Carrier Sense Multiple Access Technique

FEP3210

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Overview

- CSMA
- Non-persistent CSMA
- Slotted CSMA
- CSMA/CD

Problem statement

- Collisions in medium access diminish the throughput
- ALOHA: user selfishness
- What if the users acted more ’politely’?

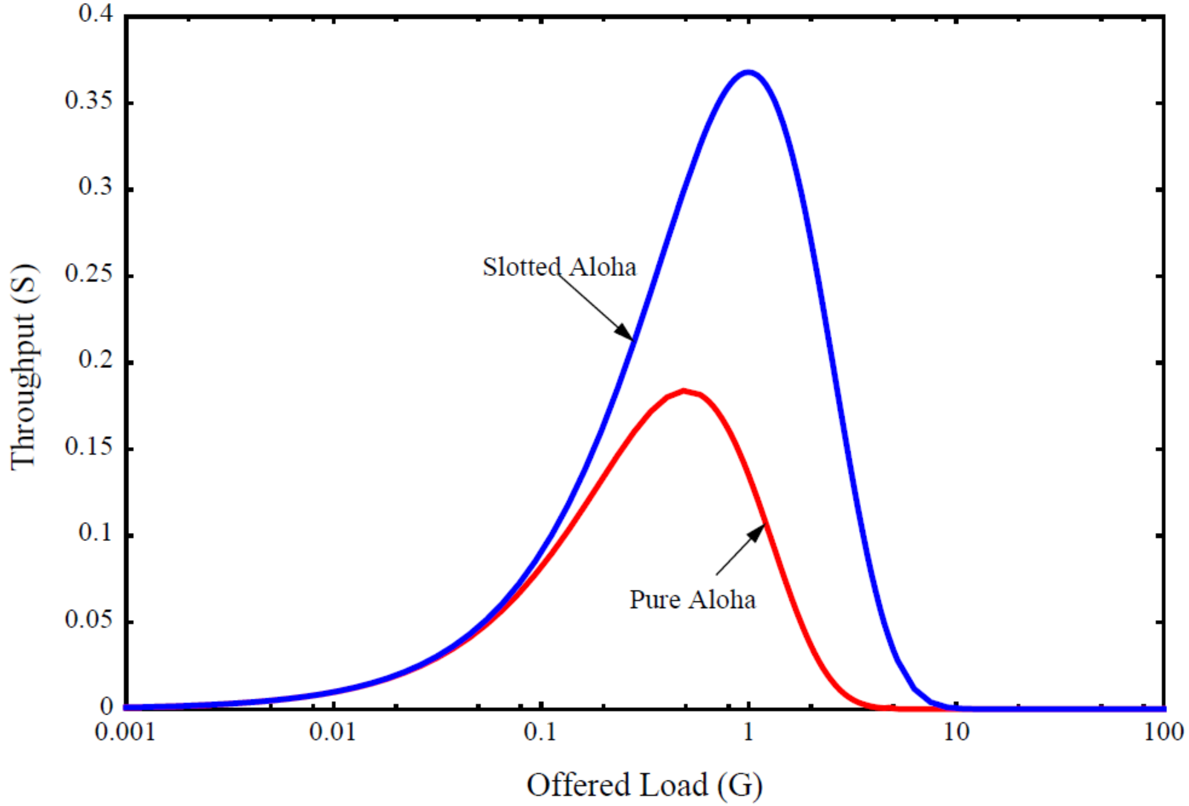


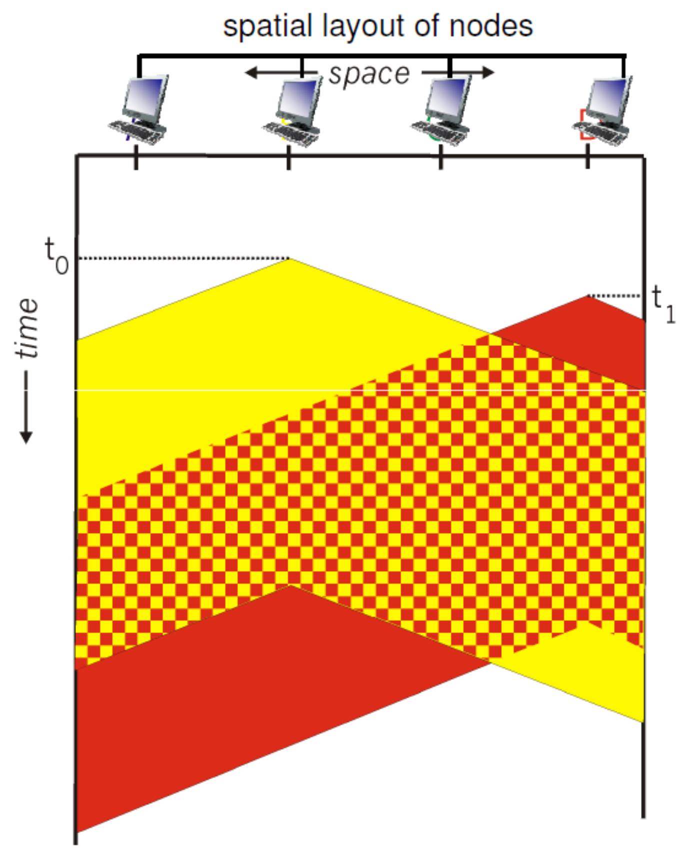
FIGURE 3.2: Throughput-Load of Pure and Slotted Aloha

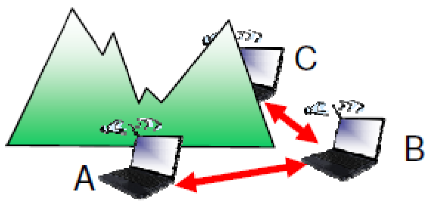
CSMA

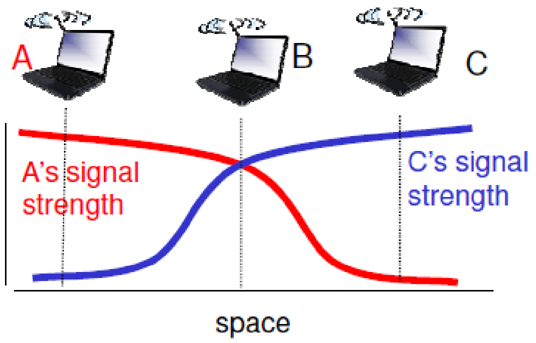
- Carrier Sense Multiple Access
- Listening prior to transmission
  - If channel idle -> transmit
  - If channely busy -> postpone the transmission
- The flavors of CSMA:
  - Non-persistent
  - 1-persistent
  - p-persistent
- Listening modes of IEEE 802.15.4
  - Carrier sense
  - Energy detection
  - Hybrid

CSMA problems

- Does listening solve the collision issue?
- Underlying issues
  - Finite propagation speed
  - Hidden terminal problem
  - When to retransmit?





