Networks and Distributed Systems

Lecture 6 – Wireless Networks

Outline

- Perspectives on Connecting nodes
- Encoding
- Framing
- Error Detection
- Reliable Transmission
- Ethernet and Multiple Access Networks
- Wireless Networks

Wireless Links

- Wireless links transmit electromagnetic signals
  - Radio, microwave, infrared
- Wireless links all share the same “wire” (so to speak)
  - The challenge is to share it efficiently without unduly interfering with each other
  - Most of this sharing is accomplished by dividing the “wire” along the dimensions of frequency and space
- Exclusive use of a particular frequency in a particular geographic area may be allocated to an individual entity such as a corporation

Wireless Links

- These allocations are determined by government agencies such as FCC (Federal Communications Commission) in USA
- Specific bands (frequency) ranges are allocated to certain uses.
  - Some bands are reserved for government use
  - Other bands are reserved for uses such as AM radio, FM radio, televisions, satellite communications, and cell phones
  - Specific frequencies within these bands are then allocated to individual organizations for use within certain geographical areas.
  - Finally, there are several frequency bands set aside for “license exempt” usage
    - Bands in which a license is not needed

Wireless Links

- Devices that use license-exempt frequencies are still subject to certain restrictions
  - The first is a limit on transmission power
  - This limits the range of signal, making it less likely to interfere with another signal
    - For example, a cordless phone might have a range of about 100 feet.

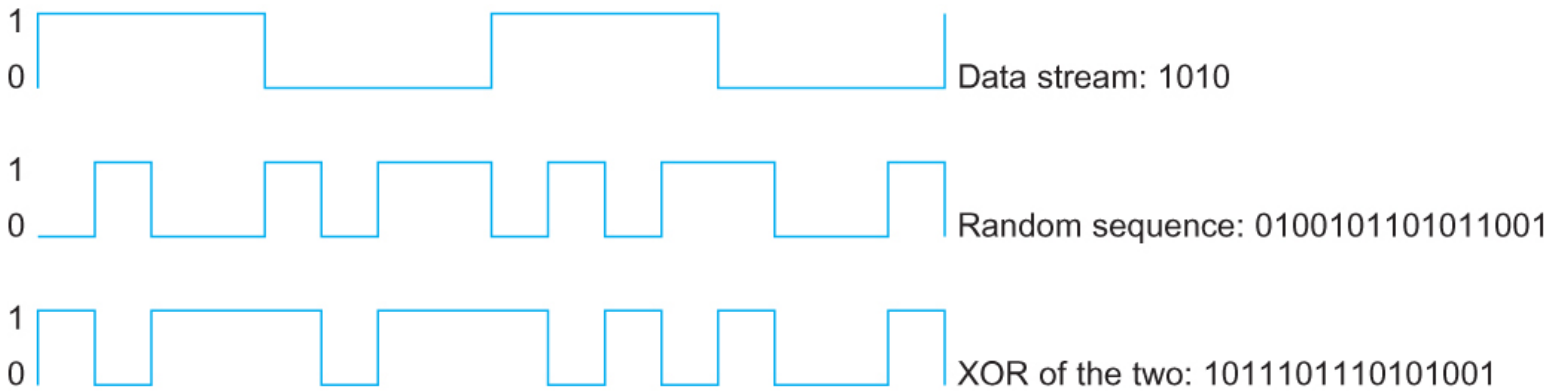
Wireless Links

- The second restriction requires the use of **Spread Spectrum** technique
  - Idea is to spread the signal over a wider frequency band
    - So as to minimize the impact of interference from other devices
    - Originally designed for military use
  - ***Frequency hopping***
    - Transmitting signal over a random sequence of frequencies
      - First transmitting at one frequency, then a second, then a third…
      - The sequence of frequencies is not truly random, instead computed algorithmically by a pseudorandom number generator
      - The receiver uses the same algorithm as the sender, initializes it with the same seed, and is
        - Able to hop frequencies in sync with the transmitter to correctly receive the frame

Wireless Links

- A second spread spectrum technique called ***Direct sequence***
  - Represents each bit in the frame by multiple bits in the transmitted signal.
  - For each bit the sender wants to transmit
    - It actually sends the exclusive OR of that bit and *n* random bits
  - The sequence of random bits is generated by a pseudorandom number generator known to both the sender and the receiver.
  - The transmitted values, known as an ***n*-bit chipping code**, spread the signal across a frequency band that is *n* times wider

