EC 551
Telecommunication System Engineering

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# Syllabus

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Compute total system capacity

- Example
  - Total coverage area = 100 mile$^2$ = 262.4 km$^2$
  - Total 1000, 1256 duplex channels
  - Cell radius = 1km , 0.5km
  - N=4 or N=7
  - What’s the total system capacity for N=4 and N=7?

\[ A = \frac{3\sqrt{3}}{2} r^2 = 2.6r^2 \]
Compute total system capacity

- # of cells = 262.4/2.6=100 cells
- # of usable duplex channels/cell
  - \( S=(\# \text{ of channels})/(\text{reuse factor}) \)
  - \( S_4=1000/4=250 \)
  - \( S_7=1000/7=142 \)
- Total system capacity (# of users could be accommodated simultaneously)
  - \( C=S*(\# \text{ of cells}) \)
  - \( C_4=250*100=25000 \)
  - \( C_7=142*100=14200 \)
Cellular concepts

- W – total available spectrum, B – bandwidth per user, N is the frequency reuse factor, m – number of cells, number of simultaneous users is given by $n = (m/B) \times (W/N)$

- # of users can be increased by
  - Increasing m (cells)
  - Decreasing cluster size (N)

- A small cell size
  - Results in longer battery life
  - Reduces handset size
  - Increases handoffs
  - Increases signaling load
  - Increases the complexity of design and network deployment
Worst-Case CCI on the Forward Channel

- Co channel interference [CCI] is one of the prime limitations on system capacity. We use the propagation model to calculate CCI.

- There are six first-tier, co-channel BSs, two each at (approximate) distances of D-R, D, and R+D and the worst case (average) Carrier-to-(Co-Channel) Interference [CCI] is

\[
\Lambda = \frac{1}{2} \frac{R^{-\beta}}{(D - R)^{-\beta} + D^{-\beta} + (D + R)^{-\beta}}
\]

Worst case CCI on the forward channel

R= cell radius
Cell splitting

- Smaller cells have greater system capacity
  - Better spatial reuse
- As traffic load grows, larger cells could split into smaller cells
Cell splitting is the technique of splitting a congested cell into smaller cells.

- New (smaller cells) have their own base stations with reduced antenna height and reduced power.
- Cell splitting increases capacity since frequency reuse can be increased.
- Cell splitting preserves the geometry of the architecture and therefore simply scales the geometry of the architecture.
- In the following figure the cell radius has been reduced by half.
the simple propagation model

\[ P_R = P_o \left( \frac{d}{d_o} \right)^{-n} \]

At the cell boundary the distance \( d \) is \( R \), the unsplit cell radius. Consider both an unsplit and a split scenario. For the unsplit case

\[ P_{r(unsplit)} = P_{t, unsplit} R^{-n} \]

For the split case

\[ P_{r(split)} = P_{t, split} \left( \frac{R}{2} \right)^{-n} \]

or

\[ P_{r, split} = P_{t, split} R^{-n} 2^n \]
For the received signal powers to be equal we must have

\[ P_{t,\text{unsplit}} R^{-n} = P_{t,\text{split}} R^{-n} 2^n \]

The ratio of transmitted powers is important. Consider the following:

\[ \frac{P_{t,\text{split}}}{P_{t,\text{unsplit}}} = 2^{-n} \]

Note the role of the path loss exponent. For \( n = 4 \), the transmitted can be reduced by a factor of 16 and still provide equal received signal powers.
A Little Piece of History

1983
1G
AMPS, TACS, NMT, etc
Analog speech

1991
2G
GSM
Digital speech, low speed data

1998
2.5G
GPRS & EDGE
Digital speech, low speed data, medium speed up to 384 kbs

200x
3G
IMT-2000/UMTS
4 QoS Class:
Conversational, streaming, interactive, & background
Elements of the Network

- **Subscriber**: user who pays subscription charges for using mobile communication services.

- **Mobile Station**: is a subscriber unit intended for use while on the move at unspecified locations. It could be a hand-held or a portable terminal.

- **Base Station**: a fixed radio station used for communication with MS. It is located at the centre of a cell and consist of Transmitters and Receivers.

