Cellular Telephony

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Lecture in EECS 122, December 1999

History

- **First public mobile telephone service introduced in 25 U.S. cities in 1946**
  - **One single high powered transmitter in each city**
  - **120 KHz of RF bandwidth in half duplex mode**
    - **FM "Push to talk" telephone**
    - **Actual telephone grade speech occupies only 3 KHz of baseband!**
  - **Mid 1960's the bandwidth per call was cut to 30KHz**
- **IMTS (Improved Mobile Telephone Service) introduced in the 1960's**
  - **Main Innovation: Automated Channel Trunking**
    - **Support a large number of subscribers from a small pool of channels**
    - **When a subscriber calls she is dynamically allocated a channel**
    - **When the call is over the channel is returned to the pool**
    - ***The probability that all subscribers will call at the same time is small***
- **IMTS was handicapped by the lack of spectrum and inefficient use**
  - **12 channels and only 543 subscribers in 1976 (NYC)**

History: IMTS Vs. Cellular

- **IMTS is low infrastructure and high power**

$$P_r = c/d^n, 2 \le n \le 5$$

- **Cellular is high infrastructure and low power**
  - **Motivation:** ***Squeeze more out of the allocated spectrum***
- **US Advanced Mobile Phone System (AMPS) spectrum allocations**
  - **1983: 40 MHz in the 800 MHZ band, 666 duplex channels**
    - **30 KHz per channel**
  - **1989: 10 MHz (166 channels) more**
  - **AMPS is FM with FDMA**
- **US Digital Cellular (USDC) came in 1991**
  - **3 users per 30 KHz**
  - **Compatible with AMPS**
  - **Digital modulation (DQPSK), speech coding, TDMA**

