Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

Ευφυή Κινητά Δίκτυα: Πρωτόκολλα Πολλαπλής Προσπέλασης

Χειμερινό Εξάμηνο 2023-24

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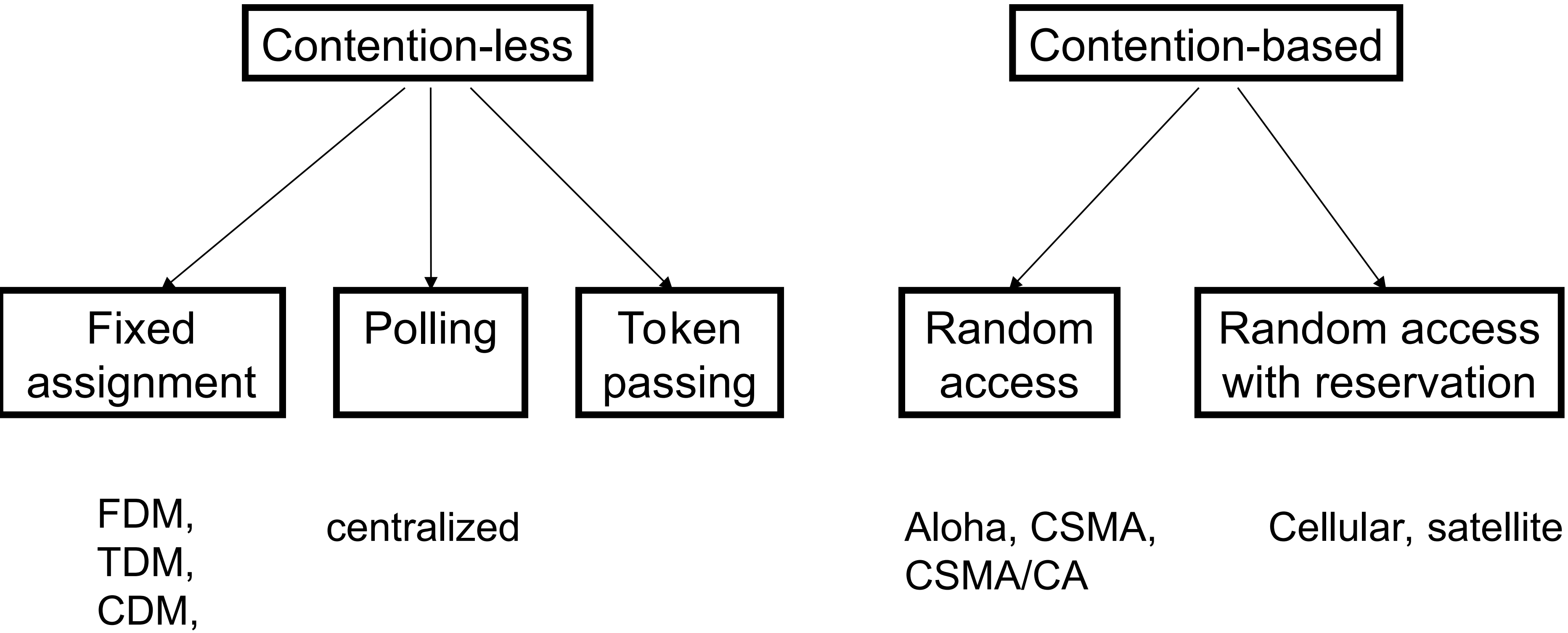
(βασισμένο σε διαφάνειες του Βασίλειου Σύρη)

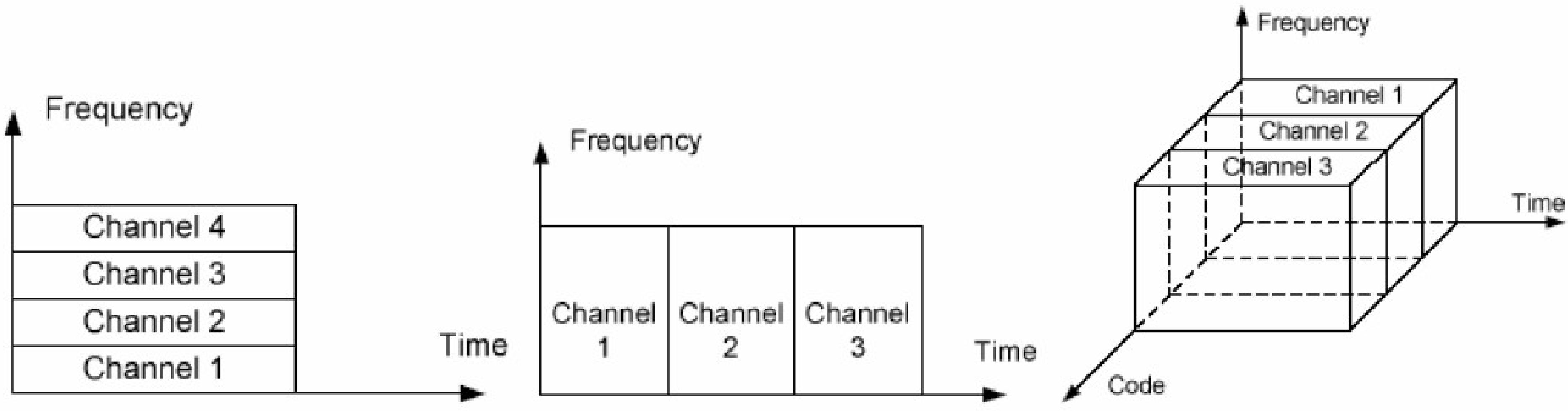
Multiple access

- Goal: share a common communication medium among multiple transmitting nodes
- Objectives/issues:
  - High resource utilization
  - Avoid starvation (fairness)
  - Simplicity