Wireless Links



Example 4-bit chipping sequence

Wireless Links

- Wireless technologies differ in a variety of dimensions
  - How much bandwidth they provide
  - How far apart the communication nodes can be
- Four prominent wireless technologies
  - Bluetooth
  - Wi-Fi (more formally known as 802.11)
  - WiMAX (802.16)
  - 3G cellular wireless

Wireless Links

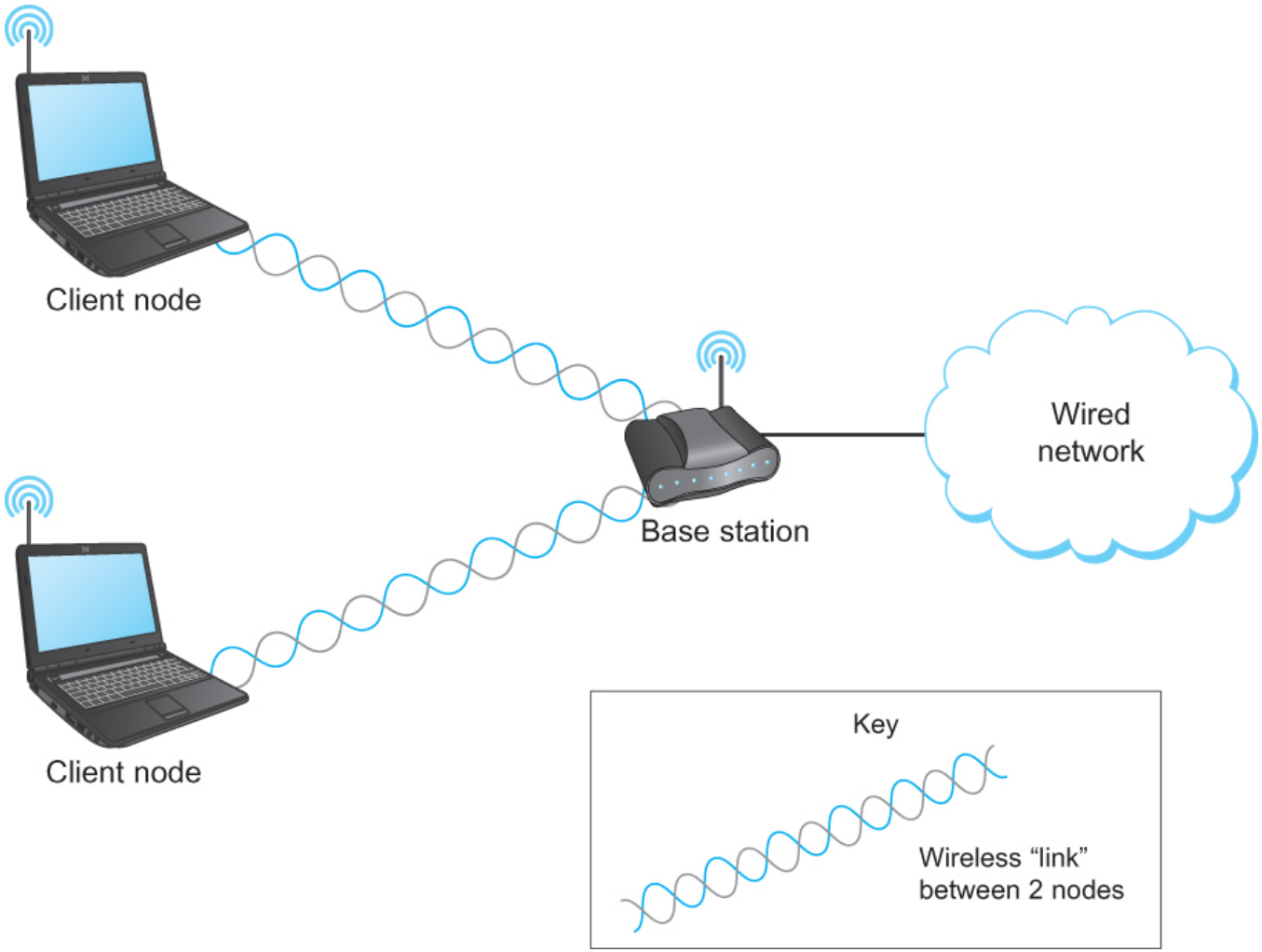
	Bluetooth (802.15.1)	Wi-Fi (802.11)	3G Cellular
Typical link length	10 m	100 m	Tens of kilometers
Typical data rate	2 Mbps (shared)	54 Mbps (shared)	Hundreds of kbps (per connection)
Typical use	Link a peripheral to a computer	Link a computer to a wired base	Link a mobile phone to a wired tower
Wired technology analogy	USB	Ethernet	DSL

