LANs: WIRELESS

Outline

- Frequency Hoping
- CDMA
- Communication Issues
- MACA
- Bluetooth
- nG
- Satellite

Frequency Hoping

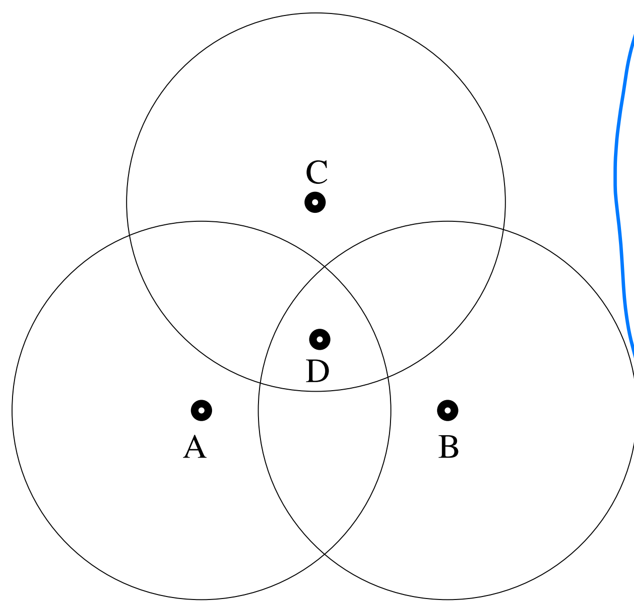
Dynamic LANs

- Wireless networks are formed by groups of nodes within "range of each other".
- BSS (Basic Service Set) is a group of nodes that coordinate their access to the medium and forming a BSA (Basic Service Area), i.e., a geographic area covered by a BSS. Each BSS has an AP (Access Point)
- A distribution system is being used to extend a set of BSSs to an ESS (Extended Service Set).
- To join an ESS a node must select an AP and establish an association with it. The node can reassociate by moving association to another AP. It disconnects by dissociating.

Collisions in Wireless Networks

- Let D be a point at the intersection of three disks centered at A, B, C.
- If A, B, C transmit at the same time then D will not be able to "hear" the message and may not even know who attempted to talk to it.

In ethernet you can hear collisions!



In wireless when a collision occurs you may not know it!

- The issue is: How do you avoid collisions?

Spread Spectrum (1/3)

- Spread-spectrum is a radio transmission technique which refers to any method that widens the frequency band of a signal.
- Frequency hopping is the simplest version of Spread-spectrum.
- Radio stations broadcast on a single carrier frequency, which makes eavesdropping deliberately easy: You tune your radio to the correct frequency and receive the programming.
- Frequency hopping prevents the interception and decipherment of a transmission by shifting the carrier frequency in a predetermined, usually pseudorandom fashionin other words, in a way that appears random but is produced by a deterministic algorithm.

Spread Spectrum (2/3)

- A receiver hopping around in synchrony with the transmitter can pick up the message, but an eavesdropper tuned to a single frequency will hear only a blip as that bit of message flashes by.
- Frequency hopping is largely jam-proof as well. If the frequencies are spaced widely enough, any jamming signal will interfere with only a small part of the message.

Spread Spectrum (3/3)

- Essential idea:

  "spread the information signal over a wider bandwidth to make jamming (and interception) more difficult."

- There are two types of spread spectrum techniques:
  1. Direct Sequencing.
  2. Frequency hopping.

- The advantage of doing this is to
  1. hide or encrypt signals,
  2. avoid various kinds of noise,
  3. use independently the same bandwidth (CDMA).

CDMA: Use orthogonal signals

DSSS (Direct Sequence Spread Spectrum)

- DSSS
  1. For chosen n, each transmitted bit is represented by a sequence of n bits.
  2. The n bit sequence is generated as follows: sender uses a pseudorandom generator to produce n bits, $b_1, b_2, \ldots, b_n$ and XORs b with each bit of the sequence.

$b \oplus b_1$

$b \oplus b_2$

b ⋮

$b \oplus b_n$

Original Bit $\qquad\qquad$ Chipping Code

B $\qquad\qquad$ $B/n \quad B/n \quad B/n$

$$\boxed{b} \quad \rightarrow \quad \boxed{b \oplus b_1, b \oplus b_2, \ldots, b \oplus b_n}$$

1 bit $\qquad\qquad$ n bits

- DSSS looks like CDMA but it is implemented in the physical layer! It is not a multiple access method.

$\ldots, b \oplus b_i, \ldots$

DSSS Example

- If chip code for 0 is 101101 and for 1 is 000111 then
- **Sender:**

Input Data	0	1	0	0	1
	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
Chip Code	101101	000111	101101	101101	000111

- **Receiver:** Must do the reverse.

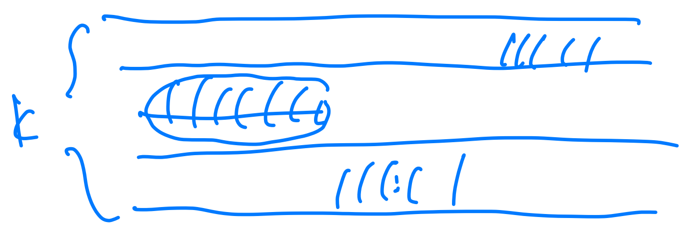
FHSS (Frequency Hopping Spread Spectrum)

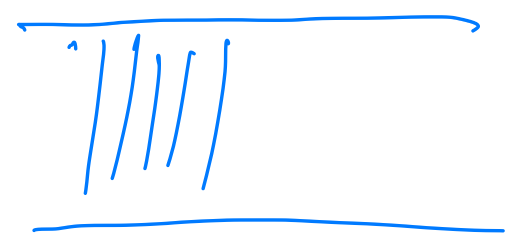
- This is a technique whereby the sender hops from frequency to frequency sending bits at each frequency for the same amount of time.
- After n hops the *cycle* is repeated.
- If B is the total bandwidth of the spectrum allocated then each hop must be allocated bandwidth B/n, this is the bandwidth of the subband.
- Sender and receiver must agree in advance on the subbands allocated for each hopping.
- The time a user stays in a subband is called the dwell time.

CDMA: Code Division Multiple Access

- CDMA is a multiplexing technique used with spread spectrum.
- Looks like DSSS but is on a different layer.
- The scheme works in the following manner.
  - Start with a data signal with rate R, called the bit data rate.

    given sequence of bits
  - Break each bit into k chips according to a fixed pattern that is specific to each user, called the user's code.
  - The new channel has a "chip data" rate of kR chips per second.





0

R_0

channel has a certain bandwidth

$$R_0 = \frac{R}{k}$$

chip (0)

k bits

$$R = k R_0$$

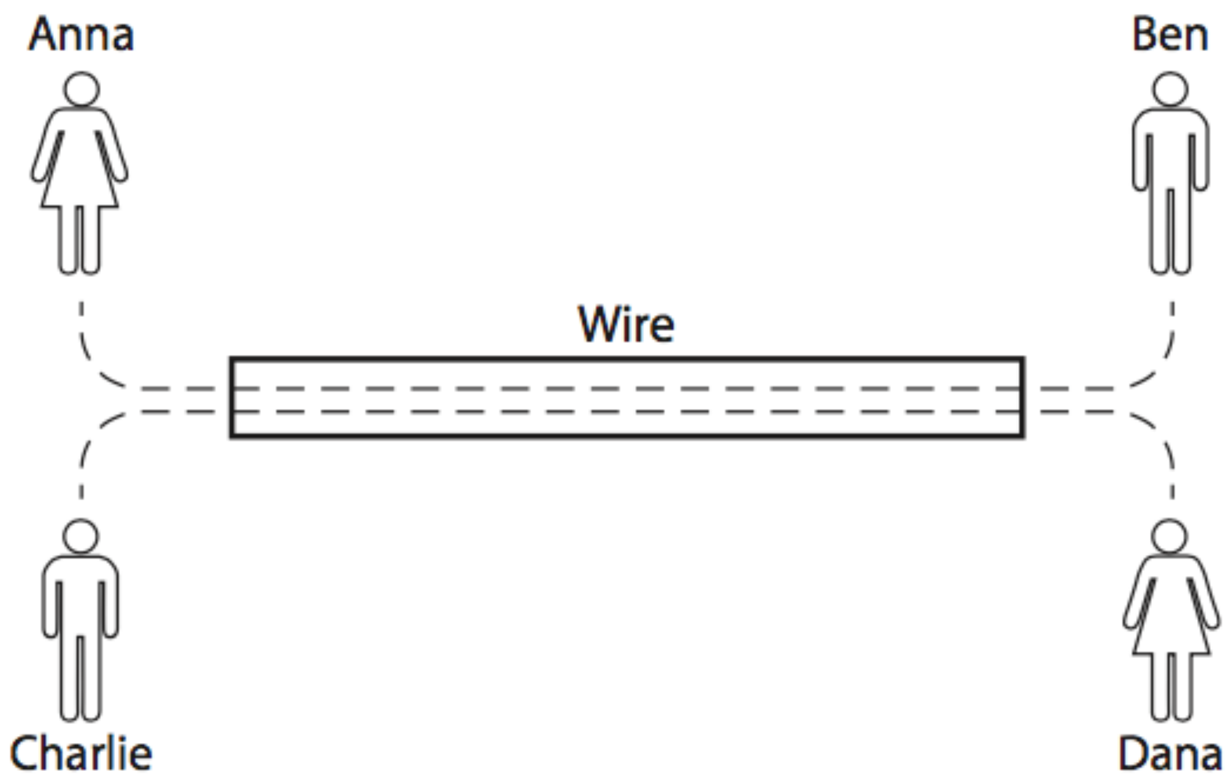
There is a limited rate R that we have: depends on the bandwidth.

To have a k-chip code, I will achieve a rate of R/k.

CDMA

Sharing a Channel

- A familiar Question:



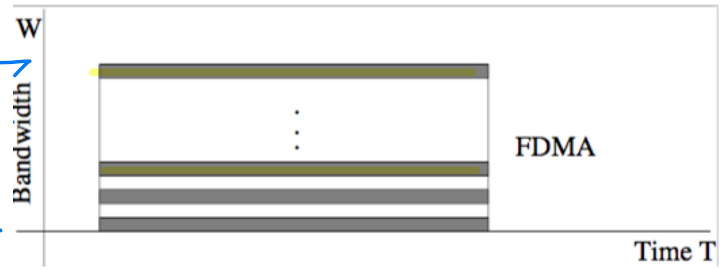
- How is it possible for both pairs to use the same wire without interfering with each other?

