Report on application of queueing theory in "Performance Analysis of the IEEE 802.11 Distributed Coordination Function" by Giuseppe Bianchi.

Pramod Kumar B. - 04010231

The IEEE has standardized the 802.11 protocol for Wireless Local Area Networks. The primary medium access control (MAC) technique of 802.11 is called distributed coordination function (DCF). DCF is a carrier sense multiple access with collision avoidance (CSMA/CA) scheme with binary slotted exponential backoff. This paper provides a simple, but nevertheless extremely accurate, analytical model to compute the 802.11 DCF throughput, in the assumption of finite number of terminals and ideal channel conditions. The proposed analysis applies to both the packet transmission schemes employed by DCF, namely, the basic access and the RTS/CTS access mechanisms. In addition, it also applies to a combination of the two schemes, in which packets longer than a given threshold are transmitted according to the RTS/CTS mechanism.

DCF adopts a discrete exponential backoff scheme. At each packet transmission, the backoff time is uniformly chosen in the range (0, w-1). The value 'w' is called contention window, and depends on the number of transmissions failed for the packet. At the first transmission attempt, 'w' is set equal to a value CW_{min} called minimum contention window. After each unsuccessful transmission, 'w' is doubled, up to a maximum value $CW_{max} = 2^{m}CW_{min}$. The values of CW_{min} and CW^{max} are physical layer specific.

The backoff time counter is decremented as long as the channel is sensed idle, "frozen" when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than a DIFS. The station transmits when the backoff time reaches zero.

Fig. 1 illustrates this operation. Two stations A and B share the same wireless channel. At the end of the packet transmission, station B waits for a DIFS and then chooses a backoff time equal to 8, before transmitting the next packet. We assume that the first packet of station A arrives at the time indicated with an arrow in the figure. After a DIFS, the packet is transmitted. Note that the transmission of packet A occurs in the middle of the Slot Time corresponding to a backoff value, for station B, equal to 5 As a consequence of the channel sensed busy, the backoff time is frozen to its value 5, and the backoff counter decrements again only when the channel is sensed idle for a DIFS.

Since the CSMA/CA does not rely on the capability of the stations to detect a collision by hearing their own transmission, an ACK is transmitted by the destination station to signal the successful packet reception. The ACK is immediately transmitted at the end of the packet, after a period of time called short interframe space (SIFS). As the SIFS (plus the propagation delay) is shorter than a DIFS, no other station is able to detect the channel idle for a DIFS until the end of the ACK. If the transmitting station does not receive the ACK within a specified ACK_Timeout, or it detects the transmission of a different packet on the channel, it reschedules the packet transmission according to the given backoff rules. The above described two-way handshaking technique for the packet transmission is called basic access mechanism.

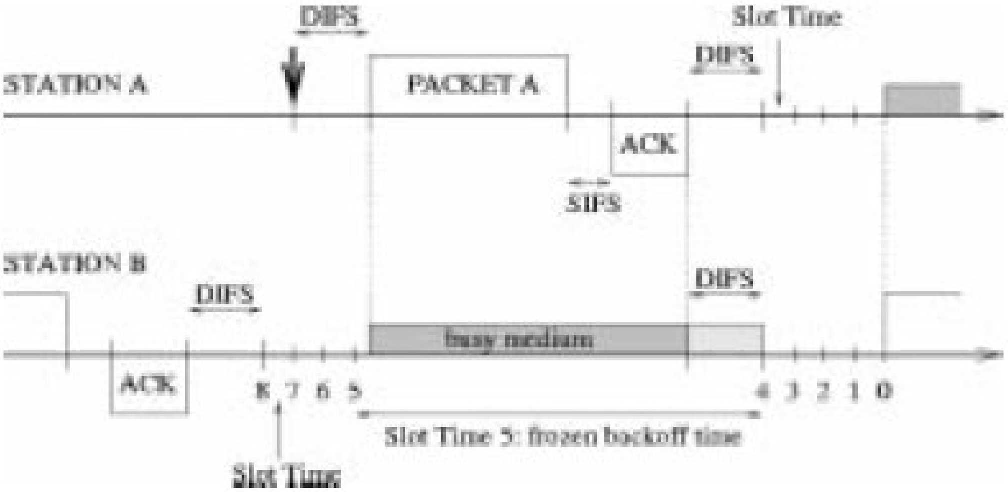

Figure 1: Basic DCF mechanism of 802.11 MAC layer

In order to evaluate the saturation throughput in the assumption of ideal channel conditions, we operate in saturation conditions, i.e., the transmission queue of each station is assumed to be always nonempty.