Overview of leading wireless technologies

Wireless Links

- Mostly widely used wireless links today are usually asymmetric
  - Two end-points are usually different kinds of nodes
    - One end-point usually has no mobility, but has wired connection to the Internet (known as base station)
    - The node at the other end of the link is often mobile

Wireless Links



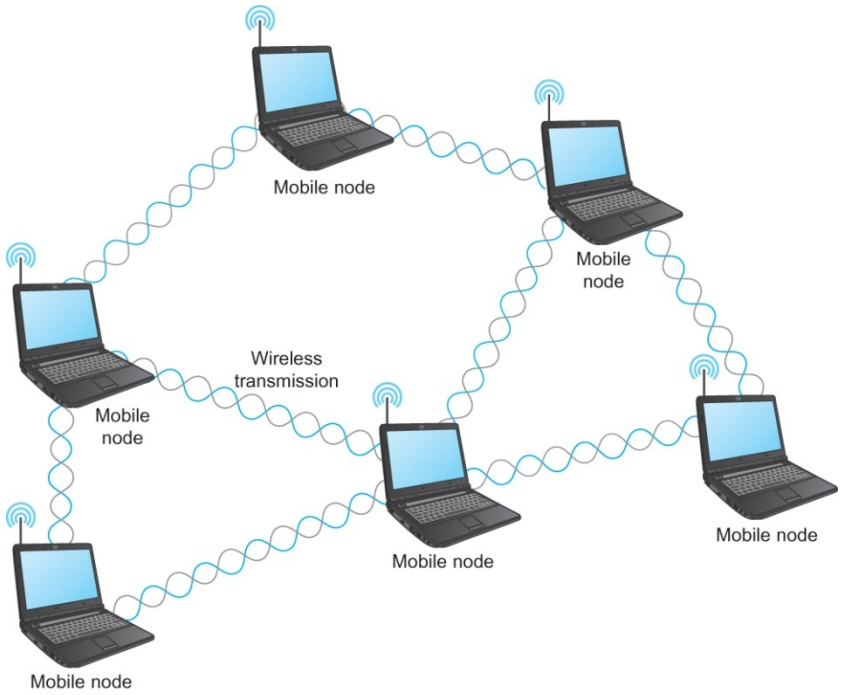
A wireless network using a base station

Wireless Links

- Wireless communication supports point-to-multipoint communication
- Communication between non-base (client) nodes is routed via the base station
- Three levels of mobility for clients
  - No mobility: the receiver must be in a fix location to receive a directional transmission from the base station (initial version of WiMAX)
  - Mobility is within the range of a base (Bluetooth)
  - Mobility between bases (Cell phones and Wi-Fi)

Wireless Links

- Mesh or Ad-hoc network
  - Nodes are peers
  - Messages may be forwarded via a chain of peer nodes



A wireless ad-hoc or mesh network

IEEE 802.11

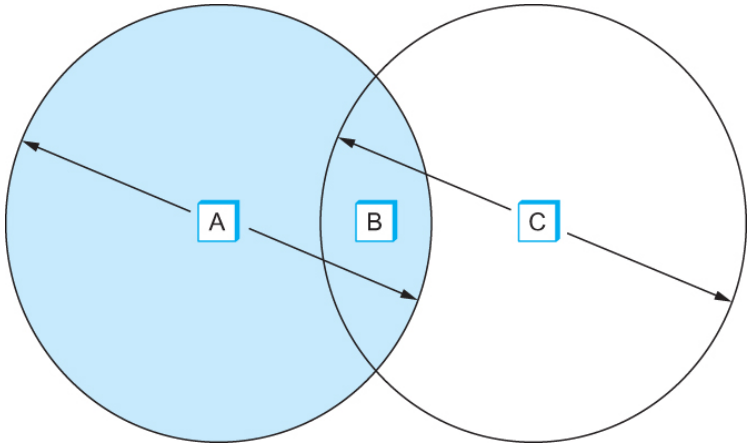
- Also known as Wi-Fi
- Like its Ethernet and token ring siblings, 802.11 is designed for use in a limited geographical area (homes, office buildings, campuses)
  - Primary challenge is to mediate access to a shared communication medium – in this case, signals propagating through space
- 802.11 supports additional features
  - power management and
  - security mechanisms

