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A Finite State Model for IEEE 802.11 Wireless LAN MAC DCF

Dillip Kumar Puthal and Bibhudatta Sahoo
Department of Computer Science Engineering
National Institute of Technology, Rourkela, India 769008
E-mail {Dillip.puthal, bdsahu}@nitrkl.ac.in

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Dillip Kumar Puthal and Bibhudatta Sahoo
Department of Computer Science Engineering
National Institute of Technology, Rourkela, India 769008
E-mail {Dillip.puthal, bdsahu}@nitrkl.ac.in

Abstract

The international standard IEEE 802.11 Wireless LAN protocol is a popular standard for wireless local area networks. Its medium access control layer (MAC) is a carrier sense multiple access with collision avoidance (CSMA/CA) design, although collisions cannot always be prevented, randomized exponential backoff rule is used in the retransmission scheme to minimize the likelihood of repeated collisions. To work around this problem, we identify state transition of the protocol that can be used to simplify the models and make verification feasible. This paper explains the state transition model of two way handshake mechanism of IEEE 802.11 standard for MAC DCF. Using these observations, a time variant generalized state transition model for channel, sender and destination station has been described. The proposed model has been validated using network simulator ns-2.

Key Words- IEEE 802.11 Wireless LAN (WLAN), Medium Access Control (MAC), Point Coordination Function (PCF), Distributed Coordination Function (DCF), State transition model

1. Introduction

The international standard IEEE 802.11 was developed in recognition of the increased demand for wireless local area networks which permit interoperability of heterogeneous communication devices. In contrast to wired devices, the stations of a wireless network cannot listen to their own transmission, and therefore unable to employ medium access control schemes such as Carrier Sense Multiple Access with Collision Detection (CSMA/CD) in a transmission channel.

Instead, the IEEE 802.11 standard describes a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [1] [2] mechanism, using a randomized exponential backoff rule to minimize the likelihood of transmission collision. The proposed model is based on two-way handshake mechanism of the IEEE 802.11 medium access control scheme, operating in a infrastructure based arbitrary network topology. This formalism allows both nondeterministic choice (which, for example, can be used to model the unspecified data packet length) and the randomized backoff procedure to coexist in the same model [1] [2]. The mechanism is formally illustrated as a state transition model.

The rest of the paper is organized as follows. In section 2, IEEE 802.11 MAC functionality is briefly reviewed. The state transition modeling is presented in Section 3. Section 4 discusses simulation analysis of the model with help of *ns-2*, and in Section 5 we conclude.

2. IEEE802.11 MAC

IEEE 802.11 defines the functionality of medium access control (MAC) layer and physical (PHY) layer specifications for WLAN [1] [2] [6] [7] [9]. 802.11 MAC defines two coordination functions, namely, the mandatory distributed coordination function (DCF) based on CSMA/CA and the optional point coordination function (PCF) based on polling mechanism [1] [2] [6]. Most of the 802.11 devices implement the DCF only because of the contention-based channel access nature, which supports best-effort service without guaranteeing any QoS and having no service differentiation [6] [7] [8] [9].

MAC PCF [6] [9] (point coordination function), the priority-based access can also be used to access the medium. PCF is a synchronous service that implements a polling-based contention-free (CFP) access mechanism. It can be used with the infrastructure mode only. Unlike DCF, its implementation is not mandatory. The reason is that the hardware implementation of PCF was thought to be too complex at the time the standard was finalized. Further, PCF itself relies on the asynchronous service provided by DCF and the beacon interval must allow at least one DCF data frame to be transmitted during the contention period (CP). When a Basic Service Set

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(BSS) is set up with PCF-enable, the channel access time is divided into periodic intervals named beacon intervals. The beacon interval is composed of a CFP and CP. During the CFP, the PC maintains a list of registered stations and polls each of them according to the list.

