



# Ευφυή Κινητά Δίκτυα: Πρωτόκολλα Πολλαπλής Προσπέλασης

Χειμερινό Εξάμηνο 2022-23

Βασίλειος Σύρης

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## Multiple access

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

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# Switching

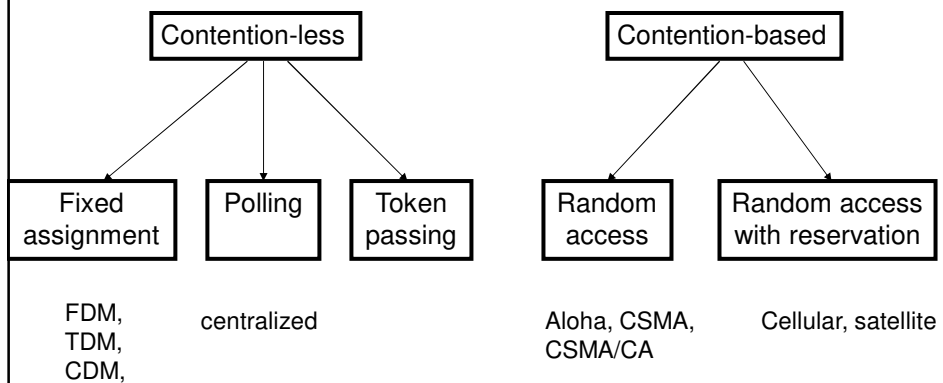
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- Circuit switched-based
  - Packet-based
    - Datagram switching
    - Virtual circuit switching
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# Multiple access

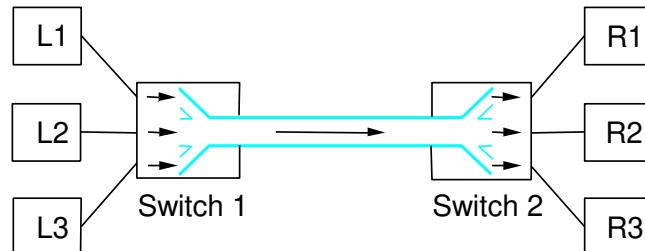
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# Multiplexing

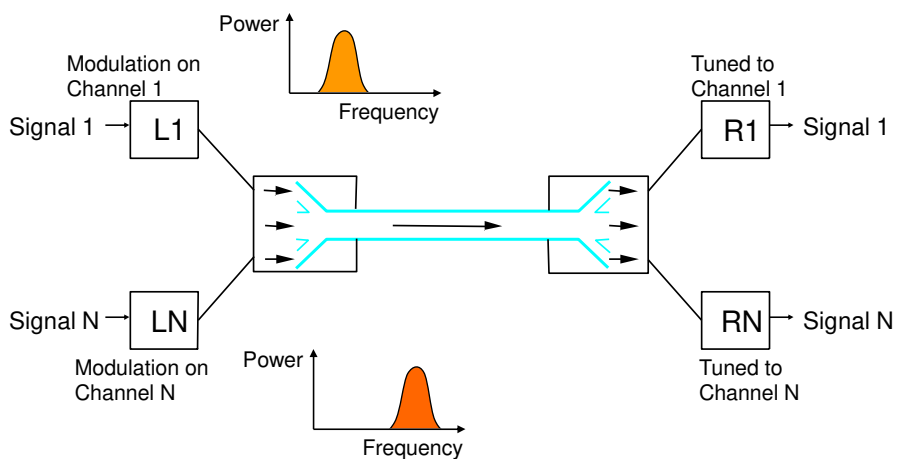
- Time-Division Multiplexing (TDM)
- Frequency-Division Multiplexing (FDM)
- Statistical Multiplexing



- Code Division Multiple Access (CDMA): wireless

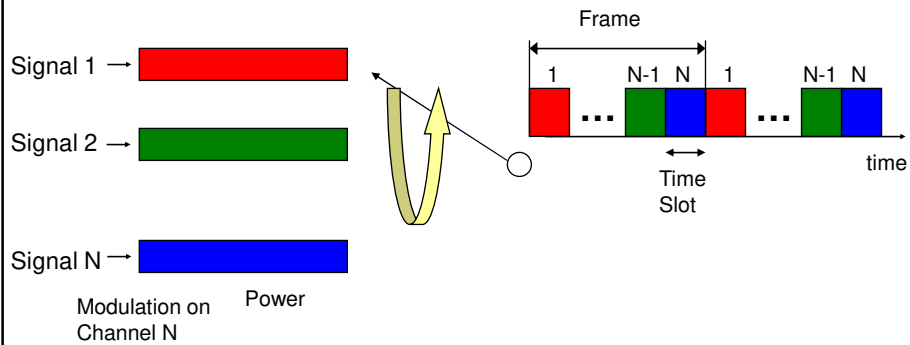
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# Frequency Division Multiplexing



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# Time Division Multiplexing



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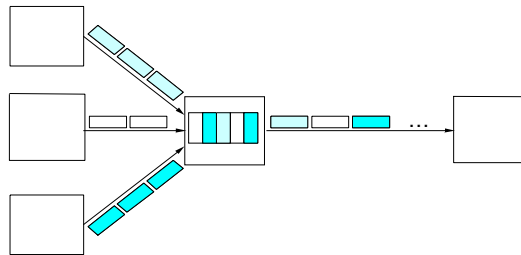
# FDM and TDM Multiplexing

