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Analysis of Delay-Throughput-Reliability Trade-off in Broadcasting Protocol for Vehicular Ad Hoc Networks

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Abstract: Broadcasting communications is critically important in vehicular ad hoc networks. Many safety applications need safety warning messages to be broadcast to all vehicles present in an area. Design of a broadcasting protocol for vehicular ad hoc networks is an interesting problem because of challenges posed by broadcasting traffic, high throughput, high reliability and low delay requirements of these networks. In this article, we present a mathematical analysis to explore the relationship between groups of parameters, namely contention windows, hidden/exposed vehicle nodes, reliability, throughput and delay of broadcasting protocol in vehicular ad hoc networks. Then, the multi-object optimization model is proposed to explore how to adjust the delay-throughput-reliability trade-off. The numerical analysis reveals that to keep balance between throughput, delay and reliability, the contention window of MAC may be dynamic adjust.

Keywords: Vehicular ad hoc networks, Broadcasting protocol, Trade-off, Contention window.

1. Introduction

Vehicular ad hoc networks (VANETs) has become an active area of research, standardization, and development because it has tremendous potential to improve vehicle and road safety, traffic efficiency, and convenience as well as comfort to both drivers and passengers, lot of research work have focused on specific areas including broadcasting protocol, Quality of Service, and security [1]. Some of the uses for broadcasting messages are: sending emergency warning messages, periodically broadcasting a vehicles state, etc.

However, since there is no MAC layer acknowledgement, retransmission and recovery on broadcasting frames within IEEE 802.11, the reliability, system throughput and reception rates of broadcast messages could be very low, especially under saturation conditions. Furthermore, the broadcasting of warning messages raises a number of challenging issues [2]. Our goal in this work is to explore the performance of the IEEE 802.11 broadcasting broadcasting protocol in VANETs. The objective is to observe the throughput, delay and reliability as a function of network density. Then, the multi-object optimization model is proposed to explore how to adjust the delay-throughput-reliability trade-off.

The rest of this article is organized as follows. In the next section, we review the related works in Section 2. The proposed mathematical analysis is explained in Section 3. Analytical performance study and numerical results are presented in Sections 4. Finally, we conclude this paper in Section 5.

2. Literature Survey

In recent years, several single broadcasting protocols are proposed considering dissemination of the safety information such as reliable neighbor broadcasting (RNB) [3], Overlay Token Ring Protocol, (OTRP) [4] which intend to deliver the information to all vehicles within senders coverage area with low delay. Authors propose building a hierarchical structure for the vehicles located in the same direction in order speed the dissemination of emergency message. Another approach of study adopted by Weiner where authors proposed to broadcast the warning for none-mobile vehicles in a single hop and concentrated on how to deliver the information to the driver and how the driver will react to the warning message. At this approach, authors didn't give their attention on how the emergency message is broadcasted, furthermore, the vehicles are static, no mobility.

In literature [5-7], authors proposed an analytic model for performance evaluation of IEEE 802.11 single-hop broadcasting protocol without the assumption of saturation condition.

The work in [5] presents a survey of VANETs MAC methods. It focuses on the benefits and limitations of the proposed MAC techniques as well as their ease of implementation in practice and future deployment. In addition some of the challenges that still need to be addressed to enable the implementation of highly efficient and high performance MAC protocols for V2V communications are discussed. In [6], it illustrates the design of a cross-layered MAC and clustering solution for supporting the fast propagation of broadcast messages in VANETs. A distributed dynamic clustering algorithm is proposed to create a dynamic virtual backbone in the vehicular network. The vehicle-members of the backbone are responsible for implementing efficient messages propagation. Markov chains and stochastic process is proposed to obtain the proper minimum contention window [8].

The work [5] qualitatively compares some MANETs MAC protocols that can be used in VANETs, since vehicles move very fast, the topology of the network changes rapidly and often. Thereby routing in inter-vehicular networks is a difficult task. Low latency and high reliability must be also taken into account because of active safety applications.

In [5], Wang Z, et. al proposed the discrete time Markov chain model for the IEEE 802.11 broadcasting is based on the assumption that every node is always ready to transmit and all communication happens in ideal channel conditions.

