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Cellular Network Planning and Optimization Part V: GSM

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GSM Briefly

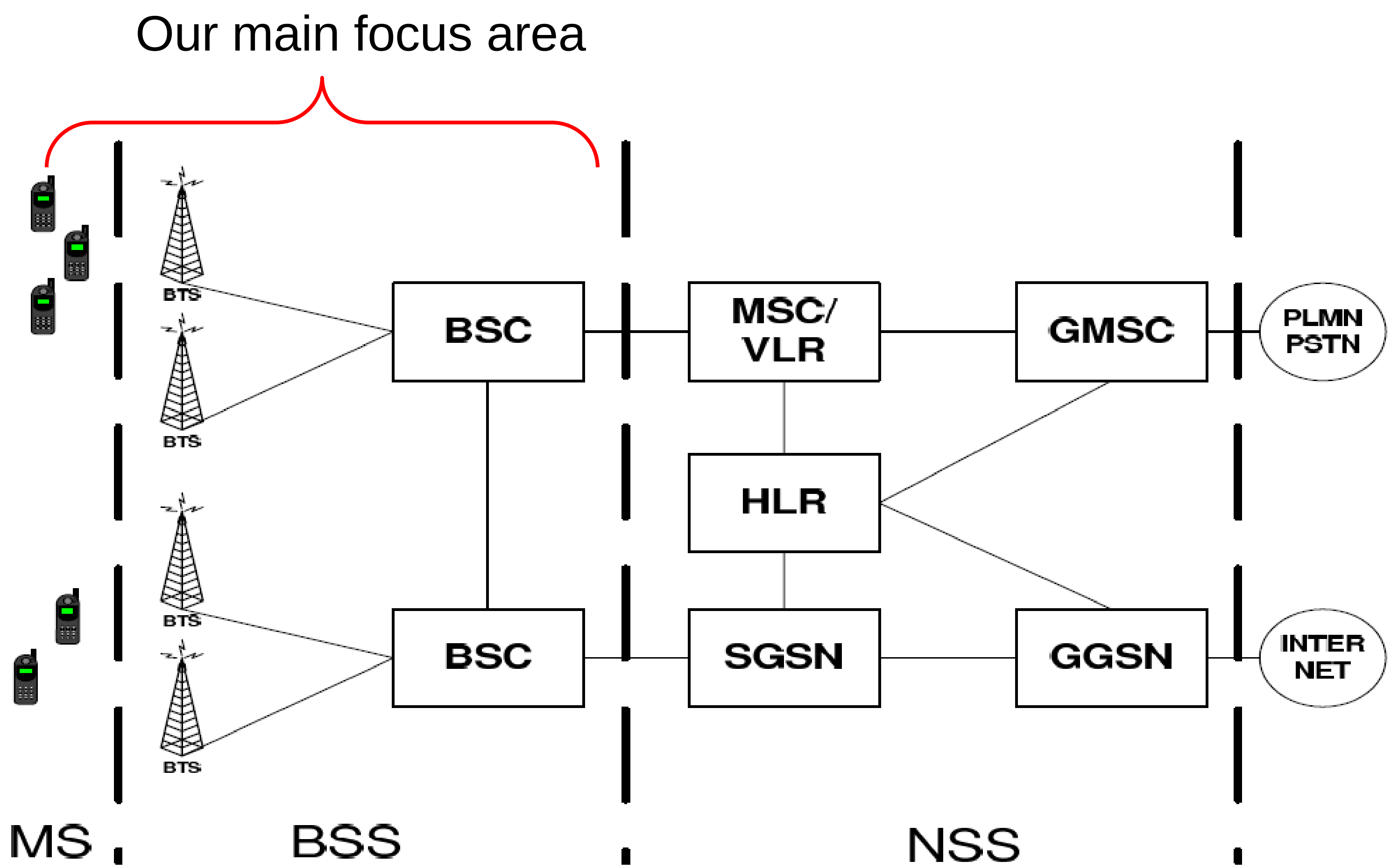
General

- GSM was the first digital cellular system.
  - GSM was launched in 1992
  - Over 2 billion subscribers worldwide
  - Over 600 million subscribers in Europe
- Conventional GSM voice is Circuit Switched (CS)
  - Call occupies the channel during the duration of the call
- The latest standard phase includes
  - General Packet Radio Service (GPRS)
  - Enhanced Data Rates for GSM (EDGE)
  - GPRS and EDGE are packet switched systems

GSM Spectrum

- Originally GSM operated only in 900 MHz band
  - Later extended to 1800 MHz and 1900 MHz bands
  - Most GSM networks operate in the 900 MHz or 1800 MHz bands
  - Also 450MHz band is used in some countries
- Spectrum example
  - In so-called primary GSM 900 MHz the uplink frequency band is 890–915 MHz, and the downlink frequency band is 935–960 MHz.
  - This 25 MHz bandwidth is subdivided into 124 carrier frequency channels, each spaced 200 kHz apart.

