**Local Area Network Addressing + ARP resolution protocol**

**Local Area Networks and MAC addresses**

**MAC** (or LAN / PHYSICAL / ETHERNET)

* A 48-bit addressed burned in a Network Interface Controller (NIC) memory (hex-based).
* Used “locally” to get a frame from one interface to another physically-connected interface, which is in the same network (IP-addressing sense).
* Are administered by the IEEE, of which manufacturers buy a portion of MAC address space.

**MAC address vs. IP address**

MAC address IP address

|  |  |
| --- | --- |
| **Hard-coded** in read-only memory when adaptor is built. | **Configured**, or learned dynamically. |
| Like a **social security number**. | Like a **postal address**. |
| **Flat name space** of 48 bits (e.g. 00-0E-9B-6E-49-76 hex) | **Hierarchical name space** of 32 bits (e.g. 12.17866.9 dec) |
| **Portable**, can move LAN cards from one LAN to another. | **NOT Portable**, depends on IP subnet of where host is attached |
| Used to get packet between interfaces on the same network | Used to get a packet to a destination IP subnet. |

**ARP: Address Resolution Protocol**

**Question:** how to determine an interface’s MAC address, know its IP address?

**ARP table**: each IP node (host, router) on LAN has a table of

* **<IP Address, MAC address, TTL>** where TTL is the time after which address mapping will be forgotten (typically 20mins)

ARP used in the same Local Area Network: Send datagram from A to B

1. A wants to send datagram to B 🡪 B’s MAC address is not in A’s ARP table.
2. A **broadcasts ARP query** packet, containing B’s IP address 🡪 All nodes on LAN receive broadcast packet.
3. B **receives A’s broadcast packet**, replies to A with B’s MAC address 🡪 Frame sent to A’s MAC address.
4. A **caches/saves IP-to-MAC address pair** in its ARP table until TTL is reached 🡪 **soft state**: info timeout unless refreshed

ARP used in different Local Area Networks: Send datagram from A to B via. R

* For A to send a datagram to B, A must know several things:
  + **B’s IP address** – subnet mask discovered via. DHCP
  + **1st hop router R’s IP address** – default router discovered via. DHCP
  + **R’s MAC address** – ARP

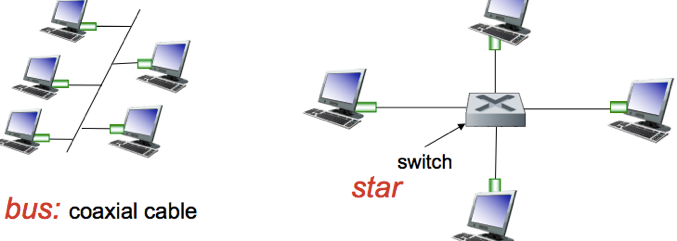
1. A creates IP datagram with src=(A) | dest=(B), and then link-layer frame with dest=(R’s MAC + IP datagram)
2. Link-layer frame is sent from A to R 🡪 Frame is received at R, datagram is detached and passed to IP.
3. R forwards datagram with IP\_src=(A) | IP\_dest=(B) using a forwarding table.
4. R creates a link-layer frame with dest=(B’s MAC + A\_to\_B IP datagram)

**Local Area Networks: Ethernet**

There are many different Ethernet standards, for diff physical layer media w/ diff speeds: fiber, cable etc.

However, they use a common MAC protocol and frame format.

**Ethernet topology**



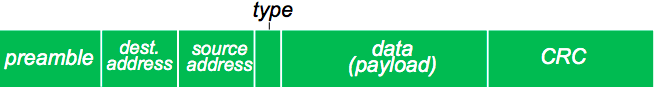
**BUS:** Popular through mid 90s, where all nodes can collide with each other. CSMA/CD for media access control.

**STAR**: Used today, where there is an active SWITCH in the centre.

* Each “spoke” runs a separate Ethernet protocol, so nodes do not collide with each other. No sharing, no CSMA/CD.

**Ethernet Frame Structure**

Sending adaptor encapsulates IP datagram (or other network layer protocol packet) in an **Ethernet Frame**.



**Preamble:** Used to sync receiver and sender clock rates. 7 bytes.

**Addresses**: 6-byte source address + destination MAC addresses.

* If adapter receives frame with matching dest address, or with a broadcast addr (e.g. ARP packet), it passes data in the frame to the network layer protocol.

