Headway based Model for Effective Broadcast in Vehicular Ad-Hoc Networks

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ABSTRACT

Wireless communications are becoming the dominant form of transferring information and the most active research field. This paper presents one of the most applicable forms of Ad-Hoc networks; the Vehicular Ad-Hoc Networks (VANETs). VANET

is the technology of building a robust Ad-Hoc network between mobile vehicles and each other, besides, between mobile vehicles and roadside units. .VANET is the technology of building a robust Ad-Hoc network between mobile vehicles and each other, besides, between mobile vehicles and roadside units. Headway based segmentation is used for lanes so as to provide effective broadcasting. The probability of collision is reduced using headway based segmentation.

Keywords

OBU, headway, MATLAB,RSU,VANET

1. INTRODUCTION

Efforts related to traffic management in big cities led to the promising technology of building a robust wireless mobile Ad-Hoc network between vehicles (with On-Board-Units, OBUs) and roadside units (RSUs, mounted in centralized locations such as intersections, parking lots or gas stations), referred to as a Vehicular Ad-Hoc Networks (VANET). Among the main applications of VANETs, categorized as Public/Non-Public Safety (S/NS) and Vehicle-to-Vehicle/RSU (VV/VR), are co -operative collision warning (S, VV), intersection collision warning (S, VR), approaching emergency vehicle warning (S, VV) , work zone warning (S,VR), traffic management (NS, VV or VR), toll collection (NS, VR), and Internet services (NS, VR).

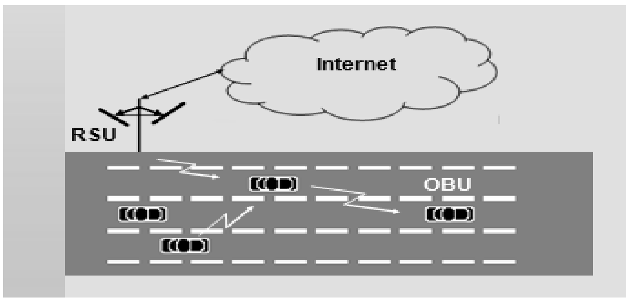

Fig 1: Nodes in VANETs

Due to the high mobility of vehicles, the distribution of nodes within the network changes so very rapidly and unexpectedly that wireless links are established and broken down frequently and unpredictably, eliminating any usefulness of prior topology information. VANET operations in the absence of a fixed infrastructure force OBUs to organize network resources in a distributed way. So, broadcasting of messages in VANET environments plays a crucial rule in almost every application and represents a critical challenge that needs novel solutions based on the unique characteristics of VANETs[3].

The target is to optimally develop a reliable highly distributed broadcasting protocol minimizing collisions and latency (especially in cases of public-safety related applications) without prior control messaging while considering different speeds, environments (urban and rural), and applications. Many broadcasting algorithms have been introduced not matching the requirements of public safety applications as summarized in Sec. II. Therefore, a new idea is proposed with an application adaptive (multi-mode) headway-based protocol for reliable broadcasting (particular for public -safety related messages) that is robust at different speeds and traffic volumes.

2. RELATED PROTOCOLS

It is assumed that the reader is familiar with the following acronyms : Ready/Clear to Send (RTS/CTS), Contention window (CW), Short Interframe Space (SIFS), Distributed Coordination Function IFS (DIFS), Network Allocation Vector (NAV), and the Hidden node problem.

Based on the IEEE 802.11 standard , 1- "There is no MAC-level recovery on broadcast or multicast frames. As a result, the reliability of this traffic is reduced.", 2- "The RTS/CTS mechanism cannot be used for messages with broadcast and multicast immediate destination since there are multiple recipients for the RTS, and thus potentially multiple concurrent senders of the CTS in response."

1.1 Reliable Protocols

Reliable protocols are managed by the source node only and are used with applications related to direct neighbors (e.g. public-safety applications). Broadcast reliability is increased through the following 3 approaches:

2.1.1 Re-broadcasting of the same message for many times

The question is, how many times are considered practically enough? Xu [18] suggested that, re-broadcasting should be for a fixed number of times after sensing the channel as idle in each time. Yang [19] suggested re-broadcasting with a decreasing rate. Alshaer [20] proposed an adaptive algorithm where each node determines its own rebroadcast probability according to an estimate of vehicle density around it which is extracted from the periodic packets of routing management.

