College of Computer Science
Northeastern University
Wireless Networks CS G250

Lecture 8
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Lecturer: R. Sundaram

Cellular Networks, Satellite Communication

1 Satellite Communication

A satellite communications system is based on antennas in a stable orbit above the earth. Satellites serve as relay stations in the sky. The basic idea of satellite communications is that two stations on earth discuss via one or more satellites.

So a little bit of satellite-related terminology:

1. **Earth station** is an antenna on or near the surface of the earth.
2. **Uplink** is a transmission from an earth station to a satellite.
3. **Downlink** is a transmission from a satellite to an earth station.
4. **Transponder** is the component in the satellite that takes an uplink signal and converts it to a downlink signal.

Satellites can be categorized according to their:

1. **Coverage area**:
   (a) LEO = low earth orbit
   (b) MEO = middle earth orbit
   (c) GEO = geostationary earth orbit
2. **Service type**
   (a) FSS = fixed service statellite
   (b) BSS = broadcast service satellite
   (c) MSS = mobile service satellite
3. **General usage**
   (a) commercial

(b) military

(c) experimental

(d) amateur

4. **Satellite orbits:**

Cicular orbit means that the earth is located at the center of the orbit. **Elliptical orbit** implies the earth is located at one of the two foci of the ellipse.

Equatorial orbit is above the equator. **Polar orbit** passes over the two poles. All other orbits (at a certain angle) are called **inclined orbits**.

Observation: people use the moon as a satellite (moon bounce).
General caracteristics of satellites communication:

1. high coverage area (e.g. GEO covers about a fourth of the earth's surface)
2. stable conditions (time invariant conditions) meaning that satellite communication links can be designed with great precision
3. transmission cost is independent of distance
4. power and allocated bandwidth are limited resources
5. broadcast, multicast and point-to-point applications are easy to implement
6. great quality of transmission
7. satellites are subject to degradation
8. very high bandwidths and data rates available

Figure 1 illustrates the geometry that dictates satellite coverage.

θ is called the elevation angle. To obtain maximum coverage, then we would like the elevation angle to be 0^o. However, as θ gets closer to 0^o, the signal quality becomes very bad, due to attenuation or multipath reflection of the signal. As θ gets bigger, the quality of the signal is better, but we get less coverage. Current designs use an elevation angle of 5^o to 20^o depending on the frequency. The coverage angle β measures what portion of the surface of the earth is visible to the satellite, given the elevation angle.

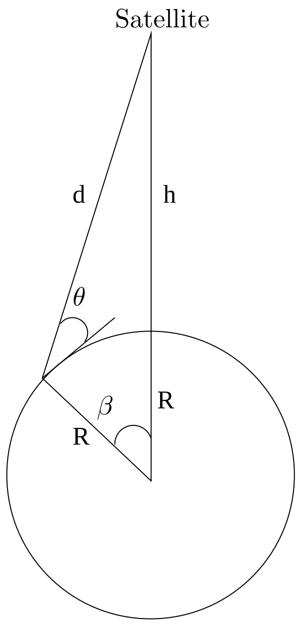

Figure 1: Coverage and Elevation Angles

The distance from the satellite to the furthest point of coverage is:

$$
\begin{aligned}
d &= \frac{(R+h)\sin\beta}{\cos\theta}, \text{ where} \\
R &= \text{earth's radius (6370km)} \\
h &= \text{altitude of the satellite} \\
\beta &= \text{coverage angle} \\
\theta &= \text{elevation angle}
\end{aligned}
$$

The round-trip transmission delay (t) is in the following range:

$$\frac{2h}{c} \leq t \leq \frac{2d}{c}$$

For example, for GEO satellites $h = 35863km$ and $t = 0.25s$.

Table 1 classifies satellites according to their altitude range. The most common type of satellite is the geostationary satellite which was invented by Arthur C. Clarke, in 1945.

The biggest company in the world manufacturing satellites is PanAmSat.

Free space loss is expressed as:

Orbits	LEO	MEO	GEO
Orbital period	1.5 to 2h	5 to 10h	24h
Altitude range	500 to 1500km	8000 to 18000km	35863km
Visibility duration	15 to 20 mins/pass	2 to 8 hours/pass	permanent
Elevation	rapid variations high and low angles	slow variations high angles	no variations low angles at high latitudes
Round-trip time	few ms	tens of ms	250ms
Coverage diameter	6000km	12000 to 15000km	16000km
Examples of systems	Iridium Globalstar Orbcomm	Odyssey Inmarsat	Intelstat Interspoutnik

Table 1: Orbital comparisson for satellite communication applications (Stallings, p242)

$$
\begin{aligned}
L_{db} &= 10 \log \frac{P_t}{P_r} \\
&= 20 \log \frac{4\pi d}{\lambda}
\end{aligned}
$$

Capacity allocation strategies:

Frequency division multiple access (FDMA) This strategy divides the overall capacity of communications into a number of channels. The number of subchannels is limited by 3 factors: thermal noise, intermodulation noise and crosstalk.

