8. MOBILE AND CELLULAR SYSTEMS

8.1 INTRODUCTION

Mobile communication systems are wireless communication systems that allow one or both users to be nomadic. Systems and applications that allow for mobility include cellular telephony, mobile TV, wireless networking (such as WiFi), WiMAX, trunking radio, cordless telephony, etc.

Mobile systems; however, have differing amount of mobility that they can allow to users, which ranges from nomadic, low mobility, high mobility to extremely high mobility. For example, nomadic will be when you sit down and use your laptop that is connected to a WLAN and after a while you change to another table and continue using your laptop, which is still connected to a network. Extremely high mobility will be when using your mobile device while you are in a plane or high speed train.

8.2. CHALLENGES OF MOBILE COMMUNICATION

Mobile communication channel is a harsh unpredictable environment compared to static, LoS links. This is mainly due to the fact that as you are moving, the environmental effects will change. Different obstacles will cause the propagating waves to scatter, reflect, or diffract to different points, thus making the strength of the signal reaching the receiver to vary randomly.

When the signal propagates through a mobile channel it will suffer from one or more of the following:

- Doppler shifts in the carrier due the relative motion between the communicating devices.
- Time dispersion, which is the spreading of the duration of the signal due to multipath propagation
- Random amplitude fluctuations of the received signal. This amplitude fluctuation is referred to as fading, and the following are some of the common types of fading
  - Slow spatial fading due to topographical shadowing effects along the propagation path.
  - Rapid spatial fading due to multipath fading as one of the communicating devices moves into region of constructive or destructive interference between the signals that have travelled different paths.
  - Temporally fading due to the mobile device passing through a spatially varying field.
  - Frequency selective fading, which occurs in broadband signals.

The effects of fading can be mitigated by one of the following techniques:

- Interleaving of digital signals to spread them out in time is commonly used to reduce the effect of fast fading and possible bursts of noise. This technique is used in second and third-generation cellular systems.

- Use of multi-carrier modulation scheme to transmit sequences in parallel can also help combat fading, and reduce the effects of ISI and possible bursts of noise.
- Use equalizers that are designed to reduce fading
- Use diversity techniques where multiple, independent samples of the digital signal are transmitted and/or received at each symbol interval. These multiple signal samples may be obtained by use of multiple antennas at transmitter (MISO), receiver (SIMO), or at both transmitter and receiver (MIMO). For example, a mobile receiver's reception in terrestrial digital video broadcasting (DVB-T) network can be improved as follows:

In order to combat the effects of signal fading and provide optimal reception, antenna diversity can be used. Antenna diversity, which is also called space diversity, uses two or more antennas at the receiver. These antennas are spaced wavelengths apart so that they can receive different combinations of samples of the transmitted signal.
Thus the fading affecting the different antennas will be uncorrelated, hence the signal composed of different signals from different antennas will exhibit less fading effects than the one provided by each individual antenna.
In order to recover the signal and present it to the receiver two techniques are used: selection combining (SC) and maximum ratio combining (MRC).