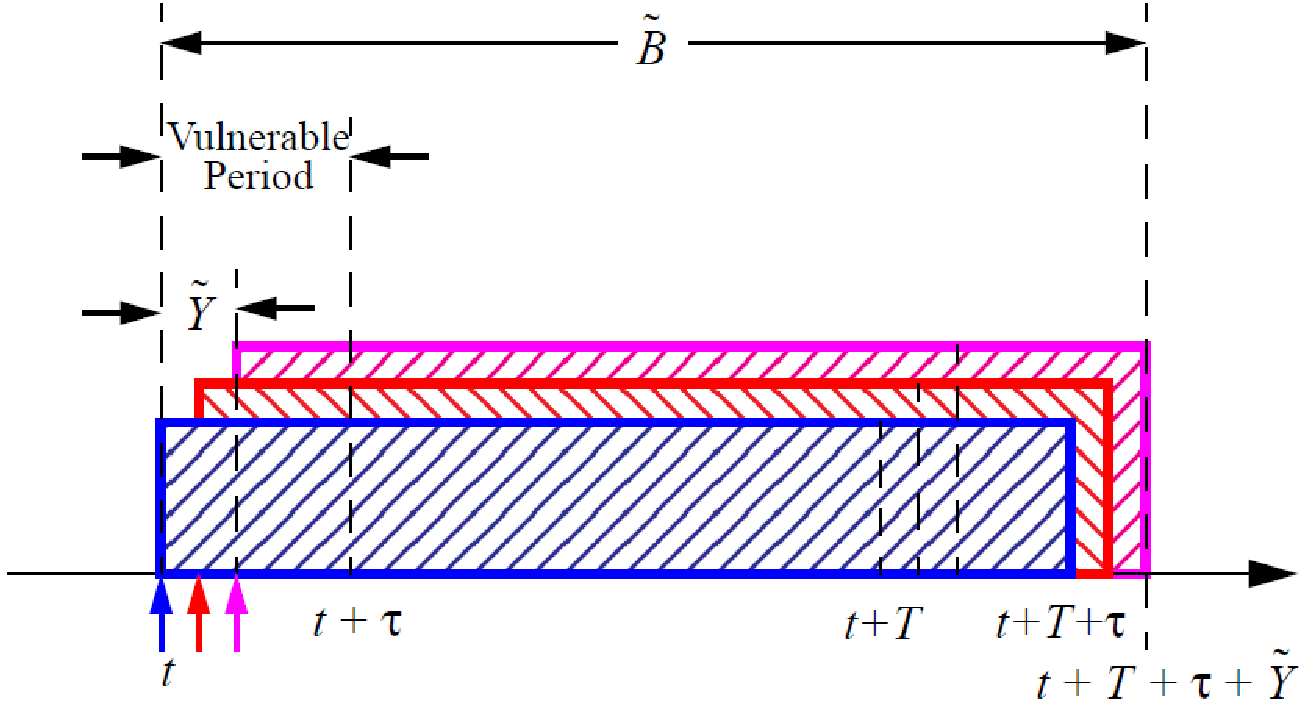


Non-persistent CSMA

- If channel sensed busy, postpone transmission to some random time in the future
- Assumptions for analysis:
  - Infinite user population
  - Total packet generation rate $\sim Poiss(\lambda)$
  - Equally long packets (T sec)
  - Traffic on the channel (new + retransmitted packets) $\sim Poiss(g)$
  - All users equally far from each other, with propagation delay τ
  - Normalized propagation time $a \triangleq \tau / T$

Non-persistent CSMA

- The first τ seconds of transmission is the **vulnerable period**
- **Transmission period duration** $\tilde{B}$ (mean value is B) is a random variable assuming values from $[T + \tau, T + 2\tau]$
- $\tilde{B}$ comprises **both useful and colliding** transmissions

