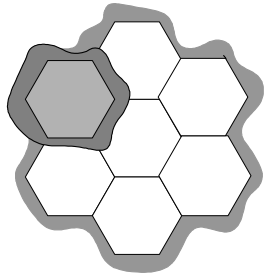
Cellular systems

Purpose:

To provide network access to a large number of fixed or mobile users

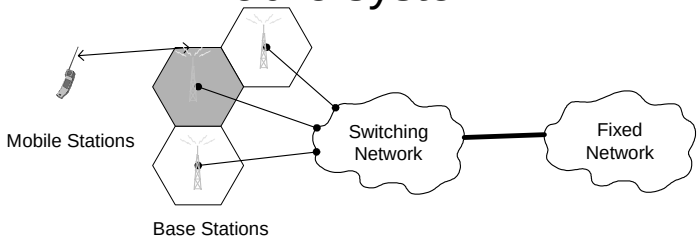
(location of the users *a priory* not known)

- Two way link to the users (duplex links)
- The signal strength deteriorates together with distance.
- Every transmitter can offer only limited amount of simultaneous radio links to the end-users.
- Cellular concept:
  - large area is divided into a number of sub-areas - cells.
  - Each cell has its BS which is able to provide a radio link for number of simultaneous users.



A clusters of cells in a cellular network

Architecture of a infrastructure based mobile system



Basic structure of a cellular network

- Large area is divided into a number of sub-areas - cells.
- Each cell has its BS which is able to provide a radio link for number of simultaneous users.
  - Each terminal is assigned to a BS
  - Coverage requirements
  - Service requirements
- Fixed network structure (not Ad-Hoc)

Coverage area: 1

- The area where BS can be accessed is called service area
  - depends on the radio propagation
  - depends on the load in the network (interference WCDMA)
  - depends on the network planning
    - Service area might have ``holes''
    - Service from different BS may overlap
- Coverage area:

  a fraction of the service area where communication with some required quality is possible.

Coverage area: 2

- Population availability :

  probability that some randomly selected user can be provided with adequate communication service depends on the radio propagation

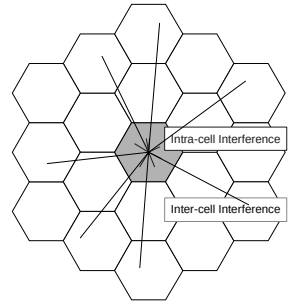
  - depends on the load in the network (interference WCDMA)
  - depends on the network planning
  - can be calculated as a weighted sum with the location probability and service quality

Challanges for a cellular system

- Problems
  - Interference due to the cellular structure, inter- and intra-cell interference
  - Mobility handling
  - Cell based radio resource scarcity
- Physical environment related limitations
  - Rang, Coverage limitations
    - Environment, antenna height, tx power, agility of the system
- Usage related limitations
  - Capacity related limitations
    - unpredicted: user demand, data rate, network load,
  - Network load related to the interference level

Interference

- Assume the asynchronous users sharing the same bandwidth and using the same radio base station in each coverage area or cell.
- Intra-cell/co-channel interference due to the signal from the other users in the home cell.
- Inter-cell/adjacent channel interference due to the signal from the users in the other cell.
- Interference due to the thermal noise.



Inter-cell and intra-cell interference in a cellular system

Methods for reducing interference:

- Frequency reuse: in each cell of cluster pattern different frequency is used
  - By optimising reuse pattern the problems of interference can be reduced significantly, resulting in increased capacity.
- Reducing cell size: in smaller cells the frequency is used more efficiently.
- Multilayer network design: macro-, micro-, pico-cells

Signal and interference

P Signal received at the BS

I_j Spectral density of interference from other users in the cell

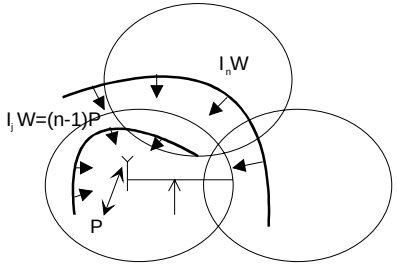
I_n Spectral density of interference from users in other cells

