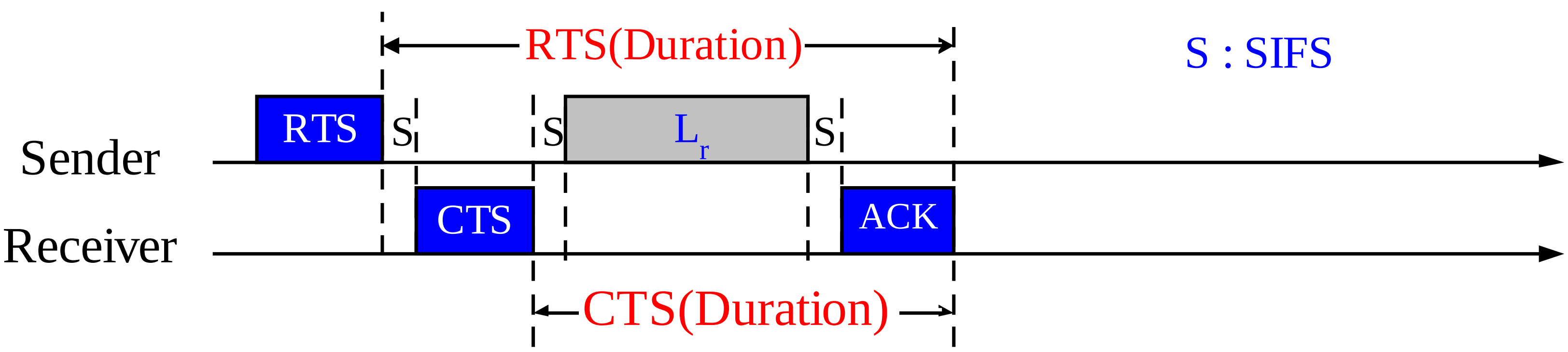
A Safe Multiple Access-Rates Transmission (SMART) Scheme for IEEE 802.11 Wireless Networks

- Outline -

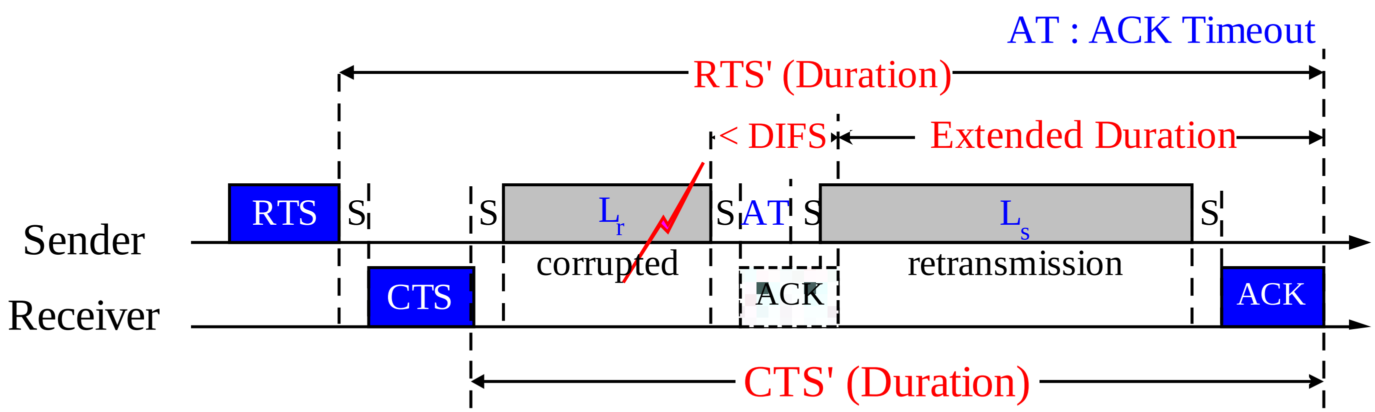
- Introduction
- System Description
  - SMART Scheme
  - ESMART Scheme
- System Analysis
- Simulation Model and Simulation Results
- Conclusions

- Introduction -

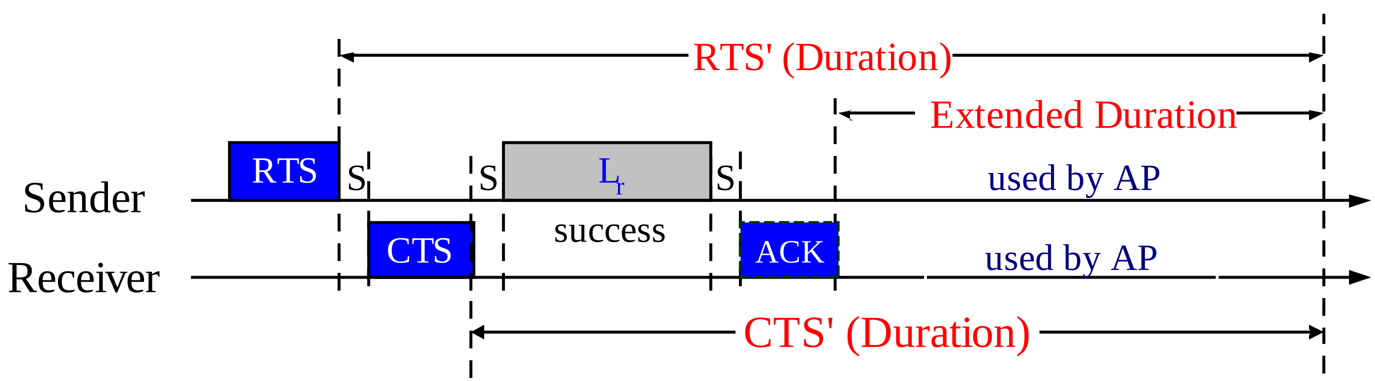


(a) CSMA/CA Standard

- SMART Scheme -

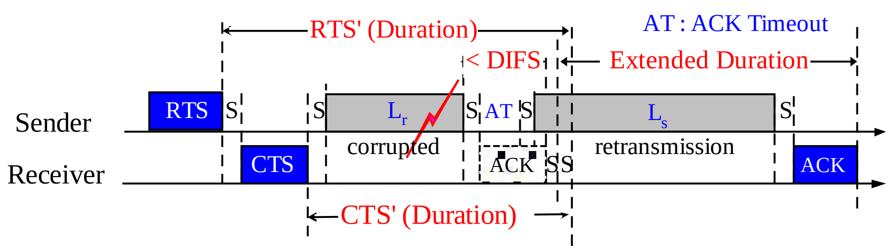


(b) SMART scheme (with retransmission)

