Lecture 8 IEEE802.11 DCF Performance

IEEE802.11 DCF Basic Access Mechanism

- A station with a new packet to transmit monitors the channel activity.
  - If the channel is idle for a period of time equal to a distributed interframe space (DIFS), the station transmits.
  - If the channel is sensed busy (either immediately or during the DIFS),
    - the station persists to monitor the channel until it is measured idle for a DIFS.
- The station generates a random backoff interval before transmitting to minimize the probability of collision with packets being transmitted by other stations. (CA = Collision Avoidance)
- In addition, to avoid channel capture, a station must wait a random backoff time between two consecutive new packet transmissions, even if the medium is sensed idle in the DIFS time

IEEE802.11 DCF Basic Access Mechanism

- For efficiency reasons, DCF employs a discrete-time backoff scale.
  - The time immediately following an idle DIFS is slotted, and a station is allowed to transmit only at the beginning of each slot time.
  - The slot time size, σ, is set equal to the time needed at any station to detect the transmission of a packet from any other station.
- DCF adopts an exponential backoff scheme. At each packet transmission, the backoff time CW is ***uniformly*** chosen in the range (CW_{min}, CW_{max}).
- The value *CW* is called contention window, and depends on the number of transmissions failed for the packet. At the first transmission attempt, is set equal to a value CWmin called minimum contention window. After each unsuccessful transmission, is doubled, up to a maximum value CWmax.

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- 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.
- 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).
- 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.

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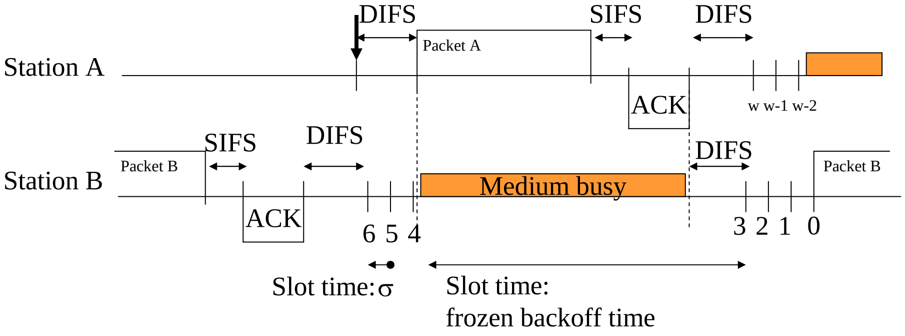
- If the transmitting station does not receive the ACK within a specified $ACK_{Timeout}$, or it detects the transmission of a different packet on the channel, it reschedules the packet transmission according to the given backoff rules.

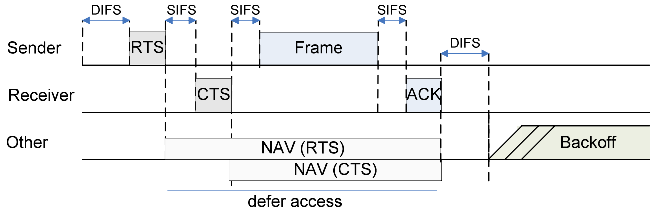


IEEE802.11 DCF RTS-CTS Access Mechanism

- A station that wants to transmit a packet, waits until the channel is sensed idle for a DIFS, follows the backoff rules explained above, and then, instead of the packet, preliminarily transmits a special short frame called request to send (RTS).
- When the receiving station detects an RTS frame, it responds, after a SIFS, with a clear to send (CTS) frame.
- The transmitting station is allowed to transmit its packet only if the CTS frame is correctly received.
- The frames RTS and CTS carry the information of the length of the packet to be transmitted. This information can be read by any listening station, which is then able to update a network allocation vector (NAV) containing the information of the period of time in which the channel will remain busy.

IEEE802.11 DCF RTS-CTS Access Mechanism

- When a station is *hidden* from either the transmitting or the receiving station, by detecting just one frame among the RTS and CTS frames, it can suitably delay further transmission, and thus avoid collision.
- The RTS/CTS mechanism is very effective in terms of system performance, especially when large packets are considered, as it reduces the length of the frames involved in the contention process.
- If perfect channel sensing would be possible, then collision could only happen among the short RTS packets and thus the time lost due to collisions would be much shorter compared to the basic access mechanism.



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- Consider saturated traffic conditions, in which all the *n* users always have packet ready for transmission.
- The channel is assumed to be perfect (no packet drop, no capture)
- Let τ denote the probability that a given station transmits a packet in randomly chosen slot time.
- A collision happens with probability *p*.
- In order to make the analysis tractable, we make the approximation that the collision probability is constant and the same for all stations regardless of the transmissions already suffered.

