3G Basics & Radio Network Planning and Optimization

3G Vision

- Universal global roaming
- Multimedia (voice, data & video)
- Increased data rates
  - 384 Kbps while moving
  - 2 Mbps when stationary at specific locations
- Increased capacity (more spectrally efficient)
- IP architecture
- Problems
  - No killer application for wireless data as yet
  - Vendor-driven

Why 3G?

- Higher bandwidth enables a range of new application
- **For the consumer**
  - Video streaming, TV broadcast
  - Video calls, video clips – news, music, sports
  - Enhanced gaming, chat, location services…
- **For business**
  - High speed teleworking / VPN access
  - Sales force automation
  - Video conferencing
  - Real-time financial information




International Standardization

- ITU (International Telecommunication Union)
  - radio standards and spectrum
- IMT-2000
  - ITU's umbrella name for 3G which stands for International Mobile Telecommunications 2000
- National and regional standards bodies are collaborating in 3G partnership projects
  - ARIB, TIA, TTA, TTC, CWTS. T1, ETSI - refer to reference slides at the end for names and links
- 3G Partnership Projects (3GPP & 3GPP2)
  - focused on evolution of access and core networks

IMT-2000 objectives

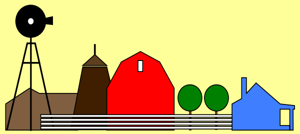
Indoor
low mobility

2 Mbit/s

Urban
reduced mobility

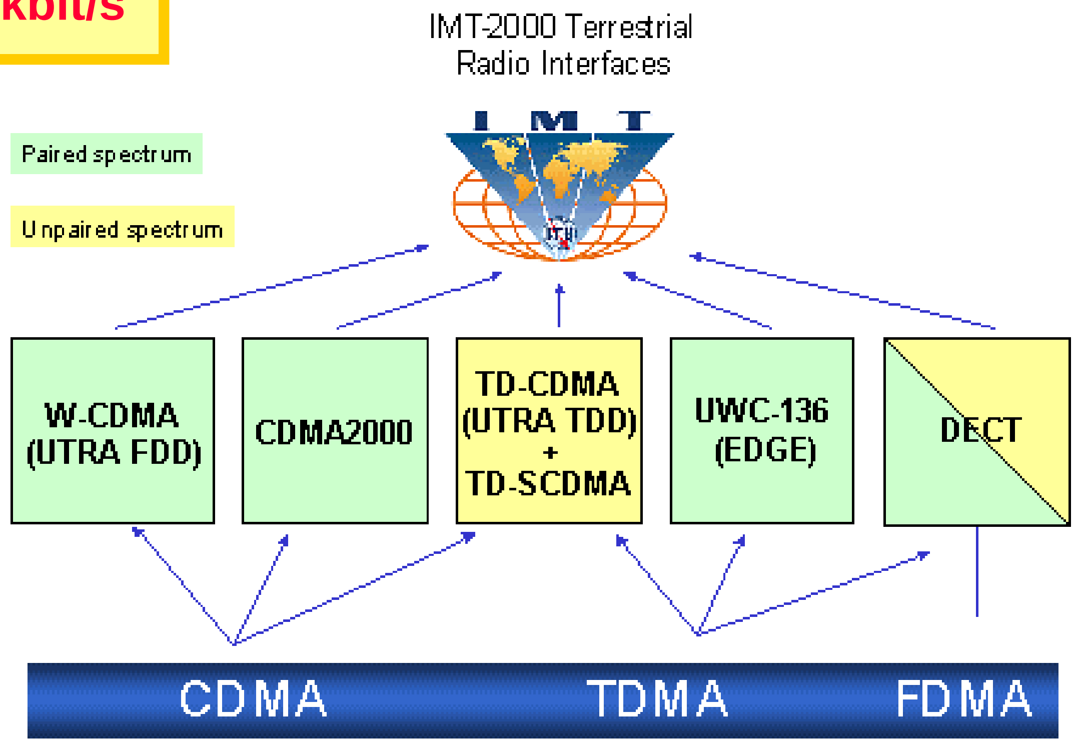
384 kbit/s

Rural outdoor
high mobility



144 kbit/s

- Variable bit rate capability
- Variable Quality Of Service (BER, delay)
- Support of asymmetric traffic
- Service multiplexing
- High spectrum efficiency
- Ensure compatibility with GSM



Prospects for Global Roaming

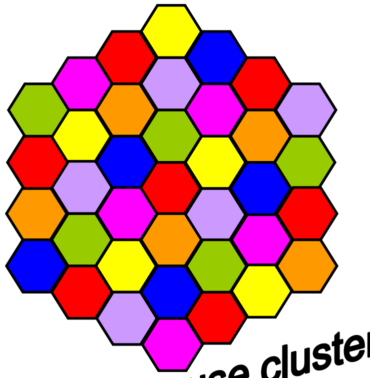
- Multiple vocoders (AMR, EVRC, SMV,…)
- Six or more spectral bands
  - 800, 900, 1800, 1900, 2100, 2500, …? MHz
- At least four modulation variants
  - GSM (TDMA), W-CDMA, CDMA2000, TD-SCMDA

The handset approach

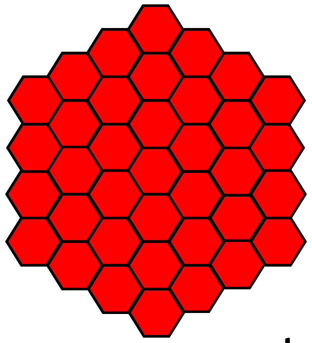
- Advanced silicon
- Software defined radio
- Improved batteries

W-CDMA

- W-CDMA = Wideband Code Division Multiple Access
- Users are separated with code sequences (spreading/de-spreading technique)
- All users are transmitting simultaneously on the same frequency
- In FDD mode, different frequencies are used on uplink and downlink

