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Cellular Network Planning and Optimization
Part VIII: WCDMA link budget

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WCDMA Network planning

High level objectives for the planning process

- Coverage
  - Guarantee the network ability to ensure the availability of the service in the entire service area.
- Capacity
  - To support the subscriber traffic with sufficiently low blocking and delay
- Quality
  - Linking the capacity and the coverage and still provide the required QoS.
- Costs
  - To enable an economical network implementation when the service is established and a controlled network expansion during the life cycle of the network.

WCDMA vs GSM, Network planning

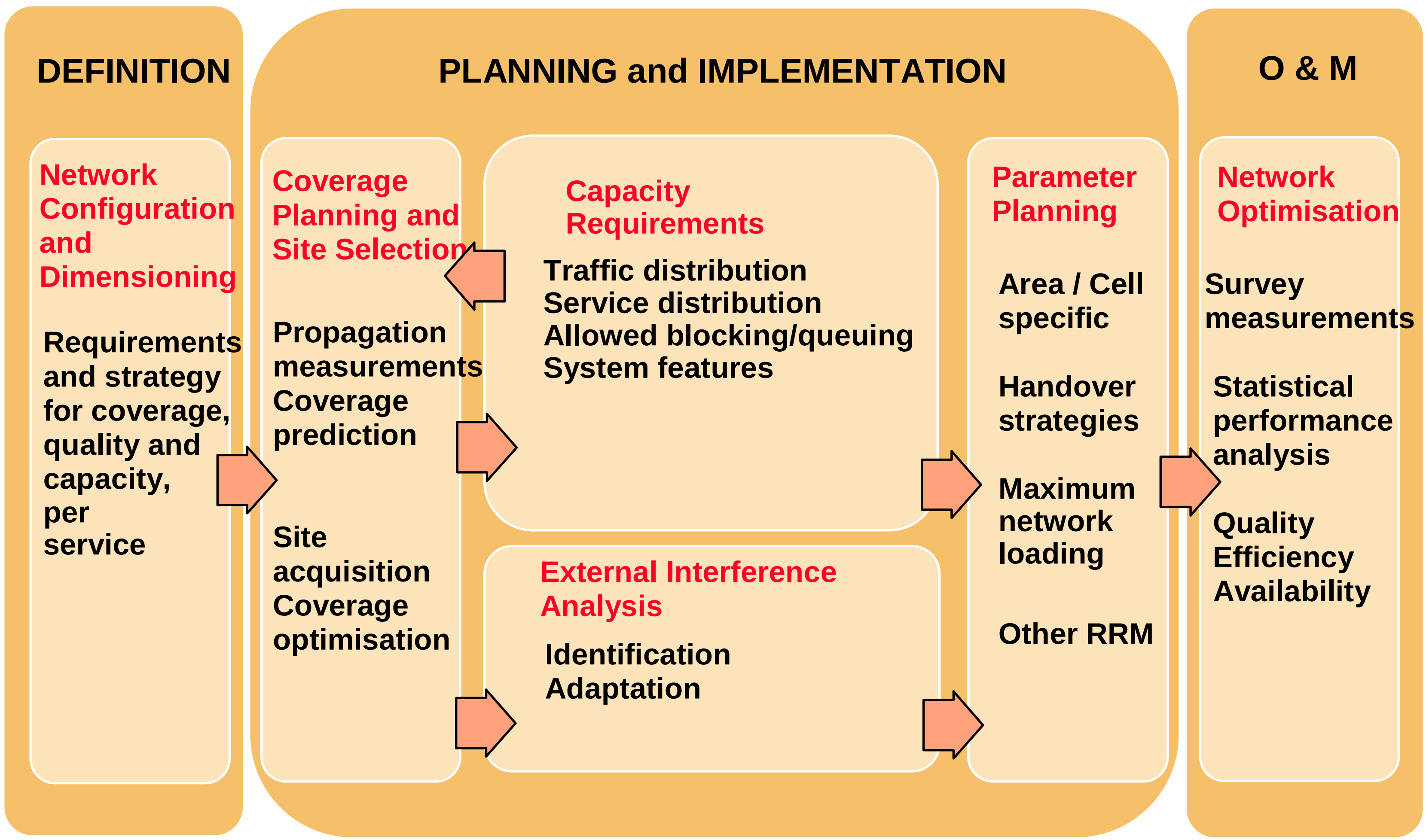
Multiservice environment

- Bit rates usually from 8 to 384 kbit/s
- Bit rate switching
- Multi-RABs
- Traffic classes
  - Error rates, 10 % FER to 10^{-6} BER
  - Delay sensitivity, from 100 ms up to seconds
- Asymmetric UL and DL traffic
- Common channel data traffic

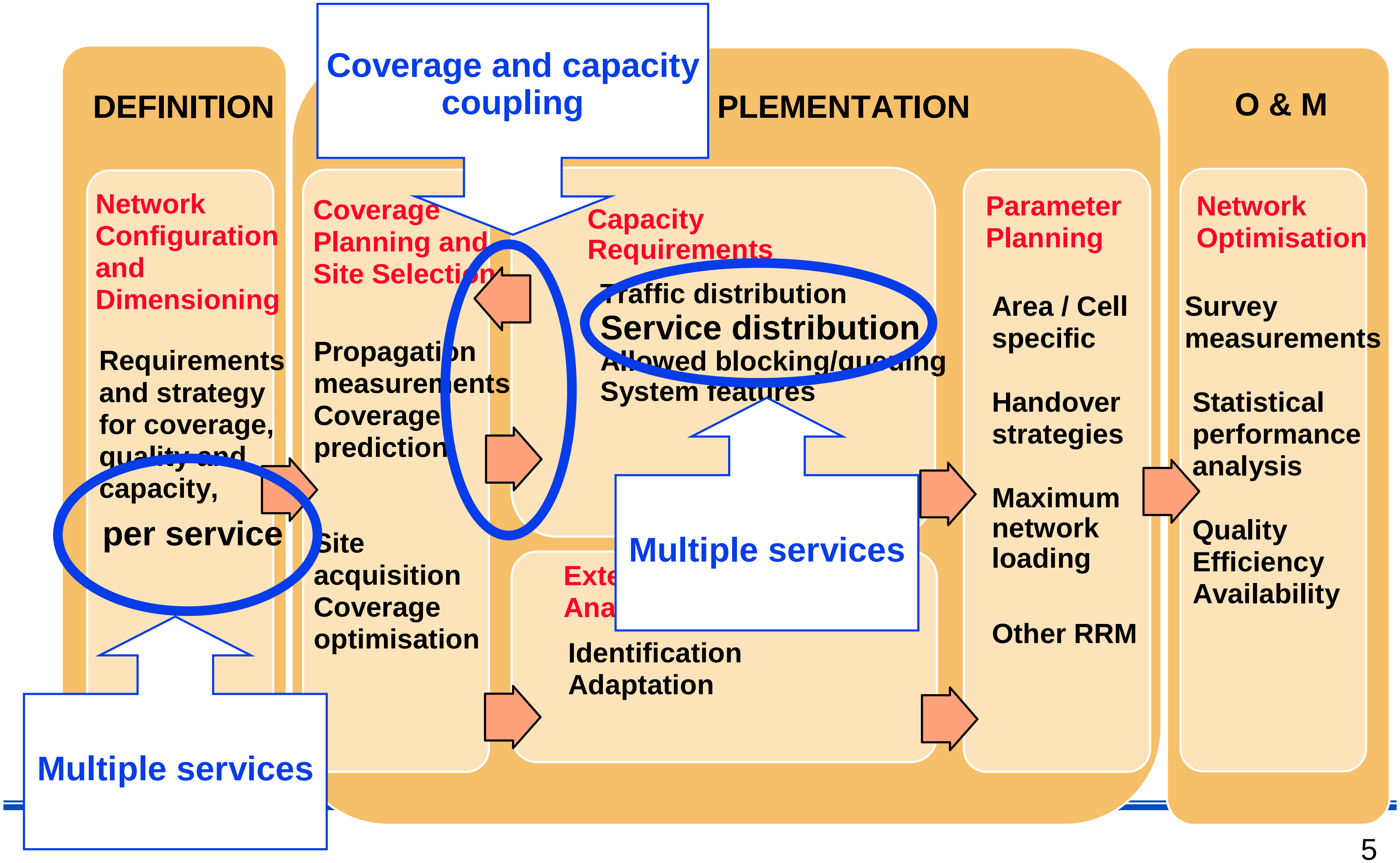
Air interface

- Capacity and coverage coupled together
- Neighboring cells coupled via interference
- Receiver performance depends on
  - bit rate, environment
- Soft handover & Fast Power Control
- Common shared resources