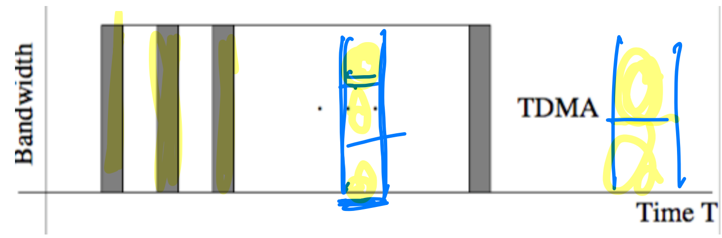
Sharing Methods

Frequency
Time

- Exclusive use of FDMA or TDMA

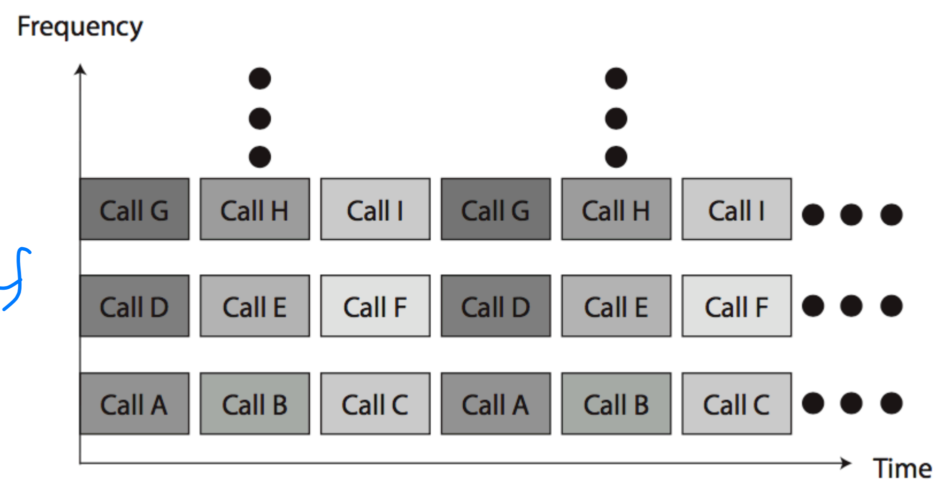
Bdw





- Simultaneous use of FDMA and TDMA

Can make simultaneous use of FDMA and TDMA

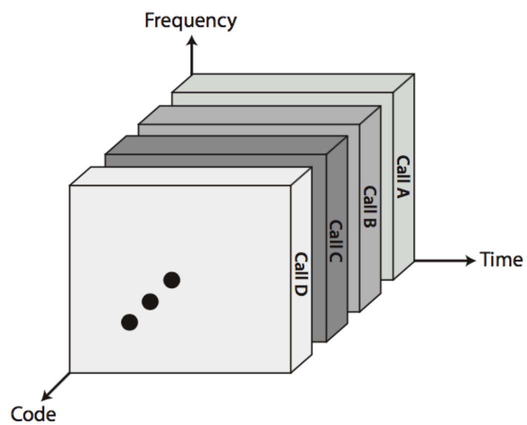


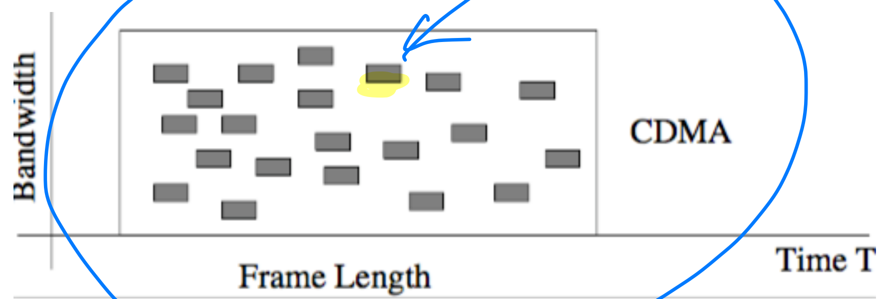
Software Radio

CDMA: Idea

- Calls are distinguished along the “code” dimension.

encoded





- All calls may operate over the same frequencies and at the same times, because each transmission in the network is assigned a unique code

Each user has a specific code to "decode" the signal.

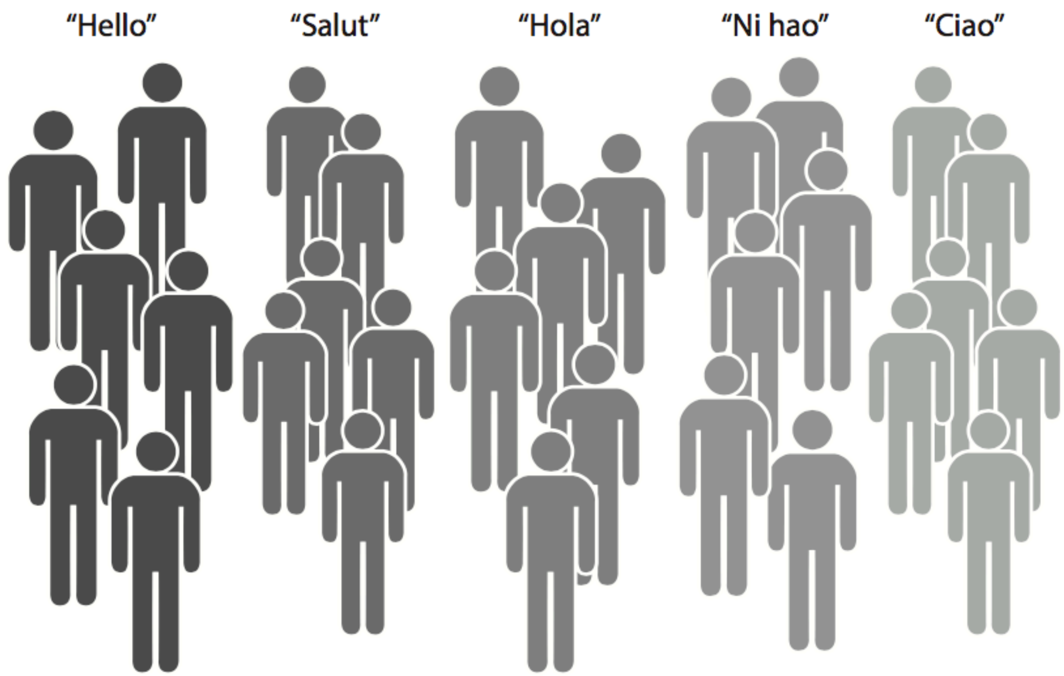
CDMA algorithm

FDMA

CDMA: Cocktail Party

- With CDMA, each code is like a separate language.

TDMA



- In the cocktail party analogy, multiple conversations can occur in a room if they use different languages.
- The issue then becomes controlling speaking volume levels.

CDMA

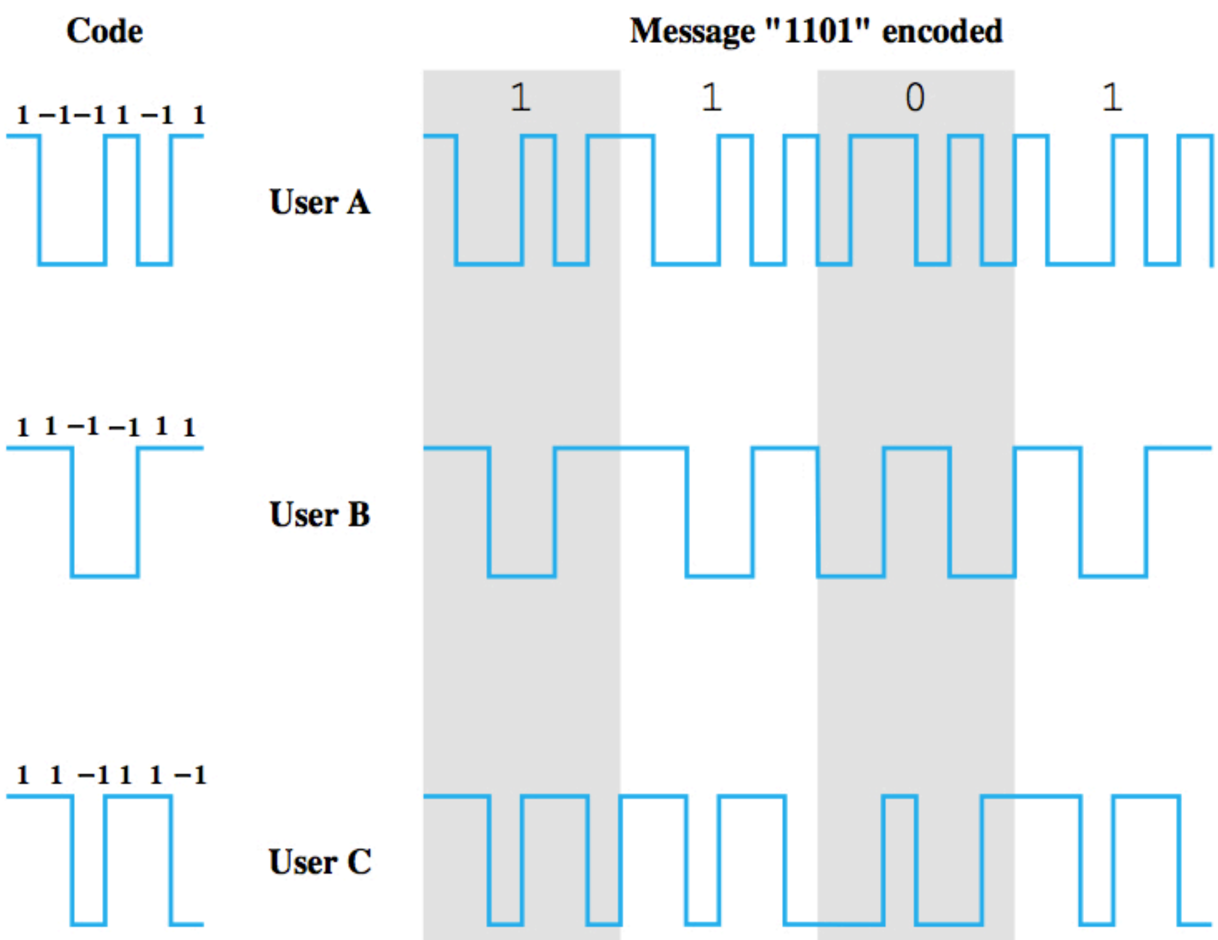
- Consider a simple example with $k = 6$.
- It is simplest to write a code as a sequence of
  - $(+1)$s and (-1)s.
- For three users, A, B, C, each of which is communicating with the same base station receiver, say R. let the codes be

$$
\begin{aligned}
c_A &= (+1, -1, -1, +1, -1, +1) \\
c_B &= (+1, +1, -1, -1, +1, +1) \\
c_C &= (+1, +1, -1, +1, +1, -1).
\end{aligned}
$$

CDMA Example

- If A wants to send a **1** bit:
  A transmits its code as a chip pattern $(1, -1, -1, +1, -1, +1)$.
- If A wants to send a **0** bit:
  A transmits the complement ($+1$s and -1s reversed) of its code, $(-1, +1, +1, -1, +1, -1)$
- Something analogous happens with B and C.