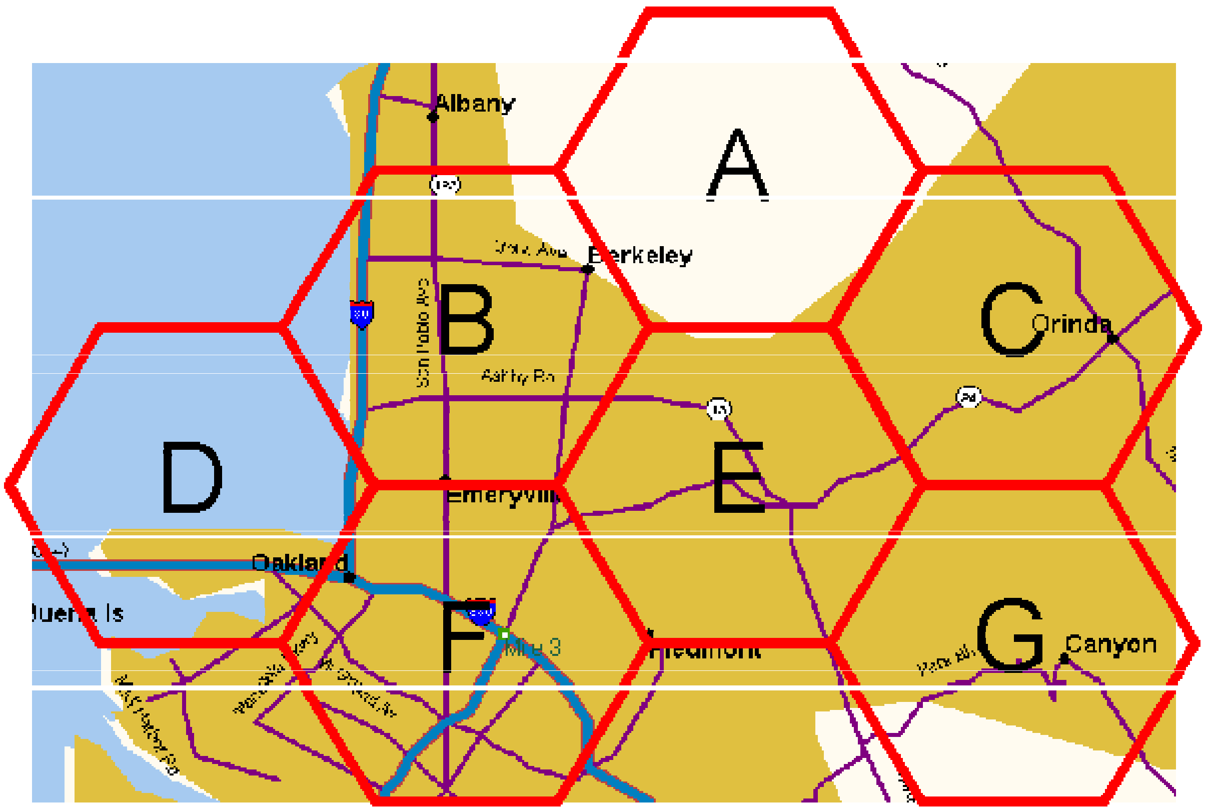
History

- **Qualcomm introduced CDMA in the 1990's**
  - **Code division instead of frequency division**
  - **Can operate at much smaller signal to interference ratios**

System	Multiple Access	Spectrum	Channel Bandwidth
AMPS 1983	**FDMA**	**824-894 MHz**	**30 KHz**
USDC 1991	**TDMA**	**824-894 MHz**	**30 KHz**
IS-95 1993	**CDMA**	**824-894 MHz** **1.8-2.0 GHz**	**1.25 MHz**
GSM 1990	***TDMA***	***890-960 MHz***	***200 KHz***

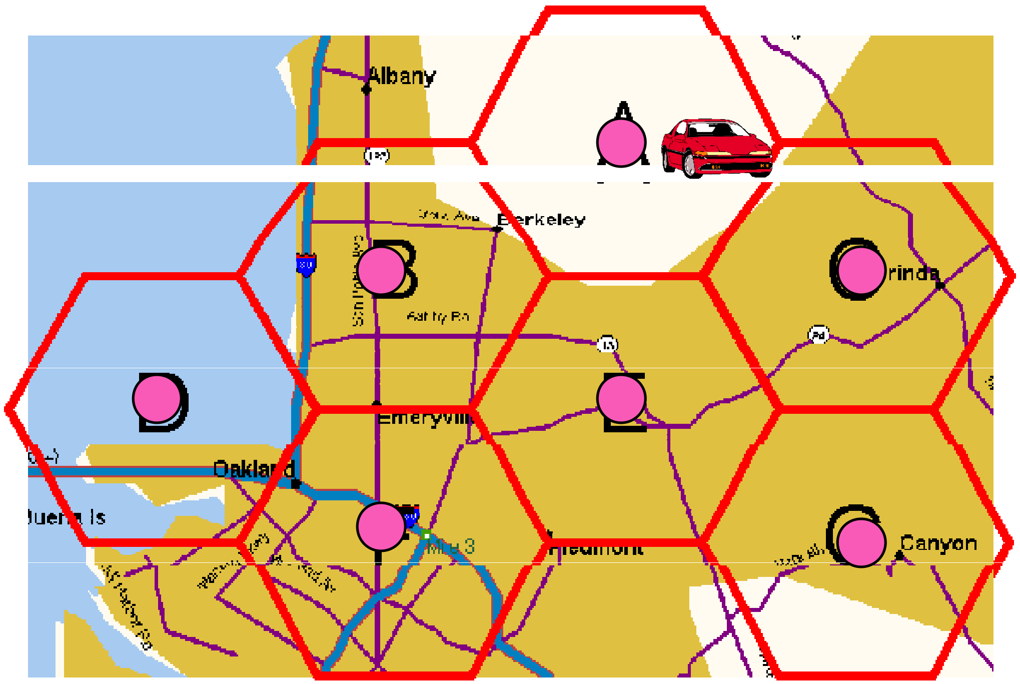
Cellular Telephony: The Basic Innovation