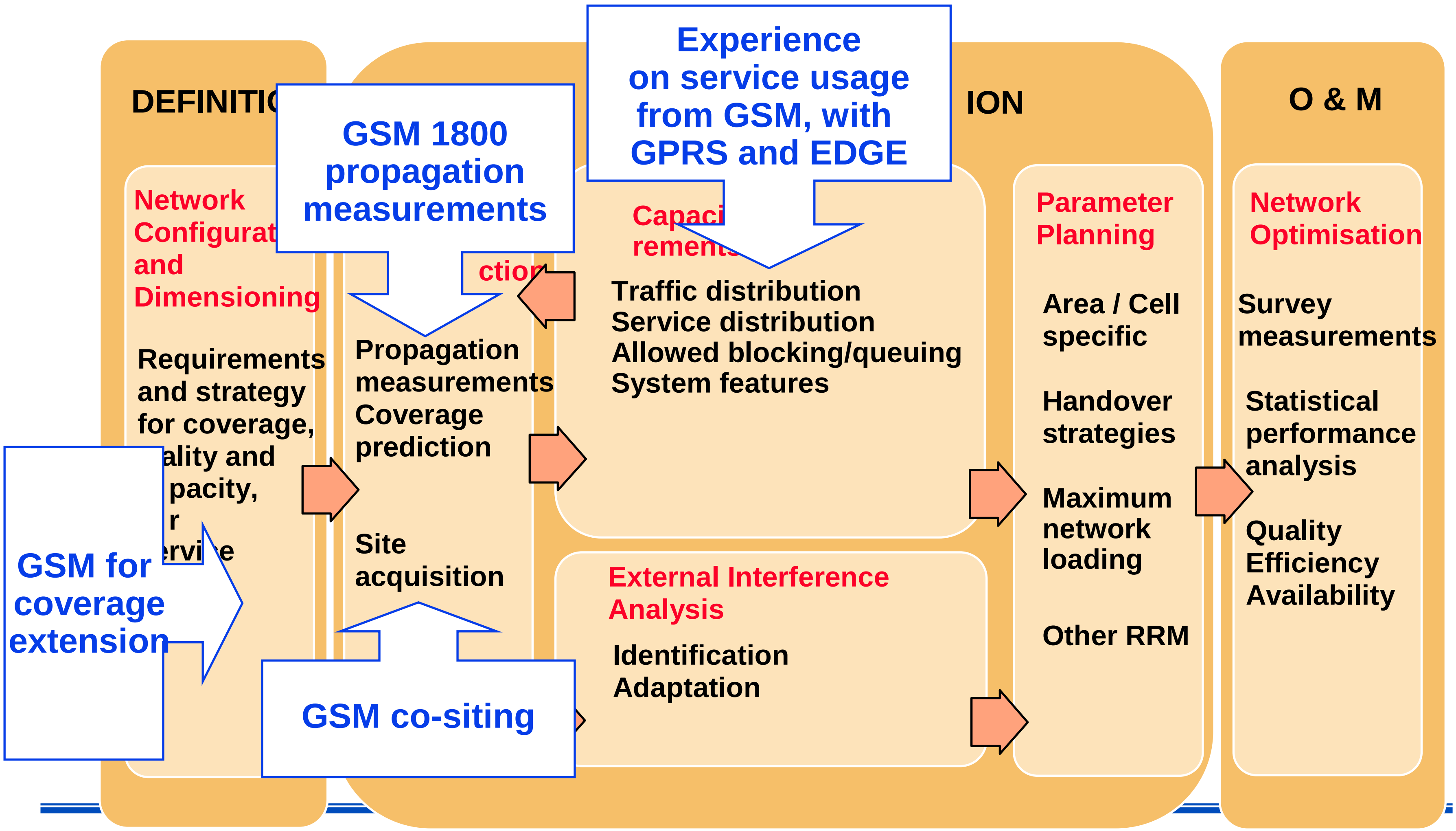
WCDMA Network planning



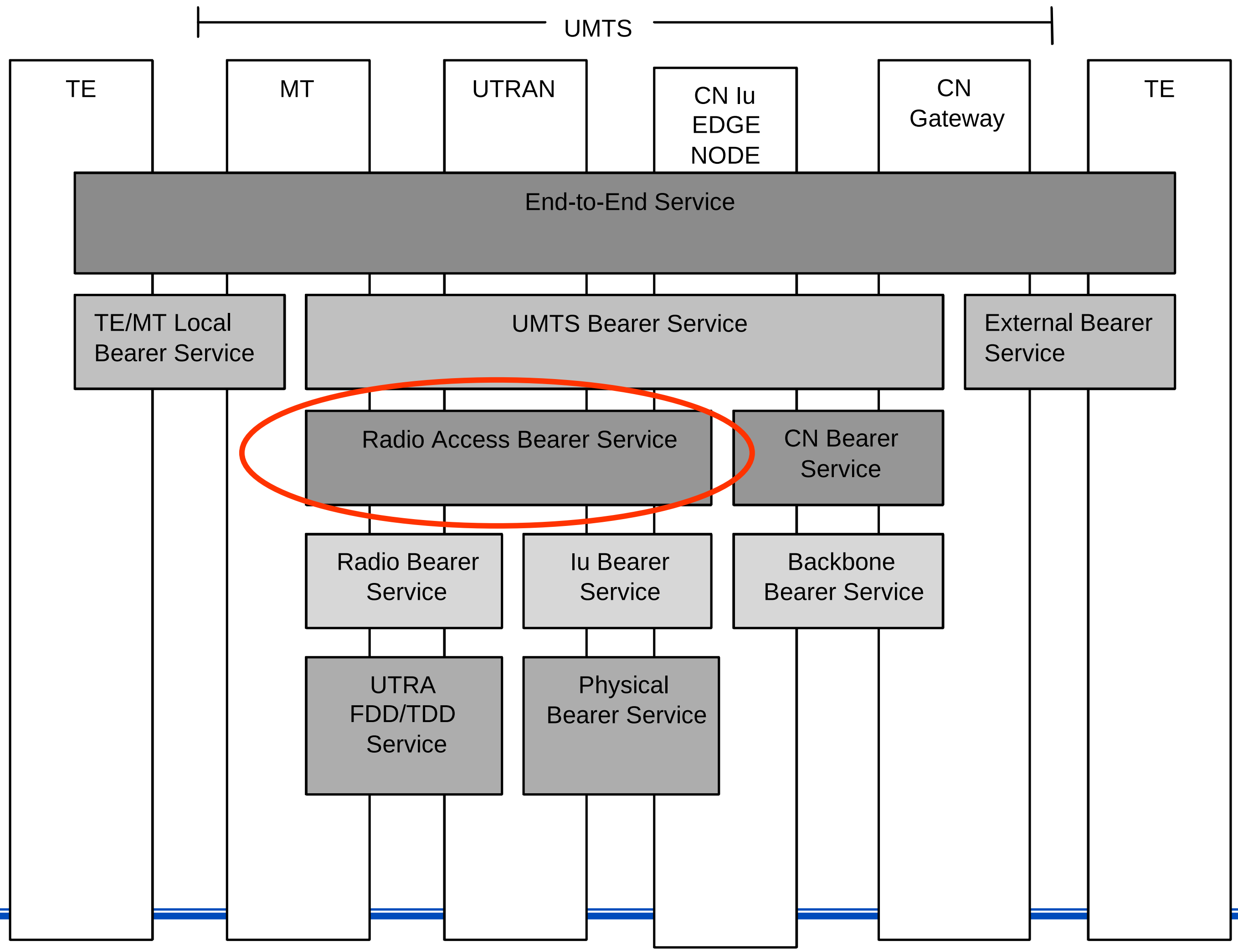
WCDMA Network planning



WCDMA Network planning



Recall: RAB concept



Recall: Service types

Typical services associated with the RABs

- **Conversational Speech:** Adaptive Multi Rate (AMR) speech
- **Conversational CS data:** Video Telephony
- **Streaming:** Video, audio streaming
- **Interactive data:** Corporate access, web browsing, WAP etc
- **Background data:** E-mails, internet access, downloads
- **Multi-RAB:** e.g.speech + e-mail, speech + internet access, etc

What's usually available

Typical first releases of R99 WCDMA

- **Conversational Speech** — 12.2 kbps Circuit Switched
- **Conversational CS Data** — 64 kbps Circuit Switched
- **Streaming** — 57.6 kbps Circuit Switched
- **Interactive** — Variable rate Packet Switched UL/DL 64/64, 64/128, 64/384
- **Multi-RAB** — Combination of Conversational Speech and Interactive 64/64

- HS-DSCH (HSDPA) — 1.8->3.6Mbps (R5, 1H2006)
- E-DCH (HSUPA) — 0.7->1,5Mbps (R6)

Typical 2004/5 releases of WCDMA (R4)

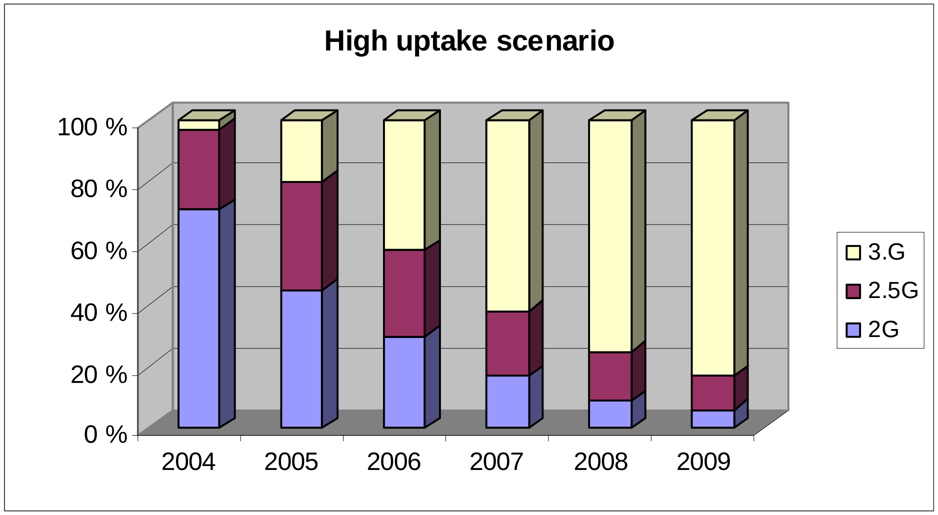
- Speech — 4,75-12,2kbps AMR CS
- **Conversational CS Data** — 64kbps CS
