Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

Ευφυή Κινητά Δίκτυα: Πρωτόκολλα Πολλαπλής Προσπέλασης

Χειμερινό Εξάμηνο 2024-25

Βασίλειος Σύρης

1

Multiple access

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

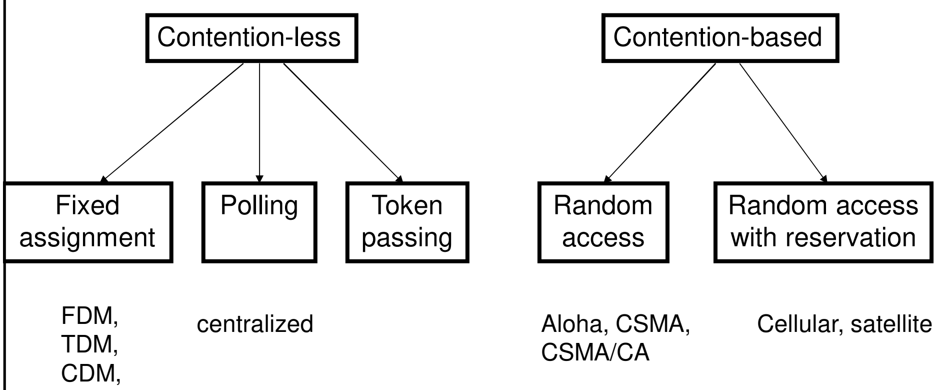
2

Switching

- Circuit switched-based
- Packet-based
  - Datagram switching
  - Virtual circuit switching

3

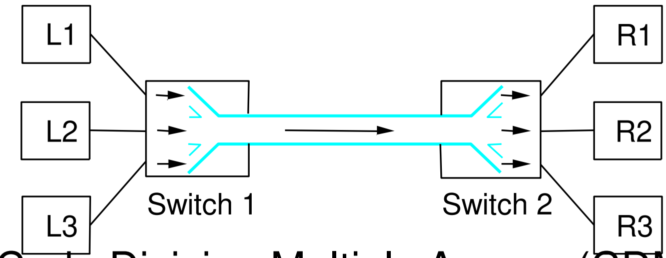
Multiple access



4

Multiplexing

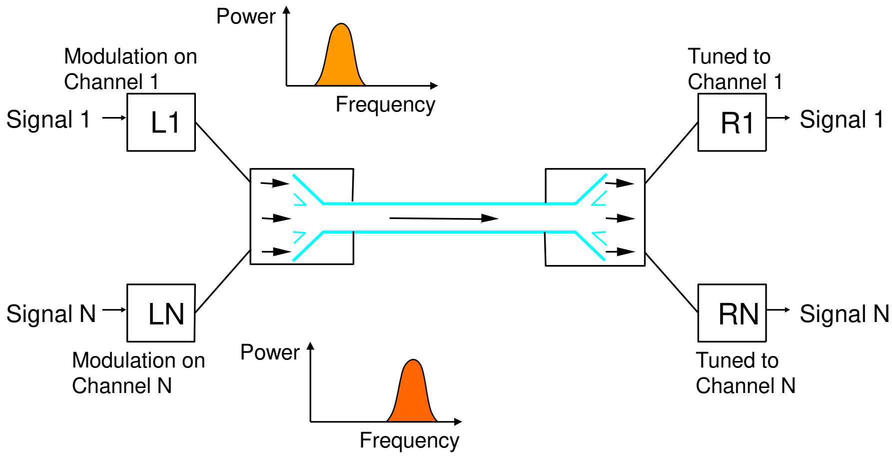
- Time-Division Multiplexing (TDM)
- Frequency-Division Multiplexing (FDM)
- Statistical Multiplexing



