EEC173B/ECS152C, Winter 2006

Review of last week's material

Wireless Channel Access

- Challenges: Hidden/Exposed Terminals
- Access Methods: SDMA, FDMA, TDMA, CDMA
- Random Access: Aloha, CSMA/CD, Reservation

Review - Wireless Communications

- What is multiplexing? Which 4 dimensions can we use for multiplexing?
- What is frequency reuse?
- What is the relationship between cluster size, N, frequency reuse distance, D, and cell radius, R?
  - Can N be any number? What equation must N satisfy?
- How do you calculate co-channel interference?
- What is handoff?

Basic things to remember about signals (for HW#1)

- Let transmitted signal = $x(t)$, received signal = $y(t)$, channel function, $h(t)$

$$y(t) = x(t) \otimes h(t)$$
$$\Rightarrow y(t) = \int_0^t x(\tau) h(t-\tau) d\tau$$

  - A convolution is an integral that expresses the amount of overlap of one function $h(t)$ as it is shifted over another function $x(t)$

- As far as this class is concerned, when we discuss multipath fading, $h(t)$ is usually represented as impulse train.

$$h(t) = \sum_{i=1}^{K} \delta(t-\theta_k)$$

3

Special Property of Delta Function

$\delta(t-\alpha) = 0$ except when $t = \alpha$

$\delta(t) = 1$ when $t = 0$, and 0 otherwise

$\delta(t-1.2T_b) = 1$ when $t = 1.2T_b$, and 0 otherwise

e.g., for HW#1:

$$h(t) = A(t) + 2A(t-1.2T_b)$$

$x(t) \otimes \delta(t-\theta) = x(t-\theta)$

e.g., for HW#1

$$p(t) \otimes \delta(t) = p(t)$$
$$p(t) \otimes \delta(t-1.2T_b) = p(t-1.2T_b)$$
$$p(t) \otimes [A\delta(t) + 2A\delta(t-1.2T_b)] = Ap(t) + 2Ap(t-1.2T_b)$$

4

EEC173B/ECS152C, Winter 2006

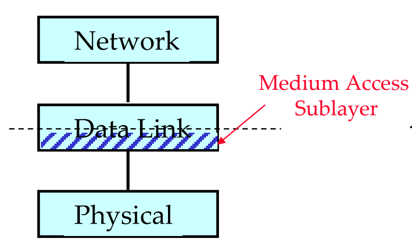
Review of last week’s material

Wireless Channel Access

- Challenges: Hidden/Exposed Terminals
- Access Methods: SDMA, FDMA, TDMA, CDMA
- Random Access: Aloha, CSMA/CD, Reservation

* Acknowledgment: Selected slides from Prof. Schiller

Medium Access Sublayer



Medium Access Control (MAC) Protocols

--- distributed algorithm that arbitrate access to a common shared channel among a population of users, i.e., determine when a node can transmit

Remarks on MAC Sublayer

- MAC is not important on point-to-point links
- MAC is only used in broadcast or shared channel networks
  - Only one can send successfully at a time
  - Two or more simultaneous transmissions => interference
  - How to share a broadcast channel?
  - Communication about "sharing" must use the channel itself!

- Examples:
  - Packet-switched Radio Network *(Aloha)*
  - Ethernet IEEE 802.3 *(CSMA/CD)*
  - Token Ring IEEE 802.5, FDDI *(Token Passing)*
  - Cellular, Satellite, Wireless LAN (MACAW)

7

Motivation

- Can we apply media access methods from fixed networks?
- Example CSMA/CD
  - **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
  - Send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)

8

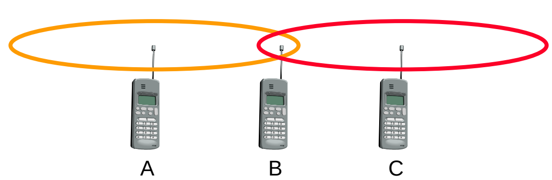
Problems in wireless networks

- Signal strength decreases proportional to the square of the distance
- The sender would apply CS and CD, but the collisions happen at the receiver
- It might be the case that a sender cannot "hear" the collision, i.e., CD does not work
- Furthermore, CS might not work if, e.g., a terminal is "hidden"