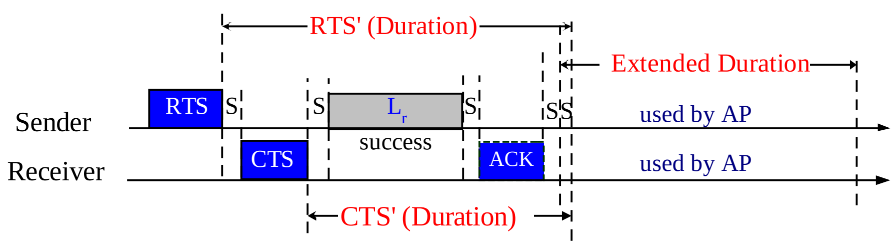


(c) SMART scheme (without retransmission)

- ESMART Scheme -

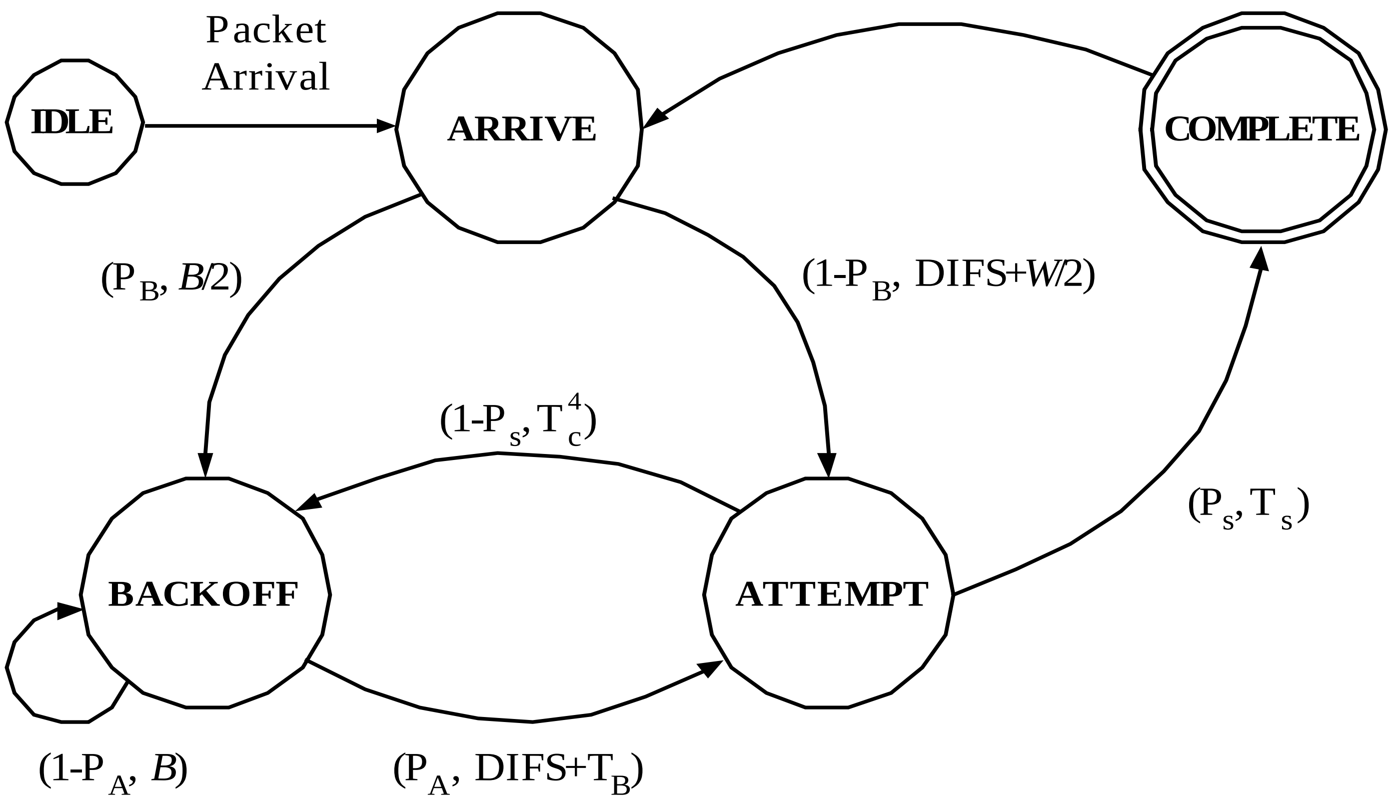


(a) ESMART scheme (with retransmission)



(b) ESMART scheme (without retransmission)