3. Channel Performance

All vehicles nodes have same transmission, which is denoted as R receiving range. Define p as the probability that the transmission channel for a station is busy. Knowing that the channel is busy if there is at least one vehicle transmitting, in steady state, we can easily infer from the analytical Markov Chain Model of the IEEE 802.11 broadcasting protocol.

$$\tau = {2(1-p)}\Big/{(W_0+1-2p)} \tag{1}$$

For an ideal channel, the probability that the channel being busy when a node is trying decrement its backoff counter is the probability that among the rest of the nodes, at least one is in transmission state.

Therefore

$$p = 1 - {(e^{-2\gamma R\tau} - e^{-2\gamma R})}\Big/{(1-\tau)} \tag{2}$$

In previous related works [8], the normalized throughput S is as follows

$$S = {(p_t p_s T_l)}\Big/{\left[(1-p_t)\sigma + p_t T_s\right]}, \tag{3}$$

where σ is the empty slot-time, P_t is defined as the probability that at least one node is transmitting in a randomly selected time slot, P_s is the probability that only one node is in the transmission state, and T_s is defined as follows:

$$T = T_s = {T_h}\Big/{T_r} + E[pk]/T_r + DIFS + \delta, \tag{4}$$

where T_r is the system transmission data rate, T_s is the average time the channel is sensed busy because of a successful transmission. It is assumed that a packet holds size pk with average packet length E[pk], and packet header includes physical layer header and MAC layer header T_h=PHY_{hdr}+MAC_{hdr}. Let $DIFS$ be the time period for a DCF inter-frame space, and δ be the propagation delay.

Since a successful transmission occurs in a slot with probability P_tP_s, the average time spent on the successful transmission is $P_tP_sT_{pl}$, where T_{pl} is the time spent to transmit the payload information of each packet.

So, the average delay $E[d]$ of broadcasting packet is as follows.

$$E[d]=[(1-p_t)\sigma+p_t p_s T_s+p_t(1-p_s)T_s] *(1+W_0)/2 \quad (5)$$

Next, the transition probability $E(\tau)$ is derived by Fig. 1. The broadcasting node denoted x and the receiver node denoted y are placed a distance of r apart on a line. The region in which hidden nodes may exist is denoted $E(x)$. In addition to collisions caused by hidden nodes, collisions may also occur if two nodes within hearing range initiate transmissions. The region in which this type of collisions occurs is given by H(r).

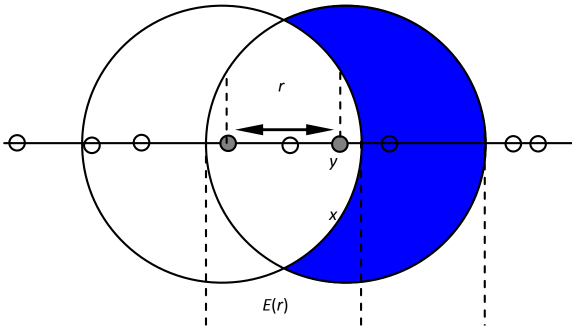

Fig. 1. Region of hidden and exposed nodes.

The probability that no nodes in region $E(x)$ transmit during one slot is as

$$p(E(r))=\exp(-\gamma\tau(2R-r)) \quad (6)$$

Similarly, the probability that no nodes in region $H(r)$ transmit during N^* slot is given by

$$p(H(r))=\exp(-\gamma\tau r N^*) \quad (7)$$

Nodes may transmit in beginning of each slot and a transmission lasts for N^*.

$$N^*=\begin{cases}\left\lfloor\frac{T_s}{\sigma}\right\rfloor & if \left\lfloor\frac{T_s}{\sigma}\right\rfloor\in i \quad (i=1,2,3\cdots)\\ \left\lfloor\frac{T_s}{\sigma}\right\rfloor+1 & if \left\lfloor\frac{T_s}{\sigma}\right\rfloor\notin i \quad (i=1,2,3\cdots)\end{cases}$$

Based on the condition for successful transmission given earlier, it has

$$p(r)=(1-\tau)\times p(E(r))\times p(H(r)) \quad (8)$$

The probability that a successful transmission occurs depends on the preconditions described initially. The transition probability E(τ) may be expressed

$$E(\tau)=\frac{(1-\tau)\exp(-2\gamma\tau R)}{\gamma\tau R(N^*-1)} \times[1-\exp(-\gamma\tau R\times(N^*-1))] \quad (9)$$

3. Numerical Results

In order to validate the proposed model, in this section, we present numerical results we compare the reliability and throughput performance of the network obtained from numerical analysis by Matlab 7.1. The parameters used for the analytical are consistent with previous related works.