2.1.2 Selective ACK

ACKing is the ultimate method of reliability, but with broadcasting we cannot let all receivers reply simultaneously. Tang [15] suggested unicasting the message to every node, one by one. Huang [16] suggested exchanging RTS/CTS with every node, then broadcasting the message once. Xie [17] proposed, on every broadcast, requesting ACK from only one receiver, on a round-robin style.

2.1.3 Changing transmission parameters

Balon [10] proposed decreasing collisions by changing the contention window size, based on an estimate of the current state of the network.

2.2 Dissemination Protocols

Dissemination protocols are managed by all nodes of the network, and are used with applications related to the entire network (e.g. traffic management). Here, the key design parameters are redundancy and dissemination speed. Researchers took two approaches to enhance the performance:

2.2.1 Flooding

Flooding protocols are highly distributive, where it is each node's responsibility to determine whether it will re-broadcast the message or not. Ni [14] was the first to study flooding techniques in Ad-Hoc networks, and introduced the well-known "broadcast storm" problem. Then, it is suggested that each node should only rebroadcast after comparing its location with the sender location and calculating the additional coverage it can provide. Heissenbüttel [13] proposed the same idea but, each node should introduces a back-off time that is shorter for greater additional areas.

2.2.2 Single relay

Single relay protocols can be used as sequential ones, where the source node handles the responsibility of the broadcast to a next hop node. The question here is how to inform the next node of this new job. Zanella [11] proposed the Minimum Connected Dominating Set (MCDS), which is the minimum set of connected nodes that every other node in the network is one-hop connected with a node in this set. If the message was forwarded only by MCDS nodes, the largest progress along the propagation line can be achieved, while guaranteeing the coverage of all other network nodes, giving the theoretical optimal performance. In the "Urban Multihop Broadcast Protocol (UMB)", Korkmaz [12] defined the term RTB/CTB (Ready/Clear to Broadcast), equivalent to the IEEE RTS/CTS, and suggested that the farthest node could be known by using black-burst, where its duration is longer for farther nodes. In the "The Smart Broadcasting Protocol (SB)" Fasolo [7] addressed the same idea but, using backoff time that is shorter for farther nodes. Reliable protocols care for all nodes randomly, but dissemination protocols care for the furthest node only.

3. HEADWAY BASED SEGMENTATION

As recommended by the DSRC [8], the communication range of the abnormal vehicle is 10 sec travel time. Vehicles beyond this range is expected to have a sufficient distance and time for an easy slowing down ([9] and [1]). In case that a following vehicle reacts aggressively, it will become abnormal and issue a new warning message itself. Consequently, there will be a transmission range surrounding all abnormal vehicles with minimum interruption to the rest of the network. There is a new modification in the protocol. The modification is done using headway based segmentation. Of course, vehicles running at high speed are in more danger than those running at low speed even if they were located further from the abnormal vehicle. Accordingly, this section studies the effect of using a novel headway-based segmentation instead of the regular distance-based segmentation. Using a headway-based segmentation leads us to a new definition:

Time headway or headway for short (Fig.2) is the time interval between two vehicles passing a point as measured from the front bumper to the front bumper. The headway is the in-between distance divided by the following vehicle's speed. It may be of different meter lengths corresponding to different speeds, with a minimum length of 4m, which is the average length of a sedan car.

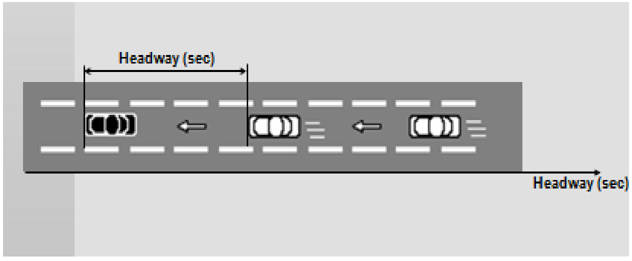

Fig 2: Headway

Although headway has never been used as a basis of segmentation, it looks more suitable to DSRC requirements [6]. According to DSRC consortium, vehicle-to-vehicle communications should have a transmission range of 10 seconds travel time, thus the transmission range will vary with vehicle speed with a minimum range of 110 meters and a maximum range of 300 meters. For example, vehicles traveling at 100 kilometer per hour should transmit at a power level appropriate to reach approximately 278 m and vehicles traveling at 40 kilometer per hour or lower should transmit at a power level appropriate to reach approximately 110 m. The only change in this step is how the following vehicles will calculate the segment number; assuming that the communication range is divided into (10) segments, each is only of one second.