- **Streaming** — 57.6 kbps CS, 64/64 kbps PS, 64/128 kbps PS, 64/256 kbps PS
- **Interactive** — PS 64/64 -> 128/384 kbps
- **Multi-RAB** — Combinations of AMR speech and up to 64/384 kbps PS Interactive
- **Multi-RAB** — Combinations of CS conversational data and up to 64/384 kbps PS Interactive/ Multiple PS Interactive
- **Conversational PS Data** — 64->128 kbps PS (R5)

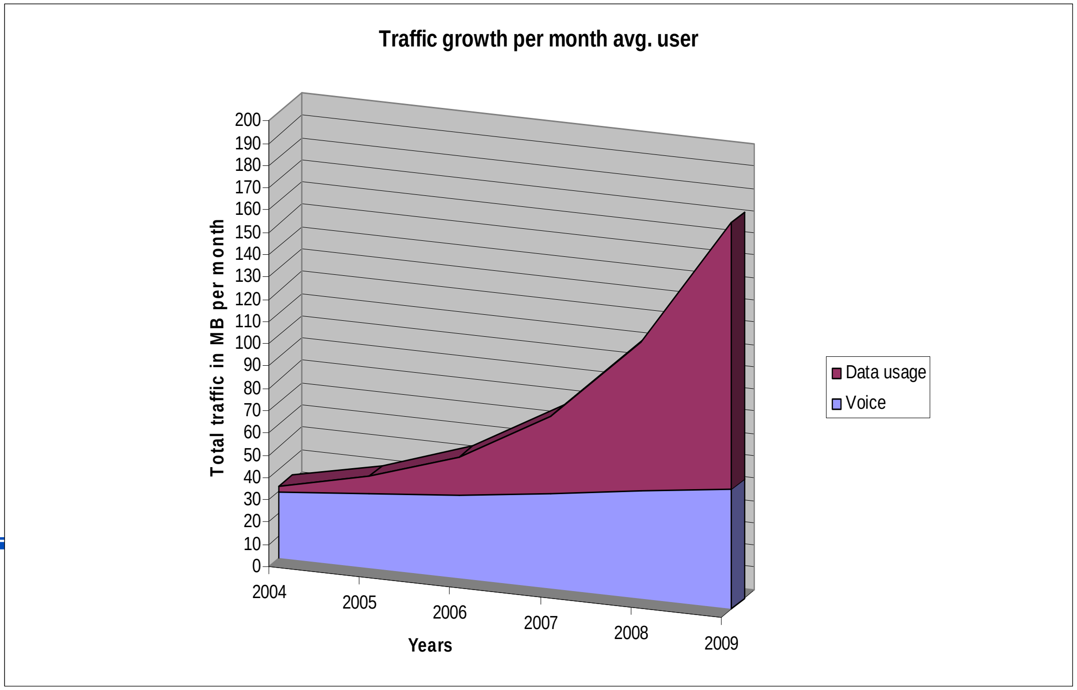
Traffic types

- RT guaranteed bit-rate & delay traffic is the most demanding type of traffic for cell design (especially high bit-rate)
  - Conversational class circuit switched voice (not demanding due to slow bit-rate)
  - Conversational class circuit switched video telephony (more demanding for maintain QoS than to the cell design, CS bearer not utilising capacity optimally)
  - Streaming class circuit and packet switched data (very demanding, especially high-bit rate packet switched)
- NRT Intercative/Background traffic is less demanding type of traffic for cell design due to bursty and non-guaranteed nature
- So far in live 3G networks, the amount of video telephony and streaming packet switched data is minimal compared to Intercative/Background traffic and voice

