Multiple Access Techniques

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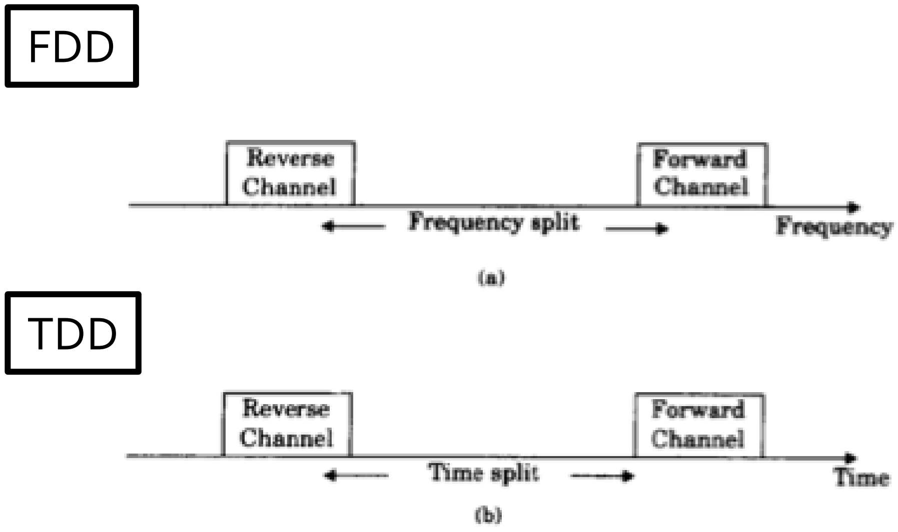
2011/12/8

Multiple Access Scheme

- **Allow many users to share simultaneously a finite amount of radio spectrum**
- **Need to be done without severe degradation of the performance**
- **Duplexing: allow one subscriber to send and receive simultaneously**

Frequency Division Duplexing & Time Division Duplexing



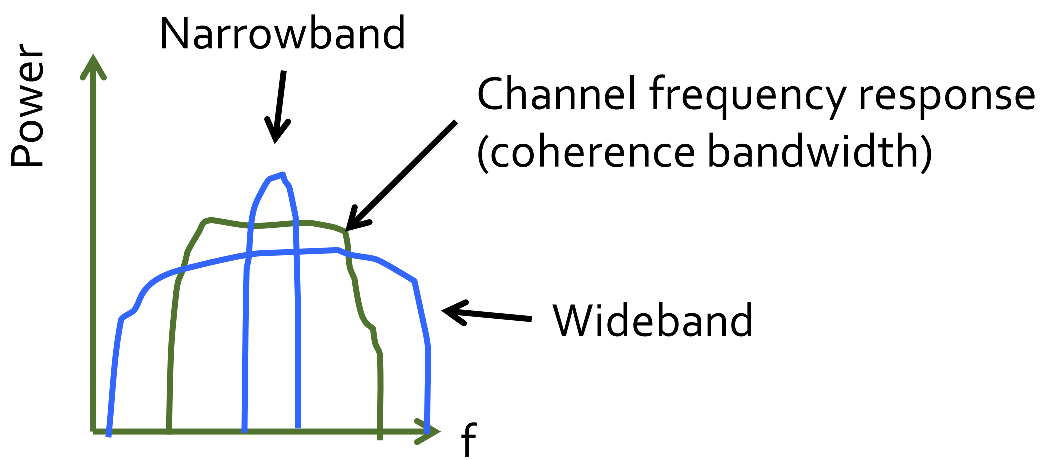
- **Frequency Division Duplexing (FDD):**
  - Two distinct frequency bands for every user
    - Forward band (BS→user) & reverse band (user→BS)
    - Frequency separation between forward band & reverse band is fixed (regardless of the channel used)
- **Time Division Duplexing (TDD)**
  - Separate time into time slots (fixed duration of time)
    - Each user use a particular forward time slot and a reverse time slot

Trade-offs between FDD & TDD

- **FDD**
  - Transmitting and receiving signals which can vary by 100 dB
  - Need to carefully allocate the frequency bands
    - Avoid interference to both in-band and out-of-band users
- **TDD**
  - Not actually full duplex (transmitting and receiving at the same time) → slight latency
  - Time slotting needs precise timing
    - Varying propagation delay is harmful
    - Would be good for services with stationary users

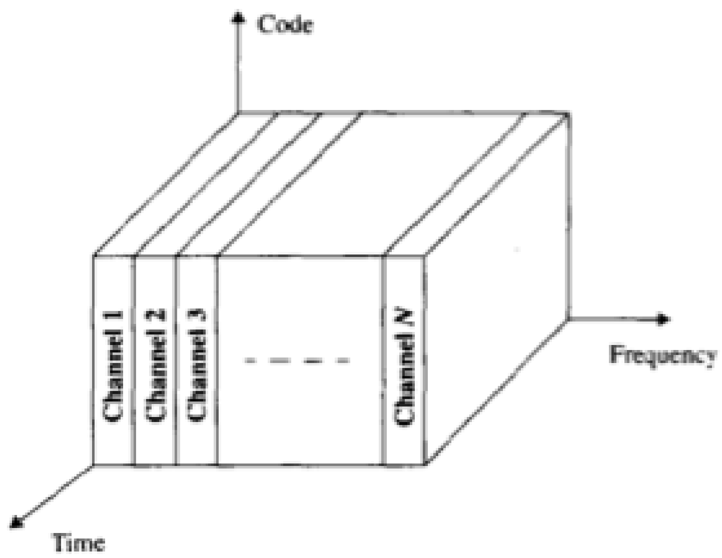
Narrowband & Wideband Systems

- **Narrowband & Wideband:**
  with respect to coherence bandwidth
- **Narrowband systems:**
  usually uses FDMA or FDD to divide the available spectrum to a large number of narrowband channels.
- **Wideband systems:**
  a large number of transmitters are allowed to transmit on the same channel; usually TDMA or CDMA.