CDMA Example



CDMA: Code Division Multiple Access

- CDMA works as follows:

  Every user U owns a specific bit pattern consisting of n bits:

$$C_U = (b_1, b_2, \cdots, b_n).$$

- The main question is

  How are patterns selected?

Patterns are selected to be pairwise mutually orthogonal.

CDMA (1/2)

- Each of n users, U, is assigned a vector $\mathbf{u} \in \{-1, +1\}^n$.

$$U \leftarrow \mathbf{u} = (u_1, u_2, \ldots, u_n)$$

  u_i are the components of the vector $\mathbf{u}$. $\bar{u} = (-u_1, -u_2, \ldots, -u_n)$

- Let $\bar{\mathbf{u}} = (-u_1, -u_2, \ldots, -u_n)$ denote the bit-complement of $\mathbf{u} = (u_1, u_2, \ldots, u_n)$.

- Note that[a]

Division by n is to normalize the values

$$< \mathbf{u}, \mathbf{u} > = \frac{1}{n} \overbrace{\sum_{i=1}^{n} u_i u_i}^{\sim n} = 1$$

$$< \mathbf{u}, \bar{\mathbf{u}} > = \frac{1}{n} \underbrace{\sum_{i=1}^{n} u_i(-u_i)}_{\sim n} = -1$$

---

[a] The notation $< \cdot, \cdot >$ means inner product of vectors.

(The inner product of

$$u = (u_1, u_2, \ldots, u_n)$$

$$v = (v_1, v_2, \ldots, v_n)$$

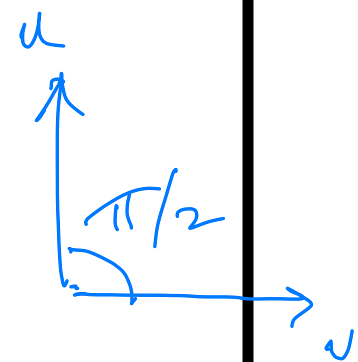
$$\langle u, v \rangle = \frac{1}{n} \sum_{i=1}^{n} u_i \cdot v_i$$

(from linear algebra)!

CDMA (2/2)

- **Orthogonality Condition:** The vectors assigned to the users are pairwise orthogonal, i.e. for any users $U \neq V$,

$$< \mathbf{u}, \mathbf{v} >:= \frac{1}{n} \sum_{i=1}^{n} u_i v_i = 0$$



$\langle \bar{u}, v \rangle = 0$

- Hence, also

$$< \mathbf{u}, \bar{\mathbf{v}} >:= \frac{1}{n} \sum_{i=1}^{n} u_i(-v_i) = 0$$

- **Transmission:** To transmit a bit 0 or 1 user U sends a vector as follows:

  To transmit 1 user U sends its vector: $\mathbf{u}$

  To transmit 0 user U sends complement of its vector: $\bar{\mathbf{u}}$

$U \leftarrow u, \bar{u}$

$V \leftarrow v, \bar{v}$

$W \leftarrow w, \bar{w}$

CDMA Example

- Code assignment

User	$\{0,1\}$-Vector	$\{-1,+1\}$-Vector
A	00011011	**a** := -1-1-1+1+1-1+1+1
B	00101110	**b** := -1-1+1-1+1+1+1-1
C	01011100	**c** := -1+1-1+1+1+1-1-1
D	01000011	**d** := -1+1-1-1-1-1+1+1

To transmit data sequence 1011:

- A sends: $\mathbf{a}\bar{\mathbf{a}}\mathbf{a}\mathbf{a} = 00011011111001000001101100011011$
- B sends: $\mathbf{b}\bar{\mathbf{b}}\mathbf{b}\mathbf{b} = 00101110110100010010111000101110$
- etc

C_U

CDMA: Additivity

- Let $\{b_U : U \text{is a user}\}$ be the vectors transmitted by the users on a given transmitted bit $b = 1$ or $b = 0$.
- According to our assumptions/definitions this means that

$$b_U = \mathbf{u} \text{ if } b = 1$$

$$b_U = \bar{\mathbf{u}} \text{ if } b = 0$$

- When a subset S of the set of users transmits simultaneously then the vector sum

$$\sum_{U \in S} b_U$$

is being transmitted.

- How does a user recover the bit from this sum?

CDMA: Decoding (1/2)

- If a station wants to recover the message transmitted by user U from a set S of users then it computes the inner product

$$< \mathbf{u}, \sum_{V \in S} b_V >$$

A user can do this because **u** is known!

- Also note that[a]

$$< \mathbf{u}, \sum_{V \in S} b_V > \quad = \quad \sum_{V \in S} < \mathbf{u}, b_V >$$

by the linearity of the inner product.

Additivity of inner-product!

[a]This is called additivity property of the inner product.

CDMA: Decoding (2/2)

- But for each user V we have that

$$
\begin{aligned}
< \mathbf{u}, b_V > &= \begin{cases} < \mathbf{u}, \mathbf{v} > & \text{if } b_V = \mathbf{v} \\ < \mathbf{u}, \bar{\mathbf{v}} > & \text{if } b_V = \bar{\mathbf{v}} \end{cases} \\
&= \begin{cases} 0 & \text{if } U \neq V \\ +1 & \text{if } U = V \text{ and } b_V = \mathbf{v} \\ -1 & \text{if } U = V \text{ and } b_V = \bar{\mathbf{v}} \end{cases}
\end{aligned}
$$

- This is because:
  - if $U \neq V$ then $< \mathbf{u}, \mathbf{v} >=< \mathbf{u}, \bar{\mathbf{v}} >= 0$;
  - if $U = V$ and $b_V = \mathbf{v}$ then $< \mathbf{u}, b_V >=< \mathbf{u}, \mathbf{v} >= 1$;
  - if $U = V$ and $b_V = \bar{\mathbf{v}}$ then $< \mathbf{u}, b_V >=< \mathbf{u}, \bar{\mathbf{v}} >= -1$;
- In other words, each user V will recover the bit that was sent to it in encoded form!

CDMA: Walsh Matrices

- The Walsh matrices of dimension 2^k are given by the recursive formula

$$W(2^1) = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

and

$$W(2^{k+1}) = \begin{bmatrix} W(2^k) & W(2^k) \\ W(2^k) & -W(2^k) \end{bmatrix}$$

Gramm-Schmidt
Orthogonalization Procedure

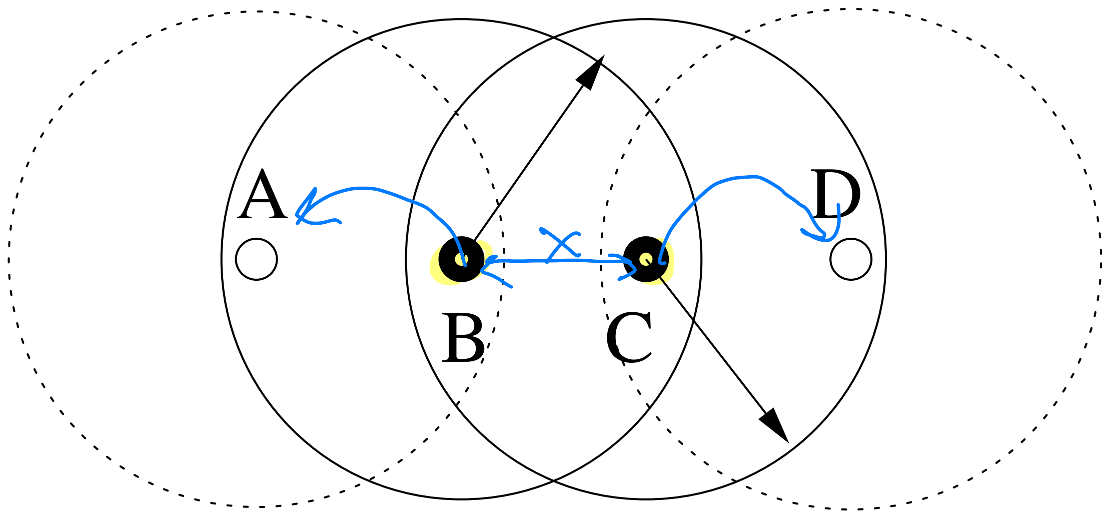
Communication Issues

Communication Problems

- Collision Avoidance
- Exposed Node
- Communication Paths
- Asymmetry
- Attenuation
- Power Level
- Interference
- SIR

Collision Avoidance

- B and C will collide if they transmit at the same time.

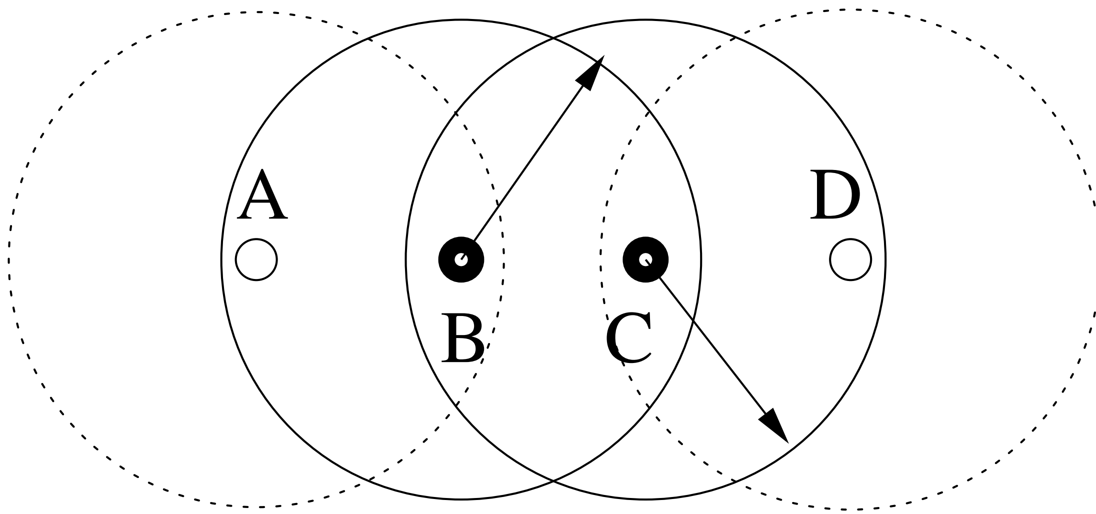


- A can reach B but is unaware of C.
- C can reach B but is unaware of A.