MAC DCF (Distributed Coordination Function) works with a single queue first-in-first-out (FIFO) transmission mechanism and is shared by all the traffics [1] [2] [9]. The CSMA/CA of DCF works as follows: when a packet arrives at the front of transmission queue, if the channel is found idle for an interval of time longer than Distributed Inter-frame Space (DIFS), the source station can transmit the packet immediately, mean while other stations defer their transmission while adjusting their network allocation vector (NAVs) and the backoff process starts.

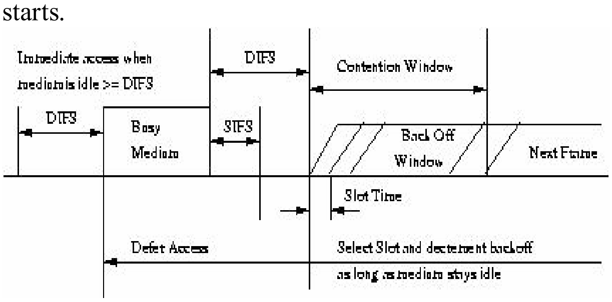


Figure 2.1. 802.11 DCF access scheme

In this process, the station computes a random interval, called backoff-timer, selected from the contention window (CW): *backoff-timer= rand [0, CW]* Slot-Time*, where $CW_{min}<CW<CW_{max}$. The backoff-timer is decreased only when the medium is idle. If the channel is busy, the MAC waits until the medium becomes idle, then defers for an extra time interval, called the DIFS. For each idle slot time interval, the backoff counter is decremented. When the counter reaches zero, the packet is transmitted. The mechanism of DCF channel access is illustrated in Fig. 2.1. For each successful reception of a packet, the receiving station immediately acknowledges by sending an acknowledgement (ACK) packet. The ACK packet is transmitted after a short inter frame space (SIFS). If an ACK packet is not received after the data transmission, the packet is retransmitted after another random backoff [1] [2] [9].

As MAC access is described with correspondence to Fig. 2.1, the Fig. 2.2 represents its flow chart. With it's starting sate represented by an arrow mark, to wait for a packet and remains in that state by default. Whenever a packet arrives it generates an RTS (request to send), and listens for an IFS (inter frame space), if it found to be idle then transmission of RTS to be done with a waiting for CTS, otherwise deferred until idle condition. If CTS arrives then Data has to transmit with a waiting for ACK (acknowledgement). If ACK arrives then it goes to the starting state, otherwise after ACK timeout it goes for the exponential backoff. After a differed time interval it goes to backoff [0, CW], then it listens for an IFS if busy then deferred until idle condition, otherwise decrement the backoff (to 0) and listen by transmitting a RTS with waiting for CTS.