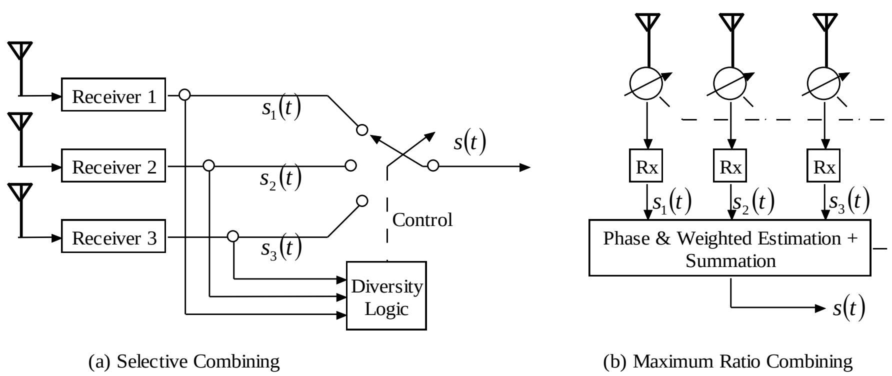

Figure 8.1 Techniques for combining signals in antenna diversity reception

In SC the signals from the diversity branches are fed to the to the "diversity logic" where the signal with the highest carrier-to-noise ratio is selected and forwarded to the detector for demodulation.
In MRC the signal from the diversity branches are first synchronized in phase. Thereafter they are weighed individually according to their momentary signal-to-noise ratio.
Lastly, the weighed and co-phased signals are summed up into one signal that is fed to the detector for demodulation.

The effect of harsh unpredictable nature of mobile channel has forced the free-space power equation to change considerable, and for cellular wireless systems, the varying received power may be modeled as

$$P_R = \alpha^2 10^{x/10} g(d) P_T G_T G_R \tag{8.1}$$

Where α^2 represents multipath fading effects, $10^{x/10}$ represents shadowing effects, while *g(d)* represents the inverse variation of power with distance. The average received power as measured at a distance *d* from the transmitter is

$$\overline{P_R} = g(d) P_T G_T G_R \tag{8.2}$$

This power is sometimes referred to as area-mean power, and the actual instantaneous received power as given by Equation 8.1 is varying statically around the area-mean power.

The path loss for mobile system depends on the environment where the communication is taking place. The most commonly used models for determining path loss were developed by Okumara *et al.* and refined by Hata. These models take into account a variety of environments and conditions. For example, for urban environment the path loss is predicted by

$$L_{S(urban)} = 69.55 + 26.16 \log f_{c(MHz)} - 13.82 \log h_t - A(h_r) + (44.9 - 6.55 \log h_t) \log d_{(km)} \tag{8.3}$$

Where f_c = the carrier frequency in MHz
h_t = height of transmitting antenna at the base station
h_r = height of the receiving antenna of the mobile station
d = distance between the two antennas
$A(h_r)$ = correction factor for mobile antenna height.

For small to medium-sized city the correction factor is given by

$$A(h_r) = (1.1 \log f_{c(MHz)} - 0.7) h_r - (1.56 \log f_{c(MHz)} - 0.8) dB \tag{8.4a}$$

For a large city, the correction factor is

$$A(h_r) = 8.29 [\log(1.54 h_r)]^2 - 1.1 dB \quad \text{for} \quad f_c \leq 300 MHz \tag{8.4b}$$

$$A(h_r) = 3.2 [\log(11.75 h_r)]^2 - 4.97 dB \quad \text{for} \quad f_c \geq 300 MHz \tag{8.4c}$$

For suburban areas the path loss is

$$L_{S(suburban)} = L_{S(urban)} - 2 \left[\log\left(f_c / 28 \right) \right]^2 - 5.4 dB \tag{8.5}$$

For the open areas, the path loss is predicted by

$$L_{S(open)} = L_{S(urban)} - 4.78 (\log f_c)^2 - 18.733 (\log f_c) - 40.98 dB \tag{8.6}$$

8.3 CELLULAR RADIO SYSTEM

As the mobile radio telephony became more popular, there was a demand to increase its capacity, and cellular radio was a technique that was developed to meet that need. Cellular radio increases capacity by dividing the geographical area into a number of small, nominally hexagonal areas, called *cells* and there after using low power system with shorter radius to cover each cell. The assigned spectrum is also divided into discrete channels. These discrete channels are then assigned, in groups, to cells covering a cellular geographic service area and are sometimes reused in different cells that are at a sufficient distant away.

The cells are arranged in clusters, as shown in Figure 8.2, and the allocated bandwidth is divided between cells in each cluster.

