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Throughput and Reliability Analysis of Single-Hop Broadcasting Protocol in VANETs

***Abstract**. The throughput and reliability indexes of traffic information single-hop broadcasting protocol is related to contention windows valve and contending nodes in vehicular ad hoc networks. In this paper, a theoretical analytic model of single-hop broadcasting protocol is proposed to analysis the relationship between the throughput and the reliability, and to find suitable contention window value which can optimize the throughput and reliability of broadcasting protocol. The analysis results show that the optimization contention windows value (W*) could improve the throughput and ensure reliability of traffic information single-hop broadcasting.*

***Streszczenie.** W artykule zaproponowano teoretyczny model protokołu komunikacji typu single-hop, który służyć ma do analizy relacji niezawodności przekazywania informacji (sieć VANET) oraz przepustowości łącza. Dodatkowo pomaga on w określeniu rozmiarów okna przesyłowego, w celu optymalizacji tych czynników. Przedstawiono wnioski z analizy. (**Analiza przepustowości i niezawodności protokołu komunikacji typu Single-Hop w sieci VANET**).*

Keywords: Vehicular ad hoc networks, single-hop broadcasting protocol, Throughput, reliability.
Słowa kluczowe: sieć ad-hoc VANET, protokół komunikacji single-hop, przepustowość, niezawodność.

1. Introduction

Vehicular ad hoc networks (VANETs) [1], as an application of mobile ad hoc networks (MANETs) on Intelligent Transportation Information System, the most important goal is to reduce the dramatically high number of accidents and fatal consequences. One of the most important factors that would make it possible to reach this goal is the design of effective broadcasting protocols. A large portion of the messages sent in a vehicular network will be broadcasting messages. Some of the uses for broadcasting messages are: sending emergency warning messages, periodically broadcasting a vehicles state, etc.

However, many research challenges must be fully studied before VANETs can be successfully deployed, since there is no MAC layer acknowledgement, retransmission and recovery on broadcasting frames within an 802.11 based VANETs, the reliability, system throughput and reception rates of broadcasting messages could be very low, especially under saturation conditions), and schedule application packet transmissions fairly and securely in vehicular networks, according to the quality of service (QoS) and security requirements of the applications.

In this paper, based on our previous related works [2], we mainly focus on contention window value which can optimize the throughput and reliability of broadcasting protocol performance analysis of IEEE 802.11 Broadcasting. So, we study the relationship between two groups of parameters, namely, the number of vehicle nodes, the contention windows, the hidden/exposed vehicle nodes and the communication reliability, the system throughput.

2. Related Works

In recent years, there have been several studies that analysis broadcasting performance of MANETs. In [2], 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. Specifically, Wang Z assumed the following: Each node always have a packet in the queue ready for transmission. Any transmitted packet is always successfully received by all nodes in the network unless it collides with another transmission (no hidden terminal), However, hidden terminal is one of most important factor that effect reliability of information broadcasting in VANETs sand MANETs.

In literature [3-4] proposed an analytic model for performance evaluation of IEEE 802.11 ad hoc broadcasting networks without the assumption of saturation condition. Ma XM used a discrete time M/G/1 queue to model occasional occurrences of safety related message in each vehicle. By means of probability generating function (PGF) and a recursive algorithm, Ma XM obtained solution to the analytic model and derived several important performance indices for IEEE 802.11 broadcasting service, such as packet delay, throughput, packet delivery ratio, and service time distribution.

In this paper, this paper propose markov analytic model to analysis the relationship between the throughput and the reliability. In VANETs, emergency warning messages broadcasting performance are influenced by many factors. Based on ideal of literature [1], we propose the discrete time Markov chain model for VANETs in highway environment based on the assumption that every node is always ready to transmit and all communication happens in ideal channel conditions.

3. System Model and theoretical analyses

3.1. System Model and Assumptions

In our model, we introduce the network and channel model used in our analysis of multi-hop emergency message propagation in VANETs. Due to the inherent difficulties of this analysis, we use a simplified network and channel model, which, however, capture relevant VANETs features.

(a) We consider a highway environment where vehicles are exponentially distributed with density β. The VANETs built along a highway is simplified as one-dimensional mobile ad hoc networks which consist of a collection of statistical identical vehicle nodes randomly located on a line.