IEEE 802.11

- Original 802.11 standard defined two radio-based physical layer standard
  - One using the frequency hopping
    - Over 79 1-MHz-wide frequency bandwidths
  - Second using direct sequence
    - Using 11-bit chipping sequence
  - Both standards run in the 2.4-GHz and provide up to 2 Mbps
- Then physical layer standard 802.11b was added
  - Using a variant of direct sequence 802.11b provides up to 11 Mbps
  - Uses license-exempt 2.4-GHz band
- Then came 802.11a which delivers up to 54 Mbps using OFDM
  - 802.11a runs on license-exempt 5-GHz band
- Most recent standard is 802.11g which is backward compatible with 802.11b
  - Uses 2.4 GHz band, OFDM and delivers up to 54 Mbps

IEEE 802.11 – Collision Avoidance

- Consider the situation in the following figure where each of four nodes is able to send and receive signals that reach just the nodes to its immediate left and right
  - For example, B can exchange frames with A and C, but it cannot reach D
  - C can reach B and D but not A

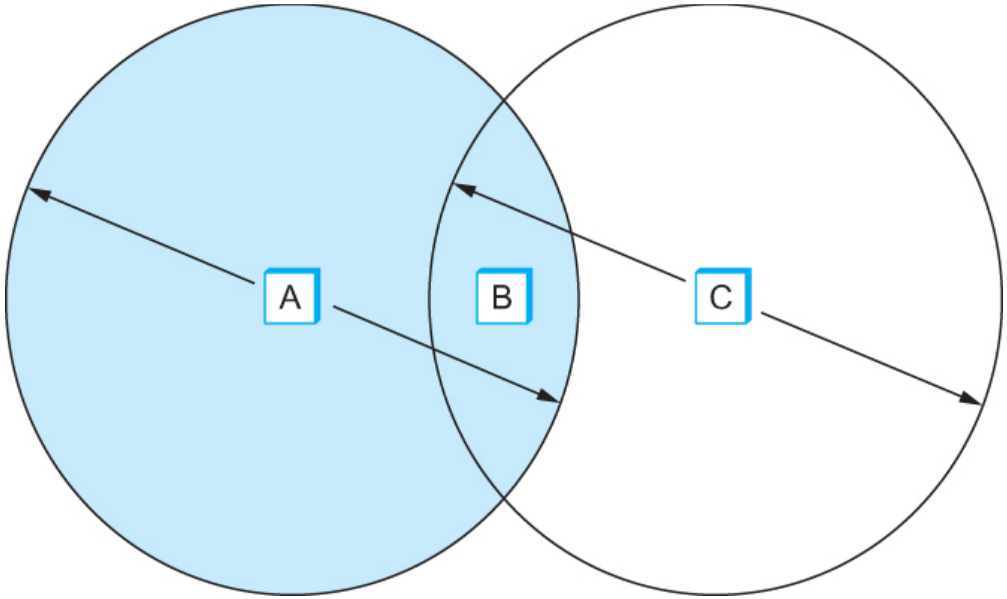


Example of a wireless network

IEEE 802.11 – Collision Avoidance

- Suppose both A and C want to communicate with B and so they each send it a frame.
  - A and C are unaware of each other since their signals do not carry that far
  - These two frames collide with each other at B
    - But unlike an Ethernet, neither A nor C is aware of this collision
  - A and C are said to *hidden nodes* with respect to each other

IEEE 802.11 – Collision Avoidance

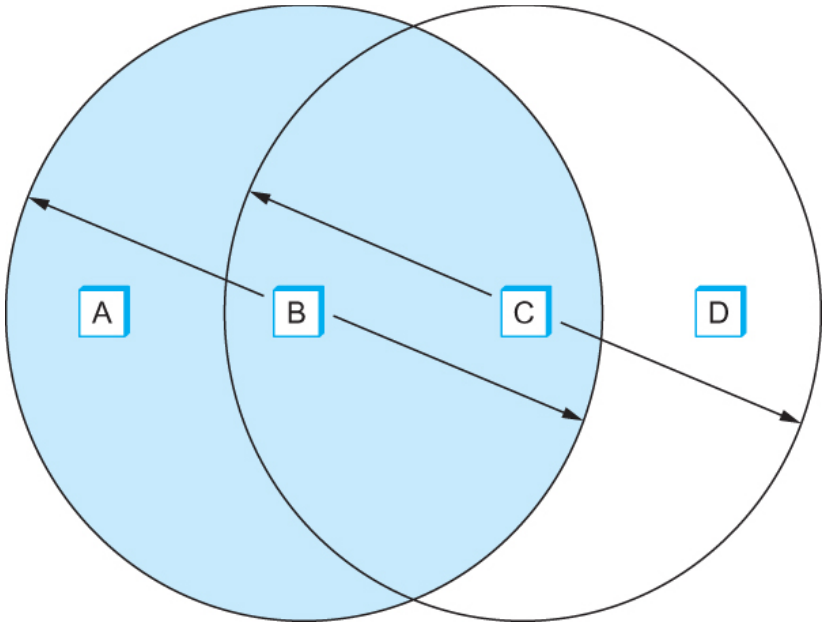


The "Hidden Node" Problem. Although A and C are hidden from each other, their signals can collide at B. (B's reach is not shown.)