- FDM:
  - Adapts signal to characteristics of media
  - e.g. TV broadcasting
- TDM:
  - Appropriate for synchronous transmission
  - e.g. fixed telephony, GSM (wireless)
- FDM and TDM allocate resources (frequency and time slots) in a static manner
- This results to inefficient multiplexing for bursty traffic

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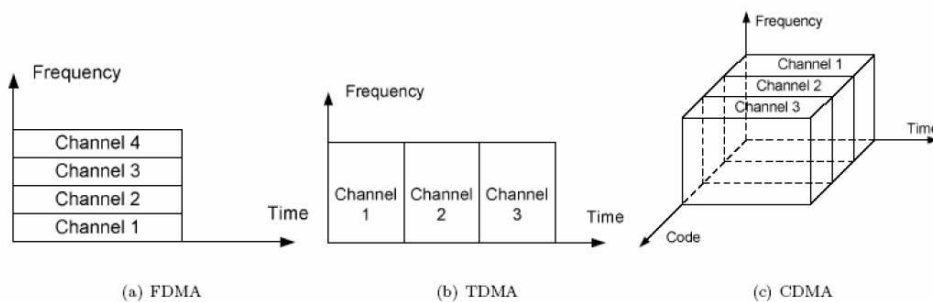
# Statistical Multiplexing

- On-demand time-division
- Schedule link on a per-packet basis
- Packets from different sources interleaved on link
- Issues:
  - Packets need labels/addresses
  - Buffer packets *contend* for the link => need buffering
- Buffer (queue) overflow is called *congestion*



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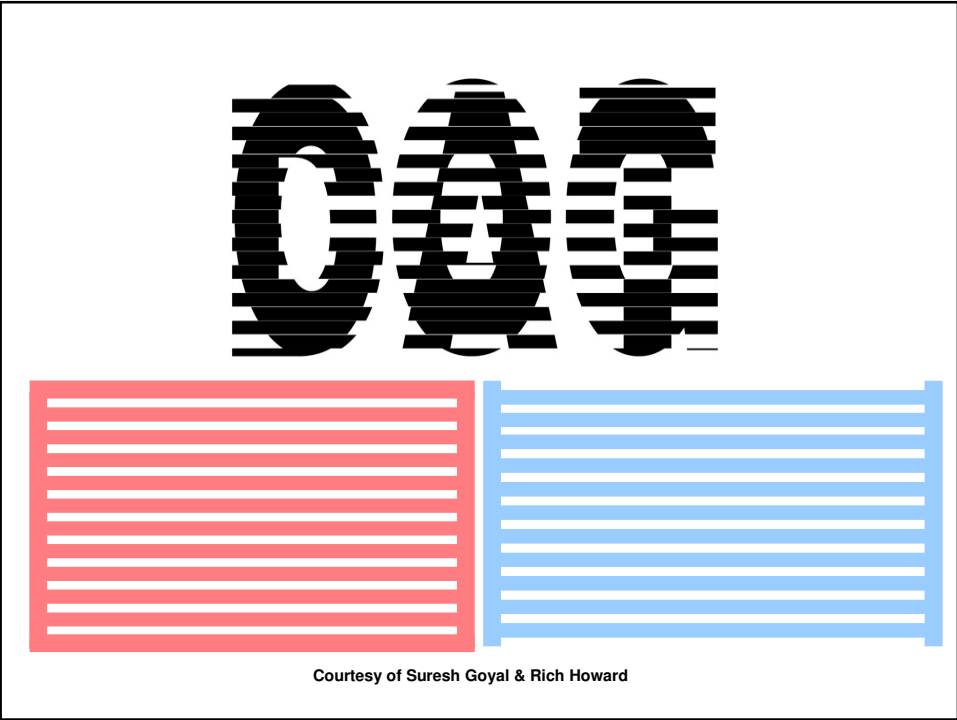
# Channel partitioning