**Type**: Indicates a higher layer protocol (mostly IP but others possible)

**CRC**: Cyclic redundancy check at the receiver. If error is detected, frame is dropped.

**Ethernet: Unreliable, Connectionless**

**Connectionless**: no handshaking between sending and receiving NICs

**Unreliable**: receiving NIC doesn’t send ACKs/NACKs to the sender NIC. Data in dropped frames recovered only if initial sender uses a higher-layer Reliable Data Transfer (e.g. TCP) otherwise the dropped data is lost.

**Ethernet’s MAC protocol**: un-slotted CSMA/CD with binary backoff.

**Local Area Network: Ethernet Switches**

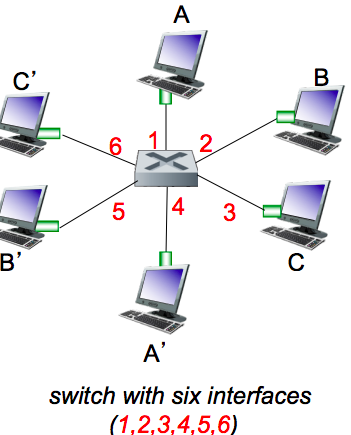
**Link Layer Device**: stores and forwards Ethernet frames.

* Examines incoming frame’s MAC address 🡪 selectively forwards the frame to one or more outgoing links.  
  🡪 uses CSMA/CD to access the segment.

**Transparent**: Hosts are unaware of the presence of switches.

**Plug-and-Play, Self-Learning**: Switches do not need to be configured.

**Switch: multiple simultaneous transmissions + forwarding table**



* Hosts have a dedicated direct connection to the switch.
* Switches buffer packets.
* **Ethernet Protocol** used on each incoming link, but no collisions  
  + full duplex (data can be transmitted in both directions at the same time)

Each link is its own collision domain.

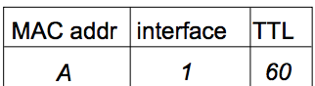
* **Switching**: A-to-A’ and B-B’ can transmit simultaneously without collisions.

Q: How does switch know A’ is reachable via. interface 4, B’ reachable via. interface 5?

A: Each switch has a **Switch Table**, where each entry =  
 **<MAC addr of host, interface to host, time stamp>**

**Switch: Self-Learning + Frame filtering/forwarding**

A switch **learns** which hosts can be reached through which interfaces.

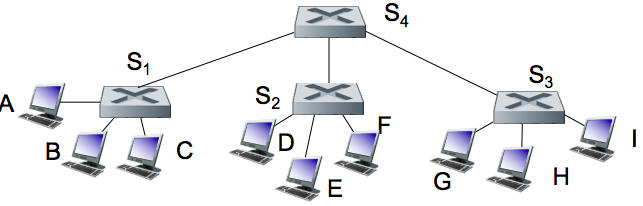
* When frame is received, the switch “learns” location of the sender in the incoming LAN segment.
* The switch records sender/location pair in a switch table.

When a frame is received at the switch:

1. Record the incoming link, MAC address of the sender.
2. Index the switch table using the MAC destination address.
3. **IF** entry is found **{**   
    **IF** dest MAC on segment exists in the switch’s table / comes from same port 🡪 drop/filter packet  
    **ELSE** forward frame on the interface indicated by the entry. **} ELSE** flood /\* forward frame to all the interfaces except the arriving interface \*/

**Interconnecting Switches**

Switches can be connected together.



**Q:** Sending from A-to-G, how does S1 know to forward frame to G via. S4 and S3?  
**A: Self-learning again**! Works exactly the same way as in the single-switch case.

**Switches vs. Routers**

**Switches Routers**

|  |  |
| --- | --- |
| Both are store-and-forward + have forwarding tables. | Both are store-and-forward + have forwarding tables. |
| Link-Layer devices (examine link-layer headers) | Network-Layer devices (examine network-layer headers) |
| Learns forwarding table using **flooding, learning, MAC addresses** | Computes tables using **routing algos, IP addresses** |

**Security Issues**

In a switched LAN, once the switch table entries are established, frames are not broadcast.

* Sniffing frames is harder than sniffing pure broadcast LANs.
* NOTE: an attacker can still sniff broadcast frames and frames for which there are no entries (as they are still broadcast)

**Switch Poisoning**: Attacker fills up switch table with bogus entries by sending large # of frames with bogus src MAC addresses.

* Since switch table is full, genuine packets frequently need to be broadcasted as previous entries have been wiped out.