IEEE 802.11 – Collision Avoidance

- Another problem called *exposed node* problem occurs
  - Suppose B is sending to A. Node C is aware of this communication because it hears B's transmission.
  - It would be a mistake for C to conclude that it cannot transmit to anyone just because it can hear B's transmission.
  - Suppose C wants to transmit to node D.
  - This is not a problem since C's transmission to D will not interfere with A's ability to receive from B.

IEEE 802.11 – Collision Avoidance



Exposed Node Problem. Although B and C are exposed to each other's signals, there is no interference if B transmits to A while C transmits to D. (A and D's reaches are not shown.)

IEEE 802.11 – Collision Avoidance

- 802.11 addresses these two problems with an algorithm called Multiple Access with Collision Avoidance (MACA).
- Key Idea
  - Sender and receiver exchange control frames with each other before the sender actually transmits any data.
  - This exchange informs all nearby nodes that a transmission is about to begin
  - Sender transmits a *Request to Send* (RTS) frame to the receiver.
    - The RTS frame includes a field that indicates how long the sender wants to hold the medium
      - Length of the data frame to be transmitted
  - Receiver replies with a *Clear to Send* (CTS) frame
    - This frame echoes this length field back to the sender

IEEE 802.11 – Collision Avoidance

- Any node that sees the CTS frame knows that
  - it is close to the receiver, therefore
  - cannot transmit for the period of time it takes to send a frame of the specified length
- Any node that sees the RTS frame but not the CTS frame
  - is not close enough to the receiver to interfere with it, and
  - so is free to transmit

IEEE 802.11 – Collision Avoidance

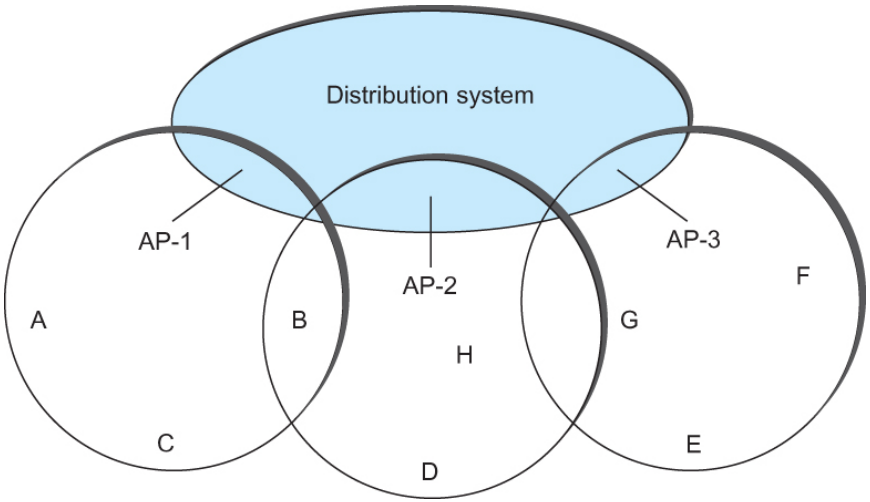
- Using ACK in MACA
  - Proposed in MACAW: MACA for Wireless LANs
- Receiver sends an ACK to the sender after successfully receiving a frame
- All nodes must wait for this ACK before trying to transmit
- If two or more nodes detect an idle link and try to transmit an RTS frame at the same time
  - Their RTS frame will collide with each other
- 802.11 does not support collision detection
  - So the senders realize the collision has happened when they do not receive the CTS frame after a period of time
  - In this case, they each wait a random amount of time before trying again.
  - The amount of time a given node delays is defined by the same *exponential backoff* algorithm used on the Ethernet.