Fig. 2 show that the Succeed probability of broadcasting in fixed and optimized window condition. Number of nodes in the broadcast area directly affects the broadcast reliability of VANETs communications. With the scaling of the network, reliability decreases indicating that the broadcasting protocol does not ensures reliability broadcast packets for saturated networks conditions. We also notice that the reliability decreases faster with a smaller contention window.

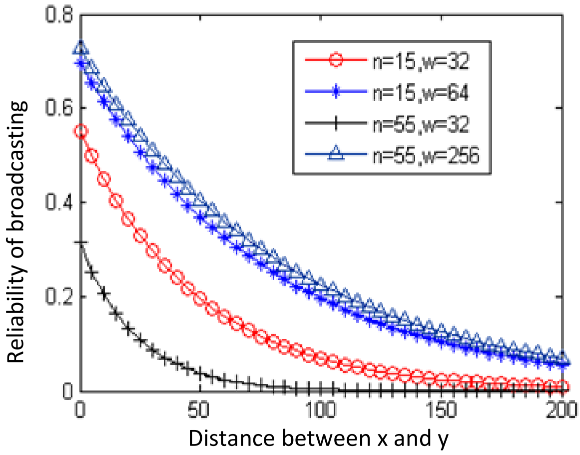

Fig. 2. Succeed probability of broadcasting.

The Index of broadcasting performance based on summarized in Table 1. To ensure optimized throughput, the reliability index of broadcasting protocol is less than 27 %, so it is rather difficult to ensure vehicle receive the valid information.

Table 1. Index of broadcasting protocol based on optimized throughput.

Node density	W_{opt}	**Delay (*ms*)**
0.05	106	6.67
0.1	210	13.09
0.15	315	19.61
0.20	420	26.39
0.25	525	32.30
τ	***E*(*t*)**	**Optimized throughput**
0.0163	0.2577	0.5683
0.0081	0.2614	0.5683
0.0054	0.2621	0.5683
0.0041	0.2592	0.5683
0.0032	0.2660	0.5684

Fig. 3 show that the number of nodes and contention window size (W^*) of MAC directly affects the broadcasting reliability and throughput of VANETs communications. We notice that the reliability decreases faster with a smaller contention window. This observation can be explained as follows, as the contention window shrinks, the nodes contend for the wireless channel more aggressively by waiting a shorter duration between each transmission, resulting in a higher probability of collision with other nodes. So, how to design broadcasting protocol based on IEEE 802.11 broadcasting protocol to ensure reliability and throughput of broadcasting information are key indexes in VANETs.

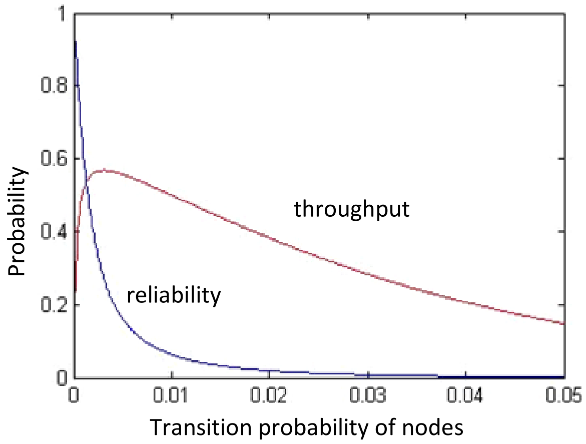

Fig. 3. Reliability and throughput (50).

To explore how to adjust the Throughput-Reliability, trade-off optimization model is set up by using multi-objective optimization theory as follow equation [9].

$$F(\tau)=\lambda_1[E(\tau)-p_0]^2+\lambda_1[S(\tau)-S_{opt}]^2, \quad \lambda_3[E(d)-T_{opt}]^2 \tag{10}$$

where P_0, S_{opt} and T_{opt} ideal value of reliability, throughput respectively.

Figs. 4-7 denote respectively (n=20, 55) change situation of $F(\tau)$ under different reliability index (P_0=0.8, 0.6), with the increasing of the node density, the $F(\tau)$ change greatly, its reason is that $F(\tau)$ must remain Adaptive Equalization between Throughput and Reliability. So, to keep balance between Throughput and Reliability, contention window must be dynamic adjust.

