Carrier Sense Multiple Access Technique

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Filip Barač
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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 channel 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 $\tau$
  • Normalized propagation time $a \triangleq \tau / T$
Non-persistent CSMA

- The first $\tau$ 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 $I$)

• $\tilde{U}$ (mean is $U$) is the **duration of a successful transmission**

• **Throughput** $S$ can be found as:

$$ S = \frac{U}{B + I} $$
Non-persistent CSMA

• The **CDF of idle period** is:

\[ F_I(x) = \text{Prob}[\tilde{I} \leq x] = 1 - \text{Prob}[\tilde{I} > x] \]

\[ = 1 - P[\text{No packet scheduling during } x] = 1 - e^{-gx} \]

• 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 $\tilde{Y}$**:

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

  $$f_{\tilde{Y}}(y) = e^{-g\tau}\delta(y) + ge^{-g(\tau - y)}$$
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

\[ a \triangleq \frac{\tau}{T} \]
Slotted CSMA

• Time divided into slots of duration $\tau$
• 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 $\tau$
  • Equally long packets ($T$ sec), where $T$ is an integer multiple of $\tau$
  • 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:

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

• 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 $k(T + \tau)$:

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

• **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:

\[ P_{suc} = \text{Prob}[\text{Successful Transmission Period}] \]
\[ = \text{Prob}\left[\text{single arrival in last mini-slot before the transmission period} \mid \text{some arrivals}\right] \]
\[ = \frac{\text{Prob}[\text{Single arrival in last mini-slot}]}{\text{Prob}[\text{Some arrivals in last mini-slot}]} = \frac{g \tau e^{-g \tau}}{1 - e^{-g \tau}} \]
Slotted non-persistent CSMA

• The **throughput** is:

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

• Normalizing by \(T\):

\[
S = \frac{a Ge^{-aG}}{1 + a - e^{-aG}}
\]

• 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
CSMA/CD

• A compromised transmission is not aborted immediately -> **CSMA wastes time**

• **Goal**: 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 $\{0,1, ..., 2^m - 1\}$
  • 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 $\tau$
  • All users sync’ed
  • Propagation delay $\tau$
  • Both $\gamma$ and $T$ are integer multiples of $\tau$
  • Traffic on the channel (new + retransmitted packets) $\sim\text{Poiss}(g)$
  • 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!
Slotted non-persistent CSMA/CD

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

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

• Mean duration of idle period is: $I = \frac{\tau}{1 - e^{-g\tau}}$

• Success probability is also the same as slotted non-per. CSMA:

$$P_{succ} = \text{Prob}[\text{Single transmission}|\text{at least one transmission}] = \frac{g\tau e^{-g\tau}}{1 - e^{-g\tau}}$$
Slotted non-persistent CSMA/CD

• A busy period consists of \( l \) transmission periods (successful and/or unsuccessful)

• **Distribution** and **mean duration of busy period**:

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

\[
= e^{-gt}(1 - e^{-gt})^{l-1}\left(\begin{array}{c} l \\ k \end{array}\right)\text{P}_{\text{suc}}^k(1 - \text{P}_{\text{suc}})^{l-k}
\]

\[l = 1, 2, \ldots, \ k = 0, 1, \ldots, l\]

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

\[
= \frac{\text{P}_{\text{suc}}(T + \tau) + (1 - \text{P}_{\text{suc}})(\gamma + \tau)}{e^{-gt}}
\]
Slotted non-persistent CSMA/CD

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

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

\[
\begin{align*}
U &= \sum_{k=0}^{\infty} kT \text{Prob}[\tilde{U} = kT] = \frac{T}{e^{-\gamma}} P_{suc}
\end{align*}
\]
Slotted non-persistent CSMA/CD

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

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

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

where \( \gamma' = \gamma/T \)

• For \( \gamma' = 1 \) the throughput is identical to non-per. slotted CSMA
Slotted non-persistent CSMA/CD

\[ \gamma' = \frac{\gamma}{T} \]

**FIGURE 4.10: Throughput-Load of Slotted Nonpersistent CSMA/CD**
When to retransmit? CSMA/CA in 802.11

**802.11 sender**
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

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