Multiple Access Techniques

MAC

Media Access Control

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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

FDD

(a)

TDD

(b)

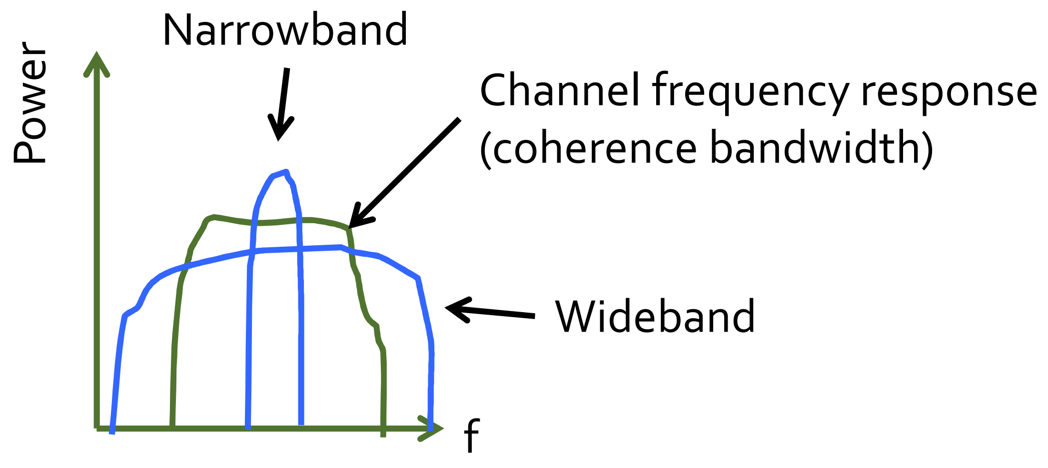
- **Frequency Division Duplexing (FDD):**
  - Two distinct frequency bands for every user
    - Forward band (BS→user) & reverse band (user→BS)
    - Frequency separation between forward band & reverse band is fixed (regardless of the channel used)
- **Time Division Duplexing (TDD)**
  - Separate time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

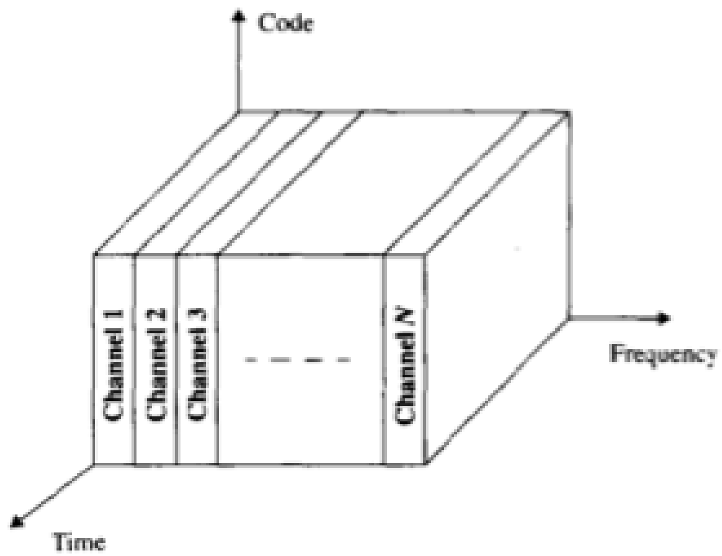
Narrowband & Wideband Systems

- **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.



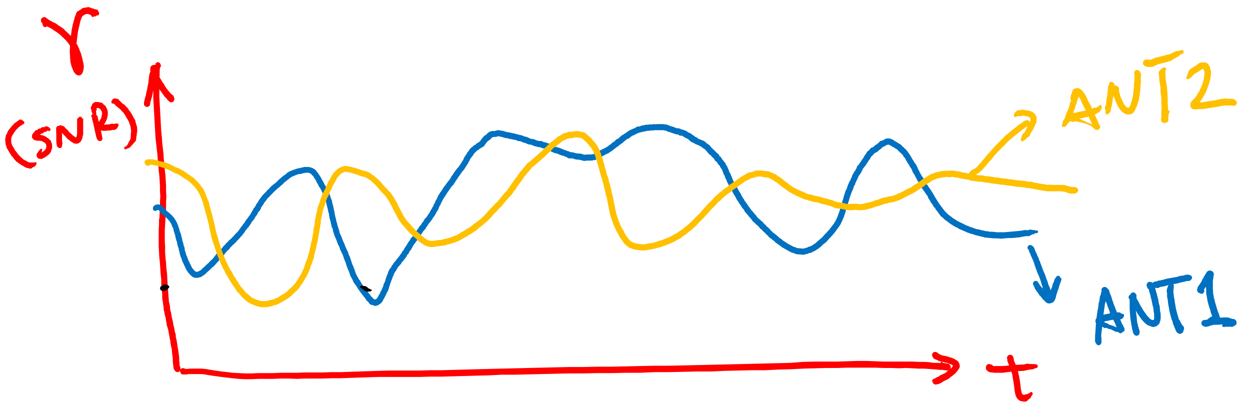
Frequency Division Multiple Access (FDMA)

- **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)



1. Please draw the SNR of the output signal when using (a) Selection Combining (SC)

(b) Switch-and-Stay Combining (SSC)