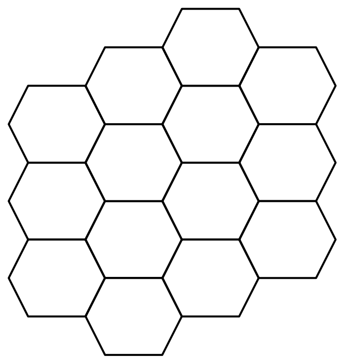

Figure 8.2 A 14-cell cluster

The physical size of cell is limited by wave propagation characteristics, for example, at VHF and UHF where propagation is line-of-sight; the coverage is influenced by buildings and the local terrain. In a town or city where there are lots of buildings to interfere with the line-of-sight propagation, it is necessary to place some antennas at the top of tall buildings and to place others at some position lower down to ensure that line-of-sight is maintained. This means that in city centers some of the cells will be as small as 1 kilometer in diameter, such cells are referred to as *micro-cells* and within a high office block you can even have smaller cells called *pico-cells*.

Since there is frequency (or discrete channel) reuse, co-channel interference (CCI) can be a big problem in cellular radio. To minimize CCI, the transmission power needs to be carefully controlled. Another technique that can be used is sectored antenna at the base transceiver station (BTS). The three-sectored antenna has a coverage angle of 120 degrees and when it is used it effectively divides the cell into three sectors, each of which can be regarded as a new cell with its set of channel frequencies. Each of the new cells is exited at the corner as shown in Figure 8.3, below.

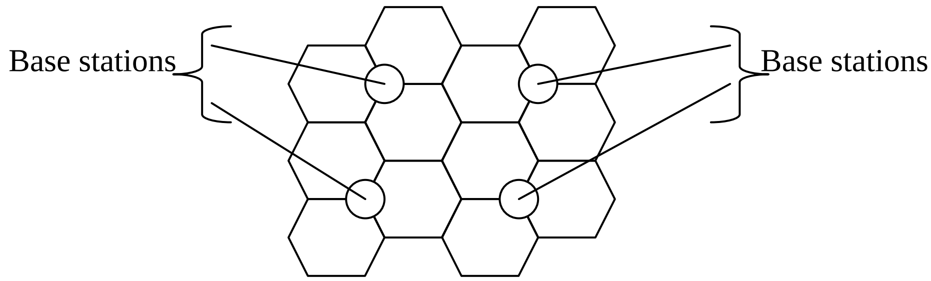

Figure 8.3 Sectored 4-cell clusters (providing 12 cells)

Each cell has a base station that has control over the physical area that is covered by the cell. When the cell gets congested it is simple subdivided into further sub-cells.

The first mobile telephone systems to be introduced were analog rather than digital, like today's newer systems. One challenge facing analogue systems was the inability to handle the growing capacity needs in a cost-effective manner. This led to the introduction of digital cellular systems. The advantages of digital systems over analog systems include ease of signaling, lower levels of interference, integration of transmission, and increased ability to meet capacity demands.

The principal elements of a cellular system include a BTS at the center of each cells mobile telecommunication switching office (MTSO) as shown in Figure 8.4. The BTS consists of an antenna system, a controller and a number of transceivers. MTSO has multiple BTSs linked to it, and it services those BTSs. MTSO is responsible for connecting calls between mobile units, and that includes assigning voice channel to each call, performing handoffs as the mobile unit moves out of the range of one cell into another during a connection, and monitoring the call for billing information. MTSO also provides a link between mobile cellular systems and the traditional public telecommunication switching network (PSTN).