9

Hidden Terminals

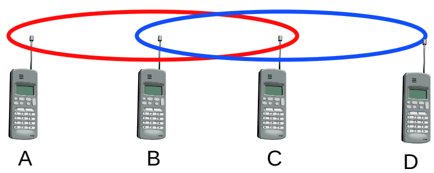
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a "free" medium (CS fails)
  - Collision at B, A cannot receive the collision (CD fails)
  - A is "hidden" for C



10

Exposed Terminals

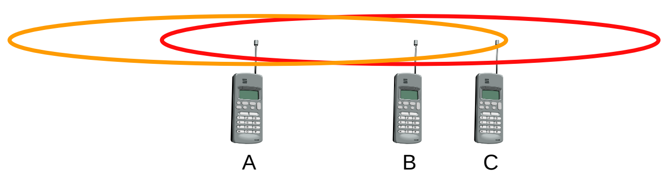
- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - But A is outside the radio range of C, waiting is not necessary!
  - C is "exposed" to B



11

Near and Far Terminals

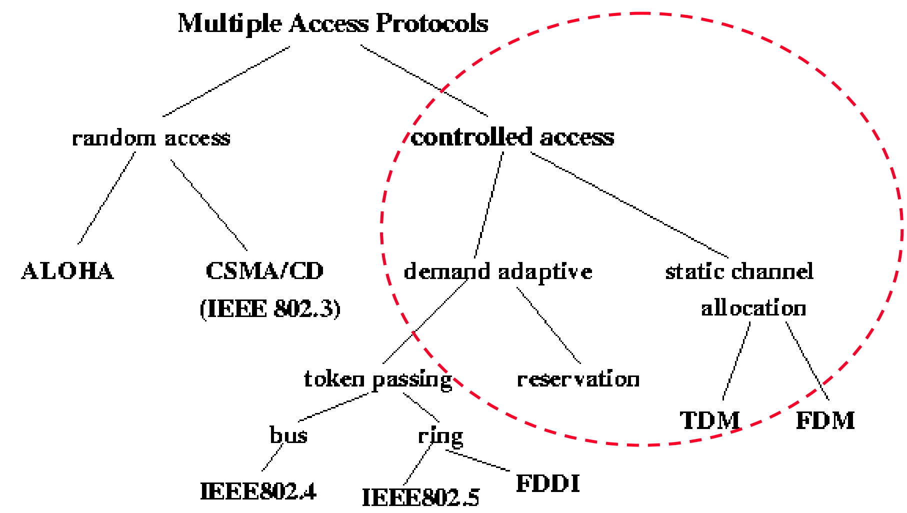
- Terminals A and B send, C receives
  - Signal strength decreases proportional to the square of the distance
  - The signal of terminal B therefore drowns out A's signal
  - C cannot receive A



- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks
  - Precise power control needed!

12

Taxonomy of MAC Protocols



13

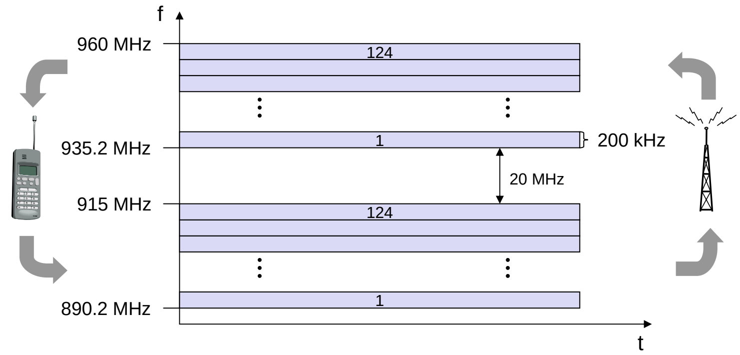
Controlled Access methods

- SDMA (Space Division Multiple Access)
  - Segment space into sectors, use directed antennas
  - Cell structure
- FDMA (Frequency Division Multiple Access)
  - Assign a certain frequency to a transmission channel between a sender and a receiver
  - Permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - Assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

=> The multiplexing schemes presented before are now used to control medium access!