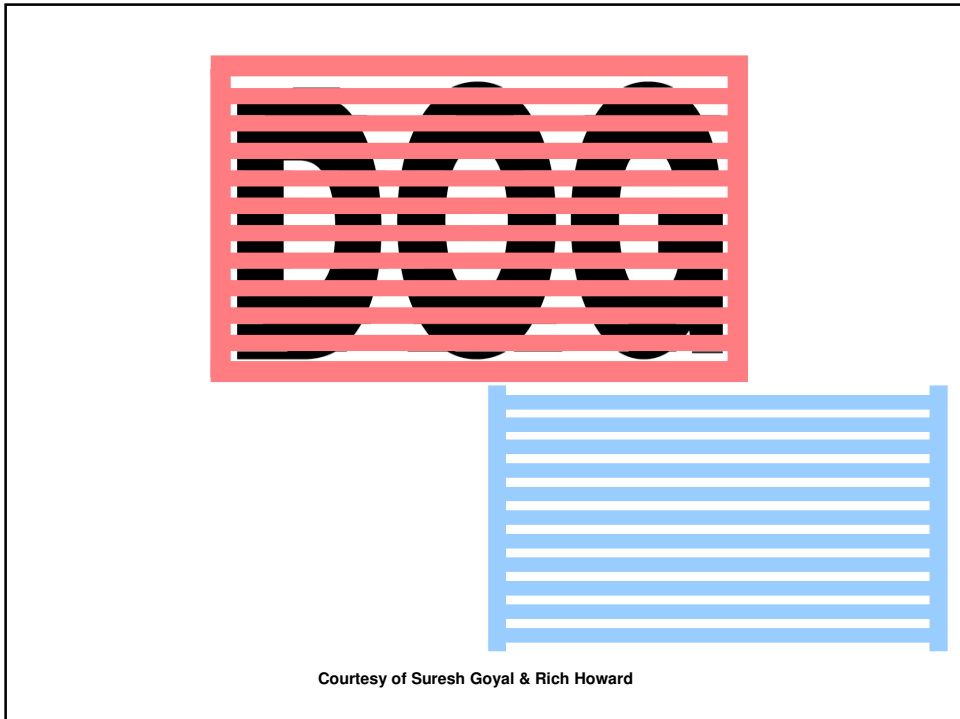
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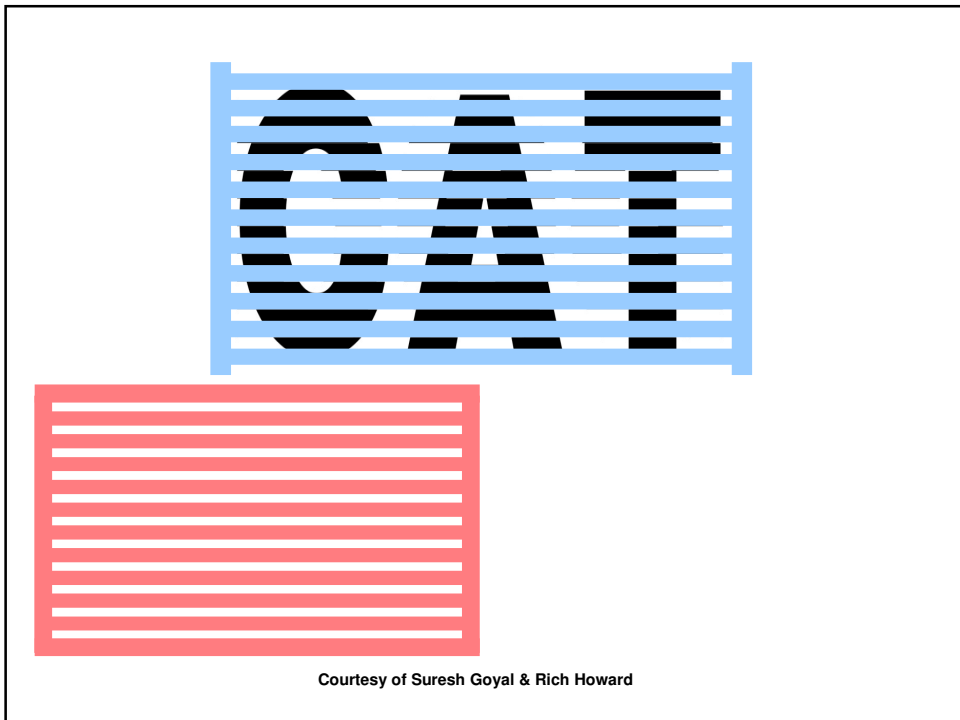
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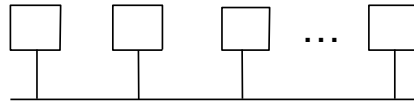
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## Multiple Access Systems

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- 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
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## Multiple Access Control

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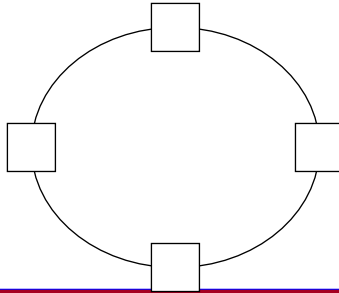
- TDM: inefficient
  - Ethernet: based on CSMA/CD (Carrier Sense Multiple Access/ Collision Detect)
    - Wait for idle channel, then send packet
    - Stop if collision detected
    - Wait for random delay after collision
  - ALOHA: less polite than Ethernet
    - Transmit whenever packet is ready
    - Stop if collision detected
    - Wait for random delay after collision
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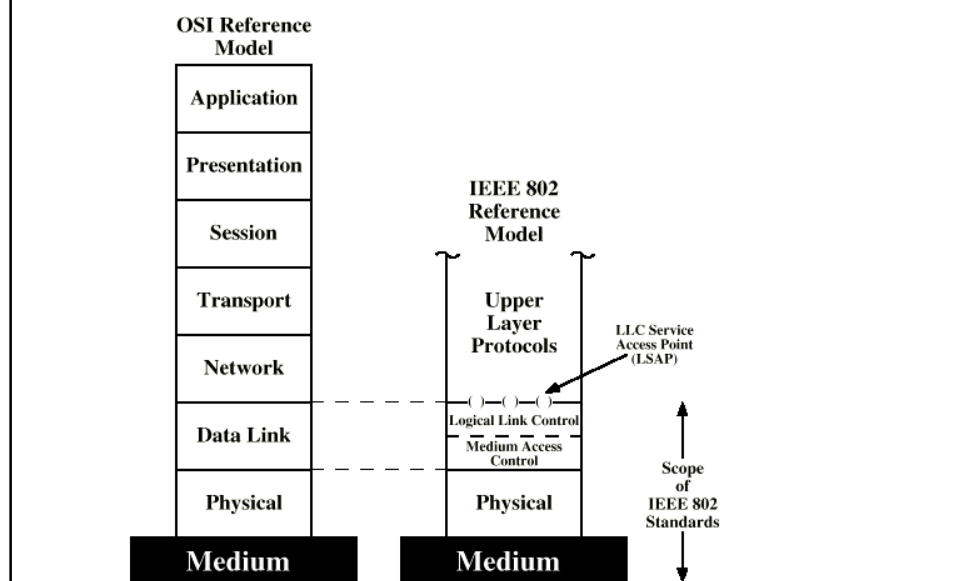
## Multiple Access Control (cont)