GSM System architecture



Base Station Subsystem (BSS)

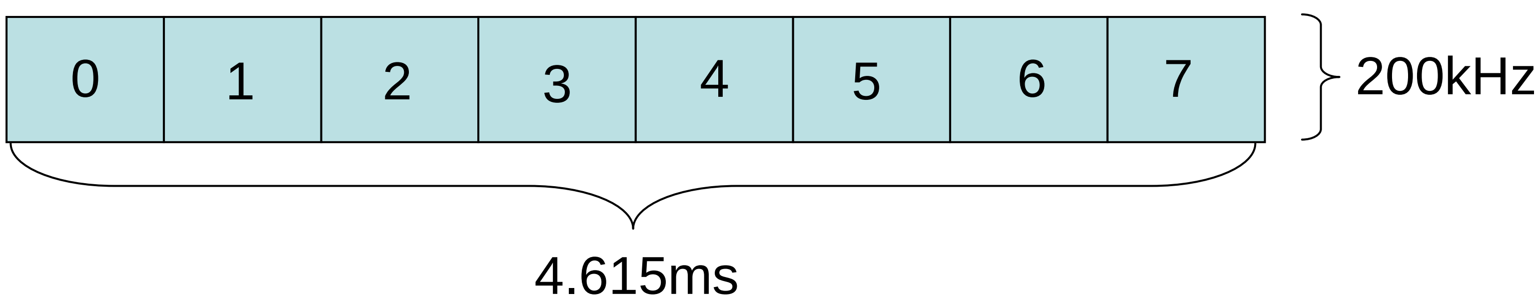
- Base Transceiver Station (BTS)
  - Radio interface control between BTS and MS
  - Transmission execution, channel encryption, diversity, frequency hopping
- Base Station Controller (BSC)
  - Handover control, channel assignments, collection of cell configuration data etc

Network Switching System (NSS)

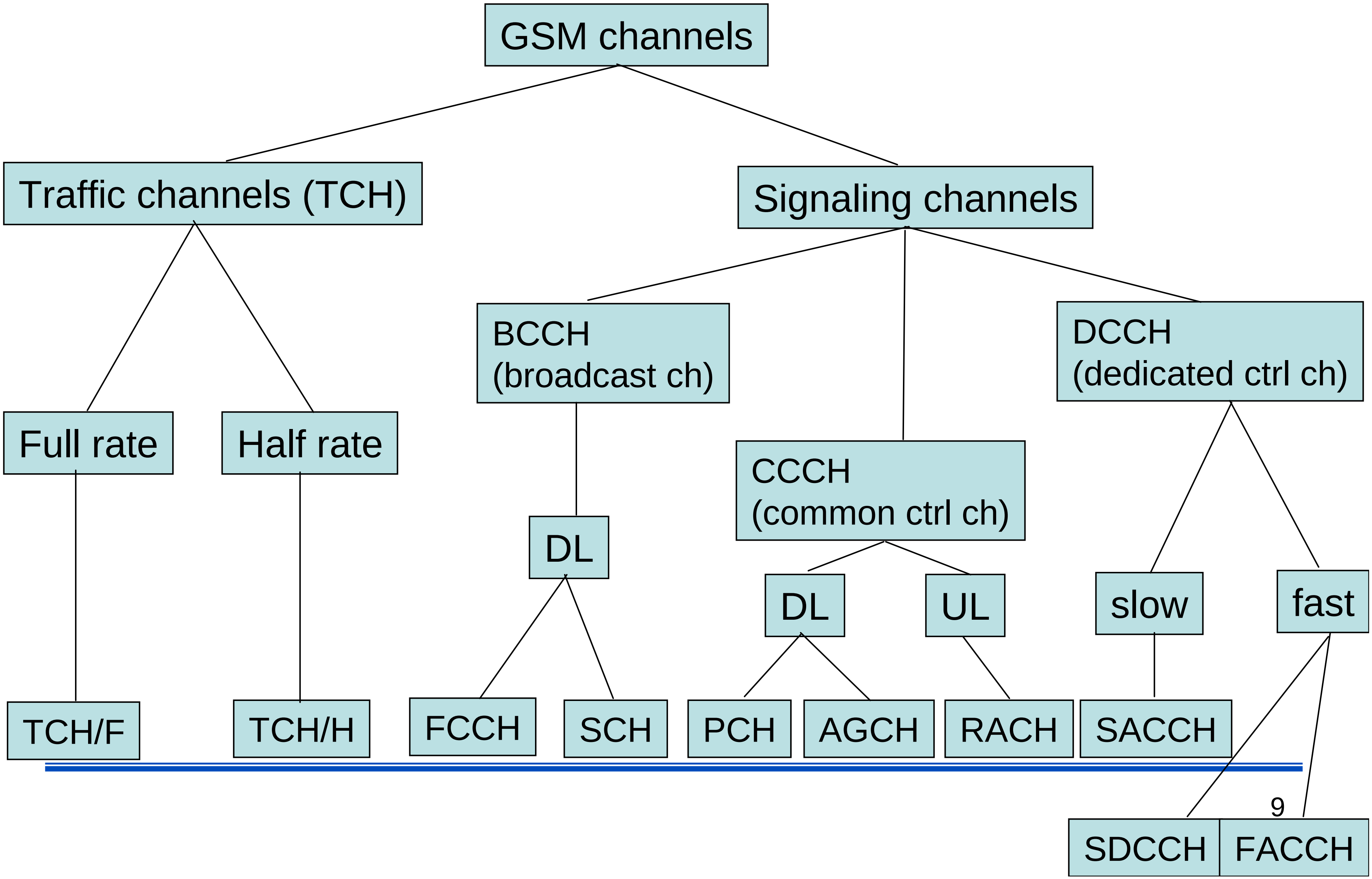
- Mobile Switching Center (MSC)
  - Call switching; MSC control calls between BSS and other networks (PSTN, PLMN)
- Gateway MSC (GMSC)
  - Executes gateway functions for MSC
- Home Location Register (HLR)
  - Database that contains information of operators own subscribers.
- Visitor Location Register (VLR)
  - Database that contains information of visiting subscribers. There is one VLR per MSC
- Serving GPRS Support Node (SGSN)
  - Handles packet data from GPRS/EDGE
- Gateway GPRS Support Node (GGSN)
  - Gateway functions for SGSN

GSM Frame structure

- Time Division Multiplexing (TDMA) is used
  - 8 full-rate or 16 half-rate speech channels per 200kHz channel. There are eight radio timeslots within a radio frame.
  - Half rate channels use alternate frames in the same timeslot. The channel data rate is 270.833 kbit/s, and the frame duration is 4.615 ms TDMA/FDMA scheme
  - On top of this frame structure there is multiframe, superframe and hyperframe structures.