Frequency Division Multiple Access (FDMA)

- **Individual channels are assigned to individual users**
- **Channels are assigned on demand to users, no other users can share the same channel**
- **Can be used together with (FDD/TDD). (think about how)**



Features of FDMA

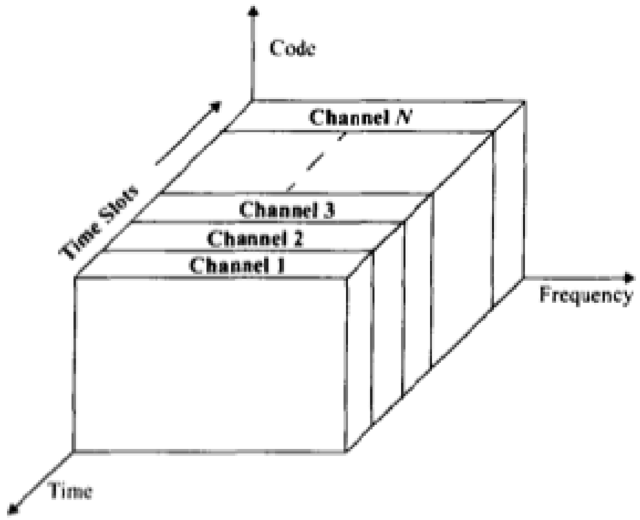
- **The FDMA channel carries only one phone circuit at a time (one user)**
- **If an FDMA is not in use, then it is wasted**
- **BS and the user transmit simultaneously**
- **ISI is low and no equalization is needed**
- **FDMA is a continuous transmission scheme, less overhead**
- **Costly bandpass filters are necessary**
- **Need tight RF filtering to minimize adjacent channel interference**
- **Costly duplexers in the transmitter and receiver (for both the user and the BS)**

Example

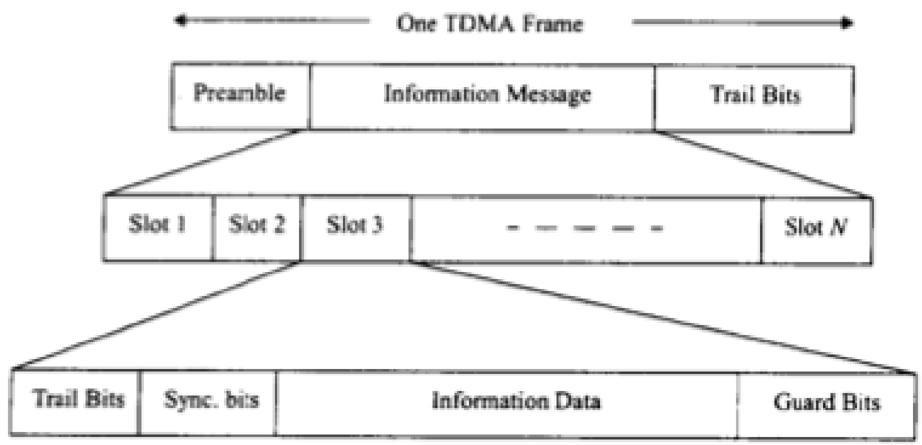
- If a US AMPS cellular operator is allocated **12.5 MHz** for each simplex band, the **guard band** at the two edges of the allocated band is **10 KHz**, and the channel bandwidth (for each user) is **30 KHz**, find the number of channels available in an FDMA systems.
- Ans:
- $N = \frac{12.5\times10^6 - 2(10\times10^3)}{30\times10^3} = 416$
- There are 416 channels. Since we need 2 channels for each user (forward and reverse channels), this can support 208 users.

Time Division Multiple Access (TDMA)

- **Divide the spectrum into time slots**
- **In each slot only one user is allowed to either transmit or receive**
- **"Buffer-and-Burst" method (transmission is NOT continuous for each user)**
- **Can be used together with (FDD/TDD). (think about how)**



TDMA Frame Structure

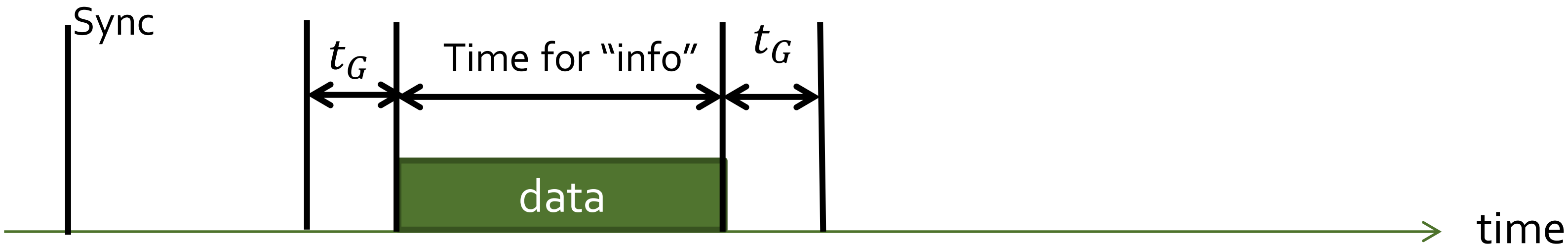


- **Need the following extra "overhead" in addition to the information bits:**
- **Preamble:**
  - Synchronization: so that all users & the BS have a common time reference
  - Address: Identify the service provider
- **Guard bits (guard time):**
  - To prevent time drift over time
- **Trail bits:**
  - Error detection bits (checksum or CRC)

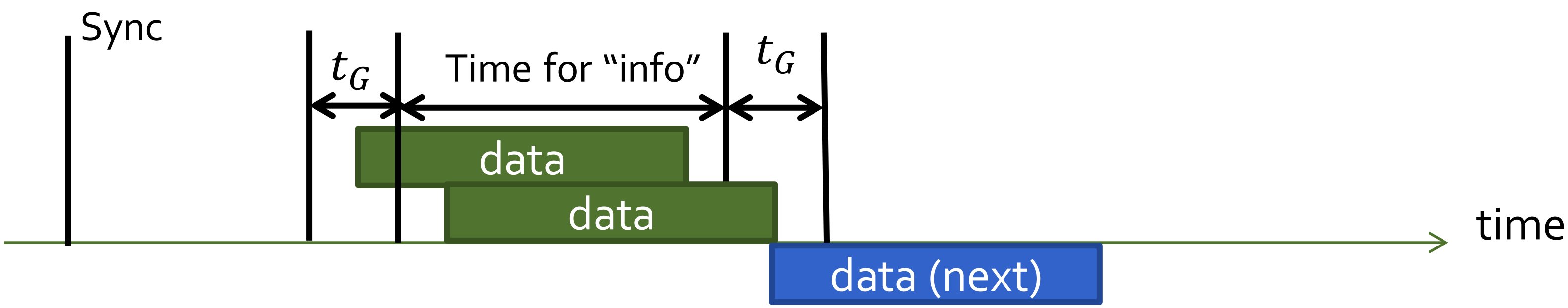
Guard bits (guard time)

- **Oscillators in each transceiver is different; accurate oscillator is expensive**
- **Maximum time drift cannot be larger than $\pm\frac{t_G}{2}$!**

When there is no difference between BS and the user's time



When the "time of the user" is going faster/slower:



For example, if it is even slower than this,
then it could collide with the transmission in the next time slot!