N_0 Thermal noise spectral density

$P = E_b P_b$

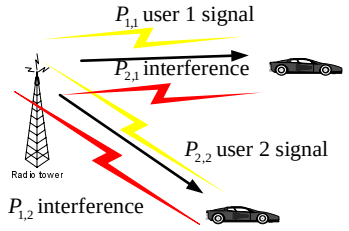
E_b Energy per bit of data

R_b data rate



$$CIR = \frac{P}{(I_j + I_n + N_0)} = \frac{E_b}{I_0}\frac{R_b}{W}$$

Interference in the network

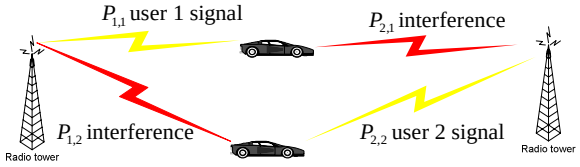


$$SIR_1 = G\frac{P_{1,1}}{P_{2,1} + N_0} \quad SIR_2 = G\frac{P_{2,2}}{P_{1,2} + N_0}$$

G processing gain

$$CIR_1 = \frac{P_{1,1}}{I_j + I_n + N}$$

Interference in one cell



Interference in multiple cells

Capacity estimation in a CDMA cell

$$-\frac{P_{0,0}}{CIR} + P_{1,0} + \ldots + P_{K_0,0} + \sum_{j=1}^{N}\sum_{k=1}^{K_j-1} P_{k,j} + \eta = 0$$

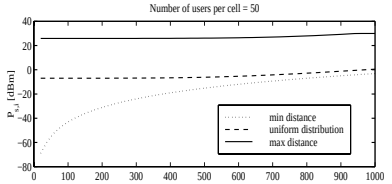
$$P_{0,0} - \frac{P_{1,0}}{CIR} + \ldots + P_{K_0,0} + \sum_{j=1}^{N}\sum_{k=1}^{K_j-1} P_{k,j} + \eta = 0$$

$$\vdots$$

$$P_{0,0} + P_{1,0} + \ldots - \frac{P_{K_0,0}}{CIR} + \sum_{j=1}^{N}\sum_{k=1}^{K_j-1} P_{k,j} + \eta = 0$$

Impact of uncertainties to the capacity in the cell

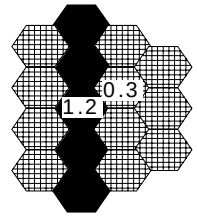
- Location of users in the cell
  - depending where users are located in the cell they get different interference from other cells and capacity varies



- Speed of users
  - target CIR function of speed
  - conditions in the cell vary with users movements
- Data rates
  - n times voice datarate corresponds to n users transmitting from that location. ("high nonuniformity")

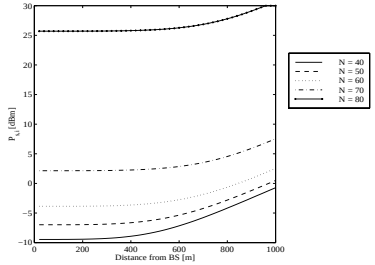
Soft Capacity

- surrounding cells lightly loaded
- less interference to the heavily loaded cell
- capacity to heavily loaded cell can be increased



Cell breathing

- Reasons
  - same spectrum for all users
  - power control
  - interference depends on location of users



- Outcome
  - system capacity sensitive to instantaneous conditions in the cell
  - for "bad" users configuration the demanded capacity will be more than available capacity
  - all users increase their transmission power
  - some users reach their available power and CIR requirement for them will be violated

Classification

- Range limited systems
  - The distance between BS is too small
    - too high attenuation in the system
- Interference limited systems.
  - Load in the system too high
  - QOS difficult to satisfy

Mobility

- Mobility provides for the end-user the possibility of being reachable anywhere and any time

The mobility is provided through:

- Handover: guarantees that whenever the mobile is moving from one BS area/cell to another, the signal is handed over to the target BS.