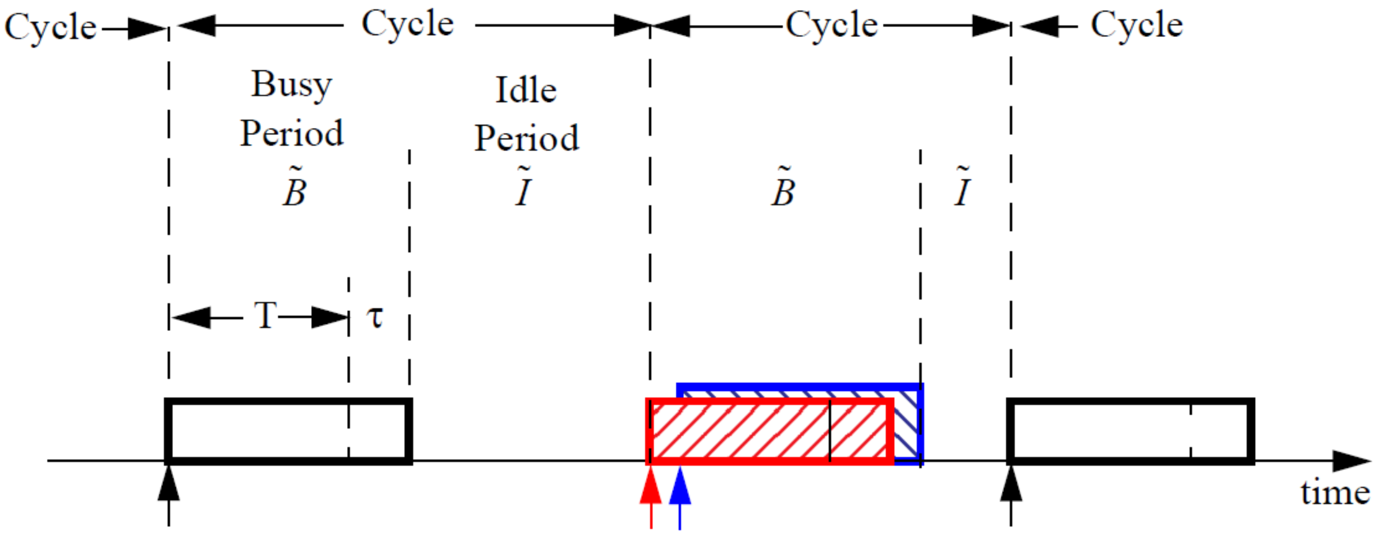


(b) Unsuccessful Transmission Period

Non-persistent CSMA

- The starting instant of a cycle is a **renewal point** – packet scheduling is memoryless
- **Idle period duration** is a r.v. $\tilde{I}$ (mean value is I)
- $\widetilde{U}$ (mean is U) is the **duration of a successful transmission**
- **Throughput** S can be found as:

$$S = \frac{U}{B + I}$$



(a) Cycle Structure

Non-persistent CSMA

- The **CDF of idle period** is:

$$F_I(x) = \text{Prob}[\tilde{I} \le x] = 1 - \text{Prob}[\tilde{I} > x]$$
$$= 1 - P[\text{No packet scheduling during } x] = 1 - e^{-gx}$$

- Scheduling is memoryless -> renewal point -> $\tilde{I} \sim Exp(g)$
- **Mean duration of idle period** is $I = \frac{1}{g}$

Non-persistent CSMA

- **Useful period** duration:

$$U = \begin{cases} T & \text{Successful Period} \\ 0 & \text{Unsuccessful Period} \end{cases}$$

- If transmission success probability is P_{suc}, the **mean duration of $\tilde{U}$** is:

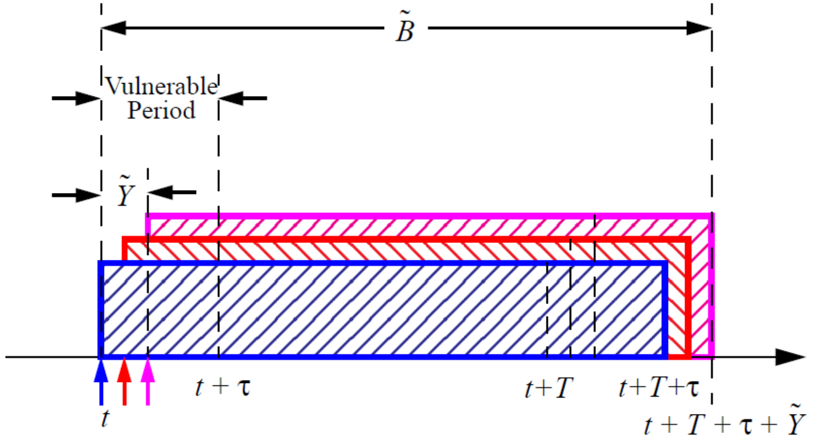
$$U = E[\tilde{U}] = T \cdot P_{suc} + 0 \cdot (1 - P_{suc}) = TP_{suc}$$

- **Success probability** is: $P_{suc} = \text{Prob}[\text{No arrival in the period } [t, t+\tau]] = e^{-g\tau}$

- Finally: $U = Te^{-g\tau}$.

Non-persistent CSMA

- Define $\tilde{Y}$ as a r.v. such that $t + \tilde{Y}$ is the time since the last interfering packet was scheduled within the period that started at time t
- **Busy period** is: $\tilde{B} = T + \tau + \tilde{Y}$
- It follows that nothing was transmitted during $[t + \tilde{Y}, t + \tau]$
- The **CDF and PDF of $\tilde{Y}$**:



(b) Unsuccessful Transmission Period

$$F_Y(y) = \text{Prob}[\tilde{Y} \le y] = \text{Prob}[\text{No packet arrival during } \tau - y] = e^{-g(\tau - y)}, \ 0 \le y \le \tau$$

$$f_Y(y) = e^{-g\tau}\delta(y) + g e^{-g(\tau - y)}$$

Non-persistent CSMA

$$E[\tilde{Y}] = \tau - \frac{1 - e^{-g\tau}}{g}$$

$$B = E[T + \tau + \tilde{Y}] = T + 2\tau - \frac{1 - e^{-g\tau}}{g}$$

$$S = \frac{U}{B + I} = \frac{Te^{-g\tau}}{T + 2\tau - \frac{1 - e^{-g\tau}}{g} + \frac{1}{g}} = \frac{gTe^{-g\tau}}{g(T + 2\tau) + e^{-g\tau}}$$

- If we define $G = gT$ then **throughput** becomes:

