fast moving vehicles disrupt the stability the network where wireless links live short. Thus, it is hard to manage the network especially on highways.

5.2 Road Pattern

Vehicles make predictable movements due to specific pattern of roads. However, ordering vehicles on lanes may lead congestion because of intersecting roads or traffic density. Furthermore, slowest vehicles lead bottleneck on roads. Thus, clustering or fragmentation issues may be encountered by vehicles on road scenarios in these cases which eventually may create a unique network connectivity. Distance parameter between sender and receiver nodes used in design of the proposed protocols in MANET come forward as an important criteria in VANET. Therefore, new approaches must be taken into consideration. On the other hand, there are several problems in routing the packet regarding different roads such as intersection or merging points. It may complicate and challenge the protocol design in VANETs.

5.3 Broadcasting

Broadcasting is a general communication technique in computer systems. In VANET, safety message is envisioned to be transmitted by broadcast. Although broadcasting seems to be only solution to VANET safety delivery, it does not perform well due its problematic behavior on the channel due to being subject to extra overhead, hidden terminal and broadcast storm problem. Broadcasting techniques are prone to packet collisions due to hostile channel conditions. Every vehicle possibly is a candidate to incur packet collision when unreliable links are formed.

5.4 Broadcast Storm

One of the most important factors for packet collision and channel congestion is broadcast storm due to existence of simple design in MAC protocols (Ni et al., 1999). In broadcast storm problem, every node floods the packet blindly to next region in 1-persistent or p-persistent fashion. This method is useful from one aspect which is the spatial gain when nodes are randomly distributed in region. However, the problem of blind flooding is that every node which have received the packet tries to transmit it a number of time. If every nodes tries to send packet, the probability of nodes having the same slot by employing DCF which exist in WLAN is increased. Additionally, even if every node assigns different slots after DIFS interval, the channel is congested by the redundant transmission of the same packet with different nodes which consequently results in broadcast storm. When the main concern is the delivery of safety message, inversely minimal amount of packet transmission should consume the bandwidth of channel. Congesting channel may lead concurrent transmission of nodes in the same shared medium as mentioned above.

5.5 Hidden Terminal

Another problem of using broadcasting technique is the exposure of nodes to hidden terminal problem. These nodes cannot receive a single packet due to spontaneous transmissions of nodes which are not in the carrier sensing range of each possible sender nodes. The problem of hidden terminal and broadcast storm problem is easily included in VANET due to ad-hoc nature and spatial diversity of MANETs. Assume that node A started its transmission and node B receives the packet. However, node C does not overhear this transmission. In the meantime, node B also transmits its packet. Unfortunately, even though these two nodes do not perform a wrong procedure in their CSMA/CA protocol, node B is in the transmission range of both node A and C. Since two or more packets are not successfully decoded at the same time due to use of same signal band interval, node B drops the packets. In conventional use of CSMA/CA MAC scheme, if a node is in the communication range of another node and if another node sends out its packet, the first node has to back off after a specific amount of time applying DCF scheme when a new packet is originated while receiving the packet. When the medium is free and back off timer is expired, the first node start its transmission.

5.6 Beaconing

Beaconing is an efficient way to monitor the status of objects and the local topology in MANETs. Many approaches utilize from general information from periodic beacon exchange in their design. Moreover, exchange of beacon message may likely prevent any possible accidents by providing warning to drivers. Basically, beacon messages include speed, position to be located virtually by neighboring receiver nodes, generation time to determine the validity and identification information of sender node which is optional due to privacy issue. Beaconing operation is activated by the application services. Poor beaconing schemes which do not take the network density into consideration turn scalability issues into an important problem in VANETS.

6 Related Works

There has been previously many studies and broadcasting MAC techniques designed for traditional ad-hoc networks in the literature before the approval of VANET by communities (Williams and Camp, 2002). However, several of these solutions are not suitable to vehicular networks due to unique characteristics emerging from each combination of traffic flow pattern, node density and the surrounding environment. In recent years, VANET has achieved to be regarded as a new and open area by researchers. There are various protocols and services specifically accommodated for the VANET applications so far. VANET applications aim to provide intelligent, efficient and safe transportation systems to vehicles. One type of these applications is a time critical emergency warning that needs more network resources to ensure that all vehicles which may possibly be in danger have been informed before coming across the triggering event. Therefore, the design of feasible and reliable MAC protocols is challenged by the VANET related problems mentioned in section VANET and the requirements of emergency warning application. All work must be done in MAC layer since DSRC defines a high proportion of PHY properties. In addition, safety applications do not need an intelligent routing mechanism in network layer since these applications interest vehicles in a particular region. This region may be defined either as the communication range or beyond the communication range of originating vehicle by the application. In case of a region beyond the communication range, application needs multi-hop dissemination of the original packet which is accomplished by simply sending packet backward to the movement direction of the originating vehicle. However, In a MAC protocol, one or more than one vehicle depending on the design should be selected to forward a multi-hop related emergency warning packet to extend the region coverage. Thus, it shows the essence of MAC design over other network protocols. The related MAC studies about the dissemination of emergency warning messages are given individually.

6.1 Urban Multi-Hop Broadcast Protocol For Inter-Vehicle Communication Systems

In (Korkmaz et al., 2004), authors propose two techniques that operate at straight and intersection road topologies in VANETs. In detail, the proposed technique called UMB modifies conventional RTS/CTS handshake to exchange broadcast packet between source node and furthest node in the communication range. Before replying to RTB packet, nodes send jamming signal proportional to distance to source node when they receive CTB packet. Only furthest node which sends the longest jamming signal finds the medium free and replies CTB packet. Recovery techniques are introduced when there are collisions between RTB/CTB or DATA/ACK packet exchange. At intersections covered with tall building blocks, repeaters are deployed to route packet to other directions. The problems with these techniques are aggressive approach of nodes to multi-hop propagation. The techniques consume the high proportion of bandwidth with jamming signal transmissions, and do not care the probability of existence of other transmissions around. In worse case, when the channel quality is not ideal, at least one node which do not overhear the first fraction of CTB packet, intervenes the allocated channel. Another problem is that they need an infrastructure to route packets at intersections but there is a lot of intersection in the same condition and this technique does not fit the concept of VANETs.

6.2 Efficient and Reliable Broadcast in Intervehicle Communication Networks : A Cross-Layer Approach

Bi et.al. (Bi et al., 2010) adopt the same approach which is an enhanced RTS/CTS handshake for relaying safety message by a single node as in (Korkmaz et al., 2004). The difference is that upon reception of BRTS packet, vehicles assign a waiting slot number from the relaying metric which comprises cross layer parameters distance, packet error rate and relative speed. Instead of jamming signal, vehicles is in silent mode until their timer is ended. The best candidate obtained from the metric will wait the shortest amount of time and win the contention of BCTS packet transmission. In the channel model they use, neighboring nodes are assumed to receive BCTS packet successfully and withdraw the duty of relaying operation but in non-deterministic channel models, signal level becomes much more lower as the distance between transmitter and receiver increases. In this case, a node which ends its back off timer later will impede the operation of the proposed technique.

6.3 An Effective Broadcast Scheme for Alert Message Propagation

Authors (Fasolo et al., 2006) propose a protocol named as SB that includes contention-resolution phase to select the next relay. As in (Korkmaz et al., 2004), SB protocol divides the communication range into sectors to reduce the number candidate relay nodes and utilizes RTB/CTB handshake mechanism to alleviate hidden terminal problem. Clustering and thus reducing the number of nodes are common techniques used to prevent concurrent transmission problem due to same slot allocation of nodes. The difference is that rather sending CTB packet upon reception of the emergency packet, relay node acts as transmitter node and broadcast its RTB packet. However, if transmitter node in the previous hop does not receive the RTB packet, there will be concurrent transmissions by nodes in two hops and lead hidden terminal problem. In relay selection procedure, nodes pick a random number in a determined CW interval depending on its segment but CW is not a scalable parameter. If the network is dense, segment will contain more number of nodes which implies a higher probability of allocating the same slot. Likewise, if network is sparse, it is more probable that bandwidth would be wasted with free slots and it would increase overall delay. In simulation studies, authors do not give a detail about the settings such communication range and channel model. Besides, simulations have been conducted with 1 Mbps data rate which is not acceptable for VANET applications. Low data rate increases the reception probability along with the channel model.

6.4 DV-CAST : A distributed vehicular Broadcast Protocol for Vehicular Ad-hoc Networks

In paper (Tonguz et al., 2010), they introduce a new distributed multi-hop broadcast approach for handling both disconnected network and broadcast storm problem. The proposed protocol relies on only topology information of neighbors in the communication range of the broadcast node. To obtain topology information, each node cooperatively exchanges hello messages with each other. As a result of neighbor detection, receiver node implements either broadcast suppression or store-carry-forward based on the directions and the number of nodes in one-hop range. Compared to main contribution of the thesis, the proposed mechanism is dependent on hello messaging and does not take directly distance into consideration but clustering. However, as they stated in their paper, frequent rate of beacon messaging is possibly a degrading factor of the network performance. Thus, they base the protocol on low rate beaconing rate(1Hz). Although, the low rate is not likely to interfere ongoing packet transmissions in case of fading environment, nodes may make false assumption due to mobility and out-dated beacon information.

6.5 Multi-hop Vehicular Broadcast (MHVB)

Authors work on a area based flooding protocol (Osafune et al., 2006) which comprises two mechanisms. One is the traffic congestion detection algorithm where nodes count the owners of the received packet. If it is higher than a threshold, it assigns a higher time interval for retransmission. Thus, another node will have a higher chance to broadcast its packet. Another mechanism is backfire algorithm in which nodes simply inversely wait for a time proportional to distance to transmitter node. If the candidate node receives the same packet more than one, it withdraws the duty of forwarding operation. However, authors do not give much detail about the MAC design and parameters used in simulations.

6.6 Distributed-Fair Transmit Power Adjustment for Vehicular Ad-hoc Networks

Authors in (Torrent-Moreno et al., 2006) propose a transmit power adjustment algorithm to increase the reliability of the distributed network in which the safety messages are disseminated. To adjust transmit power, each node exchanges beacon messages from its neighbors. Nodes check the beacon messages and select the lowest transmit power for fair spatial coverage. This way, they expect that the number of collision is reduced and more bandwidth is given to safety messages. However, they do not consider the adjustment of beacon rate. Although transmit power has an impact on the coverage, reducing power does not completely solve the interference problem. Furthermore, vehicles tend to form clusters. Therefore, the proposed algorithm does not work properly when the vehicles are not fully distributed.