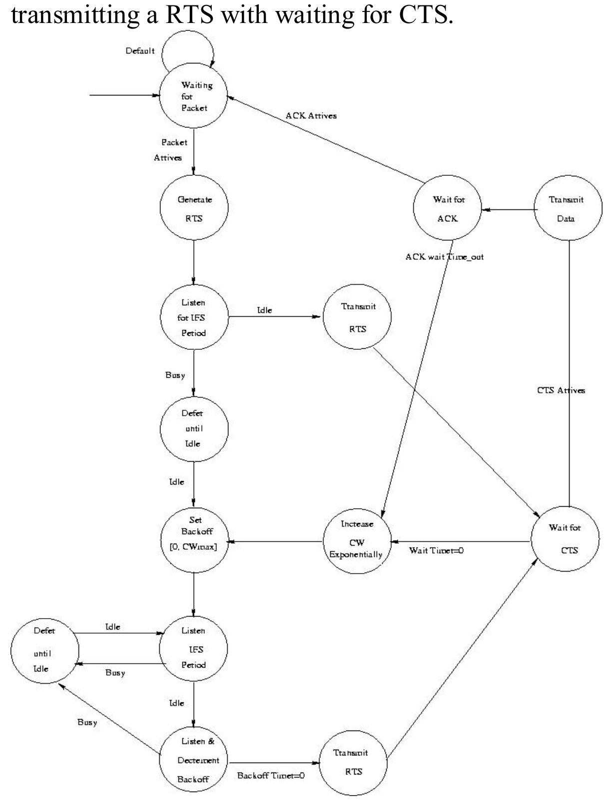


Figure 2.2. 802.11 DCF access scheme

3. Sate Transition Model of IEEE 802.11 MAC

The modelling of a system's behaviour is an aggregation of the behavioural models of its components We consider a state transition model WLAN of the IEEE 802.11 Wireless LAN which models two stations colliding and trying to send messages at the same time and then entering the randomized exponential backoff procedure. The timing constraints of the model correspond to the Frequency Hopping Spread Spectrum (FHSS) physical layer. The proposed state transition model is time variant and analyses the functionality of PCF and DCF.

3.1. PCF State Modelling of Wireless LAN

The functionality of proposed time variant PCF state model as depicted in Fig. 3.1.1 and 3.1.2. These models are based on the timed automata as suggested by Bordbar et. al [3] [4].The interaction with the access point, which makes use of PCF, is modelled as state transition for PCF. At the start of a contention free period, the medium gets busy as in Fig 3.1, and this is shown with the signal *access* of state mode for PCF. The integer value *i* ranges over the number of stations. There are *N* stations, i.e. $i = 1, \ldots , N$. Depending on the value of *i*, the downlink (*data*) is meant to be delivered to station number *i*. The start with value of *i* is 1 and, it is incremented each time before the data is delivered to the next station. After gaining access to the medium, the PCF sends data to the station. The data sent by the DCF must be broken into units of maximum length of MAC Service Data Unit (MDSU) [1] [2]. *A* denotes the amount of time required for the MDSU to reach the destination. As a result, at state *Sending_Data*, within a unit of time *data* is sent. Depending on the value of *i*, the signal *data* is used in the Application Layer of Station *i*. When the transmission of data finishes, an urgent acting *CF-poll* signal is sent to mark the end of data. To notify the medium, an *idle* signal is sent to mark the end of access. Then the PCF waits for SIFS (SIFS is 10µs). At exactly SIFS units it receives a *CF_ACK* signal from the Station that the data has been received. However, if $i < N$, in order to ensure that the next downstream goes to station *i+1*, the value of *i* is incremented. If $i = N$, this indicates that one contention free period is finished and a *CF_end* signal is sent. In this process, since no contention period is used, the CF-end is replaced with a simple acknowledgement signal *CF_ACK*. If the *CF_ACK* is sent a back-off period of SIFS is required.

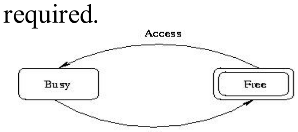


Figure 3.1.1: Medium state model

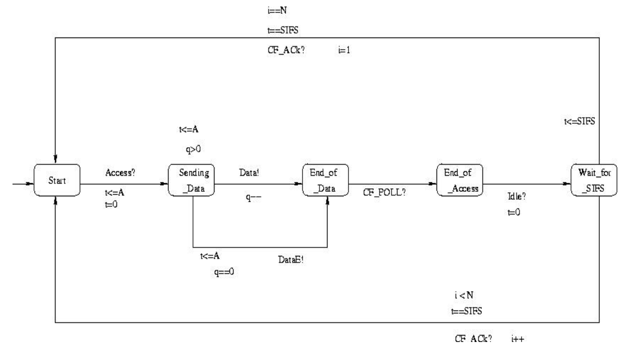


Figure3.1.2: PCF state model

3.2 DCF State Modelling of Wireless LAN

The DCF State Transition Model is based upon the integer semantics. The mode consists of three components operating in parallel, namely ***channel*** (the channel), ***sender_i*** for i=1, 2 (the sending stations) and ***recever*** (destination station), the value of parameters is given in Table 4.1.