- Code Division Multiple Access (CDMA): wireless

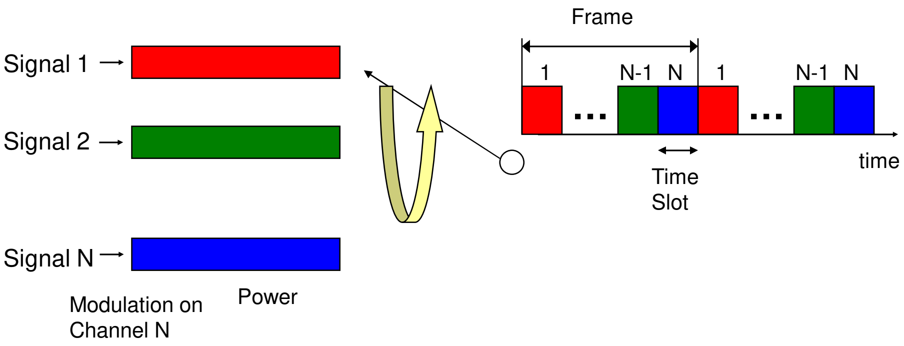
5

Frequency Division Multiplexing



6

Time Division Multiplexing

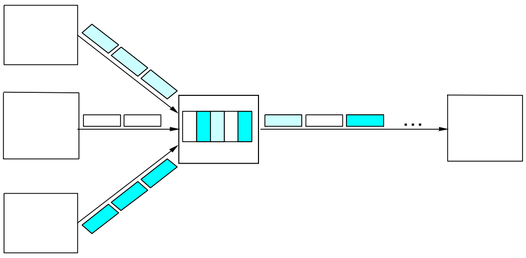


FDM and TDM Multiplexing

- 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

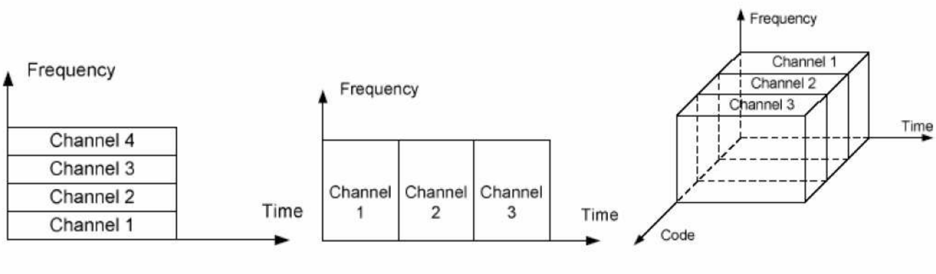
Statistical Multiplexing

- 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*



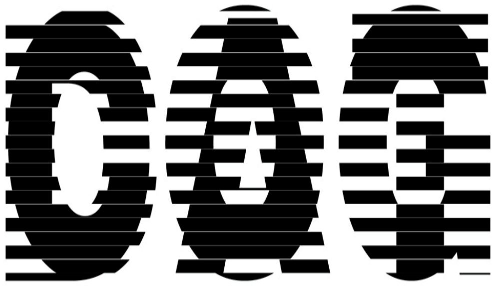
9

Channel partitioning



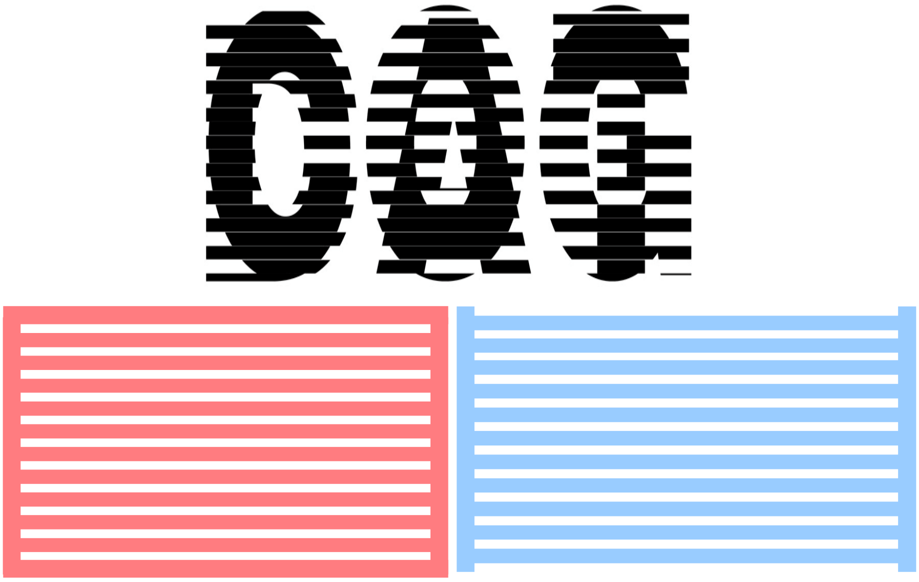
(a) FDMA (b) TDMA (c) CDMA

10



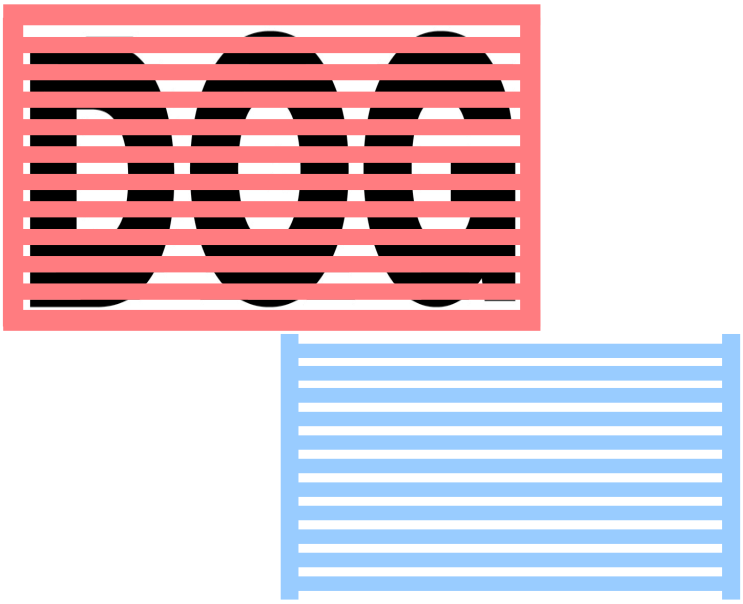
Courtesy of Suresh Goyal & Rich Howard

11



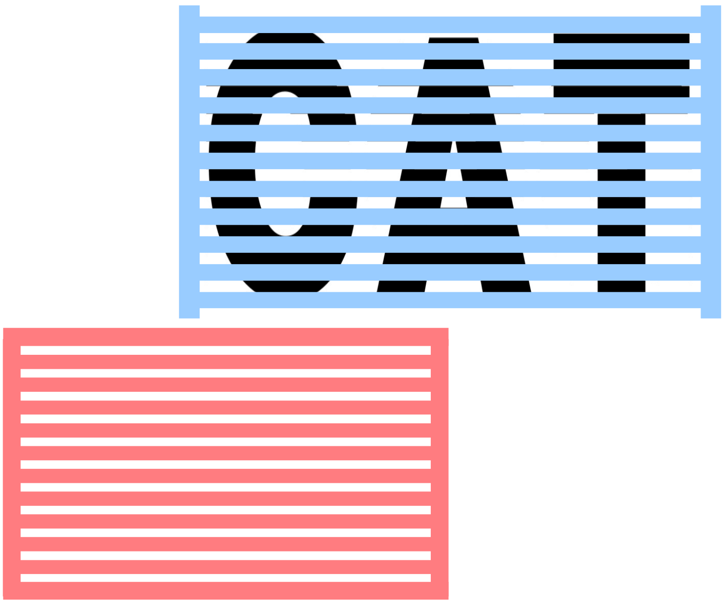
Courtesy of Suresh Goyal & Rich Howard

12



Courtesy of Suresh Goyal & Rich Howard

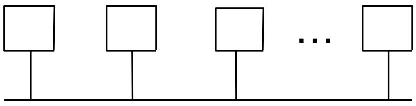
13



Courtesy of Suresh Goyal & Rich Howard

14

Multiple Access Systems



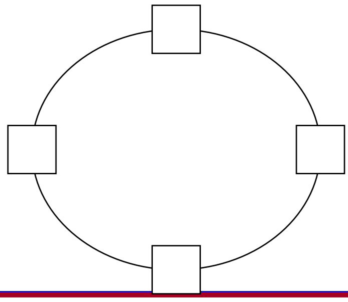
- Nodes use common transmission channel