- Divide the area into cells
- Each cell has a base station



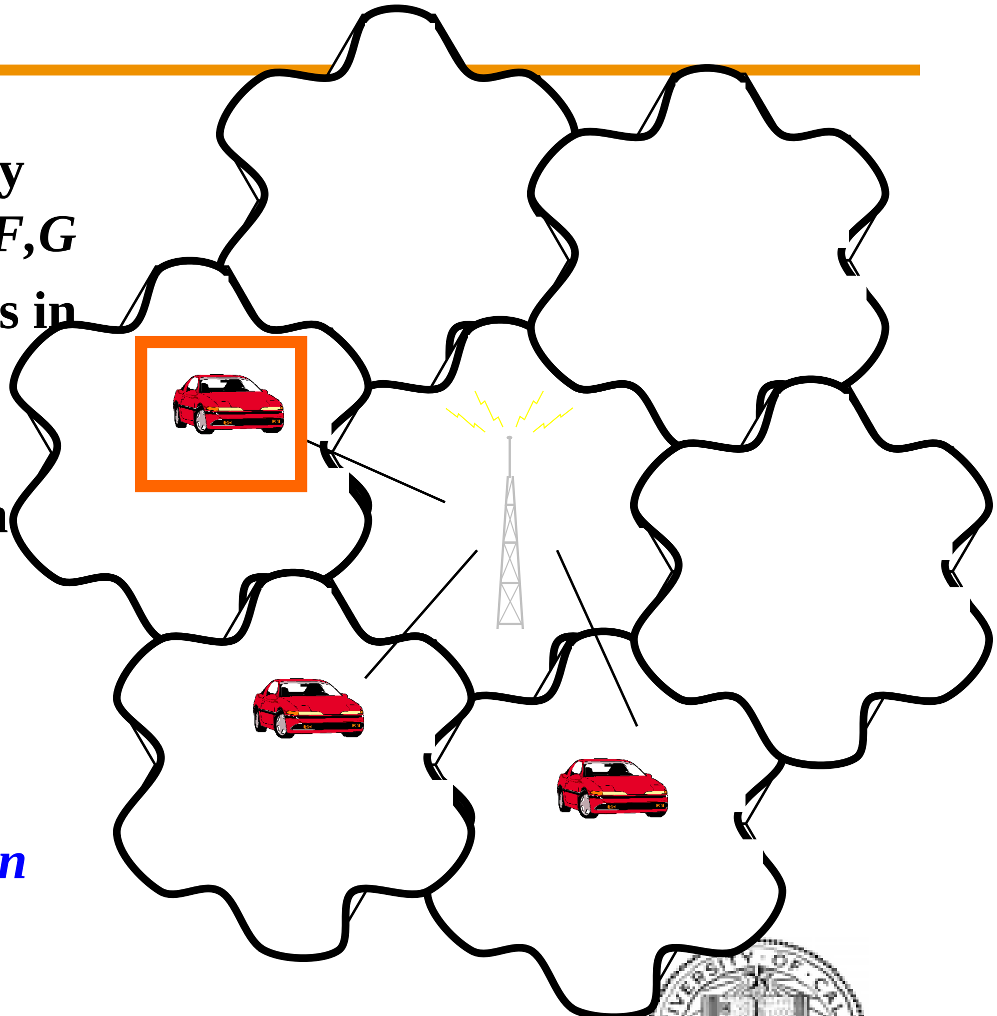
Cellular Telephony: The Basic Idea

- The base stations are connected to the public telephone network
- The cell phone connects with the base stations in its cell
- As the caller moves from one cell to another the call is handed-off from one base station to another