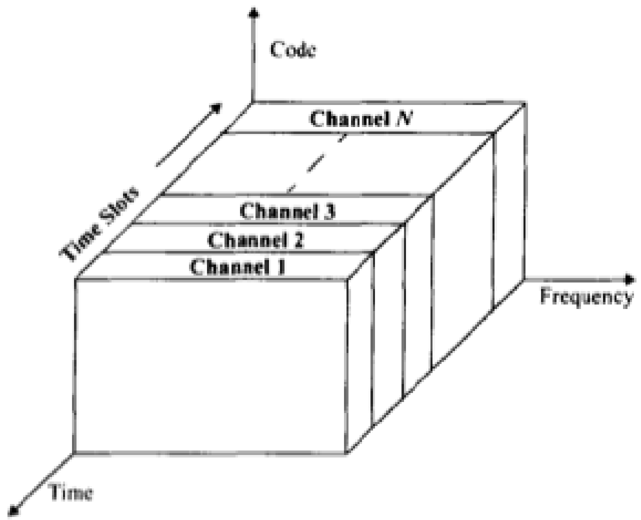
2. Assume that the threshold you pick is the minimum required SNR for a link, calculate (estimate) the outage probability when using SSC.

Example

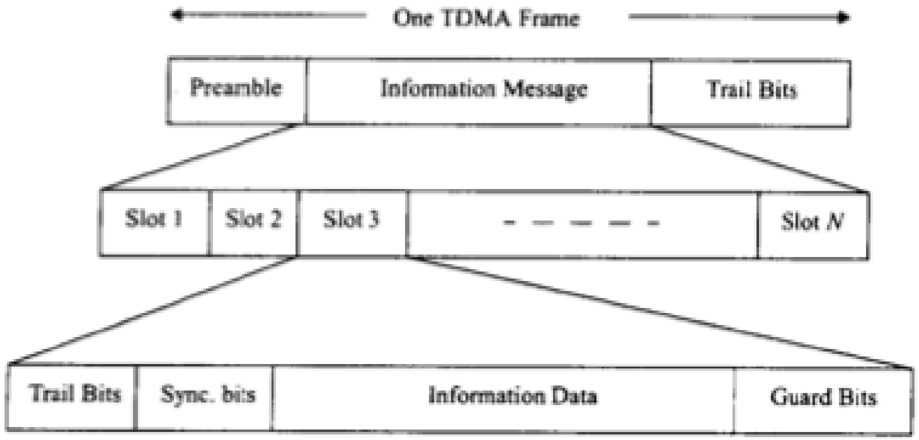
- If a US AMPS cellular operator is allocated **12.5 MHz** for each simplex band, the **guard band** at the two edges of the allocated band is **10 KHz**, and the channel bandwidth (for each user) is **30 KHz**, find the number of channels available in an FDMA systems.
- Ans:
- $N = \frac{12.5 \times 10^6 - 2(10 \times 10^3)}{30 \times 10^3} = 416$
- 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

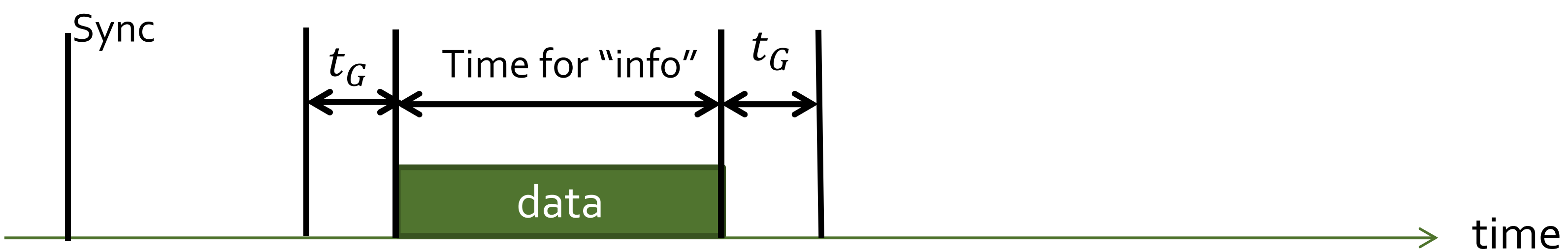


- **Need the following extra "overhead" in addition to the information bits:**
- **Preamble:**
  - Synchronization: so that all users & the BS have a common time reference
  - Address: Identify the service provider
- **Guard bits (guard time):**
  - To prevent time drift over time
- **Trail bits:**
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

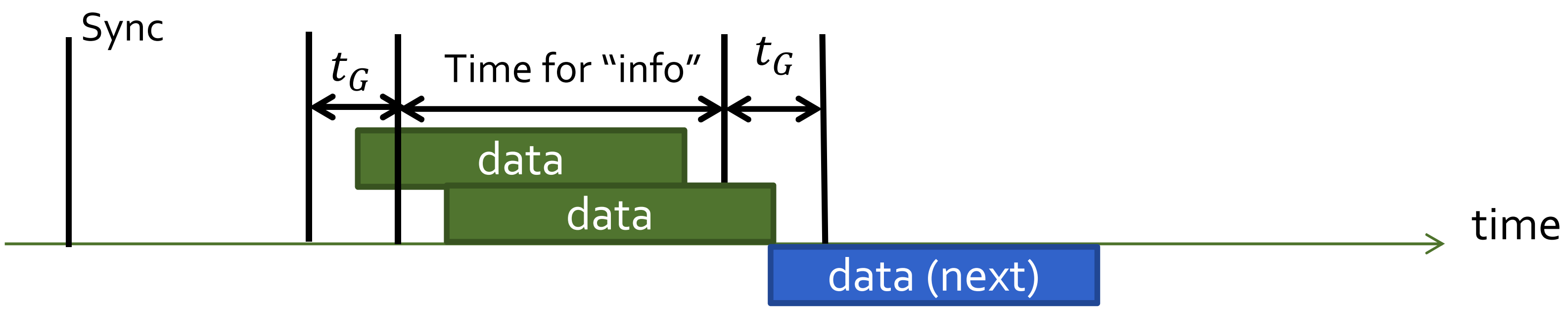
Guard bits (guard time)