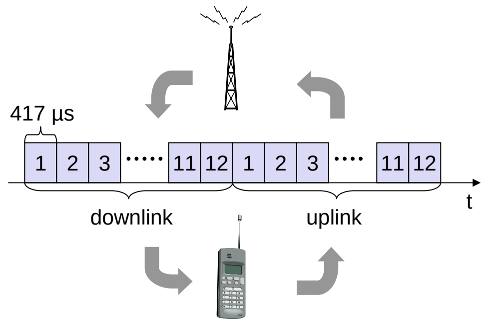
14

FDD/FDMA – e.g., GSM



15

TDD/TDMA, e.g., DECT



16

CDMA (Code Division Multiple Access)

- All terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
  - Each sender has a unique random number, the sender XORs the signal with this random number
  - The receiver can "tune" into this signal if it knows the pseudo random number, tuning is done via a correlation function

17

CDMA – Cont'd

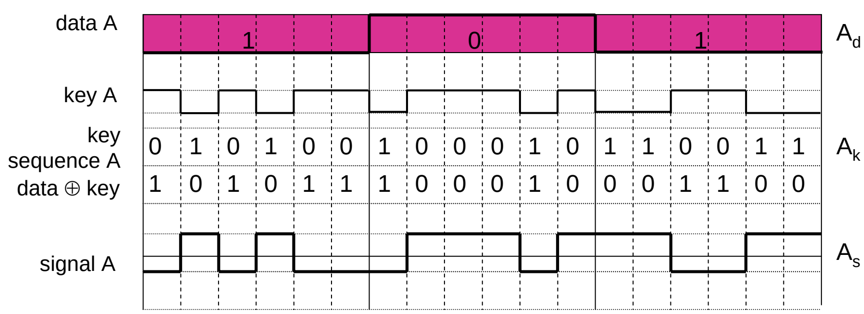
- Disadvantages:
  - Higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - All signals should have the same strength at a receiver
- Advantages:
  - All terminals can use the same frequency, no planning needed
  - Huge code space (e.g. 2^{32}) compared to frequency space
  - Interferences (e.g. white noise) is not coded
  - Forward error correction and encryption can be easily integrated

18

CDMA: An Example

- Sender A
  - Sends $A_d = 1$, key $A_k = 010011$ (assign: "0"= -1, „1"= +1)
  - Sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - Sends $B_d = 0$, key $B_k = 110101$ (assign: "0"= -1, „1"= +1)
  - Sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - Interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - Apply key A_k bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - Result greater than 0, therefore, original bit was "1"
  - Receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. "0"

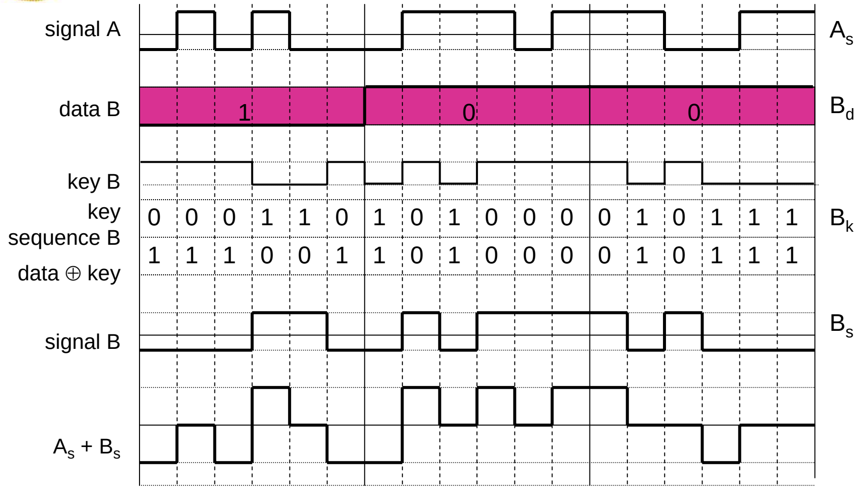
Another Example: CDMA on signal level (1)