IEEE 802.11 – Distribution System

- 802.11 is suitable for an ad-hoc configuration of nodes that may or may not be able to communicate with all other nodes.
- Nodes are free to move around
- The set of directly reachable nodes may change over time
- To deal with this mobility and partial connectivity,
  - 802.11 defines additional structures on a set of nodes
  - Instead of all nodes being created equal,
    - some nodes are allowed to roam
    - some are connected to a wired network infrastructure
      - they are called *Access Points* (AP) and they are connected to each other by a so-called *distribution system*

IEEE 802.11 – Distribution System

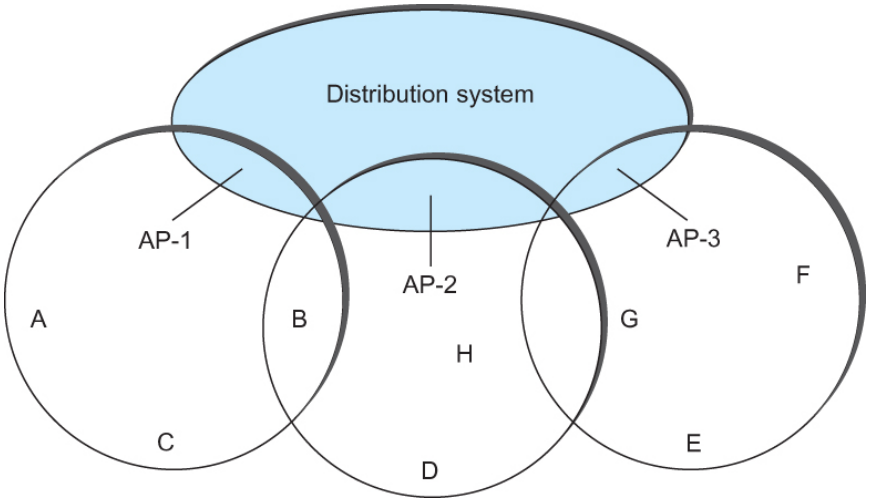
- Following figure illustrates a distribution system that connects three access points, each of which services the nodes in the same region
- Each of these regions is analogous to a cell in a cellular phone system with the APIs playing the same role as a base station
- The distribution network runs at layer 2 of the ISO architecture



Access points connected to a distribution network

IEEE 802.11 – Distribution System

- Although two nodes can communicate directly with each other if they are within reach of each other, the idea behind this configuration is
  - Each nodes associates itself with one access point
  - For node A to communicate with node E, A first sends a frame to its AP-1 which forwards the frame across the distribution system to AP-3, which finally transmits the frame to E



Access points connected to a distribution network

IEEE 802.11 – Distribution System

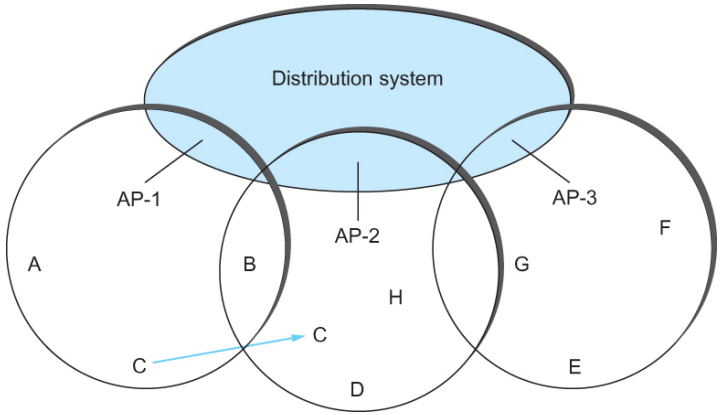
- How do the nodes select their access points
- How does it work when nodes move from one cell to another

- The technique for selecting an AP is called *scanning*
  - The node sends a *Probe* frame
  - All APs within reach reply with a *Probe Response* frame
  - The node selects one of the access points and sends that AP an *Association Request* frame
  - The AP replies with an *Association Response* frame

- A node engages this protocol whenever
  - it joins the network, as well as
  - when it becomes unhappy with its current AP
    - This might happen, for example, because the signal from its current AP has weakened due to the node moving away from it
    - Whenever a node acquires a new AP, the new AP notifies the old AP of the change via the distribution system