6.7 Reliable and Efficient Alarm Message Routing in VANET (REAR)

Another protocol which is named as REAR (Jiang et al., 2008) utilizes beacon messages for local density knowledge. It is based on the estimation of packet receipt probability and the environment via beaconing. Distance is compared with RSSI, a physical layer property. They imply that RSSI gives distance between the sender and receiver node except from low scale signal loss. The protocol the divergence of two distance information and transform this information into receipt probability. However, path loss is a varying exponent for each different channel condition. RSSI value cannot be directly transformed into distance due to path and low scale signal loss. Furthermore, concurrent transmission sent by hidden node increases signal strength of the emergency packet. Thus, in fact further node may misguidedly see itself closer to the sender node.

6.8 RR-ALOHA

RR-ALOHA (Borgonovo et al., 2002) enhances R-ALOHA protocol for reliable packet disseminations taking hidden terminal problem into consideration. Authors suppose that the frame length is divided into slots and these slot timings are the same for each node. To alleviate the hidden node problem, they propose to include information of allocated slots from the view of the sender node. When possible hidden nodes receive this information, they will know that another node transmitting its packet although they sense the medium free. However, the protocol is exposed to concurrent slot allocations of nodes waiting to transmit their packet. There is no detail about how to cooperatively access the medium. Another important point is that nodes require active beacon messages but frequent exchange of beacon messages saturates the channel and causes delays which are not tolerated in safety packets.

6.9 RR-ALOHA+ and MS-ALOHA

RR-ALOHA+ proposed by (Cozzetti and Scopigno, 2009) aims to prevent the ambiguity between busy and collided slots presented in RR-ALOHA by adding new information to the packets. In RR-ALOHA+, authors notice that RR-ALOHA leads uncontrolled packets being broadcast toward to broader regions. Thus, the packet is out-dated or not important to other nodes beyond two hops and it causes hidden terminal problem. To prevent the problem, RR-ALOHA+ information is reset in each frame interval. In MS-ALOHA (Scopigno and Cozzetti, 2009), authors improve RR-ALOHA+ by restricting the area to prevent multi-hop runaway of the packets. Furthermore, MS-ALOHA avoids packet collision and allows node to re-use of the slots efficiently. Simulation studies show that MS-ALOHA outperforms RR-ALOHA and RR-ALOHA+ with above 90% packet delivery rate up to 100m from the transmitter node and other performance metrics.

7 Proposed Design

7.1 Active Transmission Protocol(ATP)

ATP protocol is designed to disseminate warning message to all vehicles in a specified region by application service. A typical safety application requires low latency on the purpose of avoiding hazardous situation. Therefore, we focus rather on the delivery of warning messages in a minimal amount of time. Besides, the protocol aims to prevent multiple redundant transmission by selecting a single relay node per hop. If the node which receives emergency packet successfully is in the directed region, it assigns a slot for having access to medium to forward the packet. For each node, the assignment procedure is performed by evaluating the PHY properties of the received packet and its physical status according to transmitter node. Ideally, relay node should has the following properties assuming that the network is dense ;

– Further away from source node
– In a particular RSSI interval
– Low PER
– Close relative speed

Multi-hop operation is sustained by relay nodes until the end of TTL number is reached. TTL information in data message is updated and forwarded sequentially by each relay node. In design of the protocol, forwarding area is firstly restricted by position and movement direction of the current transmitter node.

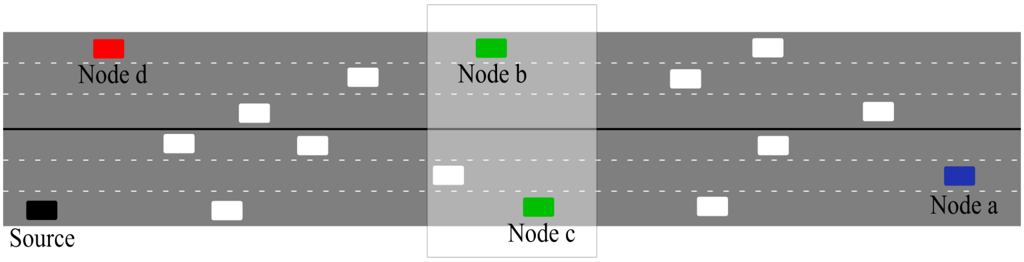

FIGURE 7.1 – Sample Scenario for ATP and H-ATP

Vehicles in front of the transmitter node are not directly involved in event after the packet is generated by source node. Even if these vehicles overhear the packet, they do not prepare themselves for forwarding the packet. Thus, they are not participated into relay selection phase. Second restriction in forwarding area is based on communication range of transmitter node. Vehicles may receive packet in a highly faded environment although they are located beyond the communication range. Transmit power determines ideal communication range along with the large scale attenuation exponent when there is no other concurrent transmission in the shared medium. In real world, signal quality deteriorates due to several factors such as absorption, reflection and interference. Therefore, communication range depends on the spatio-temporal link connectivity between transmitter and receiver node. Furthermore, nodes inside the ideal communication range may not decode the packet symbols successfully. Another reason for restricting the area with ideal communication range is that more spatial coverage implies more number of nodes in the forwarding area. Thus, more time should be allocated to include these new nodes in our back-off mechanism which means increased delay in message reception of intended nodes. After successful transmission, source node returns to listening mode for particular timeout interval until it overhears the copy of the packet from neighbor nodes. Timeout period should be determined such that the worst and single candidate in the forwarding area would perform successfully relay operation. Otherwise, source node may interrupt the allocated channel for retransmission attempt even if there is a possible candidate that has been waiting in the forwarding area. Source node assigns timeout value with the following equation ;

$$Timeout = DIFS + CW_{seg}\left(\frac{d_{ICR}}{d_{segment}}\right) + t_{transmission} + SIFS \tag{7.1}$$

where CW_{seg} is the contention window per segment, d_{ICR} and $d_{segment}$ are the lengths of ideal communication range and segment respectively. CW_{seg} and $d_{segment}$ are dynamic parameters that can be selected by transmitter node mapping the network density. If CW_{seg} is increased, vehicles assign more unique slot number. However, in this case, segment will waste more time which in turn increments overall delay during the propagation of the packet. In the same manner, if CW_{seg} is decreased, vehicles on this segment will assign closer slots to each other and the probability of having concurrent transmission will be higher. On the other hand, relay node will be selected rapidly. Transmitter node will give the forwarding operation earlier. Thus, there will be lower end-to-end delay in the network. If beacon exchange is not available, then equation utilizes from predetermined values. For simplicity and comparison issues, CW_{seg} value has been remained fixed in simulation studies.

ATP is a standalone MAC protocol that does not depend on any mechanism (i.e. RTS/CTS, beacon messaging). Thus, it does not need to perform pre-handshake transmissions or maintain local density information for cooperative contention period of candidate relay nodes. The core function behind ATP is the utilization of PHY and MAC properties of emergency packet. Upon reception of packet, node waits a specific amount of time. At the end of this back-off delay, if node senses the medium busy, it will notice that another node has already taken the responsibility of forwarding operation and it will not transmit copy of the packet. Otherwise, node will start broadcasting the packet assuming it is the first node which senses the medium free. Waiting time is calculated using the following equation ;

$$\Delta t_i = s_i t_{slot} \tag{7.2}$$

where t_{slot} is time unit for one slot and s_i denotes the function to determine the slot number of Node i. While assigning slot numbers, an effective way to prioritize a group of nodes is to use segment partitioned equally from the ideal communication range. Clustering nodes along with segment fits to timer-based contention mechanism. Smaller number of candidate nodes in the furthest segment will be prioritized with respect to slot number. In the case where at least one node is present in the furthest segment, the protocol provides the shortest bounded latency. However, in the worst case, nodes are assumed to reside on segments next to transmitter node which forms the upper bound in terms of delay per hop. On the contrary, single candidate is selected as relay based on only its distance to transmitter node due to coverage issue. However, GPS devices may not give accurate position information depending on the hardware quality. Thus, these devices have a tendency to mislead vehicles and network protocol by pointing out different coordinates from the actual ones. Although vehicles are located in different places, their GPS devices can give the same position information which leads concurrent transmissions due to same slot allocation. Considering all of these, grouping technique is included into the design of the protocol. Node i computes its slot number with the following equation ;

$$s(i) = CW_{seg}\left(\left\lceil\frac{d_{ICR}}{d_{segment}}\right\rceil - \left\lceil\frac{\Delta d\,(packet, i)}{d_{segment}}\right\rceil\right) + \kappa(i) \tag{7.3}$$

where $\Delta d\,(packet, i)$ represents the distance between Node i and source position information given in packet. Further nodes are given more privilege to reach full coverage of the communication range. Nodes that are close to the transmitter node will have high slot number by evaluating segment information. Therefore, they will wait for longer times.

Let m be the number of nodes that receive data packet from transmitter node. To propagate packet along one way, particularly opposite to the heading direction of its originating vehicle, only k number of nodes inside the ideal communication range will be eligible for the next relay selection mechanism $0 \leq k \leq m$. Vehicle is assumed to be able to receive packet even if it outside of the communication range in multi-fading environments. For a reliable relay selection, candidate node has to be positioning no further than the ideal communication range. $m - k$ nodes will set their NAV and keep active messages waiting in the transmission list until the end of NAV. Setting NAV upon the reception enhances the scheme in two ways ;

1. Interruption of another packet in the middle of handshake type multi-transmission
2. Simultaneous transmissions due to being hidden to relay or helper also known as hidden terminal problem

Each node receiving emergency packet computes its distance with Euclidian distance formula given by ;

$$distance = \sqrt{(sender_x - node_x)^2 + (sender_y - node_y)^2} \tag{7.4}$$

and direction to sender. $sender_x$ and $sender_y$ is the current global coordinate information acknowledged from on-board GPS device. Therefore, transmitter node has to enter its GPS coordinates and propagation direction into packet header before the broadcast. After k number of nodes perceive themselves as candidates for forwarding the packet, they go on to next step which is the determination process of back-off slot. Single node having set its timer to the smallest back-off slot number is an important part in timer based schemes to prevent concurrent reply message transmissions and delay in delivering safety message. Node decides mainly how many unit of time it will wait by the following probability function ;

$$P\left(overall\right) = P\left(\alpha\right) P\left(\beta\right) \tag{7.5}$$

where α represents vehicular difference between sender and receiver, β is correlated with the physical layer quantity of currently received data packet depending on proximity to boundary of ideal communication range. In other words, this composite function takes into account not only distance but also other factors that would be helpful in differentiating the waiting time of each node based on the packet. To leverage the concept of clustering, transmitter node defines additional parameters (dynamic or static) to be used by candidate nodes namely high scaled segment distance S_{high} and low scaled segment size S_{low}. For the simplicity, values remain constant for each transmission attempt. However, finding the optimum value according to network node density gives better results in terms of the protocol performance in the environments where a node is aware of neighbor nodes with periodic exchange of beacon messages.

$$index_{high} = \left[\frac{distance}{S_{high}}\right] \tag{7.6}$$

In equation 7.6, node acknowledges the segment in which it is positioned away from transmitter node by the use of $distance$ and S_{high}.

$$index_{low} = \left[\frac{D - index_{high} S_{high}}{S_{low}}\right] \tag{7.7}$$

Equation 7.7 gives low scaled index number of the encapsulating segment and utilizes from $index_{high}$. The result of Equation 7.7 directly relates to α given by ;

$$\alpha = h\left(index_{low}, \Delta v\right) \tag{7.8}$$

where Δv is the velocity difference formed with direction information between transmitter and receiver node. Velocity has been taken into consideration in the proposed design to alleviate any possible Doppler Effect between them. h is two dimensional mapping function which computes the probability of having access to medium.