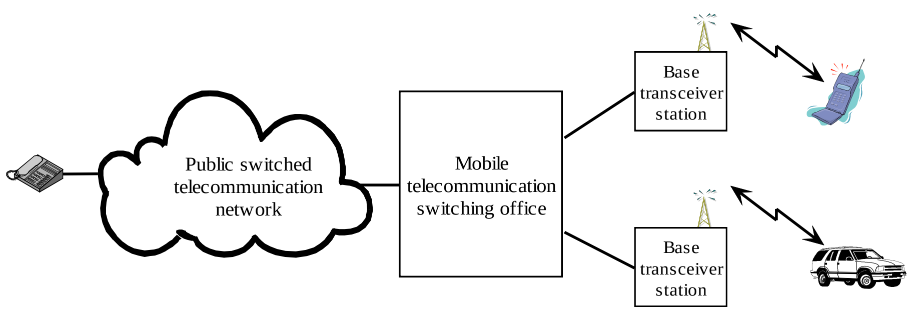

Figure 8.4 Cellular system

8.4 POWER CONTROL

The strength of the signal between the base station and the mobile unit needs to be strong enough to maintain good signal quality at the receiver, but no so strong as to create CCI with channels in another cell that are using the same frequency. In order to accomplish this, the cellular system must include a dynamic power control capability. There are two methods that can be used for power control: open-loop and closed-loop power control.

Open-loop power control depends solely on the mobile unit and there is no feedback from the base station and is based on the fact that forward and reverse link signal strength are closely correlated
The base station transmits a pilot signal continuous. The mobile unit monitors the received power level of the pilot signal and sets the transmitted power in the reverse channel; that is, mobile to base to be inversely proportional to it.
Though not as accurate as the closed-loop approach, open loop scheme can react more quickly to rapid fluctuations in the signal strength.

Closed-loop power control both the base unit and the mobile unit are involved;
On the forward channel (i.e. base station to mobile unit) the mobile unit provides the information about the received signal quality to the base station so that it can adjust its transmitted power.
On the reverse channel (i.e. mobile to base station), the base station monitors the received signal and make some power adjustment decision. The base station then communicates the power adjustment command back to the mobile unit on a control channel.

8.5 CELLULAR STANDARDS

Cellular network technologies are often classified as second, third, fourth generation; that is, 2G, 3G, 4G networks.

2G networks were designed mainly for voice communications. The 2G standards include GSM and IS-95.
However, as the times go on, there was a shift from voice centric to system that can also allow data communications so that the users can be able to access Internet. This led to the development of a 2.5G Enhanced Data Rates for the GSM Evolution (EDGE), General Packet Radio Services (GPRS).
3G was later developed to provide high-speed wireless communication to support multimedia services. Most of the 3G systems, such as EV-DO, W-CDMA and HSPA provide a combination of circuit switched voice services, and packet switched data services. They also provide a high data rates that 2G.

4G networks provide even higher bit rates of 100 Mbps or more, and many other improvements. The 4G systems that are currently widely deployed include HSPA+, WiMAX, and LTE. Unlike 3G that uses circuit and packet switching, 4G networks use only packet switching. To provide higher bit rate while maintaining the same spectral occupancy as 3G, 4G networks are using multi-carrier modulation schemes.

8.5.1 LTE and LTE Advanced

LTE, which is an abbreviation for Long Term Evolution, is a wireless communication standard for 3G/4G networks, which presents a progression or evolution from circuit-switched 2G to a packet-switched 4G. Unlike its predecessors, LTE’s upper layers use TCP/IP to enable convergence of all traffic over an all-IP network. LTE came as a result of increasing demand for mobile broadband services with higher data rates and quality of service (QoS). Compared to its predecessors, LTE and LTE Advanced offer the following benefits:

- High peak rate, which can be attributed to the use of enhanced multiple antenna transmission (MIMO) technology, along with OFDM.
- High spectral efficiency, which can be attributed to the use of M-ary modulation schemes such as QPSK and 16 or 64 QAM in LTE, and multicarrier modulation scheme (MCM) such as OFDM in LTE Advanced.
- Support for heterogeneous networks, which can be attributed to flexible channel bandwidths.
- Improved coverage due to high SNR, which is enabled by MIMO, along with OFDM.