IEEE 802.11 – Distribution System

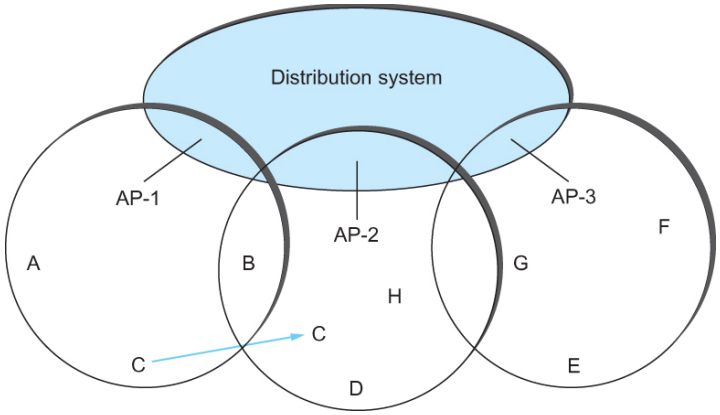
- Consider the situation shown in the following figure when node C moves from the cell serviced by AP-1 to the cell serviced by AP-2.
- As it moves, it sends *Probe* frames, which eventually result in *Probe Responses* from AP-2.
- At some point, C prefers AP-2 over AP-1 , and so it associates itself with that access point.
  - This is called *active scanning* since the node is actively searching for an access point



Node Mobility

IEEE 802.11 – Distribution System

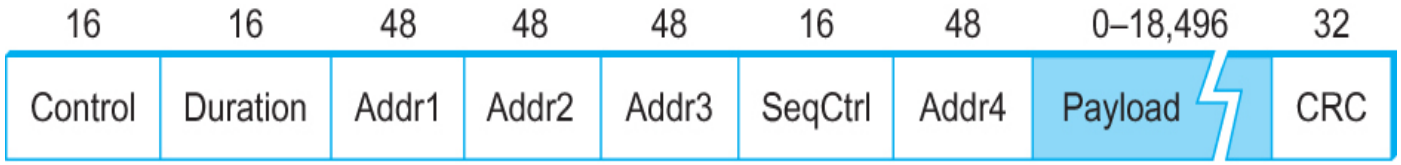
- APs also periodically send a *Beacon* frame that advertises the capabilities of the access point; these include the transmission rate supported by the AP
  - This is called *passive scanning*
  - A node can change to this AP based on the *Beacon* frame simply by sending it an *Association Request* frame back to the access point.



Node Mobility

IEEE 802.11 – Frame Format

- Source and Destinations addresses: each 48 bits
- Data: up to 2312 bytes
- CRC: 32 bit
- Control field: 16 bits
  - Contains three subfields (of interest)
    - 6 bit **Type** field: indicates whether the frame is an RTS or CTS frame or being used by the scanning algorithm
    - A pair of 1 bit fields : called **ToDS** and **FromDS**



Frame Format

IEEE 802.11 – Frame Format

- Frame contains four addresses
- How these addresses are interpreted depends on the settings of the **ToDS** and **FromDS** bits in the frame's Control field
- This is to account for the possibility that the frame had to be forwarded across the distribution system which would mean that,
  - the original sender is not necessarily the same as the most recent transmitting node
- Same is true for the destination address
- Simplest case
  - When one node is sending directly to another, both the DS bits are 0, Addr1 identifies the target node, and Addr2 identifies the source node

IEEE 802.11 – Frame Format

- Most complex case
  - Both DS bits are set to 1
    - Indicates that the message went from a wireless node onto the distribution system, and then from the distribution system to another wireless node
  - With both bits set,
    - Addr1 identifies the ultimate destination,
    - Addr2 identifies the immediate sender (the one that forwarded the frame from the distribution system to the ultimate destination)
    - Addr3 identifies the intermediate destination (the one that accepted the frame from a wireless node and forwarded across the distribution system)
    - Addr4 identifies the original source