FDMA strategies are possible in two flavors:

Fixed-assignment multiple access (FAMA) The assignment of different channels among different users is realized in a fixed manner. This has the main disadvantage of underusing the capacity as demand fluctuates.

Demand-assignment multiple access (DAMA) The assignment is changed as needed as demand fluctuates.

Time division multiple access (TDMA) The time domain is divided into timeslots. This is a very popular technique thanks to the lack of intermodulation noise and the drop in cost of digital components.

Code division multiple access (CDMA)

2 Cellular Networks

The idea in cellular networks is the use of multiple low-power transmitters. Because the area of a transmitter is small, then the area can be divided into cells, each having its own transmitter. Each cell has its own band of frequencies. Also, each cell is served by a base station. Each base station has: a transmitter, a receiver and a control unit. Adjacent cells are assigned different frequencies. Still, cells located at enough distances from each other can use the same frequency band. An overview of a cellular system is described in Figure 4.

One of the most important design decissions that need to be made is the shape of the cells. One design proposed was the cells having a square shape (Figure 2). The disadvantage of this design is that the distance between any two neighbor transmitters is not the same.

If the shape of the cells is hexagonal, then the distance between any two neighbor transmitters is the same (Figure 3). In the case of hexagonal cells, the distance between any two neighbor transmitters is $d = R\sqrt{3}$, where R is the radius of the cell.

Let N be the number of cells in a repeated pattern (also called the reuse factor). Also, let D be the minumum distance between centers of cells that use the same frequency band (called cochannels).

In a hexagonal cell pattern, only the following values of N are possible:

$$\begin{aligned} N &= I^2 + J^2 + IJ, \text{where} \\ I, J &= 0, 1, 2, 3, ... \end{aligned}$$

Hence possible values for N are 1, 3, 4, 7, 9, 12, 13, 16, etc.

Also,

$$N = \left(\frac{D}{d}\right)^2$$

Increasing the capacity of a cellular network by:

1. Adding New Channels
2. Frequency Borrowing
   Frequencies are taken from adjacent cells by congested cells. Another option is to assign the frequencies dynamically to the cells.
3. Cell Splitting
   Cells in areas of high usage can be split into smaller cells.

