Wireless Networks - Part I

Wireless Local Area Networks (WLAN)

- The dominant standard is the IEEE 802.11 standard. This standard is also known as "WiFi" from the name of the alliance of companies that promotes and certifies 802.11 products.

- Over the years, there have been many versions (with improvements) for the standard. The most common ones are: 802.11a, 802.11b, 802.11g, 802.11n and 802.11ac.

- Operation is in the 2.4 GHz and 5 GHz ISM frequency bands.

- 802.11 Network Architecture/Topology

1) INFRASTRUCTURE MODE contains one or more wireless stations from one central base station called ACCESS POINT (AP)

   Other stations talk to each other through the AP. The AP also provides connection to the Internet
Typically, at home we have one or more wireless stations—computers, gaming devices, etc.—and a router integrated together with the access point.

2) **Ad-Hoc Network Mode**  

A station can group themselves to form a network with no base station that provides a central control and connection to the wired Internet.

The most common setup for 802.11 is infrastructure mode but we'll talk more about Ad-Hoc networks later on in this same note.

802.11 Channels

In the 2.4 GHz to 2.485 GHz band (85 MHz bandwidth) the standard defines 11 partially overlapping channels of bandwidth 22 MHz (in fact, in some few countries there may be up to 14 channels)

To be non-overlapping channels need to be separated by four or more channels—this is why channels 1, 6, and 11 are the most common choice.
802.11 MAC — Medium Access Control.

- Protocol that deals with arbitrating the access of the different stations to the wireless medium (so they can transmit).

- Known as "DCF"

**DCF:** Distributed Coordination Function

This is the mechanism to allow different nodes to contend for channel access.

**DCF:** BASIC ACCESS MECHANISM

Implements CSMA/CA technique:

**CSMA** (same as for Ethernet) — the station listens to the medium and only initiates a transmission if it doesn’t hear any other transmission.

**CA** — "collision avoidance"; after finishing transmission, the sender waits for an ‘ACK’ signal from the receiver that acknowledges correct
reception of the transmission (without bit errors). If the Ack is not received, the transmitter assumes an error and initiates an exponential backoff (similar in concept to the Ethernet exponential backoff).

Note that WiFi does “CA” instead of “CD”. This is because it is very, very difficult to implement with wireless communications the “listen while transmitting” (transmitting and receiving at the same time) mechanism that forms the collision detection technique. This is because the transmitted signal is several orders of magnitude bigger than the received signal (this makes very difficult to separate the received signal from the transmitted signal).

Hidden Terminal Problem

Stations A and C want to send a packet to station B at about the same time.

Station A is within reach of B but not of C. Station C is within reach of station B but not of A.
With this configuration the problem is that when A and C monitor the channel before transmission, they sense it as being idle. Thus, they both transmit at the same time and "collide" (interfere each other) when received at station B.

To solve this problem, the DCF basic access mechanism is modified with a handshake protocol called RTS/CTS.

**RTS/CTS Mechanism**

RTS/CTS → "Request to Send/Clear to Send"

When a station wants to send packet, it follows the basic access mechanism above but instead of sending the actual data packet, it sends firstly a special packet addressed to
the destination called RTS (Request to Send). When the destination receives the RTS it answers with a special frame called CTS (Clear to Send). Only after successfully receiving a CTS frame, the intended transmitter can send the actual data packet.

Even more, RTS and CTS carry information of the length of the data packet to be transmitted and they are sent using the modulation and channel coding options that ensure that the largest number of stations can successfully receive them. The stations listening to the RTS/CTS frames use the information of the data packet length to calculate the period of time over which the channel will be busy (to stay away from it).

Something to think about:

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**Detailed Features**

**Specifications**

- **Standards:**
  - IEEE 802.3
  - IEEE 802.3u
  - IEEE 802.11g
  - IEEE 802.11b
- **Wireless Transfer Speed:** 54Mbps
- **Channels:**
  - 11 Channels (US, Canada)
  - 13 Channels (Europe)

This advertised speed is an ideal maximum. In fact, if the channel is less than perfect, this number will be smaller because of the use of AMC. Also, the transfer speed is
effectively reduced because of the overhead introduced by the MAC mechanism (e.g., the time it takes to go through the RTS/CTS exchange or the time to send the ACK signal).

Cellular Networks

still an infrastructure-type of network.

This is the wireless part.

These connections may or may not be wireless.
The basic idea is that the geographical area that is going to be covered by a cellular network is divided into smaller regions. In each of these regions a wireless phone (we usually call it a "cellular phone") can connect to the cellular network and carry on a conversation through a wireless link to a base station.

**Naming convention note:** The link from the base station to the cell phone is called "DOWNLINK". The link from the cell phone to the base station is called "UPLINK".

So, in cellular networks each of the smaller regions is served (provides wireless connectivity) by a base station. Each of the smaller regions is called a "CELL" (thus the name for these networks: cellular network). The CELL
is the area covered by the radio transmission and reception of a base station.

A cellular network then can be visualized in the following way:

![Diagram of cellular network coverage]

Total area covered by the cellular network.