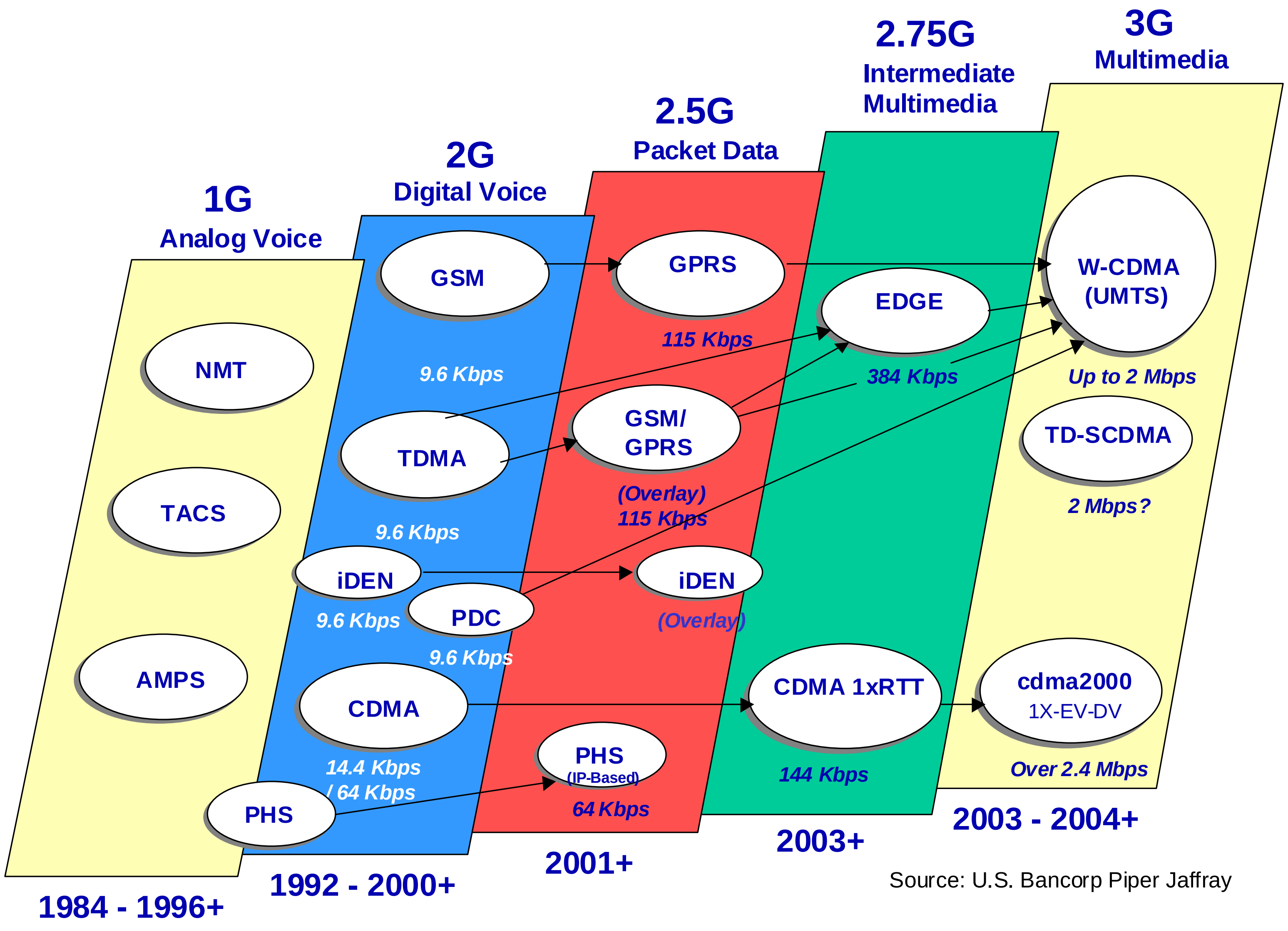


Frequency reuse cluster in GSM



Same frequency used in each cell/sector in CDMA

Migration To 3G



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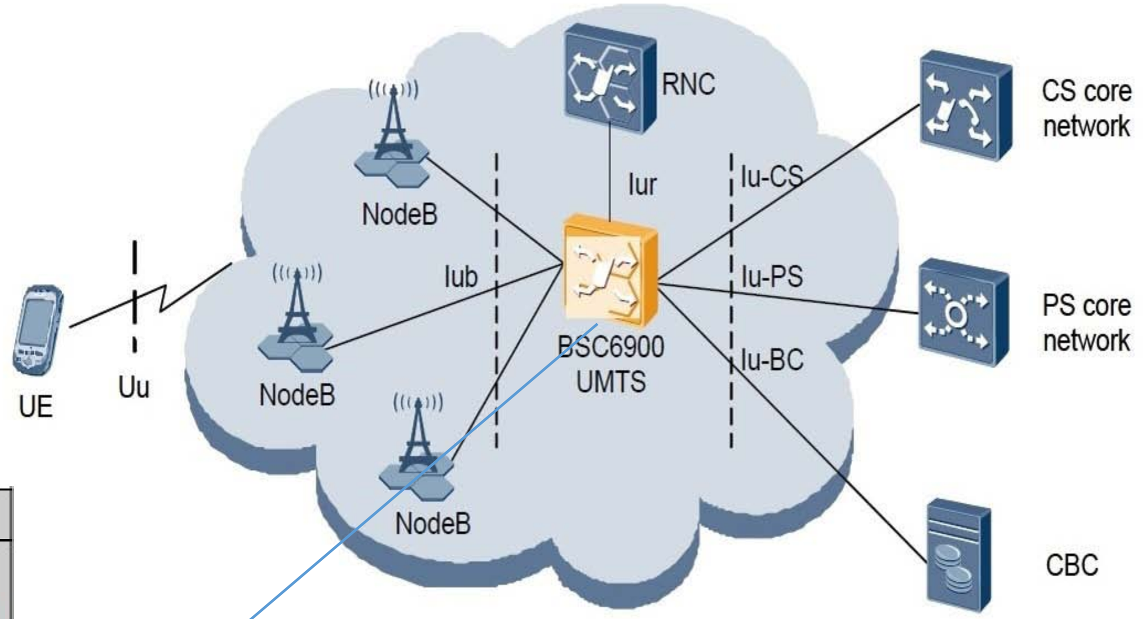
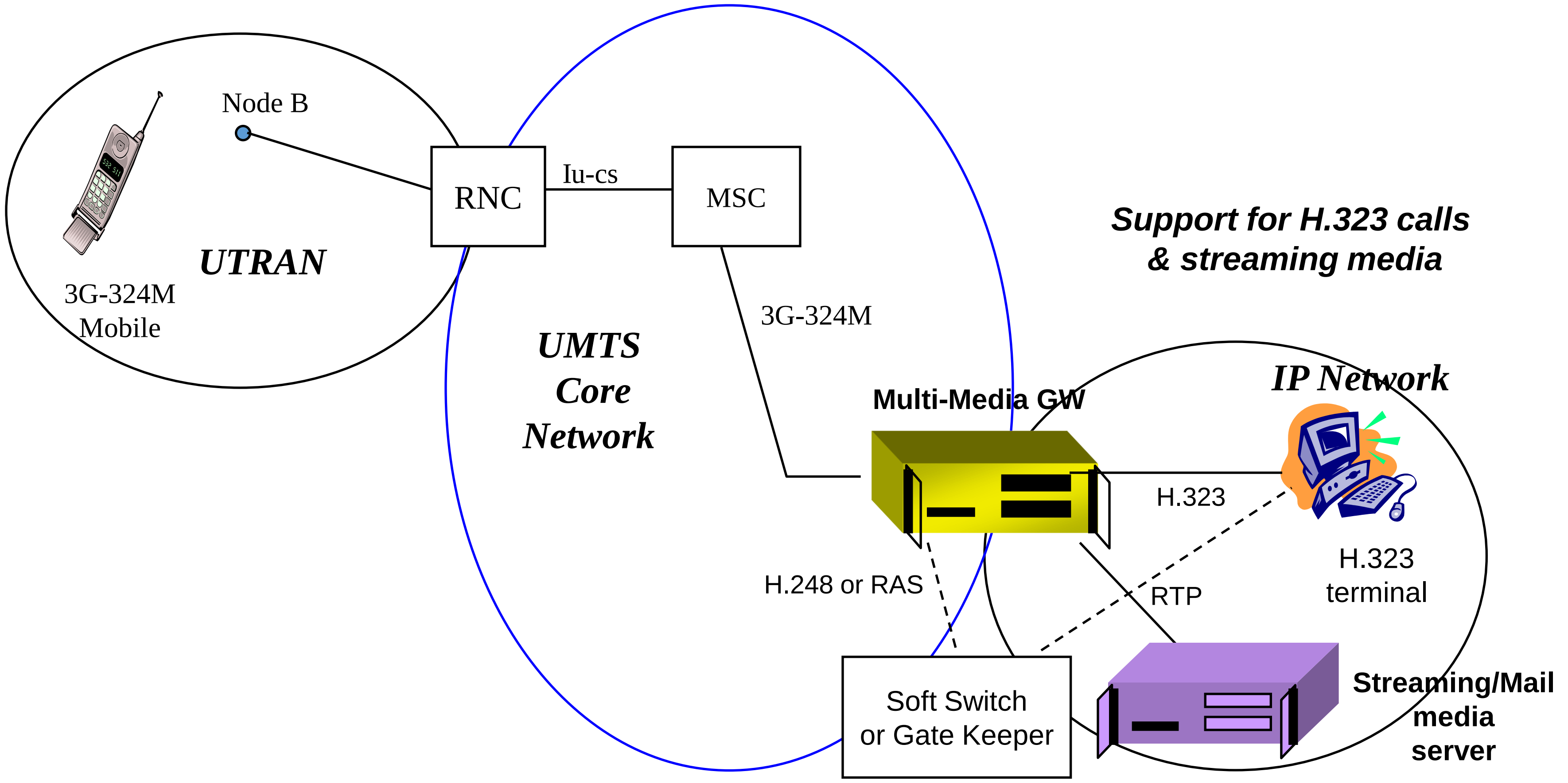