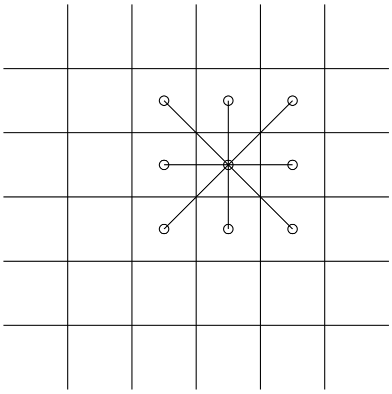

Figure 2: Cellular Network - square pattern

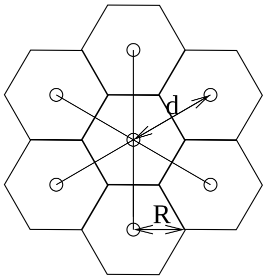

Figure 3: Cellular Network - Hexagonal pattern

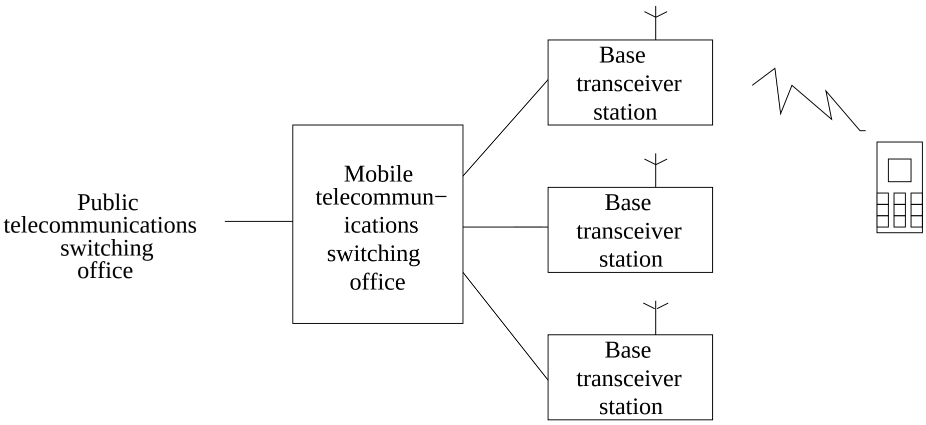

Figure 4: Cellular System

, where

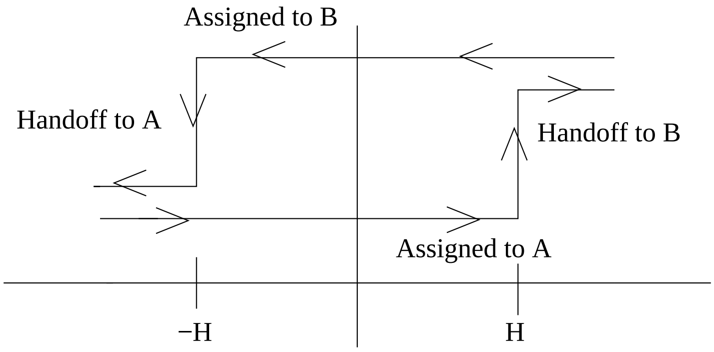

Figure 5: Hysteresis

4. Cell Sectoring
   A cell is divided into a number of wedge-shaped sectors, each with its own subset of the cell's channels.

5. Microcells
   As the size of the cell decreases, so does the radiated power. Also, the placement of the transmitters change from the top of the hill, big building to lamp posts.

Here are the steps in a typical call between two mobile users within an area control by a single MTSO (mobile telecommunications switching office):

1. Initialization
   A user is associated with the strongest base statation (BS).

2. Call Origination

3. Paging
   The MTSO controls the reservation of channels.

4. Call Accepted

5. Ongoing Call
   While the connection is maintained, the two users exchange information through the MTSO and the two BSs.

6. Handoff
   If a mobile user moves out of range in one cell and into the range of another cell during the conversation, then the user is assigned to the BS in the new cell. There are two types of handoff:

(a) hard handoff
The connection to the prior base station is terminated before or as the user is transferred to the new cell's base station. The user is connected to only one base station at a given time. The disadvantage of this approach is that the received signal from both stations often fluctuates. In this case the user might rapidly switch between base stations - an effect called in the literature *ping-pong* (Figure 5).

(b) soft handoff
In this model, a user can be connected to more than one cell at any given time. This model eliminates the ping-pong effect and is a feature of CDMA.

Other functions performed by the system might be:

1. Call Blocking
   This can occur during the initialization phase. If all traffic channels are assigned and after a preconfigured number of repeated attempts, a busy tone is returned to the user.

2. Call Termination
   When one of the users hangs up, the MTSO is informed and the traffic channels at the two BSs are released.

Here are a few reasons why *power control* is desirable:

1. The received power must be above the background noise.

2. The effects of reflection, diffraction and scattering can cause rapid changes in the received power levels.

3. We would like to reduce the power in the transmitted signal from the user to reduce interference with other channels, to save battery and limit health concerns.

Power control is achieved in two different ways:

1. open-loop power control
   In this model, the BS transmits continuously a signal known as the pilot. The mobile device listens to the pilot tone and it callibrates. This model uses no feedback from the BS. Also, the model assumes that the uplink and downlink signal strengths are comparable, which is generally the case. It reacts very fast to rapid fluctuations in signal

strength. But is not as accurate as the closed-loop power control model.

2. closed-loop power control The BS controls the power adjustment decision and sends a power adjustment command to the mobile device.

Ideally speaking, the number of available channels in a cell would equal the total number of subscribers who could be active at any given time. Practically speaking, it is not feasible to have the possibility of handling any given load at any time. This is the field of *traffic engineering*. One of the questions that traffic engineering attempts to answer is "what is the probability of blocking?".

$$\begin{aligned}
A &= \lambda h, \text{where} \\
\lambda &= \text{the mean rate of calls attempted per unit time} \\
h &= \text{the mean holding time per successful call} \\
A &= \text{traffic intensity (in Erlang)} \\
\lambda &= \lambda_1 + \lambda_2 \\
\lambda_1 &= \text{rate at which new calls are initiated} \\
\lambda_2 &= \text{calls initiated at other BS that are coming to the current BS}
\end{aligned}$$

A equals the average number of calls arriving during the average holding period. Erlang is a dimensionless unit.

$$\begin{aligned}
P &= \frac{\frac{A^N}{N!}}{\sum_{x=0}^{N} \frac{A^x}{x!}}, \text{where} \\
P &= \text{probability of blocking (grade of service)} \\
N &= \text{number of servers} \\
A &= \text{offered traffic (in Erlangs)}
\end{aligned}$$