- Collisions when two or more hosts send simultaneously
- Access Control design problem: limit inefficiencies due to collisions and idle periods

Multiple Access Control

- 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

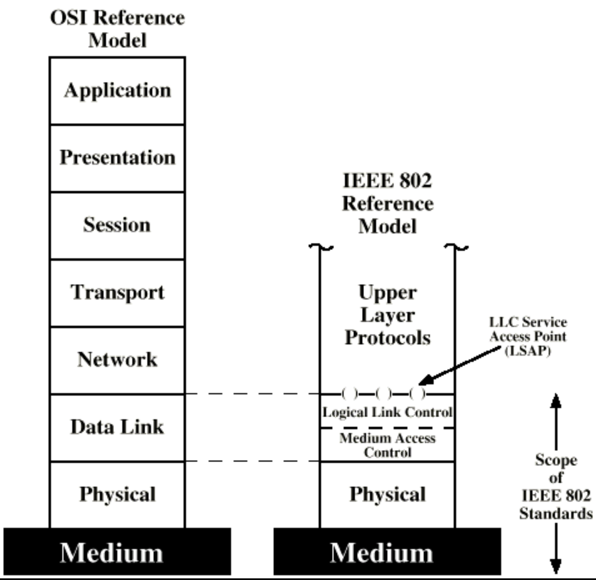
Multiple Access Control (cont)

- 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



17

OSI and IEEE 802



18

IEEE 802 Layers - Physical

- Encoding/decoding
- Preamble generation/removal
- Bit transmission/reception
- Transmission medium and topology

19

IEEE 802 Layers - Logical Link Control (LLC)

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

20

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)

21

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

22

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

23

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
- 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)