- **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

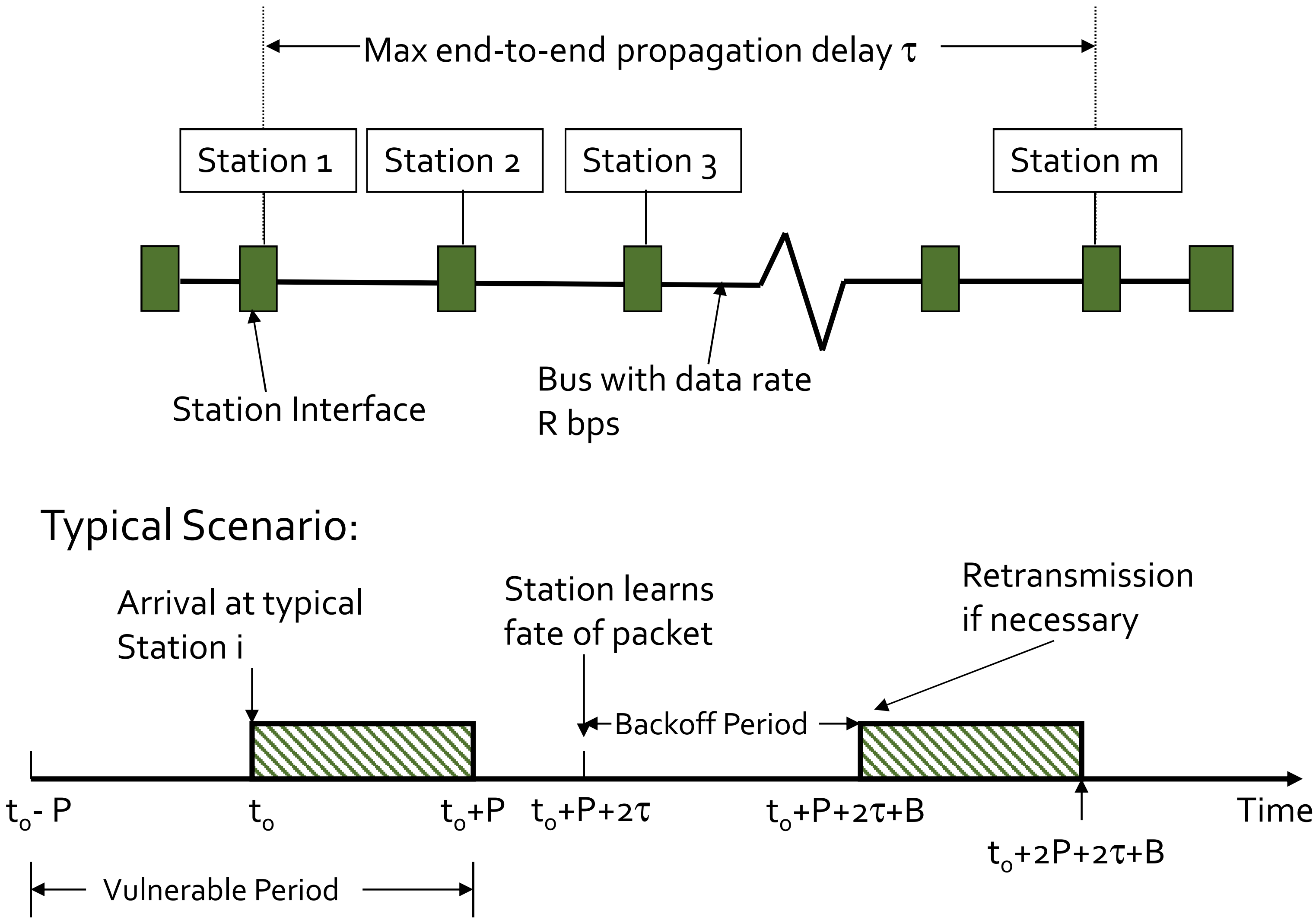
- **Other than video/voice transmissions, most data transmissions are bursty**
  - “Dedicated channel” is wasteful
  - Uncoordinated (or minimally coordinated) is more efficient
  - Data is arranged in packets for transmission
- **Collision is possible**
  - Error is detected by error detection code (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



Max end-to-end propagation delay τ
Station 1
Station 2
Station 3
Station m
Station Interface
Bus with data rate
R bps
Typical Scenario:
Arrival at typical
Station i
Station learns
fate of packet
Retransmission
if necessary
Backoff Period
t_o - P
t_o
t_o+P
t_o+P+2τ
t_o+P+2τ+B
Time
t_o+2P+2τ+B
Vulnerable Period

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 load.**
- **λ: average no. of packet arrivals per time unit**
- **G: avg. no. of packet arrivals during the time duration a packet is transmitted. (unit less; a ratio)**