In the second part, node deduces about the channel link quality from packet and transform this information into access probability. One quantity that would be used to monitor channel availability is the signal strength of packet. With an assumption that every node has the same transmission power for a fair medium sharing, receiving node can estimate distance to transmitter node under ideal environment conditions. In the previous simulation studies, we observe that there is a safe zone in terms of error rate within the communication range in highly fading channel. As the channel quality is degraded, safe zone becomes smaller toward the sender. RSSI value is used by the following ;

$$A\left(rssi\right) = \frac{10^{\left(1-\frac{rssi-rssi_{min}(per_{max})}{rssi_{max}-rssi_{min}}\right)k} - 1}{10^{k} - 1} \tag{7.9}$$

where $rssi_{max}$ is the highest value where a node can receive packet successfully and $rssi_{min}$ is the carrier sensing threshold value. $rssi_{min}$ corresponds to $rssi$ of furthest distance in safe zone. It implies that a node has prior access to medium than other nodes beyond the zone or closer to transmitter node. Another parameter k is an exponential distribution factor that can be also determined by the network density. Generally, signal is assumed to be scattered exponentially in an ideal channel condition. Since vehicles assign slot numbers in terms of distance, we utilized $rssi$ values by applying inverse-exponential distribution. The drawback of this equation is the increased or decreased signal level by several reasons such as fading, concurrent transmissions and absorption. To overcome this problem, we introduce a secondary equation using another physical layer quantity known as per.

$$B\left(per\right) = 1 - \frac{per}{per_{max}}, \quad 0 \leq \ per \ \leq \ per_{max} \tag{7.10}$$

In equation 5, per is the error rate of currently received packet and per_{max} the tolerable per constant. Packets which have a higher per than per_{max} will not be taken into consideration for relaying. Integrating equation 7.9 and 7.10, we have the following function ;

$$\beta = w_1 A\left(rssi\right) + w_2 B\left(per\right), \ \ w_1 + w_2 = 1, \quad w_1 \ > \ 0, \ \ w_2 \ > \ 0 \tag{7.11}$$

where w_1 and w_2 are weight factors to give advantage to the more trustworthy physical layer quantity. If vehicles are aware of the presence about their neighbors, they may determine which weight factor to rely on. After all, overall probability from Equation 7.5 is transformed into back off slot number and augmented along with new definitions in the following ;

$$\begin{aligned} slot &= window_{seg} - window_{seg}P\left(overall\right) \\ &+ index_{high}window_{seg} + rand\left(l\right) \\ &= window_{seg}\left[1 - P\left(overall\right) + index_{high}\right] + rand\left(l\right) \end{aligned} \qquad (7.12)$$

where $rand\left(l\right) = -l \leq x \leq q$, l and x are integer. In equation 7.12, $index_{high}$ is used to give relaying responsibility to the furthest segment as mentioned above. Additionally, $rand\left(l\right)$ randomizes the final slot value between the interval $\left(slot - l, slot + l\right)$. This technique aims to prevent nodes from assigning the same slot number of nodes having exhibited the same vehicular and physical layer quantities (i.e. nodes next to each other and having same velocity on a road).

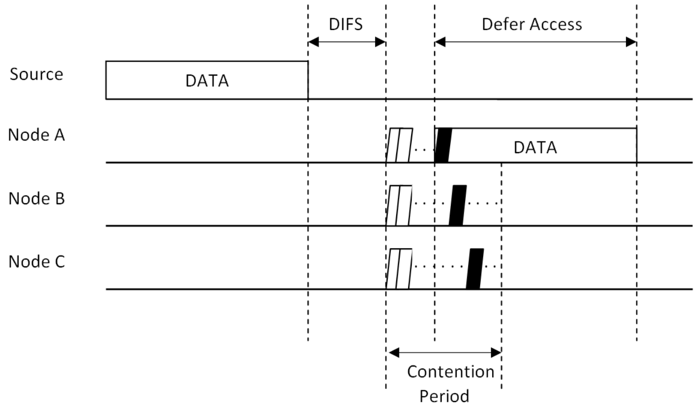

FIGURE 7.2 – Timeline of ATP in a given scenario

The timeline of contention period from sample scenario is shown in Figure 7.2. Suppose that source node originates and broadcasts packet after it detects a dangerous situation. Several vehicles especially further ones are assumed not to have received the packet successfully due to aforementioned reasons. These vehicles cannot pass into contention resolution phase. Remaining nodes compute their access probability according to PHY and MAC layer properties of the current packet. As a result, they transform their probability into slot number and finalize it along with randomization technique. Nodes after waiting for a specific amount of time will start broadcasting the packet. In Figure 7.1, white nodes receive the packet and perform the back-off mechanism but they are neglected for the simplicity. The remaining nodes start their back-off timer after waiting DIFS as in 802.11 DCF mechanism. Node A will be the first node that senses the medium since distance is also a differentiating parameter among other nodes even if other properties are the same. From the simulation studies, if beacons were used at high frequencies i.e. 100ms and the network was dense, we would not guarantee that nodes which could not receive the emergency packet do not broadcast instant beacon messages obtained from GPS device. Thus, these hidden nodes could intervene the medium and lead the proposed protocols not perform properly. Other nodes will cancel their timer in two conditions :

1. If back-off timer is ended successfully while node A transmits the packet, node will find the medium busy
2. If the packet is received successfully, node checks whether it is the intended copy except from the packet sent by source node and will assume that another node has a better link quality and spatial gain

If nodes hidden to source node transmits a packet in the contention period, candidate nodes may be misguided by applying the first condition. However, CW and other scalable parameters allow nodes to use back-off delay efficiently. Therefore, a node which has the best properties among other nodes will start forwarding the packet. Hidden nodes defer their transmission such as beacon and non-safety packets due to presence of the emergency packet after sensing the medium busy. The probability that node B and C receive the packet is almost zero. The relay node will be likely in the further region so that hidden nodes this time will know there is another transmission in the medium.

7.2 ATP Beaconing Version

In this section, ATP is enhanced to utilize from beacon messages which typically contains information related with identification and physical properties of a vehicle. Node will be aware of the local network density from neighbors. With beaconing technique, in this version a new property is added into $P(PHY)$ equation as follows :

$$P\left(PHY\right) = k_1 P\left(RSSI\right) + \frac{k_2}{2} P\left(PER\right) + \frac{k_2}{2} nc\left(i\right) \tag{7.13}$$

By the protocol design, each node inserts the total number of different beacon messages received in a specific time interval which is the frequency of beacon message exchange into its beacon message. Upon reception of emergency packet, node selects the maximum number of network density included in beacon message. Network connectivity is given by ;

$$nc\left(i\right) = \frac{Number\ of\ received\ beacon\ packet}{Maximum\ number\ heard\ from\ beacon\ messages} \tag{7.14}$$

It is expected that each node would experience different network connectivity due to spatial diversity and different traffic flow pattern.

7.3 H-ATP

H-ATP is an improvement protocol to ATP by giving feedback with message from special nodes which we call them $Helper$ nodes. Nodes which have initiated their back-off timer packet will be aware of the presence of relay node with these helper messages. Therefore, nodes also hidden to relay node will have withdrawn from the forwarding operation. The core difference of H-ATP from ATP is the dissemination of the message to all candidate nodes about the presence of relay node.

Nodes performing ATP protocol will cancel their timeout when they receive the copy of the packet. However, there is a high probability that nodes which are at the other carrier sensing edge of relay node would be hidden. It means that nodes are expected to locate closer to transmitter node in case of saturated network density. Transmitter node can be included into these nodes. Therefore, although there is an actual relay node in the forwarding area, at least one node which has not received the copy of the packet due to the low signal that is below sensing threshold misguidedly senses the medium free and leads packet collision. Let us say the first half of the forwarding area is further divided into two parts, first zone closer to source node and second zone further away. For example, while hidden nodes which are located in the second zone risk other nodes that are correctly receiving the packet, hidden nodes in the first zone risk less number of nodes due to spatial difference. It should be noted that the probability of failing to receive the packet increases as the node becomes further than the transmitter node. Thus, hidden nodes will be most probably located further than relay node depending on the intensity of the channel condition but the presence of any hidden node which is closest to relay node will prevent nodes in between from receiving the packet successfully.

After transmitter node broadcasts the emergency packet, nodes which enter into forwarding selection phase will apply the equations mentioned in ATP to access the medium. If the first node which ends the back-off timer senses the medium free, this node will send a small message encapsulating its sequence number and identification information instead of forwarding the packet immediately. In the design, there are two type of nodes considered for the dissemination of messages.

1. Relay node located further away from the middle segments of the communication range
2. A node in the middle segments of the communication range

If relay node determines that it is located in the middle segments of the communication range by comparing its position to the transmitter node's position information included in the packet, it will directly forwards the packet. Because, relay node will assume that there will be no hidden node between itself and source node by taking distance into account. Therefore, relay node will not need to send out feedback and additional time is preserved.

Relay node that meets the first condition is required to transmit the helper packet before the forwarding operation. Other nodes which have started their back-off timer will enter into a second contention period by evaluating the segment they are located according to communication range of transmitter node. This segment should be among the middle segments considered for disseminating the helper packet. Otherwise, nodes will not be qualified as the helper disseminating node. In order to disseminate the incoming this message, candidate nodes will use their slot numbers previously determined based on the emergency packet for the second contention period. Only nodes which have started their back-off timer according to emergency message will be eligible for disseminating the current message. In the same manner, the first node which finds the medium free disseminates the copy of the message.

The sample scenario for H-ATP is shown in 7.1. The timelines of the selected nodes are displayed separately. Suppose that source node transmits the emergency data. Nodes A, B, C and D start their back-off timer after SIFS and node A accesses the medium first. Node A is not in the middle segments so that it is required to transmit the helper packet. Due to unreliable channel (volatile channel condition), node d does not overhear the transmission of the helper message and keep the back-off timer working. Node B and C which are located in the middle segments will cancel their timer and initiate a new one for the second contention period after SIFS. Nodes which are located on the segment closer to source node will assign lower slot numbers so that they will get a chance to disseminate the helper packet before the further nodes. In Figure 7.1, node B and C transform their slot numbers which have been determined upon the emergency packet into new slot numbers. Node B accesses the medium first and disseminates the copy of helper packet. Node D has not overheard the helper message sent from node A. In the next phase, Node D receives the helper packet from node B by means of proximity and cancel its timer. Therefore, Node D does not intervene the medium or lead collision. Node A which becomes the relay node forwards the message to next region after delay and acts as source node. In the meantime, source node will end the forwarding responsibility after reception of helper message from either node A or B.