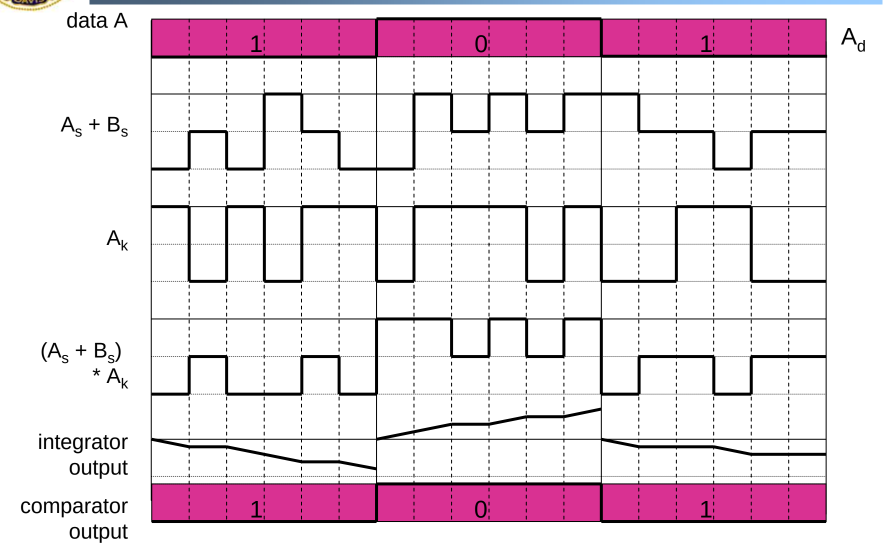
Real systems use much longer keys resulting in a larger distance between single code words in code space.

- For this example, '0' is high, '1' is low.

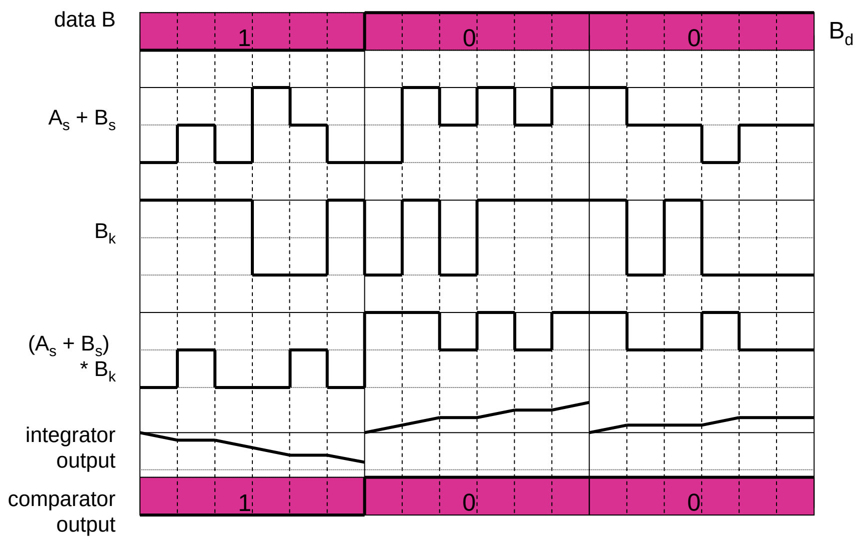
CDMA on signal level (2)



CDMA on signal level (3)