Features of TDMA

- **TDMA shares a single carrier frequency with several users**
- **Data transmission for a user is not continuous**
  - low battery consumption:
    transmitter can be turned off when not in use!)
  - Mobile Assisted Handoff (MAHO): listening to other base station when on an idle slot
- **Different slots for transmission & reception: duplexers are not required (even when FDD is used)**
- **Usually transmission rates are very high (equalization is required)**
- **Guard time should be minimized. However, this could increase the interference to the adjacent channels**
- **High overhead bits (TDMA frame structure)**
- **Can allocate different number of slots to different users: adjustable bandwidth to different users**

Example

- GSM is a TDMA/FDD system that uses 25 MHz for the forward link, with channels of 200 KHz. If 8 speech channels are supported on a single radio channel, and if no guard band is assumed, find the number of simultaneous users that can be accommodated in GSM.
- Ans:
- $N = \frac{25\ MHz}{(200\ KHz)/8} = 1000$
- Thus, GSM can accommodate 1000 simultaneous users.

Example

- If GSM uses a frame structure where each frame consists of 8 time slots, with each time slot of 156.25 bits, and data is transmitted at 270.833 kbps.
- The time duration of a bit is $T_b = \frac{1}{270.833kbps} = 3.692\ \mu s$
- The time duration of a slot is $T_{slot} = 156.25 \times T_b = 0.577\ ms$
- The time duration of a frame is $T_f = 8 \times T_{slot} = 4.615\ ms$
- A user has to wait 4.615 ms for its next transmission

Packet Radio

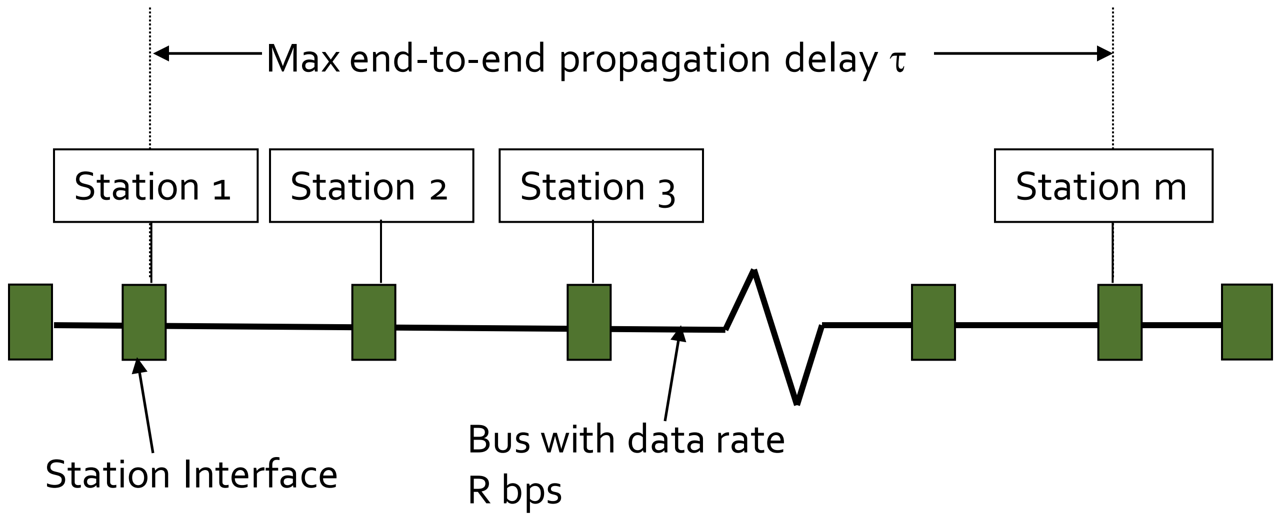
- **Other than video/voice transmissions, most data transmissions are bursty**
  - “Dedicated channel” is wasteful
  - Uncoordinated (or minimally coordinated) is more efficient
  - Data is arranged in packets for transmission
- **Collision is possible**
  - Error is detected by error detection code (in footer/trail bits)
  - ACK or NACK to notify the transmitter
  - Can do retransmission if the packet is not correctly received

Poisson Process

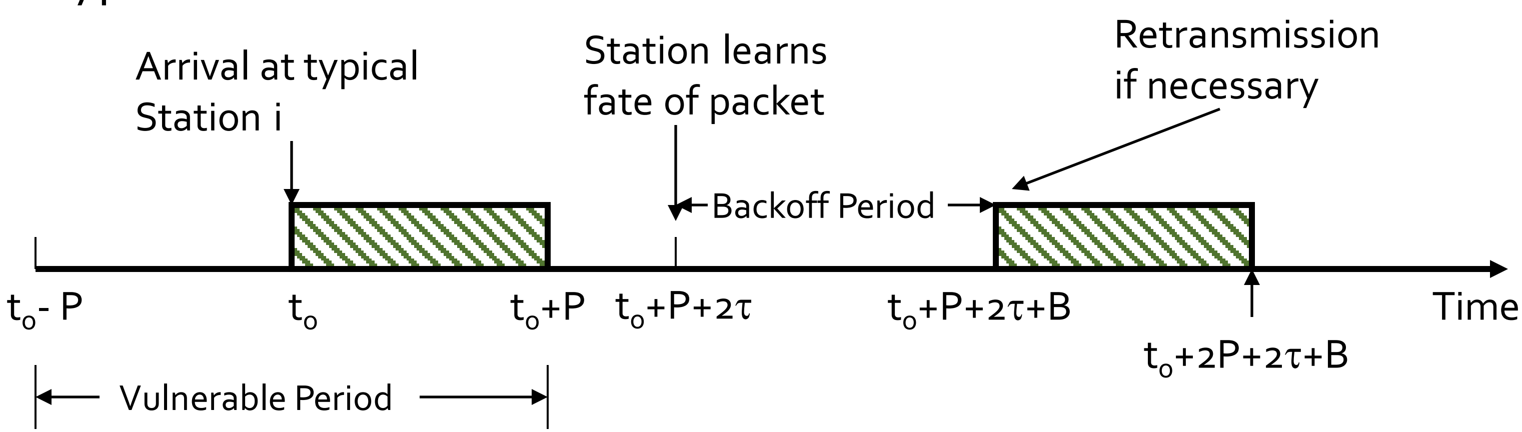
$$P[N(t+\tau) - N(t) = k] = \frac{e^{-\lambda\tau}(\lambda\tau)^k}{k!}, k = 0,1, \ldots$$