In Figure 7.3, timeline of H-ATP in the sample scenario is represented. In H-ATP, transmitter node waits for transmission time of helper messages instead of emergency message which its size is assumed to be much more. If relay node is located further than the middle segments of the ideal communication range, it informs other candidate nodes about its forwarding operation. Another candidate node that receives this message broadcasts to warn other candidate nodes which are hidden to relay node. Therefore, transmitter node has to set a new timer that contains the transmission time of helper messages and contention period.

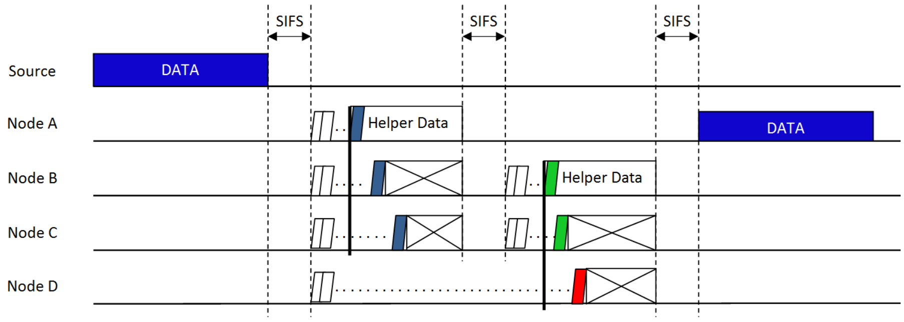

FIGURE 7.3 – Timeline of ATP in a given scenario

There may also be scenarios where there is no node to propagate the helper message in the middle segments of the communication range. Therefore, transmitter node and other candidate nodes which are in between source node and middle segments of the communication range may not receive the helper message successfully from relay node. One of them can misguidedly interfere the transmission. However, the negative effect of hidden terminal problem will be low since there will be likely a few nodes by taking reference from the density in middle segments. Further nodes will not sense the signal level of interfering transmission as much as that of the actual transmission since hidden nodes will be likely closer to transmitter node due spatial difference between transmitter and relay node. Also please note that these nodes have already been warned by transmitter node in the first step.

8 Performance Evaluation

Simulation studies consist of two consecutive sections. The first one is the establishment of road topology and generation of realistic traffic flow patterns regarding different vehicle densities. One of the dominant factors that determine the performance of low layer protocols is the environment on which they are performed as well as spatio-temporal entities. We aim to evaluate our schemes on a bi-directional highway with a length of 5km where vehicles having high and low speed could cause frequent loss in the network connectivity. Generally, safety applications are bounded by tight delays because vehicles likely move fast on this type of roads and are able to get through a hazardous event in order of seconds. Vehicles move on 6 lanes with 3 lanes in each direction. This implies that at most 6 vehicles or more number of vehicles due to GPS drift are able to see the same vertical coordinates in a time. Performance of multi-hop broadcast schemes which employ a single relay selection mechanism on only distance parameter will highly fail in this scenario. It will be much worse if the road traffic becomes dense.

Scenarios have been generated using the traffic simulation tool, SUMO. One advantage of SUMO is that vehicles autonomously accelerate or decelerate with regard to availability of the area in the moving direction. This gives us a non-uniform distribution of vehicles in the simulated region although they start their travel with a particular speed. Another feature of SUMO is the lane changing. Faster vehicles in the back change lane to left and keep their current speed or vehicles change to right assuming faster vehicles need this lane to pass. Hence, these models provide to generate realistic traffic scenarios. In all scenarios, maximum speeds (15, 21, 27 m/s) have been distributed equally to vehicles to imitate drivers following different speed pattern. Newly generated vehicles participate into simulation area with the same inter arrival time which allow us to characterize vehicular traffic density. We obtained several scenarios depending on the vehicular traffic densities (0.5, 1, 2, 4, 6 vehicle/s) by applying different inter arrival times. Also, each scenario in this category have been enhanced by different numbers of vehicles which completely travel along the road. Number of vehicles has an impact on the degree of stress test being applied to the protocols. Increasing the number of vehicles means more time will be needed relatively, there would be a convenient way of observing the performance more accurately. 600, 1200 and 1800 vehicles have been injected to observe how the protocols react to the variations in the number of vehicles. Since there is no room for all set of results, only results taken from 1800 vehicles which exhibit worst case scenarios are shown in the next section.

Second part of our simulation studies is on the networking level where we implement our broadcast mechanism and RTS/CTS handshake and obtain the results. We utilize from NS-3.10 for the network simulations. Mobility traces e.g. coordinate, speed, time recorded from SUMO simulations, have been imported into the available nodes in NS-3 in discrete but small time intervals (ms).

MAC broadcast protocols are performed over 802.11a with 10Mhz channel specifications in the physical layer. VANET is expected to support theoretically high data rates. Among them, we use 3Mbps for beacon and safety packet transmissions (Liu et al., 2009). From experimental studies, using low data rate leads two possible consequences. The first one is that transmission of a packet with the same size will last longer than that of high data rates. The time needed for a large packet in the medium can increase the packet collision probability in unreliable channel and hidden terminal conditions. On the other side, lower data rates consolidate the reliability of channel. But signal quality is deteriorated with the use of Nakagami distribution model in radio propagation (Nakagami, 1960). Setting fading parameter to 1, this channel model behaves like well known Rayleigh fading.

There are 2 types of safety packet (emergency and beacon) in the simulated environment. Emergency packet transmission is assumed to be initiated upon signal reception from input devices e.g. kinematics, sensor. In our scenario, when vehicle enters into the region bounded by 50m along the road, packet is broadcast only once with the identifier associated vehicle. Packet identifier may indicate a region or an event type but in the simulation each packet is observed differently for the performance issues. Emergency packets with the size of 512 and 1024byte are evaluated. During one simulation run, all vehicles can send either 512 or 1024byte only to see the changes in packet size. The initiated packet will propagate to further locations by means of hop information. We set this value 4. It is equal to delivering packet over 1000m with the communication range of 350m if the network density is sufficient for full spatial coverage. Several other parameters used and mentioned above are highlighted in Table 8.1.

TABLE 8.1 – Simulation Parameters

Parameter	Value
t_{sifs}	32μs
t_{slot}	10μs
PHY	802.11p
data rate	3Mbps
path loss exponent	3
Fading exponent	1
$per_{threshold}$	0.3
cw_{min}	64
cw_{max}	448
ideal CR	350m
$segment_{size}$	$50m$
σ	2
MAC header	12Byte
$data_1$ packet	$1000Byte$
reply/header packet	38Byte
beacon	41Byte
transmit power	16dBm
$sensing_{threshold}$ power	$-93dBm$
reference loss	35dBm
PLCP preamble	144μs
PLCP header	48μs

Second packet type is beacon and remains optional, thus we compare also the beacon versions of ATP and H-ATP protocols. The objective is to understand the influence of medium due to channel congestions and to determine the best among the schemes by analyzing the performance results when small packet sized(40byte) packets are exchanged among vehicles. In scenarios where beacon is exchanged, vehicles start their beacon transmissions in a random time not exceeding the inter arrival time, and periodically send beacon packets in 1 second. In the performance analysis of the protocols, several basic network metrics have been defined by mapping the requirements of safety applications. Additionally, quality of the medium is taken into consideration assuming same type with a lower priority or other packets e.g. (non-safety) need the medium free as soon as possible. Although we use two types of packet, only event based packets are evaluated when obtaining performance results of the multi-hop dissemination protocol. Except from time related graphics, we obtain the average results. To analyze our schemes, we give the definitions of performance metrics used which is also important for safety applications in VANETs.

- Message Reception Probability - This measurement provides information about packet loss due to collision or interference from all packets no matter the packet is sent for the first or retransmitted many times. It is also the indication of reliability in the medium.
- Message Dissemination - Percentage of nodes that receive the broadcast packet to all nodes in a bounded area restricted by the hop number and direction.
- End-to-End Delay - Elapsed time from packet initiation by source node to the reception of packet in the last hop.
- Retransmission - The percentage of packets retransmitted due to no reply from neighbor vehicles to the number of all packets propagated including original packets.
- Message Drop / Concurrent Transmission - It is measured by counting the packets which both its received signal is above the sensing threshold power and vehicles drop them due to same slot allocation of at least two vehicles or hidden terminal problem.
- Message Drop / Noise - It exhibits similarity with collision ratio metric but the number of packets dropped due to medium interference and no concurrent packet reception determines the noise ratio. Beacon packet transmission may lead interference.
- Success Ratio - Unlike medium success rate, it is obtained by calculating how many packets are successfully received out of the number of packets where all vehicles inside

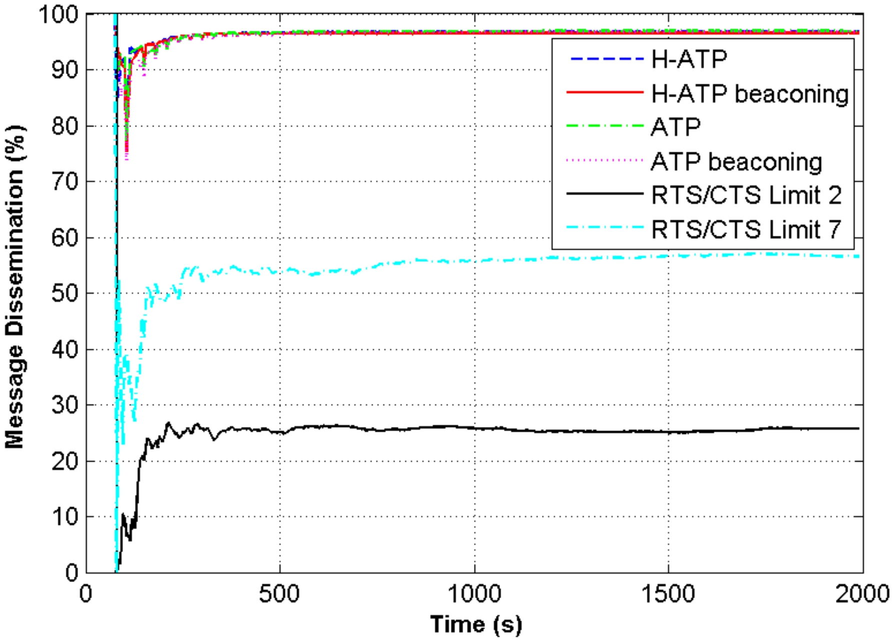

FIGURE 8.1 – Variation in Message Dissemination over time when density is 1 vehicle/s and 512 byte is used for emergency

the communication range 350m. Instead of sensing threshold, ideal communication range and travel distance of message are included into the definition.