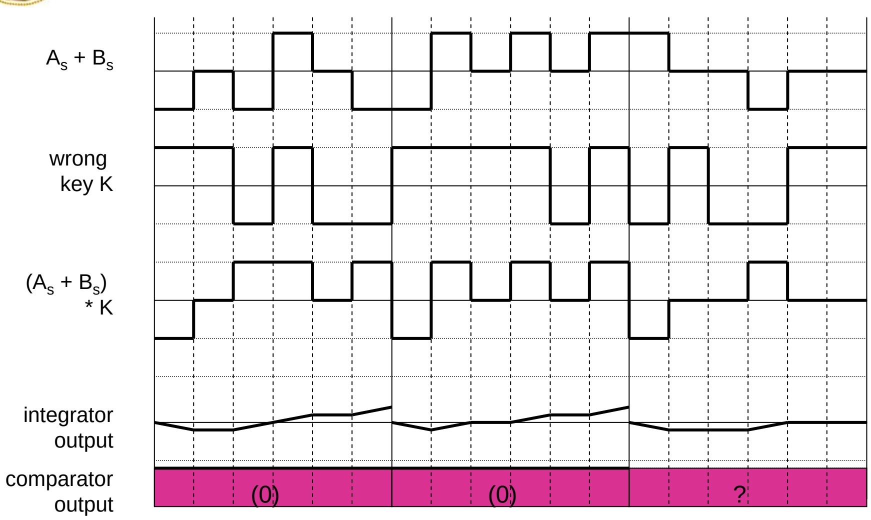


CDMA on signal level (4)



23

CDMA on signal level (5)



24

Implications for High-Speed Wireless Data

- Controlled multiple access performs well with continuous stream traffic but inefficient for bursty traffic
- Complexity:
  frequency division < time division < code division
- Multiple data rates
  - Multiple frequency bands
  - Multiple time slots
  - Multiple codes

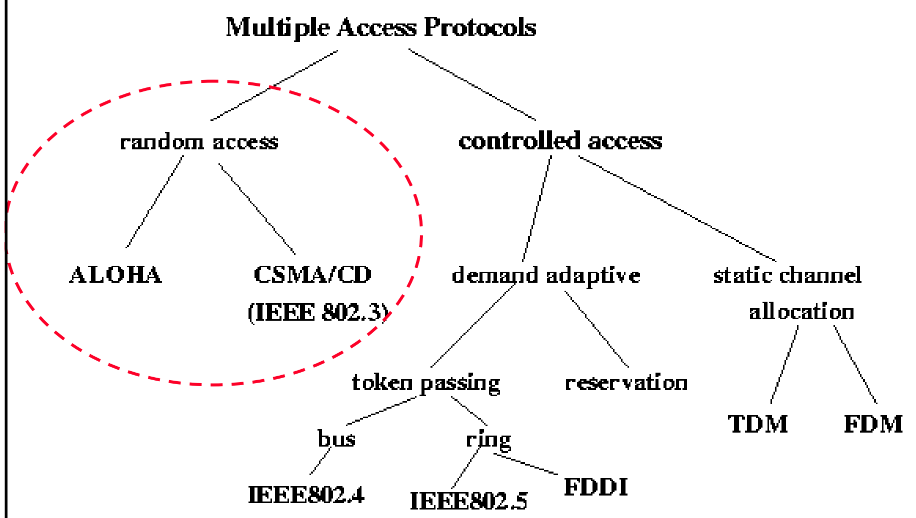
25

Comparison SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

26

Taxonomy of MAC Protocols



27

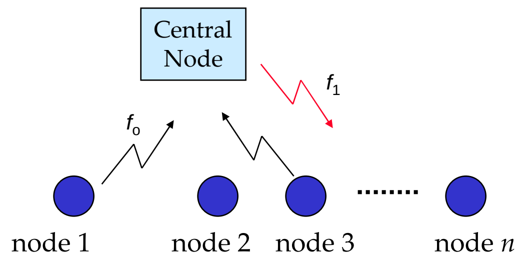
Random Access Techniques

- Design Goals
  - Fully decentralized
  - Fairness among users
  - High efficiency
  - Low delay
  - Fault tolerance
- Techniques
  - Aloha
  - Carrier Sense Techniques
  - Reservation Protocols