1 - Get the source vehicle location (Ls) from the RTB message

2 - With the receiving vehicle current location (Lr) and speed (s), calculate the Headway (H) with this very simple equation

$$H = \frac{Ls - Lr}{s} \quad (1)$$

3- The segment number is the headway rounded to $+\infty$.

Fig.3 and Fig.4 show the difference between headway-based and distance-based segmentation with vehicles running at different speeds.

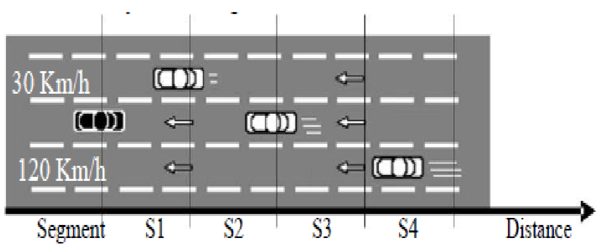

Fig 3: Distance based segmentation

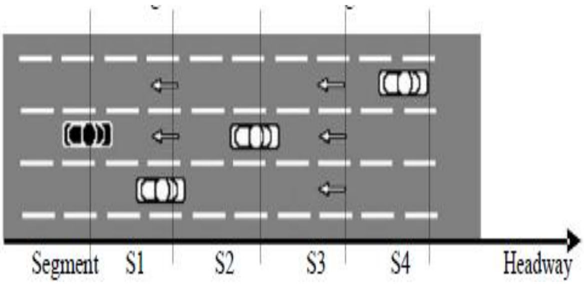

Fig 4: Headway based segmentation

Fig.3 shows a 3-lane highway with three vehicles running at different speeds,(30,60,120 Km/h) with reference to distance (meter). This figure is a real snap-shot image. Fig.4 shows the same situation after calculating the headway for each vehicle to produce an imaginary calculated image. This image reveals that headway-based segmentation mimics dangerous situations better than distance-based, that it puts the 120Km/h-vehicle into the first segment, which is identical to the intuitive analysis of the situation. From now on, figures of the highway will be of two types: the first one is figures with reference to distance (meter) (e.g. Fig.3) which is a real snap-shot image. The second one is that with reference to headway (sec) (e.g. Fig.4) which is an imaginary calculated image based on the location and speed of each vehicle.

3.1 Discussion

3.1.1 Assuming multiple lanes highway

A question that may arise if the analysis is for multiple lanes is 'do vehicles in different lanes are prone to the same danger as vehicles running in the same lane following the abnormal one?' Studies found that some drivers avoid obstacles by steering rather than by braking or even perform the both [9]. It is found that the response time for steering is about 0.3 sec faster than that for breaking. This is the cause that we should consider that the abnormal vehicle may often use steering in conjunction with breaking and that the danger area is not only the same lane of the abnormal vehicle, but also adjacent lanes.

3.1.2 Assuming a single lane highway

A question that may arise if the analysis is for a single lane is 'will a far fast vehicle overtakes a near slow one?' Let us study this problem quantitatively; assume that there are two vehicles following the abnormal one in a single lane highway as indicated in the Fig. 5.