- System Analysis -



- System Analysis -

Diagram

Variable	Description	Variable	Description
$P_n(t)$	the probability of exactly *n* packets arriving at a station during a time interval *t*	P_0	the probability that the frame is successfully transmitted
λ	mean packet arrival rate	L_r	the mean periods of transmitting a data frame at transission rate *r*
n	positive integer	L_s	the mean periods of transmitting a data frame at transission lower rate *s*
$P_S(t)$	the probability that the RTS frame is successfully transmitted	L_{Ar}	the mean period of transmitting a data frame at transission rate *r* by AP
Λ	the total packet arrival rate	nL_{Ar}	AP transmit n frames in reservation period
N	the number of stations	D	the average access delay of a RTS/CTS handshaking in SMART
T_s^4	the expected time intervals between the intervening renewal intervals for at least one successful handshaking	D_B	the delay accumulated by each transmission spending in BACKOFF state

- System Analysis -

T_c^4	the expected time intervals between the intervening renewal intervals for at least one collision occurrence	D_A	the delay caused by staying in ATTEMPT state
T_s	instead of T_s^4	T_B	the mean backoff time of each station
P_B	the state transits to BACKOFF state with probability	S	the exact user data rate and measured in Mbps. The approximate goodput in SMART
W	the minimum backoff window size	M	the mean data frame sizes sent by station
P_s	A station may successfully starts to transmit a data frame with the probability	M_{AP}	the mean data frame sizes sent by AP
P_A	The state transits to ATTEMPT state with the probability	T_I	the idle period in each contention
I	average idle periods	D_{ES}	defined as the average access delay
B	average busy period in SMART	B_{ES}	average busy period in ESMART
Y	the average time between the first and the last RTS of busy period	T_{tES}	the total transmission time in each contention period in ESMART
T_t	the total transmission time in each contention period in SMART	S_{ES}	the approximate goodput in ESMART

- System Analysis -

- $P_n(t)$ is the probability of exactly n packets arriving at a station during a time interval t as given by

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

- The radio communication starts with a RTS frame, and the probability that the RTS frame is successfully transmitted.

$$P_S(t) = e^{-\Lambda t}$$

- System Analysis -

- Let T_s^4 and T_c^4 denote the expected time intervals between the intervening renewal intervals for at least one successful handshaking and collision occurrence, respectively, where the superscript 4 is used for the IEEE 802.11 CSMA/CA 4-way handshake transmission.

$$T_s^4 = \text{RTS} + \tau + \text{SIFS} + \text{CTS} + \tau + \text{SIFS} + T_t + \tau + \text{SIFS} + \text{ACK}$$

$$T_c^4 = \text{RTS} + \tau + \text{SIFS}$$

- System Analysis -

- The probability P_B can be expressed as

$$P_B = \frac{B}{I + B}$$

- Where I and B are the average idle and busy periods, respectively .
- I can be expressed as $I = 1/\Lambda + \text{DIFS} + W/2$.
- The average busy period $B = Y + (1-P_s) + P_s T_s$

- System Analysis -

- The average busy period always consists of collision, successful transmission, and the average time between the first and the last RTS of busy period, where the average time is denoted by Y and is the same as in CSMA shown as

$$Y = \tau - \frac{1 - e^{-\Lambda\tau}}{\Lambda}$$

- System Analysis -

- The probability P_B from ARRIVE to BACKOFF will be
- $P_B = \tau -+ (1 - e^{-\Lambda\tau}) \times (\mathrm{RTS} + \tau + \mathrm{SIFS}) + e^{-\Lambda\tau} \times (\mathrm{RTS} + \tau + \mathrm{SIFS} + \mathrm{CTS} + \tau + \mathrm{SIFS} + T_t + \tau + \mathrm{SIFS} + \mathrm{ACK}) / \{ (1/\Lambda + \mathrm{DIFS} + W/2) + [\tau - + (1 - e^{-\Lambda\tau}) \times (\mathrm{RTS} + \tau + \mathrm{SIFS}) + e^{-\Lambda\tau} \times (\mathrm{RTS} + \tau + \mathrm{SIFS} + \mathrm{CTS} + \tau + \mathrm{SIFS} + T_t + \tau + \mathrm{SIFS} + \mathrm{ACK})] \}$

- System Analysis -

- T_t is total data transmission time in each contention period. and T_t can be expressed as

$$T_t = (1 - P_0) \times (L_r + L_s) + P_0 \times (L_r + n\, L_{Ar}).$$

- System Analysis -

- P_0 is the probability that a frame is successfully transmitted, and $1\text{-}P_0$ is the probability of unsuccessful transmission. L_r and L_s are the mean periods of transmitting a data frame at transmission rate r and lower rate s, respectively, while L_{Ar} indicates the mean period of transmitting frames at transmission rate r by AP. The relation between r and s can be given as

$$s = \begin{cases} \frac{r}{2} & if \;\; r > 2 \\ r & if \;\; r = 2 \end{cases}$$

- System Analysis -

- $n\,L_{Ar}$ means that AP may transmit n frames in reservation period, but it is limited by L_s, i.e., n is the largest integer such that $n\,L_{Ar}$ is less than or equal to L_s.
- D is defined as the average access delay and it is obtained by

$$D = P_B \times \left(\frac{B}{2} + D_B\right) + (1 - P_B) \times \left(\text{DIFS} + \frac{W}{2} + D_A\right)$$

- System Analysis -

- Where D_B is the delay accumulated by each transmission spending in BACKOFF state, and D_A is the delay caused by staying in ATTEMPT state. D_B can be given by

$$D_B = P_A \times (\mathrm{DIFS} + T_B + D_A) + (1 - P_A) \times (B + D_B)$$

- System Analysis -

- The state transits to ATTEMPT state with the probability of P_A, where P_A can be expressed as
- $P_A = e^{-\Lambda(DIFS+T_B)}$
- T_B is the mean backoff time of each station

$$T_B = \sum_{0}^{4}\left[P_s(\tau)\times(1-P_s(\tau))^n 2^{n-1}W\right]+1-P_s(\tau)^5 2^4 W$$