- **Mobile Switching Centre**: it coordinates the routing of calls, do the billing, etc.
Mobile Station

MS consist of:

- Mobile Equipment (ME)
- Subscriber Identification Module (SIM)
SIM Card

- Subscriber Identity Module (SIM) is a smart card which stores information about the subscription and feature of services.
- Stored information including:
  - Authentication Key “Ki”
  - Encryption
  - IMSI and TMSI
- SIM card is protected by a Personal Identity Number (PIN) of the user
Base Station Subsystem

- **BTS**: Base Transceiver station
  - 3 Antennas: 2 Rx & 1 Tx.
  - Microwave link with the network
- **BSC**: Base station controller
  - Control many (BTS)
  - It handles many functions:
    - Channel Allocation
    - Link quality Supervision
Base Station Subsystem

- Transmission of broadcast messages
- Controlling power level
- Controlling frequency hopping
- Error correction coding and decoding
- Hardware processing
- Data and signaling encryption
- Digital speech transcoding
- Data rate adaptation
Base Transceiver Station (BTS)

- BSC control RRM for BTSs.
- BSC handle radio-channel setup, frequency hopping, and handover within BSC

- BSS consist of two parts:
  - Base Transceiver Station (BTS)
  - Base Station Controller (BSC)
- BTS is a radio-end which determine a cell coverage and provide link with MS.
- BTS include Transmitters and Receivers, antenna and signal processing unit as well as interface.
- BTS communicate with MS via air interface
Mobile Switching Center (MSC)

- As a central switch for routing the traffic
- Control BSC via A-interface
- As a interconnection between GSM network with other Networks via Internetworking Function (IWF)
Home Location Register (HLR)

- HLR contain database of users, including all the subscription records
- HLR records the update location of every user for mobility management purposes
GSM Architecture

Operation and Maintenance subsystem

OMS

Switching Subsystem

MS

BSS

Mobile Station

Base Station subsystem

SS
Switching Subsystem

MSC: Mobile Service Switching center
- Co-ordinates call setup
- One MSC control several BSC
Switching Subsystem

HLR: Home Location Register
- Database of all subscribers information
Switching Subsystem

AUC: Authentication center
- Manage the security data for subscriber authentication
Switching Subsystem

EIR: Equipment Identity Register
- Database of all Mobile Equipments
Switching Subsystem

VLR: Home Location Register
- Database of all visitors information
Switching Subsystem

GMSC: Gateway MSC
- Gateway to the PSTN
Switching Subsystem

GIWU: Gateway Networking Unit
- For Communication with users outside GSM
OMS

- Operation and Maintenance Subsystem:
  - Network operation and maintenance
  - Subscription management: charging and billing.
  - Mobile equipment management
### Spectrum Sharing

<table>
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<th>Frequency</th>
<th>Service</th>
<th>Channels</th>
<th>Channel Width</th>
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<td>890 MHz</td>
<td>Uplink/Reverse Link: MS to BS</td>
<td>124</td>
<td>200 KHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>915 MHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>935 MHz</td>
<td>Downlink/Forward Link: BS to MS</td>
<td>124</td>
<td>200 KHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>960 MHz</td>
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124 Traffic Channels x 8 Slots/Ch = 992 simultaneous conversations

- 13 kbps speech coding data rate
- 9.6 kbps data rate
- Half rate coders being developed
FDD

$f \downarrow \Rightarrow \text{Att.} \downarrow$

BS

MS

Uplink

BS

MS

Downlink

890 915 935 960 MHz

Total Band=25 MHz
FDM

124 Carrier 200KHz apart

Ch1
F=890^M+100^k

Ch2
F=890^M+300^k

Ch124
F=915^M-100^k

MHz

Uplink

915

935

Downlink

890

960
FDM

Uplink

Downlink

Guard Band 100 KHz

Channel Spacing 200 KHz
FDM

124 Carrier 200KHz apart

Ch1(up)
F=890^M+100^k

Ch1(Down)
F=935^M+100^k

890 915 935
Uplink

960 MHz
Downlink
TDMA

- Every channel is shared among 8 users
- There are 124 Carriers each shared among 8 users.
- A User is assigned a certain time slot on a certain carrier \((C_n, TS_k)\)
$\left( C_n, TS_k \right)$

Frame

$C_0$

TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2

$C_1$

TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2

$C_{123}$

TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2 TS3 TS4 TS5 TS6 TS7 TS0 TS1 TS2
\((C_n, TS_k)\)
Channels Space (Copy Right)

\[
\begin{array}{cccccccccccccc}
C_0 & C_1 & C_2 & C_3 & f \\
TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 & TS0 \\
TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 & TS1 \\
TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 & TS3 \\
TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 & TS5 \\
TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 & TS7 \\
\end{array}
\]

Frame No
Channels

- **Physical Channel:**
  - It’s a time slot on any carrier \((C_n, TS_k)\).

- **Logical Channel:**
  - It’s a channel mapped on a physical channel to do a certain job
Channel Types

- Traffic Channels (TCH)
  - Used after call setup for transmission of speech.

