Indoor WLAN Design

Part I: Using IEEE 802.11b Standard Devices

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Outline

- Why wireless?
- IEEE 802.11b wireless communication standard
- How to position base stations to
  - obtain **full radio coverage** of target area, and
  - **avoid interference** problems
- How to connect base stations to a wireline network such that mobile stations may **roam** the network
- Wireless Community Networks and Hotspots

Why wireless?

- Network connections via a physical cables restrict freedom of movement

- Wireless networks enable users to work “everywhere”
  - conference rooms
  - coffee houses
  - airports
  - train stations
  - libraries

Why wireless? (cont.)

- Wireless technologies enable rapid and cheap network deployments
  - reduces the need for time-consuming and expensive laying of cables
  - once wired infrastructure is in place new users can be added quickly

- License-free operation in the 2.4-GHz band is possible worldwide

Wireless Network Devices

MS *Mobile Station*—Mobile communication device containing a radio transceiver

BS *Base Station*—Fixed radio transceiver acting as an interface between the wireless network and the wireline (core) network. The BS is also called an *access point*

Bridge A (network) bridge joins two networks at the data link layer, i.e. layer 2, in the OSI model. Higher protocols see the two networks as the same. A BS is set up as a (layer 2) bridge between the wireless network and the wireline network

Figure 1 A laptop computer can become an MS by installing a PCMCIA card implementing the IEEE 802.11b standard. The above card is made by Apple

Figure 2 This an AirPort BS made by Apple. AirPort implements the IEEE 802.11b standard

802.11b Standard (1)

- *Direct Sequence Spread Spectrum* (DSSS) in 2.4 GHz *Industrial, Scientific, and Medical* (ISM) band

- DSSS spreads the signal over a bandwidth of about 22 MHz, allowing transmissions to be robust against interference

- European regulators cap maximum radiated power at 100 mW

- 1 Mbps, 2 Mbps, 5.5 Mbps, or 11 Mbps gross data rate depending on wireless link quality

802.11b Standard (2)

- A BS (MS) has a range from 20 m to more than 300 m, depending on the specific implementation and operating environment

- *Carrier Sense Multiple Access* (CSMA) with *Collision Avoidance* (CA) medium access scheme is discussed in Part III

802.11b—Channels

- BSs and MSs transmit on different radio frequencies, called **channels**
- Standard defines 14 channels
- Only 11 channels are used in the U.S.
- Can use 13 channels in Europe. Have BSs that support all 13 channels

More on Channels

- Since many 802.11b PCMCIA cards cannot access channel 12 and 13, most wireless networks use channels 1 through 11
- A channel is selected for a BS when it is set up
- An MS automatically tunes to the channel used by the BS

Remark: Note that there is only 5 MHz separation between the channel center frequencies, and that an 802.11b signal occupies approximately 22 MHz of the frequency spectrum

Nominal Throughput

Nominal peak throughput offered to the IP layer for a *Maximum Transmission Unit* (MTU) of 1500 bytes

Bit rate (Mbps)	Nominal throughput (Mbps)
11	6.2
5.5	3.9
2	1.7
1	0.9

Error Control

- Lucent WaveLAN IEEE 802.11b networking card* utilizes an *Automatic Repeat Request* (ARQ) scheme with maximum four retransmissions

- No Forward Error Correction (FEC) is used

*This card is also denoted the Orinoco Silver Card. It is embedded in Apple's first generation AirPort base stations. The "marketing friendly" name Wi-Fi is used to refer to 802.11b-compliant networking cards

UDP Performance over 802.11b links

The *User Datagram Protocol* (UDP) is a connectionless transport protocol for real-time traffic. Retransmissions are not used (Lucent WaveLAN IEEE802.11b may cause up to four retransmissions)

Measured UDP throughput over 10.000 packets

Bit rate (Mbps)	Payload (bytes)	Good channel throughput (Mbps)	Bad channel throughput (Mbps)
	1500	6.071	1.259
	1024	5.001	1.2
11	768	4.206	1.293
	512	3.172	1.548
	256	1.763	0.999

TCP Performance over 802.11b links

The *Transport Control Protocol* (TCP) provides reliable connection-oriented service between two hosts with support for flow and congestion control as well as error recovery

Measured TCP throughput on bad channels

Bit rate (Mbps)	Test	Throughput (Mbps)
	1	2.906
	2	0.707
11	3	4.488
	4	0.501
	5	4.586

WLAN Requirements and Design

- The *Wireless Local Area Network* (WLAN) must have
  - complete radio coverage of target area(s)
  - network capacity to carry the expected load

- The requirements can be met by using a proper combination of
  - **BS locations**
  - **channel (frequency) assignments**

Transmission Barriers

- Wood, plaster, and glass are not serious barriers to radio transmissions, but brick and concrete walls can be significant ones

- Metal, such as in desks, filing cabinets, reinforced concrete, and elevator shafts are great obstacles to radio transmissions

- Typical transmission ranges up to 300 m in an open environment, but this range may be reduced to 20–60 m through walls and other partitions