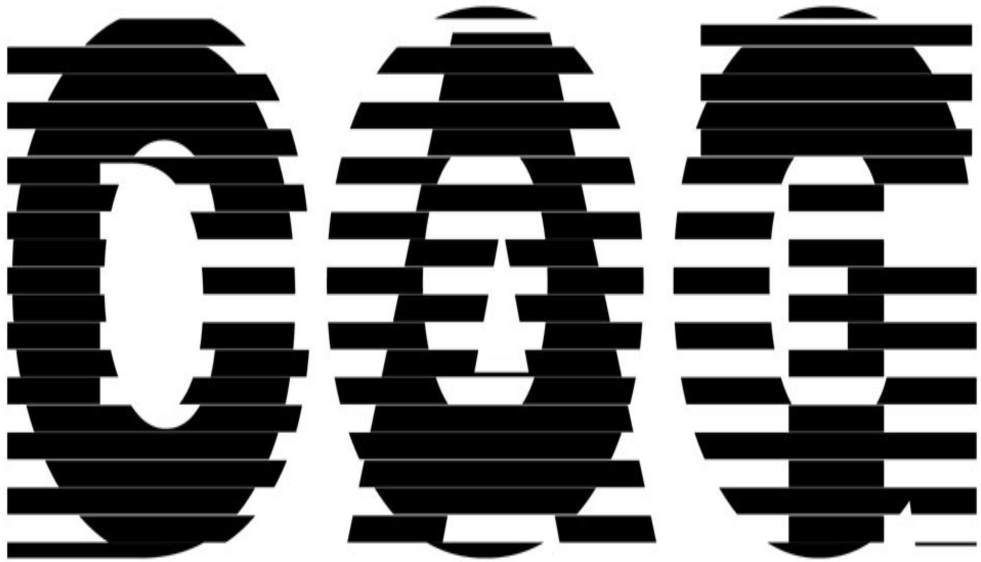
Multiple access



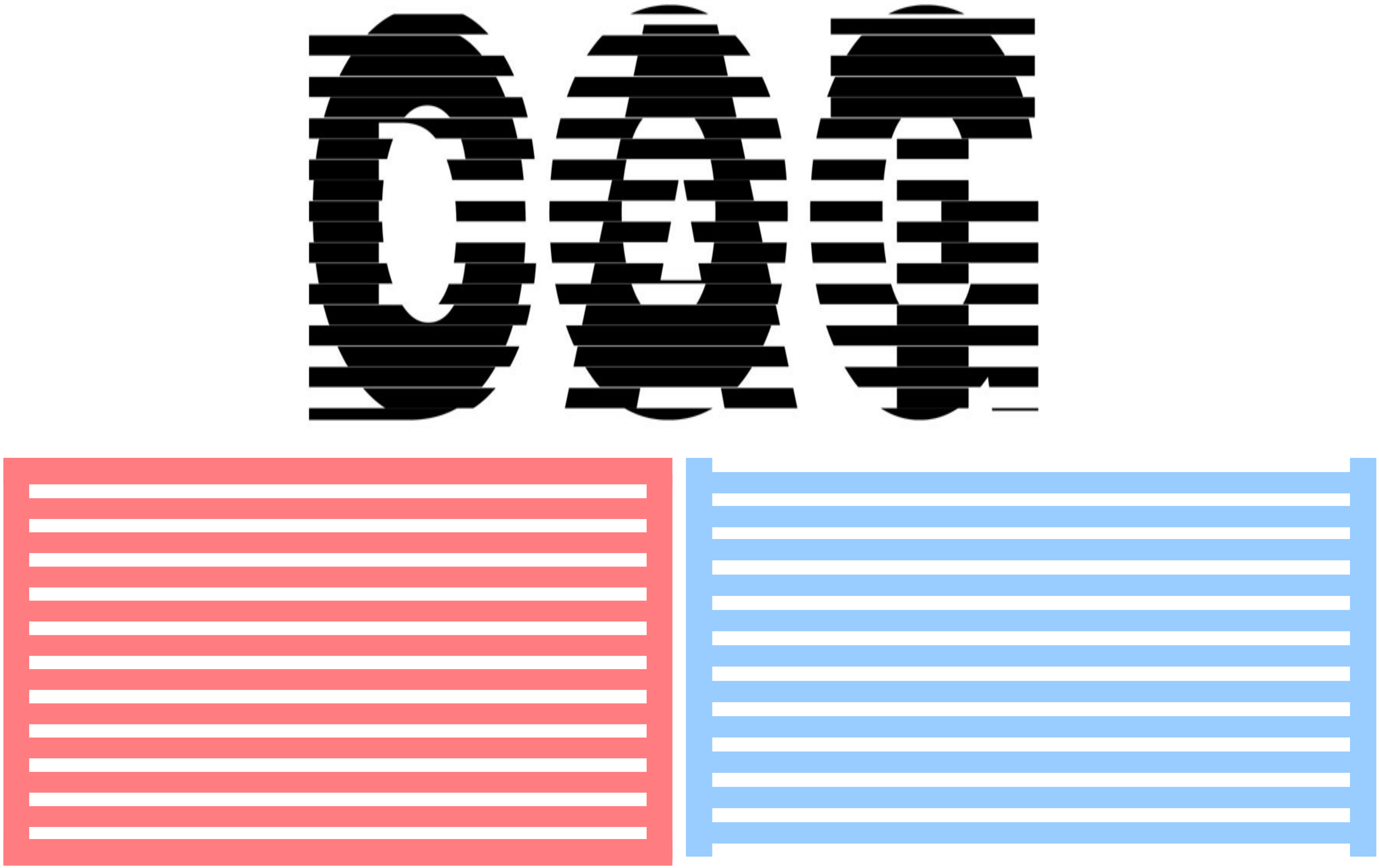
Channel partitioning



(a) FDMA (b) TDMA (c) CDMA



Courtesy of Suresh Goyal & Rich Howard



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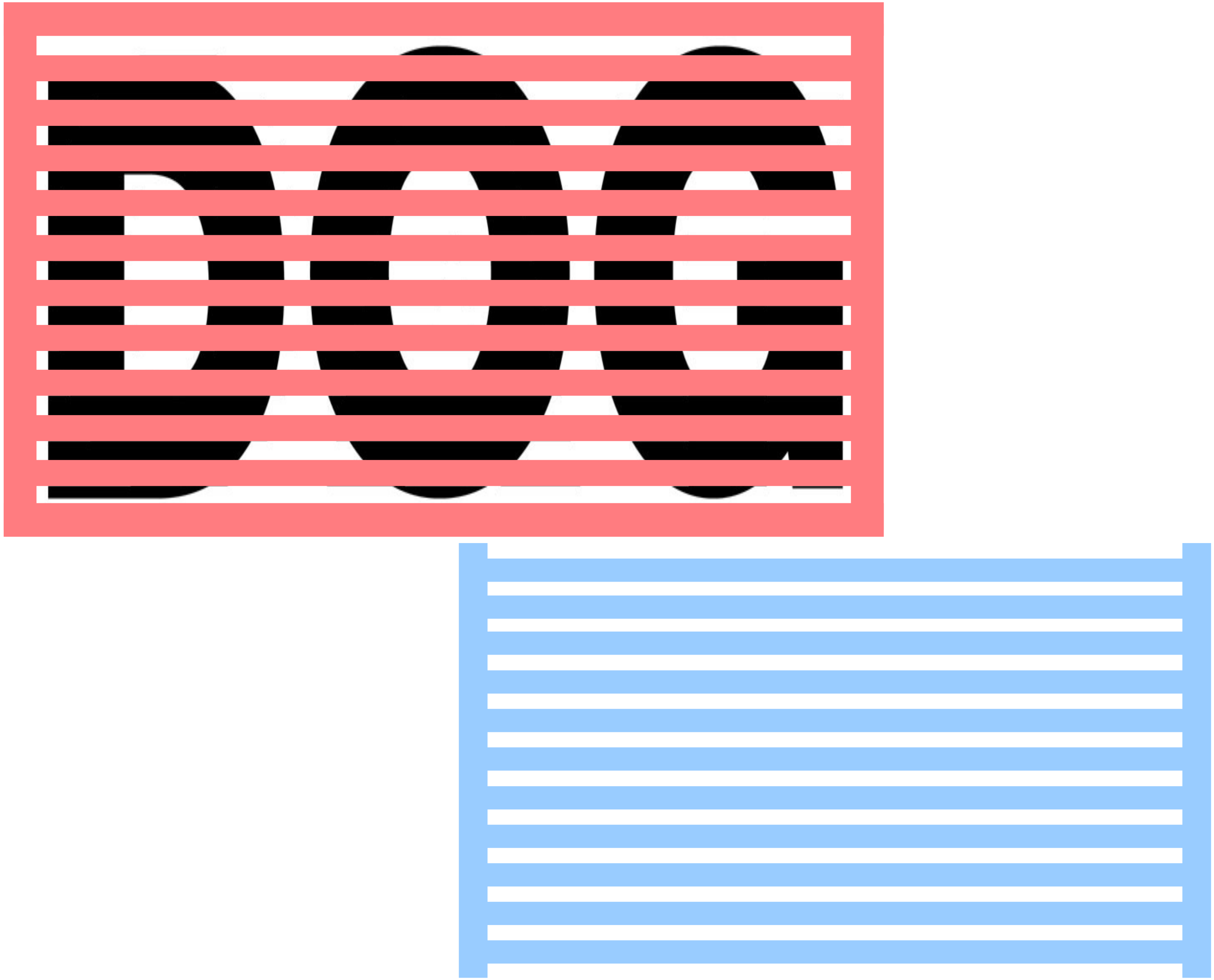

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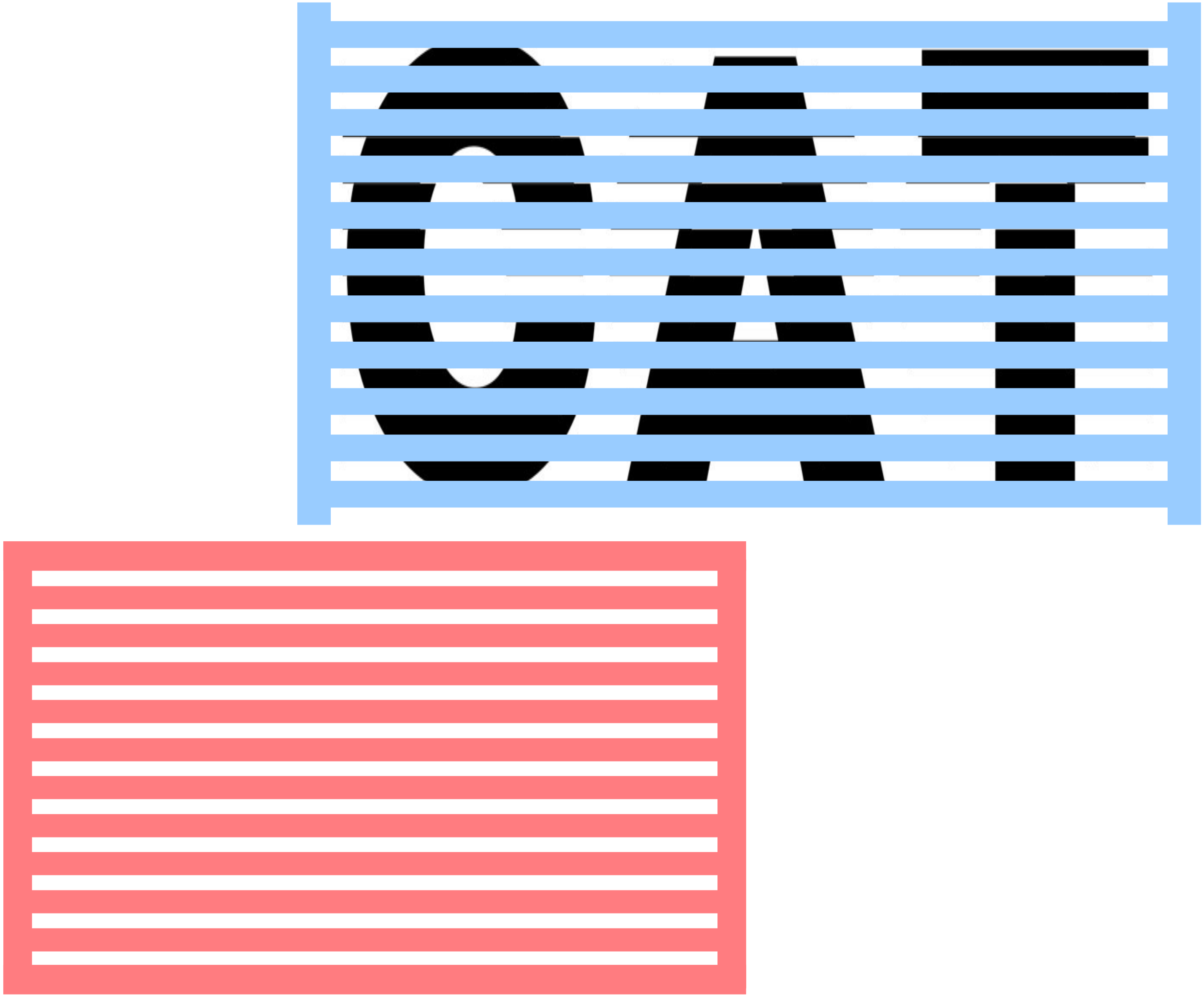
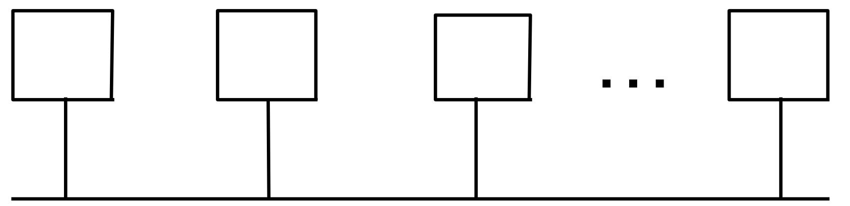


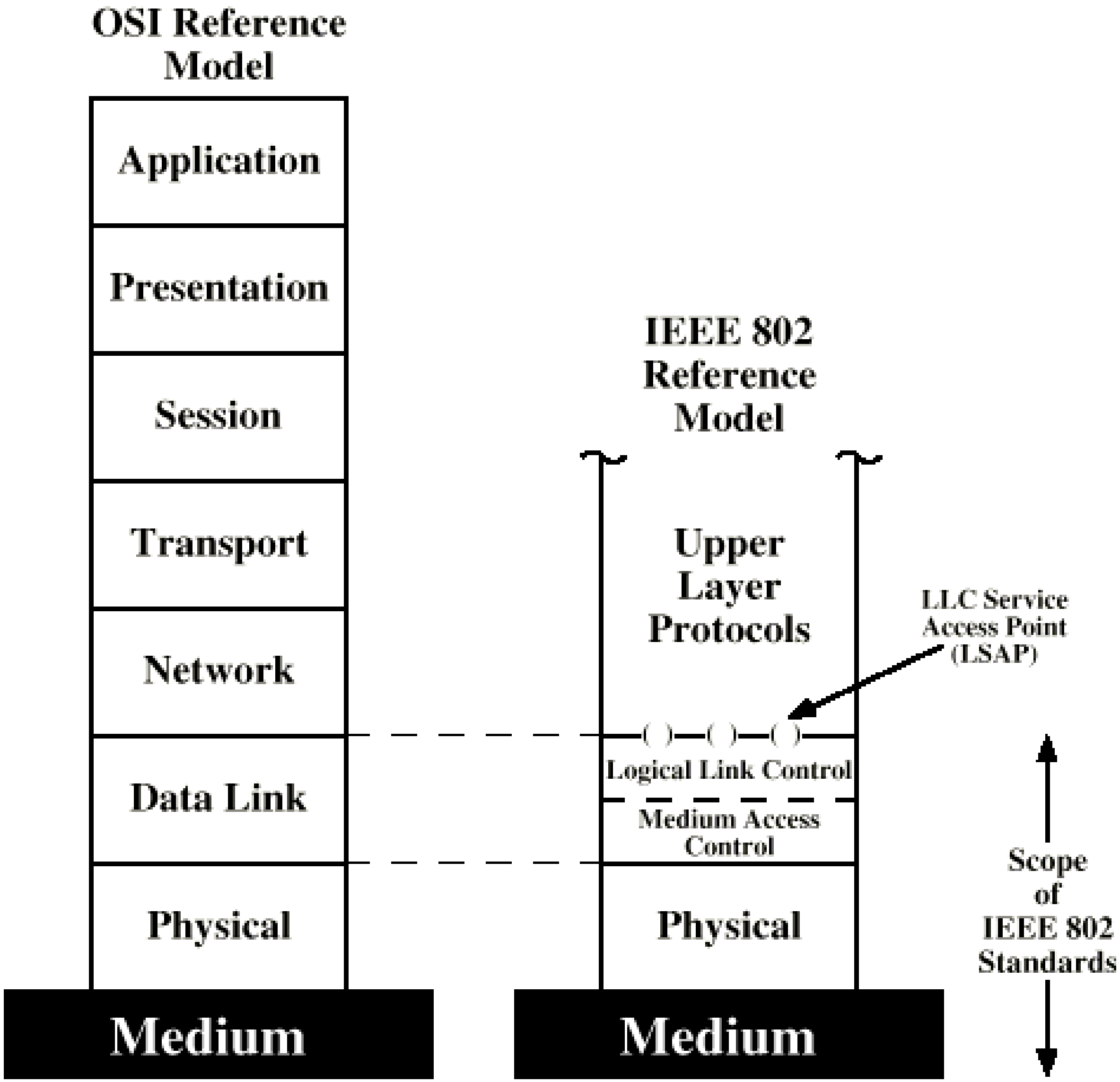
Courtesy of Suresh Goyal & Rich Howard

Multiple Access Systems



- Nodes use common transmission channel
- Collisions when two or more hosts send simultaneously
- Access Control design problem: limit inefficiencies due to collisions and idle periods