- Control Channels (CCH)
  - Over head channels used for network administration and SMS.
Control Channels

- Broadcast Channels
- Common Control Channels
- Dedicated Channels
Control Channels

- Broadcast Channels
- Common Control Channels
- Dedicated Channels
Control Channels

- Broadcast Channels
  - (FCCH): Frequency Correction Channel
    - No Data just pure carrier
  - (SCH): Synchronization Channel
    - Broadcast Mobile Network Identity Code
    - Broadcast Base Station Identity Code
    - Broadcast Current frame number
  - (BCCH): Broadcast Control Channel
    - Broadcast location area Identity
    - Broadcast maximum output power
    - Broadcast $C_0$ of neighboring cells
Control Channels

- Broadcast Channels
- Common Control Channels
- Dedicated Channels
Control Channels

- Common Control Channels
  - (PCH): Paging Control Channel
    - Declare a coming call
  - (RACH): Random Access Channel
    - Used to initiate a call
    - Used to respond to a paging
  - (AGCH): Access Grant Channel
    - Used to assign a dedicated channel for further communication
Control Channels

- Broadcast Channels
- Common Control Channels
- Dedicated Channels
Control Channels

- Dedicated Channels
  - (SDCCH): Stand alone dedicated control Channel
    - Call setup procedure
    - SMS
  - (SACCH): Slow Associated control Channel
    - (↓) Setup power level and time advance
    - (↑) Inform the BS about received power level
  - (FACCH): Fast Associated control Channel
    - Stolen for urgent hardover
Burst

- It’s the information contained in one time slot
- 1 time slot = 0.577 m.sec.
- I frame = 8 time slots = 4.615 m.sec.
Mapping

Frame No

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

C0 C1 C2 C3

f

Stand alone Control Channel

Slow Associated Control Channel

Traffic Channel
Traffic Multiframe (26 Frames)

12 Traffic bursts

TTTTTTTTTTTTSTTTTTTTTTTTTTTTTT

Slow Associated:
- Power Control
- Time Advance

12 Traffic bursts

Idle:
- Reserved for future use

It’s repeated on $C_0$, $T S_{2-7}$ and all TS’s on all other carriers
Control Multiframe (51 frames)

$C_0$, $T S_0$:

10 bursts

FSBBBBCCCCFSCCCCCC

10 bursts

10 bursts

FSSCCCCIC

Idle
Control Multiframe (51 frames)

\[ C_0, T S_1 : \]

48 bursts 3 bursts

D0 D1 D2 D3 D4 D5 D6 D7 S0 S1 S2 S3 I

48 bursts 3 bursts

D0 D1 D2 D3 D4 D5 D6 D7 S4 S5 S6 S7 I

D: Stand alone (Call setup – SMS)
S: Slow Associated (Power Level-Time Advance)
TDMA Frame Structure

- 1 time slot = \(15/26 \text{ m.sec}\)
- 1 frame = 8 time slots = \(120/26 \text{ m.sec}\)
- 1 traffic multiframe= 26 frame= \(120 \text{ m.sec}\)
- 1 Control multiframe= 51 frame= \(235 \text{ m.sec}\)
- 1 Super frame= 51 traffic*26 frame
  \[= 1326 \text{ frames} = 6.12 \text{ sec}\]
- 1 hyperframe= 2048 superframe
  \[= 3 \text{ hours 28 minutes 53.76 sec}\]
• Air Interface

- Rate = 270 kbps

- 1 of 8 slots & 12 of 13 frames are used,
  Rate = 270*(1/8)*(12/13) = 31.15 kbps

- 114 bits of 156.25 bits are useful,
  Rate = 31.15*(114/156.25) = 22.73 kbps

- 9.73 kbps used for Error Correction,
  Rate = 22.73 - 9.73 = 13 kbps
C₀ is called the beacon and is transmitted with the maximum available power in the cell.

There is a 3 time slots time shift between the uplink and the downlink, this simplify the circuits and enable using one antenna and a duplexer.
Allocated GSM Frequency Bands

GSM900:
- up: 890~915MHz
- down: 935~960MHz
- duplex interval: 45MHz
- bandwidth: 25MHz
- frequency interval: 200KHz

EGSM900:
- up: 880~890MHz
- down: 925~935MHz
- duplex interval: 45MHz
- bandwidth: 10MHz
- frequency interval: 200KHz

GSM1800:
- up: 1710-1785MHz
- down: 1805-1880MHz
- duplex interval: 95MHz
- working bandwidth: 75MHz
- frequency interval: 200KHz

GSM1900MHz:
- up: 1850~1910MHz
- down: 1930~1990MHz
- duplex interval: 80MHz
- working bandwidth: 60MHz
- frequency interval: 200KHz
The multi-path propagation of radio signals causes magnitude fading and delay time.

- **Space Diversity** (antenna diversity)
- **Polarization Diversity** orthogonal polarization diversity. horizontal polarization and vertical polarization.
- **Frequency Diversity**
  The working principle of this technology is that such fading won’t take place on the frequency outside the coherence bandwidth of the channel.