- Addr1: E, Addr2: AP-3, Addr3: AP-1, Addr4: A

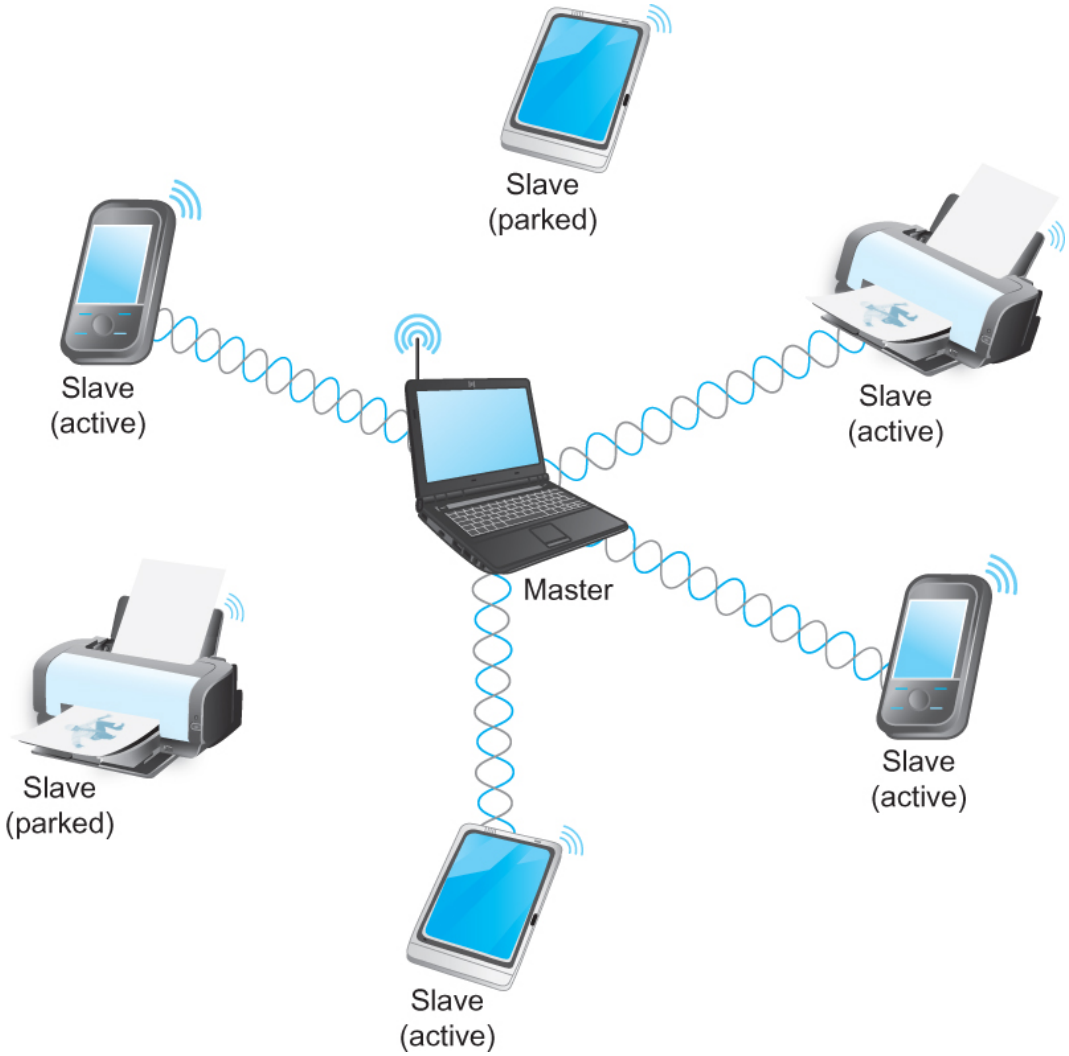
Bluetooth

- Used for very short range communication between mobile phones, PDAs, notebook computers and other personal or peripheral devices
- Operates in the license-exempt band at 2.45 GHz
- Has a range of only 10 m
- Communication devices typically belong to one individual or group
  - Sometimes categorized as Personal Area Network (PAN)
- Version 2.0 provides speeds up to 2.1 Mbps
- Power consumption is low

Bluetooth

- Bluetooth is specified by an industry consortium called the Bluetooth Special Interest Group
- It specifies an entire suite of protocols, going beyond the link layer to define application protocols, which it calls *profiles*, for a range of applications
  - There is a profile for synchronizing a PDA with personal computer
  - Another profile gives a mobile computer access to a wired LAN
- The basic Bluetooth network configuration is called a *piconet*
  - Consists of a master device and up to seven slave devices
  - Any communication is between the master and a slave
  - The slaves do not communicate directly with each other
  - A slave can be *parked*: set to an inactive, low-power state

Bluetooth



A Bluetooth Piconet

ZigBee

- ZigBee is a new technology that competes with Bluetooth
- Devised by the ZigBee alliance and standardized as IEEE 802.15.4
- It is designed for situations where the bandwidth requirements are low and power consumption must be very low to give very long battery life
- It is also intended to be simpler and cheaper than Bluetooth, making it financially feasible to incorporate in cheaper devices such as a wall switch that wirelessly communicates with a ceiling-mounted fan

Summary

- We introduced the many and varied type of links that are used to connect users to existing networks, and to construct large networks from scratch.
- We looked at the five key issues that must be addressed so that two or more nodes connected by some medium can exchange messages with each other
  - Encoding
  - Framing
  - Error Detecting
  - Reliability
  - Multiple Access Links
    - Ethernet
    - Wireless 802.11, Bluetooth