Exposed Node

Exposed Node

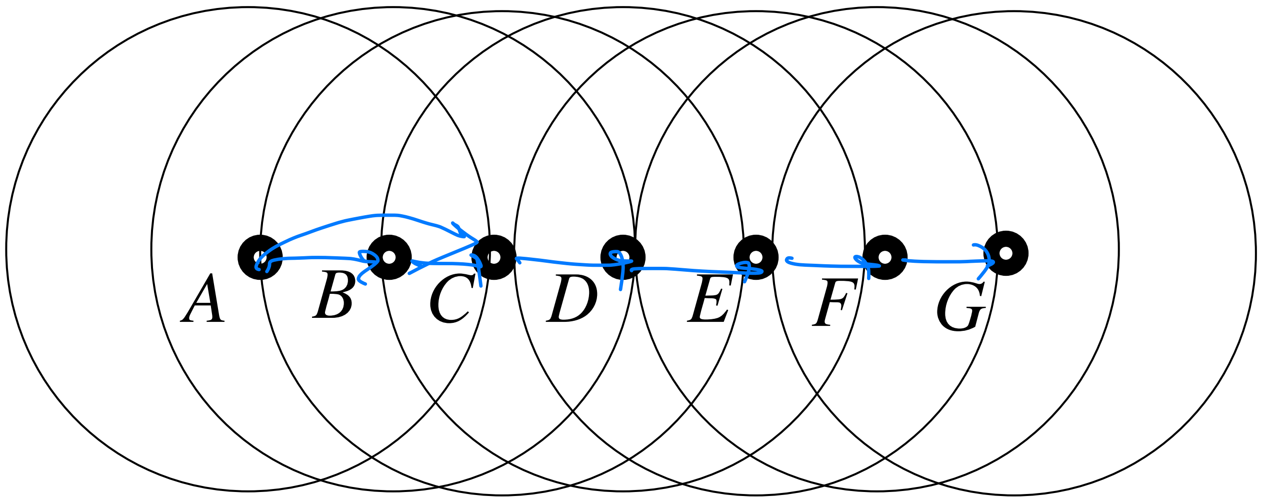
- C can hear if B sends to A.
- It is a mistake for C to assume that it cannot transmit to D.



- In fact: C can transmit to D and simultaneously B can transmit to A.

Communication Paths in Wireless

- Each node forwards to a node within its range:



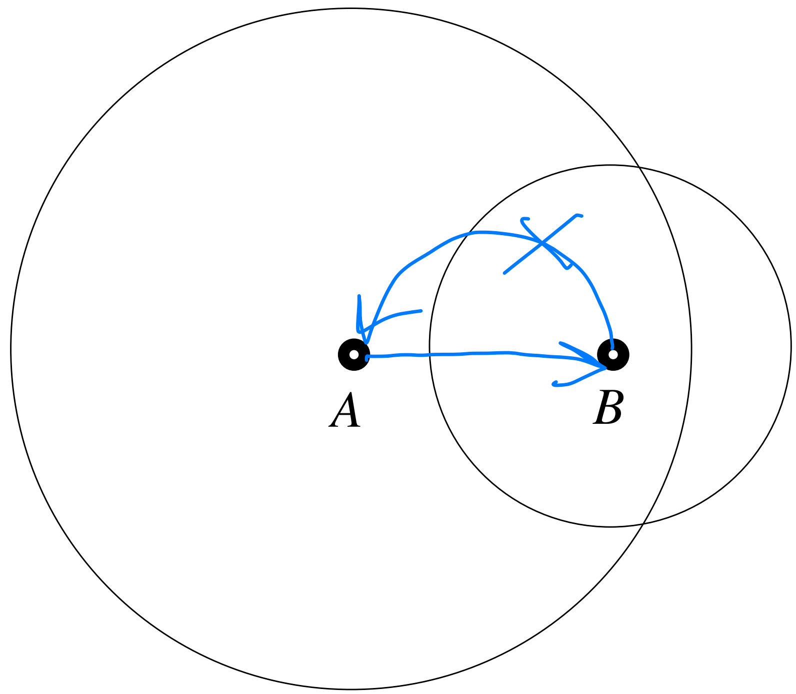
- This gives a communication path:

$$A \to B \to C \to D \to E \to F \to G$$

You are limited by your range

Communication Asymmetry in Wireless

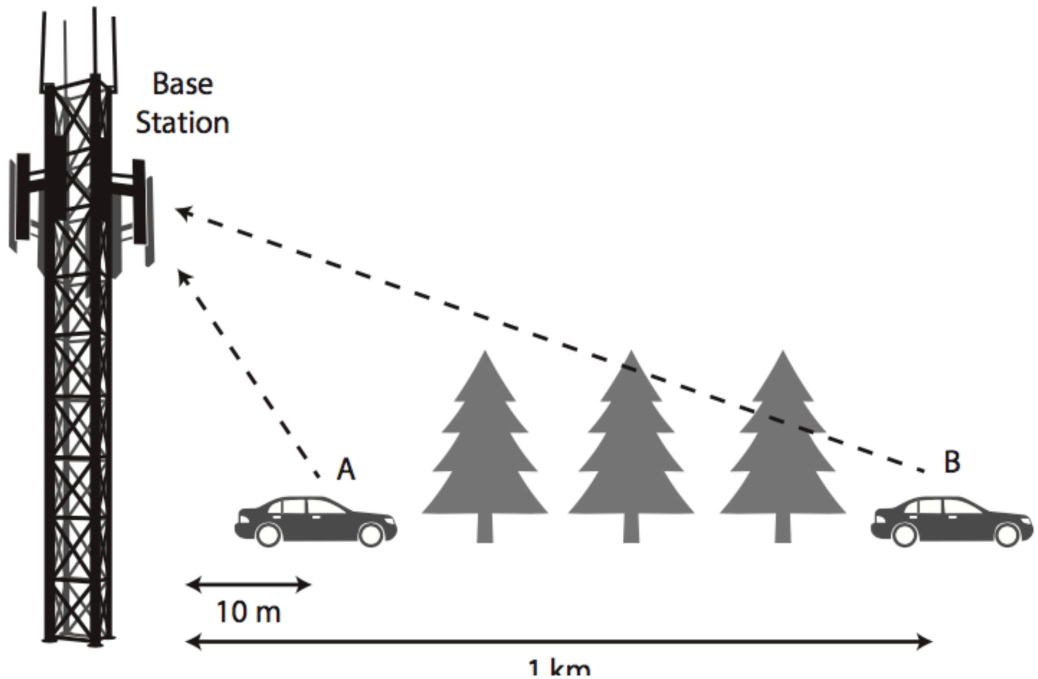
- In the real world, there is asymmetry:



- A can reach B but B cannot reach A.

Attenuation

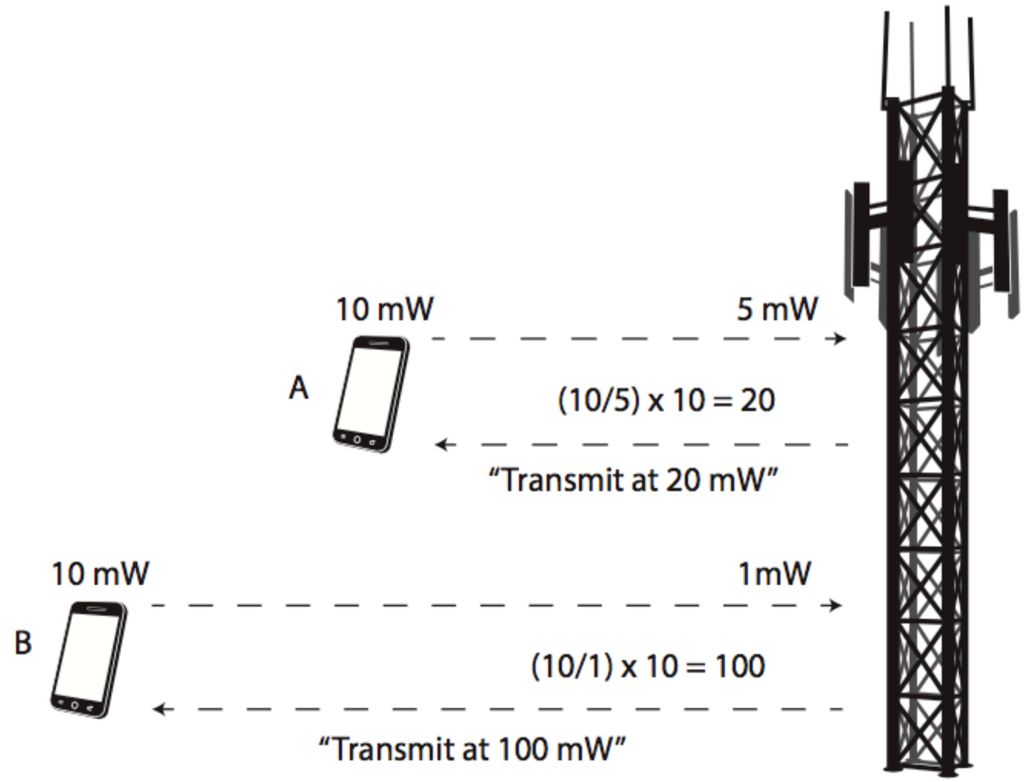
- The farther a transmitter is from its receiver, the higher the attenuation is, and the more objects there are to obstruct the path.