Traffic dimensioning

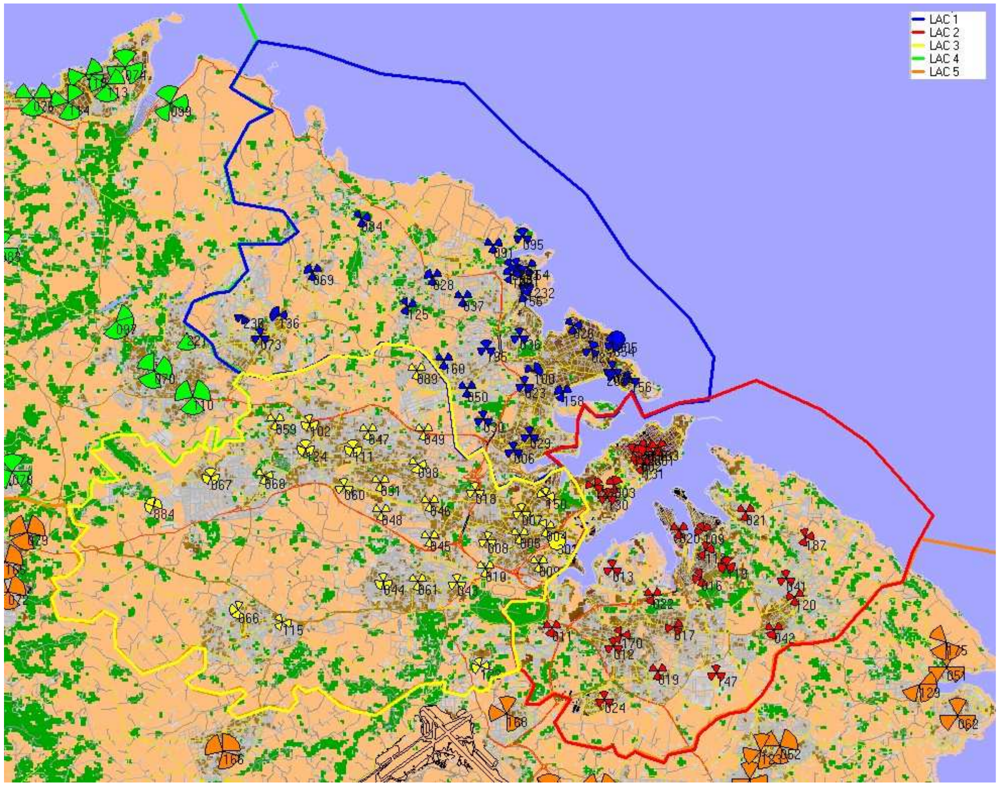
- When predicting the traffic for 3G plan, issues should be considered as
  - Terminal penetration (2G/3G)
  - Operator market share
  - Subscriber prediction
  - Amount of roamers
  - User profiles
  - Service usage per profile





Traffic dimensioning

- Due to CDMA-characteristics and multi-service nature of WCDMA, without accurate traffic modeling and predictions the capacity and coverage of the network is difficult to plan.
- The modeling can be based on the knowledge of GSM/GPRS and internet usage patterns as well as on assumptions of service usage
- Predicting the amount of usage and usage locations is of high importance, because of the fluctuating nature of the traffic –> simulations with various traffic scenarios needed.
- User scenarios/profiles should be created together with business planning and should support the selected strategy in the dimensioning



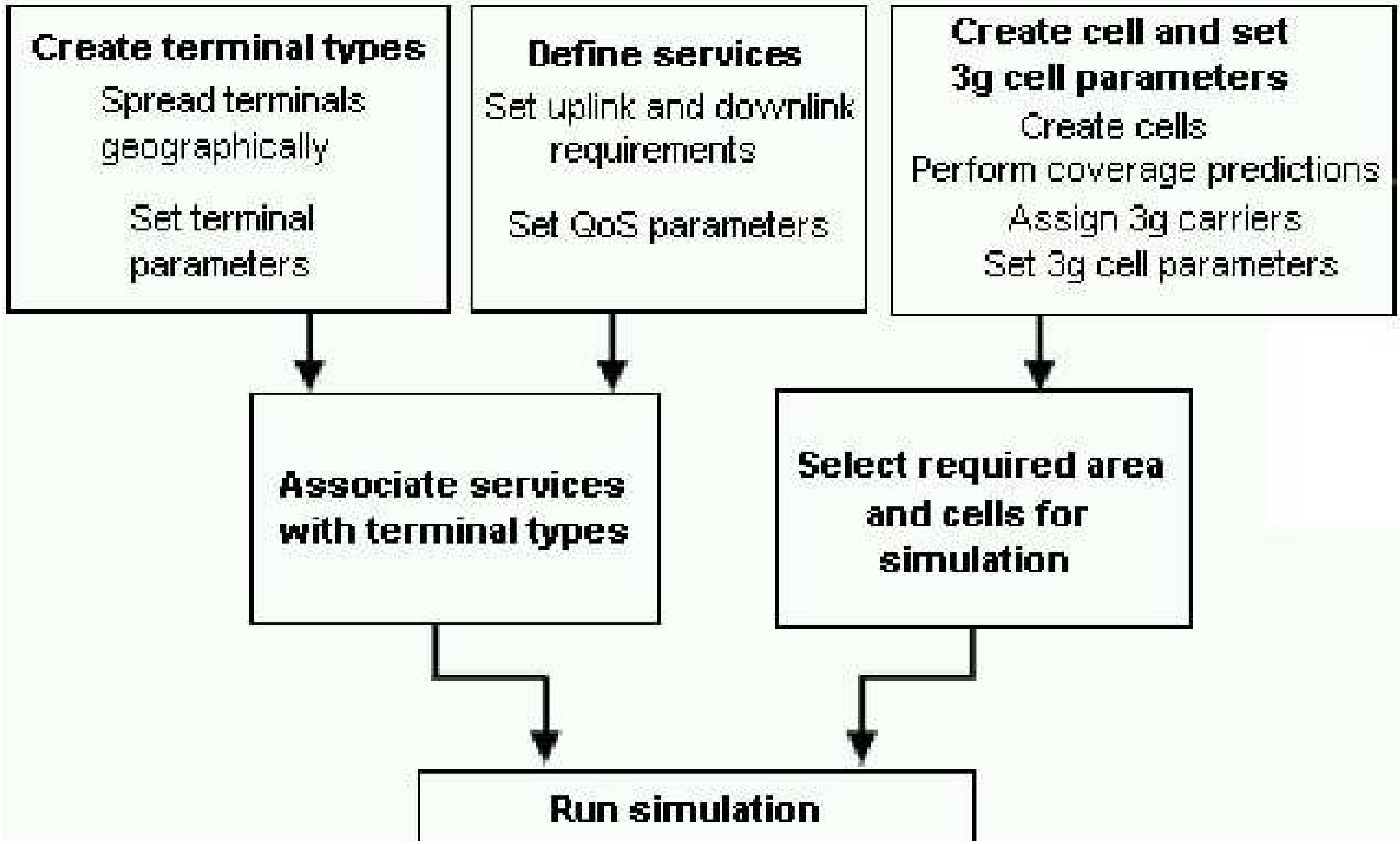
Traffic dimensioning example for interactive class

$$M \approx \frac{n_{subs} n_{pages} Y}{3600 R_{peak} \tau_{session}} = \frac{A_{bps}}{R_{peak} \tau_{session}}$$