- **Use to describe events which occur continuously and independently of one another**
- **N(t): the number of events that have occurred up to time t (starting from time 0)**
- **The number of events between time a and time b has a Poisson distribution**

Basic ALOHA



Typical Scenario:



Basic ALOHA: Performance Analysis

- **Packet lengths are constant and equal to L**
- **Packet transmission time is L/R = P**
- **Total arrival distribution is Poisson with average rate λ = G/P, where G is the offered traffic**

$$P[\text{k arrivals in } \tau] = \frac{(\lambda\tau)^k}{k!} e^{-\lambda\tau} \qquad (1)$$

P[a successful transmission] = P[0 arrivals in the vulnerable interval 2P sec]

$$= e^{-2\lambda P} \qquad (2)$$

$$S = Ge^{-2\lambda P} = Ge^{-2G} \qquad (3)$$

where S is the normalized network throughput

Slotted-ALOHA: Performance Analysis

- **Packet transmissions must be initiated at the beginning of a slot**
- **Arrival in the slot preceding the slot in which station I transmits will result in a collision**
- **Vulnerable interval is reduced to 1 slot of length P**

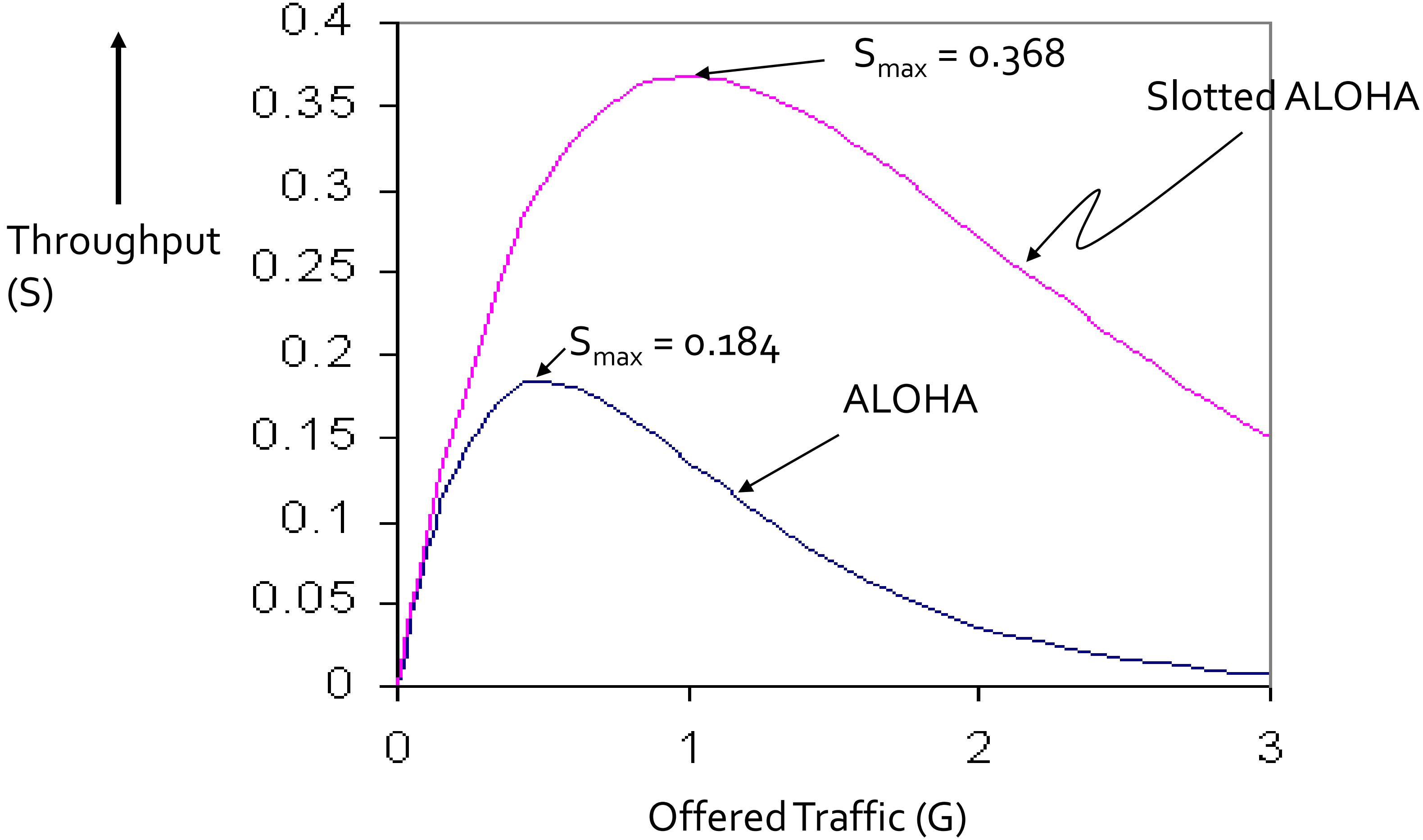
$$S = GP\{\text{successful transmission}\}$$

Therefore

$$S = Ge^{-G}$$

- **<u>Observation</u>: maximum throughput of**
  - Pure ALOHA = $\frac{1}{2e} = 0.184$
  - Slotted ALOHA = $\frac{1}{e} = 0.368$