- Here, A has a short, clear path to the tower, while B has a long path that is obstructed by objects (e.g., trees)

Power Levels

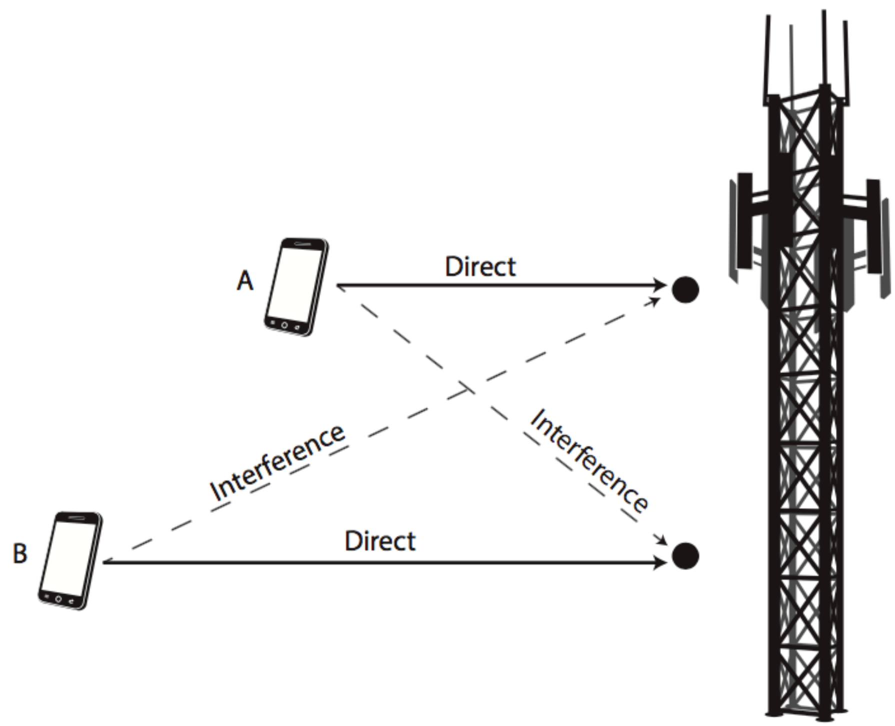
- Transmission power control (TPC) algorithm.



- Attempts to equalize received signal powers.

Interference

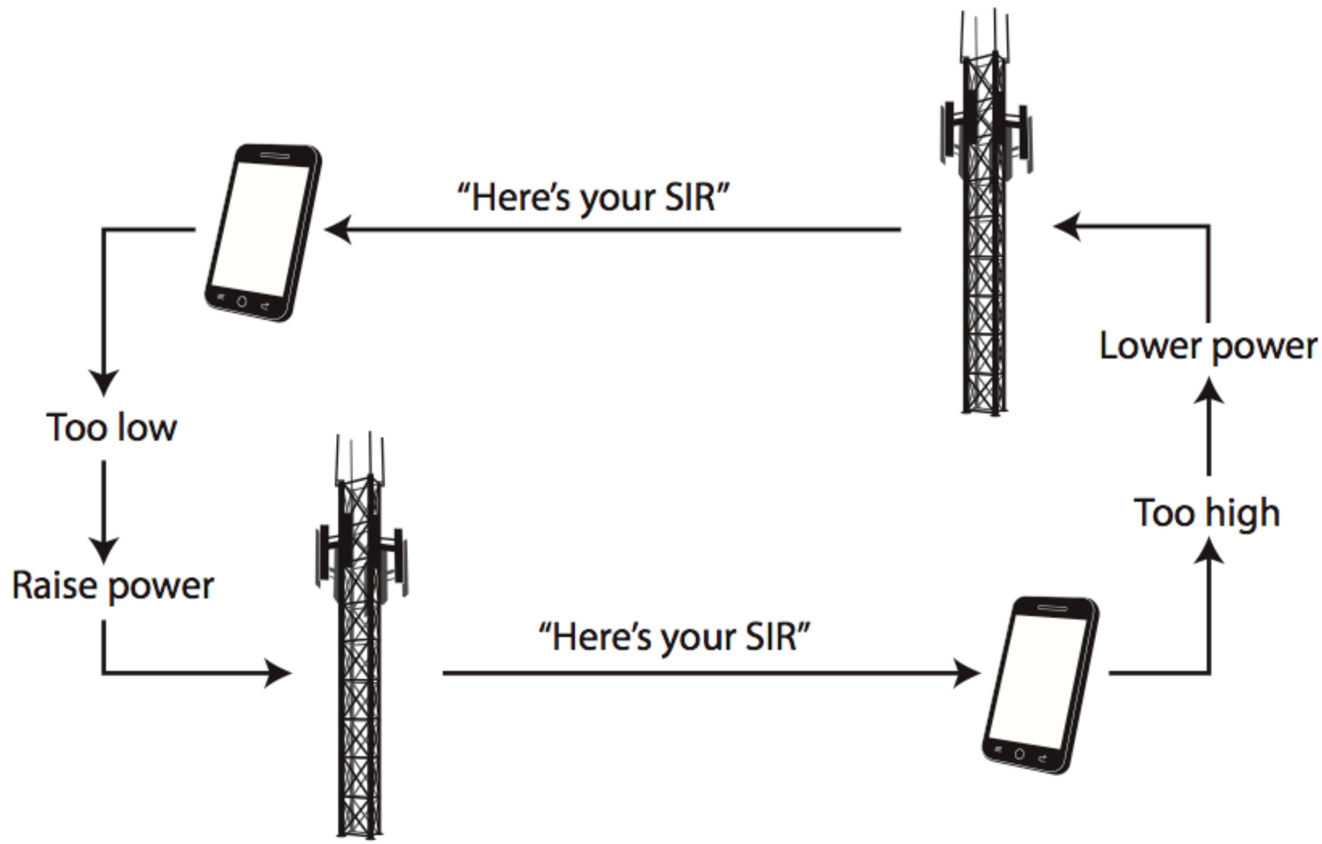
- Ideally, only the power from the transmitter of a link would be present at its receiver.



- But this is not the reality: here, some of A's transmission will be coupled into B's receiver, and vice versa.

Signal to Interference Ratio (SIR)

- Tower tells a device its current received signal-to-interference ratio (SIR), which serves as a negative feedback signal.



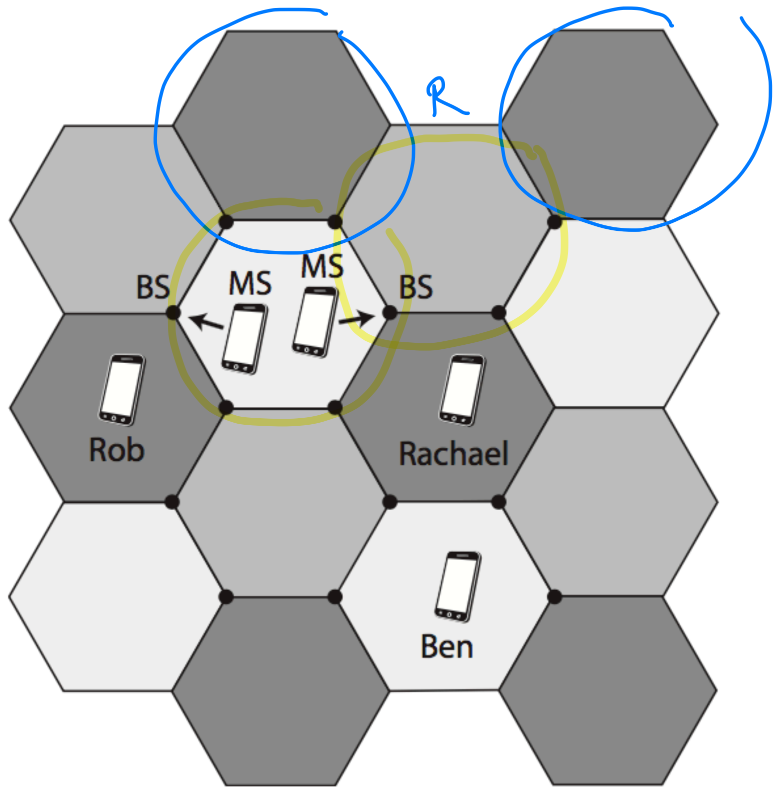
- Each device can update its transmission power independently.

MACA

Hexagonal Cell Organization

Cells

- Multiple mobile stations (MSs) & base stations (BSs).



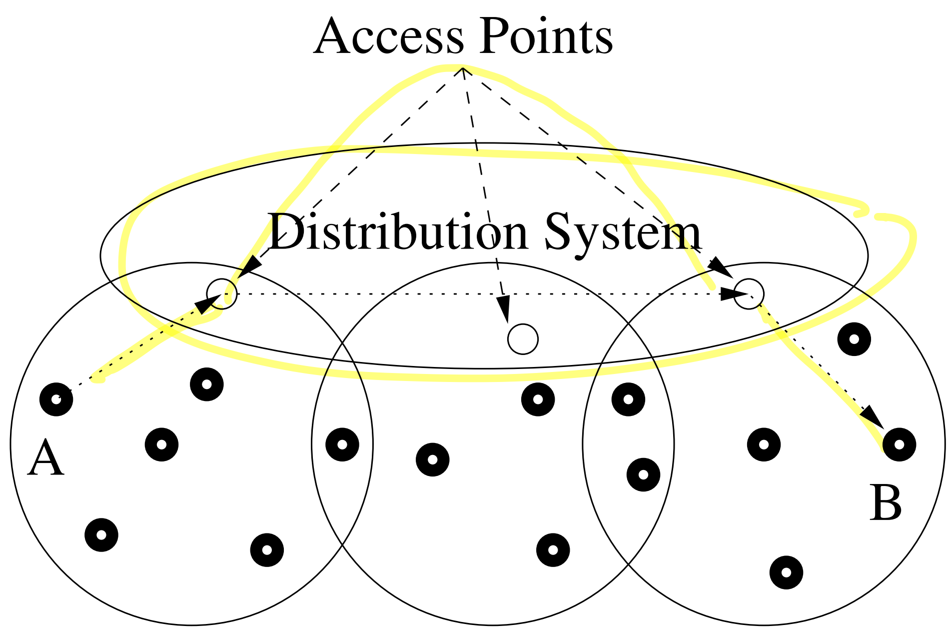
- Shading of a cell indicates frequency band that the cell is using.
- Neighboring cells have different frequency bands.

MACA Algorithm

- 802.11 uses Multiple Access Collision Avoidance (MACA):
  1. Sender sends Request To Send (RTS) message to receiver that includes how long it wants to hold medium.
  2. Receiver responds with Clear To Send (CTS) message.
  3. If CTS not received nodes realize after a period of time that collision occurred, in which case a backoff algorithm is being used.
  4. Receiver sends ACK after receiving.
  5. All other nodes must wait for ACK prior to transmitting.
- In practice, it is much more complicated than this!

Access and Distribution: Not All Nodes are Equal!

- Nodes are associated to access points.
- A sends frame to B as follows:



- A sends to A's Access Point., A's Access Point sends to B's Access Point that forwards to B.

