An Analytical Model Based on Semi-Markov Process to Incorporate Periodic Performances of Message

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Abstract

In this paper we have a model a set of interacting $D/G/1/1LCFS$ queues, one for each vehicle. Based upon the model, they have obtained all the MAC-level performance metrics including mean delay, packet delivery ratio (PDR), packet reception ratio (PRR) and normalized channel throughput. In their model, they have assumed that the sojourn times of all the channel sensing states are deterministic. Accordingly, we extend the model of Yin et al. [18] by proposing that the sojourn times for some of the channel sensing states are random and obtain the various system performance measures.

Keywords

Collision avoidance (CA), Safety warning (SW), Dedicated short Range (DSR), Inter-reception time (IRT).

1. Introduction

The DSRC adopts IEEE 802.11 MAC layer specification based on the carrier sense multiple access with collision avoidance (CSMA/CA) with minor modifications. In the 802.11 MAC layer protocols [10], distributed coordination function (DCF) is the primary medium access control technique for broadcast services. If a vehicle does not have any message to transmit, it will wait for a packet to be generated. Then, for a newly generated packet, the vehicle senses the channel activity before it starts to transmit the packet. If the channel is sensed idle for a time period of distributed inter-frame space (DIFS), the packet can be directly transmitted. Otherwise, the vehicle continues to monitor the channel until channel is detected to be idle for DIFS time period. Subsequently, according to the collision avoidance feature of the protocol, the vehicle goes through the backoff process before transmitting the packet.

2. Mathematical Distribution of the SMP Model

The behavior of a tagged vehicle is characterized using the irreducible SMP model in The channel sensing, backoff and transmission behavior matches well with the flow chart . The tagged vehicle is in *idle* state if there is no packet.

After a packet is generated, the vehicle senses channel activity for DIFS time period, which is represented by state $CS1$. If the channel is detected not busy during this period (DIFS) (with probability $1 - qb$), the vehicle goes from *idle* state to TX state, which means that a packet is transmitting. Otherwise, the vehicle will defer until channel is idle for DIFS duration represented by state DCS . Such deference behavior for the tagged vehicle includes two parts: waiting for the current packet in the channel finishing transmission and waiting for subsequent transmissions if any from other neighbors within its receiving range.

3. The SMP Model by the total replacement probability

The self-loop for state DCS represents the phenomena in that the tagged vehicle (vehicle B) waits for the current packet (from vehicle A) in the channel finishing transmission, and then senses the channel for DIFS time, which seizes the transmission from another vehicle (vehicle C) and leads to further deference for backoff procedure of vehicle B. The probability that the tagged vehicle detects another neighbors transmission during DIFS time is denoted as rb . If no other neighbors transmission is detected, the tagged vehicle will start backoff procedure and randomly choose a backoff counter in the range $[0, W - 1]$, where $W = CW + 1$ is the backoff window size. The backoff counter will be decreased by one if the channel is detected to be idle for a time slot of duration σ (with probability 1 − *pb*), which is captured by the transition from state *W* − *i* to state *W* − *i* − 1 . If the channel is busy during a backoff time slot of duration σ (i.e., another vehicle starts to transmit a packet during this time slot), the backoff counter of the tagged vehicle will be suspended, which represented by the transition from state *W* − *i* to *DW* − *i* − 1 with probability *pb* . Similar to state *DCS* , state *DW*−*i*−1 also contains self-loop because other neighbors transmission can lead to further deference of the tagged vehicle. When the backoff counter reaches zero, the packet will directly be transmitted (an SMP transition occurs from state 0 to state *TX with* probability one). In *TX* state, a packet is transmitting. To capture the out-dated packet replacement behavior, which can happen during any state except state idle, we simplify the model by considering the total replacement probability and placing it after state *TX* . If the current packet has not been replaced by the next packet(with probability 1 − *Pf*), the SMP goes to state *idle* . Otherwise, this current packet is out-dated and replaced by the next incoming packet. Such simplification is reasonable since the packet transmission delay is usually much smaller than the packet generation interval and hence the replacement occurs extremely rare. Next, the tagged vehicle starts the service for the next packet immediately and senses the channel for DIFS time (state *CS* 2). A new backoff procedure is started subsequently for the new packet instead of inheriting the backoff state of the old message. This is mainly because the out-dated message may finish the backoff procedure and is replaced during its transmission. The SMP model proposed here captures more detailed DCF behavior for periodic beacon message transmission by adding more states and self-loop structure. In addition, out-dated message replacement behavior is incorporated into the model by the newly introduced model parameter *Pf* . The sojourn time in state *j* is defined as *T j*. The mean and variance of *T j*. in the SMP model are:

$$E[T_j] = \tau_j = \begin{cases} A1 & j = TX \\ A2 & j = idle \\ A3 & j = CS1, CS2 \\ A4 & j = DCS \\ A5 & j = D_0, D_1, D_2, \cdots, D_{w-2} \\ 0 & j = 0 \\ \sigma & j = 1, 2, 3, \cdots, W-1 \end{cases}$$

$$Var[T_j] = \theta_j^2 = \begin{cases} 0 & j \in U \ (set\ of\ \ states\ except\ idle) \\ B_1 & j = idle \end{cases}$$

Where

$$\begin{cases} A1 = \dfrac{PL}{R_d} + T_H \\ A_2 = \tau - E[s] \\ A_3 = DIFS \\ A_4 = \dfrac{(A_1 + DIFS)}{2} \\ A_5 = A_1 + DIFS \end{cases}$$

And

$$B1 = var[s]$$

TH presents the time to transmit the packet header including physical layer header and MAC layer header. *E*[*S*] and *Var*[*S*] are the mean and variance of the overall message service time, which will be derived later. The sojourn time in state *idle* is the packet inter arrival time excluding the packet service time. In addition, to simplify the model, the sojourn times for channel sensing states (*CS* 1, *CS* 2, and *i* = 0, 1, · · · , *W* − 1) are modeled as deterministic using the upper bound channel sensing time (i.e., the sensing for each state only performs once). Such simplification may have impact on dense network in which channel contentions are severe. Moreover, the sojourn time in state *Dcs* is different from that in *Di* (*i* = 0, 1, · · · , *W* − 2) is because the packet transmission from another vehicle may already started before the new packet is generated from the tagged vehicle.

4. Conclusion:

On average, the tagged vehicle only defers for a half of the packet transmission time plus an additional idle DIFS duration in state *Dcs*. In contrast, for state *Di* (*i* = 0, 1, · · · , *W* − 2), the start point of packet transmission from another vehicle is detected within the backoff time slot (state *i* + 1), and hence the tagged vehicle needs to defer for the whole packet transmission time plus an additional idle DIFS duration. The embedded DTMC is solved for its steady-state probabilities for each state.

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