- System Analysis -

- D_B can further be solved as

$$D_B = \text{DIFS} + T_B + D_A + \frac{(1-P_A)}{P_A} \times B.$$

- Similarly, D_A is given by

$$D_A = P_S T_S + (1-P_S) \times (T_C^4 + D_B)$$

- D_A is further derived by above equation

$$D_A = T_S + \frac{(1-P_S)}{P_S} \times \left[T_c^4 + \text{DIFS} + T_B + \frac{(1-P_A) \times B}{P_A} \right]$$

- System Analysis -

- Finally D_B could be solved by D_A equation

$$D_B = DIFS + T_B + T_S + \frac{(1-P_S)}{P_S} \times \left[T_c^{\,4} + \mathrm{DIFS} + T_B + \frac{(1-P_A)\times B}{P_A} \right] + \frac{(1-P_A)\times B}{P_A}$$

- Finally, we can get the average access delay D by substituting D_A and D_B equation into D equation and the equation will be

$$D = P_B \times \left(\frac{B}{2} + \mathrm{DIFS} + T_B + T_S + (1-P_S)\times \left[T_c^{\,4} + \mathrm{DIFS} + T_B + \frac{(1-P_A)\times B}{P_A} \right] \times \frac{1}{P_s} + \frac{(1-P_A)\times B}{P_A} \right)$$
$$+ (1-P_B) \times \left(\mathrm{DIFS} + \frac{W}{2} + T_S + \frac{(1-P_S)}{P_S} \times \left[T_c^{\,4} + \mathrm{DIFS} + T_B + \frac{(1-P_A)\times B}{P_A} \right] \right).$$

- System Analysis -

- Goodput, *S*, is defined as the exact user data rate and measured in Mbps, where it excludes the overheads of control frames, backoff periods, PLCP (physical layer convergence protocol) preamble, PLCP/MAC headers, FCS (frame check sequence), inter-frame spaces and so on. Each successful contention period includes data transmission, thus the approximate goodput can be obtained by
- $$S = \frac{(1-P_0)P_0M + P_0(M + nM_{AP})}{(T_I + D)} = \frac{(2-P_0)P_0M + nP_0M_{AP}}{(T_I + D)}$$

- System Analysis -

- Where M and M_{AP} are the mean data frame sizes sent by station and AP, respectively, and T_I is the idle period in each contention period and given by

$$T_I = max(\frac{1}{\Lambda} - D, 0)$$

- System Analysis -

- Similarly, D_{ES} is defined as the average access delay in ESMART and obtained by

$$D_{ES} = P_B \times (\frac{B_{ES}}{2} + D_B) + (1 - P_B) \times (\text{DIFS} + \frac{W}{2} + D_A)$$

- The average busy period in ESMART, B_{ES}, can be obtained by

$$B_{ES} = Y + (1 - P_s) + P_s T_s$$

- *System Analysis* -

- The probability of ESMART P_B from ARRIVE to BACKOFF will be
- $P_B = \tau -+ (1 - e^{-\Lambda\tau}) \times (RTS + \tau + SIFS) + e^{-\Lambda\tau} \times (RTS + \tau + SIFS + CTS + \tau + SIFS + T_{tES} + \tau + SIFS + ACK) / \{ (1/\Lambda + DIFS + W/2) + [\tau - + (1 - e^{-\Lambda\tau}) \times (RTS + \tau + SIFS) + e^{-\Lambda\tau} \times (RTS + \tau + SIFS + CTS + \tau + SIFS + T_{tES} + \tau + SIFS + ACK)] \}$

- System Analysis -

- T_{tES} is total data transmission time in each contention period. T_{tES} can be expressed as
- $T_{tES} = (1 - P_0) \times (L_r + L_s) + P_0 \times (L_r + L_{Ar})$.

- System Analysis -

- Thus, we can get the average access delay D_{ES} and the equation will be

$$D_{ES} = P_B \times \left(\frac{B}{2} + \text{DIFS} + T_B + T_S + (1-P_S) \times \left[T_c^{4} + \text{DIFS} + T_B + \frac{(1-P_A)\times B}{P_A} \right] \times \frac{1}{P_s} + \frac{(1-P_A)\times B}{P_A} \right)$$

$$+ (1-P_B) \times \left(\text{DIFS} + \frac{W}{2} + T_S + \frac{(1-P_S)}{P_S} \times \left[T_c^{4} + \text{DIFS} + T_B + \frac{(1-P_A)\times B}{P_A} \right] \right).$$

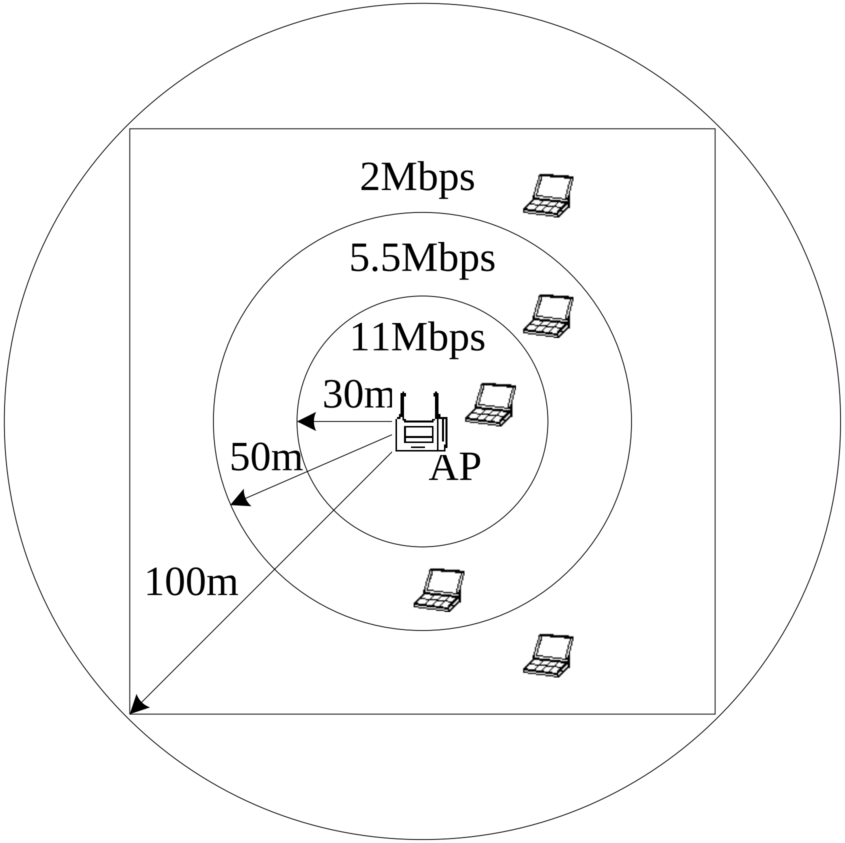
- Finally, the approximate goodput in ESMART, S_{ES}, can be obtained by