The numerical analysis reveals that high packet arrival rates increase throughput, but degrade packet delivery delay and packet delivery ratio of the network, at the same time, relatively big contention window size and short message length help improve reliability of the broadcasting communication.

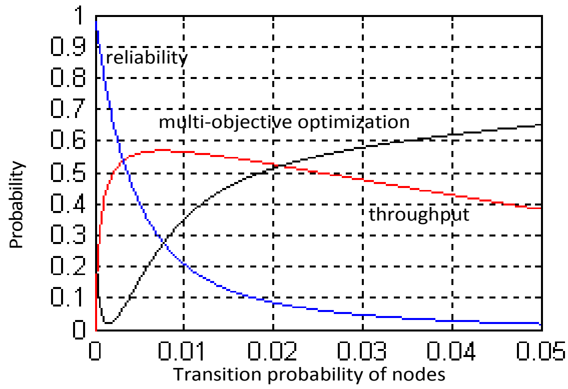

Fig. 4. Reliability and throughput (20, 0.8).

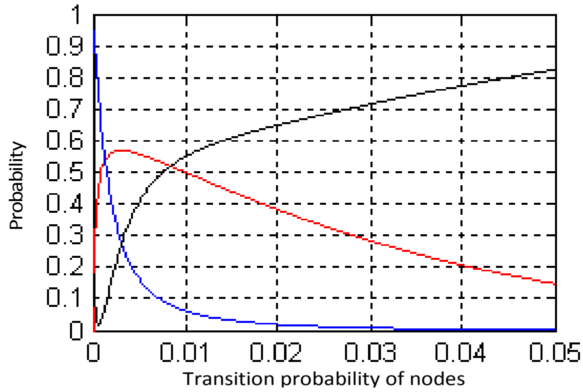

Fig. 5. Reliability and throughput (55, 0.8).

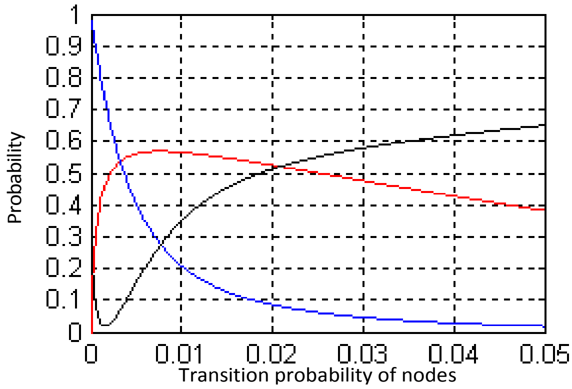

Fig. 6. Reliability and throughput (20, 0.6).

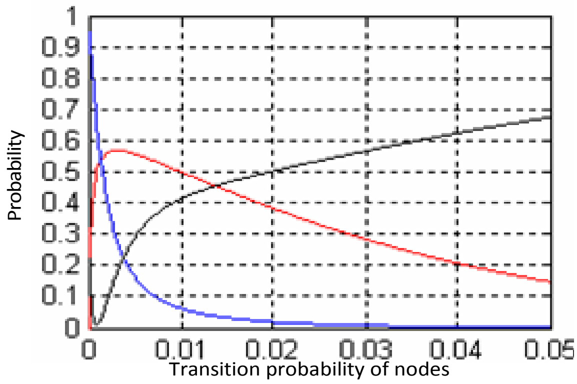

Fig. 7. Reliability and throughput (55, 0.6).

From the above observations, it may appear that, for a given broadcasting network, any arbitrarily high broadcasting reliability can be achieved by simply selecting a large enough contention window. So, to keep balance between Throughput and Reliability, contention window must be dynamic adjust. How to adjust contention window is next stage work.

4. Conclusions

In this paper, we derive closed form expressions of the throughput, delay and reliability. The numerical analysis reveals that high packet arrival rates increase throughput, but degrade packet delivery delay and packet delivery ratio of the network, at the same time, relatively big contention window size and short message length help improve reliability of the broadcasting communication.

So, to keep balance between Throughput and Reliability, contention window must be dynamic adjust. How to adjust contention window is next stage work.

Acknowledgments

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