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

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**

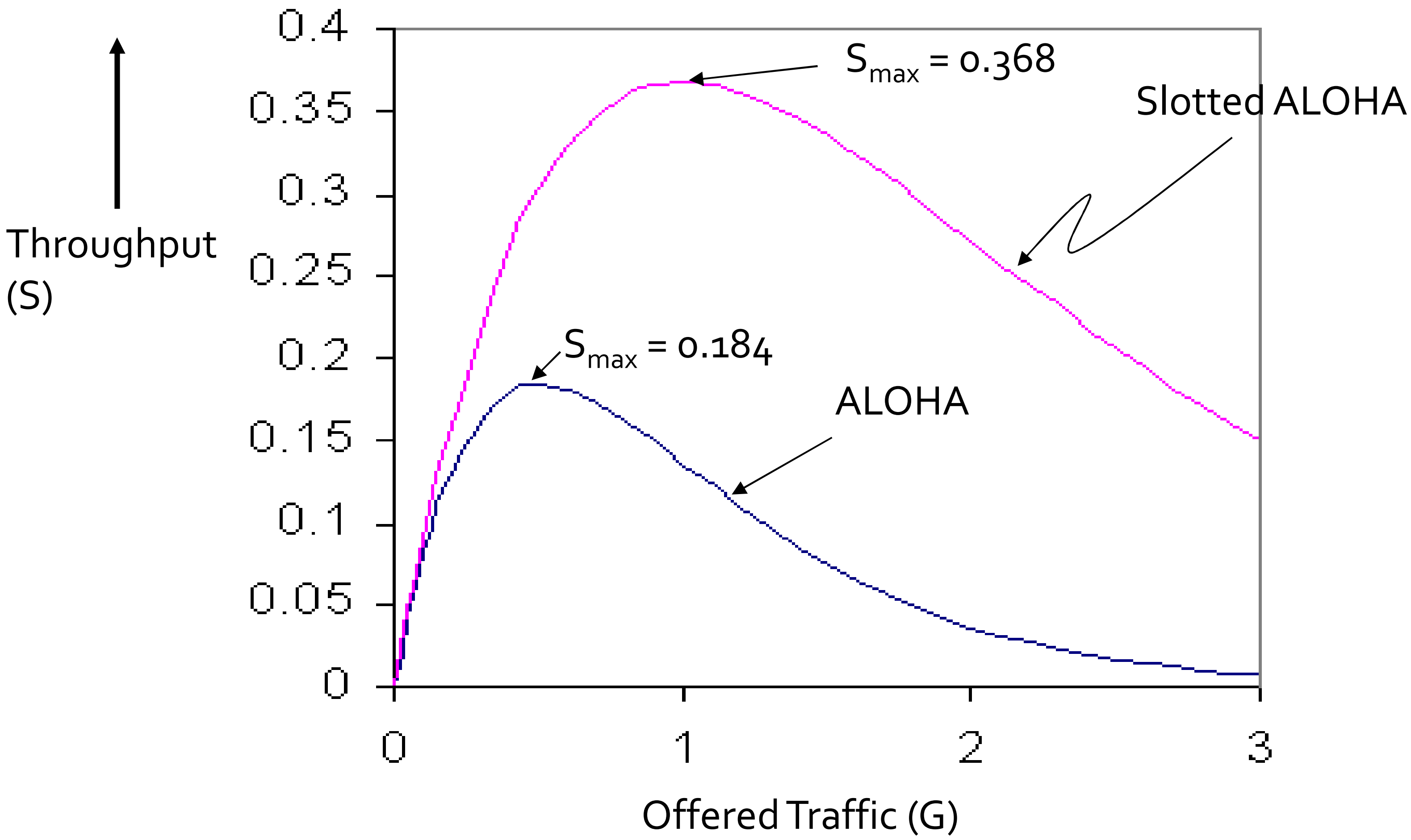
$$S = GP\{\text{successful transmission}\}$$