(b) All vehicles nodes have same transmission, which is denoted as *R* receiving range. At the same time, we only consider ideal channel conditions, so the channel is perfect and all packets involved in a collision are destroyed beyond repair.

(c) At each vehicles node, packet arrivals are Poisson process. The queue length of packets each node can store at the MAC layer is unlimited. The reason for this assumption is that the safety related message at each node is short, is too critical to drop, and is expected to arrive once in a while.

3.2. Channel Performance

Markov chain model for VANETs is depicted in Fig.1. Let b_k be the stationary distribution of the chain, define p as the probability that the transmission channel for a node is busy. Knowing that the channel is busy if there is at least one vehicle transmitting, in steady state, we can derive following relations through chain regularities.

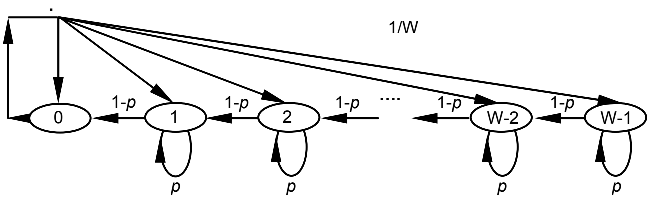

Fig.1. Markov chain of backoff protocol in IEEE802.11 broadcasting protocol

We can easily infer from the analytical Markov Chain Model of the IEEE802.11 single-hop broadcasting protocol.

(1) $$\sum_{k=1}^{W-1} b_k = \frac{1+2+\cdots+W-1}{W(1-p)} b_0$$

(2) $$p = 1-(1-\tau)^{n-1}$$

(3) $$\tau = \frac{2(1-p)}{W_0 + 1 - 2p}$$

Knowing that the channel is busy if there is at least one vehicle transmitting, in steady state, we can derive following relations through chain regularities. Equations (2) and (3) together τ and p.

In equation (2 and 3), τ depends on the probability p, which is still unknown. For an ideal channel, the probability that the channel being busy when a node is trying decrement its back off counter is the probability that among the rest of the nodes, at least one is in transmission state.

In equation (1), b_0 depends on the probability p, which is still unknown. For an ideal channel, the probability that the channel being busy when a node is trying decrement its back off counter is the probability that among the rest of the nodes, at least one is in transmission state. Therefore

(4)
$$P_i = \sum_{k=1}^{\infty} (1-\tau)^{k-1} \frac{(2\gamma R)^k}{k!} e^{-2\gamma R}$$
$$= \frac{e^{-2\gamma R}}{1-\tau} (e^{2\gamma R(1-\tau)} - 1)$$
$$= \frac{1}{1-\tau} (e^{-2\gamma R\tau} - e^{-2\gamma R})$$
$$p = 1 - p_i = 1 - \frac{1}{1-\tau} (e^{-2\gamma R\tau} - e^{-2\gamma R})$$

3.3. Throughput Analysis

Let P_{tr} 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, conditioned on that at least one node is transmitting. So the conditional probability can be derived as

$$p_{tr} = 1 - \sum_{k=1}^{\infty} (1-\tau)^k \frac{(2\gamma R)^k}{k!} e^{-2\gamma R} = 1 - e^{-2\gamma R\tau}$$
$$p_s = \sum_{k=1}^{\infty} \binom{1}{k} \tau (1-\tau)^{k-1} \frac{(2\gamma R)^k}{k!} e^{-2\gamma R} / p_{tr}$$

(5) $$= 2\gamma R\tau e^{-2\gamma R\tau} / (1-e^{-2\gamma R\tau})$$

Let T^* be the average length of a virtual slot time, then we have

$$T^* = (1-p_{tr})\sigma + p_{tr} p_s T_s + p_{tr}(1-p_s) T_c$$

Where σ is an empty slot-time. For the time intervals T_s, T_c, we follow the definition given by

$$T = T_s = T_c = T_{MAC} + T_{PHY} + \frac{E[pkg]}{tr} + DIFS + \delta$$

Related values and description of parameters are summarized in Table1. The normalized throughput S is defined as:

$$s = \frac{p_{tr} p_s T_{pl}}{(1-p_{tr})\sigma + p_{tr} p_s T_s + p_{tr}(1-p_s) T_s}$$

(6) $$= \frac{p_{tr} p_s T_{pl}}{(1-p_{tr})\sigma + p_{tr} T_s}$$

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

(7) $$T_{pl} = \frac{packet\_size \times 8}{Bit\_Rate}$$

In the backoff process, if the medium is idle, the backoff timer will decrease by one for every idle slot detected.