- M: Amount of active users
- n_{subs}: Number of subscribers
- n_{pages}: Amount of web pages to be downloaded per subscriber
- Y: Payload
- A_{bps}: Offered traffic
- R_{peak}: Maximum RAB bitrate
- $\tau_{session}$: Session efficiency, incl overhead and retransmissions

Traffic dimensioning in planning tools

- Typical traffic dimensioning in a 3G planning tool



Traffic dimensioning in planning tools

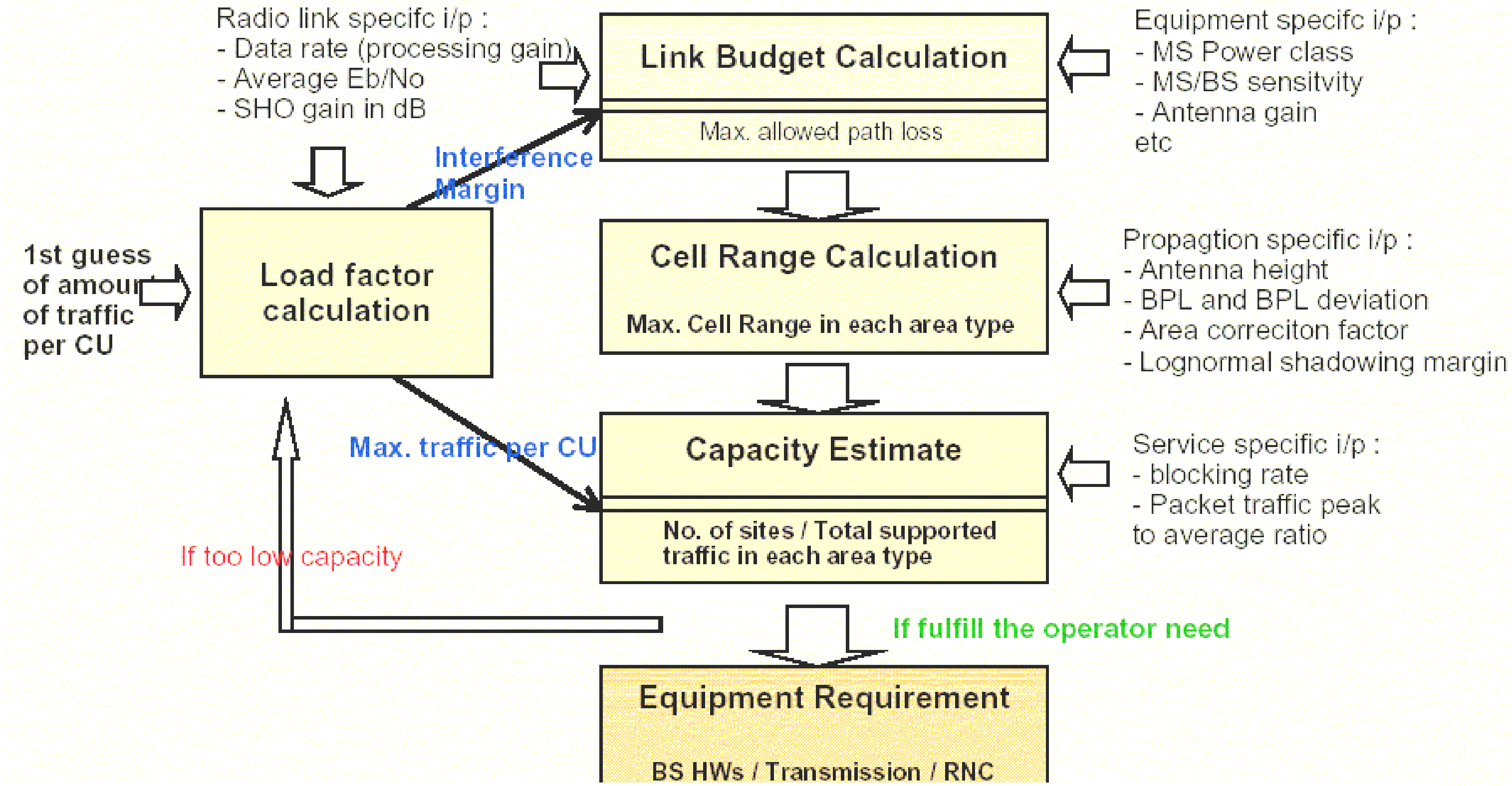
- In PS connections associated parameters need to be decided per service. Example:

Parameter	Description
Bitrate	Bitrate.
Mean packet size	Mean size of a packet.
Mean number of packet calls per session	Mean number of packet calls per session.
Reading time between calls	Reading time between calls.
Mean number of packets in call	Mean number of packets in call.
Block error rate working point	The number of blocks that are dropped in transmission.
BLER working point	This is used to calculate the percentage retransmission rate using the formula: $\frac{\text{BLER}}{1-\text{BLER}}\times 100$
Retransmission timeout	The number of radio frames waited before a dropped block is retransmitted. This is used to calculate the mean retransmission delay.
Max queuing delay	The limit in seconds of the basestation memory.
Channels required	The number of channels used by an active packet connection.

Packet based information types	Average number of packet calls within a session	Average reading time between packet calls [s]	Average amount of packets within a packet call []	Average interarrival time between packets [s][1]	Parameters for packet size distribution
WWW surfing					
UDD 8 kbit/s	5	412	25	0.5	$k = 81.5$
UDD 32 kbit/s	5	412	25	0.125	$\alpha = 1.1$
UDD 64 kbit/s	5	412	25	0.0625	
UDD 144 kbit/s	5	412	25	0.0277	
UDD 384 kbit/s	5	412	25	0.0104	
UDD 2048 kbit/s	5	412	25	0.00195	
(originally UDD 8 kbit/s)	5	12	15	0.96	