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



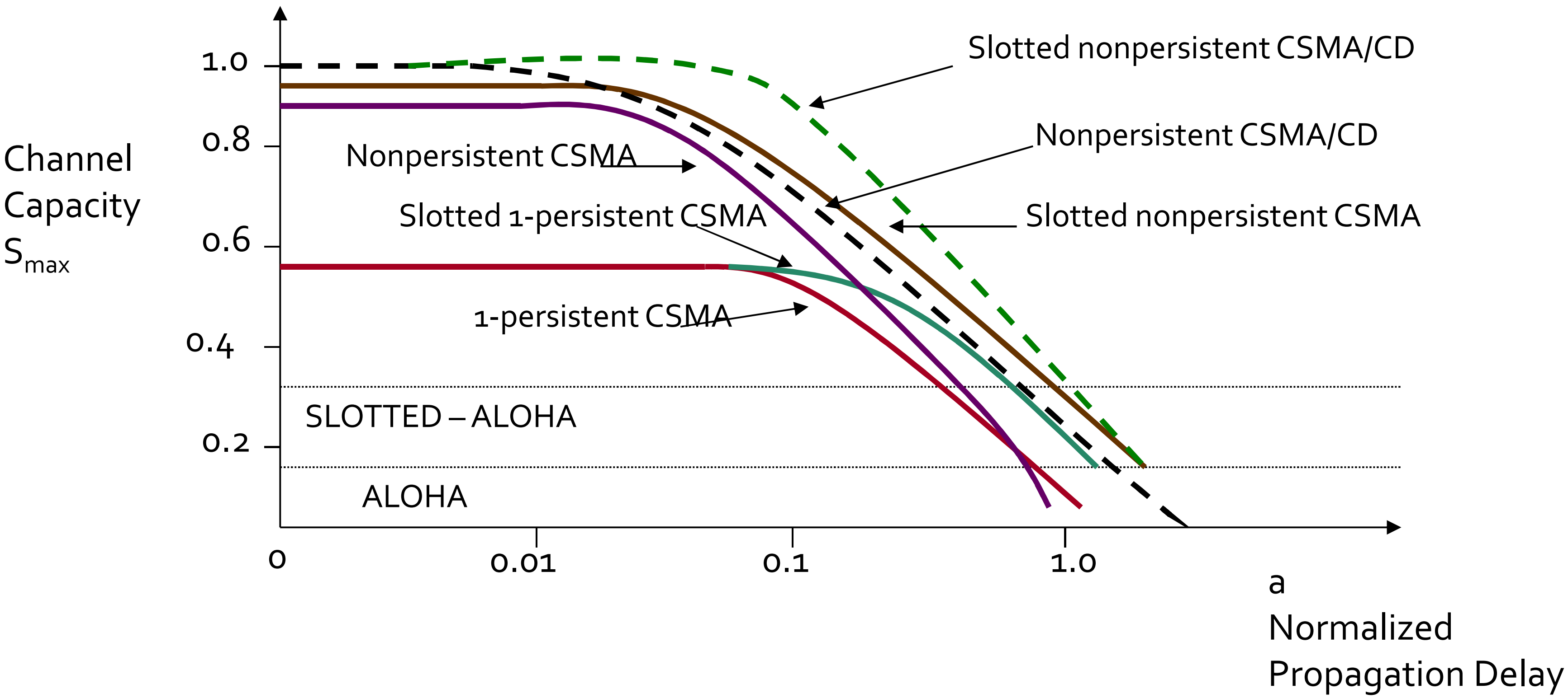
Carrier Sense Multiple Access (CSMA)

- **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

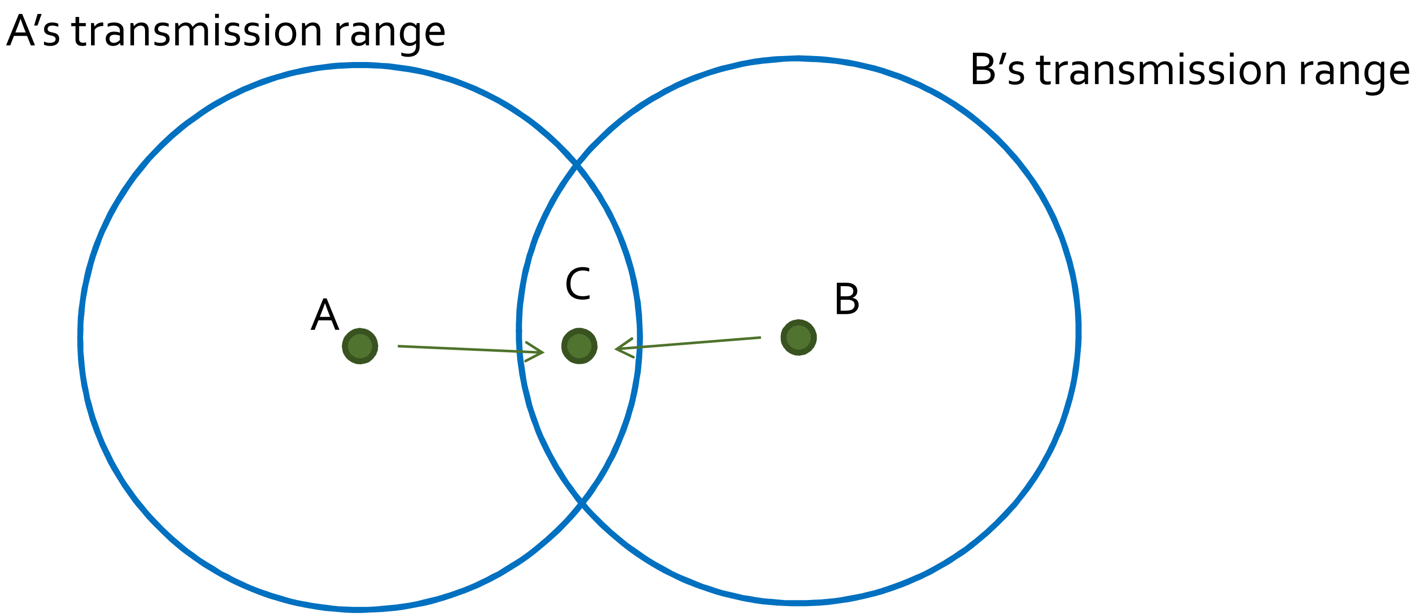
- **1-persistent CSMA:**
  Always transmit when the channel is idle
- **P-persistent CSMA:**
  When the channel is idle, the packet is transmitted:
  - in the first available time slot **with probability p**
  - or delay until later **with probability 1-p** (continue this process)
- **Non-persistent 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