Logical channel structure



Channel structure

- Traffic channels (our focus is in speech service)
  - Full rate: 9.6 kbps for speech (1 time slot/radio frame)
  - Half rate: 4.8 kbps for speech (1 time slot in alternating radio frames)
- BCCH
  - Provides general cell specific information
  - MS can register to cell only if it can detect BCCH

From our perspective TCH and BCCH are most important.

Channel structure

- FCCH = Frequency correction channel
- SCH = Synchronization channel
- PCH = Paging channel
- AGCH = Access grant channel
- RACH = Random access channel
- SACCH = Slow assosiated control channel
- SDCCH = Stand-alone dedicate control channel
- FACCH = Fast assosiated control channel

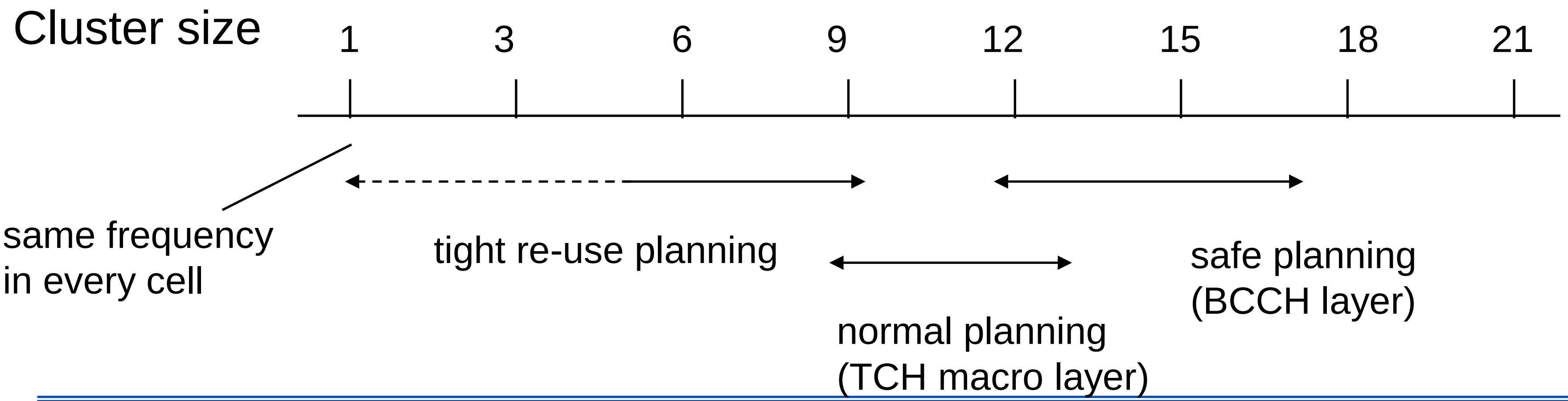
Network planning issues in GSM

Frequency reuse

- Cluster sizes up to K=12 or even more are used in some extreme cases.
  - Due to increasing traffic cluster sizes tend to decrease => replanning and optimization of present networks is ongoing activity
  - Cluster size K=1 is not used due to high co-channel interference
- BCCH and TCH may have different cluster sizes
  - BCCH is crucial for connection => larger cluster sizes

Frequency reuse

- Frequency reuse rate
  - Measure for effectiveness of frequency plan
  - Trade-off: Effectiveness vs interference
- Multiple re-use rates increase effectiveness of frequency plan
  - Compromise between safe, interference free planning and effective resource usage



TRX

- A transmission/reception facility is called as a transceiver (TRX).
  - Typically, a cell has several TRXs, and one frequency is allocated to each TRX. The capacity of a cell can therefore be measured in the number of TRXs.
- A time slot that carries user traffic is also called as Traffic Channel (TCH).
  - For user speech service 1 time slot/radio frame is reserved in TCH/F and 1 time slot in alternating radio frames in TCH/H
- For administrative purposes, e.g. providing mobile terminals with control information, there is also one BCCH in each cell.
  - This channel consumes one time slot (slot #0), and is operated by one TRX in each cell.
  - In physical BCCH there are at least FCCH and SCH + basic system related information

SINR and TX powers

- According to GSM specifications C/I > 9dB for nominal performance.
  - C/I = carrier to interference power ratio Here interference term contains also AWGN.
- MS transmission power
  - In GSM850/900 TX power is between 0.8W and 8W. Usual value is 2W = 33dBm
  - In GSM1800/1900 TX power is between 0.25W and 4W
- BS transmission power
  - In GSM-900 and 1800 TX normal BTS (= macro BTS) power is usually between 5W and 40W = 46 dBm.
  - Output powers in micro BTS's are between 14dBm and 32dBm
  - For macro BTS power is measured in combiner input
  - For micro BTS power is measured in antenna connector

Example

- Assume that
  - Operator has 5 MHz available for GSM
  - Operator makes the TCH frequency plan according to specifications (SINR > 9dB) but add 6dB marginal for BCCH SINR.
  - Propagation exponent is 4, system is interference limited
- Problems
  - What are the cluster sizes for BCCH and TCH?
  - How many TRX's are needed
  - What is the number of TCH/F and TCH/H speech channels per cell?