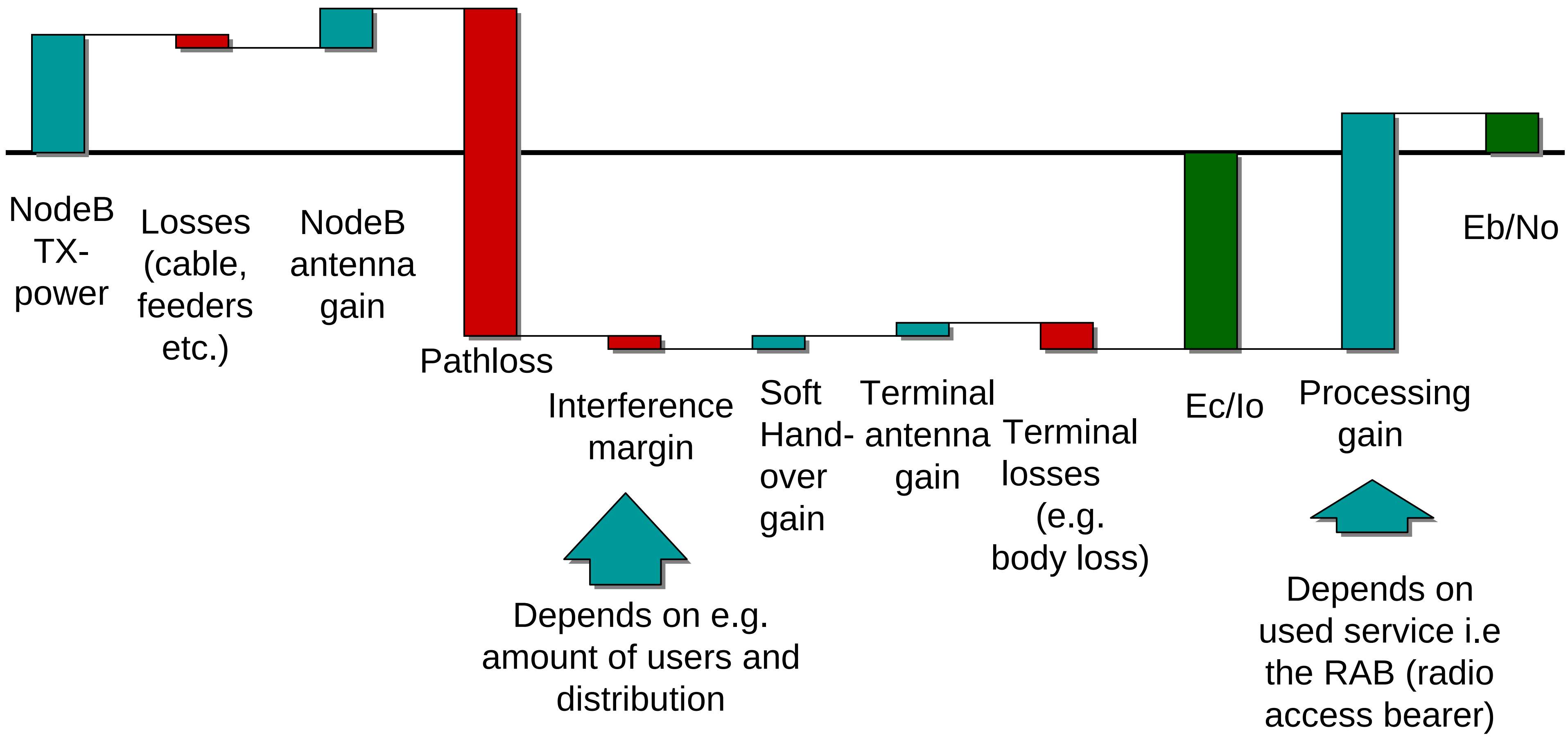
WCDMA Network dimensioning

- Typically initial dimensioning produces the rough esitimation on needed equipment amount & configuration for a service area



- As most UMTS networks are built on top of existing GSM networks, the process is focused to estimate what level of coverage/capacity can be achievied with re-use of GSM grid

WCDMA Link Budget

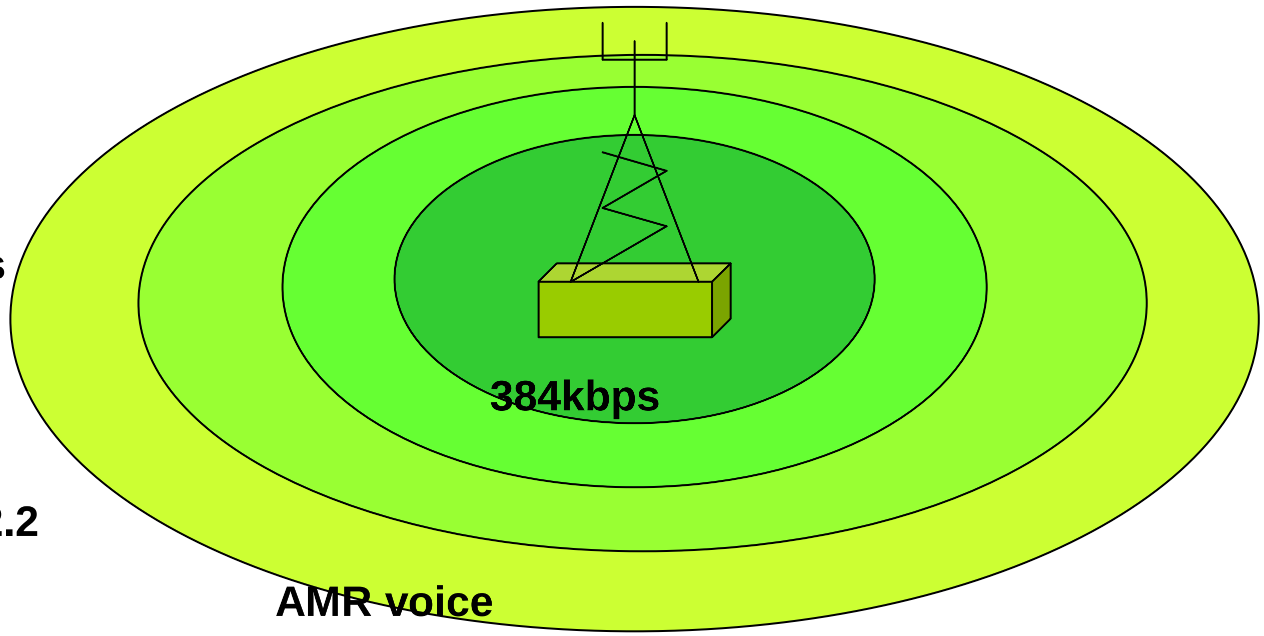


WCDMA Link Budget

- Due to difference in Eb/No requirement, processing gain and receiver sensitivity for each user, the calculated pathloss (and cell size) is different for each user.
- In WCDMA the Node B and UE also need to use more power for the demanding users, especially if connecting from a distance (large pathloss)

<u>As a rule of thumb</u>

- **coverage for 128kbps NRT PS service in normal loading conditions equals GSM1800 voice**
- **coverage for 384kbps NRT PS service in normal loading conditions is ~10dB worse than AMR12.2 voice**



Link budget, 12.2 kbps speech

		12.2kbps voice, DL	12.2kbps voice, UL
Target load		0.75	0.5
Transmitter characteristics	Total transmitter power	20 W	0.125 W
	Transmitter power on TCH	0.348718 W	0.125 W
		25.42474 dBm	20.9691 dBm
	TX antenna gain	17.42531 dBi	0 dBi
	TX cable loss	2 dB	0 dB
	TX Body loss	0 dB	2 dB
	Transmitter EIRP	**40.85005 dBm**	**18.9691 dBm**
Receiver characteristics and margins	RX antenna gain	0 dBi	17.42531 dBi
	Thermal noise density	-174 dBm/Hz	-174 dBm/Hz
	Receiver noise figure	8 dB	5 dB
	Receiver noise density	-166 dB	-169 dB
	Receiver noise power	-100.157 dBm	-103.157 dBm
	Spreading gain	24.97971 dB	24.97971 dB
	Required Eb/No	7 dB	5 dB
	Interference margin	6.0206 dB	3.0103 dB
	Required signal power	-112.116 dBm	-120.126 dBm
	RX Cable loss	0 dB	2 dB
	RX Body loss	2 dB	0 dB
	Diversity gain	0 dB	3 dB
	Fast fading margin	0 dB	3 dB
	Soft handover gain	1 dB	2 dB
	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
	Allowed propagation loss	**146.4659 dB**	**149.0205 dB**

Link budget, TX characteristics

		12.2kbps voice, DL		12.2kbps voice, UL	
Target load		0.75		0.5	
Transmitter characteristics	Total transmitter power	20	W	0.125	W
	Transmitter power on TCH	0.348718	W	0.125	W
		25.42474	dBm	20.9691	dBm
	TX antenna gain	17.42531	dBi	0	dBi
	TX cable loss	2	dB	0	dB
	TX Body loss	0	dB	2	dB
	Transmitter EIRP	**40.85005**	**dBm**	**18.9691**	**dBm**

- Network load assumption for dimensionning (target loading)
- The target load level of the network should be based on as accurate predictions of service&traffic mix distribution and growth as possible

Target load

- Target load%
  - **Urban macro cells 50-60%** (demanding traffic & user profiles, buildings restrict cell dominance, shadowing)
  - **Urban micro cells 70%** (small cells, traffic hotspots and indoor)
  - **Rural 30-40%** (coverage important, lower traffic, different user profiles)
  - **Not higher than 75%** (UL hard to manage, interference explodes)
- Too high initial target can result in too dense network (expensive) if the traffic or use of resources is estimated wrongly. Network can also be hard to manage in terms of cell overlapping → cell dominance to be guaranteed.
- Too low initial target can result to coverage holes and capacity problems, if the traffic proves to be higher than predicted or resources are utilised differently.