When there is no continuous active radio link between mobile and BS the mobility is supported by:

- Location update: user registers in the network that it can be found in given area. Mobile always initiates the location update procedure.
- Paging: indication to the user about the the need for transaction. Paging procedure is always initiated by the network.

Interference control solutions

- Standards
  - Split the spectrum
  - In time/ in space
- Dynamic handling
  - GSM
  - WCDMA
  - Flash OFDM
  - Dect

Regulation

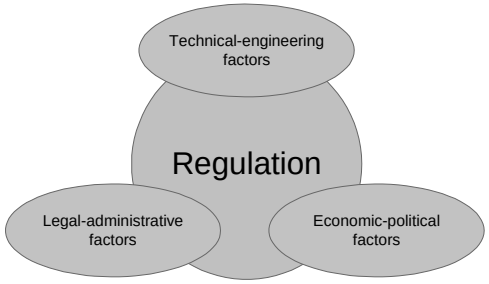
Legal-administrative aspects:

- Spectrum allocation.
- Technical standardisation.

Economic-political aspects:

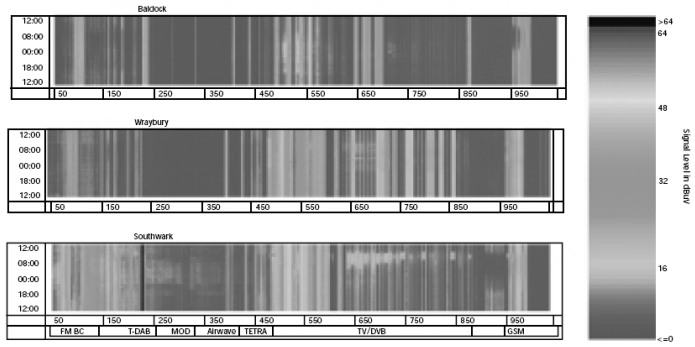
The spectrum made available such that:

- System providers and users are satisfied.
- Spectrum efficiently used.



Factors in the regulation process

Spectrum utilization

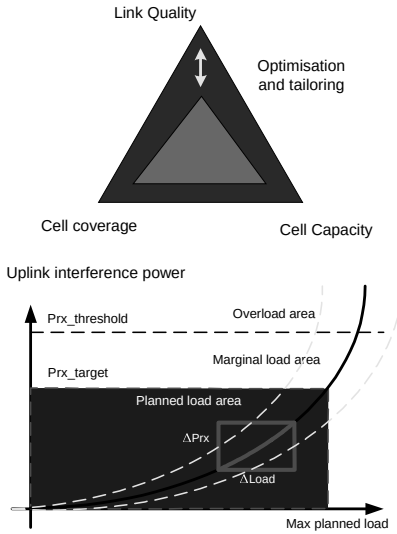


Spectrum utilization
(from IEE review May 2005)

Cellular network

- Why such high utilization in the cellular networks
  - Cellular structure
  - Separation of the user signals.
  - Attenuation, orthogonality, decoding,
  - Multiplexing methods
- Dynamic resource control

Changing Capacity



RRM purpose.

- Ensure planned coverage for each service.
- Ensure required connection quality.
- Ensure planned (low) blocking.
- Optimise the system usage in run time.

Real time RRM and Optimisation functions.

- Interference measurements.
- Soft capacity utilisation.
- Scheduling in radio interface.
- Actions to load change.
- Real time interference minimisation:
  - Handover control.
  - Service prioritisation.
  - Connection parameter settings.
  - Admission control.