Solution

- 5 MHz/200kHz = 25 subcarriers, 8 time slots in each => 200 time slots in total
- SINR for TCH = 9dB => Γ=7.943
- SINR for BCCH = 15dB => Γ=7.943
- Propagation exponent α = 4 => C(α) ~ 7
- Interference limited system => we can use equation

$$\Gamma \approx (\sqrt{3K})^{\alpha}\frac{1}{C(\alpha)} \approx \frac{9}{7}K^2 = 7.943 \quad \text{(TCH)}$$

- After solving K for TCH we find that K=2.4855
- Similarly we find for BCCH that K=4.959

Solution

- Closest cluster sizes from $\mathcal{K} = \{1, 3, 4, 7, 9, 12, \cdots\}$
  - For TCH cluster size = 3
  - For BCCH cluster size = 7
- One TRX can handle 1 subcarrier (200 kHz)
  - We need 1 BCCH-TRX/cell
  - K=7 for BCCH => 7 subcarriers needed for BCCH
  - There are 18 subcarriers left for TCH. Since K=3 for TCH we need 6 TRX/cell in addition to the one that is carrying BCCH
  - <u>In total we need 7 TRX/cell</u>
- Number of speech channels
  - TCH TRX's: 7x8 speech channels for full rate and 7x16 for half rate
  - BCCH-TRX: 7 speech channels for full rate and 14 speech channels for half rate
  - In total there will be 63 speech channels for full rate and 126 for half rate.

This is about the maximum capacity configuration for the operator

Sectorizing and range

- Three-sector sites are most common in GSM
  - Sectorization gives antenna gain in BS
- Maximum cell size is round 35 km
  - Cell size depends on the timing advance which is 232.47 μs in basic GSM system
  - Usually cell sizes are between few hundreds meters to few kilometers. Very large cells may occur e.g. in sea coasts where bunch of islands are covered by a single BS.

Cell categories

- Commonly used cell categories
  - Macro cell = cell where the base station antenna is installed on a mast or a building above average roof top level. Macro cells are common in all outdoor environments
  - Micro cell = cell where antenna is placed under roof top level. Micro cells are used in urban areas to cover few blocks of buildings
  - Pico cell = cell that admit coverage of some tens of meters (coverage can vary depending on the environment). Used indoors.

Indoor coverage

- Usually cheapest and most common way to provide indoor coverage is to use outdoor macro base stations for this purpose
  - = outdoor to indoor coverage.
  - Indoor users on the cell edge usually define the cell size since penetration loss due to buiding walls can be tens of decibels (usual value for penetration loss is 20dB)
- Indoor coverage may be provided also by indoor pico base stations.
  - Suitable in office buildings; each floor can be covered by few pico base stations
  - The large number of base stations may increase the network costs
- Radio repeaters and RF heads provide an other solution
  - In repeater distributed antennas (e.g. antenna/floor) are fed through power splitters
  - Repeater system applies an outdoor antenna that receives the outdoor BS signal after which the system repeates the signal from indoor antennas.

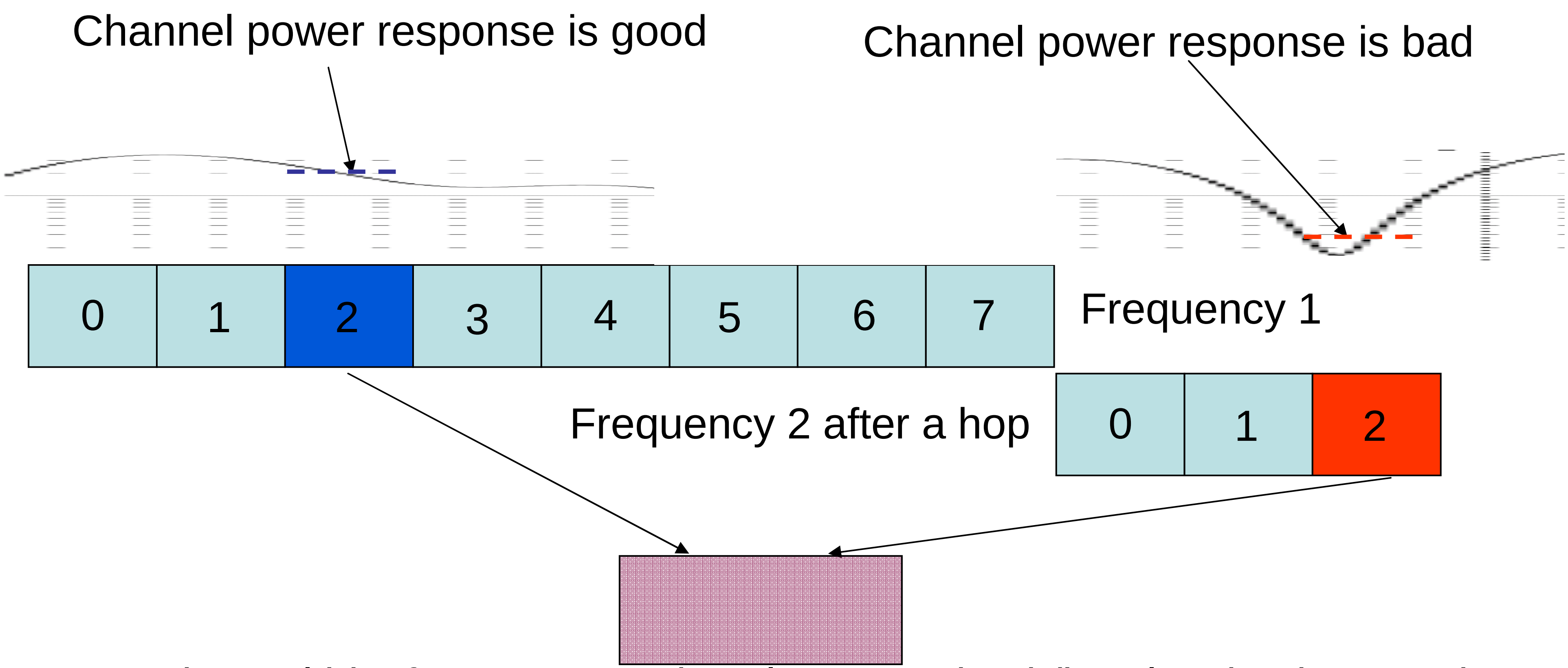
Frequency hopping (FH) in GSM

- FH means that a TRX shifts frequency at every new radio frame
  - => hopping is performed approximately 1/(4.615*0.001) = 217 times per second.
  - For a specific user, a new frequency is used from one time slot to the next.
- The advantages of FH are twofold
  - Frequency diversity
  - Interference diversity.
- The drawback with FH is that the network components become more complex and expensive.