Throughput vs. Offered traffic



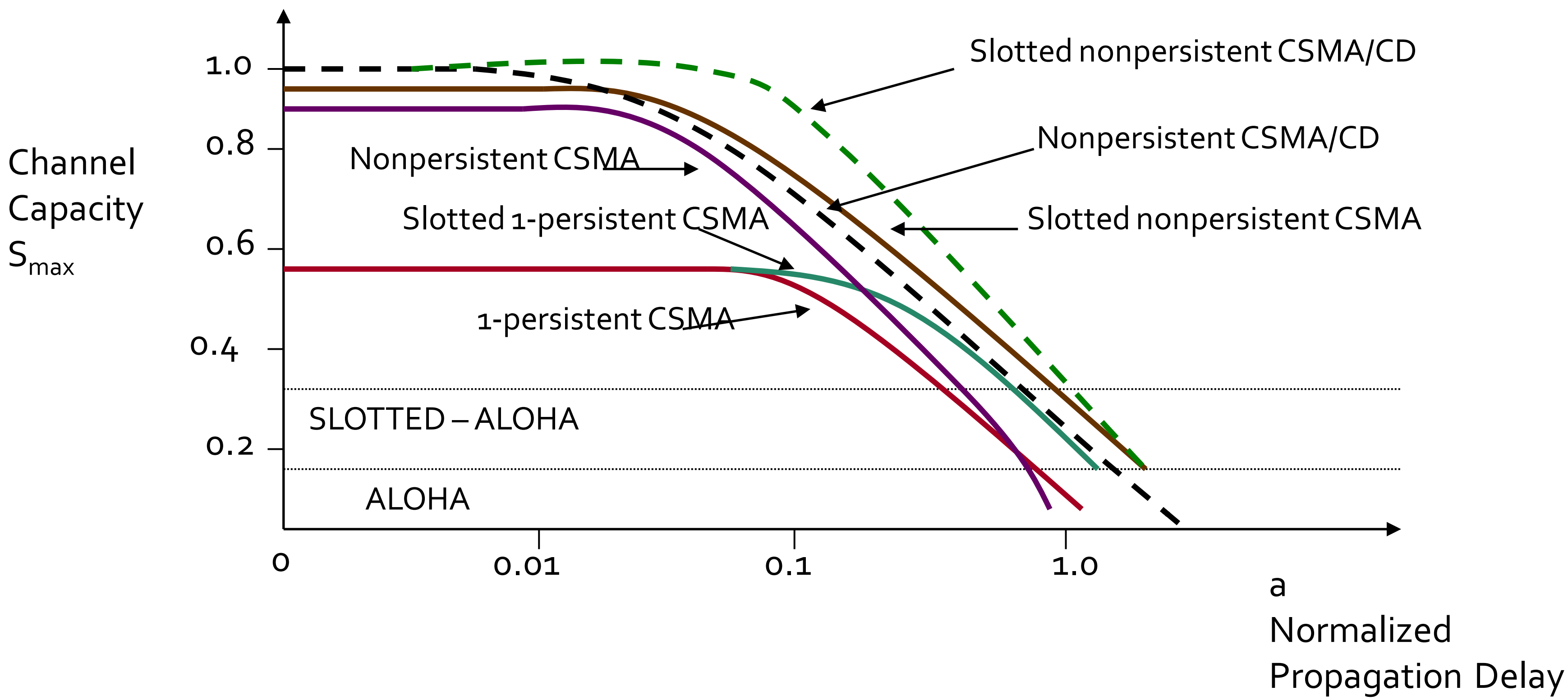
Carrier Sense Multiple Access (CSMA)

- **If the channel is "idle", then the user is allowed to transmit a packet.**
  - Idle = RSSI is below a certain threshold for a particular user
  - (Clear Channel Assessment (CCA) threshold in nano-RK)
- **Two important parameters:**
  - Detection delay: the time required to sense whether a channel is idle (usually small)
  - Propagation delay: how fast it takes for a packet to travel from the transmitter to the receiver (can be large)
- **If propagation delay is large, then**
  - The transmitted packet has not yet reached the "sensing user"
  - The user considers the channel idle → transmit its own packet → collisions

Variations of CSMA

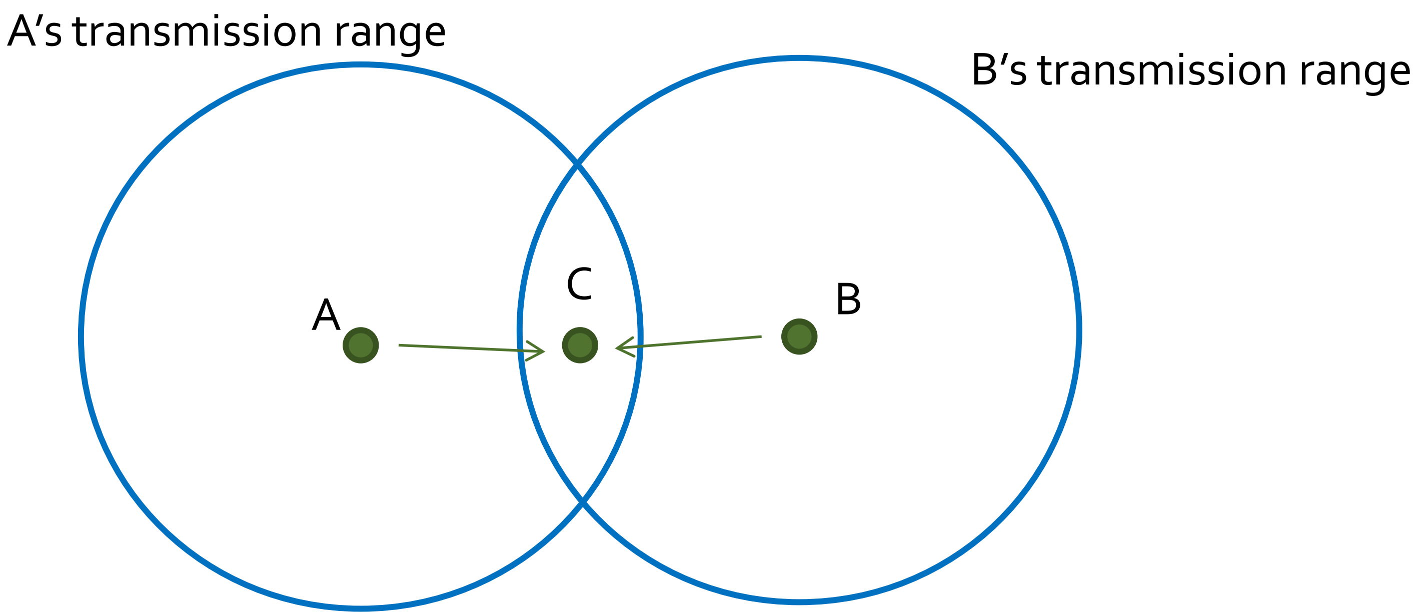
- **1-persistent CSMA:**
  Always transmit when the channel is idle
- **P-persistent CSMA:**
  When the channel is idle, the packet is transmitted:
  - in the first available time slot **with probability p**
  - or delay until later **with probability 1-p** (continue this process)
- **Non-persistent CSMA:**
  Transmit immediately when the channel is idle.
  When the channel is busy, wait for a random time and sense again.
- **CSMA/Collision Detection (CD):**
  Abort a transmission when a collision is detected.
  (Harder for wireless: need to stop the transmission to listen)