OSI and IEEE 802



IEEE 802 Layers - Physical

- Encoding/decoding
- Preamble generation/removal
  - Additional header info for checking for errors
- Bit transmission/reception
- Transmission medium and topology

IEEE 802 Layers - Logical Link Control (LLC)

- Interface to higher levels
- Multiplexing
- Flow and error control

IEEE 802 Layers - Media Access Control (MAC)

- Assembly of data into frame with address and error detection fields
- Disassembly of frame
  - Address recognition
  - Error detection
- Govern access to transmission medium
  - Not found in traditional layer 2 data link control
- For the same LLC, several MAC options may be available
- Examples:
  - 802.3 (Ethernet)
  - 802.4 (Token Bus)
  - 802.5 (Token Ring)
  - 802.11 (Wireless LAN, Wi-Fi, or wireless Ethernet)
  - 802.15 (Bluetooth)
  - 802.16 (Wireless Local Loop – WLL)

Media Access Control (MAC)

- Goal: share a communication medium among multiple hosts connected to it
- Objectives/issues:
  - High resource utilization
  - Avoid starvation (fairness)
  - Simplicity
- Solutions:
  - Centralized

    + Greater control, simple access logic and co-ordination

    - Single point of failure, potential bottleneck
  - Distributed: random access, taking turns
  - On demand or synchronous

MAC Protocol: A Taxonomy

- Channel partitioning
  - Divide channel into smaller “pieces” (time slots, frequency)
  - Allocate piece to node for exclusive use
- Random access
  - Allow collisions
  - “recover” from collisions
- “Taking-turns”
  - Tightly coordinate shared access to avoid collisions
  - Token ring, toke bus

Random Access MAC Protocols

- Stations access medium randomly
- Collisions when two or more hosts send simultaneously
- Random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions
- **Goal**: limit inefficiencies due to collisions and idle periods

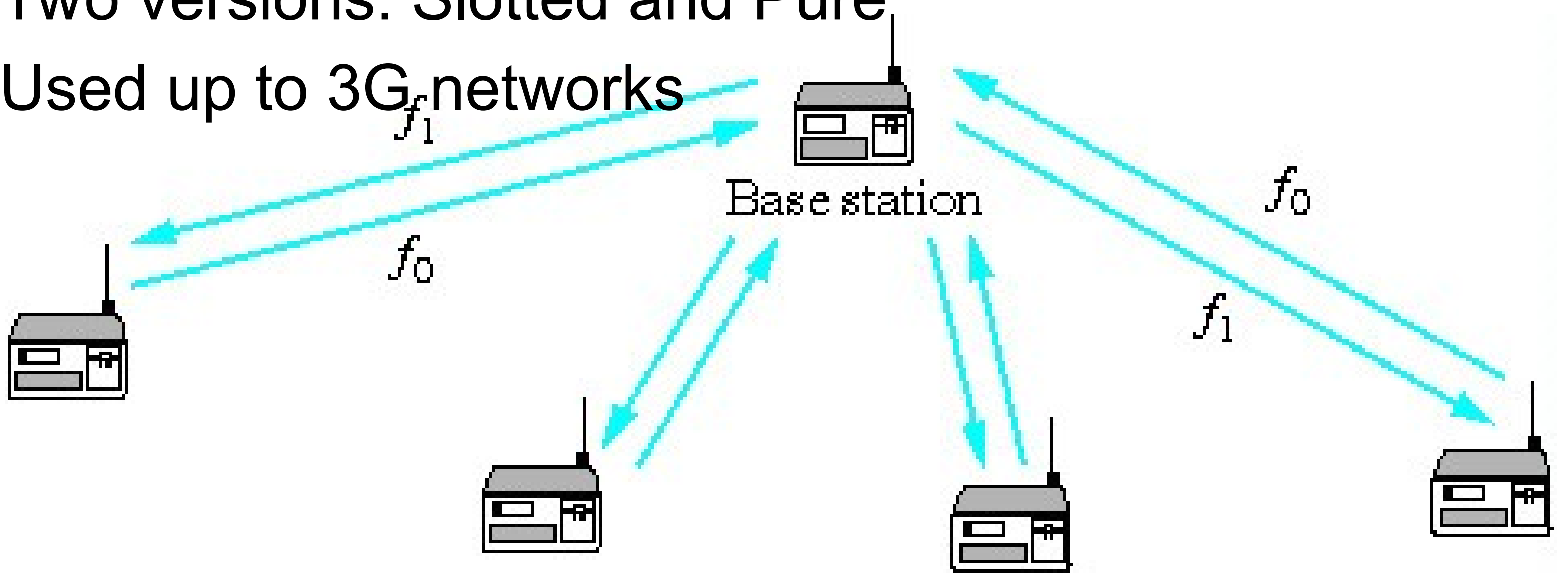
- Examples:
  - ALOHA (Slotted, Pure)
  - CSMA and CSMA/CD (Ethernet)
  - CSMA/CA (Wireless LAN/ IEEE 802.11)

Random Access MAC Protocols: Performance

- Efficiency=maximum fraction of time nodes transmit packets successfully
- Throughput=maximum rate of successful bit transmission = (Efficiency) $\times$ (Transmission rate)

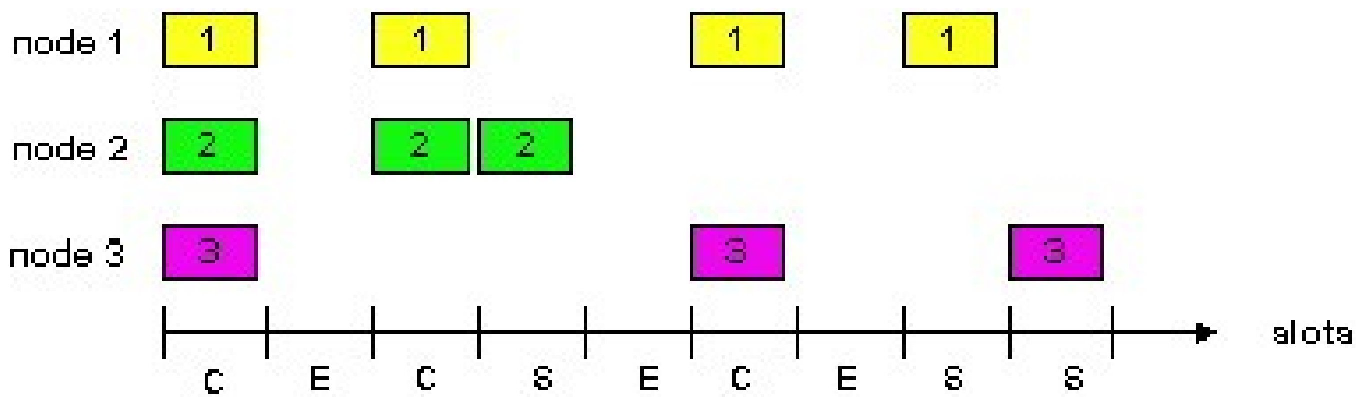
ALOHA Protocol

- ALOHA: packet-switched radio communication network
  - University of Hawaii, 1970s
  - Can also run over wired media (coaxial cable, twisted pair)
- Father of multiple access protocols
- Transmission rate of original ALOHA network : 9600 bps
- Two versions: Slotted and Pure
- Used up to 3G networks



Slotted ALOHA

- Time is divided into equal size slots (= packet transmission time)
- Node with new pkt: transmit at beginning of next slot
- If collision: retransmit pkt in future slots after random delay (why random?)



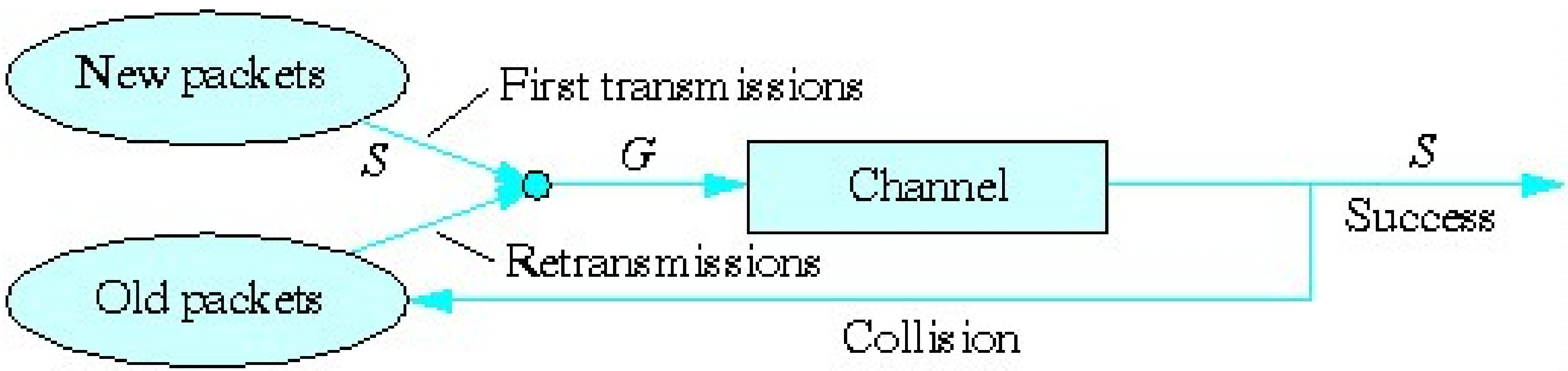
Success (S), Collision (C), Empty (E) slots

Slotted ALOHA

- Time in uniform slots equal to frame transmission time
  - All frame (packets) have fixed size
- Need central clock (or other sync mechanism)
- Transmission begins at slot boundary
- Sender (wireless stations):
  - Waits for ACK after packet transmission
  - Retransmits frame after Timeout
- Receiver (base station):
  - Error detection using Frame Check Sequence (similar to CRC)
  - Send ACK if frame OK
- Max utilization 36%

Slotted ALOHA Transmissions

- Frames either miss or overlap totally
- Wasted time:
  - Slots with collisions
  - Unused slots



Slotted ALOHA: Efficiency

- G: total rate of transmission attempts (pkts/timeslots)
- S: rate of successful transmissions (pkts/timeslots)
- p: probability of successful packet transmission

$$S = G \times p$$

- Assumptions:
  - Infinite number of stations
  - Number of packet arrivals is Poisson distributed