Scanning for Access Points

- Stations select access points by scanning:
  1. Station sends **Probe** frame.
  2. All Access Points within reach of station reply with **Probe Response** frame.
  3. Station selects access point and responds with **Association Request** frame.
  4. Access Point responds with **Association Response** frame.
- 802.11 frames include a control field indicating whether or not frame is data, RTS or CTS.
- It has four addresses to account for the fact that it must be transmitted through the distribution system.

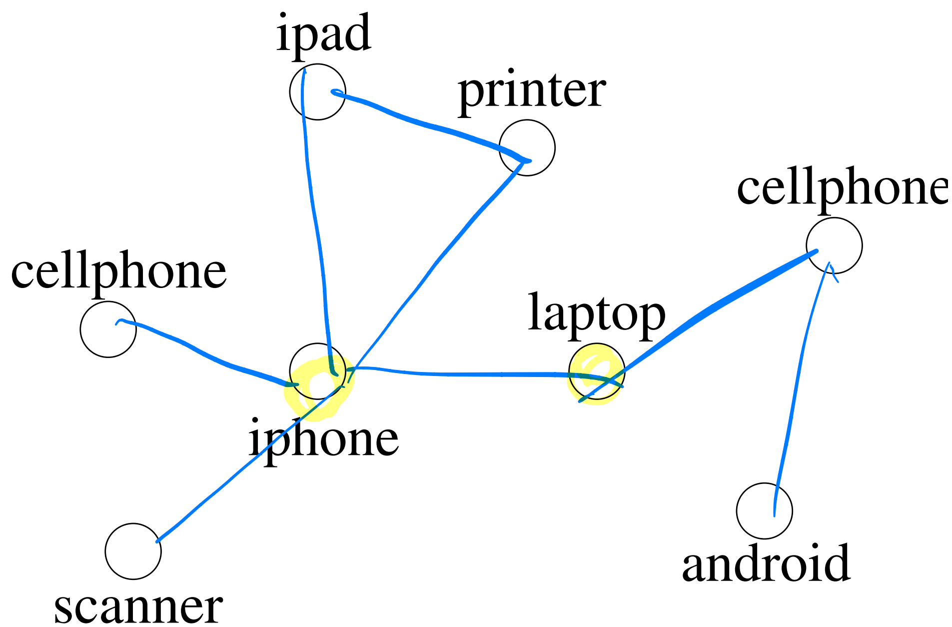
IEEE 802.11: Frames

- It has three types of frames: management frames (MF), control frames (CF), and data frames(DF).
- **MF:** Used for node association, disassociation, timing, synchronization, authentication and deauthentication.
- **CF:** Used for Handshaking and positive ACKs during an exchange.
- **DF:** Used for data transmission.
- **IEEE 802.11: MAC**
  - MAC protocol is specified in terms of a coordination function that determines when a node in a BSS is allowed to transmit and when it may be able to receive.

Bluetooth

How to Establish a Link

- A set of nodes wants to establish a connected network.



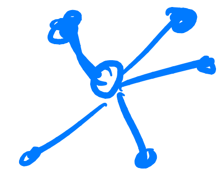
- What protocol should they follow to get connected?

"wire replacement technology"

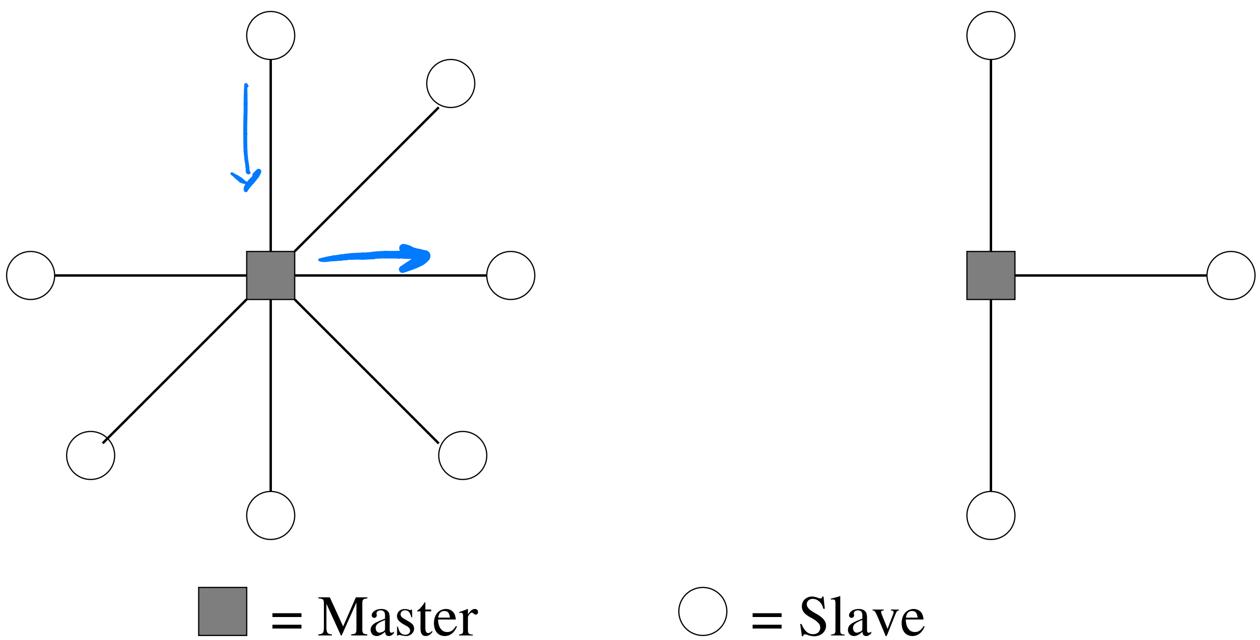
Bluetooth

- Originally conceived as cable replacement technology.
- Is the first defacto standard for ad hoc networking brought about by several companies.
- Its particular design is less suited for other applications.

Organization: Piconets



- They are **star** networks.
- In the leftmost piconet the master has seven slaves, in the rightmost it has three.



diameter = 2

Piconet

Organization: Piconets

- They are managed by a single **master** that implements centralized control over channel access.
- All other participants are called **slaves**.
- Communication is strictly
  master → slave,
  and
  slave → master.
- Direct slave-to-slave communication is impossible.
- A master has at least one and at most seven slaves.
- Piconets can be enlarged to form scatternets.

Double Personalities

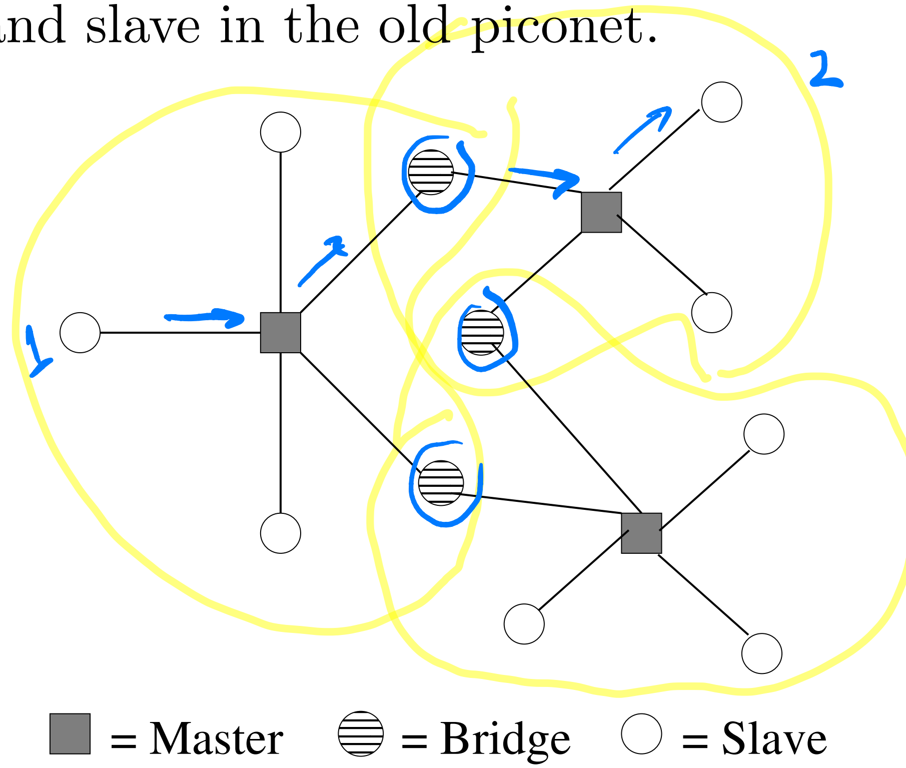
- **Roles of Master and Slave:**
  - Since a slave may want to set up a new piconet or take over an existing piconet, during the existence of a piconet the role of master and slave can be switched.
  - This is done by employing a different frequency.

Bluetooth enforces a network topology

- piconet
- scatternet

Example of a 14-node Scatternet

- Piconets are joined to form **scatternets**.
- A node can be slave in two piconets, or become master in a new piconet and slave in the old piconet.



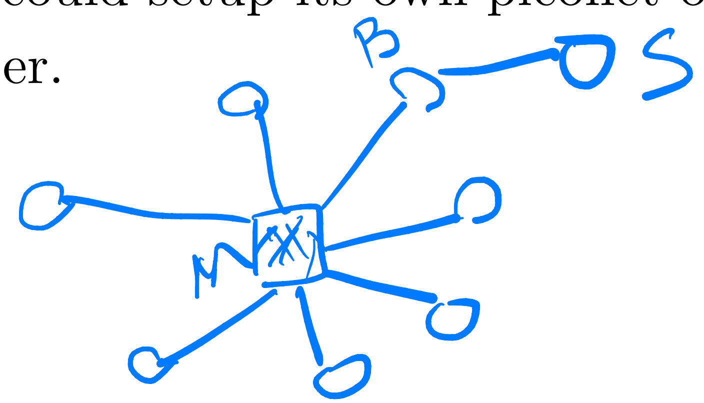
You enlarge the number of nodes: not too much

Bluetooth Communication

- If you want to communicate with more than eight nodes at the same time multiplexing is required. Moreover, nodes would need to alternate between their respective piconets.
- Bluetooth does not provide for slave-to-slave communication (maybe technology will improve in the future).

  To solve this problem one has

  1. either to channel traffic through a master (this increases communication and power consumption)
  2. or one of the two slaves could setup its own piconet or even switch roles with a master.



Scatternet

Scatternets are collections of piconets satisfying the following rules.