Performance Increase of CSMA over ALOHA



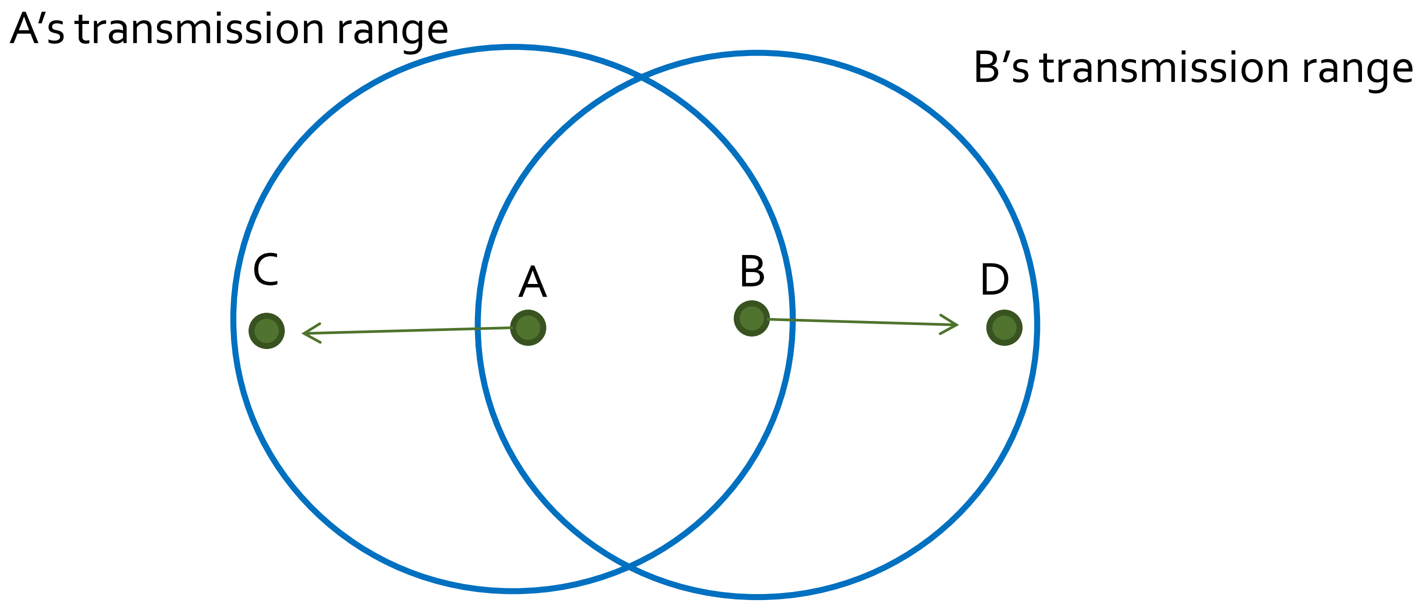
$$\text{Normalized Propagation Delay } a = \frac{\text{propagation delay}}{\text{packet length}}$$

Hidden Terminal Problem



- **A and B both want to transmit to C**
- **A collision at C is possible since A & B cannot sense each other’s transmission**

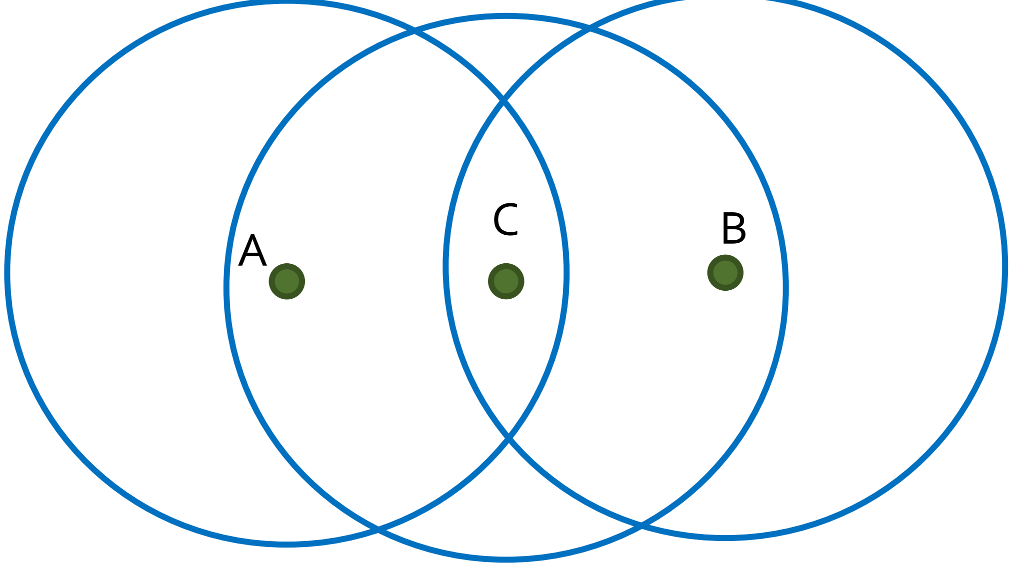
Exposed Terminal Problem



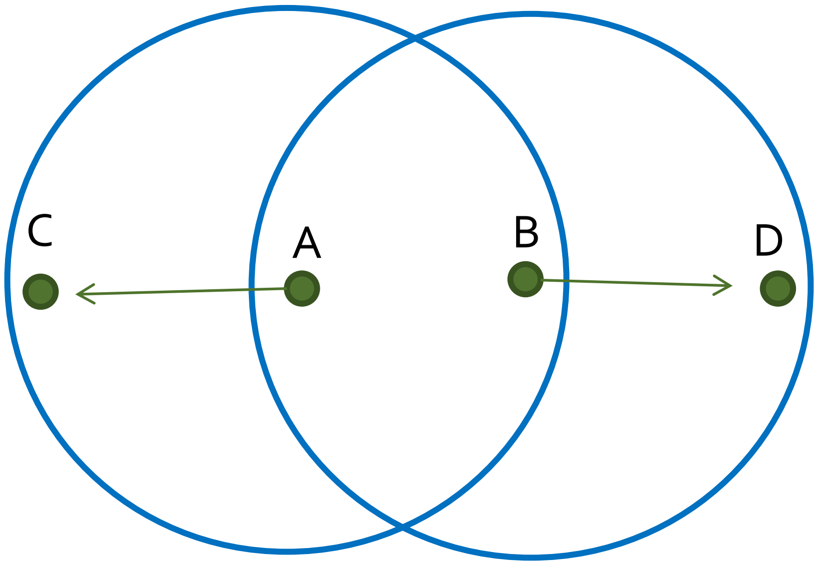
- **A and B can hear each other's transmission**
- **Although collisions at C and D are both "not possible", A & B do not transmit at the same time due to carrier sense**