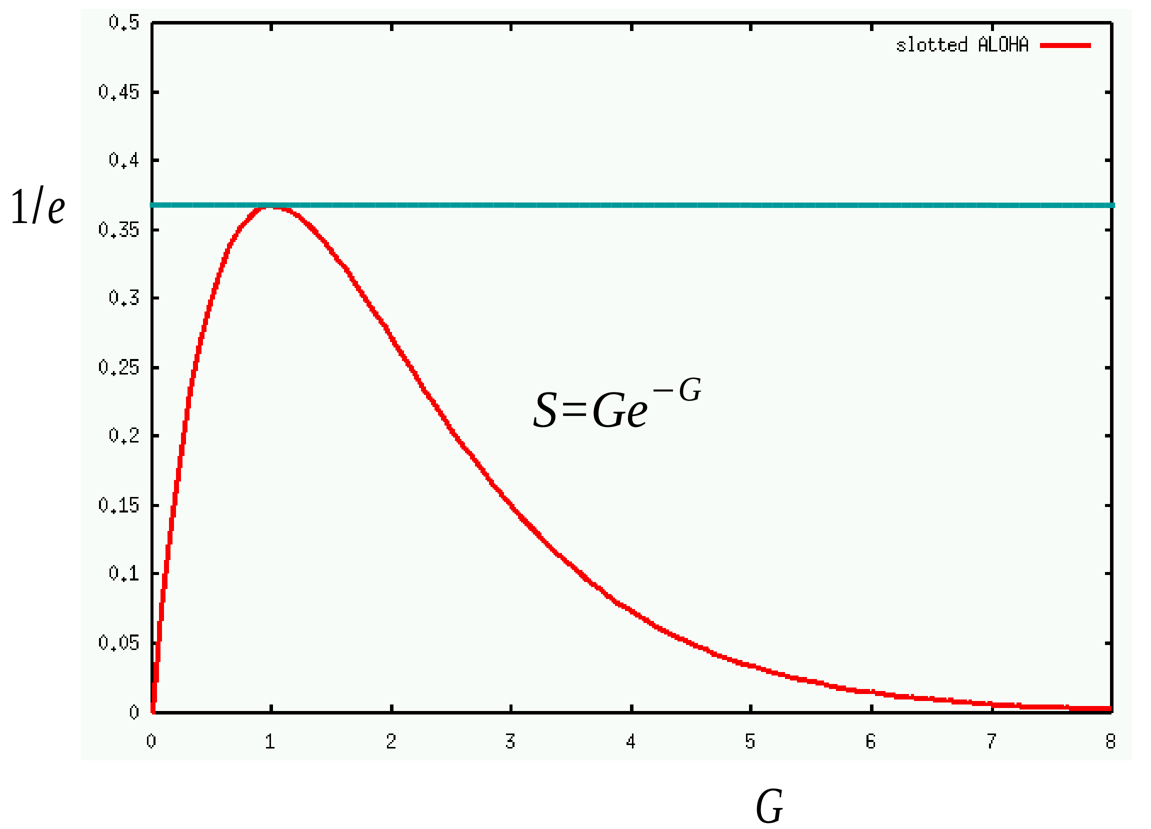
$$P\{n \text{ packets in } T \text{ slots}\} = \frac{(GT)^n}{n!} e^{-GT}$$

- From above

$$p = P\{0 \text{ packets in } 1 \text{ slots}\} = \frac{(G \cdot 1)^0}{0!} e^{-G \cdot 1} = e^{-G}$$

Slotted ALOHA: Efficiency (cont)

- Hence $S = G \times e^{-G}$
- S ≤ 1/e ≈ 36% $\eta_{S.ALOHA} \leq 36\%$
- What if there are only two stations?



Slotted ALOHA: Finite Station Population

- Finite number of stations N
  - Each transmits in slot with probability q
- Probability of successful transmission

Single station: $q\left(1-q\right)^{N-1}$ N stations: $Nq\left(1-q\right)^{N-1}$

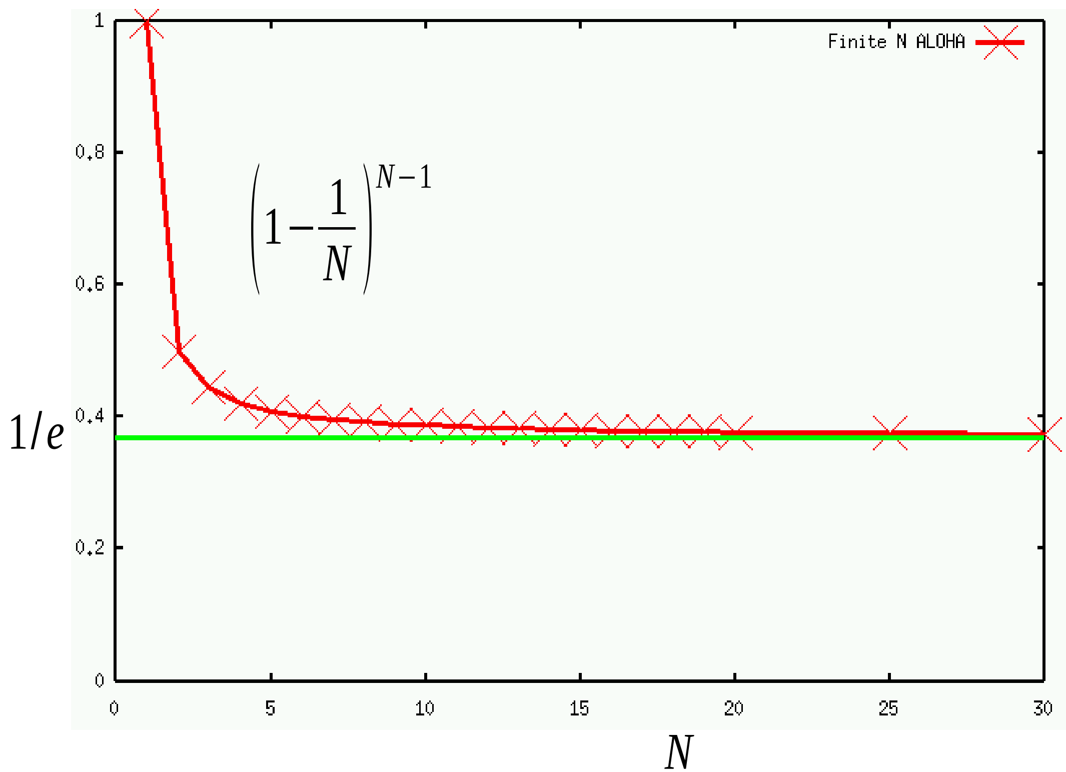
Above is maximized for q=1/N

$$\left(1-\frac{1}{N}\right)^{N-1}$$

A node does not know the number N of other stations that have packet to transmit

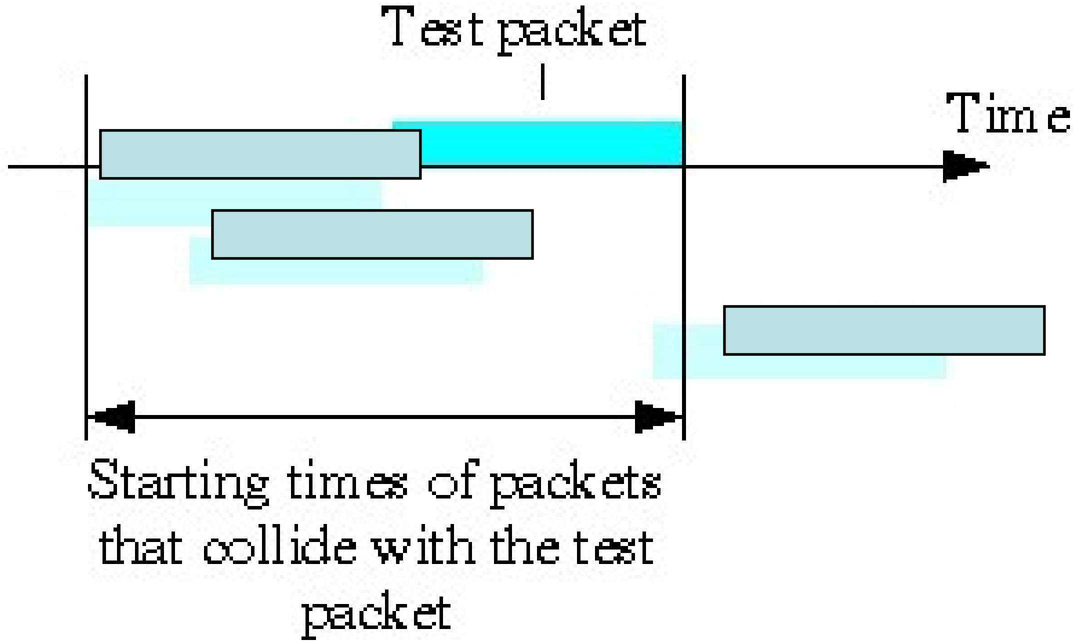
Slotted ALOHA: Finite Station Population (cont)

- Maximum efficiency for finite population ALOHA



Pure ALOHA

- No slotted time as in pure ALOHA
- When station has frame, it sends
- Any overlap of frames causes collision

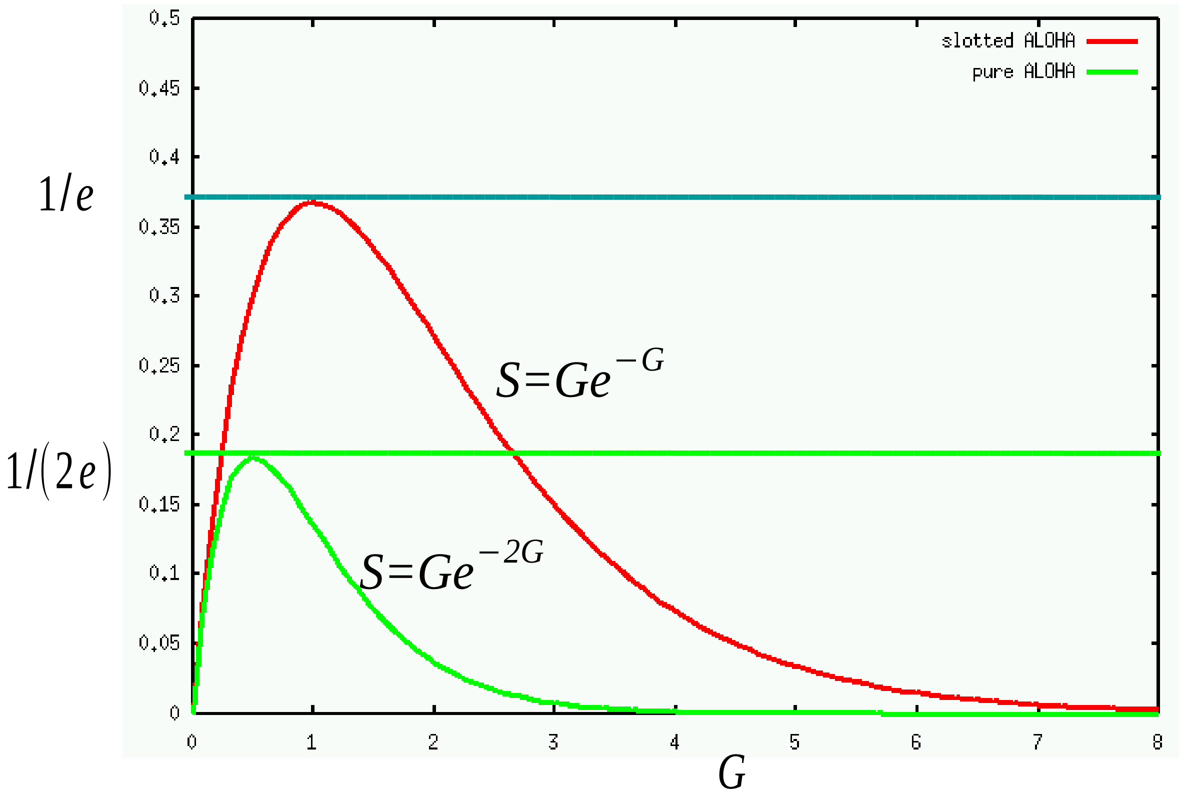


Pure ALOHA: Performance

- Probability of successful packet transmission

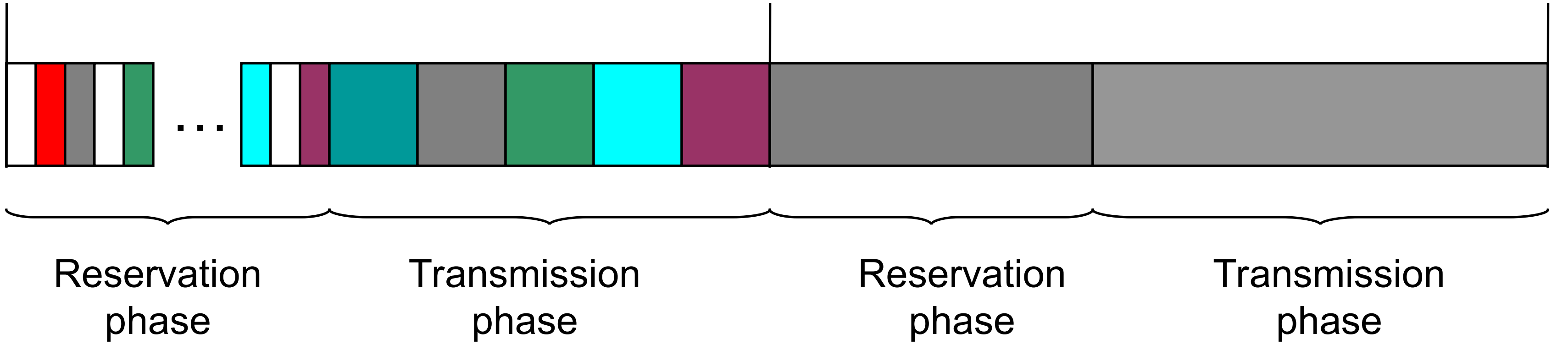
$$p = P\{0 \text{ packets in 2 slots}\} = \frac{(G \cdot 2)^0}{0!} e^{-G \cdot 2} = e^{-2G}$$