FH diversity gain

- Transmitted signal is subject to fast fading due to multipath nature of the propagation.
- Especially, if the receiver is moving, the user will experience fading dips frequently, and the distance between the fading dips depends on the frequency used.
- Changing frequency continuously is one way to reduce the influence of fading dips and the probability of good link quality is increased. The advantage of using FH is that the channel will usually not suffer severe fading dips under longer time periods.
- The number of hopping frequencies is an important factor that affects the frequency diversity gain. Higher gain is achieved with more hopping frequencies, but more than 8 hopping frequencies give less improvement

FH diversity gain



Channel bits from consecutive slots are mixed (interleaving in TX unit and deinterleaving in RX unit) => fading is averaged and detection has better probability to be successfull

FH interference diversity gain

- Without FH, neighboring cells with co-channel frequencies to the carrier frequency will interfere continuously.
  - The interference can be severe for certain frequencies and may lead to information loss.
- FH means that different frequencies will interfere with the carrier at different time slots.
  - Instead of having a constant level of interference between two cells, the interference is spread among several frequencies.
  - For a specific carrier, only some time slots will suffer from high interference. From a system point of view, strong interferers are shared between users and so called interference averaging is achieved.
  - A GSM network can be planned for average interference instead of worst case interference.
  - The interference diversity gain is dependent on the number of hopping frequencies and interference levels from the interfering cells. A significant interference diversity gain is obtained with as little as 3 hopping frequencies.

FH Strategies

- **Cyclic FH**
  - In cyclic hopping, all interfering cells use the same hopping sequence, and a channel will be affected by the same interferers all the time. No interference diversity is obtained with cyclic hopping.
- **Random FH**
  - Random hopping uses sequences that are pseudo-randomly generated => interference diversity is obtained.
  - The physical ways to perform FH in a cell are baseband hopping and synthesized hopping.
  - In baseband hopping, every TRX is assigned to a fixed frequency, while the channel is shifted between the TRXs. The number of frequency carriers must be equal to the number of TRXs.
  - In synthesized hopping, channel stays at a certain TRX, while the TRX shifts among the available frequencies. In the latter method, the number of carriers is greater than or equal to the number of TRXs.
  - Since the number of frequencies can be more than the number of transceivers in a cell when synthesized hopping is used, the reuse factor can be changed while the number of TRXs is fixed.

FH Strategies

- There are two strategies for using the frequency band for the TCH and BCCH carriers
  - <u>In common band strategy</u> both TCH and BCCH carriers use the entire band, and a TCH can receive interference from both TCH and BCCH carriers.
  - <u>In dedicated band strategy</u> the frequency band is split into two parts, one for the TCH frequencies and one for the BCCH frequencies. In this strategy a TCH carrier can only be interfered by another TCH. FH is not performed at the TRXs that operate the BCCH.
  - Simulations have shown that dedicated spectrum bands give less interference than common band strategy which suffered from severe disturbance in the downlink. <u>It is easier to put extra TCH-TRX in an existing cell when dedicated bands are used since the BCCH frequency plan does not have to be changed.</u>

Frequency assignment problem

- Classical frequency assignment problem (FAP) belongs to the class of *NP*-complete problems, which means that the problem probably can not be solved in polynomial time.
- There exist two major approaches to deal with the FAP in wireless networks
  - **Fixed Channel Assignment (FCA).** In FCA, a channel is assigned to a connection beforehand and can not be changed on-line.
  - **Dynamic Channel Assignment (DCA).** In DCA the channels are changed on-line whenever the radio connection suffers from interference and the quality requirements are not fulfilled.

FCA vs DCA

- Fixed Channel Allocation (FCA)
  - This is conventional approach where each cell is allocated to a predetermined set of channels. Channels are allocated according to frequency plan
  - Radio resources (channels) can't be transferred between cells and network planning is usually done on 'worst case' basis => trunking loss since traffic load changes.
- Dynamic Channel Allocation (DCA)
  - Channels are not allocated permanently to different cells but BS allocates channels dynamically to coming calls.
  - DCA applies algorithm that take into account e.g.
    - Likelihood of blocking, co-channel interference, other cost functions
  - In extreme case all channels are available in each cell and DCA eliminates the need for frequency planning
  - Radio resource reuse is changing dynamically => higher trunking efficiency

Frequency assignment problem in FCA

- There exist several versions of FCA approach
  - **Minimum span FAP**. In the minimum span FAP, certain soft and/or hard restrictions are given for the quality of the network. These restrictions can be interference and separation requirements. The soft restrictions can be violated at some penalty cost, but the hard restrictions must be met. The objective is to minimize the difference between the minimum and maximum frequencies assigned, the span.
  - **Minimum order FAP**. Instead of minimizing the span of frequencies, the number of frequencies is minimized in minimum order FAP.
  - **Minimum blocking FAP**. The minimum blocking and minimum interference FAP (see below) use a fixed span of frequencies. In the minimum blocking FAP, the goal is to assign frequencies in such a way that the overall blocking probability of the network is minimized.
  - **Minimum interference FAP**. The objective is to minimize the total sum of interference in the network.