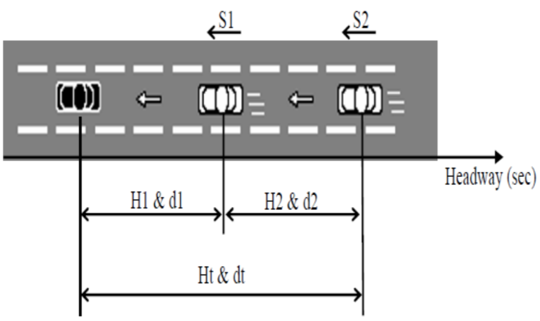

Fig 5: Single lane highway

The first vehicle is running in a speed S1, and the distance to the abnormal vehicle is d1 meters and H1 secs, where

$$H1 = \frac{d1}{s1} \tag{2}$$

The second vehicle is running in a speed S2, and the distance to the first vehicle is d2 meters and H2 secs, where

$$H2 = \frac{d2}{s2} \tag{3}$$

and the distance to the abnormal vehicle is dt meters and Ht secs, where

$$Ht = \frac{dt}{s2}$$

The condition stated in the question is

$$Ht < H1$$

$$\frac{d1 + d2}{s2} < \frac{d1}{s1}$$

$$\frac{d1}{s2} + H2 < \frac{d1}{s1}$$

$$d1(\frac{1}{s1} - \frac{1}{s2}) > H2$$

$$d1(\frac{s2 - s1}{s1 * s2}) > H2$$

$$d1 > H2(\frac{s1 * s2}{s2 - s1})$$

Thus

$$H1 = \frac{d1}{s1}$$

$$H1 > H2(\frac{s2}{s2 - s1})$$

For example, assume that S1 = 80km/h (22.2m/s), S2 = 120km/h (33.3m/s) and H2 is the average minimum headway (1 sec) [1]

i.e. H1>3sec Thus, if the two vehicles are running at 80, 120km/h (in developed countries, such a speed difference is not expected to happen in the same highway lane), this situation may happen at a minimum of three seconds away from the abnormal vehicle; i.e. a relaxed situation. Then, either the fast vehicle will slow down (not to hit the slower one) or try to pass it and truly become more threatened than the slower one and the one that should logically reply with the CTB (or ACK) message. For short, the stated situation may happen only if

- The speed difference is very large

- and the two vehicles are still far away from the abnormal vehicle

3.2 HEADWAY MODEL

The Headway Model is a mathematical equation that describes the average naturalistic headway that drivers tend to leave apart. This model is fundamental in any traffic engineering application because it provides a laboratorial method of generating vehicles in any traffic flow simulator[5].

Traffic engineering researchers introduced many headway models trying to mimic realistic situations. Some of these models are: the negative exponential distribution, the shifted exponential distribution, the gamma distribution, the lognormal distribution and the Semi Poisson distribution.