- Hence $S = G \times e^{-2G}$ $\qquad \eta_{P.ALOHA} \leq 18\%$



Reservation ALOHA

- Two phases:
  - Reservation phase
  - Transmission phase
- Reservation phase: Slotted ALOHA
- Transmission phase:
  - Divided into time slots
  - Station to transmit in each time slot determined by reservations
  - Duration of transmission phase depends on # of successful reservations



Reservation ALOHA: Efficiency

- Reservation phase is slotted ALOHA: 36% efficiency
- Transmission phase: 100% efficiency
- TRES: size of reservation slot
- TRANSP: size of transmission slot
- Average duration of reservation: TRES/0.36

$$\eta_{R.ALOHA} = \frac{TRANSP}{\frac{TRES}{0.36} + TRANSP} \approx \frac{1}{2.8 \times \frac{TRES}{TRANSP} + 1}$$

- Example: TRES/TRANSP=1/20

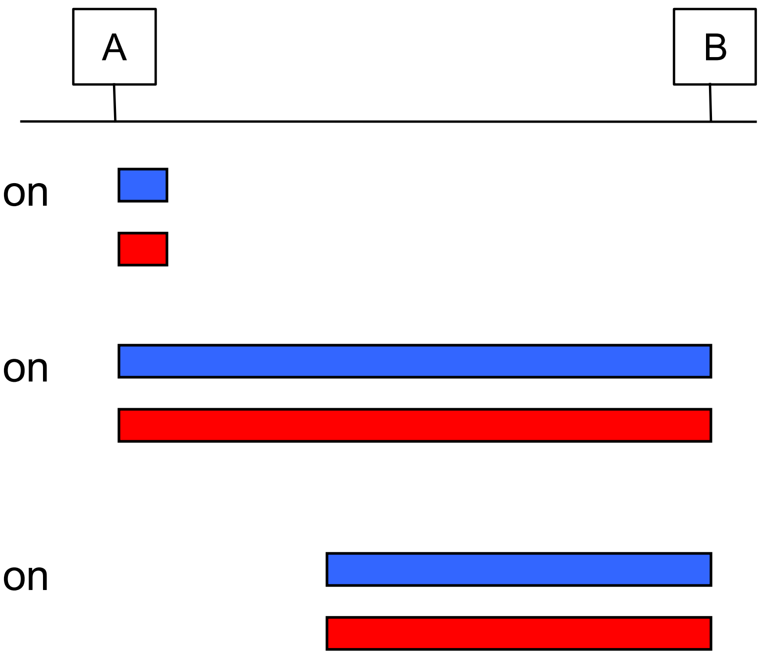
$$\eta_{R.ALOHA} \approx \frac{1}{2.8 \times 0.05 + 1} \approx 0.88$$

Carrier Sense Multiple Access (CSMA)

- Carrier Sense: “Listen before talking”
- Sender:
  - Listen for clear medium (carrier sense)
  - If medium idle
    - Transmit whole frame
    - Start Timeout and wait for ACK
  - If medium busy
    - Defer transmission -> Three alternatives
- Receiver:
  - Send ACK if packet received correctly

Carrier Sense

- PROP<<TRANSP   (PROP=propagation time)



$$PROP = \frac{frameSize}{Throughput}$$

Time T1 — A transmission / Bus signal

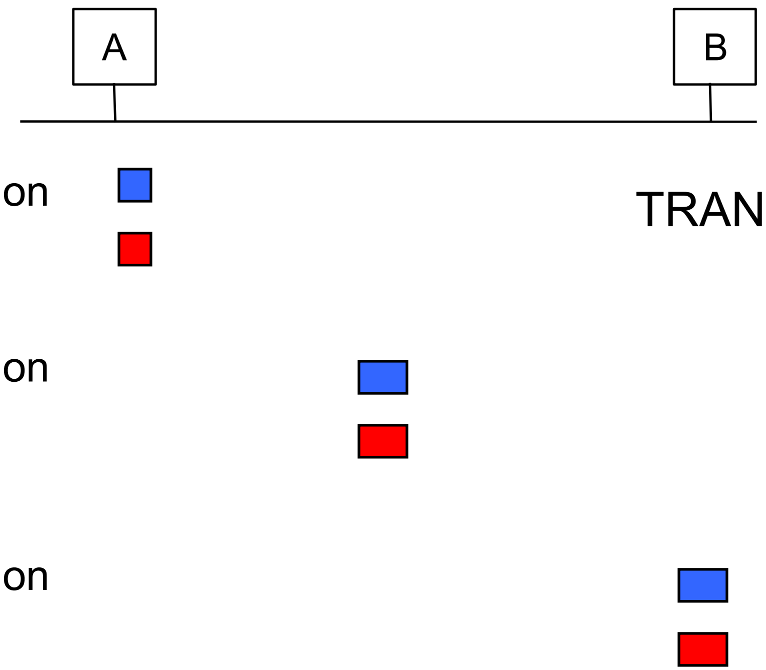
Time T2 — A transmission / Bus signal — B senses transmission doesn't send

Time T3 — A transmission / Bus signal — B senses transmission doesn't send

- When can collision occur?
  - T1 until T1+PROP
  - PROP small percentage of transmission time TRANSP
  - A has seized channel for time TRANSP-PROP

Carrier Sense

- PROP>>TRANSP



Time T1 A transmission
Bus signal

TRANSP

Time T2 A transmission
Bus signal

Time T3 A transmission
Bus signal

B senses transmission
doesn’t send

- When can collision occur?
  - T1 until T1+PROP
  - Packet transmission last very short time

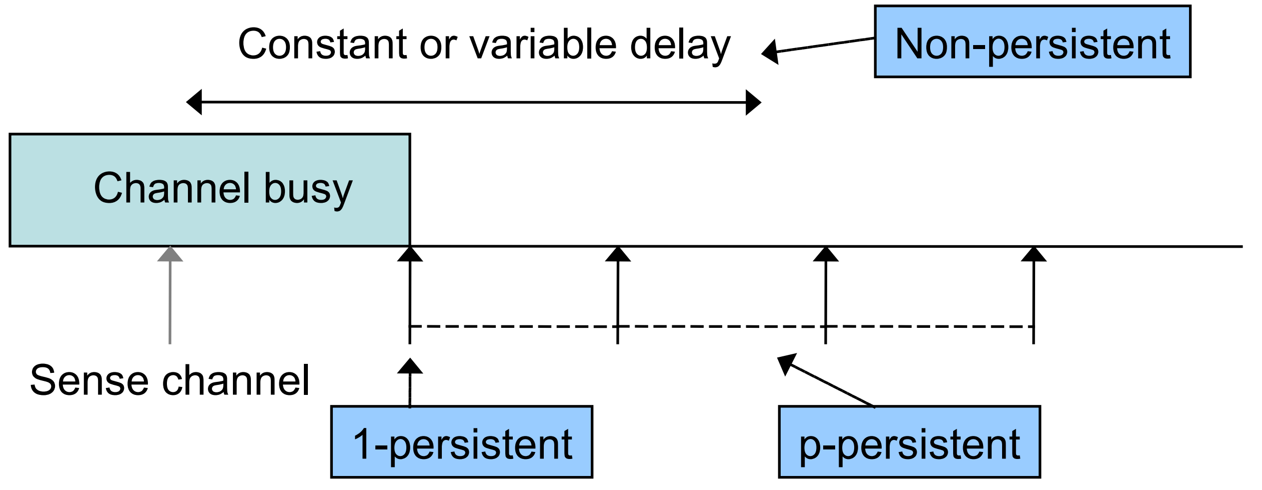
Why ALOHA doesn't listen…

- ALOHA targeted for wide area and satellite systems
  - These have long propagation delays
  - "Send and pray" is about the best you can do for random access
- ALOHA not a good choice for local area networks
  - These have short propagation delays

CSMA: What happens if channel is busy?

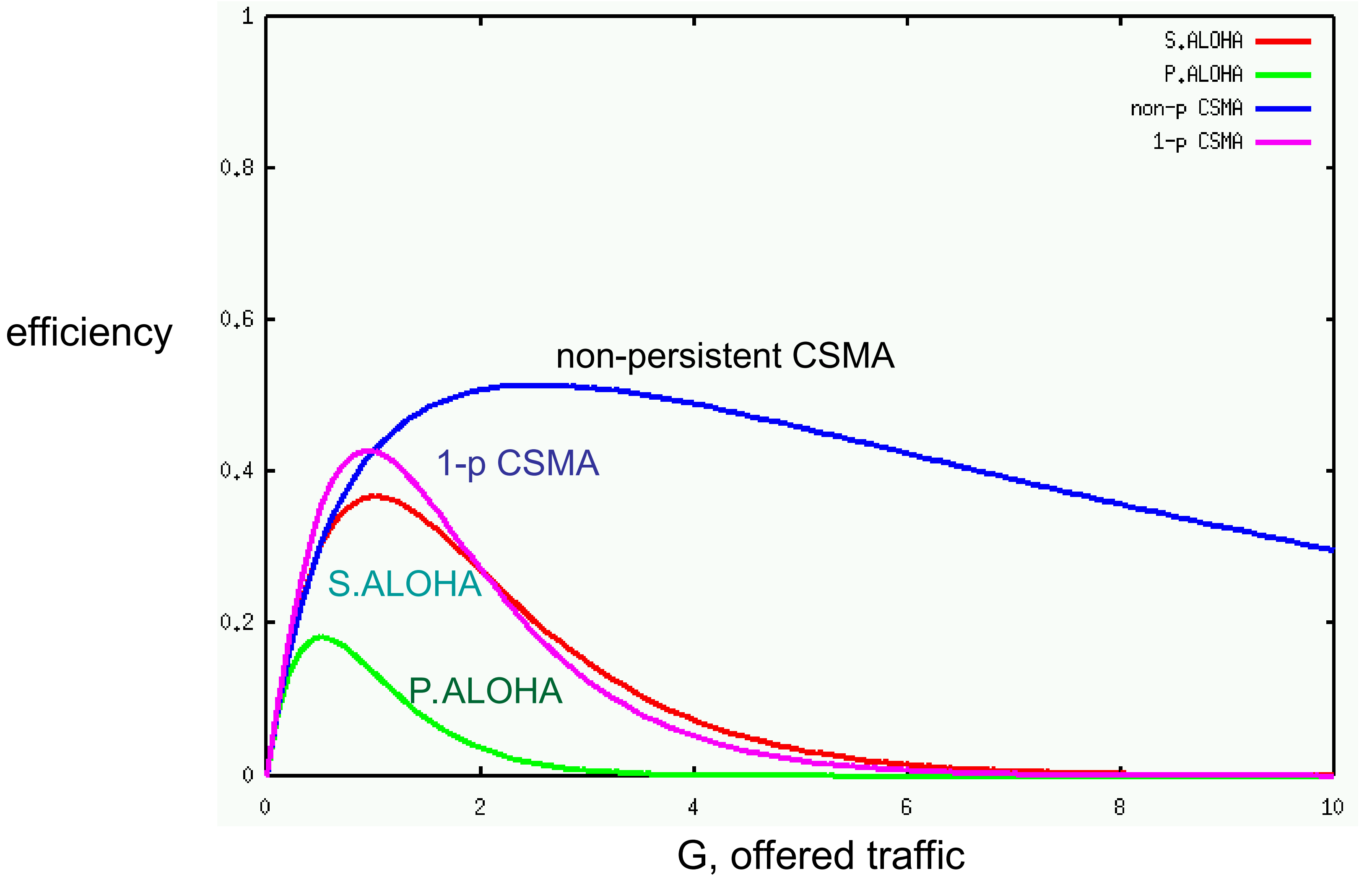
- 1-persistent CSMA:
  - Continue listening for idle channel
  - When channel becomes idle transmit whole packet immediately
- p-persistent CSMA:
  - Continue listening for idle channel
  - When channel becomes idle transmit packet with probability p
  - Assumes slotted time (like slotted ALOHA)
- Non-persistent CSMA:
  - When channel busy, wait for random time, then check channel again