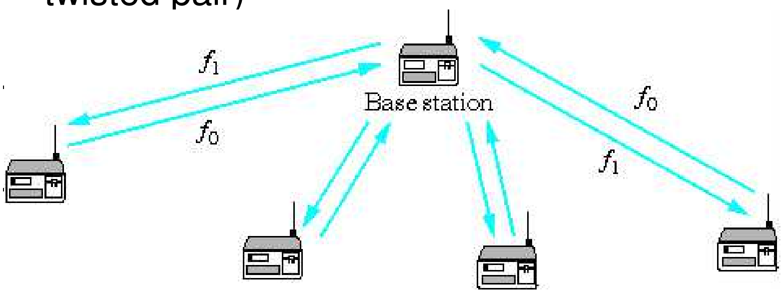
24

Random Access MAC Protocols: Performance

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

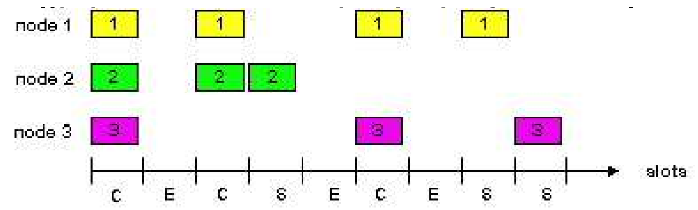
ALOHA Protocol

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



Slotted ALOHA

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



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

27

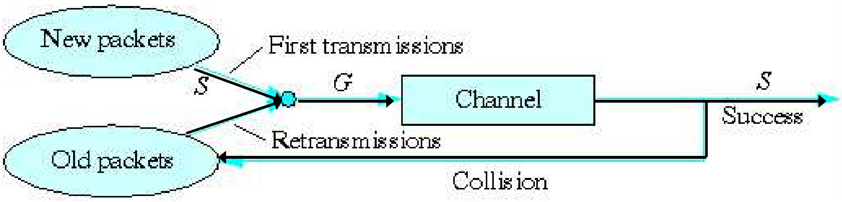
Slotted ALOHA

- 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%

28

Slotted ALOHA Transmissions

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



29

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

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

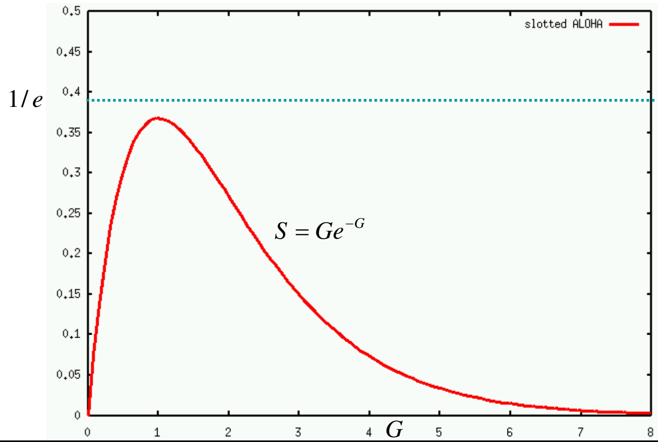
- From above

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

30

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: $q(1-q)^{N-1}$ N stations: $Nq(1-q)^{N-1}$

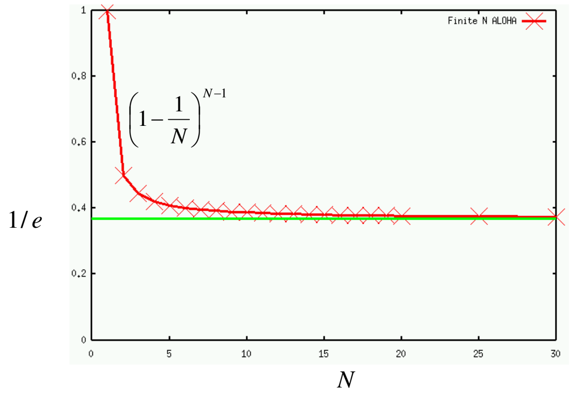
Above is maximized for q=1/N

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

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

Slotted ALOHA: Finite Station Population (cont)

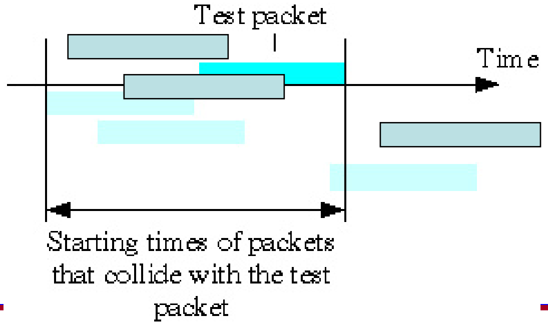
- Maximum efficiency for finite population ALOHA $\left(1-\frac{1}{N}\right)^{N-1} \underset{N\to\infty}{\to} \frac{1}{e}$