**Wireless Networks: Introduction**

Two important challenges:

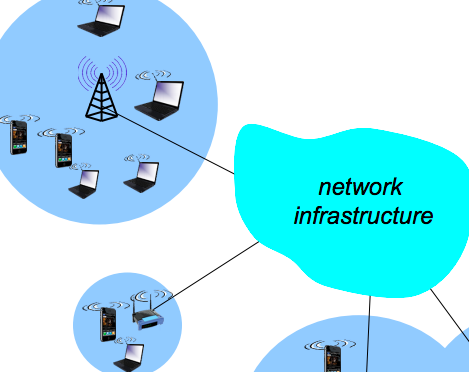
(1) **Communication** over a wireless link (2) **Mobility:** Handling mobile user who changes point of attachment to the network.

**Wireless Network Calculations**

**Frequency** **= C / λ** , where C = speed of light | λ (lambda) = wavelength

**WaveLength** = **C / f**  , where C = speed of light | f = frequency

**Elements of a wireless network**



**Wireless hosts:** laptop, smartphone, running applications. May be stationary or mobile.

**Base station** (e.g. cell towers, 802.11 access points):

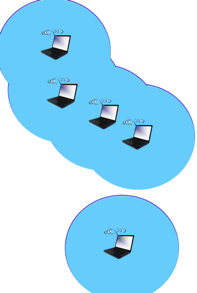
* Typically connected to wired network.
* **Relay** - responsible for sending packets between wired network and wireless hosts in its “area/vicinity”.

**Wireless Link**: typically used to connect mobiles to base stations.

* Multiple access protocol coordinates link access.
* Various data rates, transmission distances.

**Infrastructure Mode**:

* Base station connects mobiles into the wired network.
* **Handoff**: mobile changes base station providing connection into wired network.



**Ad-Hoc Mode:**

* No base stations.
* Nodes can only transmit to other nodes within link coverage.
* Nodes organise themselves into a network: route among themselves.

**Wireless Network Classification**

|  |  |  |
| --- | --- | --- |
|  | **Single Hop** | **Multiple Hops** |
| **Infrastructure (e.g. AP’s)** | Hosts connect to base station, which connects to the larger internet. | Host may have to relay through several wireless nodes to connect to the larger internet. **Mesh net**. |
| **No Infrastructure** | No base station, no connection to the larger internet.  E.g. **Bluetooth, ad hoc nets** | No base station, no connection to the larger internet. May have to relay to each other a given wireless node. |

**Wireless Link Characteristics**

**Decreased signal strength / Path Loss**: radio signal’s effect reduces as it propagates through matter.

**Interference from other sources:** standardised wireless network frequencies shared by other devices e.g. phones can interfere

**Multipath Propagation**: radio signal reflects off objects ground, arriving at the destination at slightly different times.

This all makes communication across wireless links much more difficult

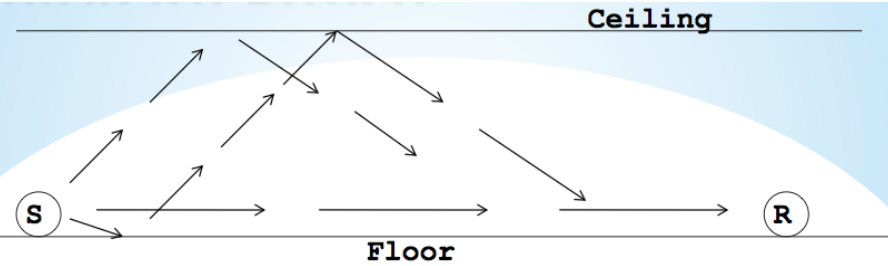
**Path Loss / Path Attenuation**

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Things that can affect path loss / attenuation:

* Reflection, diffraction, absorption | Terrain contours (urban / rural) | Humidity

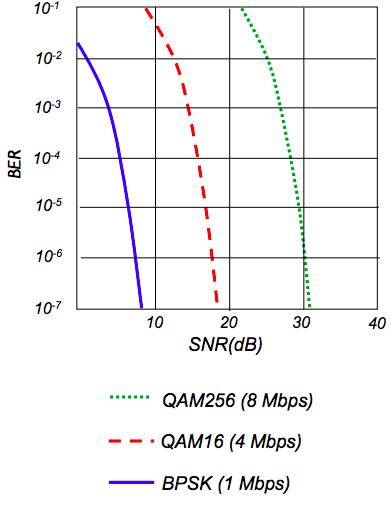
**Multipath Effects**



Signals bounce off surface and interfere with one another.