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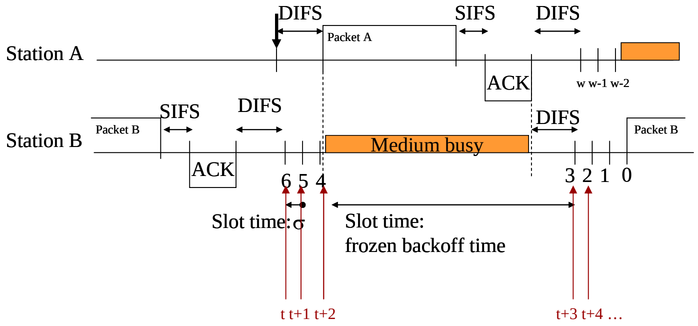
- Let $b(t)$ denote the backoff time counter for a given station at discrete slot time t. The slot time corresponds to the time instances when the backoff counter value is changed.



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- Let us define
  - $W=CW_{min}$
  - $CW_{max}=2^{m}\,CW_{min}$
  - $W_i=2^iW$, $i=0,1,2,\ldots m$
- Let $s(t)$ denote the backoff stage of the station at slot time t.
- Since the collision probability is p is assumed to be independent of the number of retransmission attempt, we can no model the behaviour of the MAC protocol as two dimensional Markov chain.

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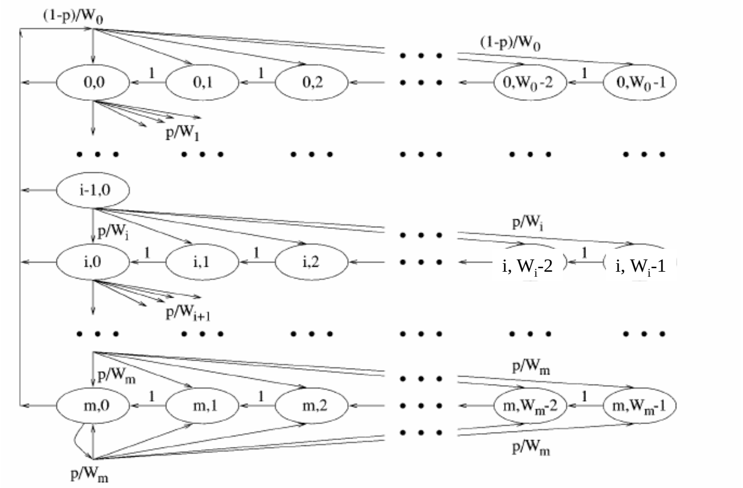

G. Bianchi, “Performance of the IEEE802.11 Distributed Coordination Function,”
IEEE Journal on Seleceted Areas in Communications, Vol. 18, No. 3, March 2000

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- Let P{i,k|j,l}=Pr{s(t+1)=1,b(t+1)=k|s(t)=j,b(t)=l}
- The state transition probabilities in the Markov chain can thus be written as

$$\Pr\left\{i,k\,|\,i,k+1\right\}=1,\quad k\in(0,W_i-2),\quad i\in(0,m)$$

$$\Pr\left\{0,k\,|\,i,0\right\}=\left(1-p\right)\frac{1}{W_0},\quad k\in(0,W_0-1),\quad i\in(0,m)$$

$$\Pr\left\{i,k\,|\,i-1,0\right\}=p\frac{1}{W_i},\quad k\in(0,W_i-1),\quad i\in(1,m)$$

$$\Pr\left\{m,k\,|\,m,0\right\}=p\frac{1}{W_m},\quad k\in(0,W_m-1)$$

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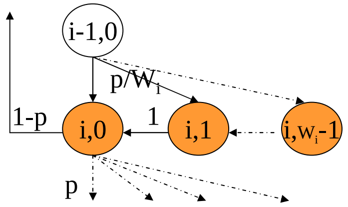
- Let $b_{i,k} = \lim_{t\to\infty} \Pr\{s(t)=i, b(t)=k\}, \quad k \in (0, W_i - 1), \quad i \in (1, m)$
  be the stationary state distribution of the Markov chain.
- Consider stage 0<*i*<*m*



Flow out = Flow in

$$b_{i,W_i-1} = p\frac{1}{W_i} b_{i-1,0}$$

$$b_{i,W_i-2} = p\frac{1}{W_i} b_{i-1,0} + b_{i,W_i-1} = p\frac{2}{W_i} b_{i-1,0}$$

$$\vdots$$

$$b_{i,k} = p\frac{W_i - k}{W_i} b_{i-1,0} \quad (1)$$

- It follows from (1) that $b_{i,0} = p b_{i-1,0} \Rightarrow b_{i,0} = p^i b_{0,0}, \quad i = 1, 2, \ldots, m-1 \quad (2)$