$$S_{ES} = \frac{(1-P_0)P_0 M + P_0(M + M_{AP})}{(T_I + D_{ES})} = \frac{(2-P_0)P_0 M + P_0 M_{AP}}{(T_I + D_{ES})}$$

- Simulation Model -

- The simulation model as follows
- All mobile stations support 2, 5.5, 11 Mbps transmission rates.
- All control frames are sent at 2 Mbps.
- The propagation delay is neglected.
- All mobile stations are active (not in power-saving mode).
- AP is static and located at the center of simulated area.

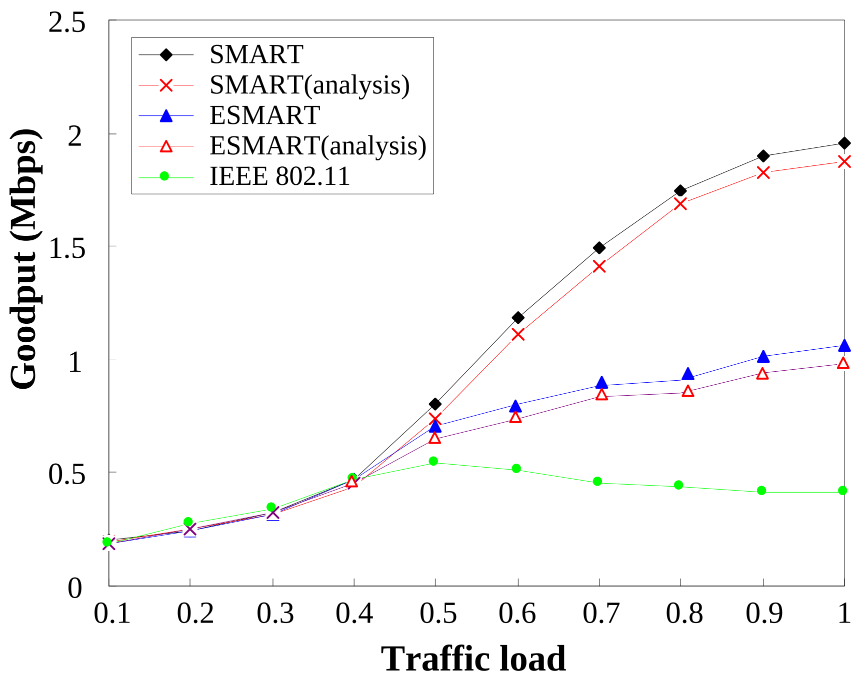
- Simulation Model -



- Simulation Model -

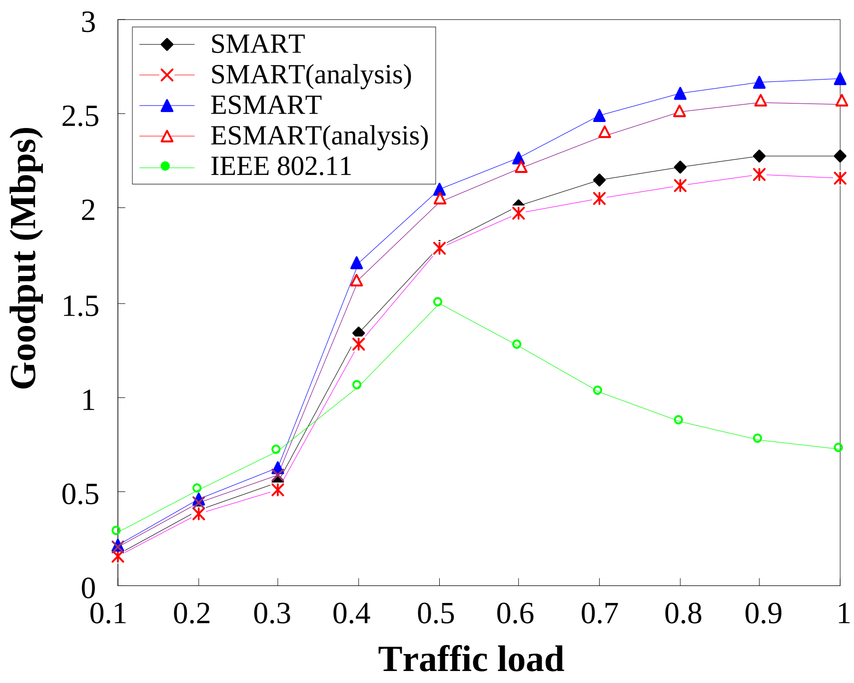
Parameters	Normal values
Transmission rate of data	2, 5.5, 11 Mbps
Transmission rate of control	2 Mbps
Slot time	20 μs
SIFS period	10 μs
DIFS period	50 μs
RTS frame period (length)	80 μs (160 bits)
CTS frame period (length)	56 μs (112 bits)
ACK frame period (length)	56 μs (112 bits)
Size of CW_{min}	31 slots
Size of CW_{max}	1023 slots
Number of nodes	10
Average frame size	30 slots