3.2.1 The channel model

The state transition model representing the channel is shown in Fig.3.2.1. This state transition model has two variables c_1 and c_2 which records the status of the packet being sent by station 1 and station 2 respectively, and updated both when, a station starts sending a packet (event send) and a station finishes sending a packet (event finish).

The value of c_i ranges from within {0, 1 and 2}. These variables have the following interpretation: $c_i=0$, nothing being sent by station i; $c_i=1$, packet from station i being sent correctly; $c_i=2$, packet from station i being sent garbled. If $c_i > 0$, i Є {1, 2} then the channel is sensed to be busy, otherwise if the channel $c_i = 0$, i Є {1, 2} then it sensed to be idle or free. The value of c_1 is taken as minimum from c_1+1, 2, and c_2 value is chosen to be minimum value from $c_2+ c_2$, 2 for event *send1* but if c_1 is found to be 0 then the station has finished sending data for event *Finish1* and has nothing to transmit. The value of c_1 is taken as minimum from $c_1+ c_1$, 2, and c_2 value is chosen to be minimum value from c_1+1, 2 for event *Send2* but if c_2 is found to be 0 then the station has finished sending data for event Finish2.

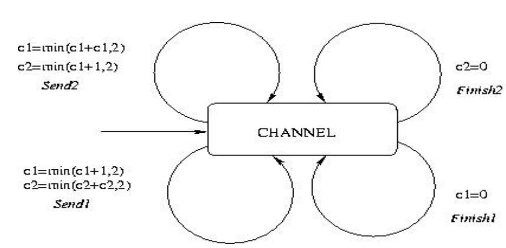


Figure 3.2.1: Channel model

The state transition model of channel, is shown in Fig.3.2.1. The *free* corresponds to the case in which the channel is available. From that location, receipt of a packet data from *station 1*(*send1* event, sent by send1) triggers the station to location RCV1, then this packet finishes successfully (*T_success* event, sent by *send1* again) and returns the channel to the state *free*, or collide with *station 2* (*send2* event, sent by send2) and channel state proceed to RCV1 RCV2. From the latter location the event *T_collide* can remove the data packets from the channel. The state ACK1 and ACK2of the model shows the model used to present the receipt of acknowledgement on the channel. It is not modeled for the situation, in which an acknowledgement is sent at the same time as a data packet and where two acknowledgements collide.

3.2.2 The sending stations model

The state transition model of sending station i.e. *sender* is shown in Fig 3.2.2, and the state transition model for sending station is symmetric. The events busy and *free* are the urgent events of the sender. The initial state is indicated by an arrow mark. The sender begins in *SENSE* with a data packet ready to send, and senses the channel. If the channel remains free for *DIFS* (50µs), then the sender enters its vulnerable period and starts sending a packet (event *send*), otherwise the station enters backoff via an urgent transition. The time taken to send a packet is nondeterministic (within *TTMIN* and *TTMAX*) i.e. Transmission Time Minimum and Transmission Time Maximum. The success of the transmission depends on whether a collision has occurred, and is recorded by setting the variable *status* to the value of the channel variable c_1. The sender then immediately tests the channel (represented by the urgent Test Channel). If the channel is busy, the sender enters the backoff procedure; otherwise it waits for an acknowledgement. If the packet was sent correctly (*status* =1), then the destination station waits for *SIFS* and sends the acknowledgement; the sending station then receives this acknowledgement and completes the process. On the other hand, if the packet was not sent correctly (*status* =2), then the destination station does nothing. In this case, the sender station times-out and enters the backoff procedure. In the backoff procedure, the sender first waits for the channel to be free for *DIFS* and then sets its backoff value according to the random assignment *backoff: =Random (bc),* where *bc,* the backoff counter, is updated if its current value is less than its maximal value (CW_{max}). The state transition then decrements *backoff* by 1 if the channel remains free for *ASLOT_Time*. However, if the channel is sensed busy within this slot, it waits until the channel becomes free and then waits for *DIFS* before resuming its backoff procedure. When the value of *backoff* reaches 0 the sender starts re-sending its data packet.