33

Pure ALOHA

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



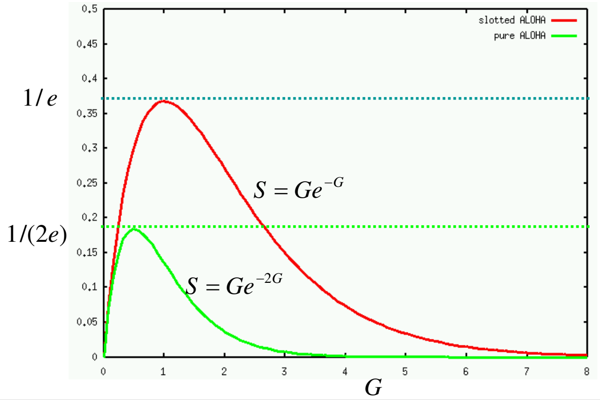
34

Pure ALOHA: Performance

- Probability of successful packet transmission

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

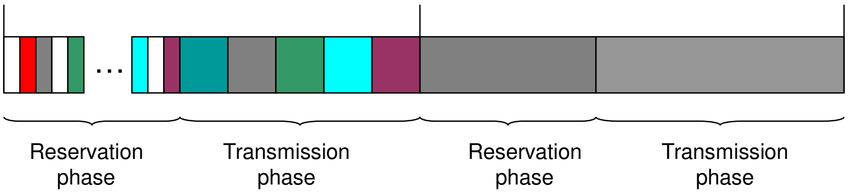
- Hence $S = G \times e^{-2G}$ $\quad \eta_{P.ALOHA} \leq 18\%$



35

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



36

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

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

37

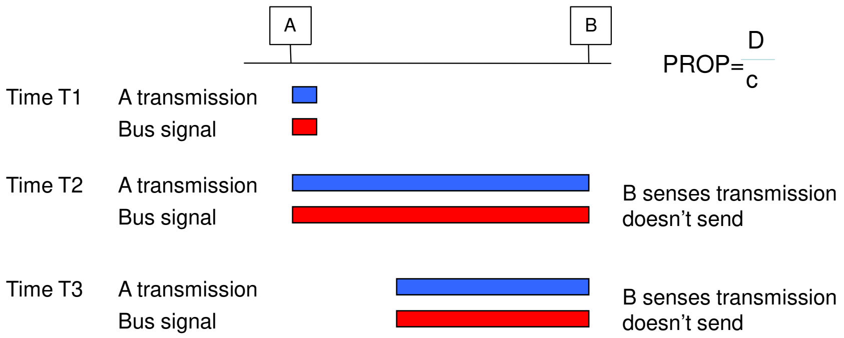
Carrier Sense Multiple Access (CSMA)

- 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

38

Carrier Sense

- PROP<<TRANSP

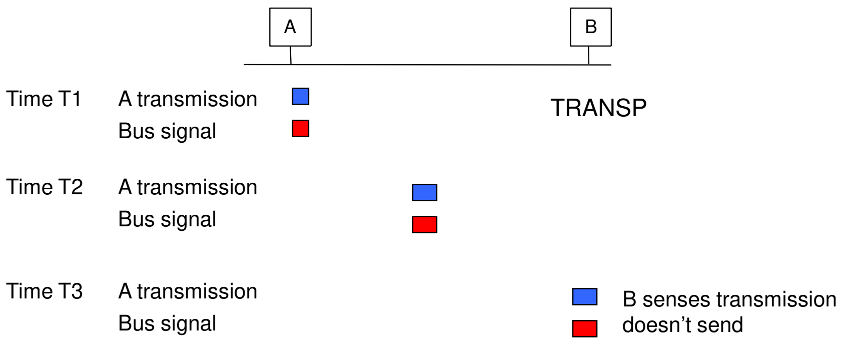


- When can collision occur?
  - T1 until T1+PROP
  - PROP small percentage of transmission time TRANSP
  - A has seized channel for time TRANSP-PROP