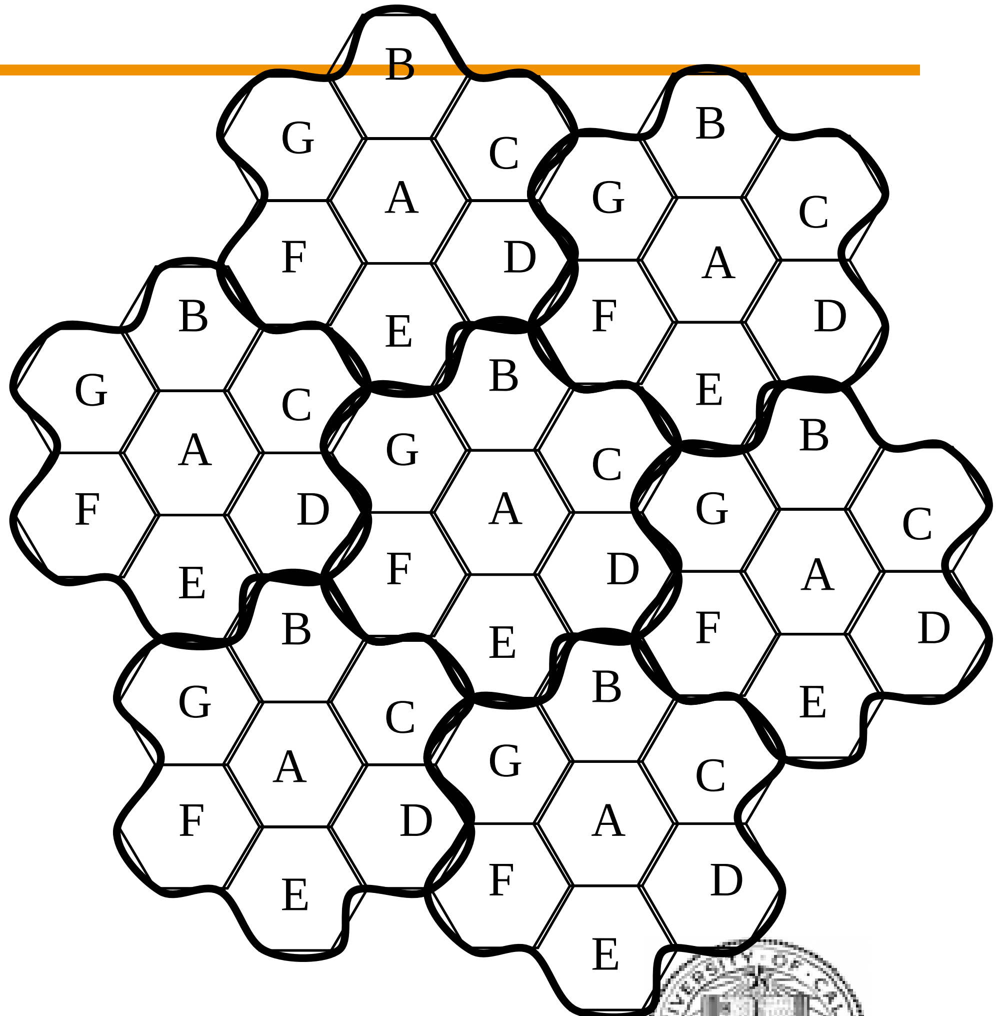
The Basic Motivation

- Suppose there are 7 frequency channels denoted *A,B,C,D,E,F,G*
- Then maxium number of calls in the area will be *7*
- If many callers use the same frequency at the same time the signal power can become too small in relation to the interference power
- Signal power, $S = c/d^n$
- Interference, $I = c/d^n + c/d^n$
- Signal to Interference ratio
  - S/I = 0.5



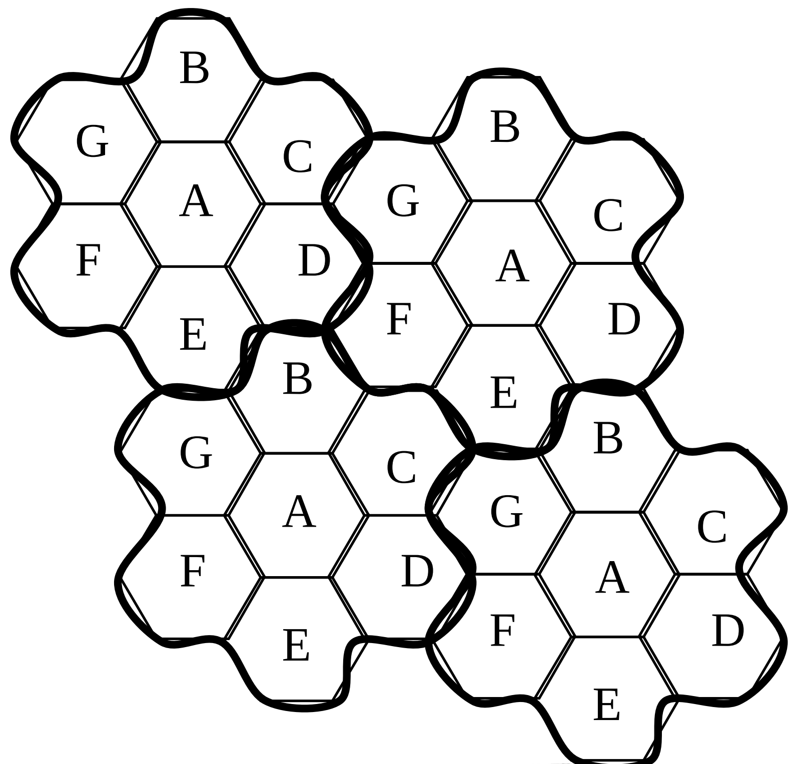
The Basic Motivation

- **Suppose there are 7 frequency channels denoted *A,B,C,D,E,F,G***
- **Suppose the frequencies can be re-used as shown**
- **Then the maximum number of calls is ideally *49***
- **How?**
- ***Keep the transmission power high enough to cover the cell***
- ***But keep it low enough to allow re-use of the frequency***



