# MAC Performance

# MAC Retries

- *Many MAC protocols use acknowledgement (ACK) frames to confirm correct data reception.*
  - *Sender receives ACK: packet was received correctly.*
  - *Sender is notified of ACK timeout: retransmit packet.*
  - *The number of retries is usually limited.*

# MAC Retries

- *Expected number of tx attempts until success is a Bernoullii process:*
  - *Assumes Binary Symmetric Channel with constant BER.*
  - *Case with unlimited number of retries:*
    - $P(n\,\text{attempts}) = (1-p_{succ})^{n-1} \cdot p_{succ}$
    - $P(>n\,\text{attempts}) = (1-p_{succ})^{n}$
    - $\bar{n} = \sum_{i=1}^{+\infty} i \cdot (1-p_{succ})^{i-1} \cdot p_{succ} = \frac{1}{p_{succ}}$
    - $p_{succ}$ = probability of data+ack success of a single TX attempt=$(1-FER_{data}) \cdot (1-FER_{ACK})$
    - *The data will be delivered sooner or later:*
      - $p_{loss}$ = probability that the packet will never be delivered $= \lim_{k\to+\infty}({FER_{data}}^{k}) = 0$
      - $p_{delivery} = 1 - p_{loss} = 1$
      - *ACKs don't matter here. But RTS/CTS would complicate the matter…*
    - *Home Exercise 1: What is the expected number of failed data+ack attempts?*
    - *Home Exercise 2: What is the expected number of retries?*
    - *Home Exercise 3:* $p_{succ}$(w/ rts+cts+data+ack)?
  - *Case with limited number of retries (R=retry limit):*
    - *There is a probability that the data frame will never be delivered:*
      - $p_{loss}(R) = {FER_{data}}^{R+1}$
      - $p_{delivery}(R) = 1 - p_{loss}(R)$
      - *ACKs don't matter here. But RTS/CTS would complicate the matter…*

# Throughput

- *Throughput is the effective data rate:*
  - $Th = \frac{\text{number of effectively received useful bits during time window } T}{T}$
  - From the perpective of some protocol layer, all bits added by the lower layer protocols constitute overhead.

- *Example with IEEE 802.11 Broadcast (no errors in the PHY preamble or header)*
  - *Maximum throughput at LLC layer:*
    - $\max Th = p_{delivery} \cdot \frac{8 \cdot L}{DIFS + T_{BACKOFF} + T_{H_{PHY}} + \frac{8 \cdot (H_{DATA} + L)}{R_{PHY}}}$
    - $L$ is the frame length in octets
    - $H_X$ is the length of the header +tail of MAC frame of type X in octets
    - $R_{PHY}$ is the physical bitrate in bits/s
    - $p_{delivery} = 1 - FER_{DATA}$

# Throughput

- *Example with IEEE 802.11 Unicast (no errors in the PHY preamble or header, infinite retries, ad-hoc WLAN w/ only one sender, no ACK losses)*
  - *Maximum throughput at LLC layer:*
    - $\max Th = \frac{p \cdot 8 \cdot L}{(1-p) \cdot T_{fail} + p \cdot T_{succ}} = \frac{8 \cdot L}{(\bar{n}-1) \cdot T_{fail} + T_{succ}}$
    - $T_{succ} = DIFS + \overline{T_{BACKOFF}} + 2 \cdot T_{H_{PHY}} + \frac{8 \cdot (H_{DATA} + L)}{R_{PHY}(DATA)} + SIFS + \frac{8 \cdot H_{ACK}}{R_{PHY}(ACK)}$
    - $T_{fail} = DIFS + \overline{T_{BACKOFF}} + T_{H_{PHY}} + \frac{8 \cdot (H_{DATA} + L)}{R_{PHY}(DATA)} + ACKTIMEOUT$
    - $p = 1 - FER_{DATA}$