28

Pure Aloha

- Originally developed for packet radio communications at the campuses of U. of Hawaii in 1970
  - between a central computer & various data terminals
- All nodes transmit on one frequency, f_o
- Central node relays packets on the other frequency, f_1

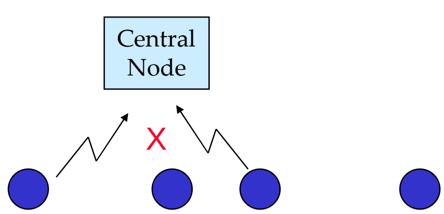


Pure Aloha Algorithm

1. Data is packetized and users transmit whenever they have something to send
   - Random, distributed (no central arbiter), time-multiplex

If more than one node transmits at the same time
=> *Collision!*

If there is a collision, both nodes need to retransmit



Pure Aloha Algorithm (cont'd)

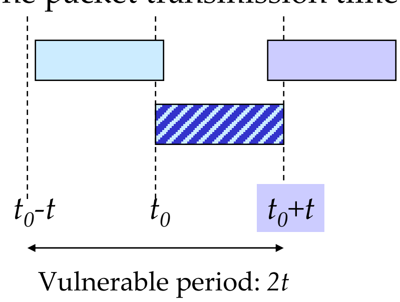
2. Listen to the broadcast
   - Assume the receiver rebroadcasts the received signal, so the sender can find out if its packet was destroyed just by listening to downward broadcast one round-trip time after sending it

3. If packet was destroyed, wait a random amount of time, and send it again
   - prevent the same packet from colliding over and over again

Contention Period in Pure Aloha

- Just send: no waiting for beginning of slot
- A collision occurs for any partial overlap of packets
  - If first bit of a new packet overlaps with last bit of a packet almost finished, both packets are destroyed.

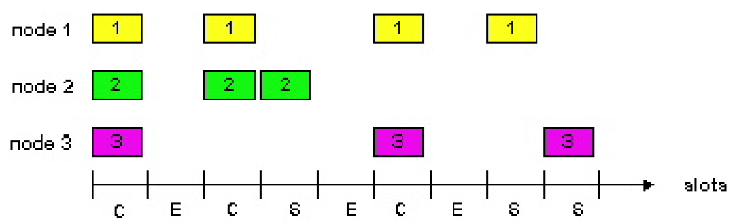
t: one packet transmission time (L/R)



Slotted Aloha

How to reduce vulnerability/contention period?

- Time is divided into equal size slots
- Avoids partial overlap of packets
  - Nodes must always start transmit at the beginning of a slot
  - Packets must be transmitted within a slot
- If collision, retransmit later

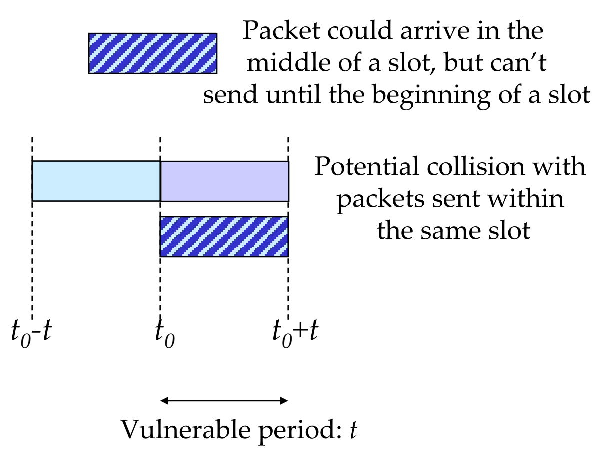


Success (S), Collision (C), Empty (E) slots

33

Contention Period in Slotted Aloha

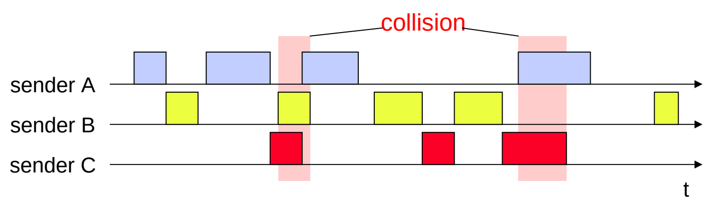
t: one packet transmission time (L/R) = slot duration