Self-interference.

**Wireless Link Characteristics cont.**



**Signal-to-Noise Ratio (SNR)**: The ratio between the maximum signal strength that a wireless connection can achieve and the noise present in the connection.

* Larger SNR = easier to extract signals from noise.

**Bit Error Rate (BER)**: #bit errors per unit of time.

SNR vs BER trade-offs

* Given a physical layer: AIM is to increase power 🡪 increase SNR 🡪 decrease BER
* Given SNR: AIM is to choose physical layer that meets BER requirement, giving highest throughput.
  + SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)

Multiple wireless senders / receivers create additional problems.

**Hidden Terminal / Node Problem**: Each node is within communication range of an AP, but nodes cannot communicate with each other as they do not have a physical connection to each other.

* E.g. A 🡪 B 🡨 C , where A can communicate with B, C can communicate with B, but not A🡨🡪 C as they are out of range of each other and cannot communicate as they do not have a physical connection to each other.
* **Signal Attenuation**: B🡨🡪A hear each other, B🡨🡪C hear each other, but not A🡨🡪C as there is interference at B + signal strength reduces during transmission from both sides.
* **Exposed Terminals**: Is when a node is prevented from sending packets to other nodes because of a neighbouring node making a transmission due to **Carrier Sense** (protocol which a node verifies absence of other traffic b4 transmitting).

**Code Division Multiple Access (CDMA): Simultaneous communication between multiple nodes.**

**Code Division Multiple Access (CDMA)**

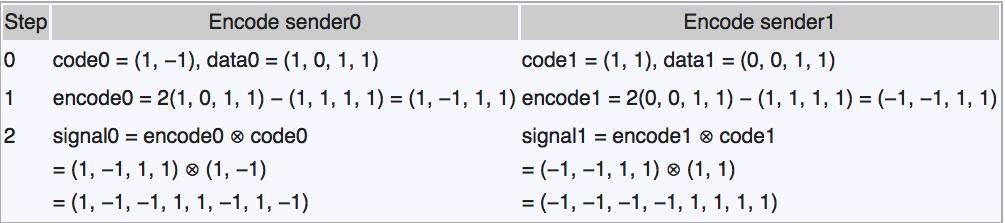
CDMA is a channel access method, a unique “code” assigned to each user.

* All users share the same frequency, but each user has their own “chipping” sequence/code to encode data.
* Allows users to send data simultaneously over a single communications channel with minimal interference.

CDMA Encoding / Decoding:

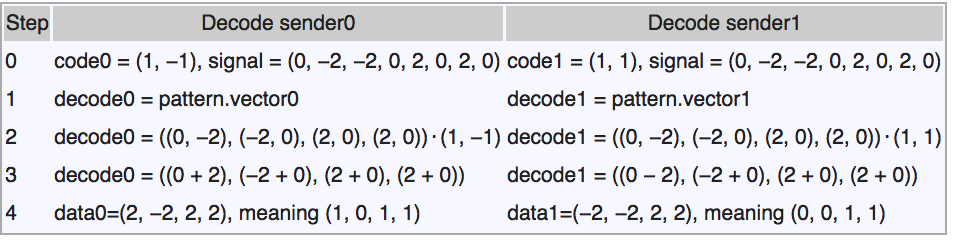
* Assume signal #1 = (1, 0, 1, 1) | chipping sequence cM = (1, -1)  
   signal #2 = (0, 0, 1, 1) | chipping sequence cM = (1, 1)
* **Encoded Signal = (original data) modulated by (chipping sequence)**

If two signals at a point are in a phase, they add to give TWICE the amplitude of each signal, then subtract to give a signal that is the difference of the amplitudes. Assuming that both are transmitting simultaneously:

  
Because signal #1 and #2 are transmitted at the same time into the air, they add to produce the raw signal:

(1, -1, -1, 1, 1, -1, 1, -1) + (-1, -1, -1, -1, 1, 1, 1, 1) = **(0, -2, -2, 0, 2, 0, 2, 0)**

* **Decoding = inner product (summation of bit-by-bit product) of encoded signal and chipping sequence**

The receiver extracts the raw signal for a sender by combining the sender’s chipping sequence code with the raw signal.  