- Token passing
  - Token passed from one node to another
  - Node transmits if it has token
  - Need to make sure token not lost, and no one node exhibits unfair behavior
- Token ring: nodes connected in ring topology



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## OSI and IEEE 802



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## IEEE 802 Layers - Physical

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- Encoding/decoding
  - Preamble generation/removal
  - Bit transmission/reception
  - Transmission medium and topology
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## IEEE 802 Layers - Logical Link Control (LLC)

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- Interface to higher levels
  - Multiplexing
  - Flow and error control
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## IEEE 802 Layers - Media Access Control (MAC)

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- 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)
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## Media Access Control (MAC)

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- 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
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## MAC Protocol: A Taxonomy

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- 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, token bus
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## Random Access MAC Protocols

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- 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
  - Access Control design problem: limit inefficiencies due to collisions and idle periods
  
  - Examples:
    - ALOHA (Slotted, Pure)
    - CSMA and CSMA/CD (Ethernet)
    - CSMA/CA (Wireless LAN/ IEEE 802.11)
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## Random Access MAC Protocols: Performance

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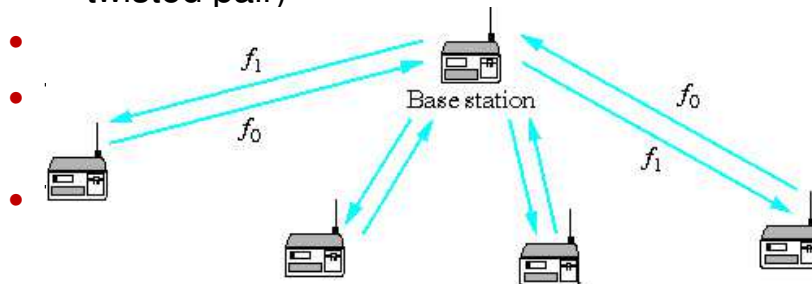
- Efficiency=maximum fraction of time nodes transmit packets successfully
  - Throughput=maximum rate of successful bit transmission = (Efficiency)  $\times$  (Transmission rate)
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## ALOHA Protocol

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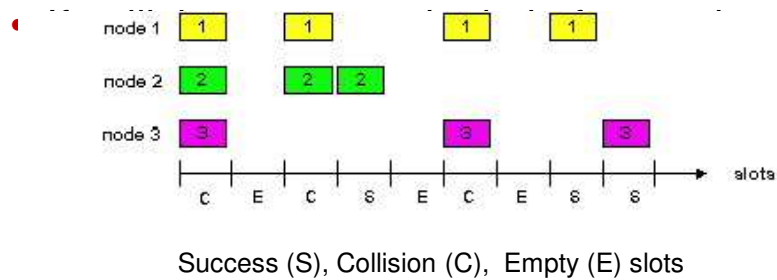
- ALOHA: packet-switched radio communication network
  - University of Hawaii, 1970s
  - Can also run over wired media (coaxial cable, twisted pair)



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## Slotted ALOHA

- Time is divided into equal size slots (= packet transmission time)
- Node with new pkt: transmit at beginning of next slot



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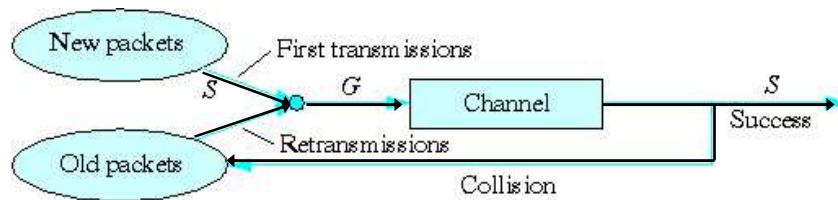
## Slotted ALOHA

- 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%

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## Slotted ALOHA Transmissions

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



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## 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

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

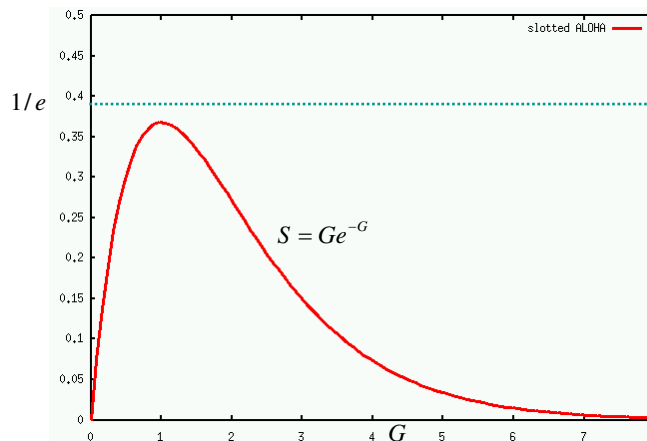
- From above

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

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## Slotted ALOHA: Efficiency (cont)