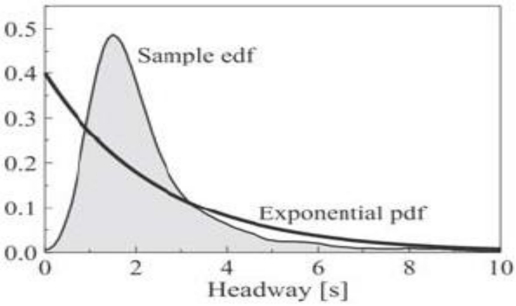

Fig 6: Negative Exponential

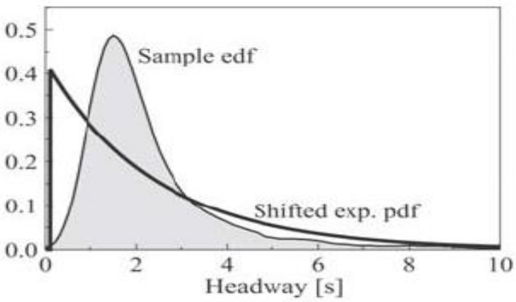

Fig 7: Shifted Exponential

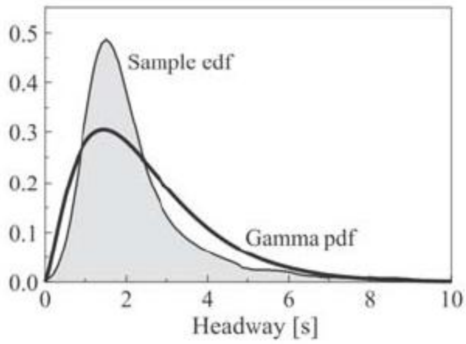

Fig 8: Gamma Distribution

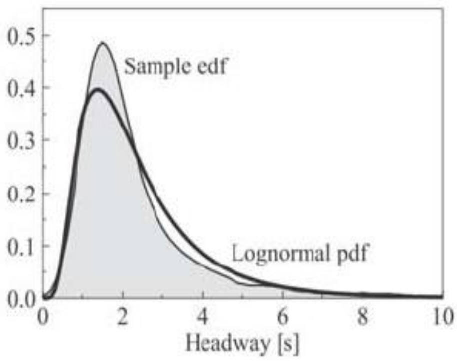

Fig 9: Lognormal Distribution

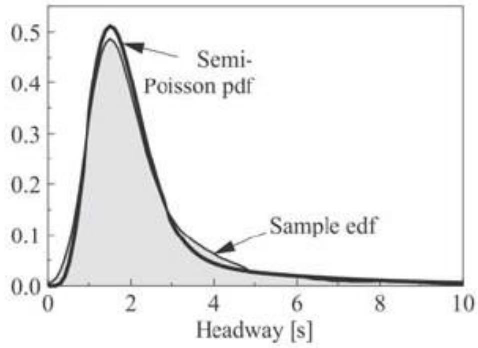

Fig 10: Semi Poisson

3.2.1 The Semi-Poisson Distribution

The probability density function (pdf) of the Semi-Poisson distribution is recalled here;

$$f(t|p,\beta,\alpha,\theta) = p\frac{(\beta * t)^{\alpha-1}}{\tau(\alpha)}\beta * e^{-\beta * t} + (1-p)\frac{\gamma(\beta,\alpha * t)}{\tau(\beta)}\left(1+\frac{\theta}{\alpha}\right)^{\beta} * \theta * e^{-\theta * t} \quad (4)$$

$$t > 0; \beta,\alpha,\theta \geq 0; 0 \leq p \leq 1$$

4. PROTOCOL IMPROVEMENT

The headway model can dramatically change the segmentation algorithm. It can be a basis for a non-uniform segmentation where the width of each segment is adapted to give any required distribution of collision probability where a minimum probability of collision leads directly to a minimum latency (Fig.11).

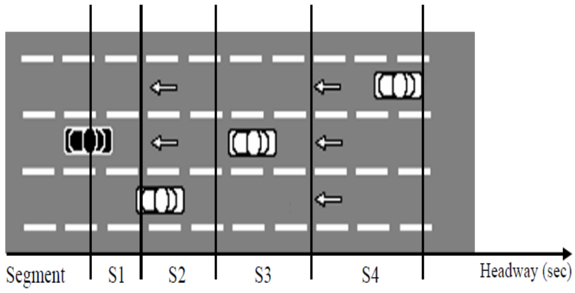

Fig 11: Non uniform headway based segmentation

Without loss of generality, assume that there are only 2 vehicles in the transmission range of the abnormal vehicle. The headway between the abnormal vehicle and the first following one is $X1$sec, and the headway between the two following vehicles is $X2$ sec as shown in Fig.12. It is clear that both $X1$ and $X2$ are random variables with a Semi-Poisson probability distribution function identical to Fig.10. According to the probability theory, both variables can be replaced with a common variable X , having the same pdf.

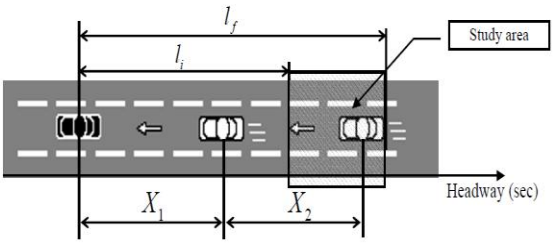

Fig 12: Study area of the analytical situation

For studying the collision probability in one of the segments, we assume that the segment is in-between any arbitrary headways l_i and l_f sec. There will be a collision in the CTB message if there are more than one node in this segment. The probabilities of collision (P_C), successful broadcast (P_b), i.e. only one node in the segment, idle (P_i), and prior nodes captured the broadcast phase (P_o) are given as follows (with discretization):

$$:Pc = \sum_{x=li}^{lf} \frac{P(X=x)}{P(li<X<lf)} \times P(X < lf - x) \quad (5)$$

$$:Pb = \sum_{x=li}^{lf} \frac{P(X=x)}{P(li<X<lf)} \times P(X > lf - x) \quad (6)$$