The behavior of a single station with a Markov model, and we obtain the stationary probability that the station transmits a packet in a generic (i.e., randomly chosen) slot time. Consider a fixed number of contending stations. In saturation conditions, each station has immediately a packet available for transmission, after the completion of each successful transmission. Moreover, being all packets "consecutive," each packet needs to wait for a random backoff time before transmitting. Let be the stochastic process representing the backoff time counter for a given station. A discrete and integer time scale is adopted: and correspond to the beginning of two consecutive slot times, and the backoff time counter of each station decrements at the beginning of each slot time.

Since the value of the backoff counter of each station depends also on its transmission history (e.g., how many retransmission the head-of-line packet has suffered), the stochastic process b(t) is non-Markovian. However, define for convenience $W=CW_{min}$. Let 'm', "maximum backoff stage," be the value such that $CW_{max}=2^mW$, and let us adopt the notation, $W_i=2^iW$ where i Є (0,m) is called “backoff stage.” Let be the stochastic process representing the backoff stage (0,1,2,….,m) of the station at time t.

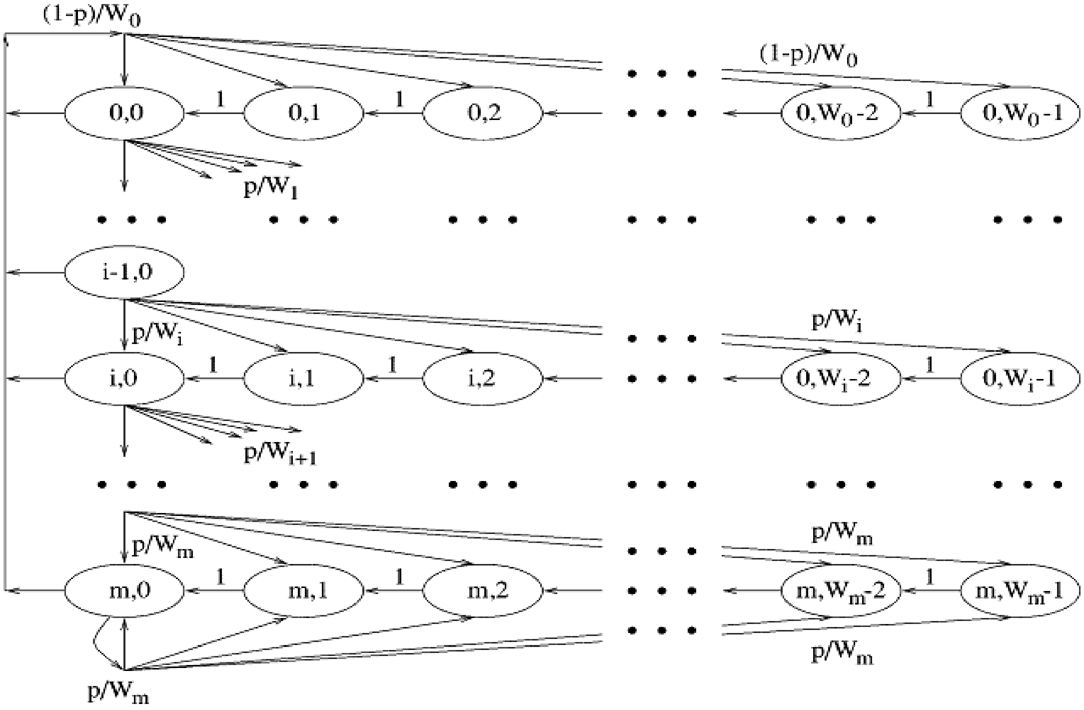

Figure 2: Discrete Markov chain representation of "backoff stages"

We make a key approximation in our model is that, at each transmission attempt, and regardless of the number of retransmissions suffered, each packet collides with constant and independent probability p. Once independence is assumed, and is supposed to be a constant value, it is possible to model the bidimensional process {s(t),b(t)} with the discrete-time Markov chain depicted in Fig. 2. In this Markov chain, the only non null one-step transition probabilities are:

$$\begin{cases} P\{i,k \mid i,k+1\}=1 & k\in(0,W_i-2) \quad i\in(0,m) \\ P\{0,k \mid i,0\}=(1-p)/W_0 & k\in(0,W_0-1) \quad i\in(0,m) \\ P\{i,k \mid i-1,0\}=p/W_i & k\in(0,W_i-1) \quad i\in(1,m) \\ P\{m,k \mid m,0\}=p/W_m & k\in(0,W_m-1). \end{cases}$$

Due to chain regularities, by simplification we obtain the probability that a station transmits in a randomly chosen time as

$$\tau=\sum_{i=0}^{m} b_{i,0}=\frac{b_{0,0}}{1-p}=\frac{2(1-2p)}{(1-2p)(W+1)+pW(1-(2p)^m)}.$$

The uniqueness of the solution is then proved and the result obtained above by using queueing theory is used to analyze the saturation throughput for different access mechanisms and the results are validated by simulation.