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



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## Slotted ALOHA: Finite Station Population

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

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

Above is maximized for  $q=1/N$

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

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

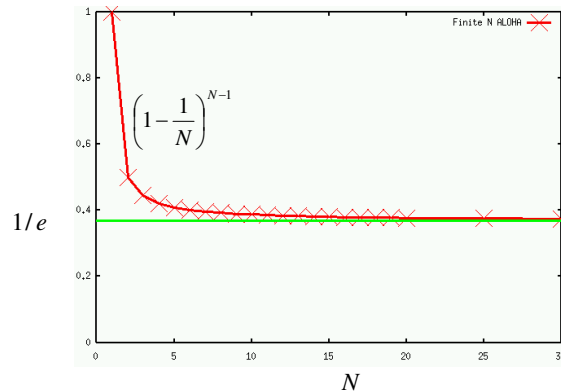
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## Slotted ALOHA: Finite Station Population (cont)

- Maximum efficiency for finite population

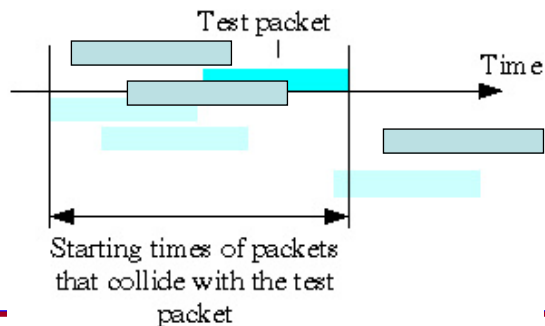
$$\text{ALOHA} \quad \left(1 - \frac{1}{N}\right)^{N-1} \xrightarrow{N \rightarrow \infty} \frac{1}{e}$$



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## Pure ALOHA

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



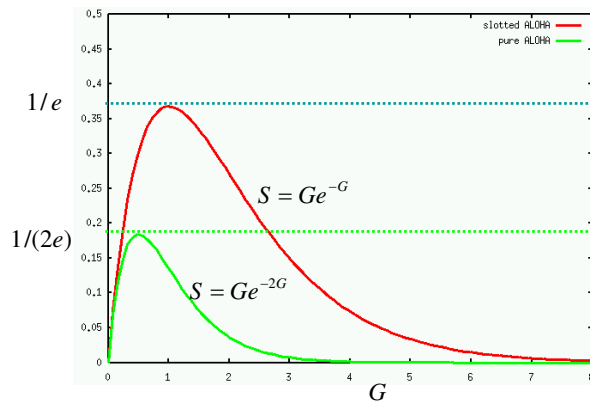
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## Pure ALOHA: Performance

- Probability of successful packet transmission

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

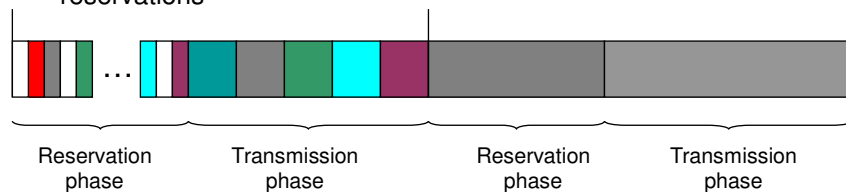
- Hence  $S = G \times e^{-2G}$   $\eta_{P.ALOHA} \leq 18\%$



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## 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



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## Reservation ALOHA: Efficiency

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- 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

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

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## Carrier Sense Multiple Access (CSMA)

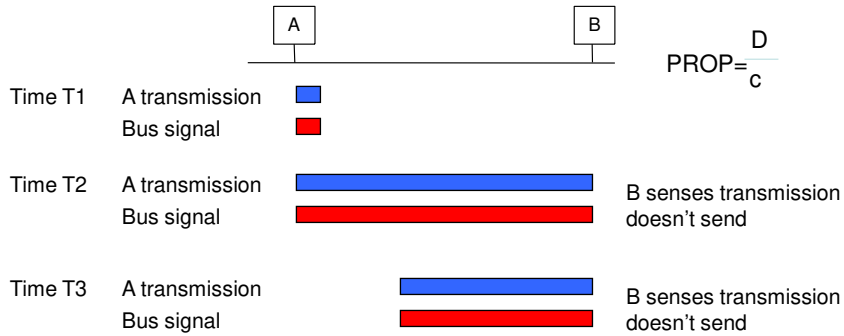
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- Carrier Sense: “Listen before talking”
  - Sender:
    - Listen for clear medium (carrier sense)
    - If medium idle
      - ◆ Transmit whole frame
      - ◆ Start Timeout and wait for ACK
    - If medium busy
      - ◆ Defer transmission -> Three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