Frequency assignment problem in DCA

- All or almost all frequencies are available in each cell
  - Very general optimization problem faced
  - Like in FCA related FPA different approaches can be adopted (starting from blocking, interference or other measures)
  - The information change between base stations is slow => fast interference mitigation is difficult
  - Slow interference avoidance methods can be designed based on interference matrices.
  - Different companies have their own solutions

Simplified link budgets

Background information

- RX sensitivity (3GPP TS 05.05 V8.20.0 (2005-11))
  - GSM 900 MS:
    - for GSM 900 small MS -102 dBm
  - GSM 900 BTS
    - for normal BTS -104 dBm
    - for micro BTS from -87 down to -97 dBm depending on the BTS class
    - For pico BTS -88 dBm
  - DCS 1 800 MS
    - for DCS 1 800 MS -102 dBm (for some classes also -100 dBm)
  - DCS 1 800 BTS
    - for normal BTS -104 dBm
    - for micro BTS from -92dBm down to -102 dBm depending on the class
    - for pico BTS -95 dBm

Note: RX sensitivity is the the minimum received power for which the predefined SNR requirement is achieved.

Recall: SINR and TX powers

- According to GSM specifications C/I > 9dB for nominal performance.
  - C/I = carrier to interference power ratio Here interference term contains also AWGN.
- MS transmission power
  - In GSM850/900 TX power is between 0.8W and 8W. Usual value is 2W = 33dBm
  - In GSM1800/1900 TX power is between 0.25W and 4W
- BS transmission power
  - In GSM-900 and 1800 TX normal BTS (= macro BTS) power is usually between 5W and 40W = 46 dBm.
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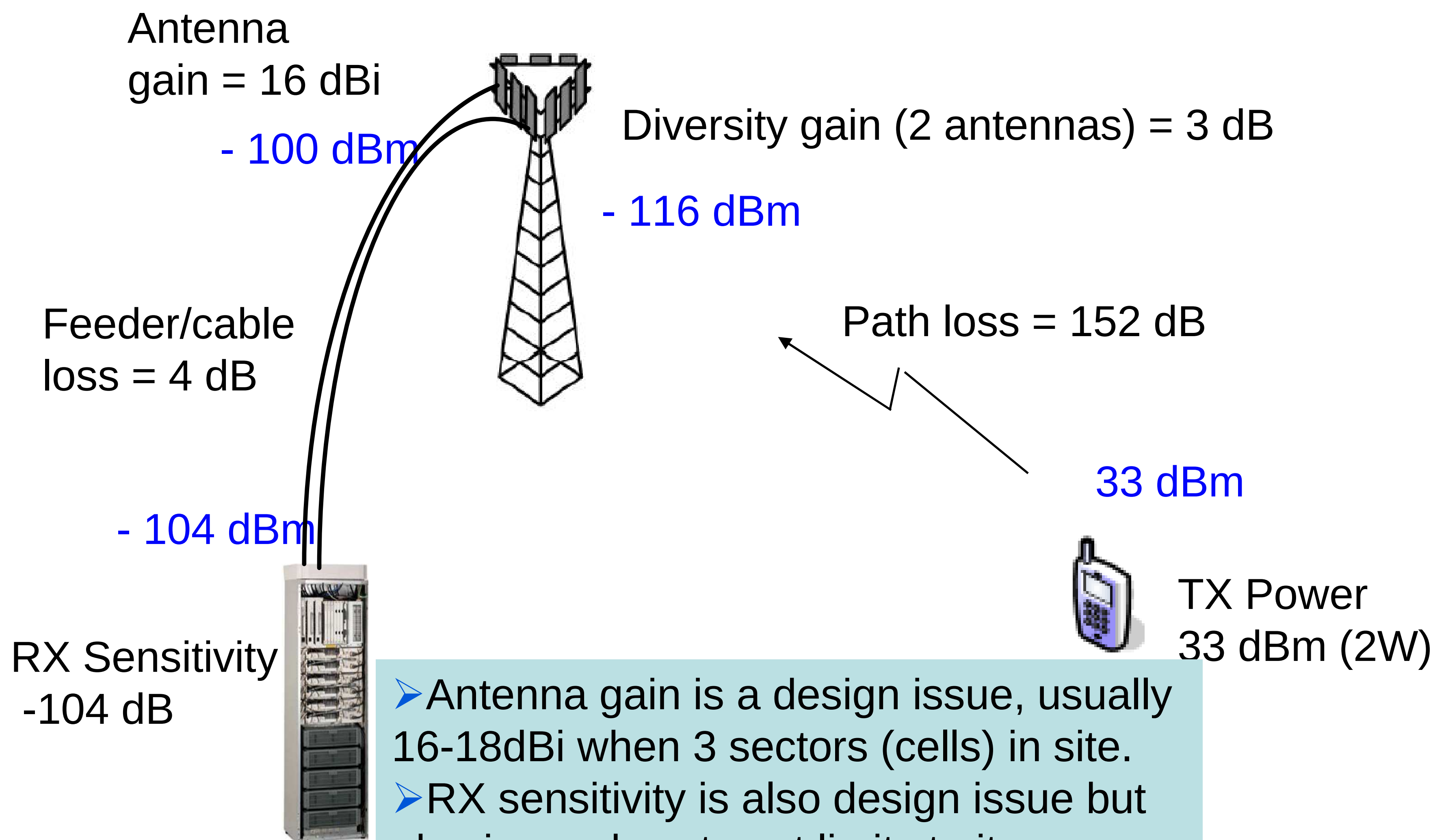
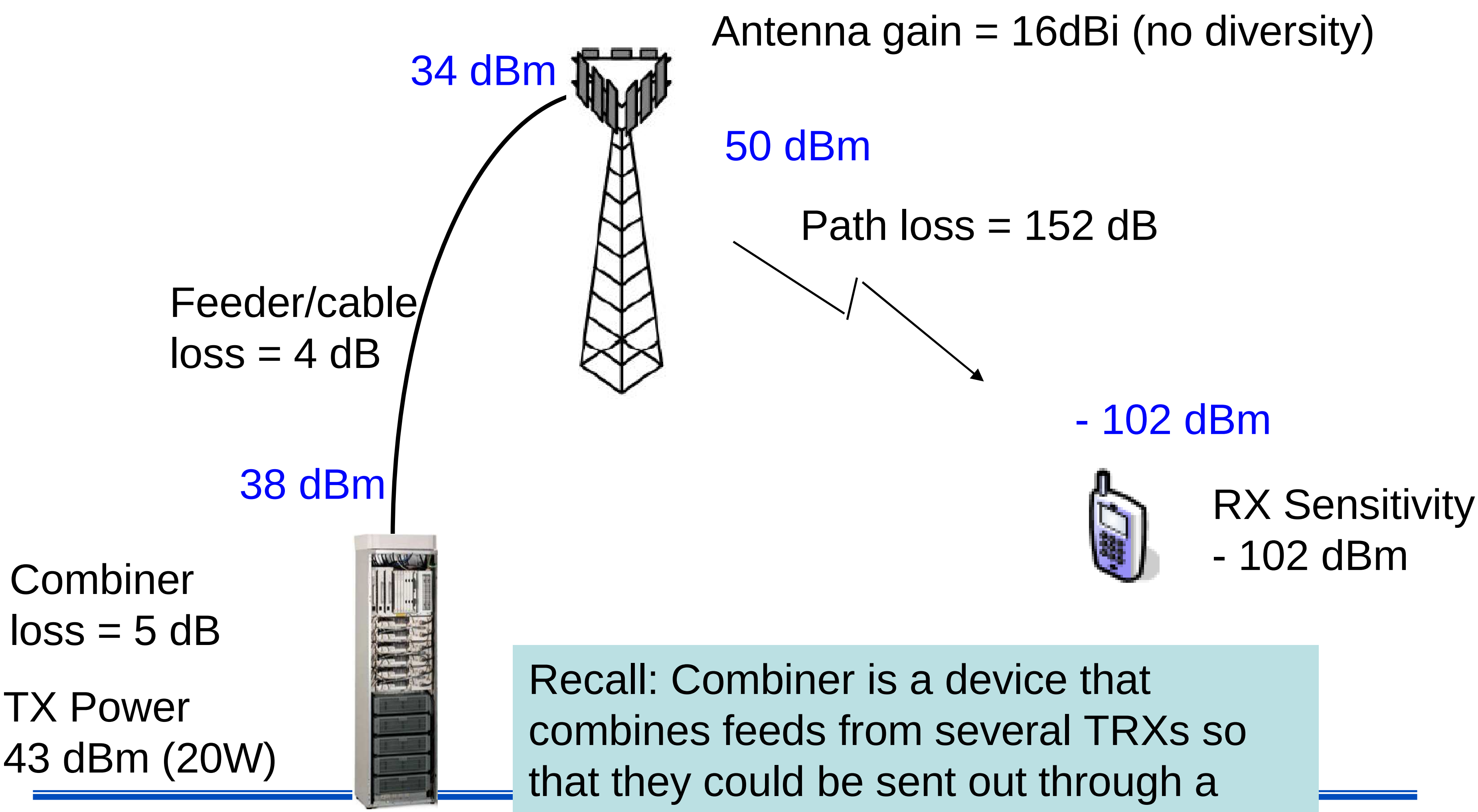
Simple UL link budget: Illustrative example