Target load

- DL load can be dimensioned to be higher than UL load
- With high and very asymmetric traffic load (~80/20) or indoors, DL can easily limit the capacity of a cell in practise
  - DL power shared with users, coverage very dependent of loading
  - DL capacity depends more on propagation and multipath than the UL capacity, because of the use of orthogonal codes
- DL load usually bigger than UL load (traffic asymmetry, bigger Eb/No requirements, overhead due to SHO...)
- DL is not so hard to manage when close to maximum loading is utilised, due to effective averaging of transmitted powers
- DL resources will usually be utilised in full (available capacity is given to the users in the cell → no waisting of air capacity → happier users

TX power

		12.2kbps voice, DL	12.2kbps voice, UL
Target load		0.75	0.5
Transmitter characteristics	Total transmitter power	20 W	0.125 W
	Transmitter power on TCH	0.348718 W	0.125 W
		25.42474 dBm	20.9691 dBm
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	TX cable loss	2 dB	0 dB
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	Transmitter EIRP	**40.85005 dBm**	**18.9691 dBm**

In calculation of TCH transmission power we have used the formula

$$P_{TX,TCH} = \frac{(1 - \text{Control overhead}) \cdot \text{Total TX power}}{\text{Load target} \cdot \text{Maximum number of users}}$$

In this case we have assumed that maximum number of speech users is 65

TX power in BS

- Recall the control overhead

	Activity [%]	Percentage of the maximum base station power [%]	Power allocation with 20 W. maximum power [W]
Common pilot channel (CPICH)	100	10	2.0
Primary synchronization channel (SCH)	10	6	1.2
Secondary synchronization channel (SCH)	10	4	0.8
Primary common control physical channel (CCPCH)	90	5	1.0
Total common channels	**-**	**~ 15**	**~ 3**

- The maximum number of users for a certain service can be computed using DL load equations (to be explained later)
- It is important to notice that by decreasing the DL load target the TCH power can be increased and cell coverage increased.

RX characteristics

Receiver characteristics and margins	RX antenna gain	0	dBi	17.42531	dBi
	Thermal noise density	-174	dBm/Hz	-174	dBm/Hz
	Receiver noise figure	8	dB	5	dB
	Receiver noise density	-166	dB	-169	dB
	Receiver noise power	-100.157	dBm	-103.157	dBm
	Processing gain	24.97971	dB	24.97971	dB
	Required Eb/No	7	dB	5	dB
	Interference margin	6.0206	dB	3.0103	dB
	Required signal power	-112.116	dBm	-120.126	dBm
	RX Cable loss	0	dB	2	dB
	RX Body loss	2	dB	0	dB
	Diversity gain	0	dB	3	dB
	Fast fading margin	0	dB	3	dB
	Soft handover gain	1	dB	2	dB
	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

Receiver noise figure is usually between 5 to 9 dB and BS have better NF. Precise value of this parameter is product specific.

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Receiver noise density (per Hz) is a sum of receiver noise figure and thermal noise density.
Receiver noise power is equal to receiver noise density x chip rate

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Processing gain is the chip rate divided by user bit rate

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Eb/No values can be obtained by link simulations. There are also informative values given in 3GPP specifications. Eb/No values are usually provided by the network vendor

Eb/No

- While Ec/Io is defined *before* the signal de-spreading operation and Eb/No *after* de-spreading.
  - Ec/Io can be be determined for the signal ”in the air”
- So Eb/No depends on the service (bit rate, CS/PS, receiving end) & vendor
- Ec/Io is service independent
- Typical Eb/No values
  - AMR 12.2 kbps speech (BLER <7*10^-3) [UL 4-5 dB, DL 7-8 dB]
  - CS 64 kbps data (BER <10^-4) [UL 2-3 dB, DL 6-7 dB]
  - PS Streaming 64 kbps (BER<10^-3) [UL 3-4 dB, DL 7-8 dB]
  - PS data 64 kbps (BLER <7*10^-3) [UL 2-3 dB, DL 5-6 dB]
  - PS data 384 kbps (BLER <7*10^-3) [UL 2-3 dB, DL 5-7 dB]

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Interference is a function of loading. In UL the value can be obtained from equation

$$\text{Interference margin} = -10 \cdot \log_{10}\left(1 - \text{Target load}\right)$$

This value can be used also in DL. 50% load => 3dB margin, 75% load => 6dB margin

Interference margin

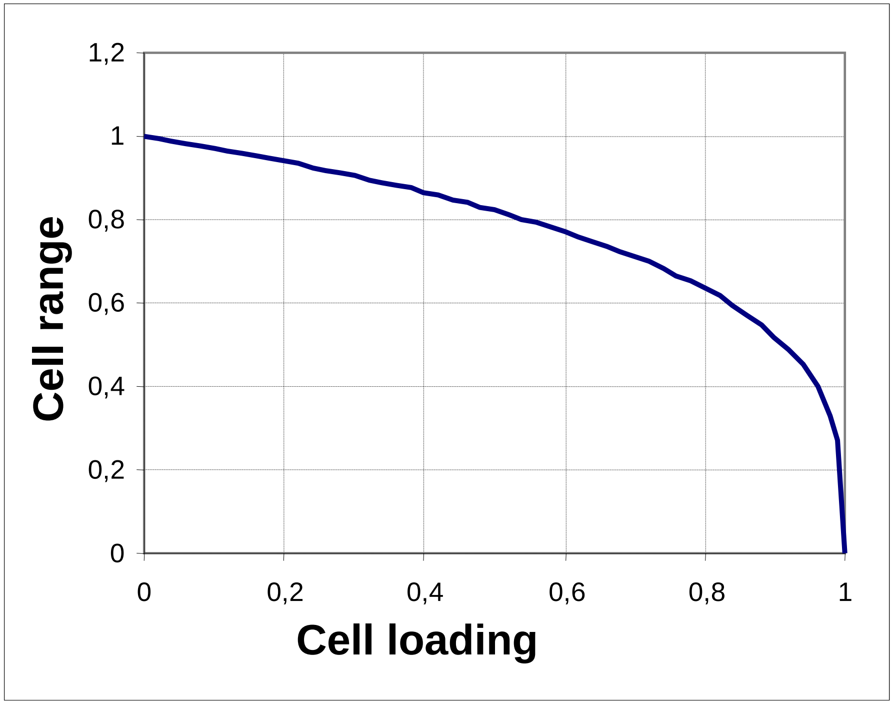
- Receiver background noise increases in proportion to the increase of the users
- This needs to taken into account in the link budget with a specific interference margin, which is directly related to the loading

Interference margin

Interference binds the capacity and coverage

The more traffic is brought to the cell, more interference is produced

In order to win the interference the terminals have to increase their TX-power



When the interference grows in the cell the most far away terminal from the NodeB cannot win the interference even with the maximum TX-power

New users cannot access the cell from distance

Cell range decreases

RX characteristics

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The required signal power (also called as sensitivity) represents the weakest signal that can be received by the receiving antenna.