CSMA persistence schemes



- 1-persistent:
  - If two or more stations waiting to transmit, collision is guaranteed
- Non-persistent:
  - Reduces probability of collisions
  - Wasted idle time before transmissions
- p-persistent:
  - How is p selected ? Must be $Np<1$
  - $Np>1$ instability, $Np<<1$ unnecessarily long delays

CSMA: efficiency



- PROP/TRANSP=0.1

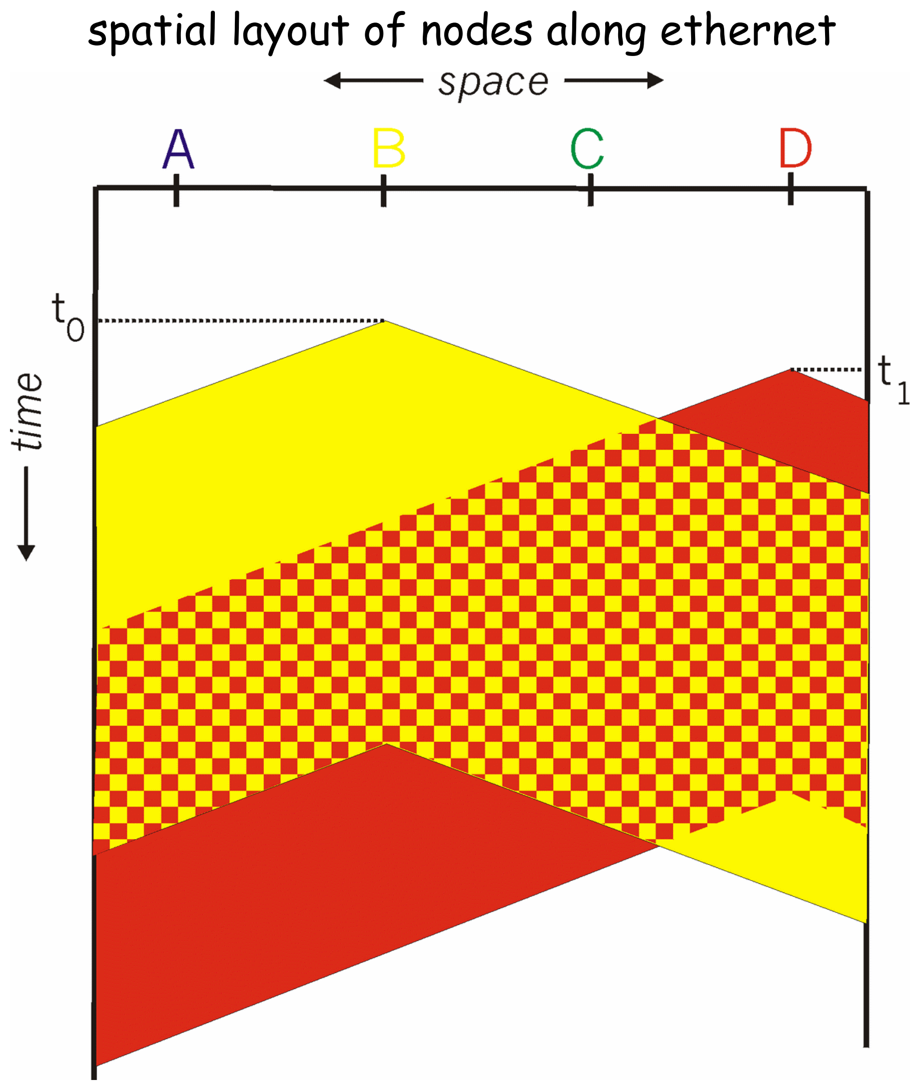
CSMA Collisions

Collisions *can* occur:

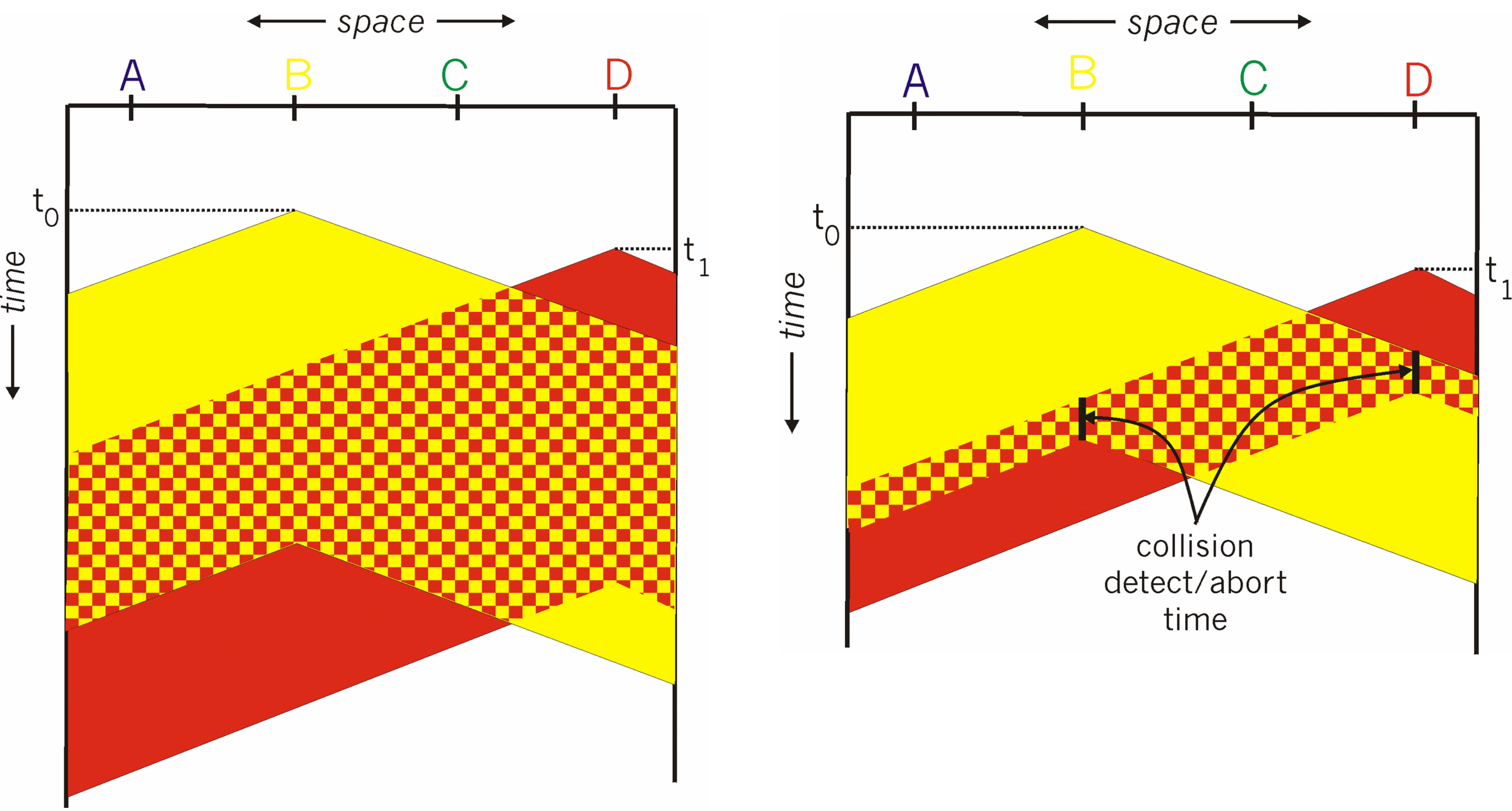
propagation delay means two nodes may not hear each other's transmission

Collision:

entire packet transmission time wasted



Gains of Collision Detect



CSMA/CD (Collision Detect)

- Collision Detect: listen while transmitting

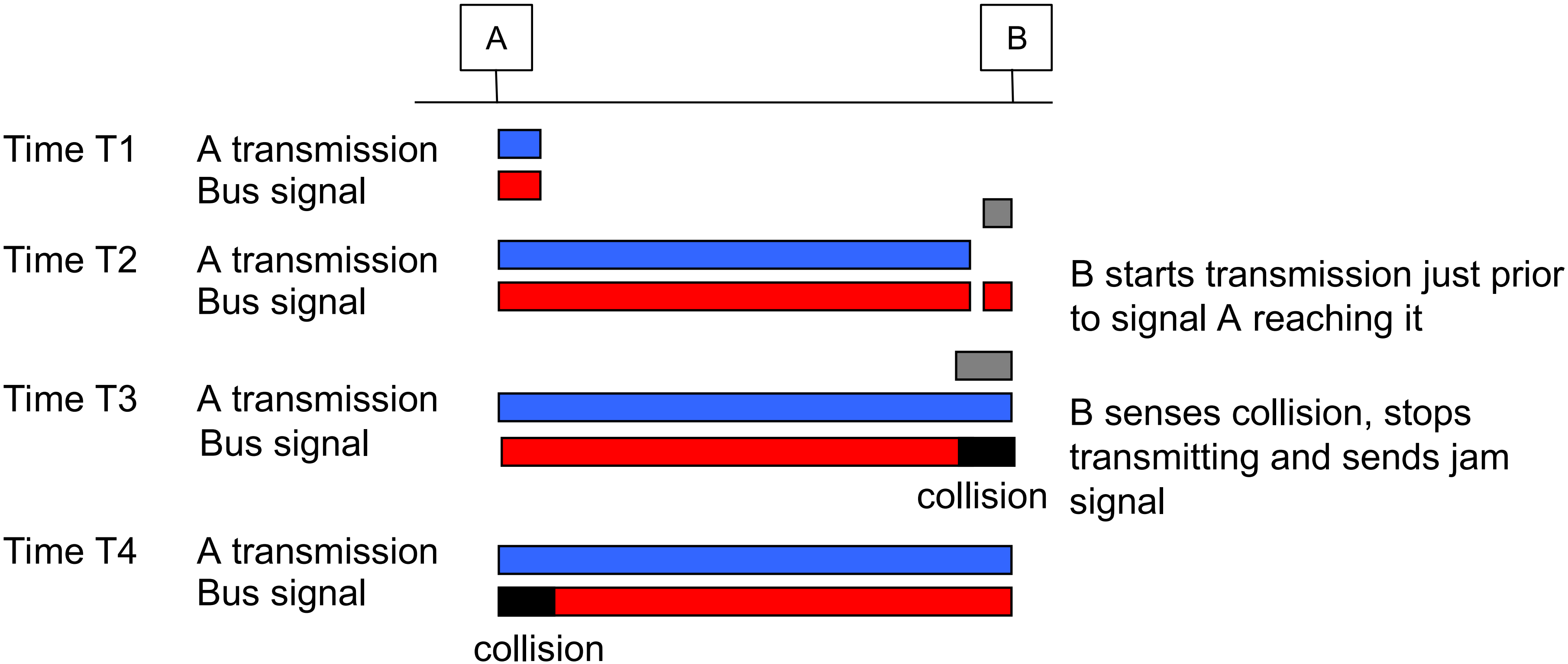
CSMA/CD steps

- If medium idle, transmit
- If busy, listen for idle, then transmit (1-persistent)
- If collision detected, jam then cease transmission
- After jam, wait random time then start again
  - Binary exponential back off