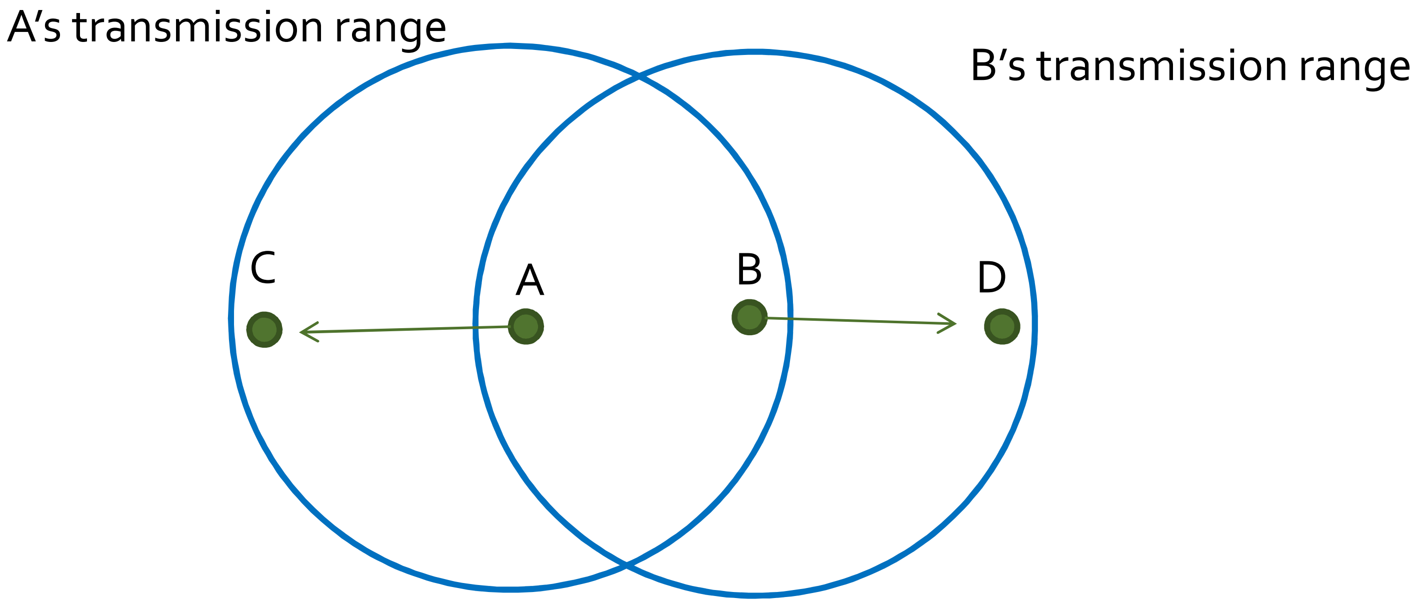
Normalized Propagation Delay $a = \frac{\text{propagation delay}}{\text{packet length}}$

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**

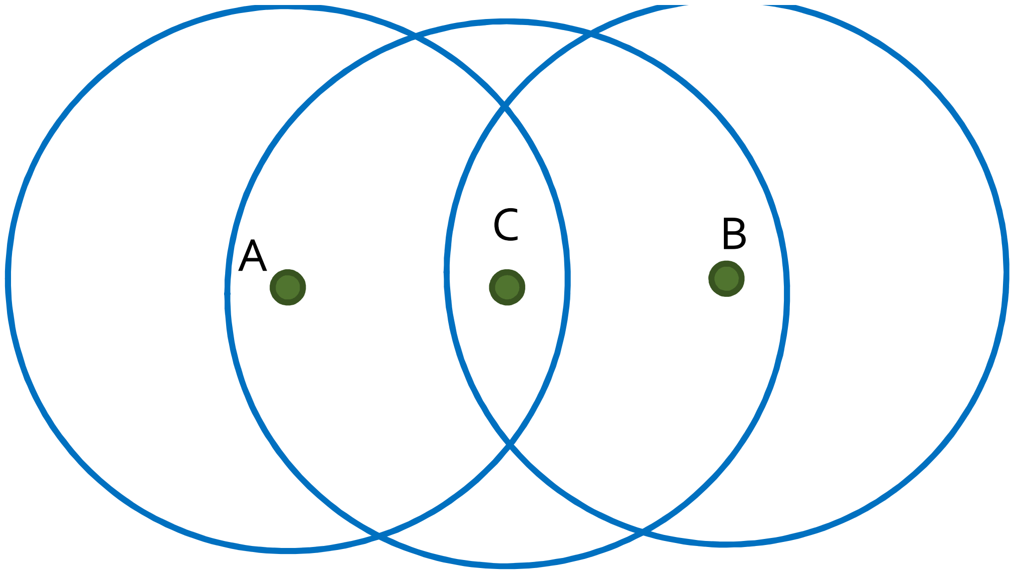
Exposed Terminal Problem



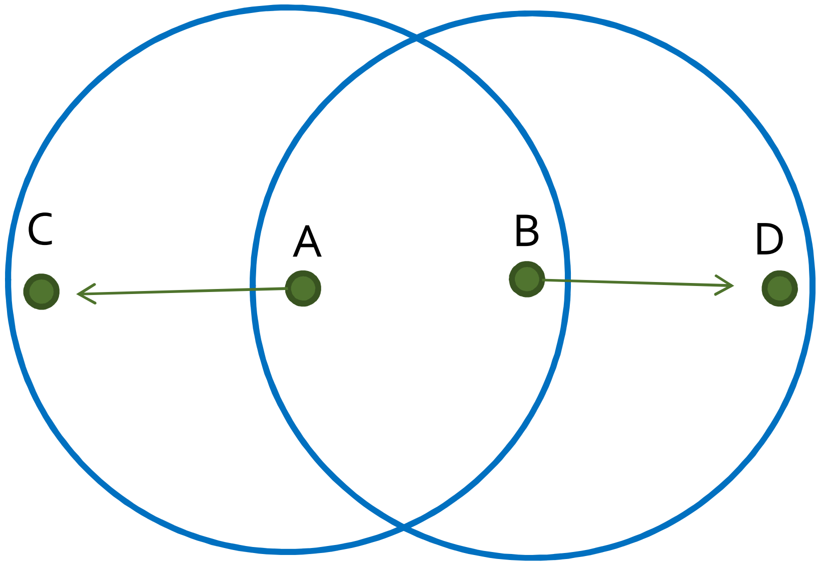
- **A and B can hear each other's transmission**
- **Although collisions at C and D are both "not possible", A & B do not transmit at the same time due to carrier sense**