Resources to be managed

- Radio frequence spectrum
- Orthogonality
- Power
  - Data speed
  - Data processing compexity
- Costs

Radio Resource Management targets

- Quality of service
- Contracts - guarantees for certain level of service
- Mapping of service requirements to various technical QOS requirements: e-q
  - error performance
  - delay
  - data rate (throughput)
- Non RT v. RT.
  - Guaranteed minimum throughput
  - Utilize all available throughput at any time
  - Guaranteed constant data rate & delay

Performance measures

- Coverage
- Outage
  - interference different in uplink downlink
- Quality requirements

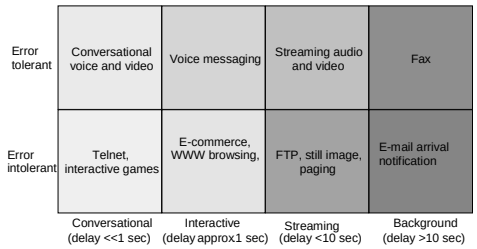
Evolution from voice to data

- Many data applications are extremely bursty
  - Voice users have fixer rate demand over relatively long time
- Voice has relatively tight latency requirements
  - Data application have wide range of latency requirements

Information quality

- **Maximum transfer delay:** Transfer delay is the time between the request to transfer the information at one access point to its delivery at the other access point.
- **Delay variation:** The delay variation of the information received information over the bearer has to be controlled to support real-time services.
- **Bit Error Ratio:** The ratio between incorrect and total transferred information bits.
- **Data rate:** The data rate is the amount of data transferred between the two access points in a given period of time.

UMTS QoS Classes



- Conversational: end-to-end delay is low and the traffic is symmetric of nearly symmetric.
  - Speech, Video telephony, … .
- Streaming: data is transferred such that it can be processed as a steady continuous stream.
  - Video, audio, … .
- Interactive: interaction between human or machine and remote equipment.
  - Web browsing, tele-mechanics, ...
- Background: non real time data traffic.
  - email … .

QoS requirements

	Real Time (Constant Delay)	Non Real Time (Variable Delay)
Operating environment	**BER/Max Transfer Delay**	**BER/Max Transfer Delay**
Satellite (Terminal relative speed to ground up to 1000 km/h for plane)	Max Transfer Delay less than 400 ms BER 10-3 - 10-7 (Note 1)	Max Transfer Delay 1200 ms or more (Note 2) BER = 10-5 to 10-8
Rural outdoor (Terminal relative speed to ground up to 500 km/h) (Note 3)	Max Transfer Delay 20 - 300 ms BER 10-3 - 10-7 (Note 1)	Max Transfer Delay 150 ms or more (Note 2) BER = 10-5 to 10-8
Urban/ Suburban outdoor (Terminal relative speed to ground up to 120 km/h)	Max Transfer Delay 20 - 300 ms BER 10-3 - 10-7 (Note 1)	Max Transfer Delay 150 ms or more (Note 2) BER = 10-5 to 10-8
Indoor/ Low range outdoor (Terminal relative speed to ground up to 10 km/h)	Max Transfer Delay 20 - 300 ms BER 10-3 - 10-7 (Note 1)	Max Transfer Delay 150 ms or more (Note 2) BER = 10-5 to 10-8

NOTE 1; There is likely to be a compromise between BER and delay.
NOTE 2; The Max Transfer Delay should be here regarded as the target value for 95% of the data.
NOTE 3; The value of 500 km/h as the maximum speed to be supported in the rural outdoor environment was selected in order to provide service on high speed vehicles (e.g. trains). This is not meant to be the typical value for this environment (250 km/h is more typical).

End-user performance expectation conversational/real time traffic

Medium	Application	Degree of symmetry	Data rate	Key performance parameters and target values		
				End-to-end One-way Delay	Delay Variation within a call	Information loss
Audio	Conversational voice	Two-way	4-25 kb/s	<150 msec preferred <400 msec limit Note 1	< 1 msec	< 3% FER
Video	Videophone	Two-way	32-384 kb/s	< 150 msec preferred <400 msec limit Lip-synch : < 100 msec		< 1% FER
Data	Telemetry - two-way control	Two-way	<28.8 kb/s	< 250 msec	N.A	Zero
Data	Interactive games	Two-way	< 1 KB	< 250 msec	N.A	Zero
Data	Telnet	Two-way (asymmetric)	< 1 KB	< 250 msec	N.A	Zero