8.1 Time Variations

Figures in this section shows changes in terms of given metrics over time depending on highly dynamic network. For this set of results, scenario settings and packet size variables have been fixed to 1 vehicle/s penetration rate and 1800 active vehicles during the simulation and 512byte respectively.

As shown in all these figures, there are high and frequent changes at the beginning of simulation time due to topology of the road. Vehicle has to spend some time to reach the event triggering area after they start their travel. The road does not immediately get saturated from both directions in terms of vehicular density. Initial results from the first arriving vehicles directly affect the cumulative result. As the time passes, this effect of

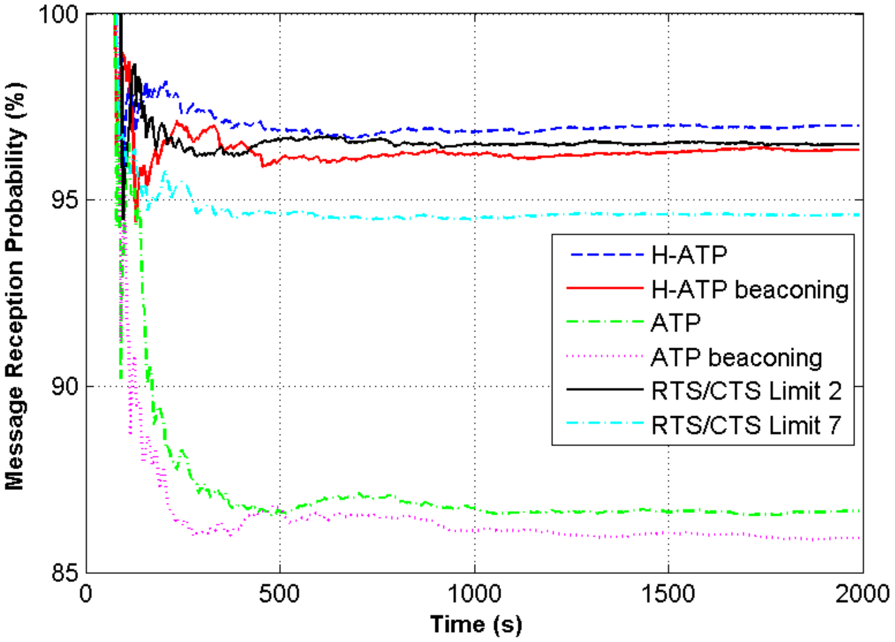

FIGURE 8.2 – Variation in Message Reception Probability over time when density is 1 vehicle/s and 512 byte is used for emergency

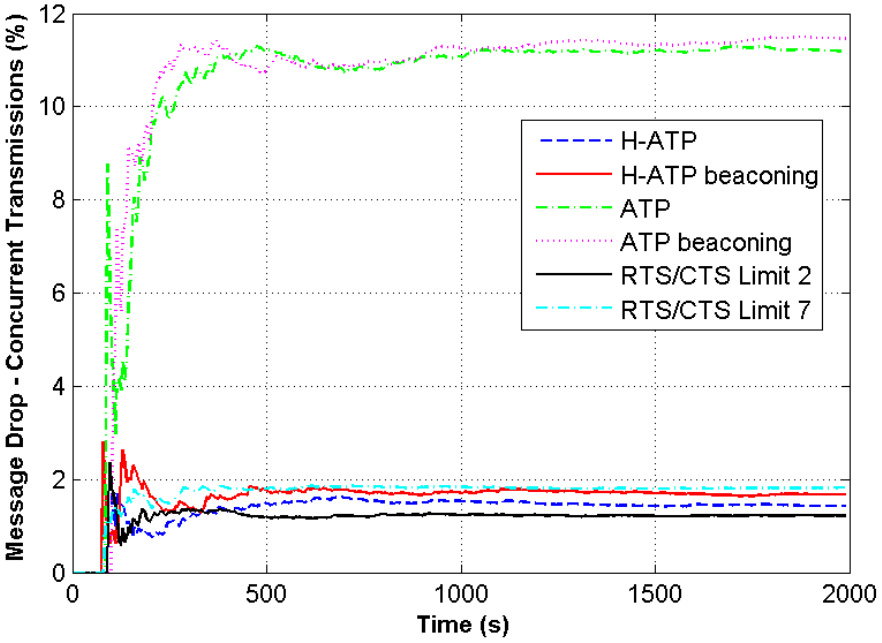

FIGURE 8.3 – Variation in Message Drop due to Concurrent Transmission over time when density is 1 vehicle/s and 512 byte is used for emergency

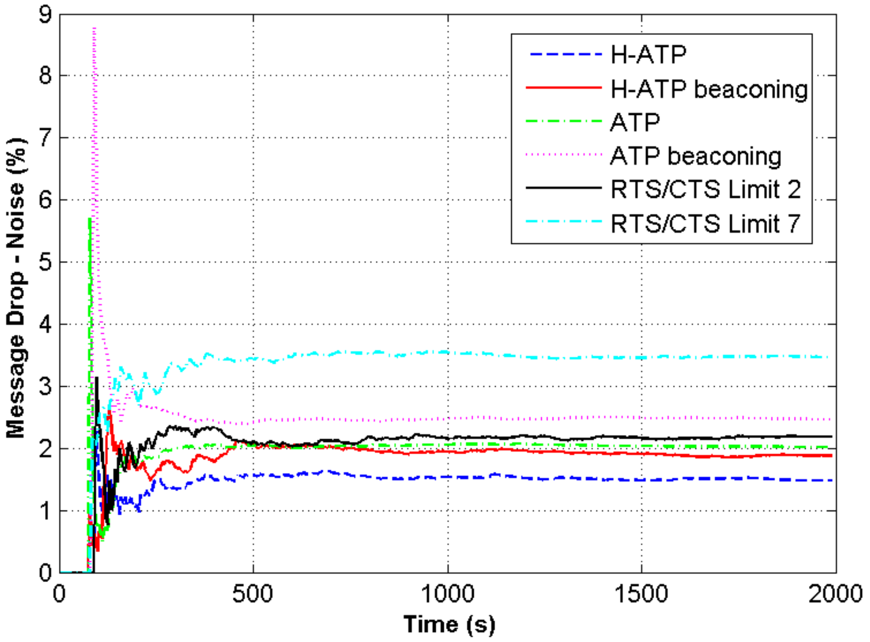

FIGURE 8.4 – Variation in Message Drop due to Concurrent Transmission over time when density is 1 vehicle/s and 512 byte is used for emergency

these results received continuously gets lower and later the cumulative result becomes nearly stable. In Figure 8.1, there is almost 10% discrepancy between ATP and H-ATP protocols. Also, beaconing versions have negative impact on the medium success ratio. Though the same back-off procedure is performed in both, this discrepancy occurs from additional packets (helper) employed in H-ATP. In both of these schemes, after the back-off timer of candidate node expires and the medium is sensed free or responsible node which has broadcast the safety packet previously does not overhear the same packet after a certain amount of time which is called timeout, the node is allowed to send safety packet. One of the candidate nodes with the smallest slot value senses the medium free and forwards the packet. Distance of candidate node to transmitter node is an important factor still it is not the only one. Although the candidate node whose distance is further away from the transmitter node starts its transmission for multi-hop propagation and becomes the relay node in fact, some group of candidate nodes senses the medium free misguidedly due to Nakagami-m fading effect in case of timer expiration. Transmitter node also could be hidden since it should receive the same packet from the directed area. Among them, one node which takes this action is sufficient for the packet collision and eventually decreases the medium success ratio. In RTS/CTS schemes, transmitter node has to acknowledge which candidate node has accessed the medium and replied with CTS successfully before sending the raw data. The most significant feature that differs RTS/CTS from ATP and H-ATP protocols is the use of small packets instead of the data itself. Transmitter node does not have to wait for longer times which is necessary for the transmission of big size packets. Therefore, any other candidate nodes hidden to relay node does not have a time to intervene the medium. The RTS/CTS scheme cannot outperform H-ATP although it exhibits a good performance in message reception probability. Also, note that as the number of transmission attempt is increased, the reception probability of nodes becomes lower but still in acceptable levels. Message drops due to concurrent transmissions of safety messages and noise are represented in Figure 8.3 and 8.4 respectively. Message reception probability is directly correlated with these figures. Most of the packet loss in ATP is incurred from collisions when compared to H-ATP and RTS/CTS scheme. In H-ATP, candidate node which senses the medium first broadcasts small packet (helper) instead of the copy of the packet. Another candidate node which is located in the middle segments of the communication range and receives the helper packet, prevents any transmission caused by hidden terminal by disseminating this helper packet. Hence, there will be no node(candidate and responsible) to interrupt the channel. Yet, H-ATP cannot provide a 100% message reception probability. It can be reasoned by further examining Figure 8.3 and 8.4. Even though the proposed solutions aim to distribute slots to candidate nodes, they cannot always guarantee different slot allocation since vehicles can exhibit the same PHY and MAC properties such as same speed, direction and distance. Candidate nodes which take the same slot value and wait for the same time, will sense the medium free and lead packet collision. Another reason for message drop is the interference coming out of the current hop communication field as depicted in Figure 8.4. Beaconing based on vehicular density and transmission frequency determines the degree of hidden terminal problem and so packet loss. Beaconing versions are higher in Figure 8.4. Thus, we can state that periodic beaconing increases the packet drop ratio. Another point is that RTS/CTS are exposed to noise proportional to the number of retransmission limit while keeping concurrent transmission low.

Message drops may occur due to interference even though no beaconing is utilized. It is likely from deteriorated signal-noise ratio by Nakagami model and concurrent safety packet transmissions around.

In Figure 8.2, ATP and H-ATP disseminates active messages to 97% of overall nodes. The reason for not being full dissemination ratio can be explained in two ways. The first one is that from the design of the protocols candidate node is selected based on PHY and MAC properties(e.g. RSSI, PER). It implies that distance of relay node to the responsible node can be closer than another candidate which is further away from relay node and still is in the communication range of the responsible node. In the definition of packet delivery ratio, area is specified by the hop number and formed by the nodes having maximum distance in the communication range per hop. Thus, the coverage of the protocols will be lower than the area which will decrease the delivery ratio since we do not focus on selecting the farthest node in the communication range. The backmost nodes which are located in the gap between these areas will not have received the packet. The second reason is the discontinuation of packet travel due to limited number of retransmission or the link disconnectivity. In the 1.protocol, high number of retransmissions increases the packet delivery ratio. But more importantly, the second protocol achieves nearly the ratio of ATP without applying any high number of retransmission. Also in Figure 8.2, RTS/CTS schemes performs poorly at disseminating messages to further locations. Relaying operation relies on the successful exchange of control messages between the transmitter node and one candidate node. However, these small messages are not decoded properly due to highly fading environment. When the number of retransmission attempt is limited to 2, RTS/CTS scheme can only perform 25% in dissemination ratio. After transmitter node reaches the limit, it cuts off the propagation of emergency message in order to not congest the channel with additional control and data messages. When the limit number is increased to 7, RTS/CTS scheme exhibits a better performance. It implies that some of the control messages which fail previously after 2 limit are exchanged successfully until 7 retransmission attempt. Thus, more number of data messages can be delivered to vehicles in further locations. However, more number of control and data messages are dropped at the expense of disseminating the data messages only once.