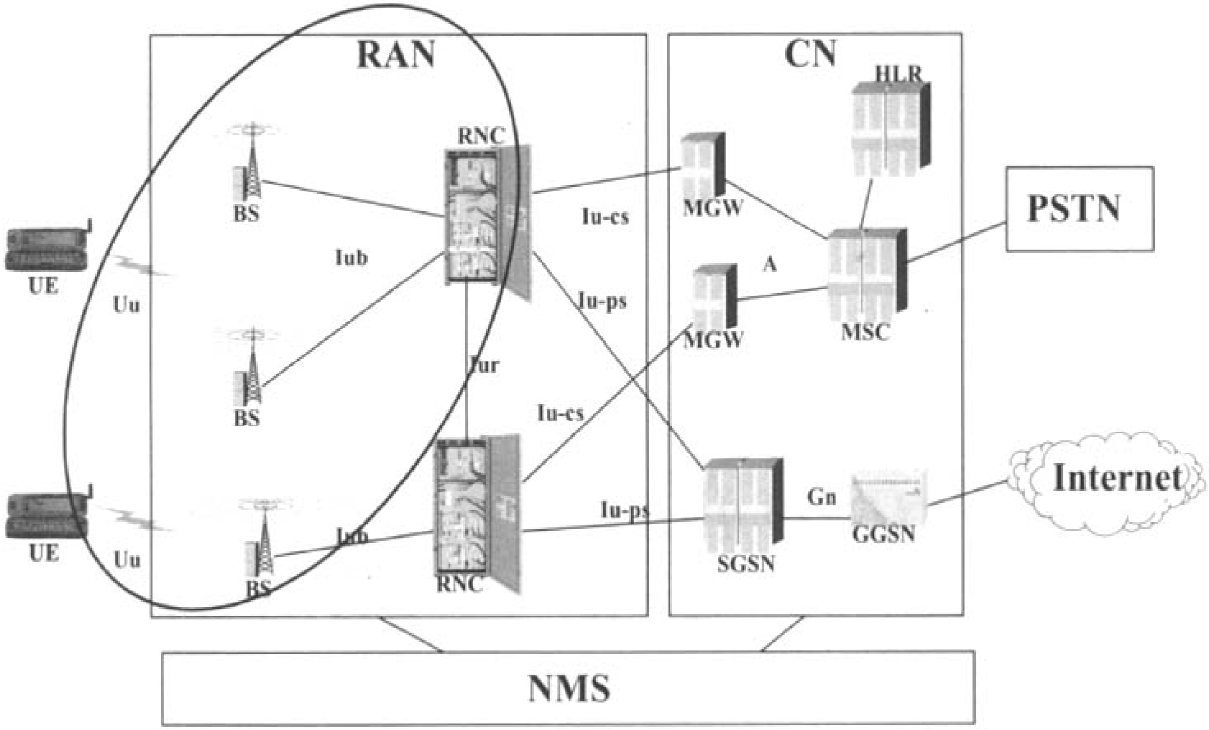
ITEM	SPECIFICATION	
	System Capacity(BSC6000R8&BSC6810 R11Boards)	**System Capacity(BSC6900R11Boards)**
UMTS Network		
Traffic Volume (Erl)	54000	67000
PS(UL+DL) data throughput (Mbit/s)	3450	6700
Number of NodeBs	1500	2700
Number of Cells	4500	4500
GSM Network		
Traffic Volume (Erl)	13000	19500
Number of Cells	2048	2048
Number of TRXs	2048	3072
Number of Configured PDCHs	15360	23040
Number of Actived PDCHs(MCS-9)	8192	12288
Gb Interface Throughput (Mbit/s)	512	1024

Common Technology Platform for 3G-324M Services



Radio Network Planning and Optimization

Scope of radio network planning in a 3G system (WCDMA)



- Maximum user bit rates up to 384 kbps
- Efficient handover between different operators and technologies (e.g. GSM and UMTS)
- An ability to deliver requested bandwidth
- An ability to deliver different services (both CS and PS) with the required quality.

WCDMA Radio Fundamentals

- The WCDMA system supports higher bit rates, so a large bandwidth of 5 MHz is used as compared to 200 kHz in GSM.
- Packet data scheduling in WCDMA is load-based, while in GSM/GPRS it is time-slot based.
- Theoretically, only one frequency channel is used in WCDMA, while GSM uses many frequency channels.
- The limited bandwidth of 5 MHz is sufficient for radio network design. Multipath diversity is possible with rake receivers, while in GSM techniques like frequency hopping are used for (frequency) diversity.
- Users/cells/channels are separated by codes instead of time or frequency.

Service Classes in UMTS

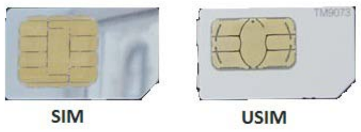
Four types of Traffic:

- Conversational class (voice, video telephony, video gaming)
- Streaming class (multimedia, video on demand, webcast)
- Interactive class (web browsing, network gaming, database access)
- Background class (email, SMS, downloading)

Elements is a WCDMA Radio Network

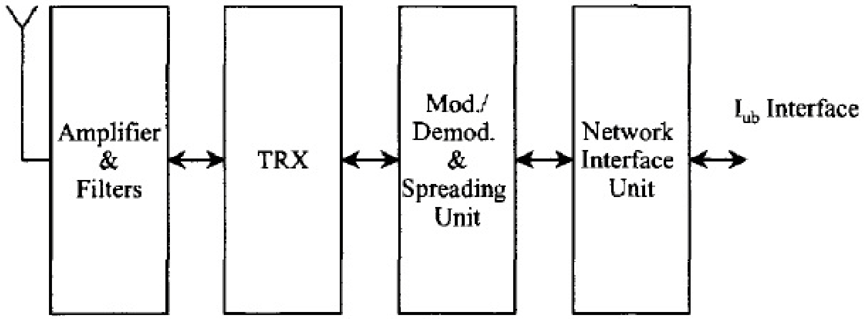
User Equipment (UE)

- User equipment can be divided into three parts, USIM, ME and TE.
- A 3G (UMTS) handset equipped with a USIM card can be used to make video calls, assuming the calling area is covered by a 3G network;
- Your calls and data exchanges are encrypted using keys computed by the USIM, and these keys are stronger than those provided by SIMs.
- The phonebook is much bigger on the USIM, allowing thousands of contacts (instead of a maximum of 255 in a SIM). Each USIM contact is also richer, for instance it can contain email addresses, a second or third phone number, etc.
- The Terminal equipment (TE) is responsible for termination of the entire control and user-plane bearer with the help of the ME.



Base *Station (BS)*

- The base station is also known as 'node B' in a WCDMA radio network. It is more complex than the base station of a GSM network.



Amplifiers and Filters

- This unit consists of signal amplifiers and antenna filters. The amplifiers are used to amplify the signal coming from the transceiver and going towards the RF antenna (the downlink signal), while the filters select the required frequencies coming in from the RF antenna (the uplink signal) and amplify the signals for further processing before sending them to the receiver part of the TRX.

Transceiver

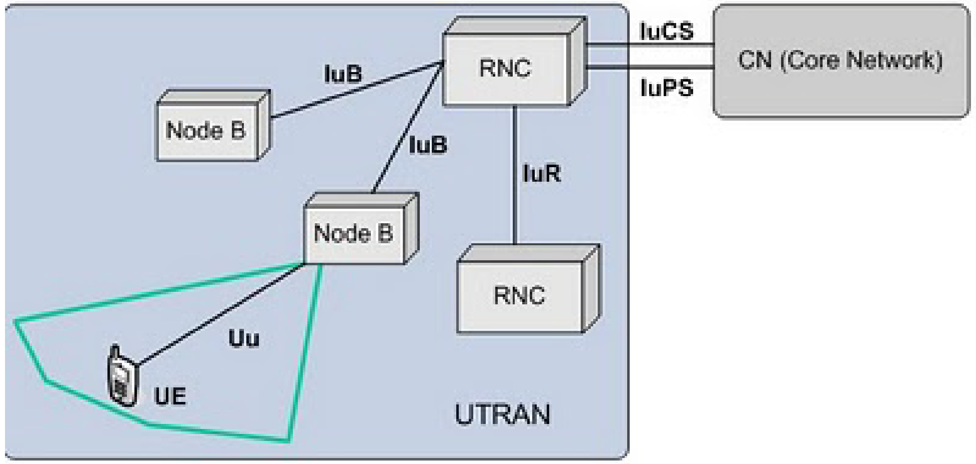
- The TRX is capable of transmitting and receiving signals, by handling uplink and downlink traffic. It consists of one transmitter and one or more receiver.