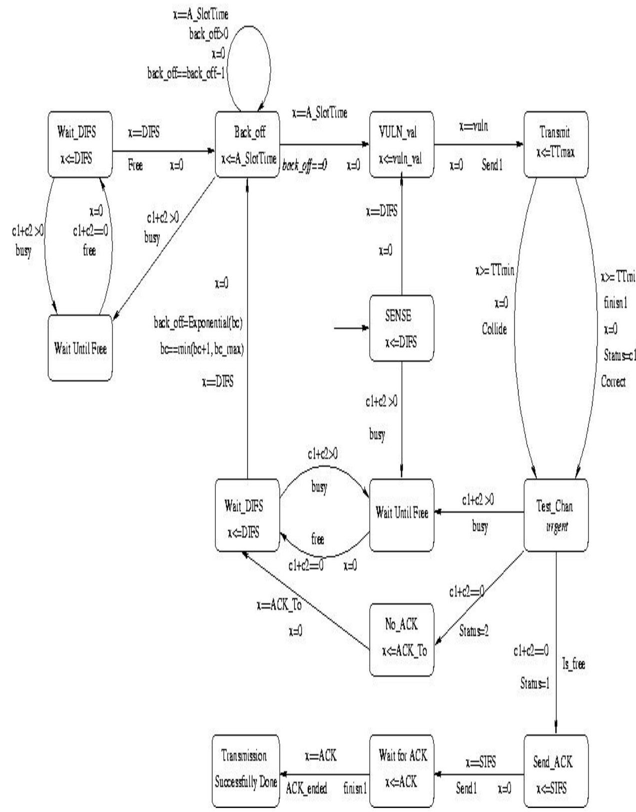


Figure 3.2.2: Sender Station Model

3.2.3 The Destination stations model

For the destination station as in Fig 3.2.3, having start state given by arrow mark, waits (*waiting* event) for an incoming packet. If a packet arrives correctly (*correct* event), then the destination station waits for *SIFS* and subsequently sends the acknowledgement (*ACK_start)*. On the other hand, if the message arrives garbled (*collide* event), the destination station has to do nothing, i.e. it remains in the same state.