The total area covered by the cellular network is divided into smaller areas, the cells, which are visualized as an hexagon.

The reality is that, of course, the radio coverage area of a cell is not an hexagon but this is a way of visualizing the coverage area that shows how many base stations combine to cover the whole network area and is also convenient for mathematical analysis.
So, why is that we want to subdivide the whole network coverage area into cells? Why don't just use one big transmitter that covers it all (just like TV or the police)?

The short answer is because of network capacity.

To understand the answer to this question in more detail we will need to learn about another concept known as "frequency reuse".

NOTE: In the following explanation we will go back to the first cellular systems (twenty years ago) and explain the different concepts as applied to this early system. Since then, some of the details have changed but the basic concepts still remain true.

Cellular networks are based on low power transmitters at the cell base station. Each
cell is allocated a band of frequencies. Adjacent cells are assigned different frequencies to avoid interfering with each other. Assume that the frequency bands assigned to each cell are divided into "channels", each capable of maintaining one conversation. So, we can say that any frequency band that can be assigned to a base station can support up to \( N \) calls.

The entire frequency band for the network can support \( 7N \) calls.

Suppose \( N = 100 \), then the entire network could support \( 7N = 700 \) calls at the same time. This
is a small number, which as presented here cannot be increased either (not a good thing for the operator who wants to make money by supporting more and more cells).

Frequency reuse, or the cell concept, provides a solution to this problem. With frequency reuse we can assign frequency bands so that no two neighboring cells share the same frequency band. For example:

Also, the transmit power of each base station is set so they could reach to neighboring cells (maybe) but they cannot reach cells beyond the neighboring cells. In this way, it is possible to reuse the frequency bands with no risk of creating interference.
by assigning reused frequency bands to cells that are separated by at least one other cell from the cell with the repeated frequency band (see, for example, cells 1 and 8, cells 3 and 9 and cells 4 and 10 in the picture above). When reusing frequency bands, the capacity they provide, in terms of supporting cells, can now be added to the network. For example, continuing with the earlier example (that when the network was limited to \( N = 700 \) simultaneous cells), the network formed by cells one through ten can support \( 10 \text{ cells} \times N \text{ cells per cell} = 10N = 1000 \text{ cells} \). So, cells are used in a cellular network to expand the capacity of the wireless network.

**LTE - Long Term Evolution Cellular Network**

Often considered a fourth-generation (4G) cellular
network (although, technically speaking, it is quite yet a 4G system - but it is close to it).

- Some goals intended for an LTE network:
  * For a system bandwidth of 20 MHz, achieve 100 Mbps on the downlink and 50 Mbps on the uplink (data rates to be distributed across active mobiles).
  * Short latencies (delays) of 5 ms for mobiles.
  * Cell radius of up to 10 km
  * Mobiles speed of up to 350 km/h
  * Architecture to function as an “All-IP” network (all traffic are Internet-type packets)

- LTE Physical layer is based on variations to OFDMA.

- More information about the Physical layer can be found in the standard document: http://www.3gpp.org/dynareport/36211.htm

3GPP TS 36.211 V11.3.0 (2013-06)
Technical Specification

3rd Generation Partnership Project;
Evolved Universal Terrestrial Radio Access (E-UTRA);
Physical Channels and Modulation
(Release 11)
One LTE radio frame is divided into 20 subframes, each further divided into two slots:

One radio frame, $T_f = 10$ ms

- One slot is made from seven OFDM-like symbols. Recall from the explanation of OFDM that transmission is over multiple subcarriers in parallel. This results in a structure where one slot can be visualized as a time-frequency grid.

- One square in the grid is called a "resource element." A grid of 12 subcarriers x 7 symbols is called a "resource block."
The resource block is the minimum unit of resource allocation to a specific user. This is, at the base station there is a scheduler whose function is to distribute the total
number of available resource blocks between the different users requiring service. This is one way we can look at the job of the scheduler in the downlink in this case:

Multiple active cells, each with a queue where data packets line up waiting for their transmission:

\[ \sum_{i=1}^{n} R_{Bi} \leq \text{Total RBs} \]

- One more variable to keep in mind about the job of the scheduler:
Each link will experience a different quality and a different Signal-to-Interference plus Noise ratio (SINR).

- LTE uses Adaptive Modulation and Coding (AMC), which means that it can switch between different modulation schemes and channel coding settings, depending on the link quality (signal-to-noise ratio, SNR). Different choices for modulation type and channel coding provide a tradeoff between throughput and link SNR. This can be seen in the following figure.
Each mode of operation gives a maximum throughput at higher SNR but the throughput decays as SNR decreases.

- Modes that operate at lower SNR but of low throughput
- Modes that have high throughput but only at high SNR.

Since each cell experiences a different SNR on the link, the scheduler decides to which cell to assign the resource blocks but also it decides on the modulation and channel coding setting for each resource block.

How is the link quality as perceived by the mobile is known by the base.
station (where the scheduler is)?

By transmitting in every frame, overload "pilot" signals are necessary. This reference signals are called known. From the LTE standard, different resource blocks are transmitted in pilot signals are also used.