- PROP << TRANSP

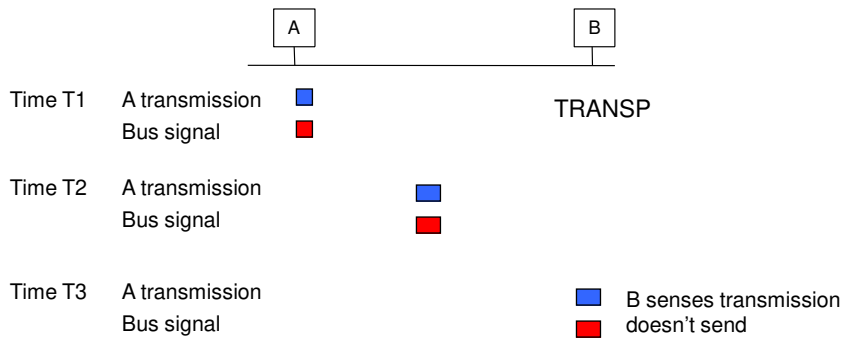


- When can collision occur?
  - T1 until T1+PROP
  - PROP small percentage of transmission time TRANSP
  - A has seized channel for time TRANSP-PROP

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# Carrier Sense

- PROP >> TRANSP



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

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## Why ALOHA doesn't listen...

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- 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
- 

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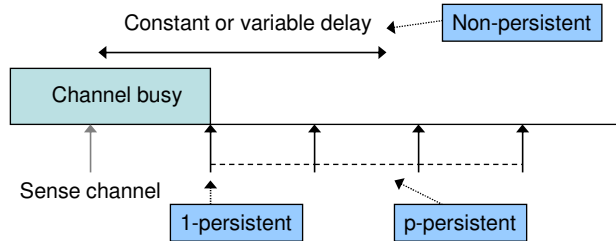
## CSMA: What happens if channel is busy?

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- 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
- 

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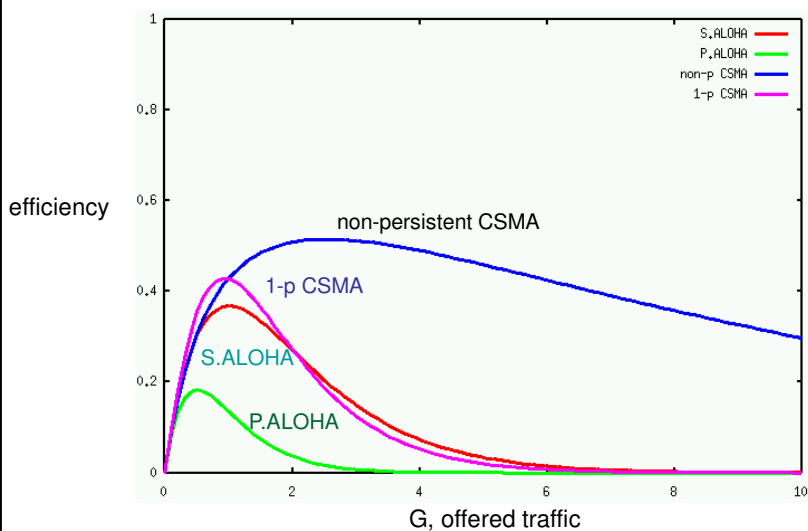
# CSMA persistence schemes



- 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,  $Np \ll 1$  unnecessarily long delays

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# CSMA: efficiency



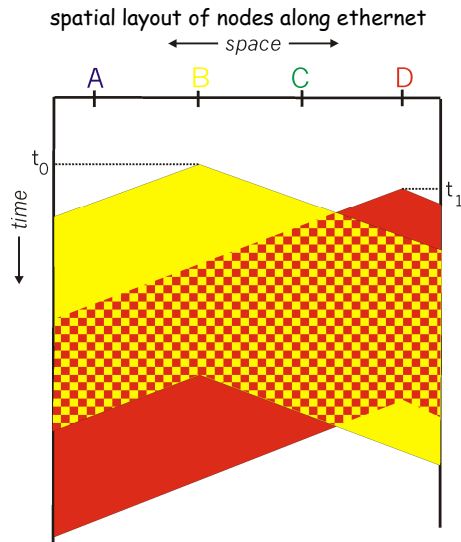
- PROP/TRANSP=0.1

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# CSMA Collisions

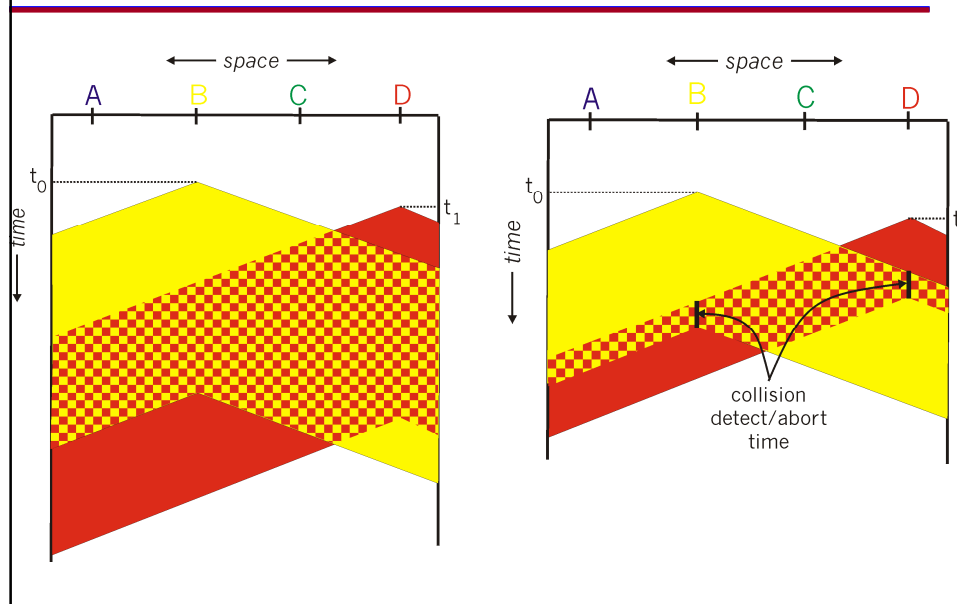
**Collisions can occur:**  
propagation delay means  
two nodes may not  
hear each other's  
transmission