Understanding the Frequency Re-use Concept

- Divide the metropolitan area into cells
- Allocate a frequency channel(s) to each cell
- Put a base station in the center of each cell that transmits with equal power in all directions
- The cell area is that which can be reached by the base station
  - Assume each cell is the same size and shaped like a hexagon
  - In practice this is only an approximation



Understanding the Frequency Re-use Concept

- ***N*= Cluster size**
  - **Cluster is a group of cells that collectively use all the available channels, e.g., N = 7**
  - **From the geometry of hexagons feasible cluster sizes are**

$$N = i^2 + ij + j^2$$

  where *i,j* are non-negative integers

  - **Typical N values used are 7, 12**
- ***S* = Total number of duplex channels available**
- ***k* = number of channels given to each cell**
- **Then *S* = *k N***
- **If the cluster is replicated M times in the area then the total number of channels used in the area is the capacity (C),**

$$C = M\,k\,N = M\,S$$

Example: Allocating channels to cells

- **Total bandwidth = 33 MHz**
- **Channel bandwidth = 50 KHz/duplex channel**
- **Total available channels = 33,000/50 = 660 channels**
  - **For N = 4, Channels per cell = 660/4 = 165 channels**
  - **For N = 7, Channels per cell = 660/7 = 95 channels**
  - **For N = 12, Channels per cell = 660/12 = 55 channels**
- **Suppose there are 84 cells, 600 voice channels, 60 control channels**
  - **N=7 implies M = 12 implies C = 12 x 600 = 7200 calls**
  - **N= 12 implies M = 7 implies C = 7 x 600 = 4200 calls**

Control Channels

- Suppose 1 MHz is allocated to control channels with 50 KHz per duplex channel
- Then number of control channels = 1000/50 = 20
- Thus number of voice channels = 640
- If each cell needs only one control channel then for N=7 we need only 7 control channels
- Thus 653 channels voice channels can be divided amongst 7 cells

Interference and System Capacity

- **Interference is the major limiting factor in cellular systems**
- **Source of interference**
  - **Other mobile in the same cell or neighboring cells**
  - **Other base stations**
  - **Non-cellular transmissions that leak energy into the cellular band**
- **Interference on voice channels causes cross-talk and bad connections**
- **Interference on control channels causes missed and blocked calls**
- **Co-channel interference**
  - **Interference from cells that use the same frequency channels**
- **Adjacent channel interference**
  - **Interference from signals which are adjacent in frequency to the desired signal**
  - **Results from imperfect receiver filters or powerful nearby transmitters**

Co-channel Interference and System Capacity

- **Received power at distance d**

$$P_r = c/d^n, 2 \le n \le 5$$

- **The call quality depends on the bit-error rate, which depends on the signal to interference ratio**

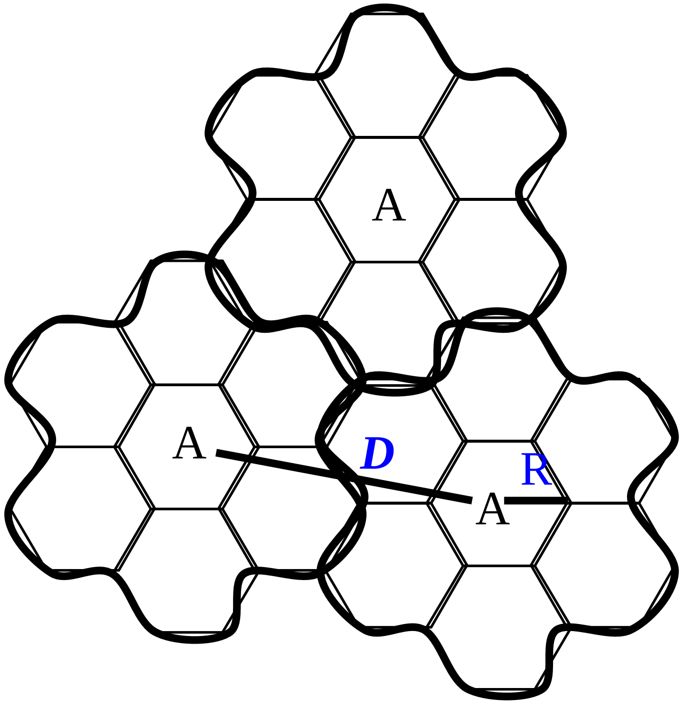
$$S/I = (c/R^n)/(\sum_{i=1}^{i_o}(c/D_i^n))$$