1. The scatternet is a connected network formed from piconets.
2. It has masters and slaves. Slaves are of two types:
   "pure" slaves (i.e., slaves belonging to a single piconet), and
   "bridge" slaves (i.e.. slaves that belong to multiple piconets).
3. Two masters can share only a single slave.
4. A bridge may connect only two piconets.
5. A piconet can have at most seven slaves.

How to Establish a Link

Bluetooth nodes want to establish a connected network.

They follow the protocol below:

1. Start
2. Synchronization
3. Discovery
4. Paging
5. Connection established.

1-2sec

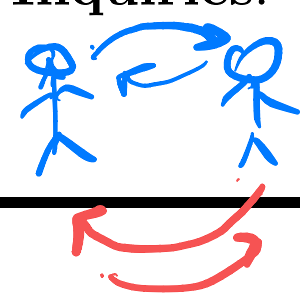
Discovery Delay Procedure

Bluetooth supports the paradigm of **spontaneous connectivity**. The procedure used for node discovery is called **Inquiry** and connections are established based on information exchange.

1. Bluetooth node is set into **Inquiry** mode by the application.
2. Then sends **Inquiry** messages to probe for other nodes.
3. Other Bluetooth nodes (within the range) only listen.
4. They reply to **Inquiry** messages only when they have been set explicitily to **InquiryScan** mode.

To prevent “collisions” and since **Inquiry** needs to be initiated periodically then some type of randomness must be employed in order to determine the time interval between two **Inquiries**. This technique is called **Collision Avoidance**.

Backoff protocol

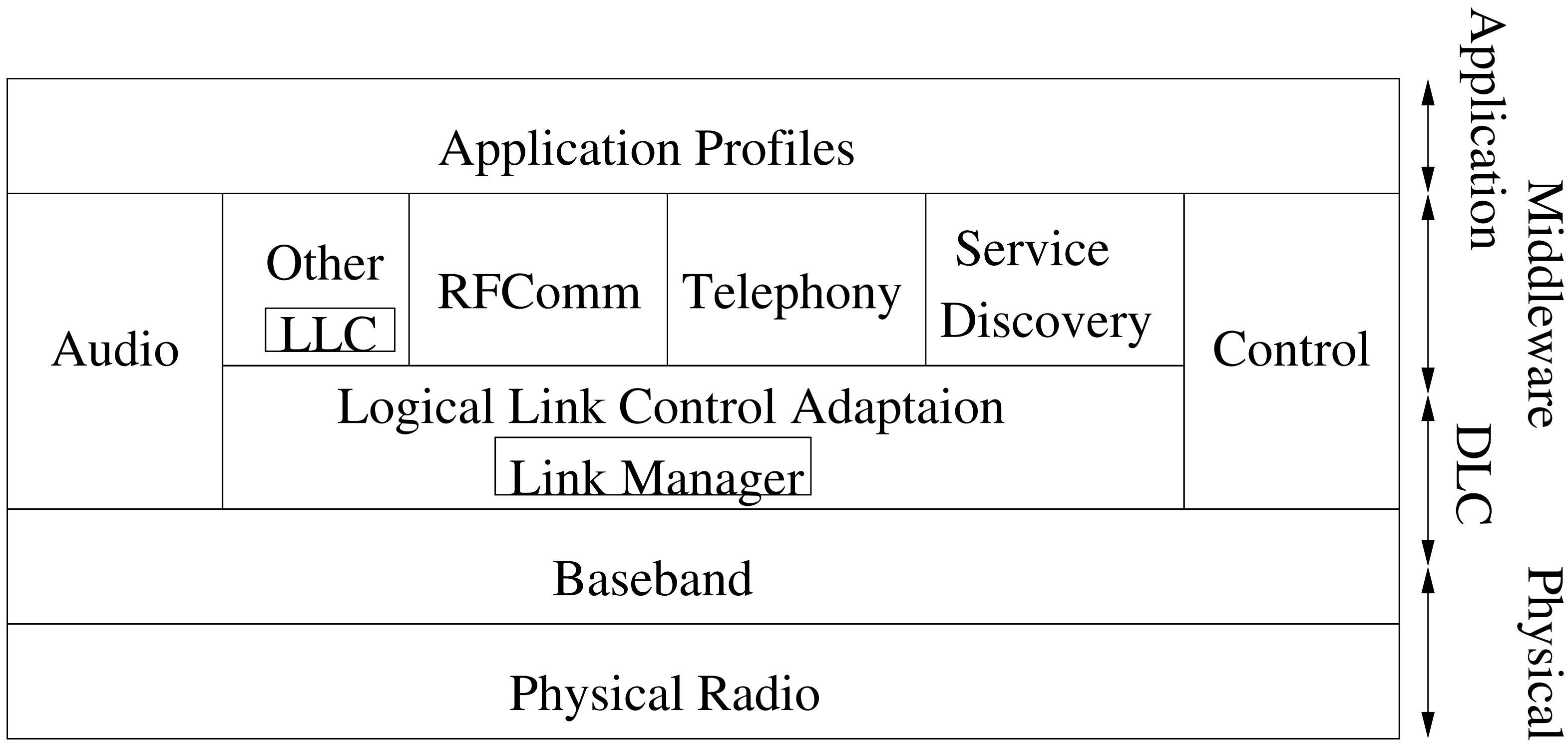


Connection Establishment

- Once a unit has discovered another unit, connection establishment is very fast.
- In an ideal scenario, the expected delay for link formation (Discovery plus Connection) is about 1 sec when both nodes follow the uniform distribution between the **Inquiry** and **InquiryScan**.
- In practice this takes several seconds.

IEEE 802.15 (Bluetooth Protocol Architecture)

Does not follow any of the OSI, TCP/IP or 802 models.



The Radio layer moves bits from master to slave. The baseband resempbles the MAC sublayer.

IEEE 802.15 (Bluetooth Frames)

The Bluetooth frame includes an access code identifying the master so that slaves can tell which traffic belongs to them.

72	54	0–2744
Access Code	Header	Data

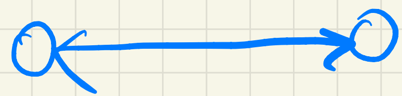
In the Header, Addr identifies which of the active devices frame is intended for. Type identifies frame type.

3	4	1	1	1	8
Addr	Type	F	A	S	Checksum

NFC (Near Field Communication)

Tag technology

Comm. between



two entities

nG

nG (n-th Generation Wireless)

- Provides high quality, reliable communication and each new generation of services represents a big leap in that direction.

Features	1G	2G	3G	4G	5G
Start/Devlopment	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Technology	AMPS, NMT, TACS	GSM	WCDMA	LTE, WiMax	MIMO, mm Waves
Frequency	30 KHz	1.8 Ghz	1.6 - 2 GHz	2 - 8 GHz	3 - 30 Ghz
Bandwidth	2 kbps	14.4 - 64 kbps	2 Mbps	2000 Mbps to 1 Gbps	1 Gbps and higher
AccessSystem	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDMA
Core Network	PSTN	PSTN	Packet Network	Internet	Internet

5G has wider Bandwidth

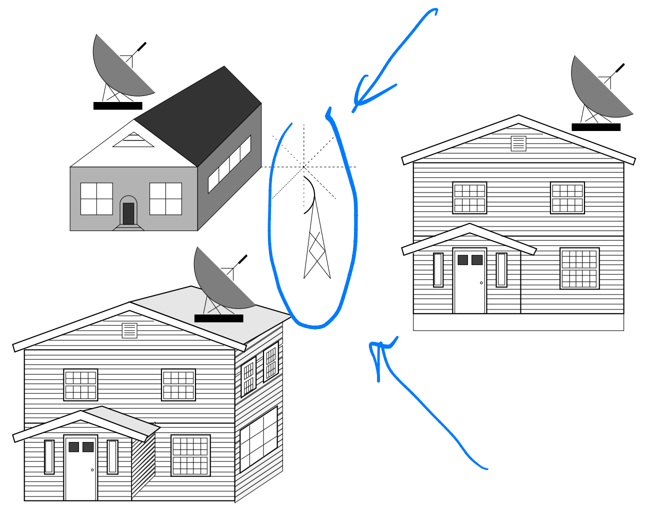
- Each Generation defined by telephone network standards.
- Evolution started in 1979 with1G and is still ongoing with 5G.
- Each of the Generations has standards that must be met to officially use the G terminology.
- There are institutions in charge of standardizing each generation of mobile technology.

nG (n-th Generation Wireless)

- **(1G)** Introduced in the late 70's with fully implemented standards being established throughout the 80's
- **(2G)** Main difference between 1G and 2G, is that the radio signals used by 1G are analog, while 2G networks are digital.
- **(3G)** Utilizes UMTS (Universal Mobile Telecommunications System); combines aspects of 2G with new technology and protocols to deliver a significantly faster data rate.
- **(4G)** Currently in use. Made possible by MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing). Important 4G standards are Broadband Wireless, WiMAX (fizzling out) and LTE (has seen widespread deployment).

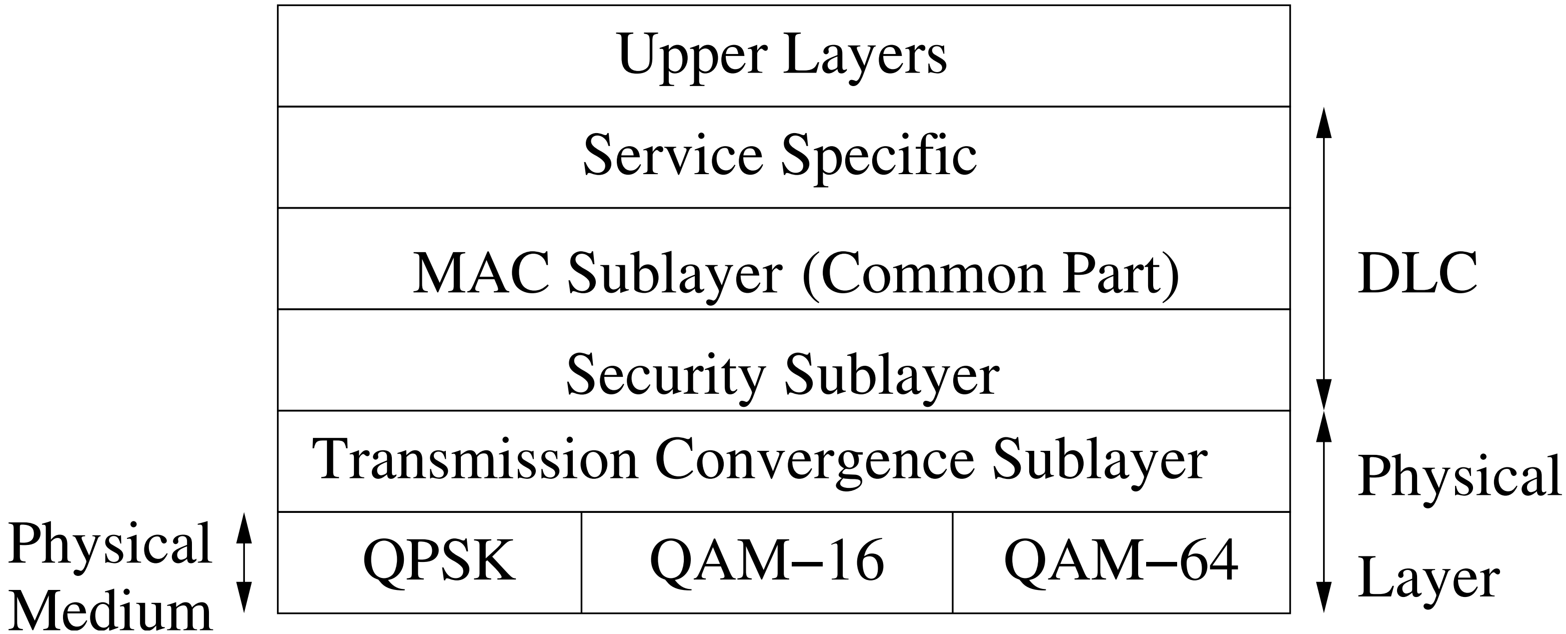
Broadband Wireless (IEEE 802.16): Wireless Last Mile