$$:Pi = P(X > lf) \quad (7)$$

$$:Po = P(X < li) \quad (8)$$

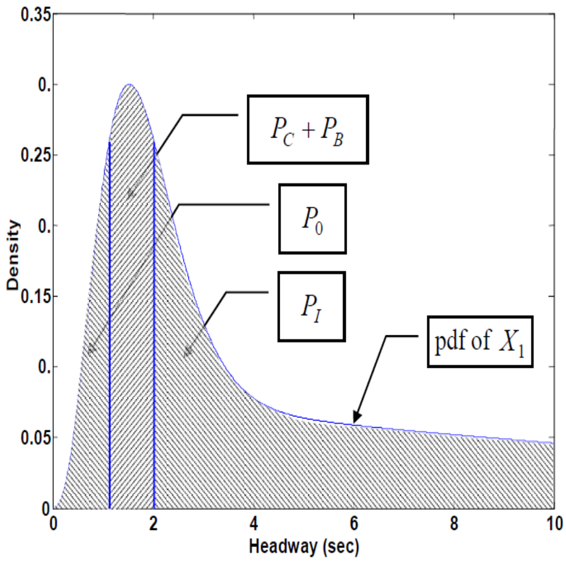

Fig 13: Probabilities associated with an arbitrary segment

5. SIMULATIONS

According to the complexity of tasks, it is preferred to use the well-known Matlab commercial program for being popular, intuitive and easy to use. Matlab offers a full control of all simulation parameters. Simulation is done to analyze headway model using different traffic volumes i.e.700, 1200.

Table 1. Simulation assumptions

Time-Slot	**16 µs**	**CTB**	**14 bytes**
SIFS	32 µs	Messages	512 bytes
DIFS	64 µs	ACK	512 bytes
RTB	20 bytes	Data rate	3 Mbps

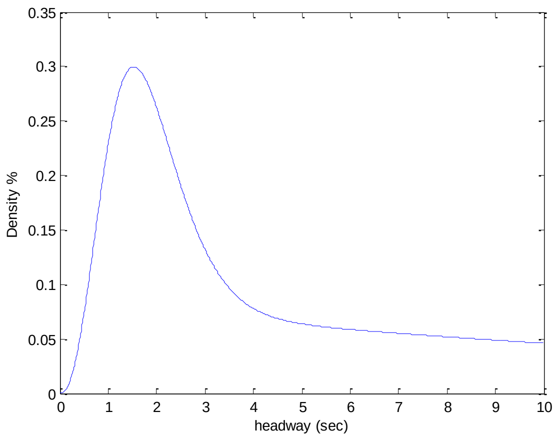

Fig 14: Headway Distribution at 700 v/h

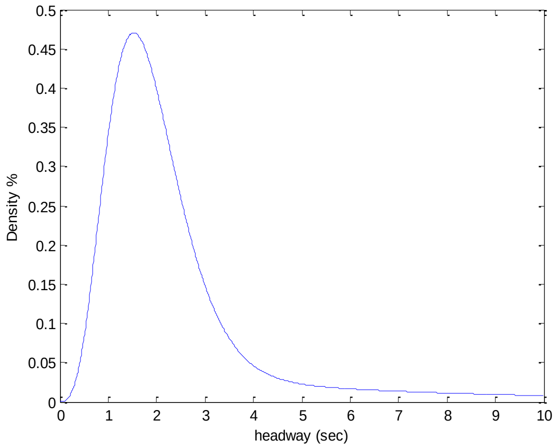

Fig 15: Headway Distribution at 1200 v/h

6. CONCLUSION

The performance of almost all previously published protocols, changes drastically with changing the traffic volume. However, the proposed protocol possesses unique robustness at different traffic volumes. It could be seen that increasing the traffic volume results in increasing the ratio of short headways and decreasing that of long headways. We intended to use the concept of headway-based segmentation and to include effects of human behaviors in its design with the headway model.

Unique robustness is seen at different speeds and traffic volumes rooted to the headway robustness at different traffic volume variations. Application adaptability with special multi-mode operations. This model offers a solution to applications never discussed in literature, like “Approaching Emergency Vehicle”.

Further analysis and simulation will be conducted to accommodate more complicated highway situations.

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