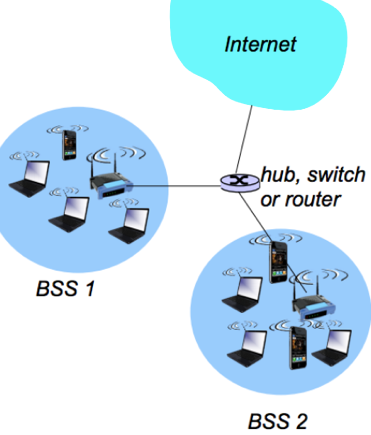
* **Post-decoding:** All values > 0 are interpreted as 1, while all values < 0 are interpreted as 0.  
  E.g. if the extracted signal was (2, -2, 2, 2) 🡪 translate to (1, 0, 1, 1)

**IEEE 802.11 Wireless LAN**

802.11b / 802.11a / 802.11g / 802.11n are all part of a set of media access control (MAC) and physical layer specifications for implementing wireless LAN communications within certain frequency bands.

* They all use **CSMA/CA** **for multiple access** + all have **base-station** and **ad-hoc network versions**.

**802.11 LAN architecture**



Wireless host communicates with base station.  
(base station = access point AP)

**Basic Service Set (BSS) / Cells** in infrastructure mode contains:

* Wireless hosts
* Access point AP: Base station
* Ad-hoc mode: hosts only

**802.11: Channels, association**

Before an 802.11 client can send data over a LAN network, it goes through three-stages:  
(1) **Probing** – the search for a specific network involves sending a probe request out on multiple channels that specifies a SSID and bit rates. (see below on passive / active scanning for more)  
(2) **Authentication** – WEP/WPA/WPA 2, public/shared key authentication.

(3) **Association** – Finalise the security + bit rate options and establishes the data link between the LAN client and AP.

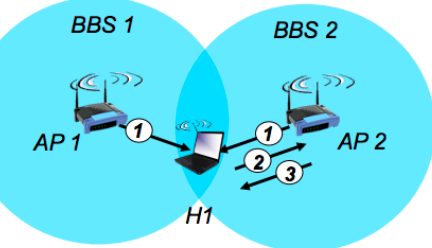
**802.11b:** 2.4GHz 🡪 2.485GHz spectrum is divided into 11 channels at different frequencies.

* AP admin chooses frequency for the AP.
* Interference possible: channel can be same as that chosen by neighbouring AP.

**Hosts:** must associate with an Access Point.

* Scans channels, listens for **beacon frames** containing AP’s name (SSID) and MAC address + selects AP to associate with
* May **perform authentication**
* Will typically **run DHCP to get IP address in AP’s subnet**.

**802.11: passive / active scanning**



**Active Scanning**

(1) Probe Request frame broadcast from H1  
(2) Probe Response frames sent from APs

(3) Association Request frame sent from H1 🡪 selected AP

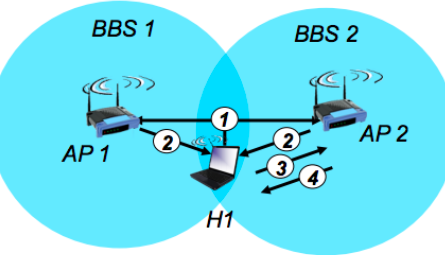
(4) Association Response frame sent from selected AP 🡪 H1

**Association Steps in PASSIVE/ACTIVE are the same.**

**Passive Scanning**

(1) Beacon frames sent from Access Points  
(2) Association Request frame sent from H1 🡪 selected AP

(3) Association Response frame sent from AP 🡪 H1



**802.11: Multiple Access**

Avoid collisions: 2+ nodes transmitting at the same time.

**CSMA:** carrier sense before transmitting  
**No collision detection:** Difficult to receive (sense collisions) when transmitting due to weak received signals

**802.11: Key Points of Multiple Access**

**No concept of a global collisions**: different receivers hear different signals. Different senders reach different receivers.

**Collisions are at receiver, not sender**: We only care if the receiver can hear the sender clearly. Does not matter if senders can hear someone else, as long as the signal doesn’t interfere with the receiver.

**Goal of protocol:** Detect if the receiver can hear the sender + tell senders who might interfere with the receiver to shut up.