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**



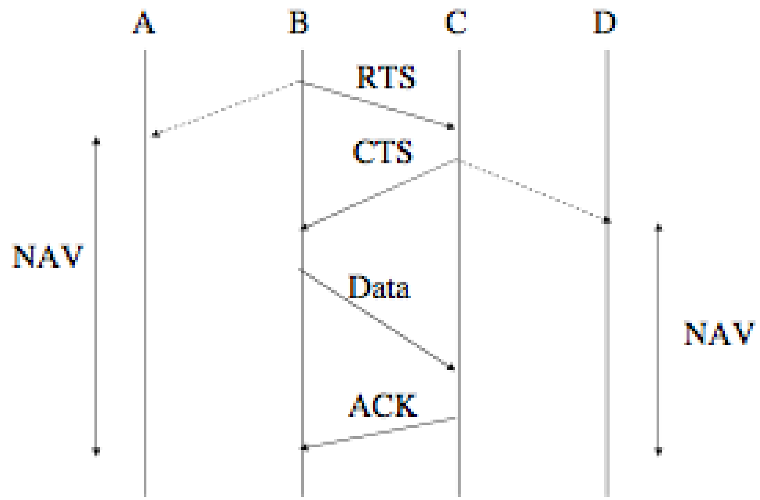
CTS is received by both A&B,
So that they are aware of each other



CTS of C→A is not received by B
CTS 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



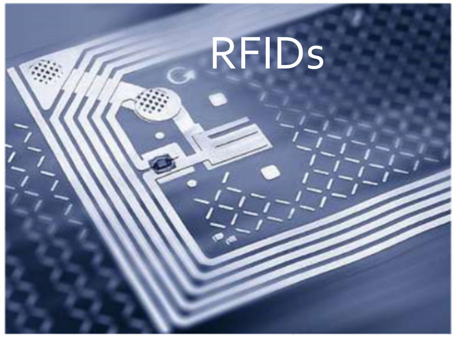
Example:
Wireless Sensor Network MAC

- **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

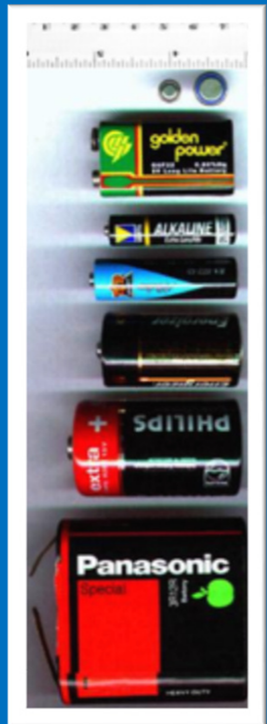
Energy Supply for Sensor Nodes

Passive

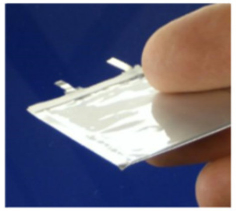
Energy from a base station (transmitted wirelessly)