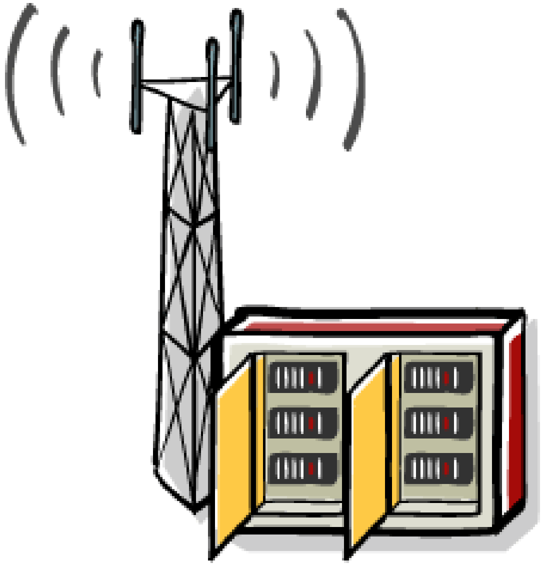
Modulation/Demodulation and Spreading Unit

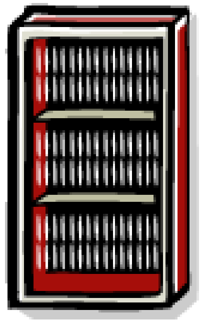
- This unit is responsible for modulating the signal in the downlink direction and demodulating in the uplink direction. It is responsible for summing and multiplexing the signals. This unit contains the digital signal processors that are responsible for coding and decoding signals.

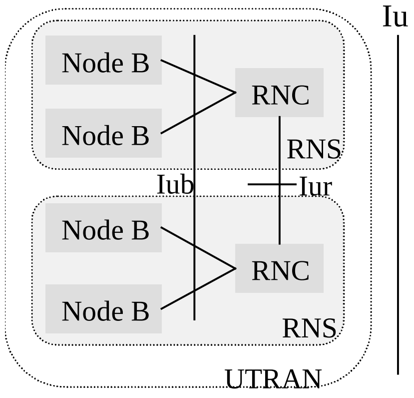
Network Interface Unit

- This unit acts as an interface between the BS and the transmission network or any other network element, such as co-sited cross-connect equipment.





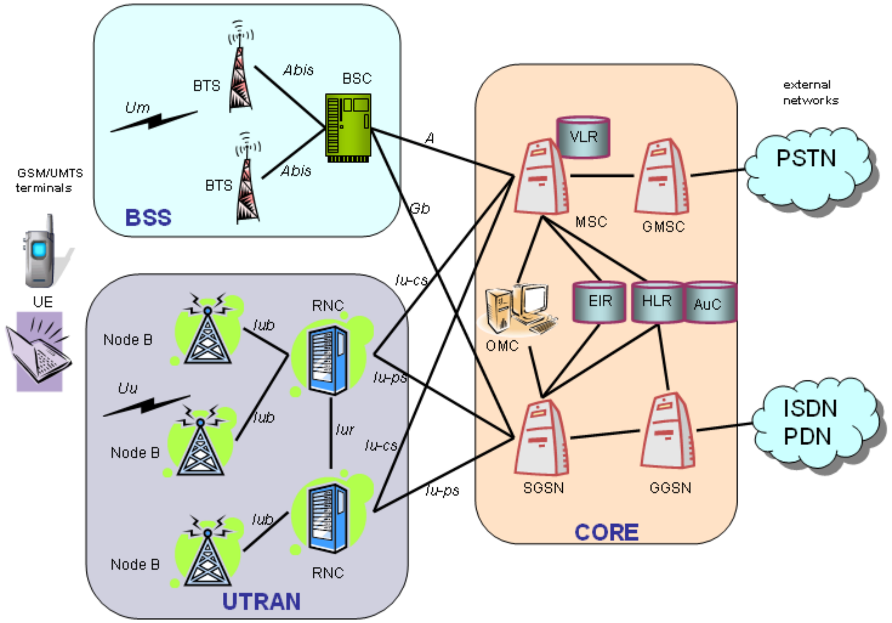




UMTS Radio Access Network

Radio Network Controller (RNC)

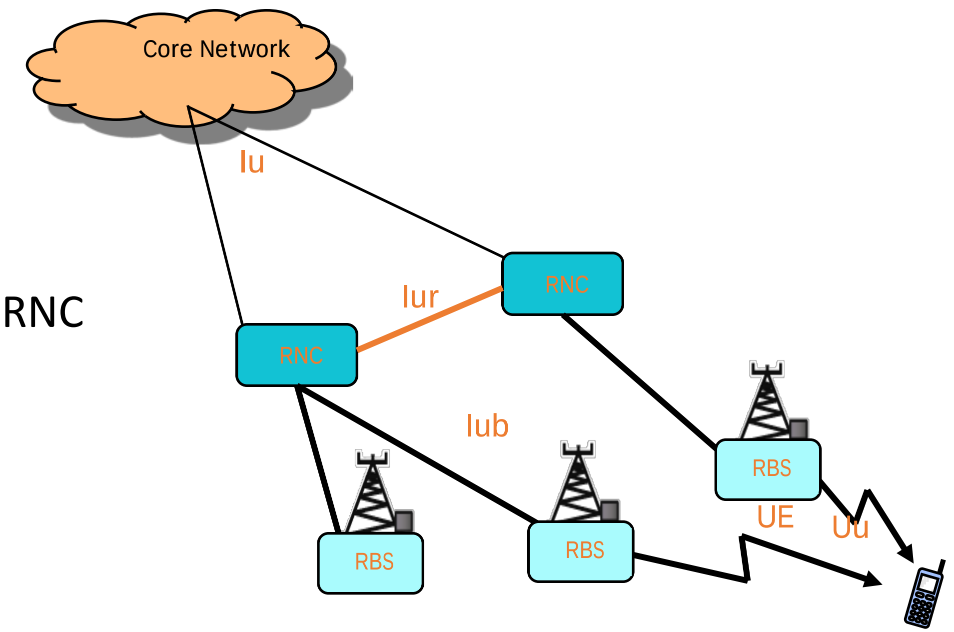
- The radio network controller (RNC) is similar to the BSC in GSM/GPRS networks
- Intra UTRAN handover
- Frame synchronization



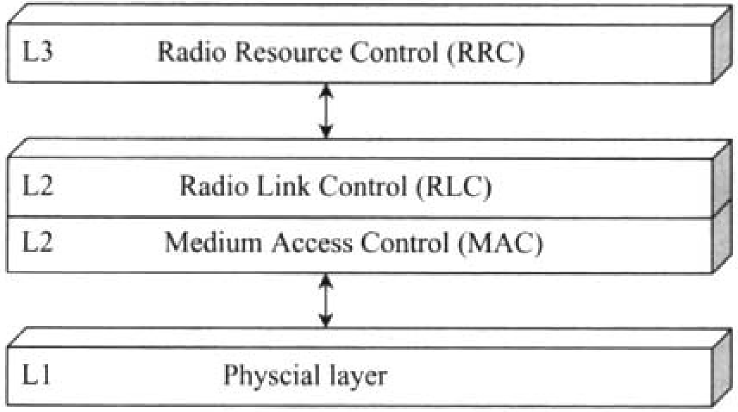
- Radio resource management instead of frequency planning.
- Frame selection/distribution function necessary for soft handover (functions of UMTS radio interface physical layer)
- A radio network controller can be SRNC (serving RNC) or DRNC (drifting RNC).