- Simulation Results -



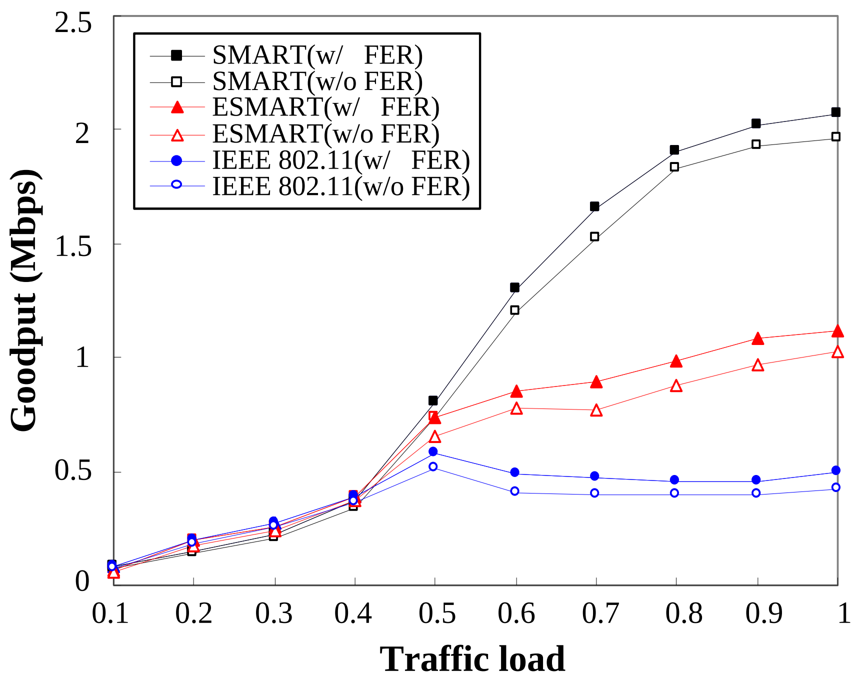
- Figure 5.2 Comparisons of goodputs obtained by analysis and simulation, the average data length of 100 and 1000 bytes at AP and stations, respectively.

- Simulation Results -



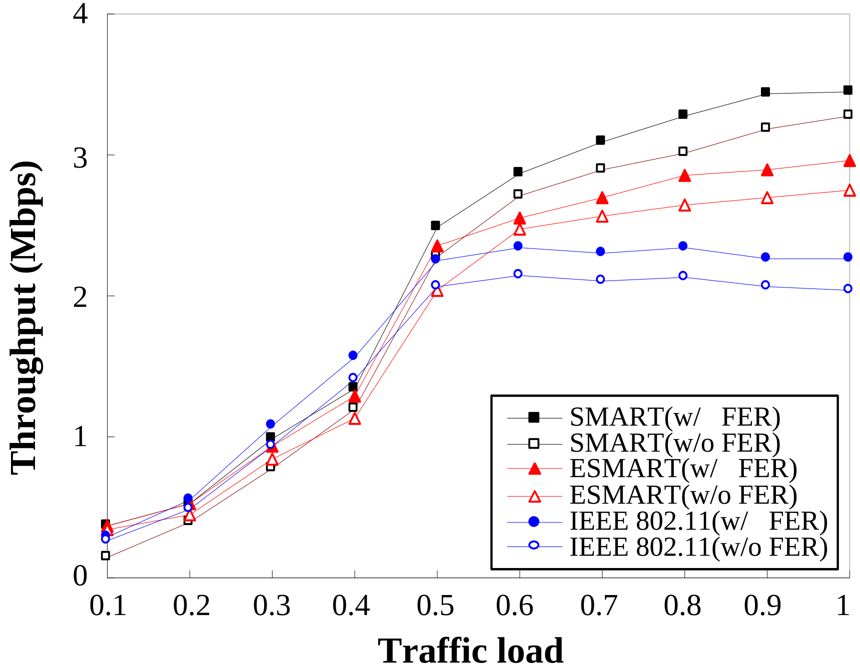
- Figure 5.3 Comparisons of goodputs obtained by analysis and simulation, the average data length of 1000 bytes at both AP and stations.

- Simulation Results -



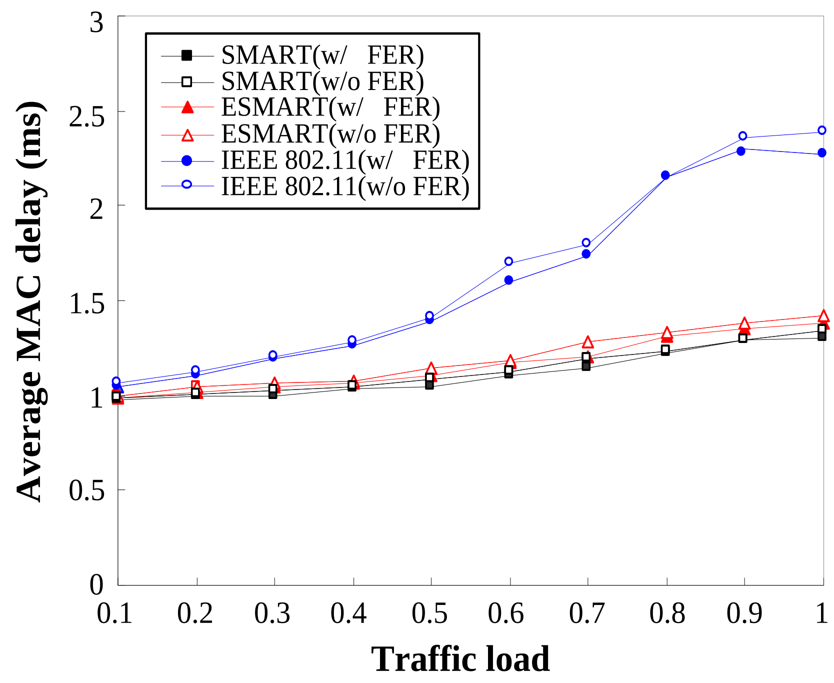
- Figure 5.4 Comparisons of goodput obtained from SMART, ESMART, and IEEE 802.11 with or without FER factor against traffic load.