8.2 Density Variations

In these figures, we take a general view of the performance and observe the reaction of the protocols according to different vehicular densities. The same scenario settings is shown. The only difference is that experimental values are averaged at the end of the simulation. In Figure 8.5, as the vehicular density grows, the message reception probability of nodes drops but in a more stabilized fashion. Similar to the previous section, H-ATP and RTS/CTS exhibit a better performance in terms of message reception probability. The divergence between beaconing and the other version is also distinguishable according to vehicular density. It is obviously due to the following reasoning. As the density becomes denser, the frequency of beaconing and so the probability of hidden terminal problem is increased relatively. In RTS/CTS schemes, retransmission limit number becomes negligible in case of high network densities. In Figure 8.6, packet delivery ratio of ATP and H-ATP increases from 94% to 98-99% with a higher density. This growth is related to the number of nodes in the communication range. As the vehicular density becomes sparse, the probability of having node further away from the responsible node gets lower. But the high density makes the protocols cover more wider area since there will be more number of nodes towards to the communication range boundary. However, RTS/CTS schemes do not perform better as the network becomes denser. The discrepancy between these schemes have remained the same regardless of network density. After all, ATP achieves higher dissemination ratio due to high number of packet retransmissions. However, H-ATP achieves better performance when taking redundant transmission ratio which is a good indicator of the medium quality into account. The best performance in the proposed protocols has been obtained when the vehicular density is 4 vehicle/s. In Figure 8.7, ATP has more stabilized pattern with higher density and increases from 35% to 55%. However, at the highest network density the ratio is kept under 20% by H-ATP. RTS/CTS limit 2 scheme lead more retransmissions than H-ATP in all densities but not as much as ATP. In RTS/CTS with limit 7 performs between 50% and 60% which means almost half of the generated packets are retransmitted. Transmitter node is not rapidly acknowledged by CTS or ACK messages. Therefore, it has to retransmit the same copy after timeout to acknowledge in the next step. Combining Figure 8.8 and 8.9, in RTS/CTS schemes, channel

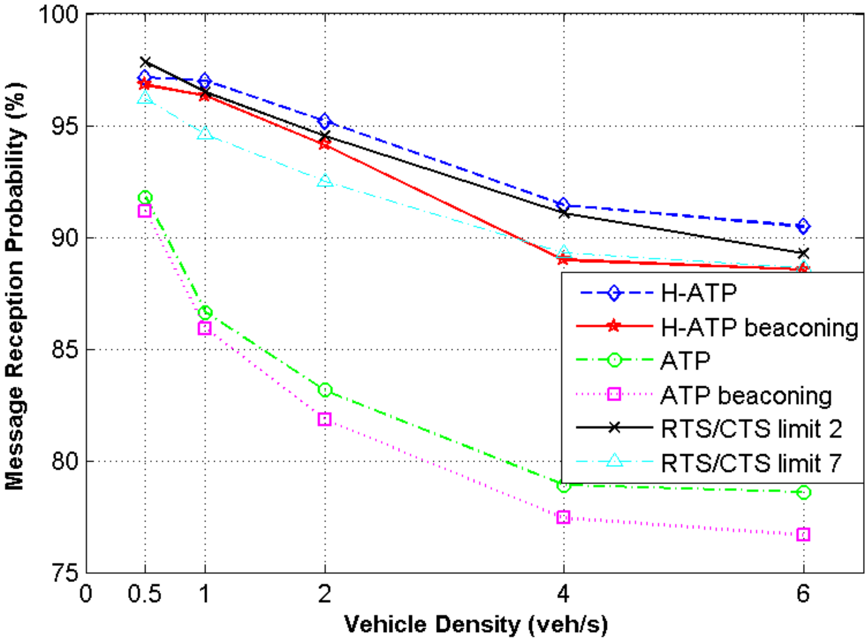

FIGURE 8.5 – Message Reception Probability under different vehicle density regimes when 512 byte is used for emergency

can be congested with redundant transmissions but these transmissions are required for transmitter node to ensure a reliable handshake of messages.

The last metric in this section is end-to-end delay. In the previous figures, the H-ATP gives better performance in every aspect. But in Figure 8.8, ATP delivers packets to vehicles with a shorter delay. Note that these delay values have been averaged over the successful packet propagation. As the vehicular traffic becomes denser, delay is shortened and converged into optimal value. As mentioned previously, in high densities, a further candidate node with better channel condition is selected for the relay operation. The node also takes smaller slot value and waits a shorter time before broadcasting the packet. The difference between the delays comes with the transmission time of helper packet and contention period for the transmission of second helper packet per hop. Delay is multiplied by hop number. Additional 8ms is not very crucial at the expense of more improving the medium. Furthermore, packets are delivered to vehicle over 1000m under 20ms. In beaconing versions, delays are longer. It is highly due to packet drops from concurrent beacon transmission and retransmission for the same packet. RTS/CTS scheme

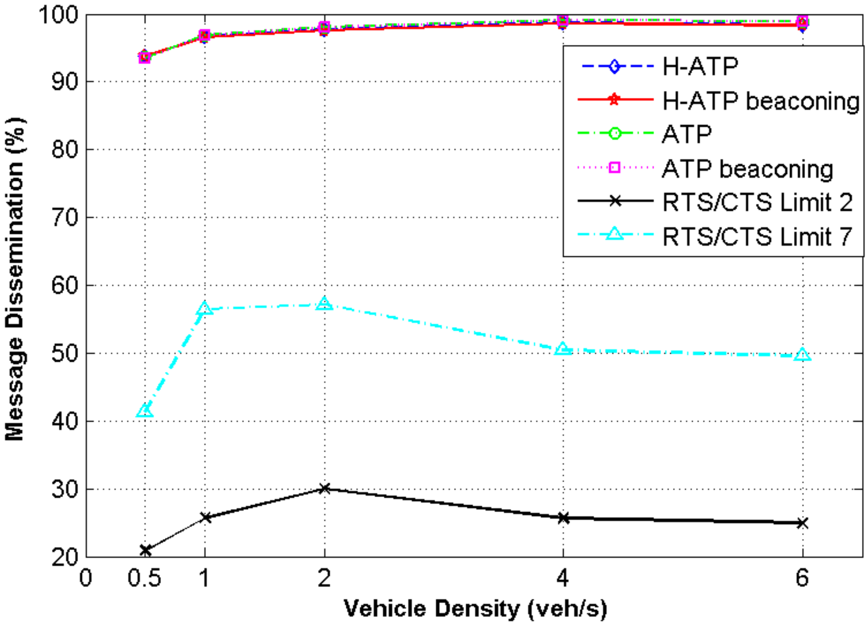

FIGURE 8.6 – Message dissemination ratio under different vehicle density regimes when 512 byte is used for emergency

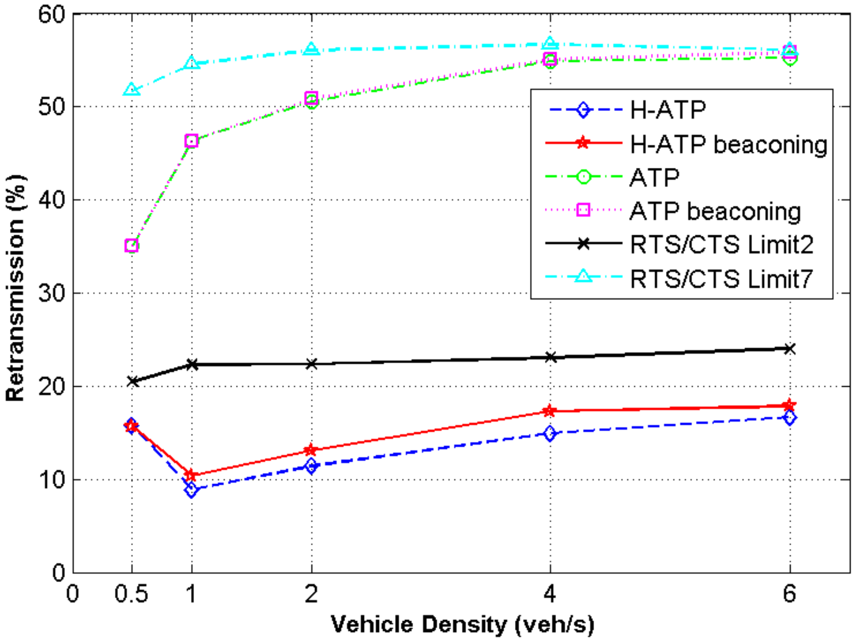

FIGURE 8.7 – Retransmission ratio under different vehicle density regimes when 512 byte is used for emergency

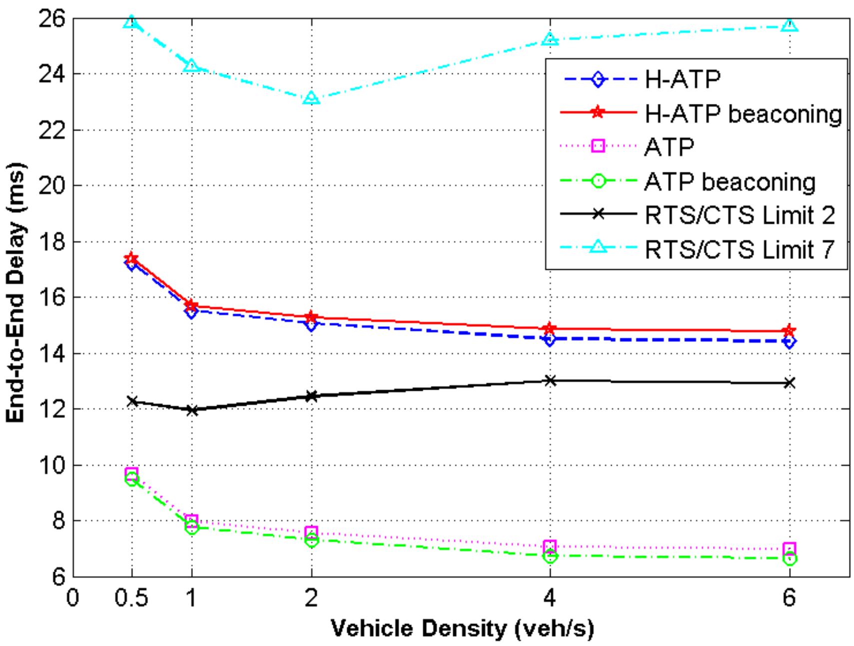

FIGURE 8.8 – End-to-End Delay of message under different vehicle density regimes when 512 byte is used for emergency

with limit 2 represents an average delay. However, in RTS/CTS with limit 7, nodes start over the handshake process when one of the messages is not received successfully. This message may be ACK as well in worst case. RTS,CTS, DATA and contention period will be wasted in each iteration.