LTE Advanced came as an improvement to the initial released LTE standard. It has flexible channel bandwidths, which are scalable to allow it to be deployed where other narrowband systems such as GSM exist; that is, to co-exist and interwork with 2G and 3G cellular systems. It is also an IP-based network to enable all traffic: data, voice, video and messaging. LTE Advanced uses OFDM to minimize ISI that typically limits the performance of high-speed systems, and MIMO techniques to boost data rates (Akildiz *et al.*, 2010). Compared to LTE, it has the following advantages:

- Reduced latency for packets to enable real-time interactive traffic and to provide QoS.
- Enhanced peak data rates to support advanced mobile services and applications
- High SNR at the receiver to help improve coverage and throughput
- Spectral efficiency that is three times greater than that of LTE

The architecture for the LTE Advanced is as shown in Figure 8.5 below

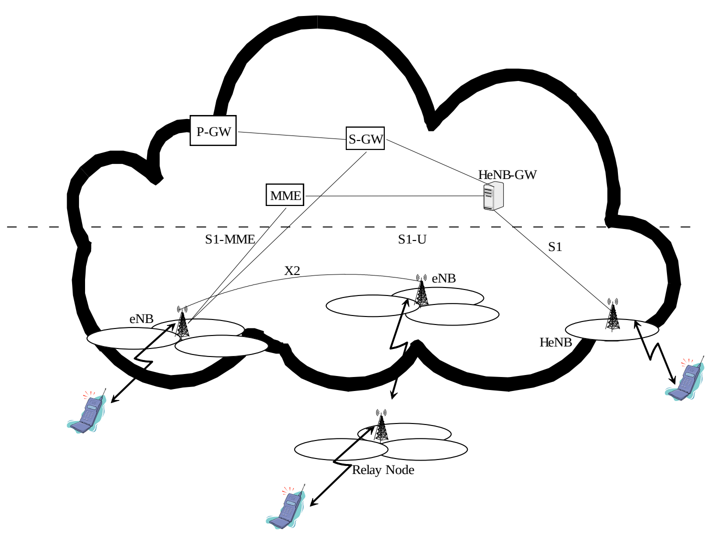

Figure 8.5 LTE Advanced architecture

The LTE Advanced architecture consists of the Enhanced Node B (eNB), Home eNB (HeNB), Home eNB gateway (HeNB-GW), Relay Node (RN), Mobility Management Entity (MME), Serving Gateway (S-GW) and Packet Data Network Gateway (PDN-GW or P-GW).

eNB provides the air interface with user and control plane protocol terminations. Each eNB serves one or more cells. eNBs are connected together using X2 interface.

HeNBs, also called femtocells, are low-cost eNBs, which are used for improving indoor coverage. They are connected via HeNB gateway, which provides additional support for a large number of HeNBs.

Relay nodes are used for enhancing network performance, especially where there is poor coverage.

MME is a control node for the LTE access network that is responsible for managing security functions, such as authentication, registration and authorization. It is also responsible for handling idle-state mobility, mobility between LTE and 2G/3G access networks, roaming, handovers and selecting S-GW and PDN-GW. MME connects to eNBs using S1-MME interface.

S-GW serves as a mobility anchor point for both local inter-eNB handover and between LTE and other 3GPP technologies (i.e. inter-3GPP mobility). It also performs inter-operator charging as well as packet routing and forwarding.

P-GW provides the user equipment (UE) with access to Packet Data Network (PDN) by assigning an IP address from PDN to the UE. It acts as an anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX. It also provides security connection between UEs connected from untrusted non-3GPP access networks by using IPSec tunnels.

8.5.1.1 LTE Advanced relaying

High capacity technologies like LTE advanced suffer from reduced data rates at the cell edge due to low power levels and high noise and interference levels. Though MIMO and OFDM do improve throughput they fail to mitigate the low power levels at the cell edge. So to enhance the performance at the cell edge and to improve coverage in difficult conditions, relaying is used.

A relay node (RN) is connected wirelessly to the radio access network (RAN) either directly or via a donor eNB (DeNB) cell using in-band (or in-channel) or out-band backhaul, where in the in-band DeBN-to-RN link shares the same frequency with RN-to-UE links, while in the out-band DeBN-to-RN link and RN-to-UE links use different frequencies.

There are a number of scenarios where an LTE relay will be advantageous, and some of them are as follows:

- To extend coverage in rural areas;
- To provide coverage in dead zones, and
- To improve urban or indoor throughput.

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