39

Carrier Sense

- PROP>>TRANSP



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

40

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

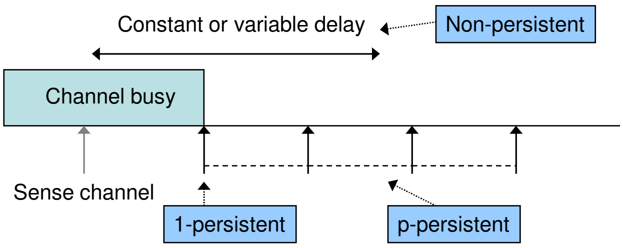
41

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

42

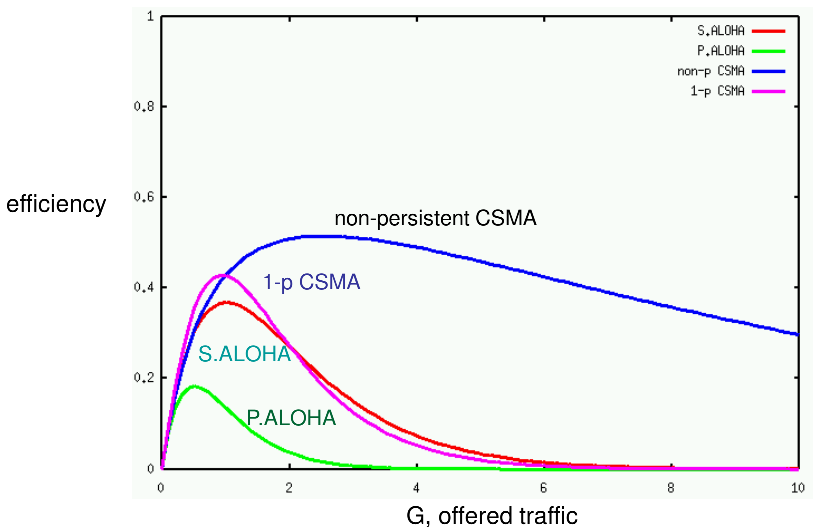
CSMA persistence schemes



- 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

43

CSMA: efficiency



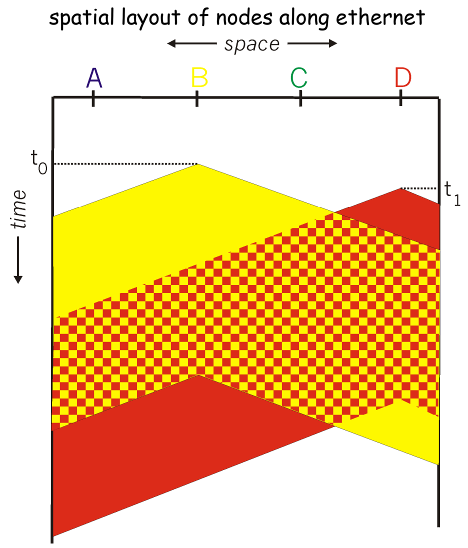
- PROP/TRANSP=0.1

44

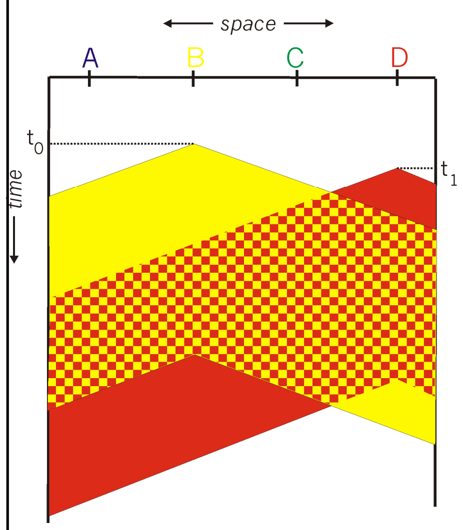
CSMA Collisions

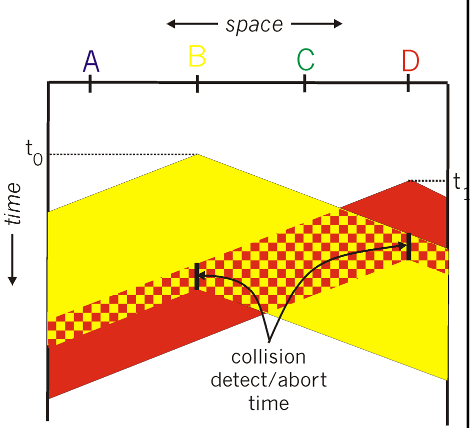
Collisions *can* occur:
propagation delay means two nodes may not hear each other's transmission