End-user Performance Expectations - Interactive Services

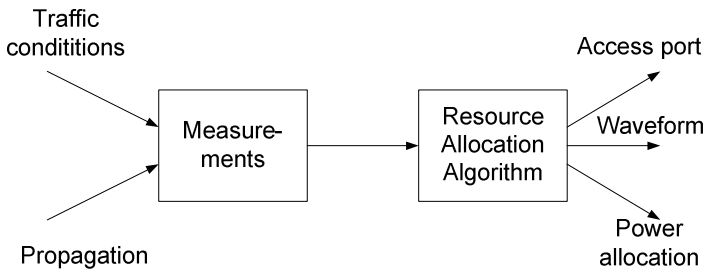
Medium	Application	Degree of symmetry	Data rate	Key performance parameters and target values		
				One-way Delay	Delay Variation	Information loss
Audio	Voice messaging	Primarily one-way	4-13 kb/s	< 1 sec for playback < 2 sec for record	< 1 msec	< 3% FER
Data	Web-browsing - HTML	Primarily one-way		< 4 sec /page	N.A	Zero
Data	Transaction services – high priority e.g. e-commerce, ATM	Two-way		< 4 sec	N.A	Zero
Data	E-mail (server access)	Primarily One-way		< 4 sec	N.A	Zero

End-user Performance Expectations - Streaming Services

Medium	Application	Degree of symmetry	Data rate	Key performance parameters and target values		
				One-way Delay	Delay Variation	Information loss
Audio	High quality streaming audio	Primarily one-way	32-128 kb/s	< 10 sec	< 1 msec	< 1% FER
Video	One-way	One-way	32-384 kb/s	< 10 sec		< 1% FER
Data	Bulk data transfer/retrieval	Primarily one-way		< 10 sec	N.A	Zero
Data	Still image	One-way		< 10 sec	N.A	Zero
Data	Telemetry - monitoring	One-way	<28.8 kb/s	< 10 sec	N.A	Zero

Performance criteria

- Capacity
  - number of subscribers served
  - Bitrate/ Bandwidth provided
- Quality
  - BER
  - Delay
- Service Probability
  - coverage
  - outage probability
  - Blocking, service denial

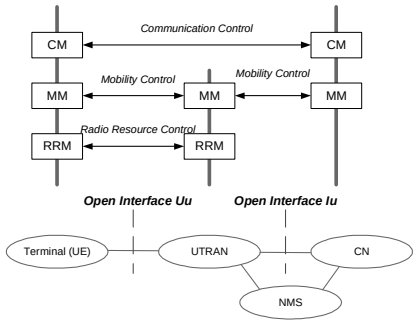


General resource allocation methods

- Static resource allocation
  - Allocation is based on the prior statistics
    - Channel conditions
    - Load conditions
    - QoS requirements
- Dynamic resource allocation
  - Measurements rate is high enough to track changes in the network

Resource Management Architecture in WCDMA

- Communication Management: functions and procedures related to the user connections.
- Mobility Management: functions and procedures related to mobility and security.
- Radio Resource Management: algorithms related to the radio resource.
- The functions are related to the control mechanisms:
  - Communication Control.
  - Mobility Control.
  - Radio Resource Control.



RRM methods

Network based functions.

- Admission control (AC).
  - Handles all new incoming traffic. Check whether new connection can be admitted to the system and generates parameters for it.
  - Occurs when new connection is set up as well during handovers and bearer modification.
- Load control (LC).
  - Manages situation when system load exceeds the threshold and some counter measures have to be taken to get system back to a feasible load.
- Packet scheduler (PS).
  - Handles all non real time traffic, (packet data users). It decides when a packet transmission is initiated and the bit rate to be used.
- Resource Manager (RM).
  - Controller over logical resources in BTS and RNC and reserves resources in terrestrial network.

Connection based functions.

- Handover Control (HC).
  - Handles and makes the handover decisions.
  - Controls the active set of BS of MS.
- Power Control (PC).
  - Maintains radio link quality.
  - Minimise and control the power used in radio interface.