Collision Detection

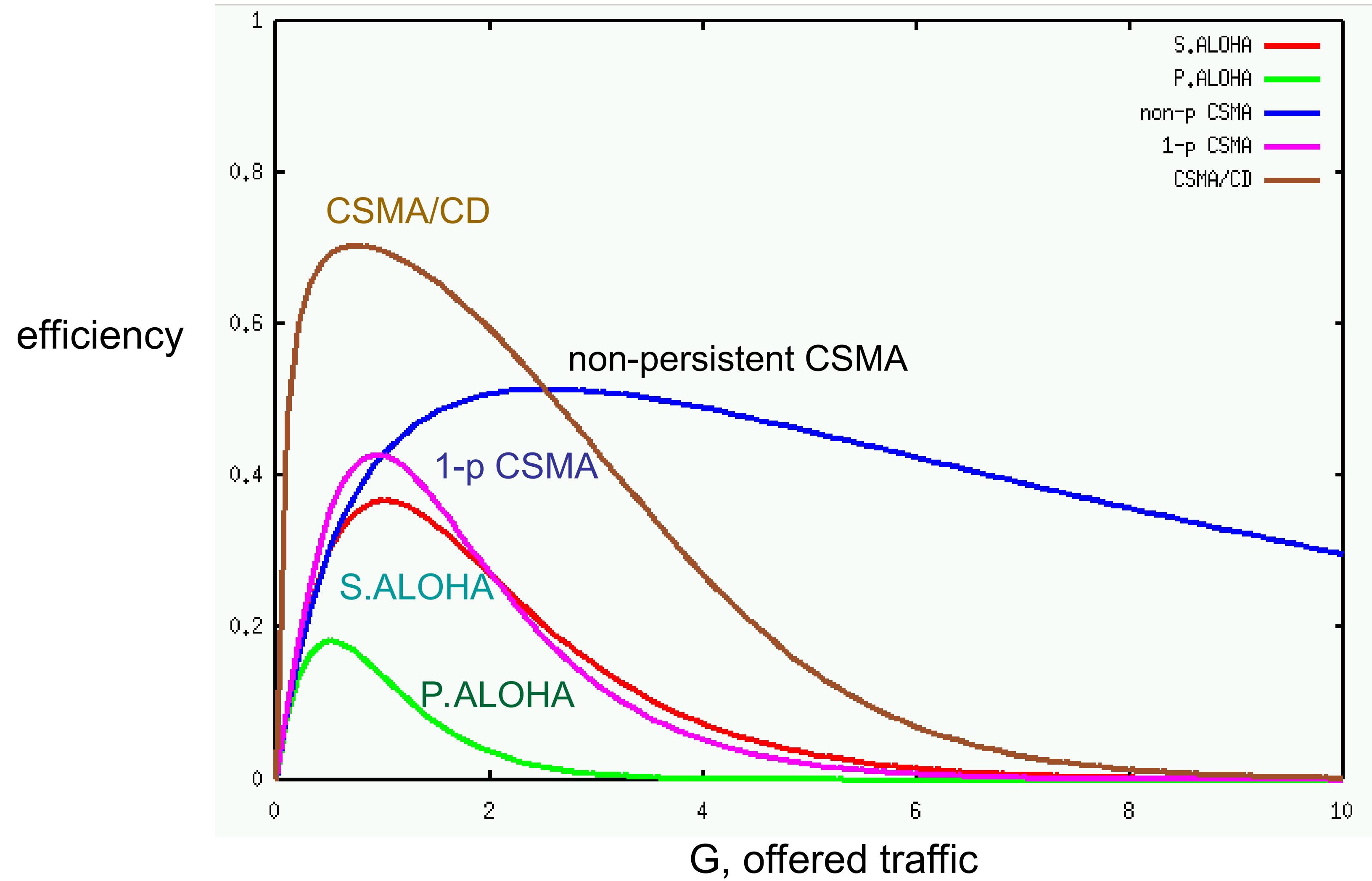
- Easy in wired LANs: measure signal strengths, compare transmitted, received signals
- Difficult in wireless LANs
  - receiver shut off while transmitting
  - one station cannot hear all other stations

Maximum Time to Detect Collision



- T2-T1=T4-T3=PROP
- Minimum time to detect collision: T4-T1=2×PROP
- Minimum frame length: TRANSP > 2×PROP

CSMA/CD Efficiency



- PROP/TRANSP=0.1

Frequency hopping

- Frequency hopping based on pseudorandom numbers
- Spreads power over wide spectrum: spread spectrum
- used to:
  - avoid (narrow-band) interference (or DoS),
  - prevent eavesdropping, and
  - enable code-division multiple access (CDMA) communications.
- Initially developed for military

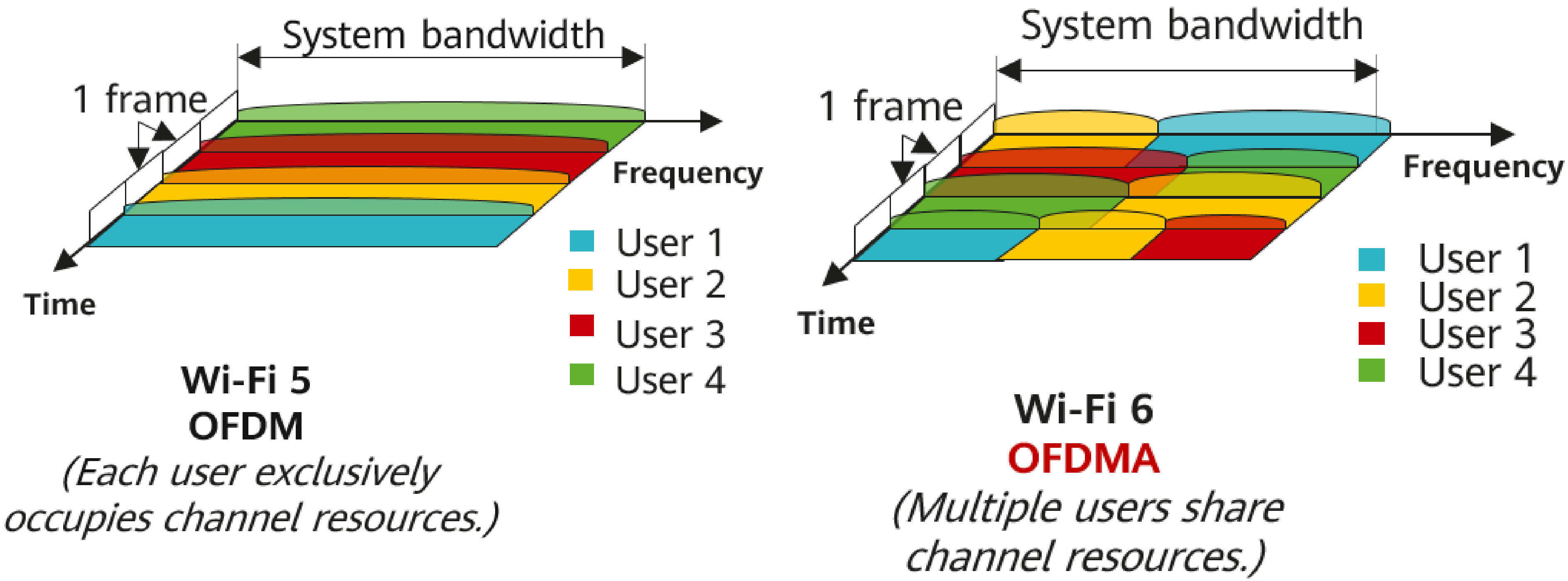
Orthogonal Frequency Division Multiple Access (OFDMA)

- Used by Wi-Fi 6 and 5G networks
- multi-user version of orthogonal frequency-division multiplexing (OFDM)
  - “Like” OFDM with time-division multiple access (TDMA)
  - Low-data-rate users can send continuously with low transmission power instead of using a "pulsed" high-power carrier.

OFDMA (cont.)

- Strengths:
  - simultaneous low-data-rate transmission from several users.
  - Shorter delay and constant delay
  - frequency diversity by spreading the carriers all over the used spectrum.
  - per-channel or per-subchannel power.
- Weaknesses
  - Higher sensitivity to frequency offsets and phase noise
  - Consumes energy even when idle

OFDM Vs. OFDMA (visual)



Src: https://info.support.huawei.com/info-finder/encyclopedia/en/OFDMA.html

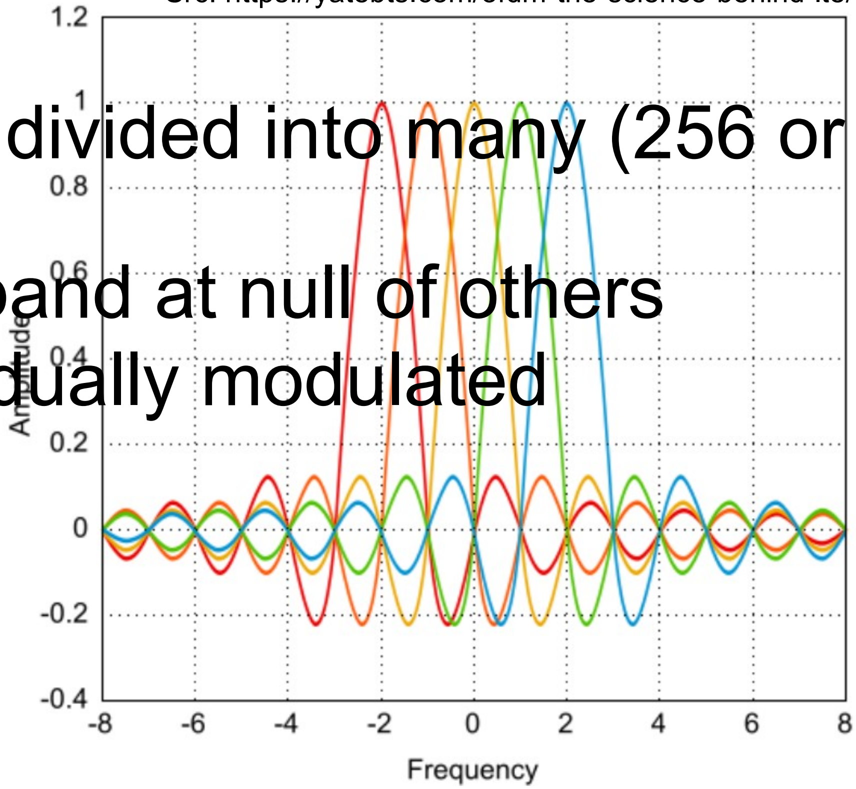
OFDMA - how it works?