$$S = \frac{Ge^{-aG}}{G(1 + 2a) + e^{-aG}}.$$

Non-persistent CSMA

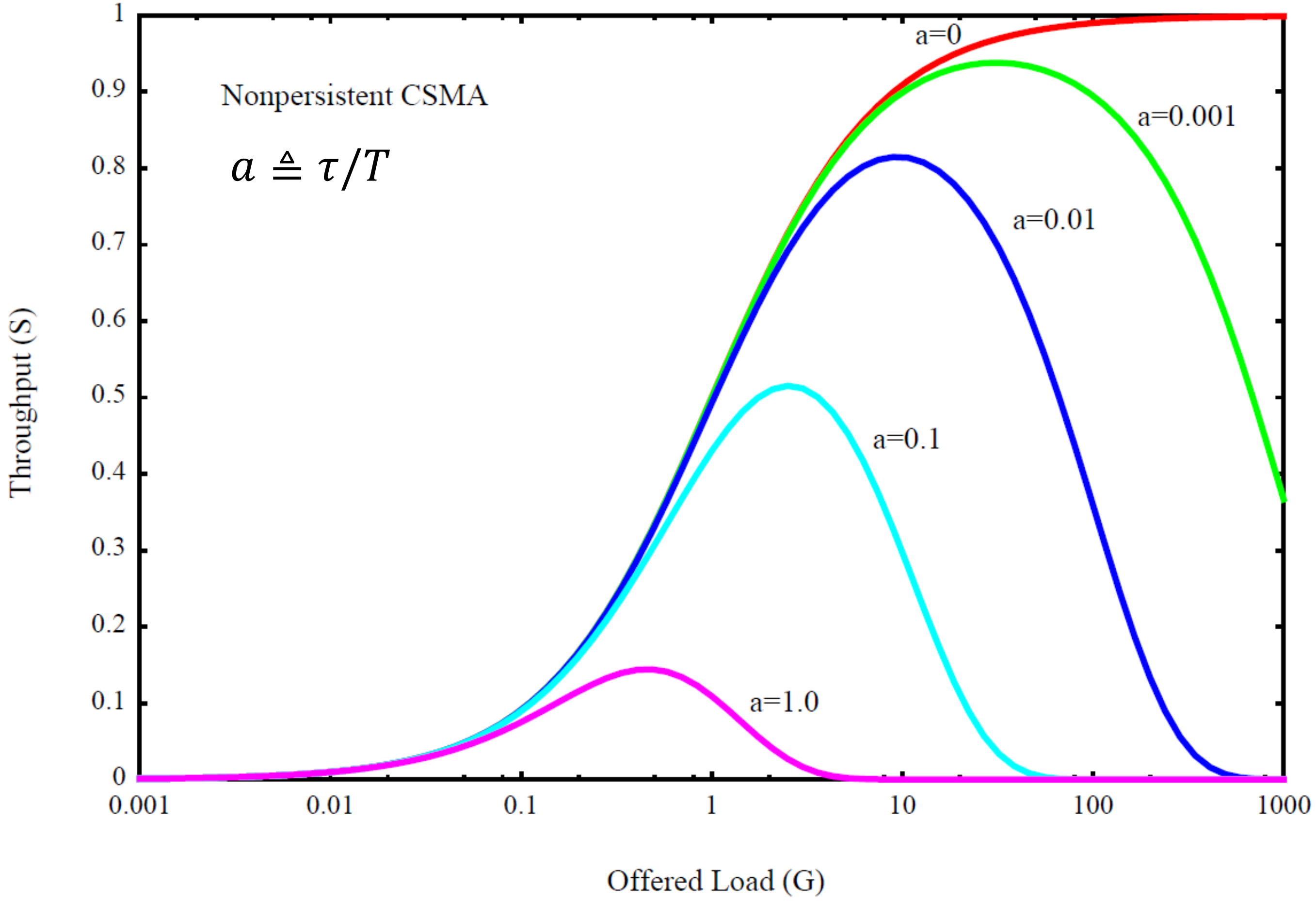


FIGURE 4.2: Throughput-Load of Nonpersistent CSMA

Slotted CSMA

- Time divided into slots of duration τ
- Users can send only at slot boundaries
- Assumptions for analysis:
  - Infinite user population
  - Total packet generation rate $\sim Poiss(\lambda)$
  - All users equally far, with propagation delay τ
  - Equally long packets (T sec), where T is an integer multiple of τ
  - Traffic on the channel (new + retransmitted packets) $\sim Poiss(g)$
  - Normalized propagation time $a \triangleq \tau/T$
  - Carrier sensing is instantaneous

Slotted non-persistent CSMA

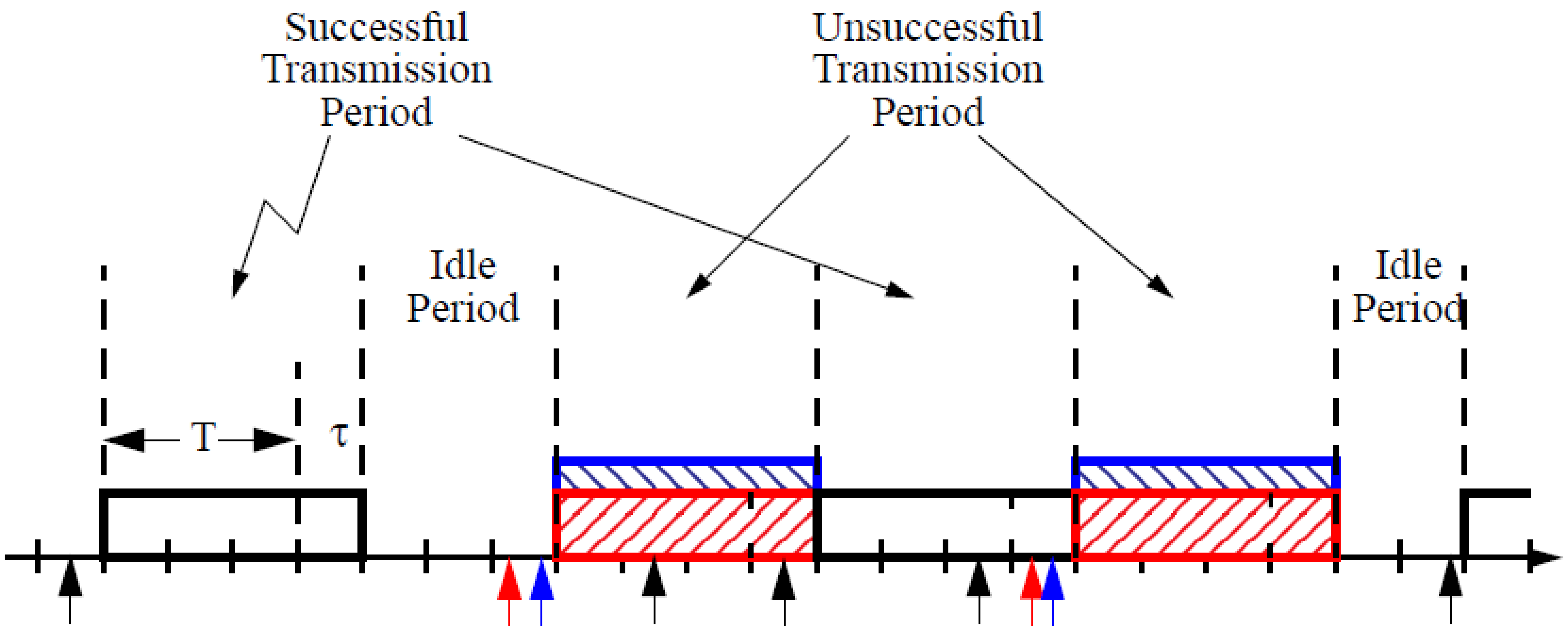


FIGURE 4.6: Slotted Nonpersistent CSMA Packet Timing

Slotted non-persistent CSMA

- Busy period $\tilde{B}$, idle period $\tilde{I}$ (at least one-slot long)
- Probability that $\tilde{I}$ is exactly k slots-long:

$$P[\tilde{I} = k\tau] = (e^{-g\tau})^{k-1}(1 - e^{-g\tau}) \qquad k = 1, 2, \dots$$

- **Mean length of idle period** is: $I = \frac{\tau}{1-e^{-g\tau}}$
- From model definition it follows that both successful and wasted time periods last for $T + \tau$
- Note: a busy period may comprise either of the two!