- Simulation Results -



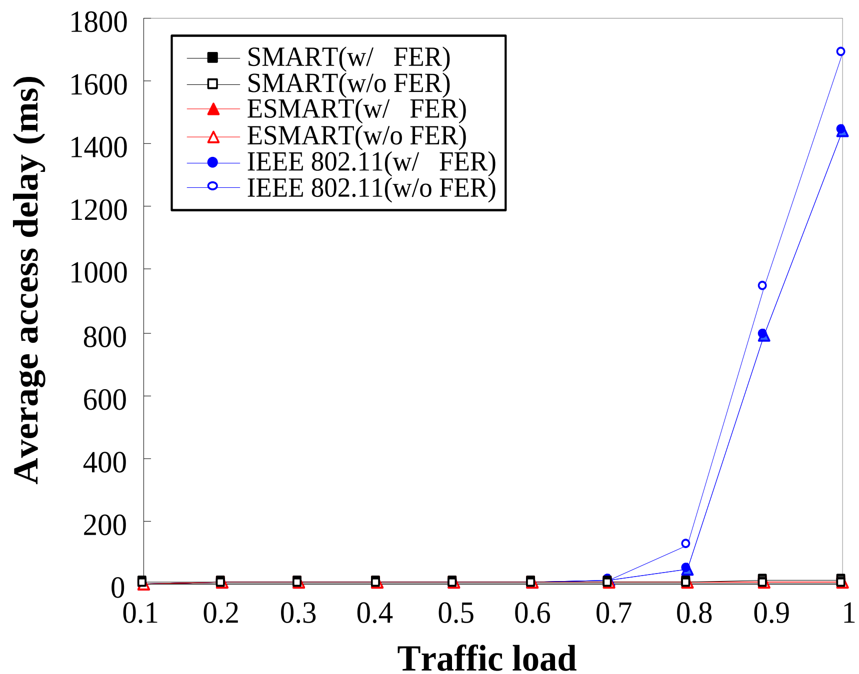
- Figure 5.5 Comparisons of throughput obtained from SMART, ESMART, and IEEE 802.11 with or without FER factor against traffic load.

- Simulation Results -



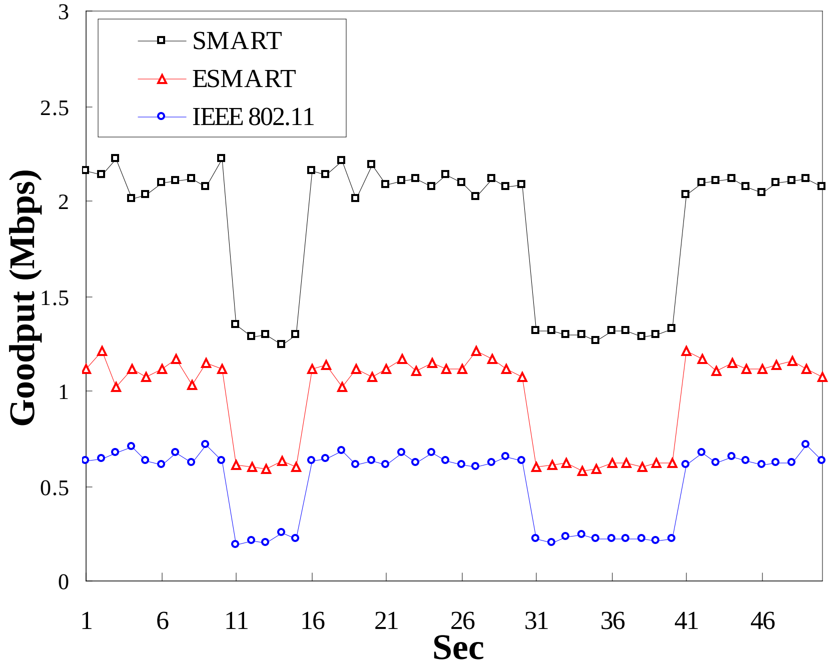
- Figure 5.6 Comparisons of average MAC delay obtained from SMART, ESMART, and IEEE 802.11 with or without FER factor against traffic load.