Measurements are Needed

- The BS layout must be based on measurements, not just on "rule of thumb" calculations

- Extensive testing and careful consideration of radio propagation issues are needed when the intended coverage area is large

- *Indoor measurements can be particularly challenging because a building constitutes a three-dimensional space*

  – a BS located on one floor provides signal coverage to adjacent floors

Channel Interference

Co-channel interference is caused by devices transmitting on the same channel

Interchannel interference is caused by devices transmitting on adjacent channels

Both co-channel and interchannel interference may severely limit the transfer rates of a wireless network

Design Approach (1)

- Space the BSs as far apart as possible while ensuring complete radio coverage. This approach will help reduce the co-channel interference and the cost of equipment and installation

- *Single-floor network:* Use only channels 1, 6, and 11 to avoid nearly all interchannel interference

- *Multi-floor network:* Use channels 1, 4, 7, and 11 to limit inter-channel interference*

*This technique is not without problems

Design Approach (2)

- Single-floor network:
  - Assign channels 1, 6, and 11 such that no two adjacent BSs use the same channel (see Figure 3)

- Multi-floor network:
  - Assign channels 1, 4, 7, and 11 such that no two adjacent BSs use the same channel
  - Make sure that closely spaced BSs do not use adjacent channels, i.e., do not use channels 1 and 4

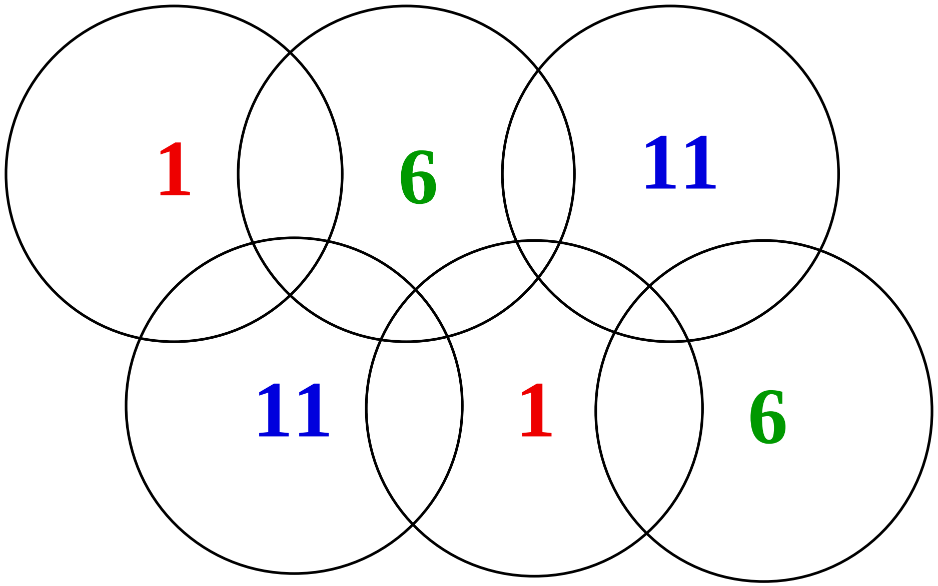

Figure 3 Channel assignment causing no interference

High-Density User Areas

- The design must also consider service to areas with high and low densities of users

- Most areas will be low-density (user) areas. However, classrooms and lecture halls will be high-density areas with high concentrations of students

- A good design approach is to use up to three BSs with different channel frequencies to cover the same high-density area

Design Procedure

1. Initial selection of BS locations

2. Adjust the BS locations based on signal strength measurements

3. Create coverage map

4. Assign channel frequencies to BSs using the coverage map

Simplified Design Example (1)

- The coverage volume of a single BS may be represented by three coaxial cylinders, as depicted in Figure 4

- The radius of each cylinder is such that nearly all MSs may communicate with the BS

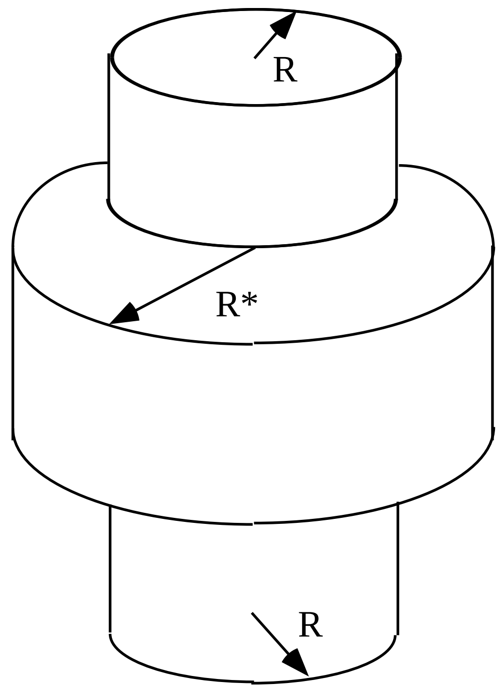

Figure 4 Idealized BS coverage. The middle cylinder, representing the coverage on the floor on which the BS is located, has radius R^*. The upper and lower cylinder, representing the adjacent floors, have radius $R < R^*$