**802.11 MAC Protocol: CSMA/CA**

**DCF Interframe Space (DIFS)**: is the minimum medium/channel idle time.

**802.11 Sender:**

#1 IF sender senses that the channel is idle for the DIFS duration

* Transmit the entire frame (no CD)

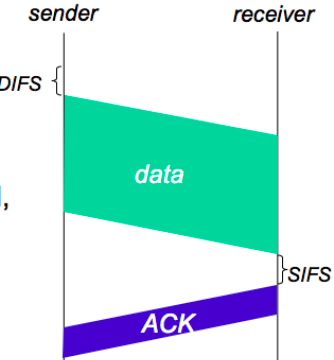
#2 IF sender senses channel is busy

* Start random back-off time, timer countdown while channel idle, transmit when timer expires.
* IF no ACK, increase random back-off interval + repeat #2

**802.11 Receiver:**

#1 IF frame received is OK, return ACK after **SFIS** (amount of time required for a wireless interface to process a received frame + to respond with an ACK).

* ACK is needed due to the **hidden terminal / node problem**



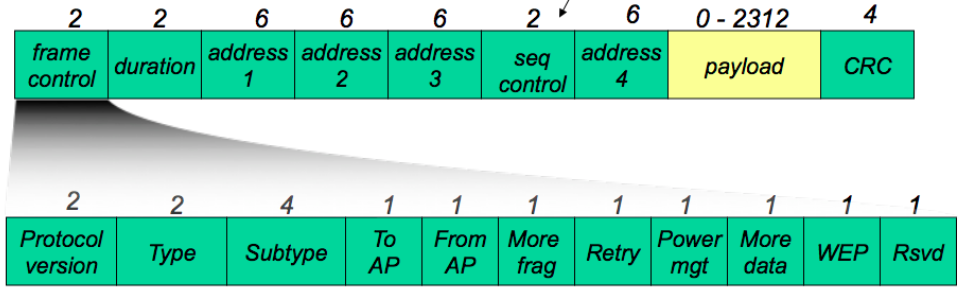
**Collision Avoidance Method: RTS-CTS**

**RTS-CTS (Request to Send / Request to Clear)** is an optional mechanism in 802.11 to reduce frame collisions introduced by the **hidden terminal/node problem**.

1. Sender first transmits small RTS packets to broadcasting signal using CSMA. RTSs may still collide but they’re short.
2. BS broadcasts CTS in response to the RTS
3. Clear To Send (CTS) is then heard by all nodes 🡪 sender transmits the data frame + other stations defer transmissions.

**The idea is that you can** **avoid frame collisions completely by using small reservation packets (RTS-CTS)!!!**

**802.11 Frame Addressing**



**Address 1** = Receiver (host or AP) MAC address | **Address 2** = Sender (host or AP) MAC address

**Address 3** = Router Interface MAC address to which AP is attached | **Address 4** = Used only in ad-hoc mode.

**Duration** = Duration of reserved transmission time (RTS / CTS)

**Seq Control** = Frame sequence number (for Reliable Data Transfer RDT)

**Frame Control 🡪 Type** = Frame type (RTS, CTS, ACK, data)

**802.11: Advanced Capabilities**

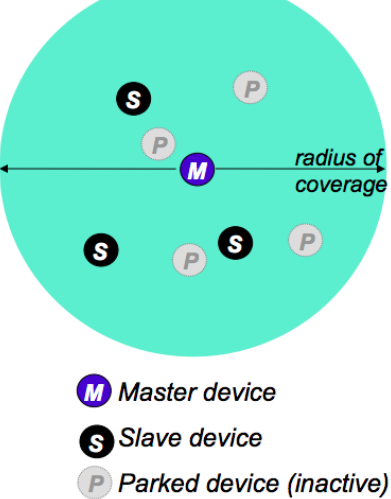
**Rate Adaptation**: Dynamically change the transmission rate to adapt to the current wireless channel conditions. E.g.

* If SNR decreases, increase BER as node moves away from base station
* When BER becomes too high, switch to lower transmission rate but with lower BER.

**Power Management**:

* **Node-to-AP:** “I am going to sleep until next beacon frame”
  + AP knows not to transmit to this node. Node wakes up just before the next beacon frame.
* **Beacon frame**: contains a list of mobiles with AP-to-mobile frames waiting to be sent.
  + Node stays awake if there are AP-to-mobile frames to be sent, otherwise sleep again until next beacon frame.

**802.15: Personal Area Network**



Less than 10m in diameter.

**Replacement** for cables (mouse, keyboard, headphones etc.)

**Ad-hoc:** no need for infrastructure.

**Master/slaves:** slaves request permission to send to master

802.15 evolved from Bluetooth specification.