$$= (D/R)^n / i_0$$

where i0 is the number of interfering base stations

- **From the hexagonal geometry**

$$D = \sqrt{3N}R \Rightarrow S/I = (\sqrt{3N})^n / i_o$$



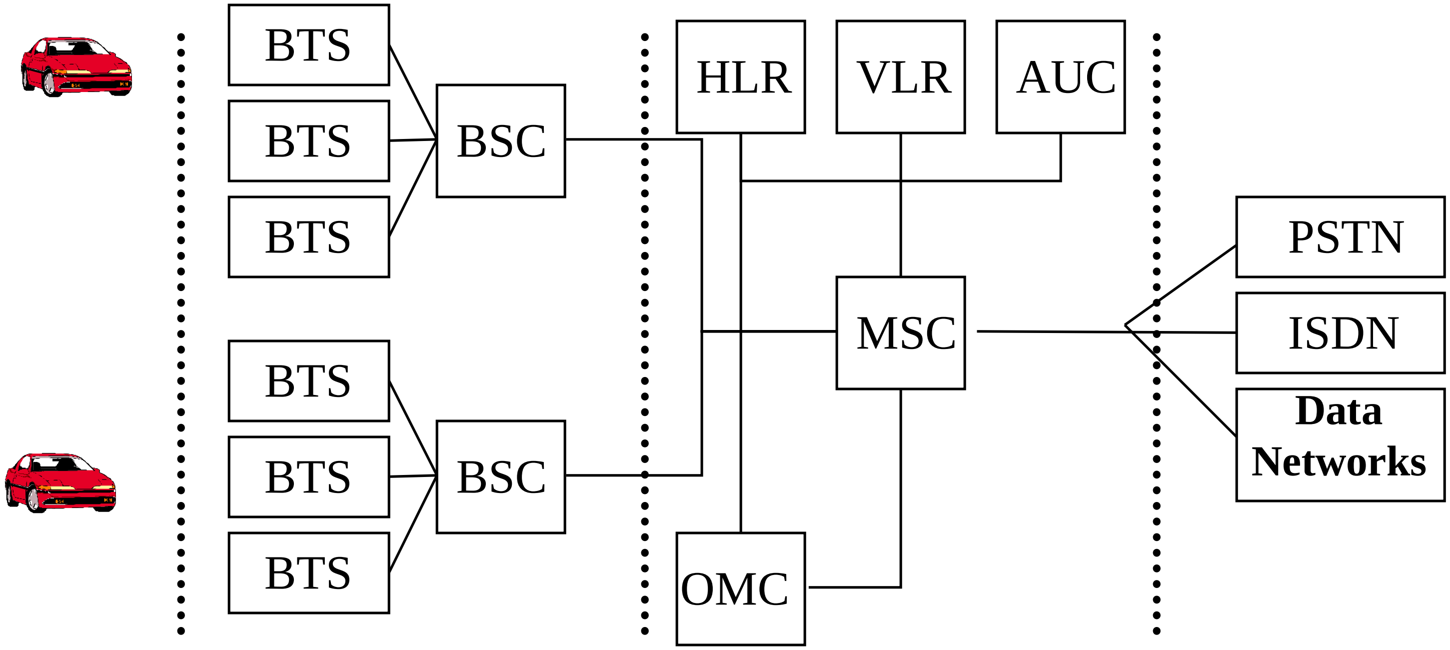
Deriving Cluster Size from Signal to Interference Ratio

- **In the USAMPS cellular system with 30 KHz voice channels the signal to interference ratio should be no less than 18 dB**

$$S/I = (\sqrt{3N})^n / i_o$$

- **Putting this and i0 = 6 in the equation we get N > 6.43, i.e., N = 7**
- **This equation is optimistic**
- **If the mobile is on the boundary of the cell then the distances from the first tier interfering cells is *D-R, D+0.5R, D, D-0.5R, D+R***
  - **This is the worst-case**
  - **The signal to interference ratio turns out to be *17 dB***
  - **Thus *N* has to be increased beyond *7* to *12 (i=2, j=2)***
  - **This causes a capacity reduction of *7/12***
- **In this way co-channel interference determines the cluster size and the capacity of cellular systems**

The GSM Architecture



- Each frequency channel is 200 KHz with a data rate of 270.833 Kbps
- 8 users share each channel by TDMA
- Each user gets to send data at 24.7 Kbps
- The rest is control channel