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Fast fading margin = power control headroom

Fast fading margin

- PC headroom is an overhead on the transmit power a terminal needs to make in the UL. This overhead ensures that the UL PC is able to compensate for deep fades at cell border
- PC Headroom is a function of UE speed, and the overhead is largest for relatively slowly moving UEs (<50km/h)
  - Typical value is 3dB for urban and 4dB elsewhere
  - Depends on assumed SHO gain and Eb/No -values
  - In an operational network, the required TPC headroom can vary from 0 to over 8dB
- PC headroom is usually not needed in the downlink, since all mobile terminals are served simultaneously with comparatively less power than the maximum output power of the node B.

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	Indoor penetration loss	0	dB	0	dB

In soft handover two signals are combined

Soft/Softer handover

- Soft/Softer Handover gain develops from combining of signals either in node B's RAKE or RNC. In Downlink signals are combined in terminal's RAKE receiver
- Uplink Soft Handover gain comes from RNC frame selection combining. Gain is not achieved as concrete gain in radio interface, but as more stable power control.
- In Uplink Softer HO maximum ratio combining is performed in node B's RAKE => gain 1-3 dB
- Downlink Soft HO:n maximum ratio combining is performed in terminal's RAKE => gain 1-2 dB

RX characteristics

Receiver characteristics and margins	RX antenna gain	0	dBi	17.42531	dBi
	Thermal noise density	-174	dBm/Hz	-174	dBm/Hz
	Receiver noise figure	8	dB	5	dB
	Receiver noise density	-166	dB	-169	dB
	Receiver noise power	-100.157	dBm	-103.157	dBm
	Processing gain	24.97971	dB	24.97971	dB
	Required Eb/No	7	dB	5	dB
	Interference margin	6.0206	dB	3.0103	dB
	Required signal power	-112.116	dBm	-120.126	dBm
	RX Cable loss	0	dB	2	dB
	RX Body loss	2	dB	0	dB
	Diversity gain	0	dB	3	dB
	Fast fading margin	0	dB	3	dB
	Soft handover gain	1	dB	2	dB
	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

Shadow fading margin has been discussed previously, but let's recall some issues

Shadow fading margin (SFM)

- SFM is needed because the buildings and other obstacles between the UE and Node B are causing changes in the received signal level at the receiver
- SFM is taken into account in the WCDMA link budget to assure a minimum signal level with the wanted probability
- According to measurements in live UMTS network, it has been noticed that the practical SFM and standard deviation values are nearly the same for WCDMA and GSM

Some values that are used based on measurements

Network area/ Parameter	Standard deviation	Shadow fading margin	
		Area probability 90%	Area probability 95%
Dense urban / Urban	8,5 dB	6 dB	9,5 dB
Sub-urban	7,2 dB	4,7 dB	7,6 dB
Rural	6,5 dB	3,9 dB	6,6 dB

Cell range

Allowed propagation loss	146.4659 dB	149.0205 dB

Range (Okumura-Hata path loss model)			Unit
	Carrier frequency	2100	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	1.800742	km
	Uplink range	2.12287	km
	Cell range	**1.800742**	**km**

It seems that WCDMA and GSM 1800 admit pretty same speech coverage (recall that GSM 1800 range were round 1.58 km). Actually if we would have used the same cable loss then cell range would have been 1.58 km also for WCDMA. Yet, WCDMA link budget contains much more parameters => more potential error sources in dimensioning.

Link budget, 384kbps data

		384kbps data, DL		384kbps data, UL	
Target load		0.75		0.5	
Transmitter characteristics	Total transmitter power	20	W	0.25	W
	Transmitter power on TCH	5.666667	W	0.25	W
		37.53328	dBm	23.9794	dBm
	TX antenna gain	17.42531	dBi	0	dBi
	TX cable loss	2	dB	0	dB
	TX Body loss	0	dB	0	dB
	Transmitter EIRP	**52.95858**	**dBm**	**23.9794**	**dBm**
Receiver characteristics and margins	RX antenna gain	0	dBi	17.42531	dBi
	Thermal noise density	-174	dBm/Hz	-174	dBm/Hz
	Receiver noise figure	8	dB	5	dB
	Receiver noise density	-166	dB	-169	dB
	Receiver noise power	-100.157	dBm	-103.157	dBm
	Processing gain	10	dB	10	dB
	Required Eb/No	7	dB	3	dB
	Interference margin	6.0206	dB	3.0103	dB
	Required signal power	-97.1361	dBm	-107.146	dBm
	RX Cable loss	0	dB	2	dB
	RX Body loss	0	dB	0	dB
	Diversity gain	0	dB	3	dB
	Fast fading margin	0	dB	4	dB
	Soft handover gain	1	dB	2	dB
	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
	Allowed propagation loss	**143.5947**	**dB**	**140.0511**	**dB**

TX power

		384kbps data, DL		384kbps data, UL	
Target load		0.75		0.5	
Transmitter characteristics	Total transmitter power	20	W	0.25	W
	Transmitter power on TCH	5.666667	W	0.25	W
		37.53328	dBm	23.9794	dBm
	TX antenna gain	17.42531	dBi	0	dBi
	TX cable loss	2	dB	0	dB
	TX Body loss	0	dB	0	dB
	Transmitter EIRP	**52.95858**	**dBm**	**23.9794**	**dBm**

Data terminal may have higher TX power

Recall the calculation of TCH transmission power

$$P_{TX,TCH} = \frac{(1 - \text{Control overhead}) \cdot \text{Total TX power}}{\text{Load target} \cdot \text{Maximum number of users}}$$

Now maximum number of users is only 4 => BS TX power on TCH is high

Receiver characteristics

Receiver characteristics and margins	RX antenna gain	0 dBi	17.42531 dBi
	Thermal noise density	-174 dBm/Hz	-174 dBm/Hz
	Receiver noise figure	8 dB	5 dB
	Receiver noise density	-166 dB	-169 dB
	Receiver noise power	-100.157 dBm	-103.157 dBm
	Processing gain	10 dB	10 dB
	Required Eb/No	7 dB	3 dB
	Interference margin	6.0206 dB	3.0103 dB
	Required signal power	-97.1361 dBm	-107.146 dBm
	RX Cable loss	0 dB	2 dB
	RX Body loss	0 dB	0 dB
	Diversity gain	0 dB	3 dB
	Fast fading margin	0 dB	4 dB
	Soft handover gain	1 dB	2 dB
	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

Processing gain is smaller due to higher data rate
Eb/No in UL is also slightly smaller.

Cell range

Allowed propagation loss	143.5947 dB	140.0511 dB

Range (Okumura-Hata path loss model)			Unit
	Carrier frequency	2100	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	1.496663	km
	Uplink range	1.191201	km
	Cell range	**1.191201**	**km**

Now system is clearly uplink limited (it was downlink limited for speech). Yet this is only problem for symmetric services. Usually 384kbps is used for web browsing which is putting more pressure on DL. If cell dimensioning is done for speech then DL 384kbps coverage may not be a serious problem but capacity becomes soon a bottleneck since system may support only few 384kbps users.

Cell range

- In previous link budgets indoor penetration loss were 0dB. If we assume 20dB penetration loss (usual value) then

12.2kbps speech

Allowed propagation loss	126.4659 dB	129.0205 dB
Downlink range		0.496488 km
Uplink range		0.585303 km
Cell range		**0.496488 km**

384kbps data

Allowed propagation loss	123.5947 dB	120.0511 dB
Downlink range		0.41265 km
Uplink range		0.32843 km
Cell range		**0.32843 km**

Inter-site distance (3 sector cell) = 3 x range. Hence, inter-site distances are 1488m for speech and 984m for 384kbps data (UL). In practise inter-site distances are even smaller in urban areas due the more pessimistic (realistic) parameters.