3.4. Reliability Analysis

The considered scenario is depicted in Fig2.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 $H(r)$.

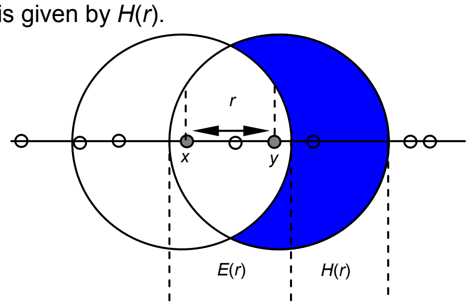

Fig. 2. Region of hidden and exposed nodes

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

(8)
$$p(E(r)) = \sum_{i=0}^{\infty} (1-\tau)^i \frac{[\gamma(2R-r)]^i}{i!} e^{-\gamma(2R-r)}$$
$$= \exp(-\gamma\tau(2R-r))$$

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

(9)
$$p(H(r)) = \left\{ \sum_{i=0}^{\infty} (1-\tau)^i \frac{[\gamma r]^i}{i!} e^{-\gamma r} \right\}^{N^*}$$
$$= \exp(-\gamma\tau r N^*)$$

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

(10)

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

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

(11)

$$p(y) = (1-\tau) \times p(E(r)) \times p(H(r))$$
$$= (1-\tau) \times \exp(-\gamma\tau(2R-r) - \gamma\tau r N^*)$$

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

(12)

$$E(\tau) = \int_0^R \frac{1}{R}(1-\tau) \times e^{-\gamma\tau(2R-r)} \times e^{-\gamma\tau r N^*} dr$$
$$= \frac{(1-\tau)\exp(-2\gamma R\tau)}{\gamma R\tau(N^*-1)}[1 - \exp(-\gamma R\tau \times (N^*-1))]$$

4. Numerical Results

In order to validate the proposed model, we compare the reliability and the throughput performance of the network obtained from numerical analysis by matlab7.1. The parameters used for the analytical are summarized in Table 1. Considering VANETs as a typical application of broadcasting communication, all broadcasting packets have the same size. So, it is 128-byte per packets.

Table 1 IEEE802.11 physical and MAC parameters

Parameter	Value
Channel data rate	2Mbit/s
Slot time	10 μs
PHY size	28bits
MAC size	20 μs
SIFS	16 μs
Propagation delay	1 μs
Packet payload size	128bits
Contention window size	variable

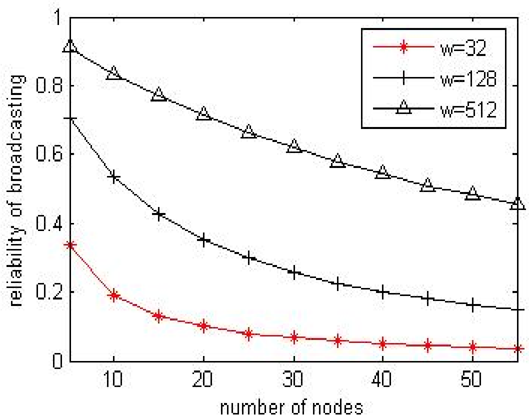

Fig.3. Successful transmission Probability

Fig 3 show that the number of nodes in the broadcasting area directly affects the broadcasting reliability of VANETs communications. With the scaling of the network, reliability decreases indicating that the broadcasting protocol does not ensures reliability broadcasting packets for saturated networks conditions.

We also notice that the reliability decreases faster with a smaller contention window. For example, with a window of 32, the reliability drops below 10% when 60 nodes lies in transmission range (*R*=250m) of nodes broadcasting network.

Fig4 and Fig5 show that the number of nodes and contention windows size (W^*) of MAC directly affects the broadcasting reliability and throughput of VANETs communications. It obviously from equation (6) and numerical analysis, we can see that existence of the appropriate window size (W^*) raises an optimal throughput for the number of network nodes, IEEE802.11 single-hop broadcasting protocol would need to operate under window sizes much lager than the size, selecting a window lager than the optimal size W^* would prevent the networks from achieving the maximum throughput[5].