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

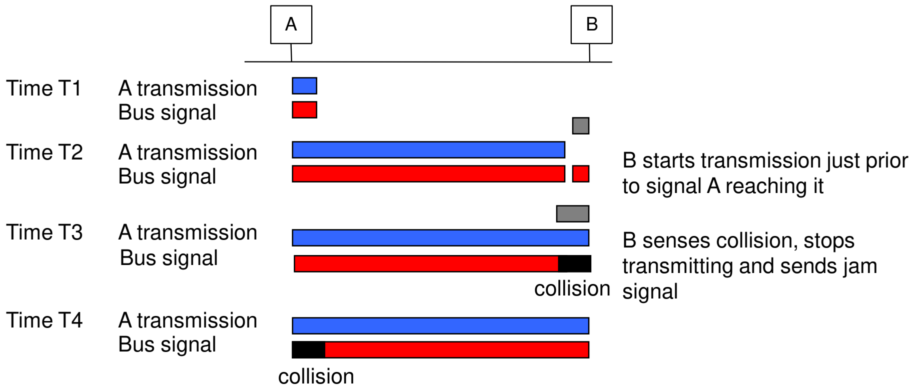
47

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

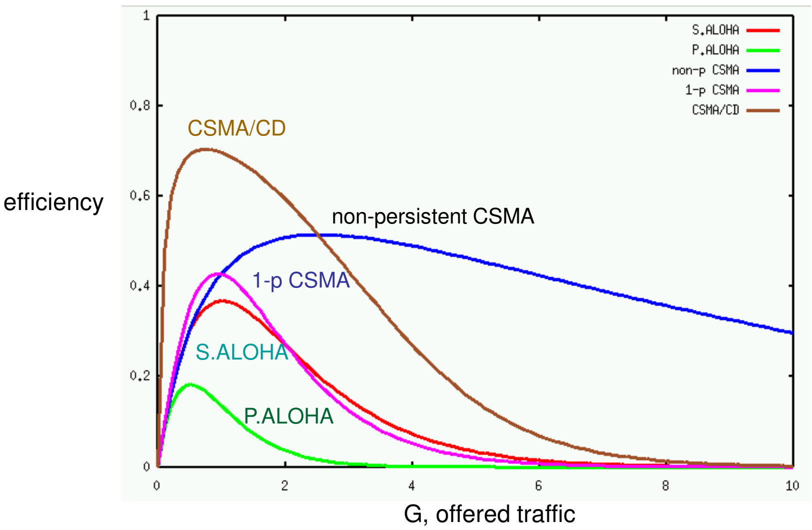
48

Maximum Time to Detect Collision



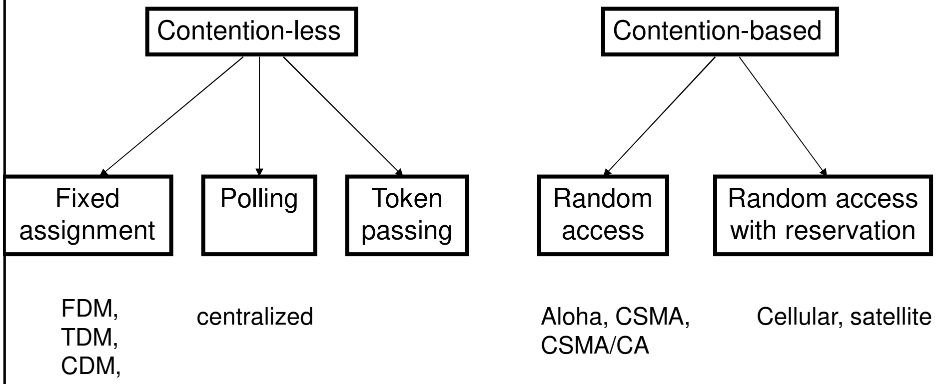
- T2-T1=T4-T3=PROP
- Minimum time to detect collision: T4-T1=2×PROP
- Minimum frame length: TRANSP > 2×PROP