RN Interfaces

- **Iu**
  - Iu PS
    - Connection to the packet switched core network domain
      - SGSN/GGSN
  - Iu CS
    - Connection to the circuit switched core network domain
      - MSC
- **Iur**
  - RNC interconnection
- **Iub**
  - Connection for the RBS to the RNC
  - Protocol NBAP
- **Uu**
  - Air Interface to the UE
  - Protocol RRC, RLC, MAC



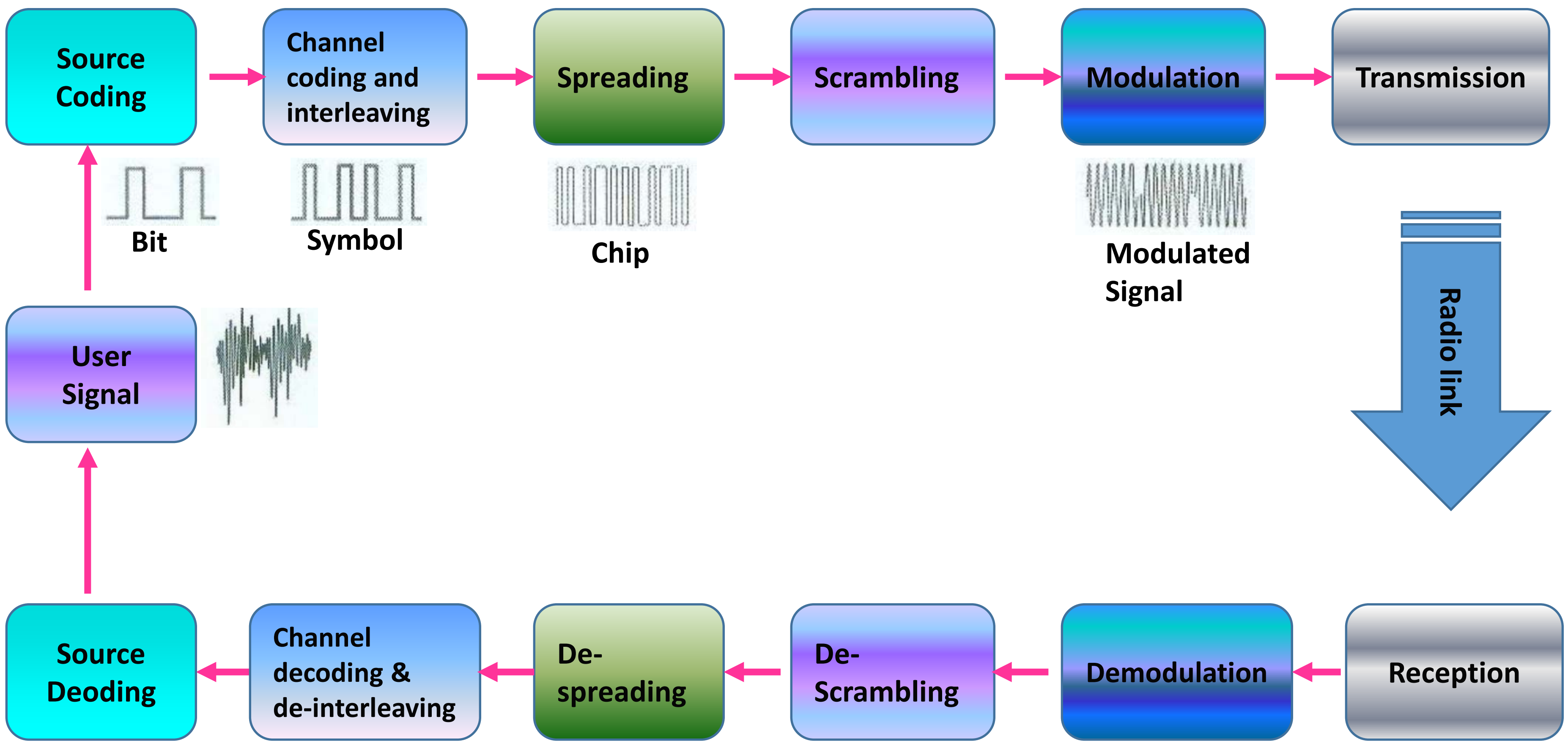
RADIO INTERFACE PROTOCOL ARCHITECTURE



- 3 layers of the WCDMA radio interface protocols
- Layer 1 is the physical layer, the actual medium of transfer.
- The main functions of layer 1 include RF processing, modulation/demodulation of the physical channels, multiplexing/de-multiplexing of the physical channels, error detection and correction, rate matching, power control, synchronization, etc.
- Layer 2 is the link layer. It is required because of the need to allocate minimum resources for a constantly changing data rate. It has two main sub-layers within itself: RLC and MAC.
- The MAC (medium access control) layer in an entity that is responsible for the mapping of the logical channels to the transport channels. As it is an interface between L1 and L3, it also provides functions like multiplexing and demultiplexing of packet data units to/from the physical layer.
- The MAC layer is also responsible for measurements related to traffic volume on the logical channels and further reporting to layer 3.

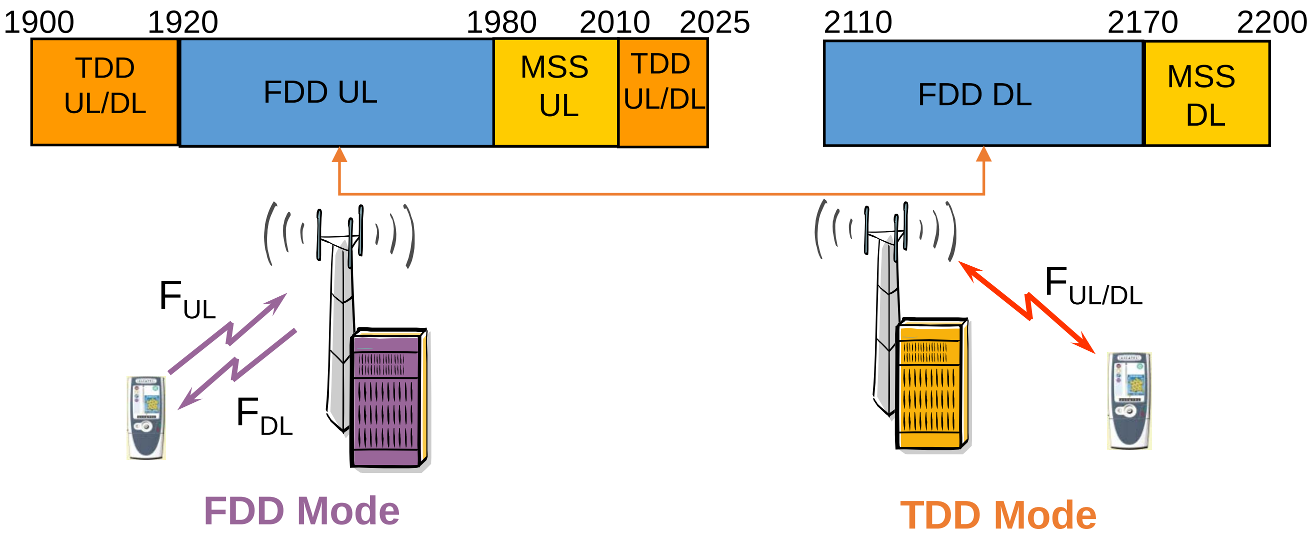
- Functions like segmentation and reassembly of the variable-length packet data into smaller payload units is done by the RLC (radio link control) layer.
- Another important function of this sub-layer is error correction by re-transmission in an acknowledged data transfer mode.
- There are three modes of configuring an RLC by layer 3: transparent mode (no protocol overhead added), unacknowledged mode (no re-transmission protocol in used, so data delivery is not guaranteed), and acknowledged mode (a re-transmission protocol is used and data delivery is guaranteed).
- Layer 3 radio resource control (RRC) sub-layer handles the control plane signaling between the UE and network in connected mode.
- Functions of the RRC include radio resource management and mobility management, as well as power control, ciphering and paging.