- Three types of *carrier signal waves*, called **subcarriers**
  - data subcarriers, reference-signal subcarriers or null subcarriers.
    - Only data subcarriers used for data transmission.
- Channel splits into smaller frequencies, resource units (**RUs**),
- Assigns subsets of time-frequency RUs to multiple users
  - Different RUs for different QoS classes
- Greater performance by
  - Exploiting spectrum more efficiently.
  - moving small bits of information in a more streamlined fashion (due to using carrier signals)

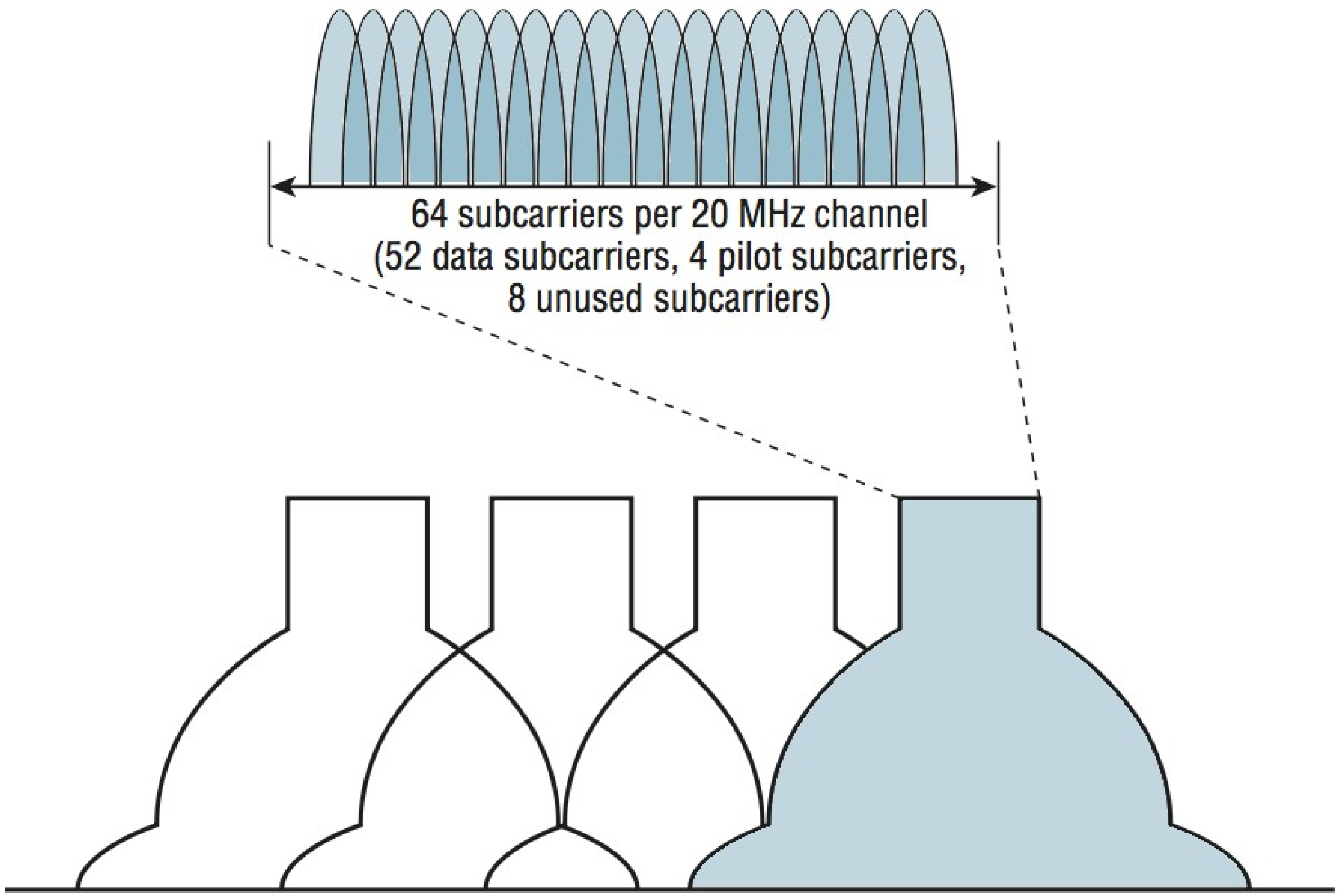
OFDMA

- **Multicarrier** modulation akin to DiscreteMultiTone (DMT)
  - resilient to interference, narrow-band fading and multipath effects.
- Available frequency band divided into many (256 or more) sub-bands
- Orthogonal: peak of one band at null of others
- Each carrier can be individually modulated

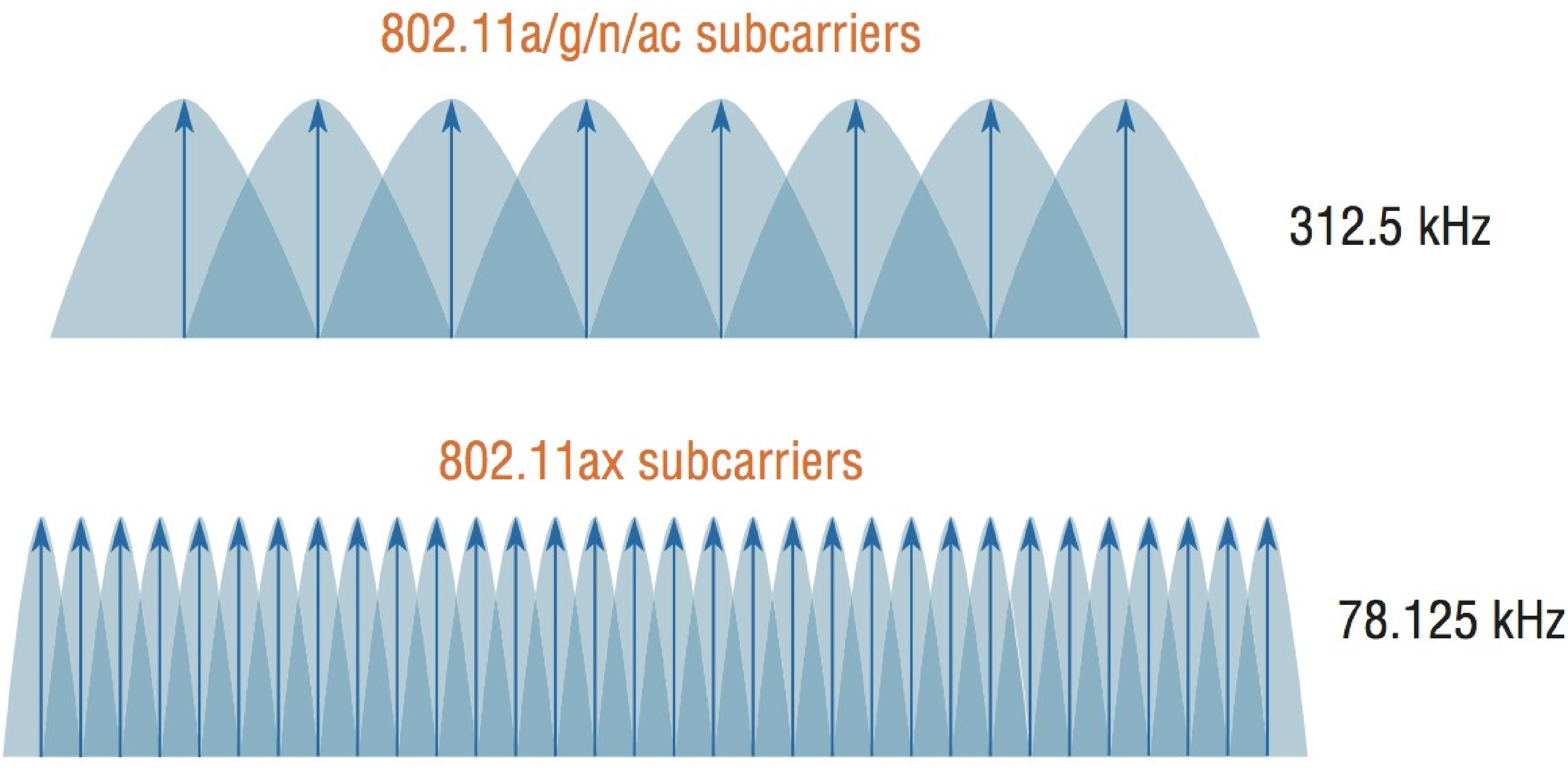
Src: https://yatebts.com/ofdm-the-science-behind-lte/



802.11n/ac 20 MHz channel **OFDM** subcarriers

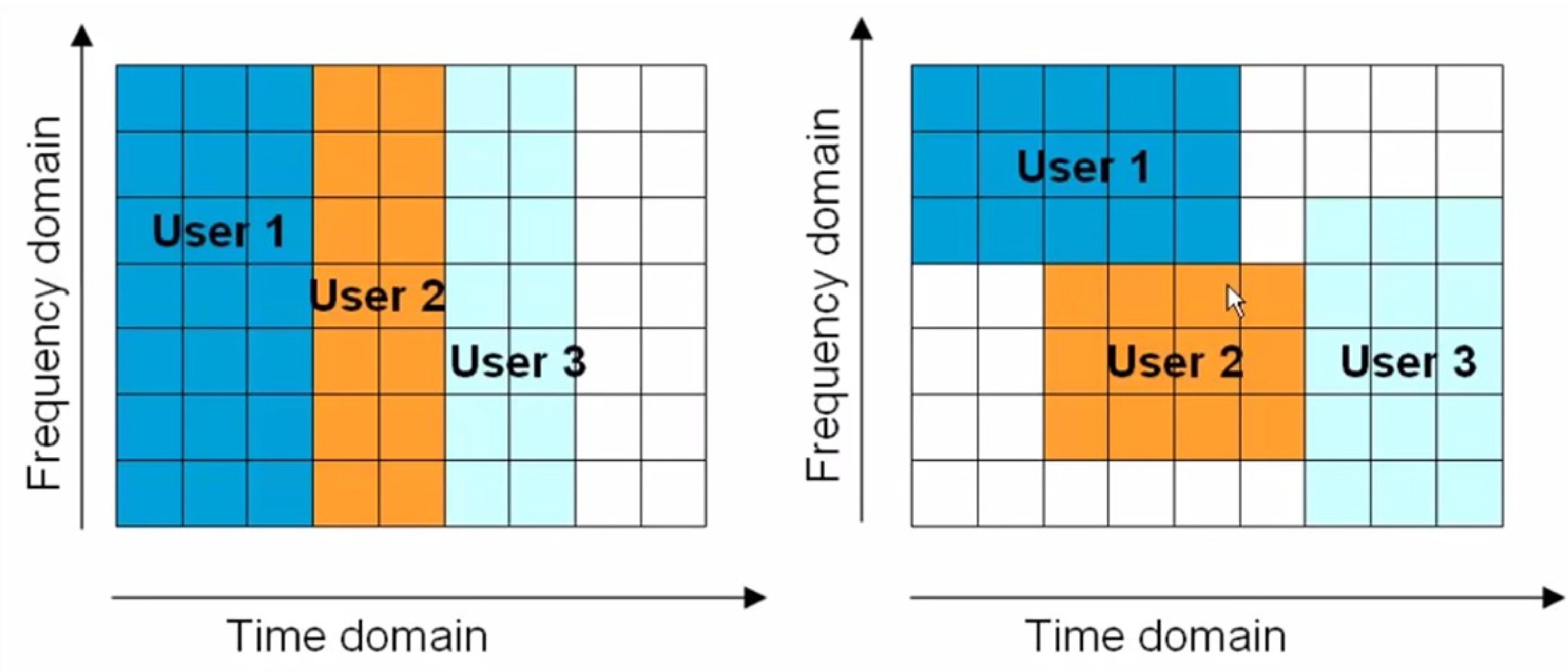


802.11ax – WiFi 6



- 802.11ax utilizes OFDMA

OFDM versus OFDMA



OFDM

OFDMA

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