CSMA/CD Efficiency



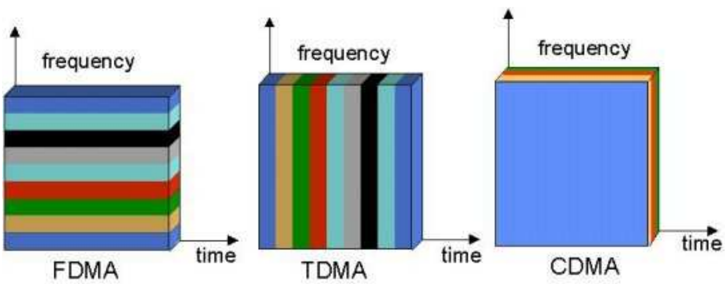
- PROP/TRANSP=0.1

Multiple access



51

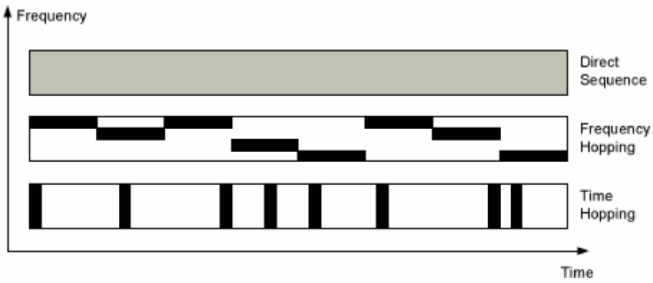
Channel partitioning



Courtesy of Petri Possi, UMTS World

52

CDMA



53

Frequency hopping

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

54

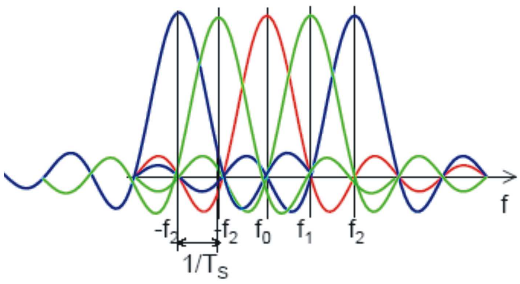
Wideband CDMA

- Bandwidth >= 5MHz
- Multirate: variable spreading and multicode
- Power control:
  - open power control
  - fast closed-loop power control
- Frame length: 10ms/20ms (optional)
- Used in 3G systems

55

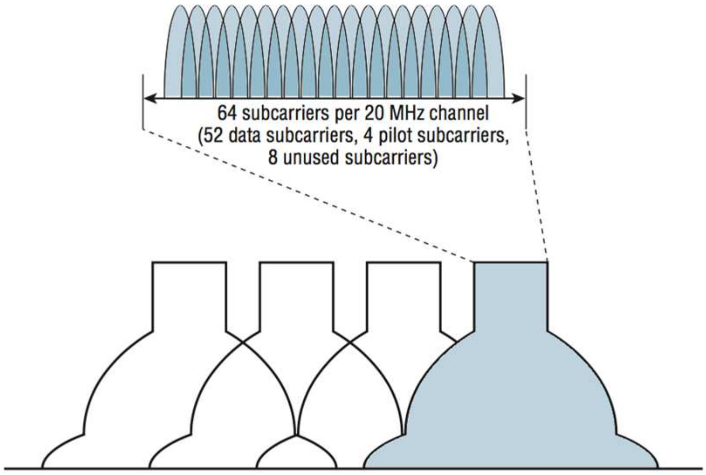
OFDMA

- 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)



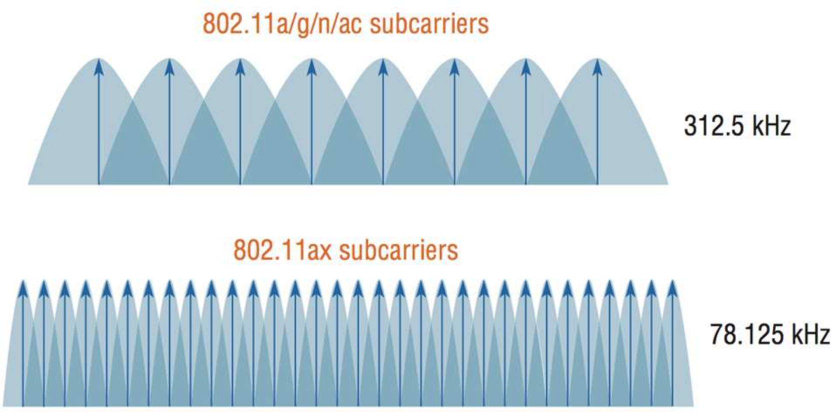
56

802.11n/ac 20 MHz channel OFDM subcarriers



57

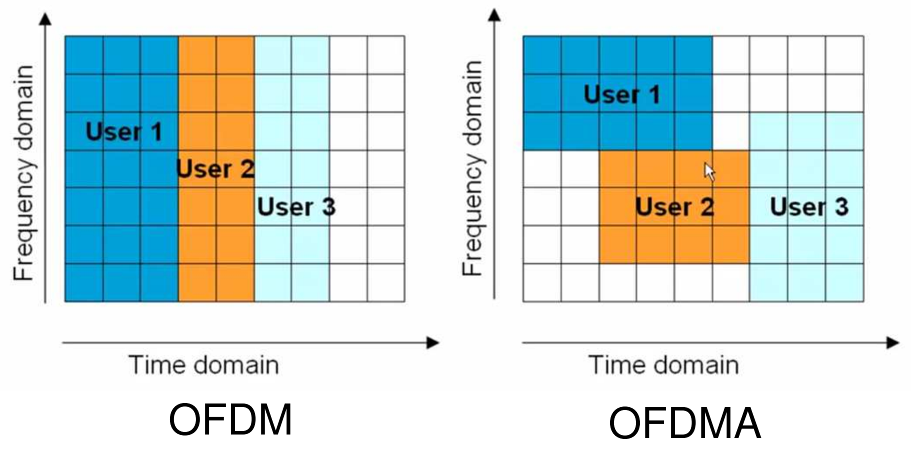
802.11ax – WiFi 6



- 802.11ax utilizes OFDMA

58

OFDM versus OFDMA



59