Processing procedure of the WCDMA System



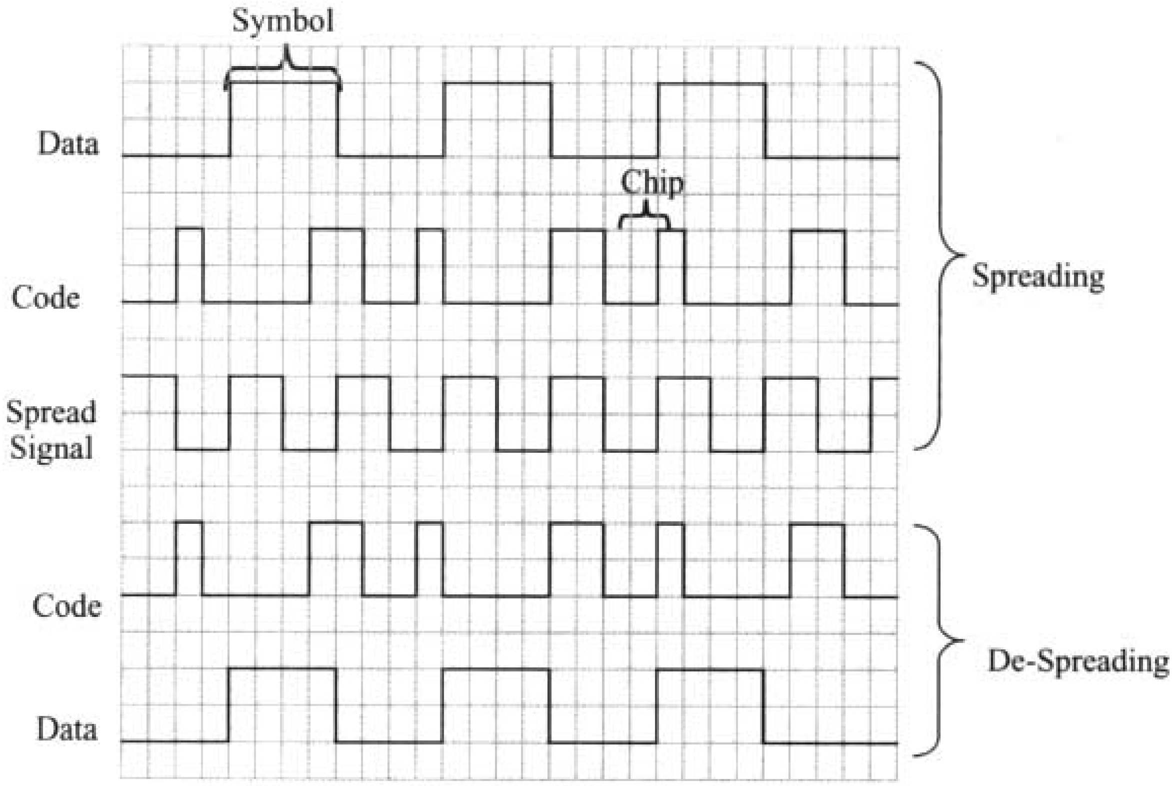
THE SPREADING PHENOMENON

- DS-WCDMA_FDD (direct-sequence WCDMA frequency-division duplex)
- DS-WCDMA_TDD (direct-sequence WCDMA time-division duplex)
- MC-CDMA (multi-carrier code-division duplex)
- With DS-WCDMA_FDD, the information is spread over the frequency spectrum, while with DS-WCDMA_TDD the frequency band is located on both sides of the WCDMA_FDD signal. Both of the techniques FDD and TDD will be implemented, but in the initial phase of a third-generation system only the FDD mode is used because it is more suitable for outdoor coverage purposes.

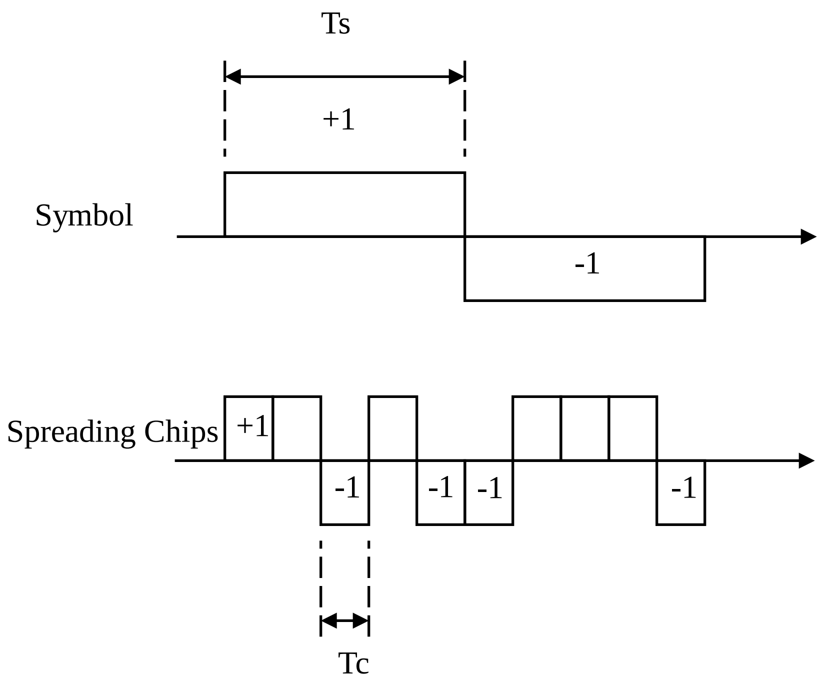


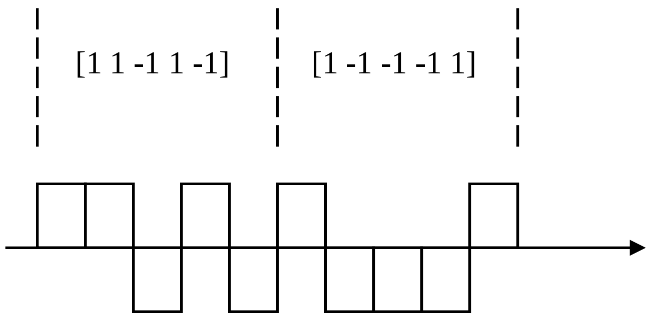
Symbols and Chips

- Usually, a BPSK (binary phase-shift keying) modulated signal is used as the original signal.
- This original data signal (obtained after BPSK modulation) is then modulated by multiplying it by a sequence of bits.
- Each bit of the original signal (also known as a 'symbol') is multiplied by a sequence of bits called 'chips'.