CSMA/Collision Avoidance (CA)

- **In IEEE 802.11 (WiFi)**
- **Use a four-way handshake**
  - RTS (Request to send)
  - CTS (Clear to send)
  - Data
  - ACK (Acknowledgement)
- **Need NAV**



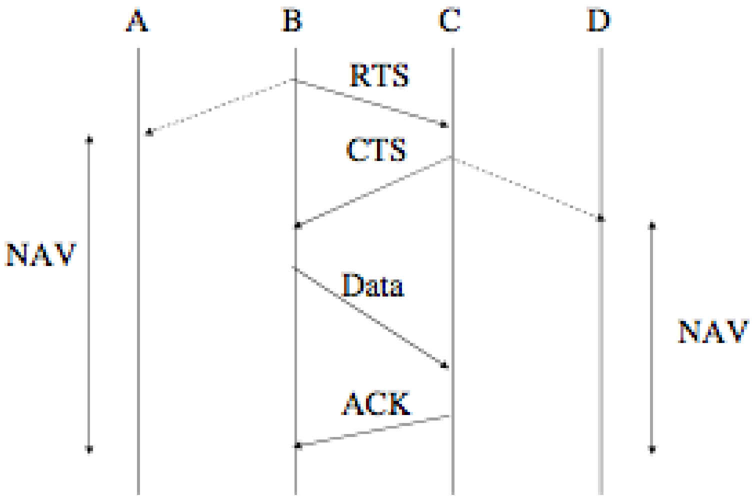
CTS is received by both A&B,
So that they are aware of each other



RTS of C→A is not received by B
RTS of D→B is not received by A
They can transmit at the same time

Network Allocation Vector (NAV) in CSMA/CA

- **NAV is an indicator**
- **Transmission will not be initiated even though the channel is sensed to be idle**
- **Why is RTS/CTS not enabled in most systems?**
  - Additional overhead: packet length threshold for using it
  - Cannot resolve all collision problems
- **Alternative solution?**
  - Busy tone channel



Example:
Wireless Sensor Network MAC

- **MAC=Media Access Control**
- **Energy constrained scenario**
  - Limited energy supply
  - Need years of operation time
- **Communications spend lots of energy**
  - Compared to computation: an order of 10^6 per bit
- **Today we will talk about two examples**
  - B-MAC
  - WiDOM

Energy Supply for Sensor Nodes

Passive

Energy from a base station (transmitted wirelessly)

Active

Batteries

Energy harvester

Convert heat, vibration, pressure to electricity

Minimize Energy Consumption

1. $E_{rx} \approx E_{tx} >> E_{idle}$

Operation	Current consumption at 3V
Radio Transmitting	17.4 mA
Radio Receiving (or waiting for incoming pkts)	18.8 mA
Microprocessor	6 mA
Radio Idle + Microprocessor Idle	**0.0002 mA**

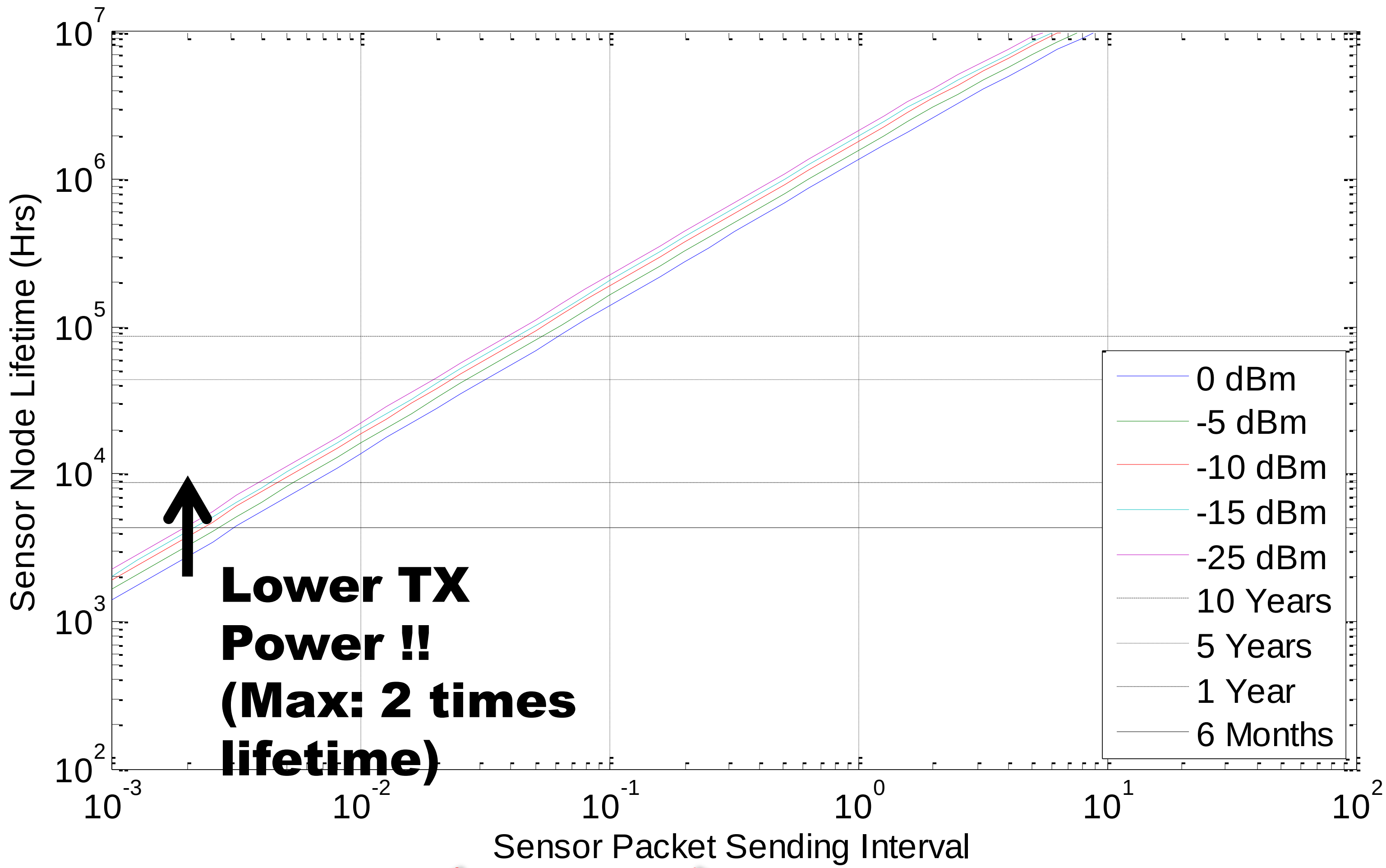
2. $E_{tx,0} > E_{tx,-5} > \ldots > E_{tx,-25}$