Making a Call

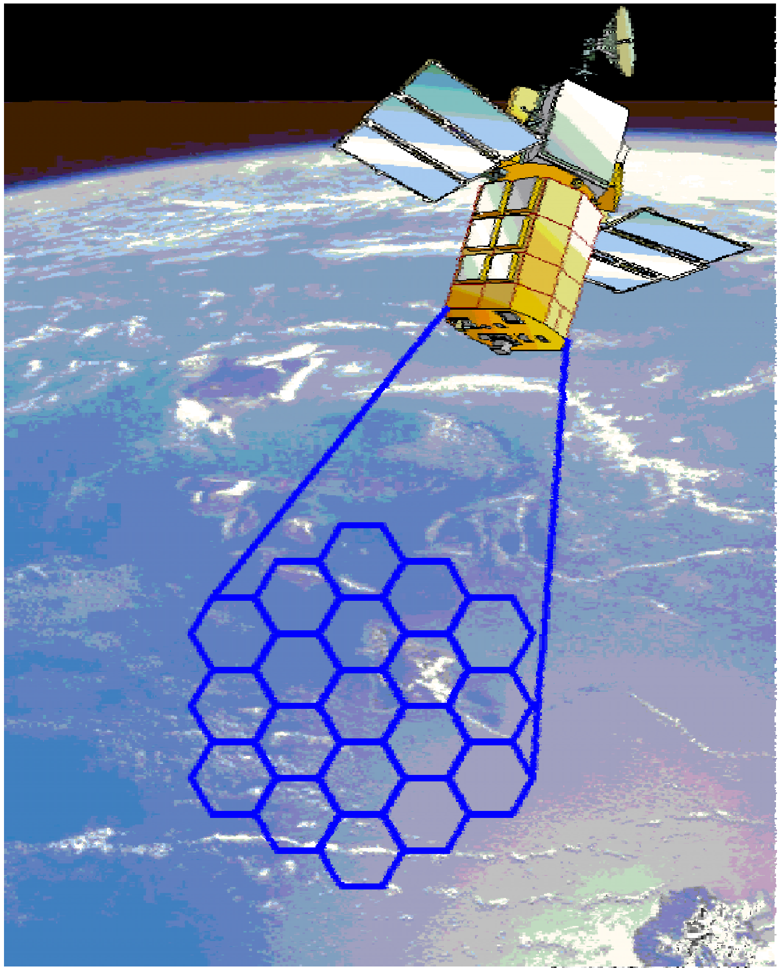
- Base stations send synchronization signal
- When a GSM mobile is powered on it first locks on to this signal
- To originate a call the user dials the number and pushes the “send”
- The mobile transmits the request to the base station on random access channel running Slotted Aloha
- If the base station receives the signal time slots are allocated to the mobile and it receives timing and transmit power commands
- Meanwhile the subscribers IMSI (International Mobile Subscriber Identity) is authenticated by the MSC
- If authentication is successful the dialed party is called and the connection established to the BTS serving the mobile
- The BTS then transfers the mobile to new channels and time slots that are to be used for the call

Receiving a Call

- **The HLR is a database that contains subscriber and current location information for each subscriber in the same city as the MSC**
- **VLR is a database that temporarily stores the IMSI and customer information for each roaming subscriber in the area of the MSC**
  - **Every mobile that is powered on synchronizes with the nearest BTS and registers in the VLR which then updates the current location information in the appropriate HLR**
- **When someone calls a subscriber the call first goes to the HLR of the subscriber**
- **The HLR directs the call to the current MSC of the subscriber which in turn directs it to the appropriate BSC and BTS**
- **The BTS pages the mobile which responds on the random access channel**
- **New channels and slots are then assigned by the BTS for the call**

Satellite Telephony

- Low earth orbit satellites are used to connect mobiles
- Data rates are low (< 20 Kbps)
- Promises ubiquitous coverage



Summary

- Wireless telephony is in a period of explosive growth
  - By the ear 2010 there should be equal number of wired and wireless subscribers
- Most of this growth is cellular telephones
- Based on an intensive terrestrial infrastructure to achieve high capacities
  - Cells are getting smaller making infrastructure more intensive
- Basic capacity calculations for FDMA cellular systems
- Looked at the architecture of the GSM cellular system
  - This architecture is well defined
  - Others such as AMPS, USDC are similar