Direct Sequence Spread Spectrum





Spread Chip Sequence

Spreading Factor

$$L = \frac{T_s}{T_c}$$

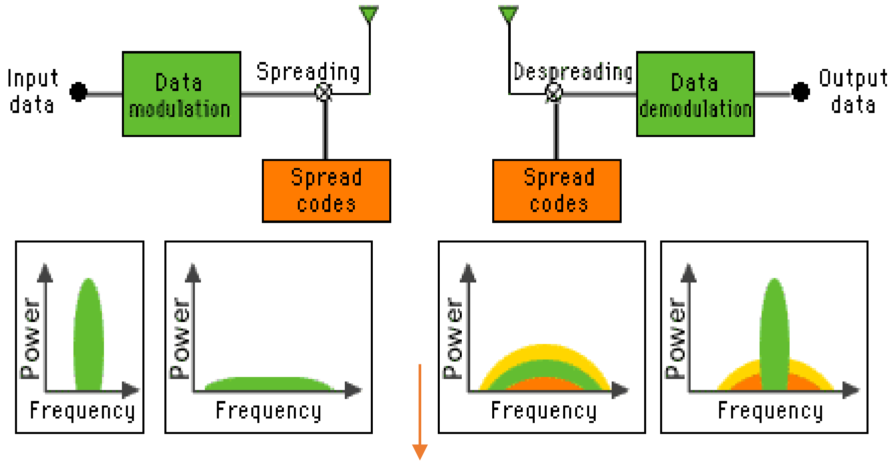
Spreading / Despreading

In the receiving path, de-spreading is achieved by **auto-correlation** with the same code

Due to low cross-correlation properties with other codes, the received signal energy is increased compared to noise and other signal interference

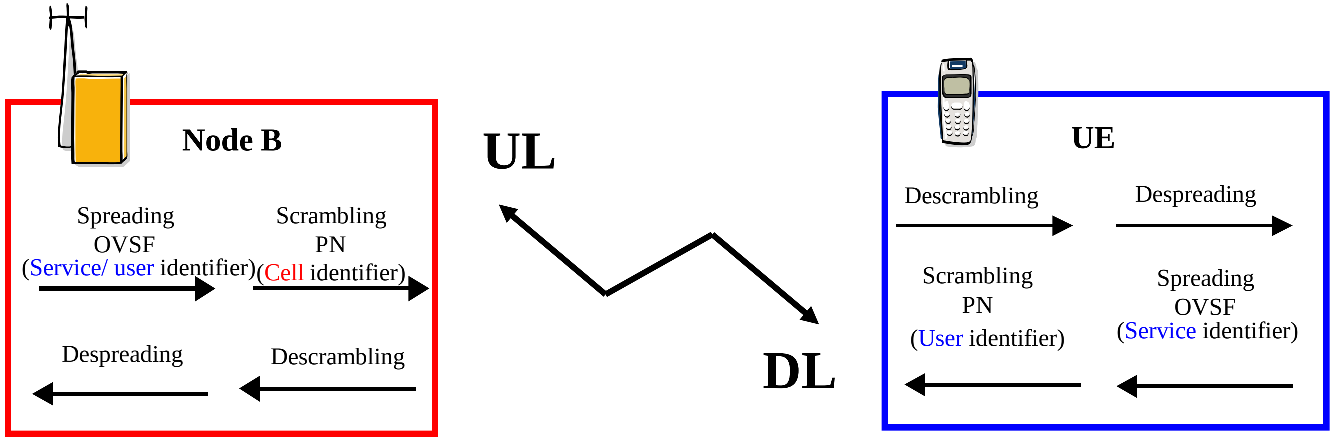
The gain due to dispreading is called **processing gain**

The chip rate is defined to be 3.84Mcps (million chips per second). This means that one chip is 0.26 us.



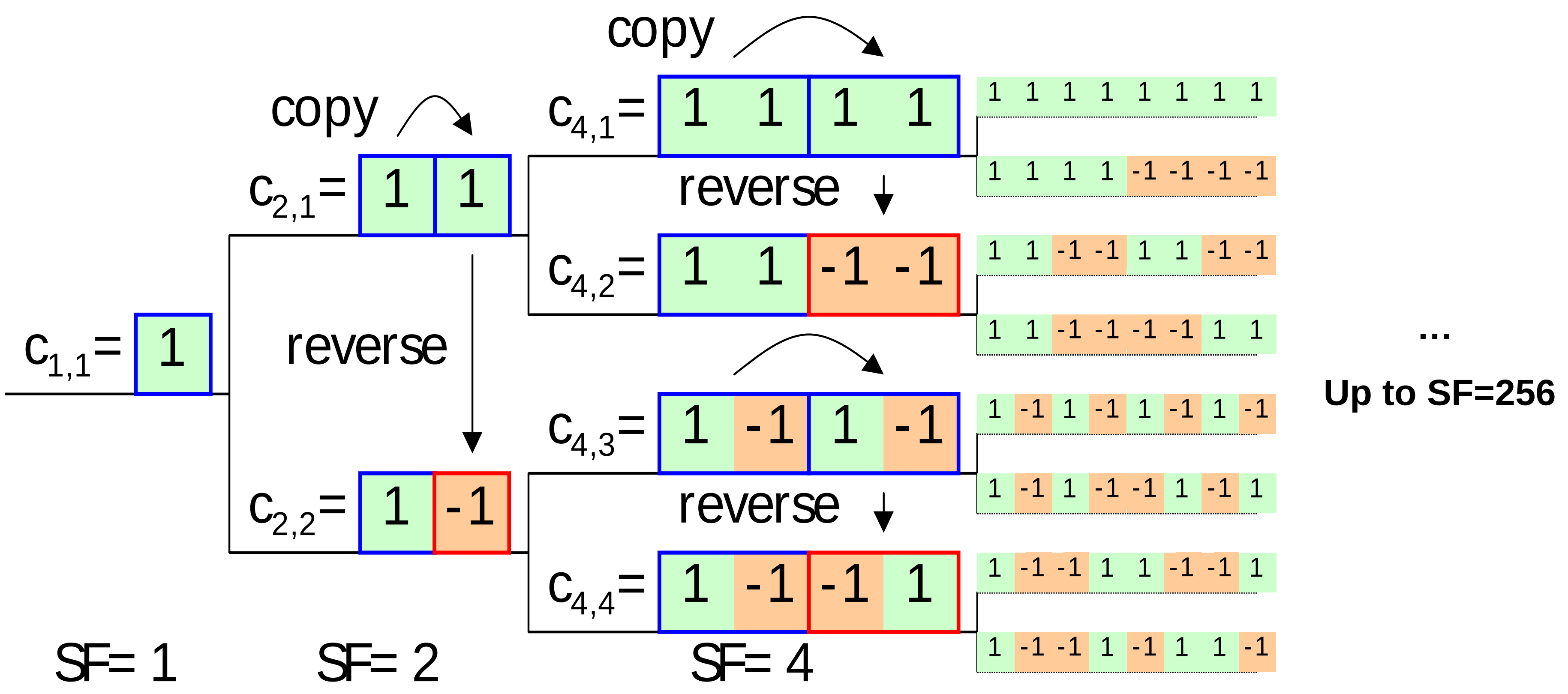
$$PG = \frac{Chip\ Rate}{User\ Bit\ Rate} = \frac{3840\ kcps}{12.2\ kbps} = 314.75 = 25dB$$

Spreading and scrambling codes



- **Spreading codes** (channelization codes)
  - used to differentiate mobiles and services
  - different lengths (spreading factor) according to service in UMTS
  - Orthogonal Variable Spreading Factor (OVSF) in UMTS
- **Scrambling codes**
  - used to differentiate un-synchronized codes (from other UEs or Node-Bs)
  - 1 scrambling code per sector on downlink
  - PN code family in UMTS

Spreading codes: OVSF code tree (like Walsh matrix)