- Antenna gain is a design issue, usually 16-18dBi when 3 sectors (cells) in site.
- RX sensitivity is also design issue but physics and costs put limits to it.
- Neither interference nor shadow fading is taken into account here

Simple DL link budget: Illustrative example



Recall: Combiner is a device that combines feeds from several TRXs so that they could be sent out through a single antenna

Cell range

- After the maximum allowable path loss has been determined, the cell size can be evaluated
- Determination is done by using basic propagation prediction formulas
  - Okumura-Hata
  - Walfish-Ikegami
- We typically want to have 90% location probability over the cell area => shadow fading margin needs to be added accordingly.

Link budget test example

- We have made a simple excel tool for GSM link budget computation
- In the following we go through an example.
- It is suggested that all participants play with the tool (it can be loaded from course pages)
  - Learn how different parameters are computed
  - Examine the impact of parameteres like antenna hight etc

Link budget example/TX characteristics

	Downlink	unit	Uplink	unit
Transmitter power	20	W	2	W
	43.0103	dBm	33.0103	dBm
TX antenna gain	17.42531	dBi	0	dBi
TX cable loss	-4	dB	0	dB
TX Body loss	0	dB	-2	dB
Combiner loss	-4	dB	0	dB
Transmitter EIRP	**52.43561**	**dB**	**31.0103**	**dB**

Horizontal 3dB beam width	65	degrees
Horizontal gain	7.493795	dB
Number of dipoles	6	
Vertical gain (dBd)	7.781513	dBd
Vertical gain (dBi)	9.931513	dBi
Total antenna gain	**17.42531**	**dBi**

Link budget example/RX characteristics

	Downlink	unit	Uplink	unit
RX antenna gain	0	dBi	17.42531	dBi
RX sensitivity	102	dBm	104	dBm
RX Cable loss	0	dB	-4	dB
RX Body loss	-2	dB	0	dB
Diversity gain	0	dB	3	dB
Total receiver gain	**100**	**dB**	**120.4253**	**dB**
System gain	**152.4356**	**dB**	**151.4356**	**dB**