Slotted non-persistent CSMA

- The probability that busy period lasts exactly $k(T+\tau)$:

$$\text{Prob}[\tilde{B} = k(T+\tau)] = (1-e^{-g\tau})^{k-1}e^{-g\tau} \qquad k = 1, 2, \ldots$$

- **Mean length of busy period** is:

$$B = \frac{T+\tau}{e^{-g\tau}}$$

- During each successful transmission period, T sec is spent on information transfer; within one $\tilde{B}$, there exists $\frac{\tilde{B}}{(T+\tau)}$ transmission periods (successful and/or unsuccessful)

Slotted non-persistent CSMA

- **Mean useful time** is hence:

$$E[\tilde{U}] = T\frac{B}{T+\tau}P_{suc}$$

where:

$$\begin{aligned}
P_{suc} &= \text{Prob}[\text{Successful Transmission Period}] \\
&= \text{Prob}\left[\begin{array}{c}\text{single arrival in last mini-slot} \\ \text{before the transmission period}\end{array} \middle| \text{some arrivals}\right] \\
&= \frac{\text{Prob}[\text{Single arrival in last mini-slot}]}{\text{Prob}[\text{Some arrivals in last mini-slot}]} = \frac{g\tau e^{-g\tau}}{1-e^{-g\tau}}
\end{aligned}$$

Slotted non-persistent CSMA

- The **throughput** is:

$$S = \frac{U}{B+I} = \frac{T\frac{B}{T+\tau}P_{suc}}{\frac{T+\tau}{e^{-g\tau}} + \frac{\tau}{1-e^{-g\tau}}} = \frac{Tg\tau e^{-g\tau}}{T+\tau-Te^{-g\tau}}$$

- Normalizing by T:

$$S = \frac{aGe^{-aG}}{1+a-e^{-aG}}$$

- Asymptotic case:

$$S_{a\to 0} = \frac{G}{1+G}$$

- The last expression is equivalent to the unslotted case when $a \to 0$

Slotted non-persistent CSMA

What do the curves tell us?

1-persistent is an attempt to reduce the idle period

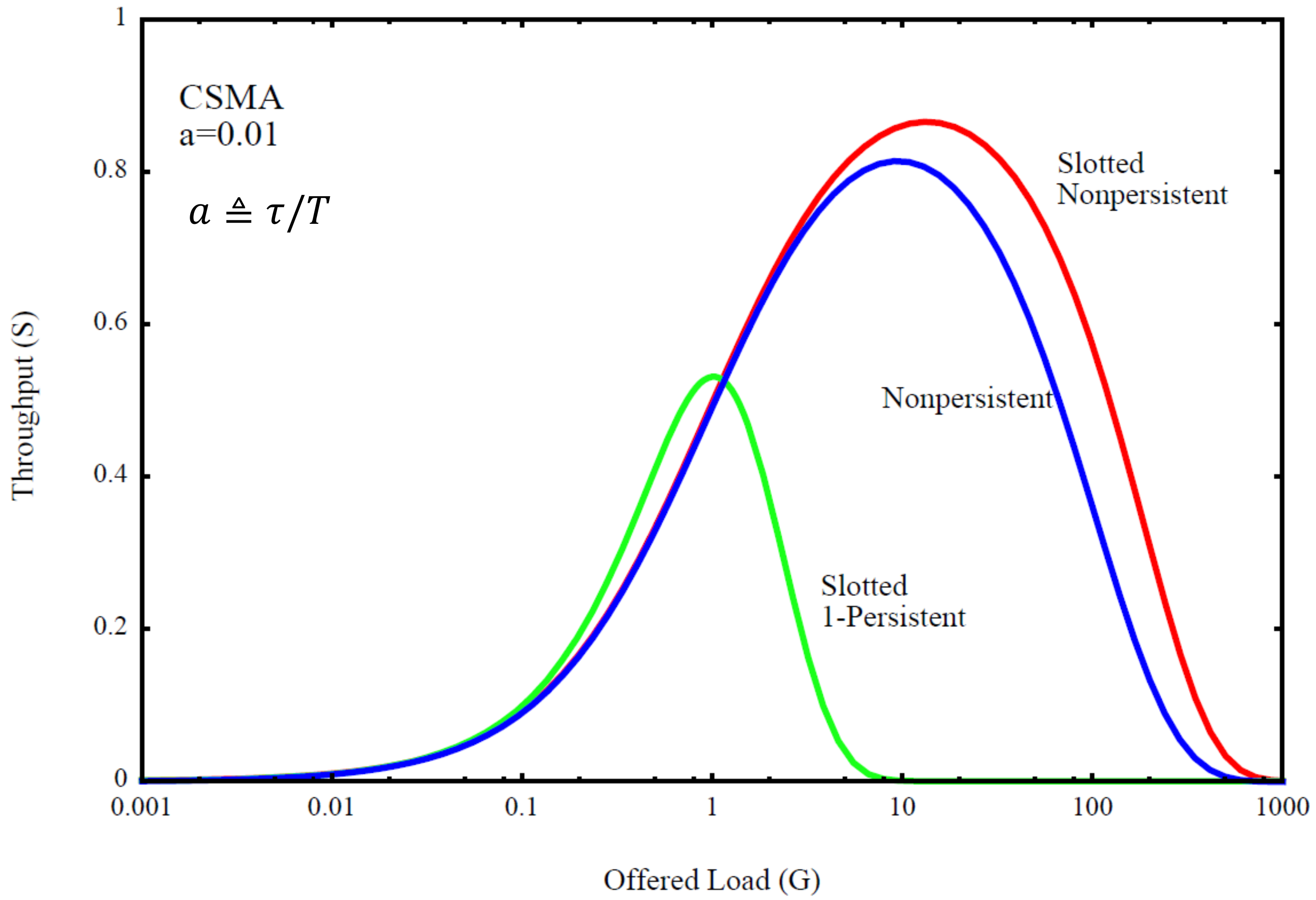
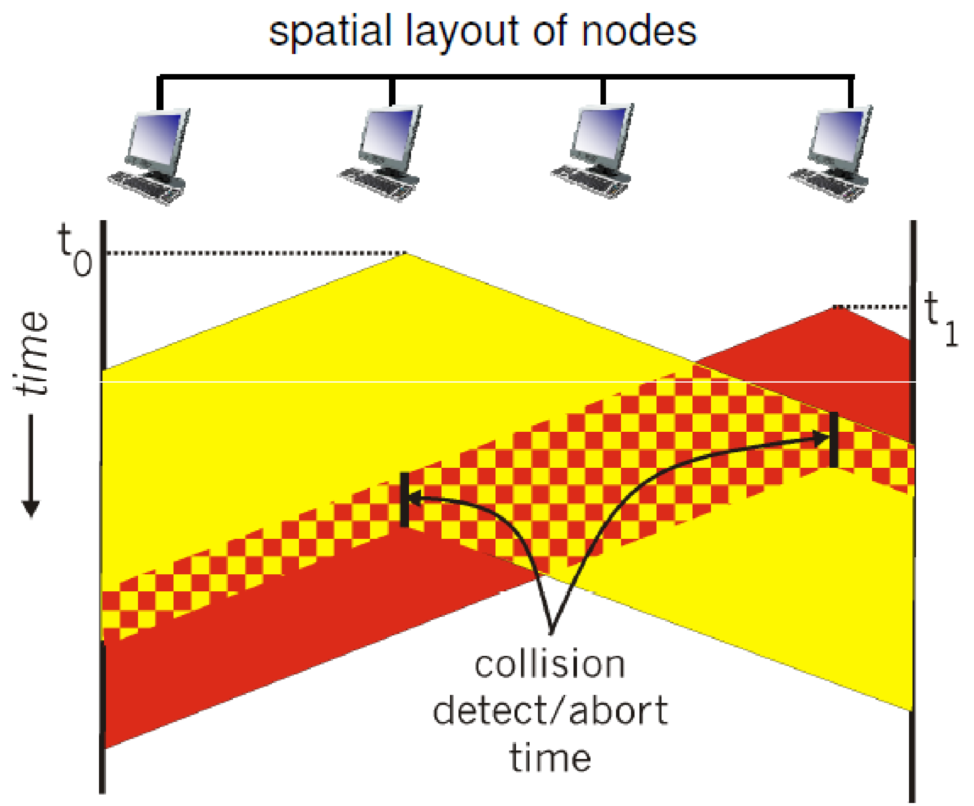