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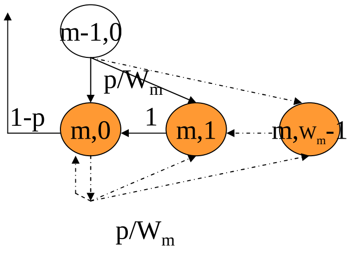
- For the last stage we have



Flow out = Flow in

$$b_{m,W_m-1} = p\frac{1}{W_m} b_{m-1,0} + p\frac{1}{W_m} b_{m,0} = p\frac{1}{W_m}\left(b_{m-1,0} + b_{m,0}\right)$$

$$b_{m,W_m-2} = p\frac{1}{W_m} b_{m-1,0} + p\frac{1}{W_m} b_{m,0} + b_{m,W_m-1} = p\frac{2}{W_m}\left(b_{m-1,0} + b_{m,0}\right)$$

$$\vdots$$

$$b_{m,k} = p\frac{W_m - k}{W_m}\left(b_{m-1,0} + b_{m,0}\right) \quad (3)$$

- It follows from (2) and (3) that

$$b_{m,0} = p\left(b_{m-1,0} + b_{m,0}\right) \Rightarrow b_{m,0} = \frac{p}{1-p} b_{m-1,0} = \frac{p}{1-p} p^{m-1} b_{0,0} = \frac{p^m}{1-p} b_{0,0} \quad (4)$$

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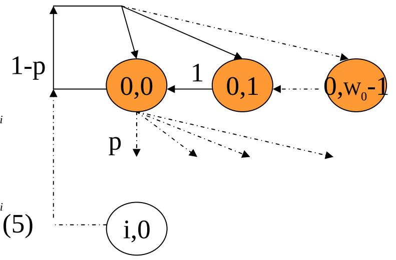
- For the first stage i=0, we have

$$b_{0,W_0-1} = (1-p)\frac{1}{W_0}\sum_{i=0}^{m} b_{0,i}$$

$$b_{0,W_0-2} = b_{0,W_0-1} + (1-p)\frac{1}{W_0}\sum_{i=0}^{m} b_{0,i} = (1-p)\frac{2}{W_0}\sum_{i=0}^{m} b_{0,i}$$

$$\vdots$$

$$b_{0,k} = b_{0,k+1} + (1-p)\frac{1}{W_0}\sum_{i=0}^{m} b_{0,i} = (1-p)\frac{W_0-k}{W_0}\sum_{i=0}^{m} b_{0,i} \qquad (5)$$



- It thus follows from (5) that

$$b_{0,0} = (1-p)\sum_{i=0}^{m} b_{i,0} \Rightarrow \sum_{i=0}^{m} b_{i,0} = \frac{b_{0,0}}{(1-p)} \qquad (6)$$

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- The state probabilities must sum to 1

$$\begin{cases} b_{i,k} = p\dfrac{W_i-k}{W_i}b_{i-1,0} \\ b_{i,0} = p^i b_{0,0} \end{cases} \Rightarrow b_{i,k} = p^i\frac{W_i-k}{W_i}b_{0,0} = \frac{W_i-k}{W_i}b_{i,0}$$

- The probabilities must sum to 1

$$\sum_{i=0}^{m}\sum_{k=0}^{W_i-1} b_{i,k} = \sum_{i=0}^{m}\sum_{k=0}^{W_i-1}\frac{W_i-k}{W_i}b_{i,0} = \sum_{i=0}^{m} b_{i,0}\sum_{k=0}^{W_i-1}\frac{W_i-k}{W_i} = \sum_{i=0}^{m} b_{i,0}\frac{W_i+1}{2}$$

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

$$\Rightarrow b_{0,0} = \frac{2(1-2p)(1-p)}{(1-2p)(W+1)+pW\left(1-(2p)^m\right)}$$

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- We can now express the probability τ that a station transmits during a randomly chosen slot time. The transmission occurs when the backoff time counter is equal to zero, regardless of the backoff state, hence

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

- The probability that there is collision is that more than one user tries transmission at the same slot time:

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

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- Probability that at least one user transmits

$$\boxed{P_{tr}=1-(1-\tau)^{n}}$$

- Probability of succesful transmission conditioned that at least one user transmits

$$\boxed{\begin{aligned}P_s&=\Pr\left\{\text{exactly one user transmit}\,\middle|\,\text{at least one user transmit}\right\}\\&=\frac{\Pr\{\text{exactly one user transmit}\}}{\Pr\{\text{at least one user transmit}\}}=\frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^{n}}\end{aligned}}$$