8.3 Packet Size Variations

In this section, we observe the variations in the performance applying two different packet size. This time network density is set to 4vehicle/s. In Figure 8.9, the higher packet size travelling in the network reduces the performance of both protocols which can be expected since packet with the larger size increases the transmission time and so the collision probability due to hidden terminal problem. Conversely, RTS/CTS schemes are not affected with bigger packet transmissions. This is because the same size control messages are exchanged between nodes but in ATP and H-ATP, nodes decide upon reception of data message. More transmission time means that more number of nodes can be hidden to relay node according to their slot numbers. This negative effect is severe in ATP protocol. Beaconing versions follow the same pattern as the base protocols with 1.5% lower degree.

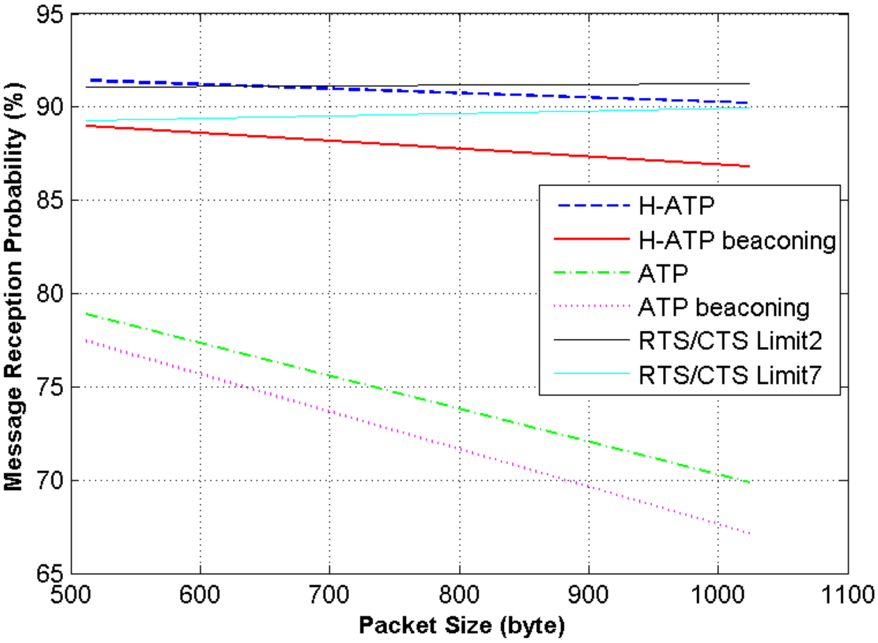

FIGURE 8.9 – Variation in Message Reception Probability when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

In Figure 8.10, packet size does not have an impact in the packet delivery ratio, 0.5% decrease at most. However, as the packet size is increased, the dissemination ratio of RTS/CTS with limit 7 drops. Packets with bigger size are not received correctly by relay node. Transmitter node consumes the overall retransmission limit but has to cut off the propagation of the emergency packet. In Figure 8.11, H-ATP with 1024 packet size pulls the retransmission ratio to 15% redundant ratio. However, there is increase in ATP. One of the critical factor in delay is the packet size which directly relate to transmission time. In Figure 8.12, ATP and H-ATP is not affected from bigger size packets. RTS/CTS limit 7 does not need to consume the whole retransmission attempt when 512 byte is deployed in the simulation. However, 1024 byte packets increase the retransmission number. The additional delay except from transmission time of the packet is reasoned by collisions in bigger size transmissions. From the results in Figure 8.13 and 8.14, packet size impairs

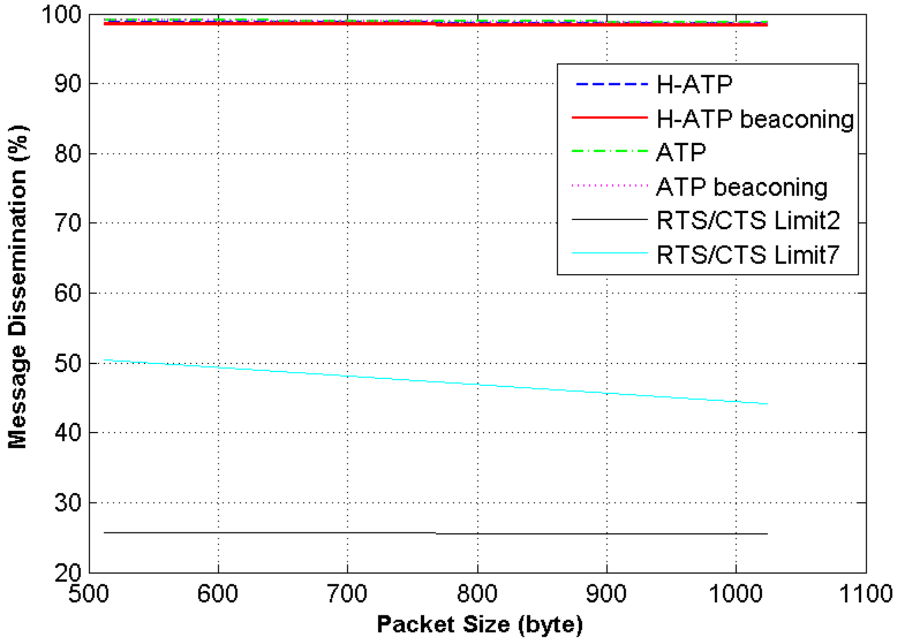

FIGURE 8.10 – Variation in Message Dissemination ratio when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

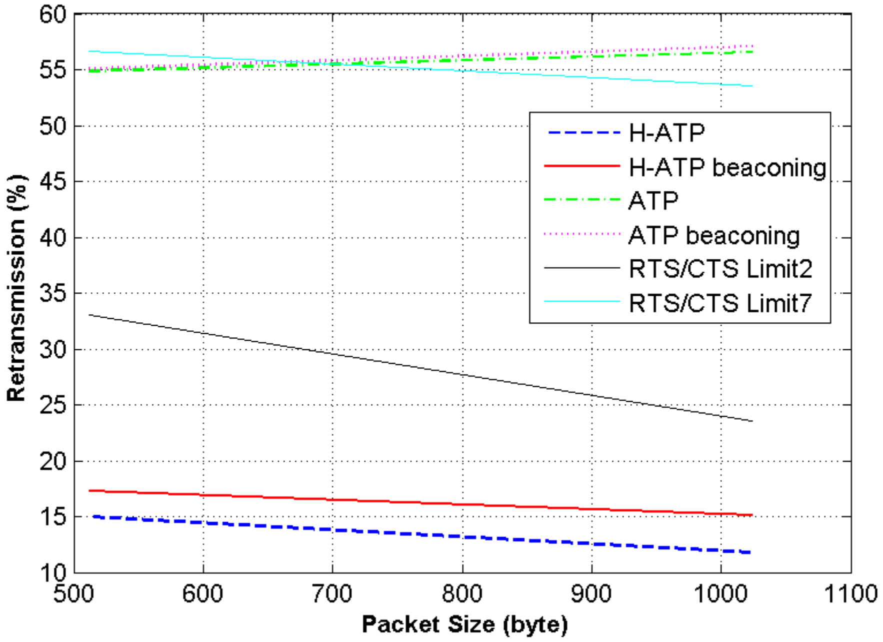

FIGURE 8.11 – Variation in Retransmission when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

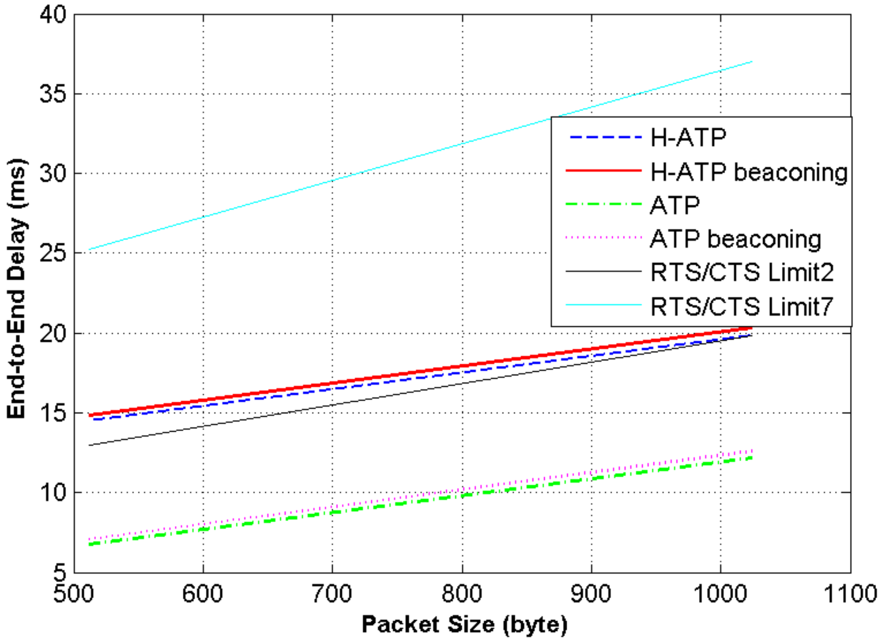

FIGURE 8.12 – Variation in End-to-End Delay when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

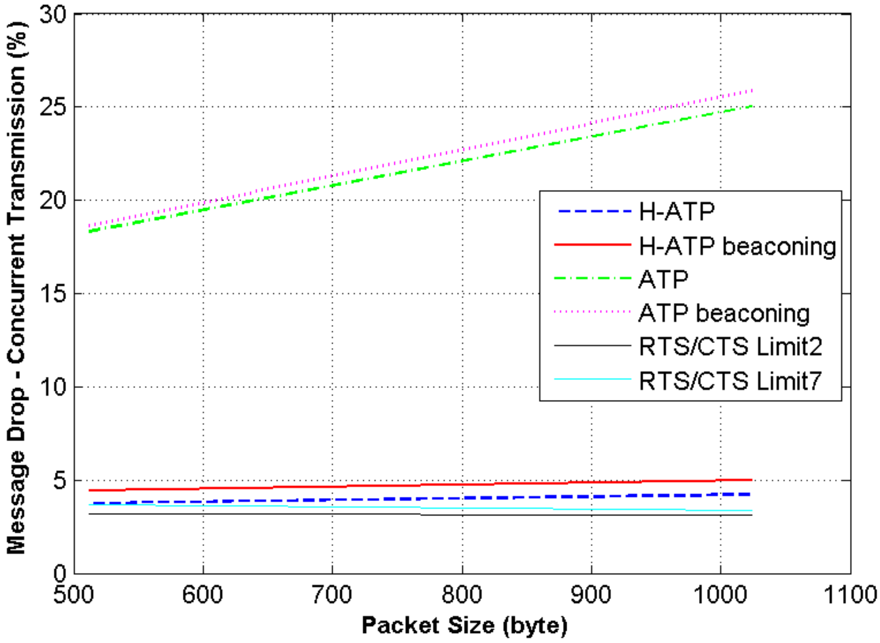

FIGURE 8.13 – Variation in Message Drop due to Concurrent Transmission when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