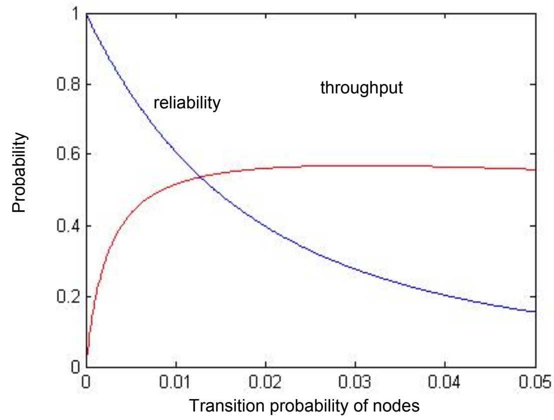

Fig.4. Reliability and throughput (5)

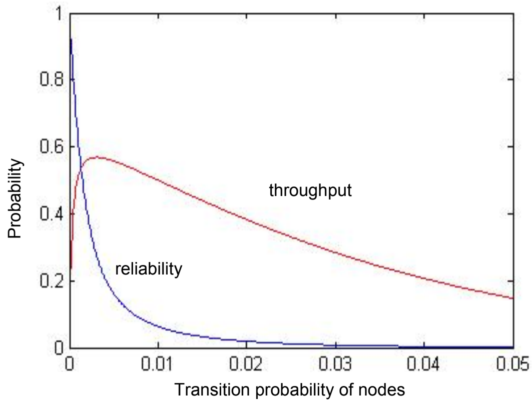

Fig.5. Reliability and throughput (50)

However, we also 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 IEEE802.11 protocol to ensure reliability and throughput of broadcasting information are key indexes in VANETs.

In the backoff process, if the medium is idle, the backoff timer will decrease by one for every idle slot detected.

From equation (6), we can see that existence of the appropriate window raises an optimal throughput for the number of network nodes, IEEE802.11 broadcasting protocol would need to operate under window sizes much lager than the values, selecting a window lager than the optimal value would prevent the networks from achieving the maximum throughput.

So, we can find that for maximum throughput under the number of network nodes.

Since T_{pl} ,T are constants, the normalized throughput becomes a function of the transmission probability τ . Rearranging Equation (6), we obtain:

(13) $$s = T_{pl} / \{(\sigma((1-p_t)/p_t + T_s)/p_s\}$$

we suppose $k = \sqrt{T_s/(2\sigma)}$, and obtain optimal transmission probability τ_{opt} .

(14) $$\tau_{opt} = \frac{\sqrt{[n+2(n-1)(T_s/\sigma-1)]/n}-1}{(n-1)(T_s/\sigma-1)} \approx \frac{1}{n\sqrt{T_s/(2\sigma)}} = \frac{1}{nk}$$

(15) $$p = 1-(1-\tau)^{n-1} = 1-(1-\frac{1}{nk})^{n-1} = 1-(1-\frac{1}{nk})^n/(1-\frac{1}{nk})$$

we set $p^* = (1-\frac{1}{nk})^n$, then $(p^*)^k = (1-\frac{1}{nk})^{nk}$

when nk is larg enough , then

(16) $$(p^*)^k = (1-\frac{1}{nk})^{nk} = \frac{1}{e}, \quad p^* = e^{-\frac{1}{k}}$$

From equeation (15) and (16), p can be denoted as

(17) $$p = 1-e^{-\frac{1}{k}}/(1-\frac{1}{nk}) = 1-\frac{1}{e^{1/k}(1-1/nk)}$$

(18) $$W_0 = \frac{2nk-2}{e^{1/k}(1-1/nk)}+1$$

The approximate optimized transmission probability is given as

(19) $$W_{opt} = \frac{2nk-2}{e^{1/k}(1-1/nk)}+1$$

5. Conclusion

In this paper, we develop an analytical model for IEEE 802.11 broadcasting protocol to derive closed form expressions of the throughput and the reliability. Several important performance indices are derived from the proposed analytical model taking IEEE 802.11 standard MAC-broadcasting protocol and saturation traffic into account.

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. 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. However, as we shall see in the next section, scaling up the contention window may negatively impact the system throughput, leading to the so called reliability-throughput trade-off.

Acknowledgments

This work is partly supported by Natural Science Foundation Project of Chongqing (cstc2011jjA40034).

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