**Collision:**  
entire packet transmission  
time wasted



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# Gains of Collision Detect



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## CSMA/CD (Collision Detect)

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- 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
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## Collision Detection

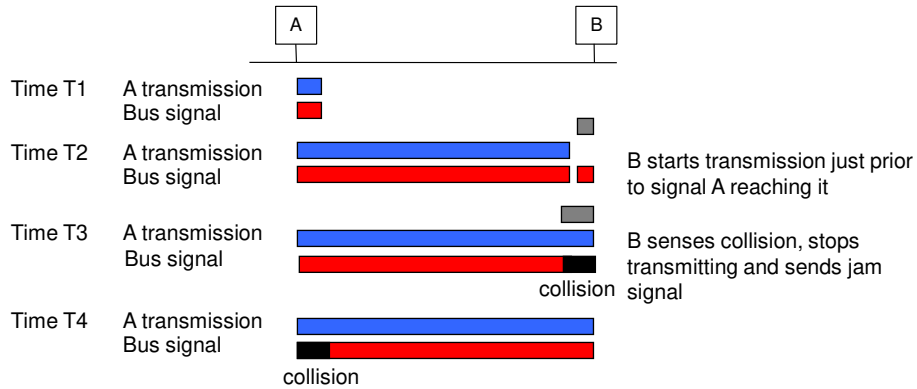
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- Easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - Difficult in wireless LANs
    - receiver shut off while transmitting
    - one station cannot hear all other stations
- 

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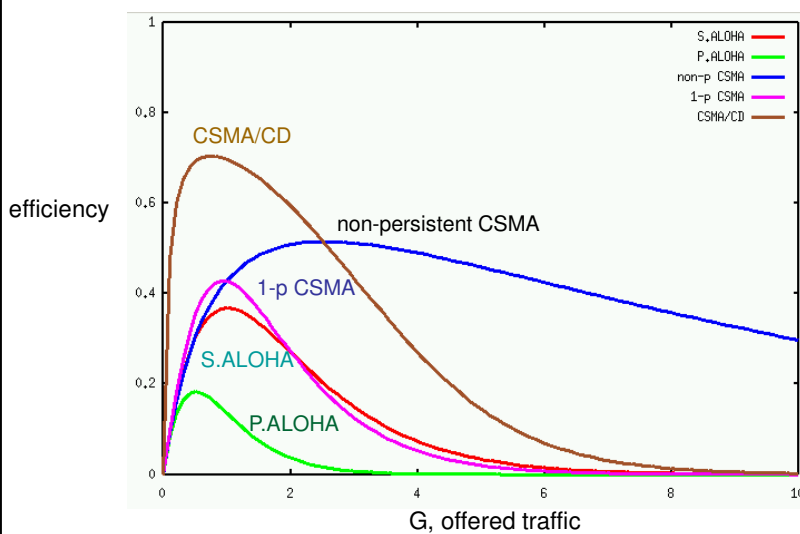
## Maximum Time to Detect Collision



- $T2 - T1 = T4 - T3 = \text{PROP}$
- Minimum time to detect collision:  $T4 - T1 = 2 \times \text{PROP}$
- Minimum frame length:  $\text{TRANSP} > 2 \times \text{PROP}$

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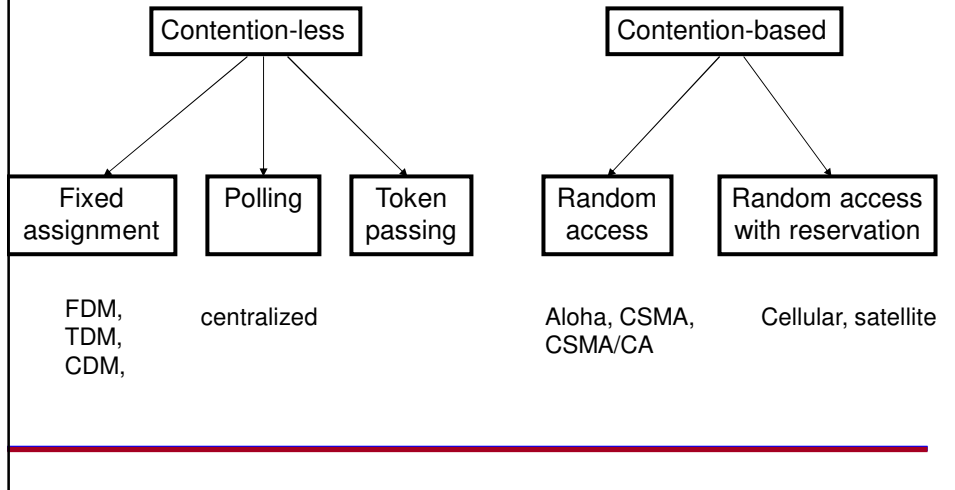
## CSMA/CD Efficiency