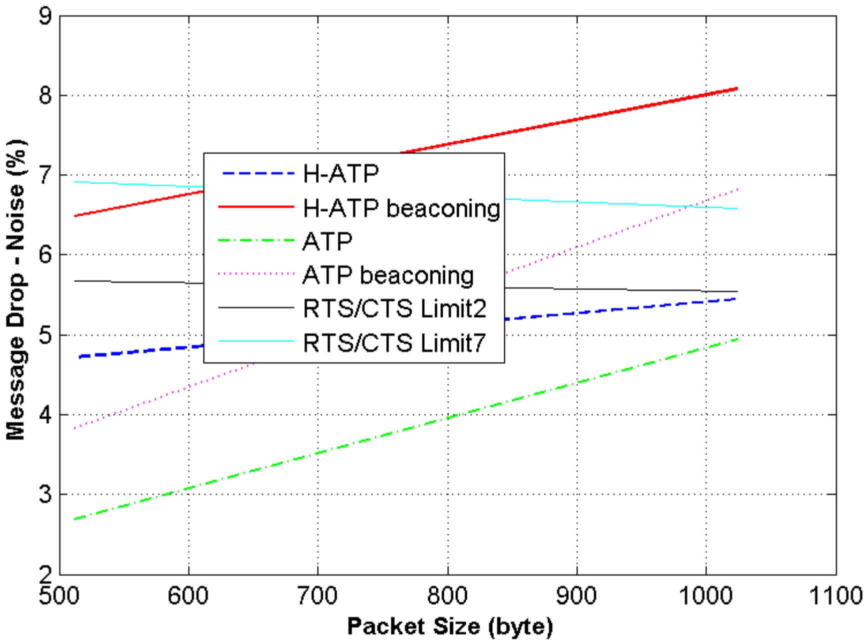

FIGURE 8.14 – Variation in Message Drop due to Noise when increasing the size of emergency message from 512 to 1024 byte under 4 vehicle/s penetration rate

the link quality and allows vehicles which are closer to transmitter node interfere the ongoing packet transmission more frequently. In H-ATP, helper packets stop vehicles from transmitting packet regardless of the size in Figure 8.13. Thus, the ratio remains almost the same. In RTS/CTS schemes, transmitter node react rapidly to CTS and ACK transmissions. Therefore, concurrent transmissions do not occur most of time. Besides, nodes assign slot numbers based on only their distance to transmitter node. The accuracy between two consecutive slot number is 4m. Nodes wait specific amount of time. However, when the network density is low, the probability of nodes which locate in further locations is reduced. It implies more time needed for successful operation of RTS/CTS scheme. In Figure 8.14, the most explicit observation is the increase of packet drop due to noise when 1024byte packets are propagated. ATP gives better result than H-ATP. Recall that H-ATP uses two additional packets in the procedure which may lead small noise. RTS/CTS schemes exhibit a similar behavior as in 512 byte.

8.4 Success Ratio

In the last section of the performance analysis, we evaluate the results obtained from success rate. Message Reception Probability can been seen similar to success rate but there are distinct properties between them. The first one is the signal strength of emergency packet. Message reception probability evaluates the successful receptions among the messages which their signal strength is above the carrier sensing threshold for a node in the neighbor. However, success rate not focuses on the node itself but the message transmitted. Rather than measuring only the medium quality, the number of received message by nodes that are inside the ideal communication range of the message transmitter is investigated. Therefore, nodes may experience the negative effect of Nakagami-m channel fading in terms of received signal strength and SNR. Secondly, the maximum distance which the message could reach contributes to the definition of success rate. Both protocols have a maximum retransmission number in order to not further congest the channel when transmitter node does not receive the acknowledgement from a candidate node. When the hop number is 1, the corresponding values represent the ratio of successful message receptions assuming after all the number of packets is originated and broadcast by source nodes. According to results obtained from simulations, ATP and H-ATP are able to send all the emergency messages initiated by every node. It implies that the channel supports at most 80% success ratio in the best case. However, in RTS/CTS handshake mechanism, message is not started to propagation since there is no reliable exchange of RTS/CTS and data messages between transmitter and relay node. While the ratio is 55% in RTS/CTS limit 2, RTS/CTS limit 7 start propagating more number of message since it gives the transmitter node more retransmission attempt.

In Figure 8.15, both protocols go down and become more stabilized as the message is propagated to further locations. At the end of travel, H-ATP exhibits the highest success ratio among them. ATP performs 60% as the second protocol. Although almost the same number of emergency message propagates through 4 hop, more number of concurrent transmissions in ATP degrade the performance of success ratio. Both beacon versions follow the corresponding protocols with slight lower values due to hidden terminal prob-

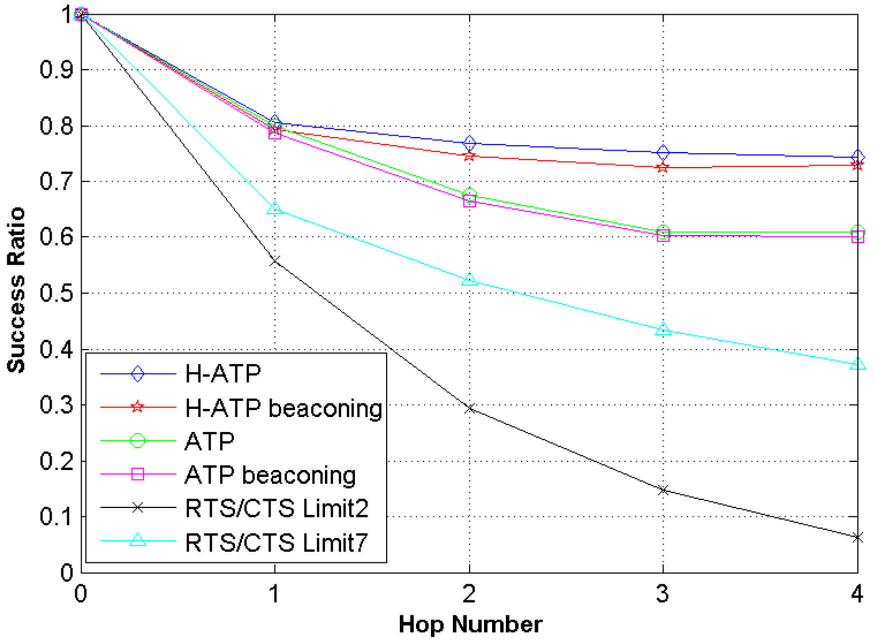

FIGURE 8.15 – Success Ratio of the protocols with different hop number information in message

lem but it can be neglected under low beaconing frequency. Also, the degree of hidden terminal problem varies depending on the number of nodes in the network. RTS/CTS limit 2 and 7 draws different patterns between themselves. The most obvious reason for this discrepancy is the number of retransmission limit. When the number of limit is set to 2, RTS/CTS fails at exchanging RTS,CTS and ACK between transmitter and relay node. Thus, the propagation of emergency message is cancelled and this handshake mechanism hinders the successful reception of more vehicles at the further locations due to channel congestion concern. When RTS/CTS limit 7 is used, the messages which their travel is stopped are given more retransmission attempt. Therefore, transmitter node establishes a reliable link between relay node and gives the forwarding operation to relay node. Thus, some fraction of these messages continue their travel along the propagation direction. After messages reach the end of their travel, the success ratio of RTS/CTS limit 7 is ended at 6% while RTS/CTS limit 2 performs better around 40% success ratio.

9 Conclusion

Providing single and multi-hop communication between vehicles in VANET environment is a nontrivial task due to new problems arising from the characteristics of VANET. Safety packet dissemination among the vast array of applications is the driving force for future of VANET. Although several conventional MANET MAC schemes can be integrated into VANET, these schemes do not meet requirements imposed by safety application services. Therefore, reliable and efficient MAC scheme adjusted to the need of safety packets is needed. First of all, we examined the features of vehicular environments in terms of limitations and capabilities in order to designate a new protocol in MAC layer for the dissemination of safety packet. Then, related broadcasting techniques presented in VANET MAC layer have been investigated in detail. Motivated by the examination and research about the related works, we present a new MAC broadcasting technique which is considered for the dissemination of safety packets in VANET. The proposed protocols, called ATP and H-ATP, mainly aim to deliver safety message to every vehicle moving toward the triggering event as soon as possible. Thus, the driver will have time to react the warning message. Another goal is to keep channel free most of the time by minimizing the number of transmission. Both ATP and H-ATP adapt the timer based approach to give forwarding operation to single node. Nodes find their slots by means of our core function which takes PHY properties of packet and information about the transmitter node included in packet into consideration. Node with a smallest slot determines itself as relay node. What differs H-ATP from ATP protocol is the transmission of additional and small sized packets to ensure that no candidate node which is hidden to relay node misguidedly transmit the same packet and interrupts the transmission of relay node. Although ATP protocol is enhanced by H-ATP with new additional transmissions, it helped us to understand the characteristics of vehicular environment in a more accurate way. To verify the functionality of back-off procedure and performance of H-ATP, we evaluated ATP and H-ATP with respect to the performance metrics using urban mobility simulator, SUMO and network simulator NS-3.10 respectively. For comparison issue, we implemented RTS/CTS mechanism which relies on the same back-off procedure for reliable multi-hop dissemination of safety packet. The simulation results reveal that H-ATP exhibits better performance in terms of our performance metrics except from end-to-end delay. In H-ATP, relay node will have to wait for a specific amount of time for another node contending and accessing the medium for the dissemination of helper packet which will add extra time to end-to-end delay. The time gap between ATP and H-ATP which is 8ms over 1000m is negligible at the expense of presented performance of H-ATP in every aspect. Future work will be focused on designing a more capable protocol that is performed in different vehicular environments such as intersection, rural and urban roads in addition to highway. Besides, we plan to analyze and compare the performance of the proposed protocols via real vehicular testbeds.

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Biographical Sketch

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2. Y. Pekşen and T. Acarman, "Multihop Safety Message Broadcasting in VANET : A Distributed Medium Access Mechanism with a Relaying Metric," International Symposium on Wireless Communication Systems (ISWCS), pp. 346-350, August, 2012, Paris, France.