- Running fiber optic, coaxial cable, etc, to millions of homes is rather expensive. A big antenna on a hill solves last mile transmission problems.



- 802.16 is different than 802.11: 1) it provides service to static buildings not nomadic devices, 2) buildings can have more than one computer, 3) uses full-duplex 4) more spectrum in the range 10-66 GHz is used, 5) provides QoS.

Broadband Wireless (IEEE 802.16): Protocol Stack



Broadband Wireless (IEEE 802.16): Wireless Last Mile

- 802.16a, 802.16b planned: to operate on differenct frequency ranges.
- Service specific sublayer interfaces with the network layer.

Modulation	Mbps	Bits/Baud
QAM-64	150	6
QAM-16	100	4
QPSK	50	2

Broadband Wireless (IEEE 802.16): MAC Sublayers

- The DLC has three sublayers.
- **Security:** Only the payloads are encrypted with symmetric DES (or triple DES). Authentication is done with RSA using X.509 certificates. Integrity uses SNA-1.
- **MAC Sublayer (Common Part).** In downstream: the base station decides what to put in which subframe. In upstream: four classes of service are defined. CBR (for uncompressed voice), RTVariable Bit Rate (for compressed multimedia), Non-RTVariable Bit Rate (for large file transfers), Best Effort (for everything else).
- Bandwidth allocation is either per station (subscriber station makes collective requests for all users in a building) or per connection (base station manages each connection directly).

Broadband Wireless (IEEE 802.16): Frames

- MAC frames begin with a generic header: EC (tells if payload is encrypted), Type (gives frame type), CI (indicates presence or absence of final checksum), EK (tells which encryption key is being used), Connection ID (gives connection frame belongs to), Header CRC uses polynomial $x^8 + x^2 + x + 1$.

1	1	6	1	1	2	1	11	16	8		4
0	EC	Type		CI	EK		Length	Connection ID	Header CRC	Data	CRC

- Frames requesting bandwidth have different header type and do not carry payload. Instead of 0 they start with bit 1.

1	1	6	16	16	8
1	0	Type	Bytes needed	Connection ID	Header CRC

WiMax (Fizzling Out)

- The name ”WiMAX” was created by the WiMAX Forum, which was formed in June 2001 to promote conformity and interoperability of the standard.
- WiMAX (Worldwide Interoperability for Microwave Access) is a trademark for a family of telecommunications protocols that provide fixed and mobile Internet access.
- The 2005 WiMAX revision provided bit rates up to 40 Mbit/s with the 2011 update up to 1 Gbit/s for fixed stations.
- WiMAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL.
- WiMax requires special antennae and Network Interface Cards.

LTE Wireless (Currently in Use)

- Long Term Evolution (LTE) is a standard for wireless communication of high-speed data.
- Goal of LTE is to increase the capacity and speed of wireless data networks utilizing cutting-edge hardware and DSP techniques that have recently been developed.
- Its wireless interface is incompatible with 2G and 3G networks, and so it must be operated on separate wireless spectrum.
- LTE includes an all-IP flat network architecture, end-to-end QoS including provisions for low-latency communications, peak download rates nearing 300 Mbps and upload rates of 75 Mbps, capacity exceeding 200 active users per cell, the ability to manage fast-moving mobiles, and support for multi-cast and broadcast streams.

5G (5-th Generation Wireless)

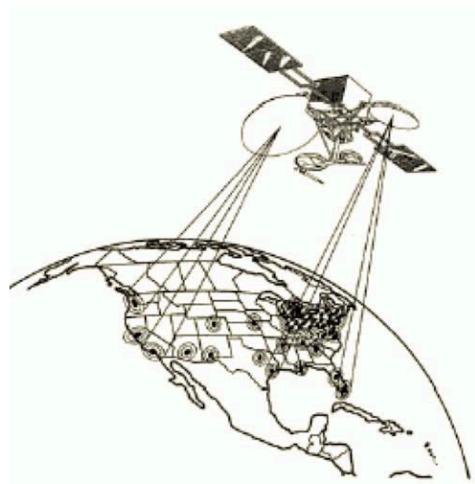
- Currently being rolled out.
- Includes device-to-device communication, better battery consumption, and improved overall wireless coverage.
- May include Massive MIMO, Millimeter Wave Mobile Communications, small cells, Li-Fi
- New technologies could be used to give 10Gb/s to a user
- Expected low latency, and allows connections for billions of devices.

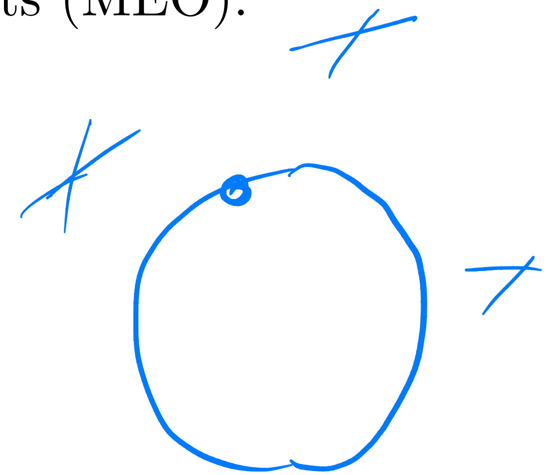
Satellite

Satellite Based

- Three types of satellite orbits: geostationary orbits (GSO), low earth orbits (LEO) and medium earth orbits (MEO).

Delay Tolerant

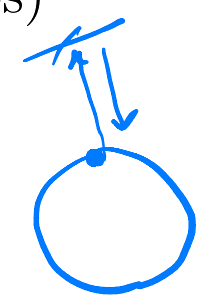




- MEO is mainly utilized for navigation services such as GPS and Galileo, while GSO and LEO orbits are used for point?to?point and point?to?multipoint satellite communications
- Several providers available and currently in development.

Satellite Based

- Satellite based services deliver broadband to customers in the US and Canada.
- ViaSat (a recent satellite) with a total data throughput of some 140 Gbps, the satellite has more capacity than all other commercial communications satellites over North America combined.
- This is a wave of new satellites operating in the Ka-band, a part of the satellite-apportioned radio spectrum that allows high data-rates (download range of 8-12 Mbps)



Satellite Based: Latency

- Satellite signals travel near the speed of light. frequency
- The basic time delay formula is

$$\text{Time Delay} = \frac{\text{Distance to Satellite}}{\text{Speed of Light}}$$

Planetary TCP/IP

- Example:
  A Distance to Satellite $= 35,786\ km$,
  and Speed of Light $= 300,000\ km/s$
  yields a Time Delay $= 120\ ms$.
- The total delay for one-way communication between two ground stations is between 250 and 300 ms. For two-way communications (when one satellite customer communicates with another satellite customer), the round-trip time would typically be between 500 and 600 ms.

Exercises[a]

1. What are the differences between TDMA, FDMA, and CDMA.
2. Can you devise an algorithm for sharing a given bandwidth both with TDMA and FDMA? Give details of how it would work.
3. What are the difference between Multiple Access Collision Avoidance and Multiple Access Collision Detections? Why do they have to be different?
4. Compute
   (a) the inner product of the vectors
   $\mathbf{u} := (-1, +1, +1, +1, -1, -1)$,
   $\mathbf{v} := (+1, +1, -1, +1, -1, +1)$,
   (b) and the complements $\bar{\mathbf{u}}, \bar{\mathbf{v}}$, where $\mathbf{u}, \mathbf{v}$ are as above.

[a] Not to submit!

5. Generate two vectors $\mathbf{u} = (u_1, o_2)$ and $\mathbf{v} = (v_1, v_2)$ such that u_1, u_2, v_1, v_2 are $+1$ or -1 with probability $1/2$ independently at random. What is the probability that the inner product of $\mathbf{u}$ and $\mathbf{v}$ is 0?

6. The power of a signal attenuates according to the inverse square law $P(d) = P(0)/d^2$, where $d > 0$ is the distance, $P(d)$ is the power at distance d, and $P(0)$ is its power at the start. How far can a signal reach if its power at distance d has to be at least $1/4$ its power at the start?

7. Due to the presence of obstacles, the power of a signal attenuates according to the inverse cubic law $P(d) = P(0)/d^3$, where $d > 0$ is the distance, $P(d)$ is the power at distance d, and $P(0)$ is its power at the start. If the power at distance $d = 1$ is 8, up to what distance d is the power of the signal at least $1/10$ its power at the start?

8. Two stations located at A and B transmit wireless signals simultaneously and against each other. The signal at station A has speed u and the signal at station B has speed v. Determine the point at which the two signals collide.
   (a) Do the same exercise as above when the signals are transmitted with a time difference $\Delta t > 0$.
9. Why is the number of slaves of a piconet limited to a small number (in our case seven)?
10. Consider bluetooth networks.
    (a) How many bluetooth networks with exactly one master are possible? Describe them all.
    (b) Recall that two masters can share only a single slave. How many bluetooth networks with at most two masters are possible? Draw one with a total of 13 nodes.