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- The trhoughput is

$$S = \frac{P_{tr} P_s \mathrm{E}\{P\}}{(1-P_{tr})\sigma + P_{tr} P_s T_s + P_{tr}(1-P_s) T_c}$$

where

- δ is the slot length (propagation delay)
- P_s is the probability of successful transmission in a busy period
- P_{tr} is the probability that there is transmission at given slot
- E{P} is the expected length of the packet
- T_s is the average time the channel is busy in case of succesful transmission
- T_c is the is the time the channel is busy in case of collision

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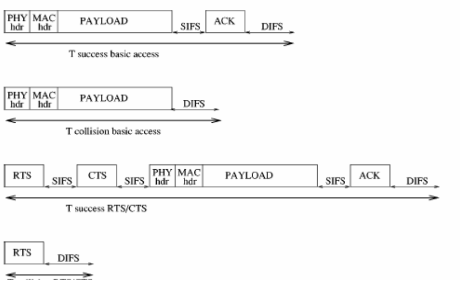
- Basic access method:

$$\begin{aligned} T_s &= H + \mathrm{E}\{P\} + SIFS + \sigma \\ &\quad + ACK + DIFS + \sigma \\ T_c &= H + \mathrm{E}\{P\} + DIFS + \sigma \end{aligned}$$

where H denotes the total length of PHY and MAC headers

- RTS-CTS handshake

$$\begin{aligned} T_s &= RTS + SIFS + \sigma + CTS + SIFS + \\ &\quad H + \mathrm{E}\{P\} + SIFS + \sigma \\ &\quad + ACK + DIFS + \sigma \\ T_c &= RTS + DIFS + \sigma \end{aligned}$$



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- The throughput can be written as

$$S = \frac{\mathrm{E}\{P\}}{T_s + \dfrac{\sigma\left(1-P_{tr}\right)/P_{tr} + \left(1-P_s\right)T_c}{P_s}}$$

Hence, the throughput is maximized if

$$\frac{P_s}{\left(1-P_{tr}\right)/P_{tr} + \left(1-P_s\right)\dfrac{T_c}{\delta}} = \frac{n\tau\left(1-\tau\right)^{n-1}}{\dfrac{T_c}{\delta} - \left(1-\tau\right)^n\left(\dfrac{T_c}{\delta} - 1\right)}$$

is maximized.

Maximum occurs when

$$\left(1-\tau\right)^n - \frac{T_c}{\delta}\left(n\tau - \left(1-\left(1-\tau\right)^n\right)\right) = 0$$

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- For low load $\tau << 1$

$$\left(1-\tau\right)^n \approx 1 - n\tau + \frac{n(n-1)}{2}\tau^2$$

- The transmit probability that maximizes throughput is given by

$$\tau^* = \frac{\sqrt{\dfrac{n + 2\left(n-1\right)\left(\dfrac{T_c}{\delta} - 1\right)}{n}} - 1}{\left(n-1\right)\left(\dfrac{T_c}{\delta} - 1\right)} \approx \frac{1}{n\sqrt{\dfrac{T_c}{2\delta}}}$$

- Hence, the throughput depends only on the network size and on the system parameters *m* and *W*.

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- The transmission probability depends on the parameters m and W which should be tuned such that

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW\left(1-(2p)^m\right)} \approx \frac{1}{n\sqrt{\frac{T_c}{2\delta}}}$$

- For m=0, we have

$$\tau = \frac{2}{(W+1)}$$

Hence, the window size should be selected as

$$\boxed{W \approx n\sqrt{2\frac{T_c}{\delta}}}$$

That is, the optimal performance is obtained when the window size depends on the number of users and the average transmission time of the packets.

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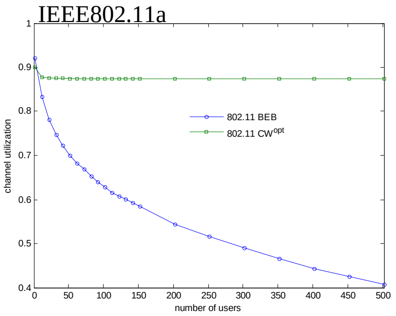
- In practice, it is very difficult to estimate *n.*
- BEB can be viewed as an attempt to estimate the optimal window size, but it does not do a very good job for large n.
- A comparison between
  - 802.11 BEB (normal)
  - 802.11 CW^{opt}, uses the optimal CW
  - BEB used in 802.11 is far from optimal,
  - especially for large number of users
  - for few stations the result is satisfactory



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