FIGURE 4.7: Throughput-Load of Slotted 1-Persistent and Nonpersistent CSMA

CSMA/CD

- A compromised transmission is not aborted immediately -> **CSMA wastes time**
- <u>Goal</u>: shorten the B
- CSMA/CD aborts the transmission as soon as a collision is noticed
- **Conflict resolution** in Ethernet after m-th collision:
  - Randomly choose a number K from the set $\{0,1,\dots,\dots,2^m-1\}$
  - Postpone the transmission for $512K$ bit times



CSMA/CD

- User A sees:

$\gamma = 2\tau + \tau_{cd} + \tau_{cr}$

and completes the transmission at $t_0 + \gamma$

- B completes the transmission period at $t_1 + \gamma$

- Channel is busy for $t_1 + \gamma - t_0$

- Worst case: $t_1 = t_0 + \tau$

i.e. unsuccessful period lasts for $\gamma + \tau$

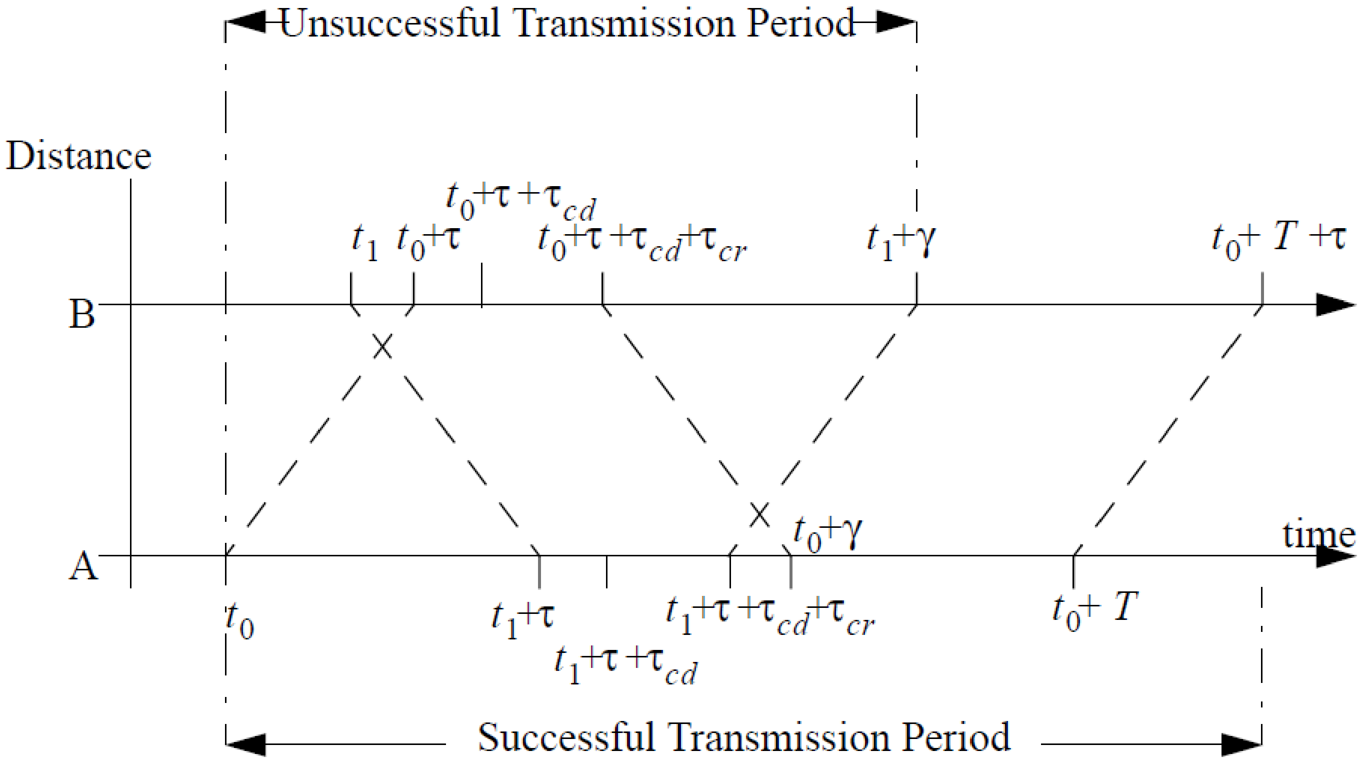


FIGURE 4.8: Collision detection Timing

CSMA/CD

- Denote the length of the transmission period as $\tilde{X}$:

$$\tilde{X} = \begin{cases} T + \tau & \text{Successful transmission period} \\ \gamma + \tau & \text{Unsuccessful transmission period} \end{cases}$$