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**

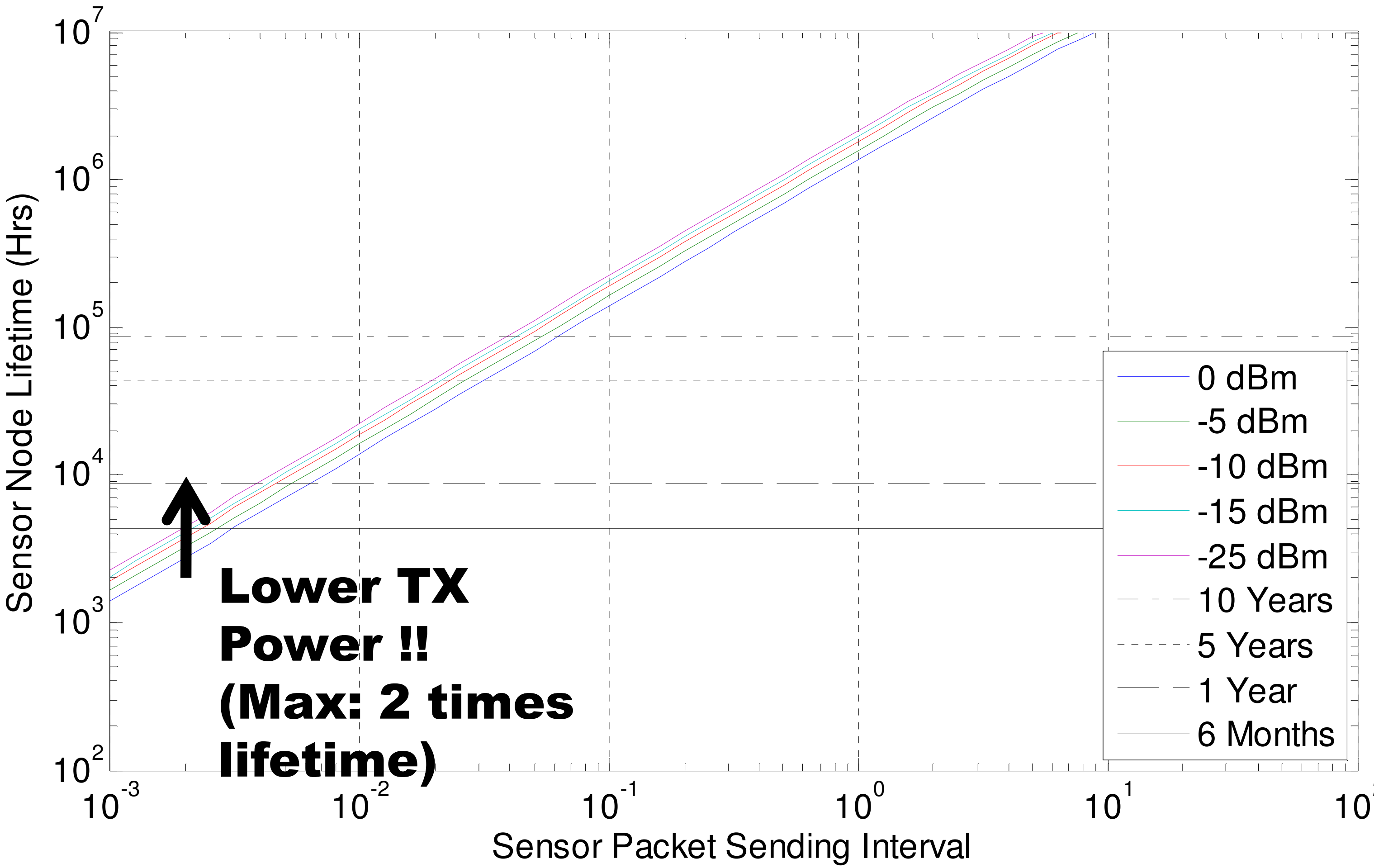
2. $$E_{tx,0} > E_{tx,-5} > \ldots > E_{tx,-25}$$

- 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**

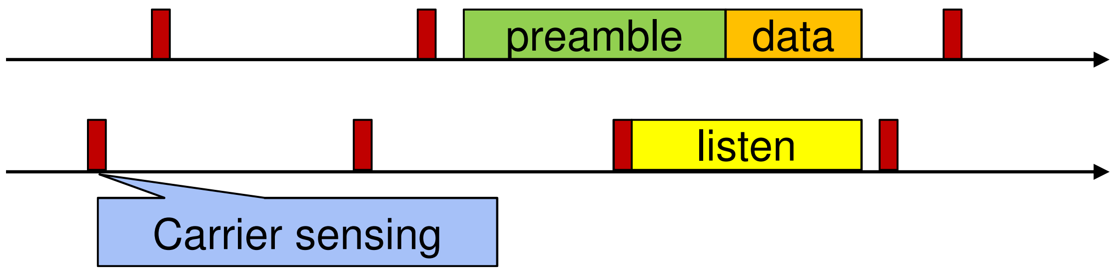
Sensor Node Lifetime

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)

overhearing 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.

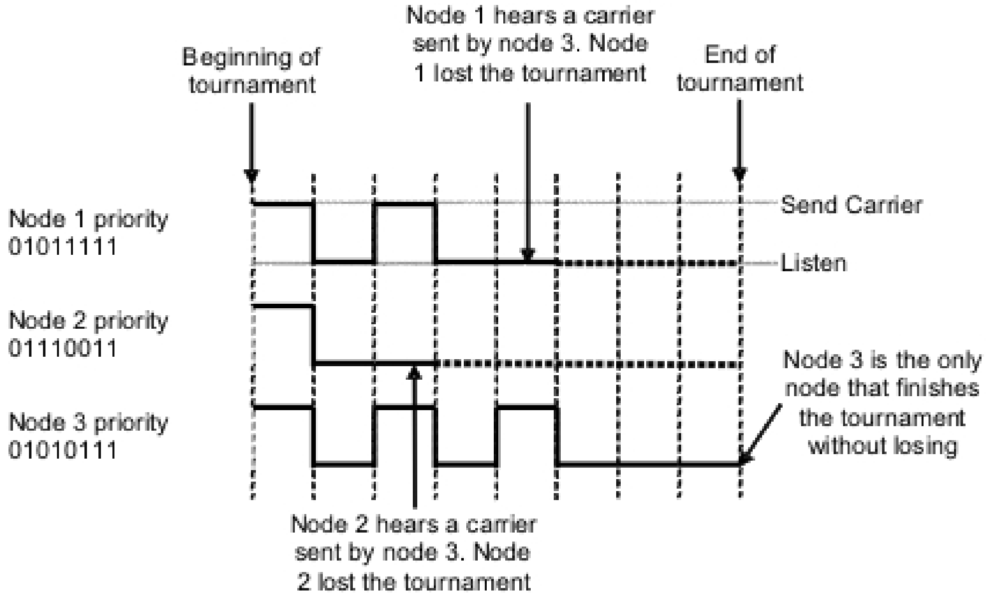
- **Idea: Learn wake-up schedules from neighboring nodes.**
  - Start sending preamble just before intended receiver wakes up.
  - WiseMAC

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.