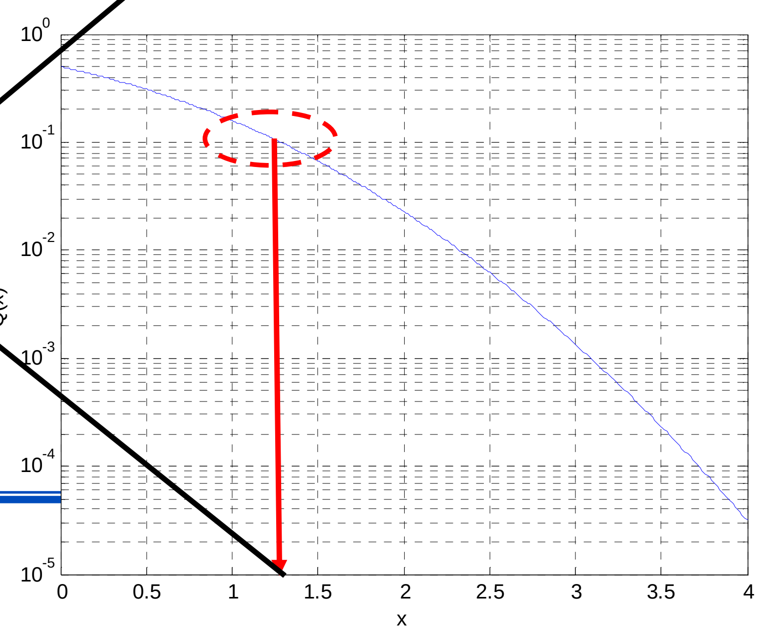
System gain defines the attenuation that system can tolerate

Link budget example/margins

	Downlink	unit	Uplink	unit
Coverage probability (cell edge)	0.9		0.9	
Shadow fading std deviation	6	dB	6	dB
Shadow Fading Margin	7.5	dB	7.5	dB
Indoor penetration loss	0	dB	0	dB
Total margin	7.5	dB	7.5	dB

Given coverage probability on cell edge (P)	0.9	
Shadow fading standard deviation	6	dB
1-P	0.1	
Closest 1-P in table	0.1	
Argument (inverse of Q)	1.25	
Shadow fading margin	**7.5**	**dB**

1-P(=Q)	Argument
0.5	0
0.4	0.25
0.3	0.5
0.22	0.75
0.17	1
0.1	1.25
0.07	1.5
0.04	1.75
0.023	2
0.01	2.25



Note: this is simplified approach. Usually we need to compute shadow fading margin based on predefined cell coverage probability

Allowed propagation loss

Allowed propagation loss = System gain - margins

There is slight imbalance between UL and DL

Allowed propagation loss	**144.9356 dB**	**143.9356 dB**

Allowed propagation loss defines how much system can stand propagation loss. Hence, we can next calculate the cell range

		Unit
Carrier frequency	1800	MHz
BS antenna height	25	m
MS antenna height	1.5	m
Parameter A	46.3	
Parameter B	33.9	
Parameter C	44.9	
MS antenna gain function (large city)	-0.00092	
Path loss exponent	3.574349	
Path loss constant	137.3351	dB
Downlink range	1.631697	km
Uplink range	1.529898	km
Cell range	**1.529898**	**km**

Okumura-Hata model has been used

Example exercise

- Assume GSM system such that
  - TX power in BS is 10W and 1W in MS
  - For BS antenna
    - Horizontal 3dB beam width is 60 degrees
    - Four dipoles are used to form vertical antenna beam
  - MS antenna gain is 0dBi
  - Cable loss is 3dB, combiner loss is 3.5dB
  - Body loss is 2.5dB
- Compute transmitter EIRP in both BS and MS
  - BS antenna gain is 16dBi and TX power is 40dBm (find out details). Then BS EIRP = 40dBm+16dBi-3dB-3.5dB = 49.5dBm
  - MS TX power is 30dBm and EIRP = 30dBm+0dBi-2.5dB = 27.5dBm
- It is useful to spend some time with link budget!

How to find detailed technical information

- GSM (and GPRS, EDGE, WCDMA, LTE) specifications are available on 3GPP pages
  - 3GPP = 3rd Generation Partnership Project
  - The original scope of 3GPP was to produce globally applicable Technical Specifications and Technical Reports for a 3rd Generation Mobile System based on evolved GSM core networks and the radio access technologies that they support (e.g. WCDMA, HSPA, etc).
  - The scope was subsequently amended to include the maintenance and development of the GSM Technical Specifications and Technical Reports including evolved radio access technologies (e.g. GPRS and EDGE).

Specifications define precisely the functionalities and requirements of MS, BS other network elements of 3GPP systems like GSM, WCDMA, …

Standardization

- In addition to ready specifications 3GPP databases contain technical discussion concerning to ongoing standardization of various topics
  - Related documents are not ‘easy reading’ but they contain latest technical ideas.
  - Companies like Nokia, NSN, Ericsson, Motorola, Samsung, Huawei and many others propose competing solutions (about which they have patent applications) in standardization documents (called contributes).
  - Once standard release is ready companies negotiate on their share of so-called ‘essential patents’ (patents related to standardized solutions).
  - The shares of patents give guidelines for cross-licensing between companies. Licensing contracts define how much manufacturer pay or receive fees when using the standardized technology in its products.
  - Some companies (those who are not doing standardization research/are not successful in it) may need to pay tens or even hundreds of millions of euros per year in order to have a right to use certain technologies in products they make.

Standardization documents

- 3GPP databases are mostly public
- Easies way to find technical documents
  - Google ‘3GPP’ and go to 3GPP main page
  - Click ‘Technical bodies’
    - You find TSG (Technical Specification Group) organization
    - Under ‘TSG GERAN’ you find GSM and its evolution (GPRS, EDGE) radio specifications
    - Under ‘TSG RAN’ you find WCDMA, (+HSDPA, HSUPA, LTE) radio specifications
- Also, if you know number of the specification/standardization document you can google it directly