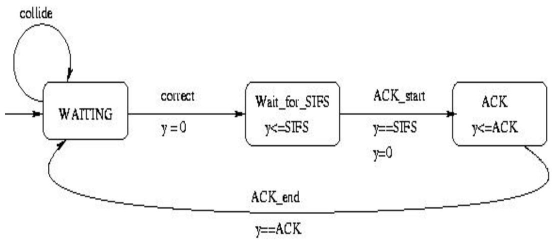


Figure 3.2.3: Destination Station Model

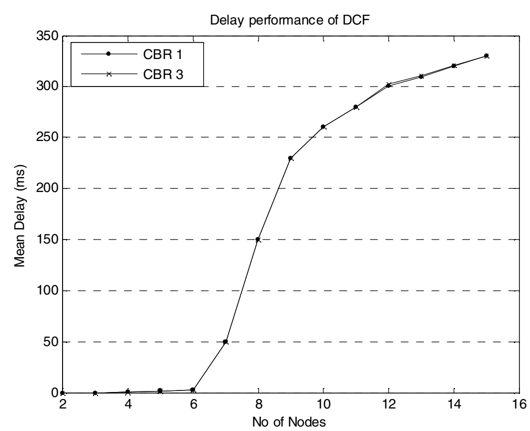
4. Model Validation and Result

This model have been validate and the performance of 802.11 MAC DCF evaluated, using *ns-2* simulator[5]. Simulation topology consists of up to 15 stations operates at IEEE 802.11 physical mode and transmits two types of traffics (general and multimedia) to each other and the stations are mobile. The packet size of general is equal to 512 bytes and the inter packet arrival interval is 30ms. The multimedia packet size is 1024 bytes and the inter packet arrival interval is 50ms. Simulation time is 10 simulated seconds and all traffics are CBR sources. We varying load by increasing the no of stations from 2 to 15. Stations having drop tail queue with maximum capacity 50. Each connection uses a constant bit rate (CBR) generator as a traffic source, and each traffic flow has assigned traffic CBR1 or CBR3.Other simulation parameters DIFS (Distributed Interframe space), SIFS (Shortest Interframe Space), CW_{min} and CW_{max} (Contention Window minimum and maximum), RTS (Request to Send), CTS (Clear to Send), ACK (Acknowledgement) are mentioned in Table-4.1. Here uses the parameters of the Frequency Hopping Spread Spectrum (FHSS) physical layer, with a transmission bit rate of 2Mbps for the data payload with parameters as given below.

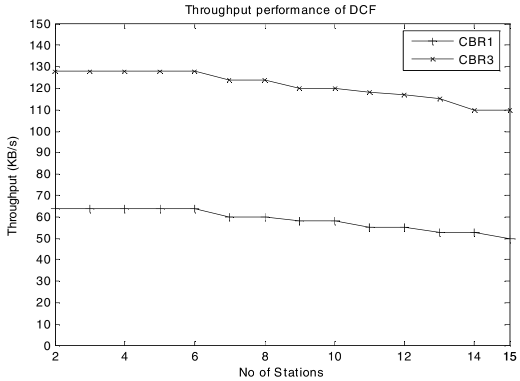
Table-4.1 Simulation parameters and its values

Variable	Description	Value
SIFS	short inter-frame space	10µs
DIFS	DCF inter-frame space	50µs
A Slot Time	length of each backoff slot	20µs
CW_{min}	Contention window minimum	31
CW_{max}	Contention window maximum	1023
ACK	Time to send an Acknowledgement	205µs
ACK_TO	time sender waits for acknowledgement before timing-out	300µs
CCA	time receiver needs to asses the medium	27µs
Turnaround	time a station needs to change from receiving to sending	20µs
TT_MIN	minimum time to send a packet	224µs
TT_MAX	maximum time to send a packet	15,717µs
AIRPROP	the air propagation time	1µs
VULN	vulnerable period (AIRPROP+CCA+Turnaround)	48µs
Frame Types		**Size in byte**
RTS	Request to send	20
CTS	Clear to send	14
ACK	Acknowledgement	14
MAC Header		28

In infrastructure mode all stations are mobile and capable to transmitting and receiving the packets. Nodes are move within a specified region and communicate among themselves through one another. Here the problems associated is hidden station and exposed station problem. Nodes are increases from 2 to 15 in order to increase the network load. From Fig. 4.1, when the no of station increases, the throughput of two flow decreases and delay increases. So this simulation clearly shows that there is neither throughput nor delay differentiation between the different flows. The reason is that all flow shares the same queue. So DCF cannot provide QoS, rather it provides only best-effort services.



(a)



(b)

Figure-4.1: (a) Delay and (b) Throughput analysis in infrastructure mode

5. Conclusion

DCF only supports best effort services but does not provide any QoS guarantee [7]. A framework for DCF has been developed using NS-2 to study the state transition and performance of DCF. The state transition model presented can be alternate sub-protocol for IEEE 802.11 standard for WLANs. The use of modeling state transition diagram allows us to model asynchronous behaviour of stations. Further work could lift several simplifying assumption that were made in this model: (i) such as fixed network topology in which sending station cannot also be destination station, (ii) the absence of the timing synchronization, and (iii) by increasing the number of participating stations etc. In DCF all stations compete for the channel with same priorities, also shares the common queue. There is no differentiation mechanism to guarantee bandwidth, packet delay and jitter for high-priority multimedia flows. These are the problem area in WLAN, which needs a greater attention for future research. There is no service differentiation policy is associated with different flows, so the delay for real time multimedia flows should be reduced for better performance.

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