- Assumptions for analysis:
  - Slots of length τ
  - All users sync'ed
  - Propagation delay τ
  - Both γ and T are integer multiples of τ
  - Traffic on the channel (new + retransmitted packets) $\sim Poiss(g)$
  - Normalized propagation time $a \triangleq \tau/T$
  - Carrier sensing is instantaneous, collision detection is not

Slotted non-persistent CSMA/CD

Note: successful and unsuccessful periods can have different durations!

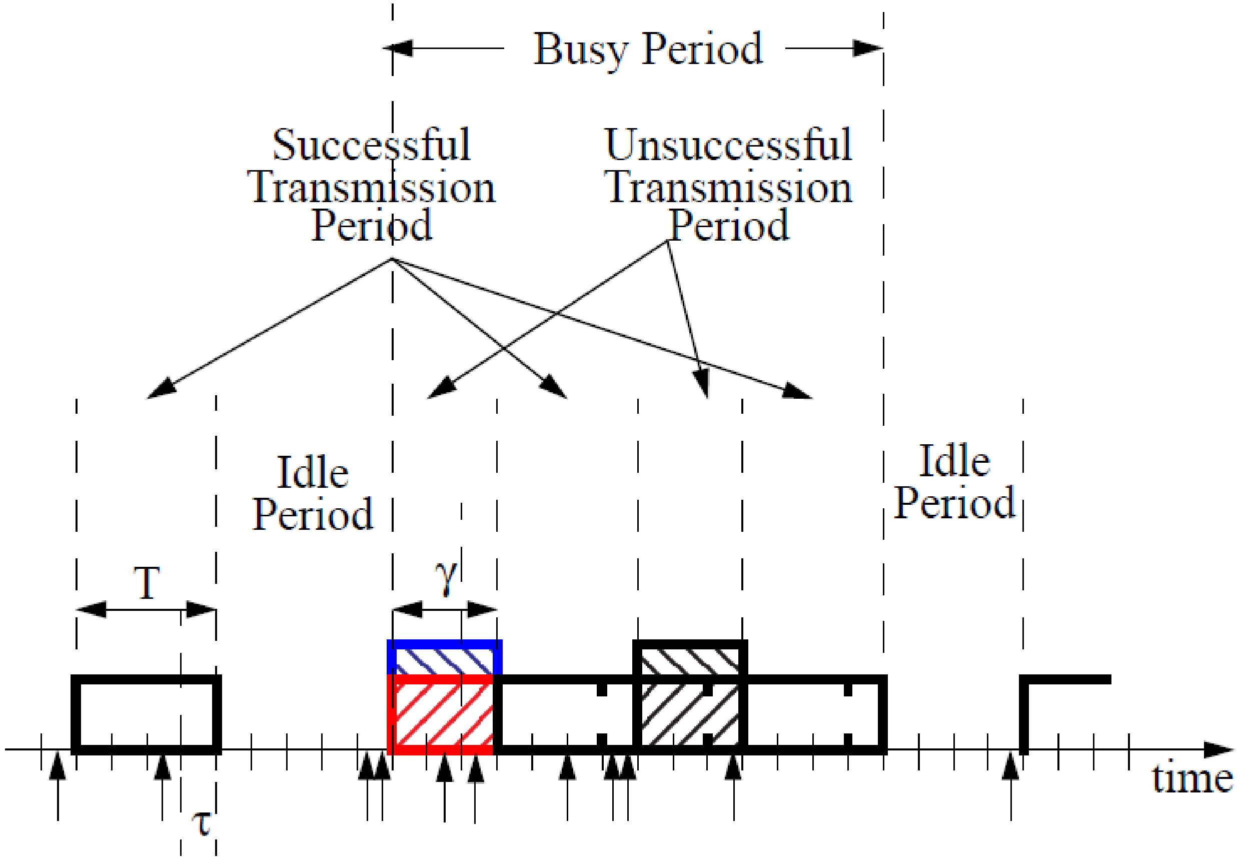


FIGURE 4.9: Slotted Nonpersistent CSMA/CD Packet Timing

Slotted non-persistent CSMA/CD

- The **distribution of $\tilde{I}$** is the same as slotted non-per. CSMA:

$$P[\tilde{I} = k\tau] = (e^{-g\tau})^{k-1}(1 - e^{-g\tau}) \qquad k = 1, 2, \ldots$$

- **Mean duration of idle period** is: $I = \frac{\tau}{1-e^{-g\tau}}$
- **Success probability** is alsp the same as slotted non-per. CSMA:

$$P_{suc} = \text{Prob}[\text{Single tranmission} \mid \text{at least one transmission}] = \frac{g\tau e^{-g\tau}}{1 - e^{-g\tau}}$$