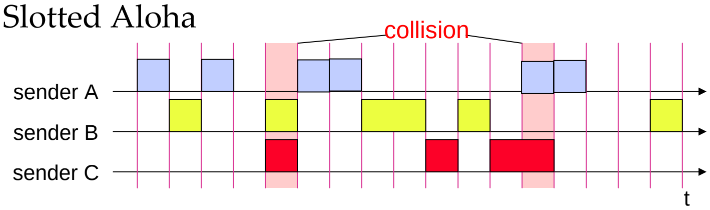
34

Pure Aloha vs. Slotted Aloha

- Pure Aloha



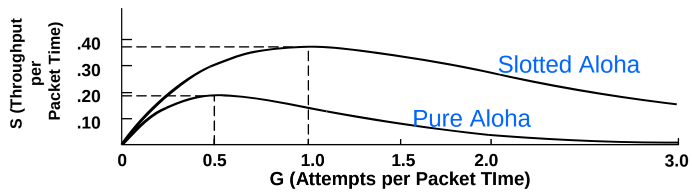
- Slotted Aloha



35

Performance of Aloha

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)



- Comments
  - Inefficient for heavily loaded system
  - Capture effect improves efficiency
  - Combining SS with ALOHA reduces collisions

36

Demand Assigned Multiple Access (DAMA)

- Use a common reservation channel to assign bandwidth on demand
  - A sender *reserves* a future time-slot => Sending within this reserved time-slot is possible without collision
  - Typical scheme for satellite links
- Reservation can increase efficiency to 80%
  - Very efficient if overhead traffic is a small percentage of the message traffic

37

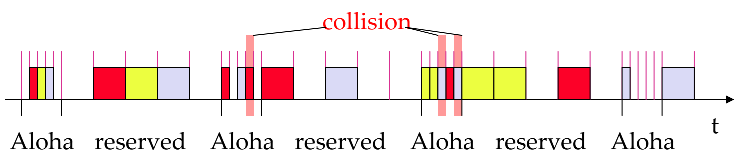
DAMA (2)

- Issues
  - Reservation also causes higher delays
  - Reservation channel requires extra bandwidth
- Example reservation algorithms:
  - *DAMA w/ Explicit Reservation: Reservation-ALOHA*
  - *DAMA w/ Implicit Reservation: PRMA (Packet Reservation MA)*
  - *Reservation-TDMA (Time-Division MA)*

38

DAMA w/ Explicit Reservation

- Explicit Reservation (Reservation Aloha)
  - Two modes:
    - *ALOHA mode* for reservation: competition for small reservation slots, collisions possible
    - *Reserved mode* for data transmission within successful reserved slots (no collisions possible)
  - It is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



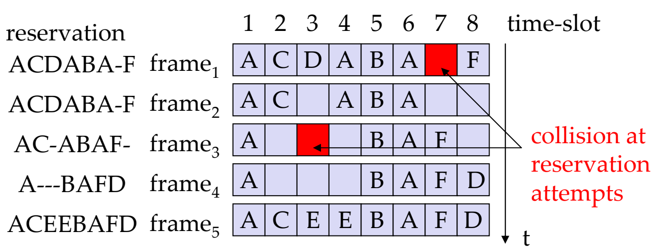
39

DAMA w/ Implicit Reservation (PRMA)

- PRMA - Packet Reservation MA:
  - A certain number of slots form a frame, frames are repeated
  - Stations compete for empty slots according to the slotted aloha principle
  - Once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
  - Competition for this slots starts again as soon as the slot was empty in the last frame