Simplified Design Example (2)

- The object consisting of the three cylinders moves about as the location of the BS is changed

- The placement of the BSs within a building can be viewed as the problem of locating the cylindrical shapes such that the building space is filled and such that the shapes overlap as little as possible

More advanced design

- It is important to remember that the communication speed decreases with increasing distance between a BS and MS
- Using many BSs with small transmission power give a larger network throughput than using fewer BSs with larger transmission power
- It may be necessary to have a lot overlap between adjacent BSs to achieve a high aggregate throughput in a network

Extension to 802.11g/a

- Since 802.11g has the same channel map as 802.11b, the 802.11g networks are constructed in much the same way as 802.11b networks

- 802.11a has 12 *non-overlapping* channels, 8 for indoor use, making it much easier to carry out the channel assignments

- **Remark**: 802.11b/g networks are more popular than 802.11a networks

Network Communication Techniques

Roaming Multiple BSs can be set up to create a single wireless network. An MS is able to **roam** the network when it can move from BS to BS with no interruption in service

DHCP *Dynamic Host Configuration Protocol*—Method of automatically assigning network parameters including

- MS's own IP address
- IP address of default Internet gateway (for outgoing packets)
- IP address of local DNS (Domain Name Server)

Setting up a Wireless Network for Roaming

1. Connect all BSs to the same physical subnet on Ethernet network (i.e., all BSs connect to the same router)

2. Give the same "network name"

3. Set up the BSs as bridges

4. To optimize performance, set the BS density to *High*, *Medium*, or *Low* depending on how far apart the BSs are from each other

Why Roaming is Possible

- DHCP server on Ethernet subnet provides IP addresses to MSs
- An MS retains its IP address when it moves from one BS to another BS
- Tables in BS bridges defining active MSs are updated when MSs move between BSs ("hand off")

The roaming protocol is not defined in the 802.11b spec, so manufacturers have implemented their own methods. The IEEE 802.11f standard from June 2003 recommends an Inter-Access Point Protocol (IAPP)

Setting BS Density (1)

- The wireless network performance can be improved by setting BS density
- The setting tells MSs that are in motion to look for and switch to a new BS's signal when the signal strength of the BS it is connected to goes below a certain level

Example: In a high-density (user) area where the BSs are close together, setting BS density to High achieves higher transfer rates by forcing an MS to look for a new BS when the signal of the BS it is connected to goes below 11 Mbps

Setting BS Density (2)

The following “rule of thumb” assignments indicate how to set the BS density:

Max distance between BSs	30m	60m	120m
BS density setting	High	Medium	Low

Wireless Community Networks

- 802.11 devices are used to build *Wireless Community Networks* (**WCNs**) that connect neighborhoods, schools and businesses to the Internet

- WCNs are popular in areas where it is difficult to get DSL (Digital Subscriber Line) service

- WCNs are also used to share one DSL connection between many users

More on WCNs

- Large WCNs often have outdoor links between buildings. A good understanding of antenna technology is needed to successfully instal such WCNs
  - good and cheap antenna designs are available

- There exist many groups building WCNs. See `http://wiki.personaltelco.net/index.cgi/WirelessCommunities`
  - each member of a WCN is responsible for keeping his equipment online

Public Wireless Hotspots

- For a public wireless hotspot to be successful, the following conditions must be satisfied:
  - a sufficient number of individuals must be passing through the hotspot with laptops and PDAs that are *Wi-Fi enabled*
  - the individuals must spend a sufficient amount of time in the hotspot
  - they, or their organization, must place a sufficient level of value on public wireless access to justify whatever cost is associated with access

Common Hotspots (1)

Airports A very large number of business travelers with laptops pass through airports. These travelers all need to read their e-mail. Business people must also answer e-mail while travelling because many customers expect a quick reply

Hotels In-room dial-up access has been the traditional way of providing Internet connectivity. However, these days dial-up speeds are impractical for e-mail and Web surfing. Since (nearly) all laptops have Wi-Fi cards, there is a marked for in-room wireless broadband

Common Hotspots (2)

Convention centers It is increasingly common for Wi-Fi access to be available on and around a trade show floor

Coffee shops and cafes Wi-Fi hotspots are symbiotic to the core business of serving coffee and the like. Wi-Fi access attracts more customers that stay longer

Open spaces Public institutions like city governments and larger universities have implemented outdoor hotspots

Billing?

- Billing can be done on a pay-per-use basis and a subscription basis. The two models are more complementary than competing

- Hotspots can also be free, offered by individuals or public agencies like city governments

- *War drivers* and *war chalkers* find and use unsecured Wi-Fi LANs
  - this activity may diminish over time when more networks employ the IEEE security standard (802.11i)

Conclusions

- 802.11 networks are very useful additions to wireline networks
- It is difficult to set up an indoor wireless network with many BSs
  - extensive measurements and testing are needed
- The total information rate per 802.11b BS is no more than 4–5 Mbps