Slotted non-persistent CSMA/CD

- A busy period consists of l transmission periods (successful and/or unsuccessful)
- **Distribution** and **mean duration of busy period**:

$$\text{Prob}[\tilde{B} = k(T+\tau) + (l-k)(\gamma+\tau)]$$

$$= e^{-g\tau}(1-e^{-g\tau})^{l-1}\binom{l}{k}P_{suc}^{k}(1-P_{suc})^{l-k} \qquad l = 1, 2, \ldots, \quad k = 0, 1, \ldots, l$$

$$B = \sum_{l=1}^{\infty}\sum_{k=0}^{l}[k(T+\tau)+(l-k)(\gamma+\tau)]\text{Prob}[k(T+\tau)+(l-k)(\gamma+\tau)]$$

$$= \frac{P_{suc}(T+\tau)+(1-P_{suc})(\gamma+\tau)}{e^{-g\tau}}$$

Slotted non-persistent CSMA/CD

- **Distribution** and **mean duration of useful period**:

$$\begin{aligned}\text{Prob}(\tilde{U} = kT) &= \text{Prob}[k \text{ successful transmission periods in a busy period}] \\ &= \sum_{l=k}^{\infty} \text{Prob}[\tilde{B} = k(T+\tau) + (l-k)(\gamma+\tau)]\end{aligned}$$

$$U = \sum_{k=0}^{\infty} kT\,\text{Prob}[\tilde{U} = kT] = \frac{T}{e^{-g\tau}} P_{suc}$$

Slotted non-persistent CSMA/CD

- Finally, the **throughput** and **normalized throughput** are:

$$S = \frac{U}{B+I} = \frac{g\tau T e^{-g\tau}}{g\tau T e^{-g\tau} + [(1-e^{-g\tau}) - g\tau e^{-g\tau}]\gamma + \tau}.$$

$$S = \frac{aGe^{-aG}}{aGe^{-aG} + (1 - e^{-aG} - aGe^{-aG})\gamma' + a}$$

where $\gamma' = \gamma / T$

- For $\gamma' = 1$ the throughput is identical to non-per. slotted CSMA

Slotted non-persistent CSMA/CD

$\gamma' = \gamma / T$

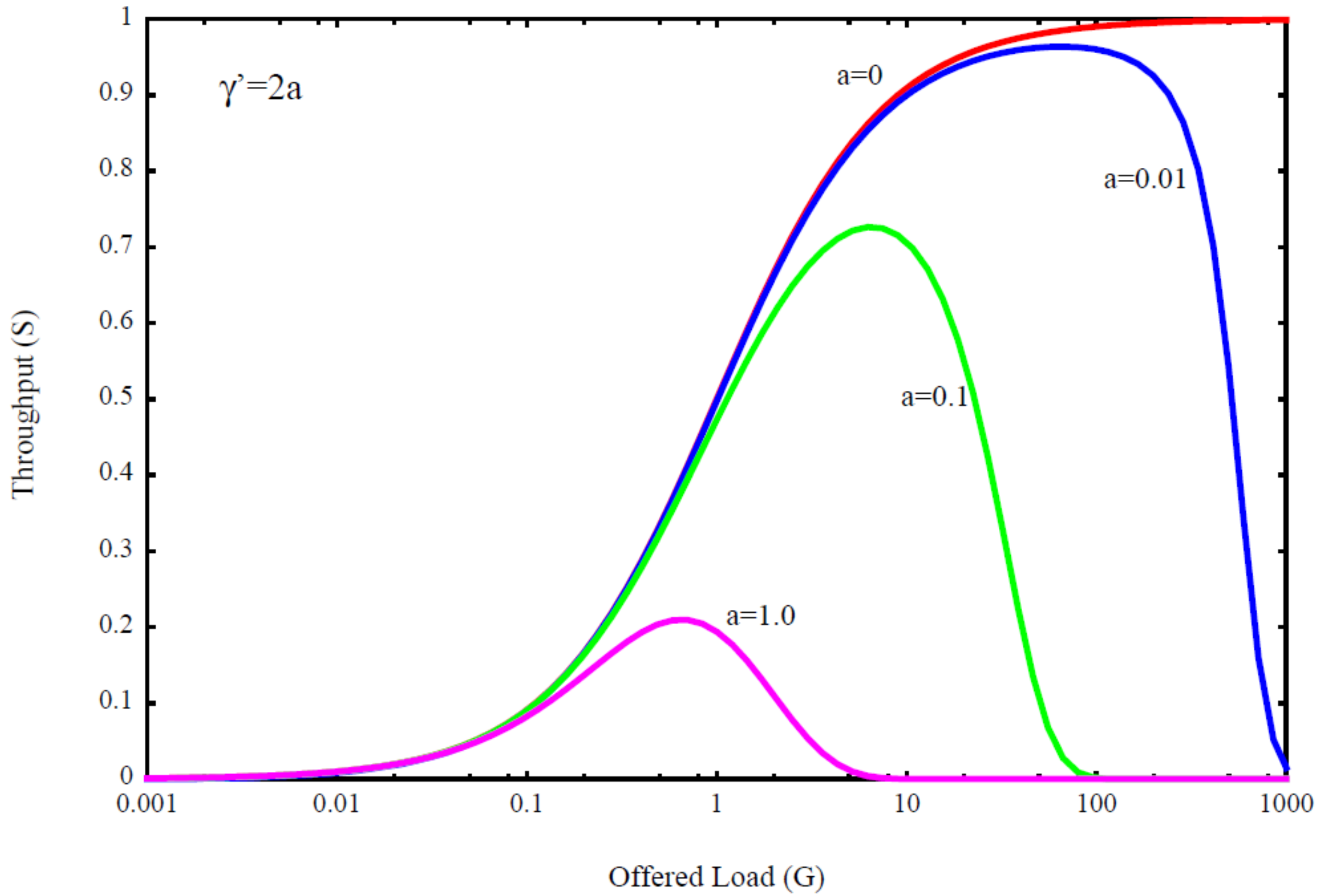


FIGURE 4.10: Throughput-Load of Slotted Nonpersistent CSMA/CD

When to retransmit? CSMA/CA in 802.11

<u>802.11 sender</u>

1. if sensed channel idle for DIFS then transmit entire frame (no CD)

2. if sensed channel busy then
   - start binary exponential backoff
   - timer counts down while channel idle
   - transmit when timer expires (no interruption)
   - if no ACK, increase random backoff interval, repeat 2

<u>802.11 receiver</u>

- if frame received OK, return ACK after SIFS (ACK needed due to hidden terminal problem)