- Simulation Results -



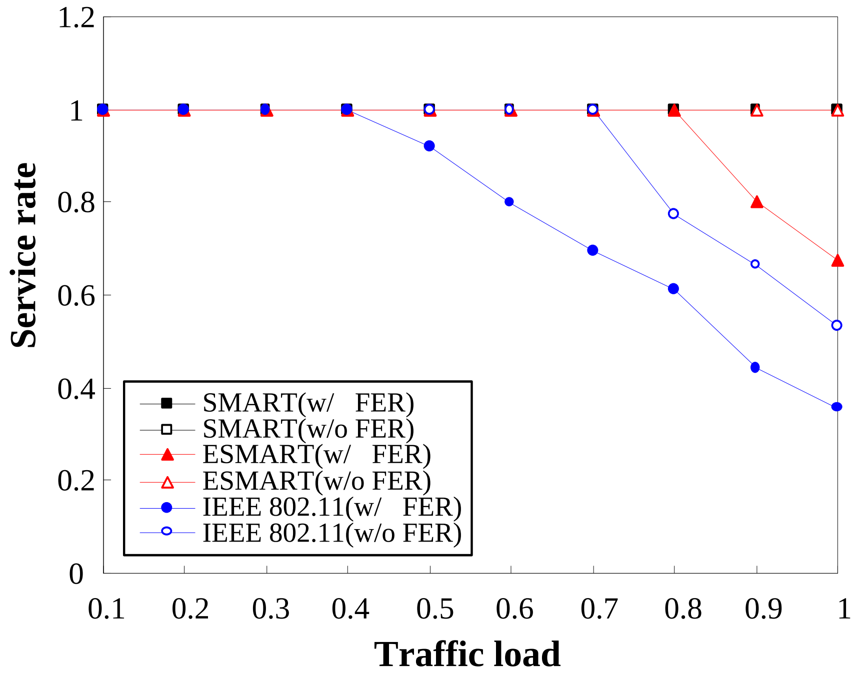
- Figure 5.7 Comparisons of average access delay obtained from SMART, ESMART, and IEEE 802.11 with or without FER factor against traffic load.

- Simulation Results -



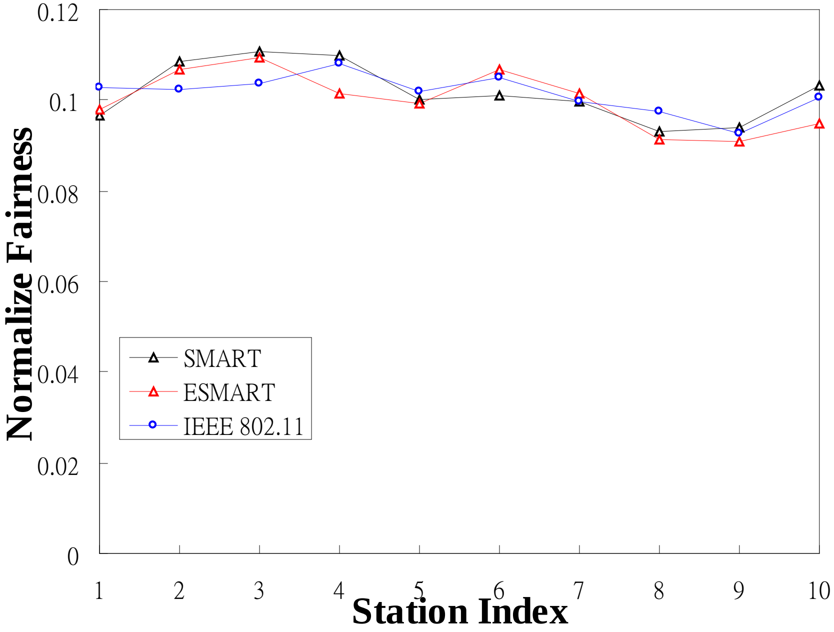
- Figure 5.8 Total traffic received in all stations.

- Simulation Results -



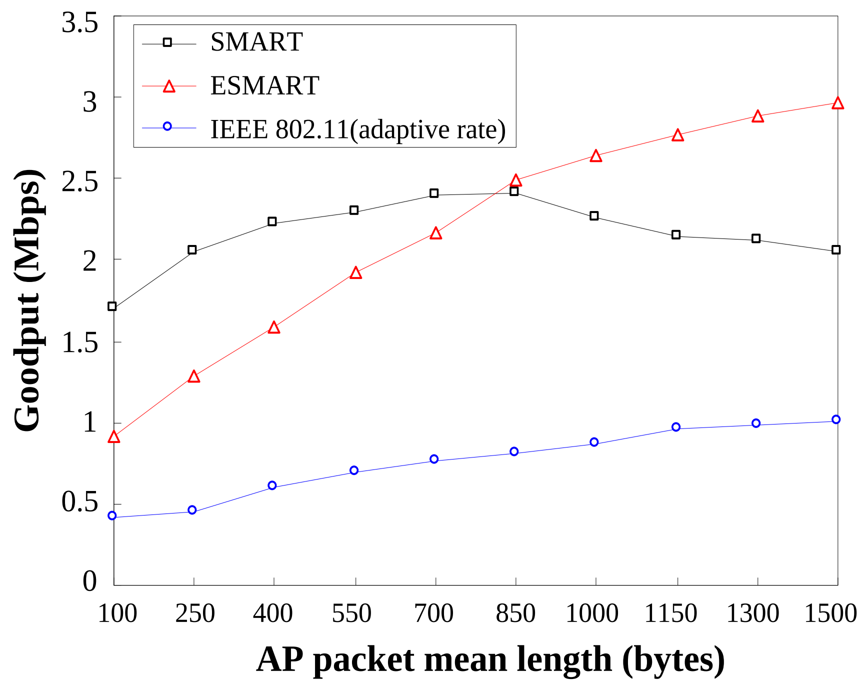
- Figure 5.9 Comparisons of service rate obtained from SMART, ESMART, and IEEE 802.11 with or without FER factor against traffic load.

- Simulation Results -



- Figure 5.10 The transmitting fairness of each station is simulated by the SMART, ESMART, and IEEE 802.11.

- Simulation Results -



- Figure 5.11 Goodput against mean packet length of AP when the traffic load is 80% and without frame error.

- Conclusions -

- SMART scheme provides reliable transmission by reserving a retransmission period. The sender will retransmit a frame right away by using a lower transmission rate to make sure of successful retransmission if any error occurs.

- Conclusions -

- The reserved period will be taken by AP. Based on this scheme, more than one frame could be served for each transmission opportunity and the channel utilization and network throughput would become higher.

- However, SMART seems to be a good scheme except that light traffic load and long packet length. Instead, ESMART is used to improve the bandwidth waste.