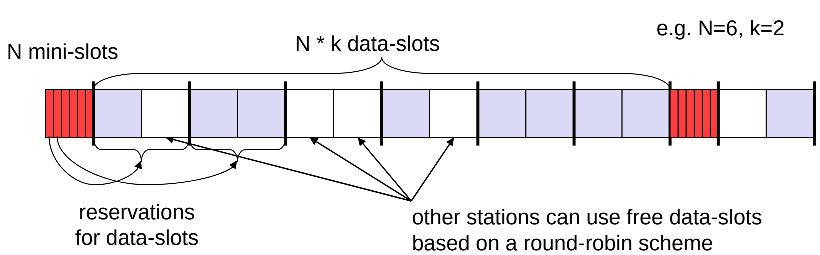
40

Access method DAMA: PRMA



DAMA – Reservation (TDMA)

- Time Division Multiple Access (TDMA)
  - Every frame consists of N mini-slots and x data-slots
  - Every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - Other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)



Carrier-Sense Techniques

- Channel is sensed before transmission to determine if it is occupied
- More efficient than ALOHA
  - Fewer retransmissions
- Carrier sensing is often combined with collision detection in wired networks (e.g., Ethernet)
  - NOT POSSIBLE in a radio environment
- Collision avoidance is used in current wireless LANs.
  - WLAN, Spectral Etiquette

43

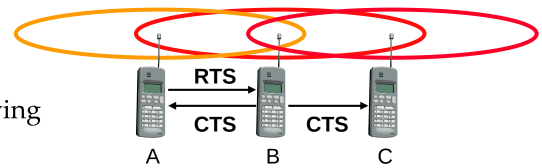
MACA - Collision Avoidance

- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - Sender address
  - Receiver address
  - Packet size
- Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

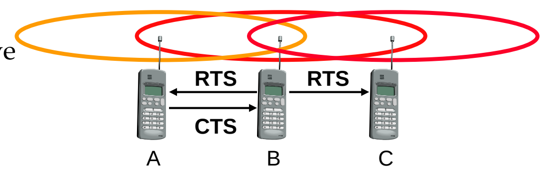
44

MACA examples

- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - Now C does not have to wait for it cannot receive CTS from A



45

Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme
  - Now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)

46

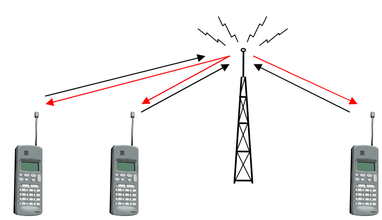
Example: Randomly Addressed Polling

- Base station signals readiness to all mobile terminals
- Terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
- The base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
- The base station acknowledges correct packets and continues polling the next terminal
- This cycle starts again after polling all terminals of the list

47

ISMA (Inhibit Sense Multiple Access)

- Current state of the medium is signaled via a "busy tone"
  - the base station signals on the downlink (base station to terminals) if the medium is free or not
  - terminals must not send if the medium is busy
  - terminals can access the medium as soon as the busy tone stops
  - the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
  - mechanism used, e.g., for CDPD (USA, integrated into AMPS)



48

Example Wireless Packet Data Services

- ARDIS (Advanced Radio Data Integrated System)
  - Joint venture of Motorola/IBM
  - Slotted CSMA
- RAM Mobile Data (Mobitex)
  - Joint venture of Ericsson/BellSouth
  - Provides communication link between base and mobile
  - Typical applications: host access and dispatch
  - Slotted CSMA
- CDPD
  - DSMA/CD - Digital Sense Multiple Access
  - Collisions detected at receiver and transmitted back
- WaveLAN
  - CSMA/CA

Implications for High-Speed Wireless Data

- Retransmissions are power and spectrally inefficient.
- ALOHA cannot satisfy high-speed data throughput requirements.
- Reservation protocols are also ineffective for short messaging.
- Delay constraints impose throughput limitations.