- Lower transmission power

Transmission Power	Current consumption at 3V
0 dBm	17.4 mA
-5 dBm	13.9 mA
-10 dBm	11.2 mA
-15 dBm	9.9 mA
-25 dBm	**8.5 mA**

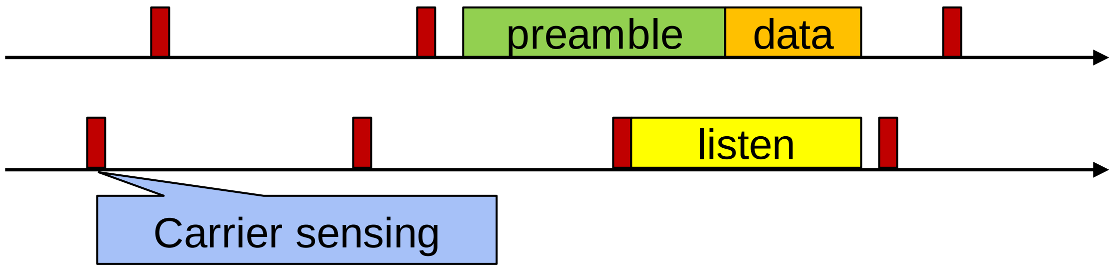
Sensor Node Lifetime

2 AA Batteries



Low Power Listening (B-MAC)

- **Nodes wake up for a short period and check for channel activity.**
  - Return to sleep if no activity detected.
- **If a sender wants to transmit a message, it sends a long preamble to make sure that the receiver is listening for the packet.**
  - preamble has the size of a sleep interval



- **Very robust**
  - No synchronization required
  - Instant recovery after channel disruption
- **Save energy for receivers (transfer to transmitters)**
  - Good since there is only 1 transmitter, but many receivers

Low Power Listening (B-MAC)

overheating problem

- **Problem: All nodes in the vicinity of a sender wake-up and wait for the packet.**
  - Solution 1: Send wake-up packets instead of preamble, wake-up packets tell when data is starting so that receiver can go back to sleep as soon as it received one wake-up packet.
  - Solution 2: Just send data several times such that receiver can tune in at any time and get tail of data first, then head.

- **Communication costs are mostly paid by the sender.**
  - The preamble length can be much longer than the actual data length.

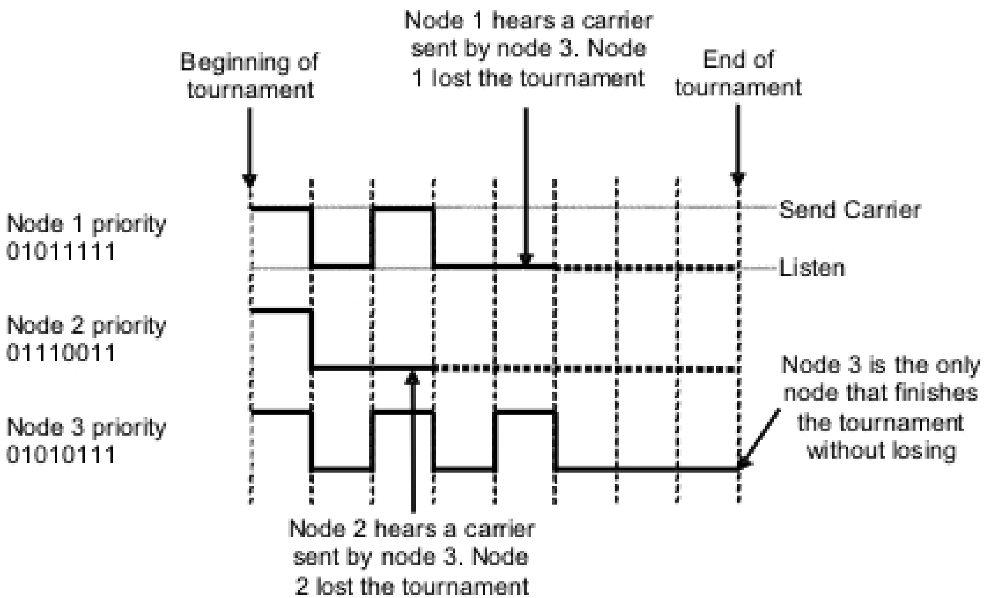
- **Idea: Learn wake-up schedules from neighboring nodes.**
  - Start sending preamble just before intended receiver wakes up.
  - WiseMAC

encode wake-up pattern in ACK message

WiDOM

- **Wireless Dominance Protocol**
- **Idea:**
  - Packets have different importance
  - How to let the ones with higher priority to use the channel first?
  - Provide upper bounds to the delay
  - Distributed protocol – no central authority (BS) to assign time slots
- **Requirements:**
  - Everyone can hear each other (for the basic version)
  - Need time synchronization

WiDOM



- **Each node which has a packet to transmit goes through a tournament phase to determine the winner:**
  - The winner gets the channel (to transmit)
  - The losers wait for the next chance
- **Tournament: in each small slot for that priority bit**
  - Transmit if you have a "1" bit in the priority
  - Listen if you have a "0" bit in the priority
    - If you hear something, that means someone else has a higher priority, you lose (go back to sleep)
    - If you hear nothing, continue.