- $\text{PROP}/\text{TRANSP} = 0.1$

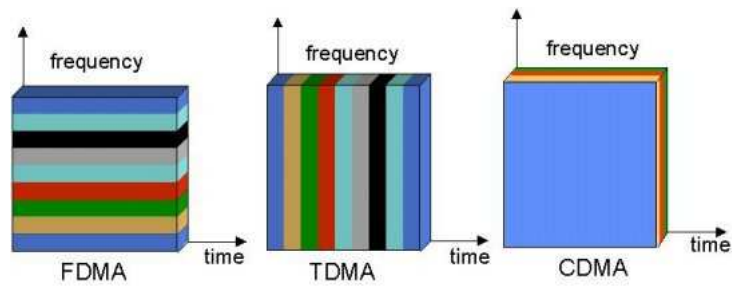
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# Multiple access



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# Channel partitioning

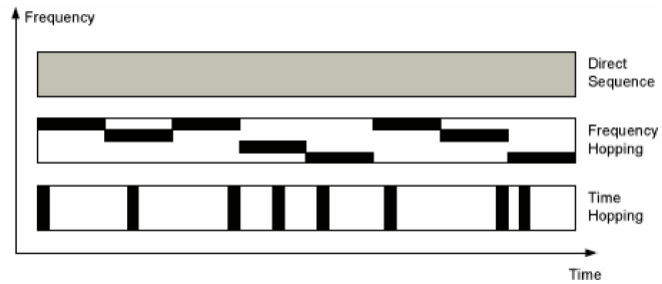


Courtesy of Petri Pössi, UMTS World

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# CDMA

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## Frequency hopping

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- Frequency hopping based on pseudorandom numbers
  - Spreads power over wide spectrum: spread spectrum
  - Narrowband interference not effective
  - Initially developed for military
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## Wideband CDMA

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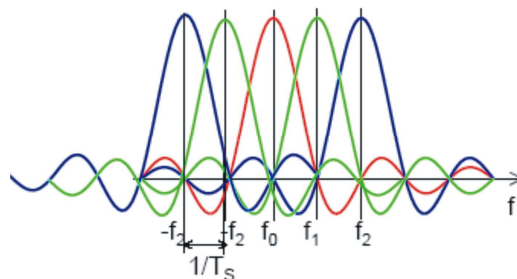
- Bandwidth  $\geq 5\text{MHz}$
  - Multirate: variable spreading and multicode
  - Power control:
    - open power control
    - fast closed-loop power control
  - Frame length: 10ms/20ms (optional)
  - Used in 3G systems
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## OFDMA

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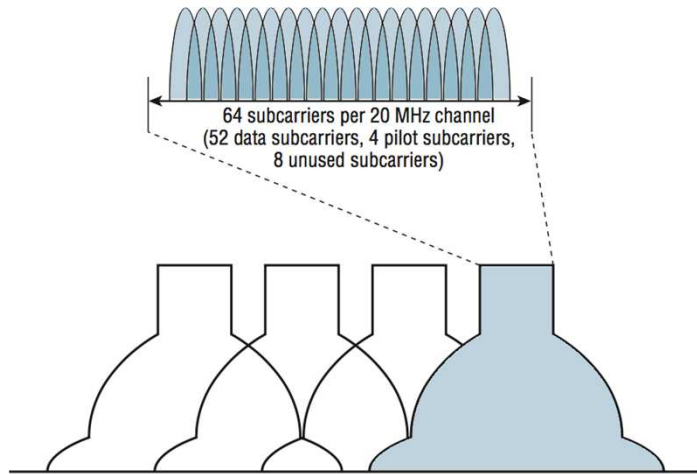
- Orthogonal Frequency Division Multiple Access
- Multicarrier modulation similar to DMT
- Available frequency band divided into many (256 or more) sub-bands
- Orthogonal: peak of one band at null of others
- Each carrier can be individually modulated
- Used in 4G, 5G, 802.11ax (WiFi 6)



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## 802.11n/ac 20 MHz channel OFDM subcarriers

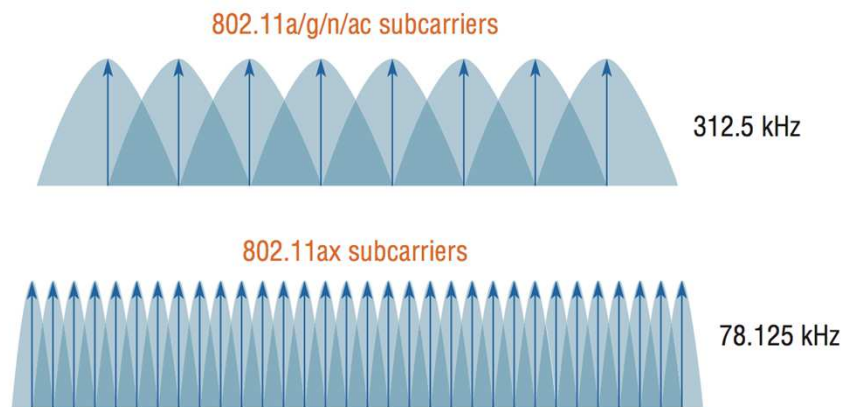
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## 802.11ax – WiFi 6

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- 802.11ax utilizes OFDMA
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# OFDM versus OFDMA