DL & UL Scrambling Codes

DL Scrambling Codes

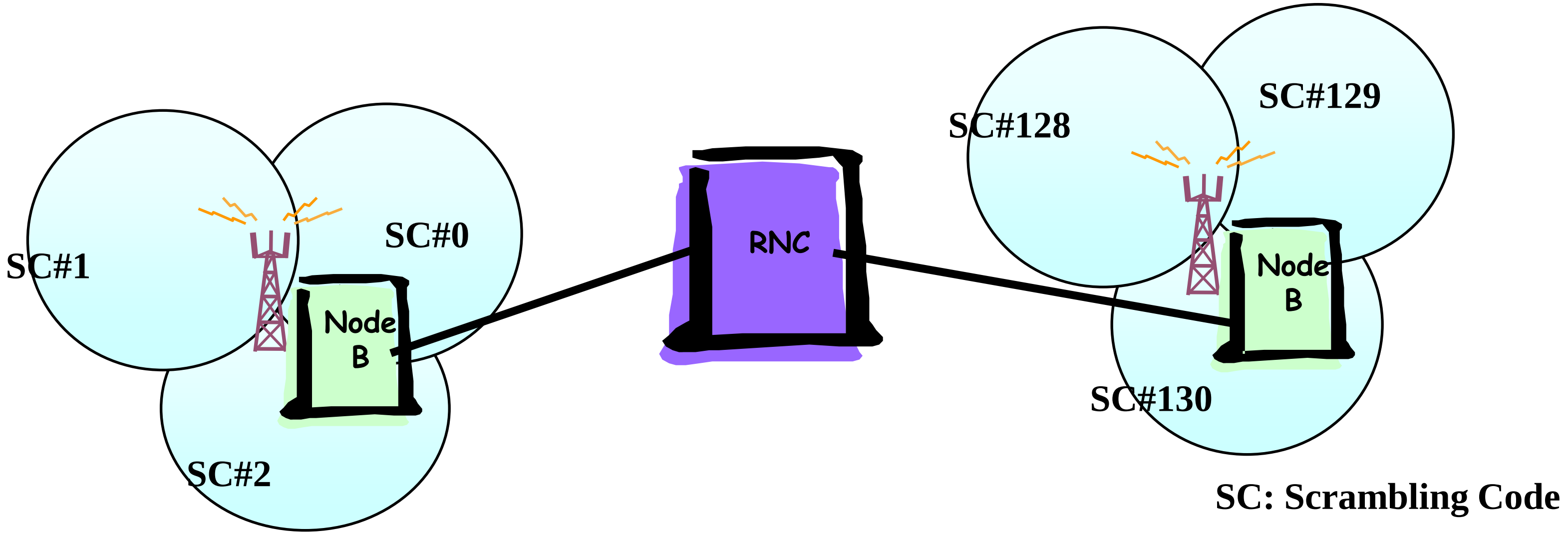
- Pseudo noise codes used for cell separition
- Generated with the shift register of length 18 ($\Rightarrow 2^{18}$-1=262 143 codes can be generated)
- The first 8192 first codes from 262 143 code set are exclusively used in DL, they are organised into hierarhical groups:
  - 512 Primary Scrambling Codes
  - 512·15 Secondary Scrambling Codes

UL Scrambling Codes

- Two different types of UL scrambling codes are generated:
  - Long scrambling codes created from the Gold pseudo-noise sequence (length of 38 400 chips)
  - Short scrambling codes generated by the quaternary S(2) pseudo-noise sequence (256 chips are periodicaly repeted to get the scrambling code of the frame length)
- For the common physical channels long scrambling codes must be used
- For the dedicated channels both long and short scrambling codes can be used

Scrambling Code

- One code per cell (sector/carrier) : Configurable by operator
- 512 sets of 16 codes each (1 primary and 15 secondary)
- Only the primary scrambling code is used for all Common Channels

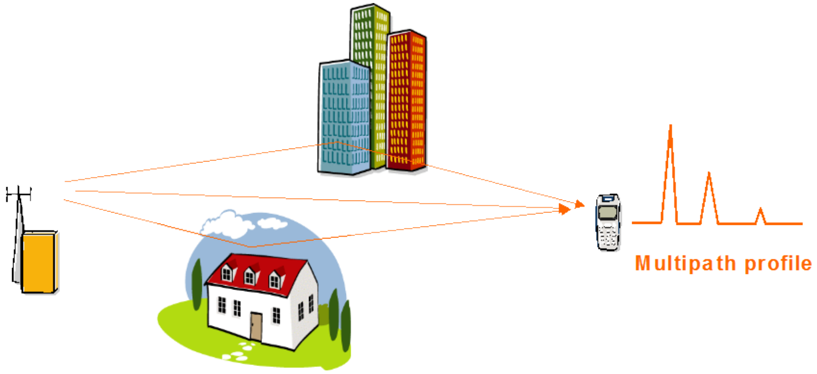


WCDMA Modulation

•UL: BPSK

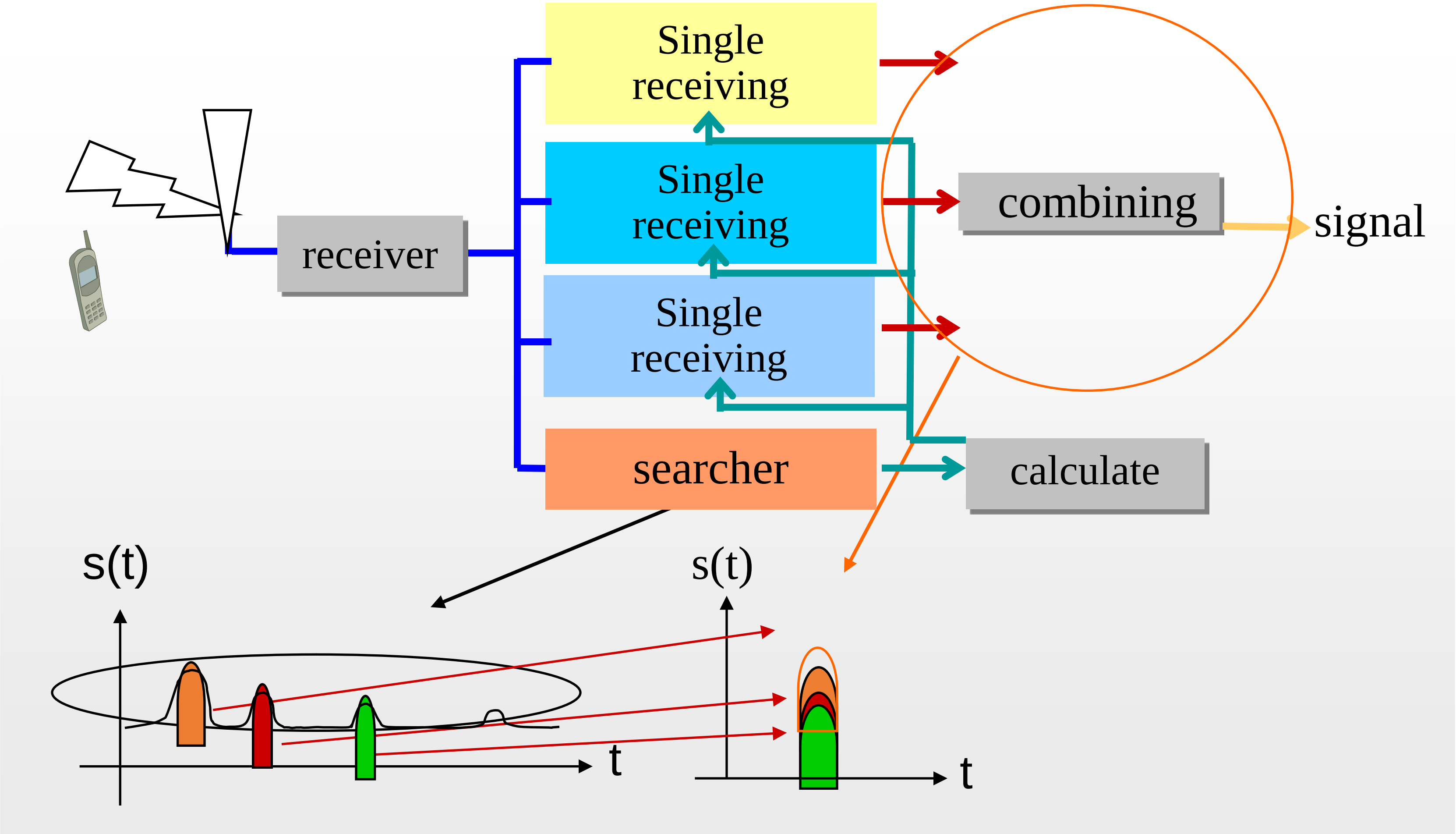
•DL:QPSK（HSDPA introduce 16QAM）

▪Due to Reflection and diffraction of the transmit signal on obstacles there is not only one path but a large number of paths with different delays and amplitudes



▪In W-CDMA, due to larger bandwidth, RAKE receiver will take benefit of this diversity

RAKE Receiving

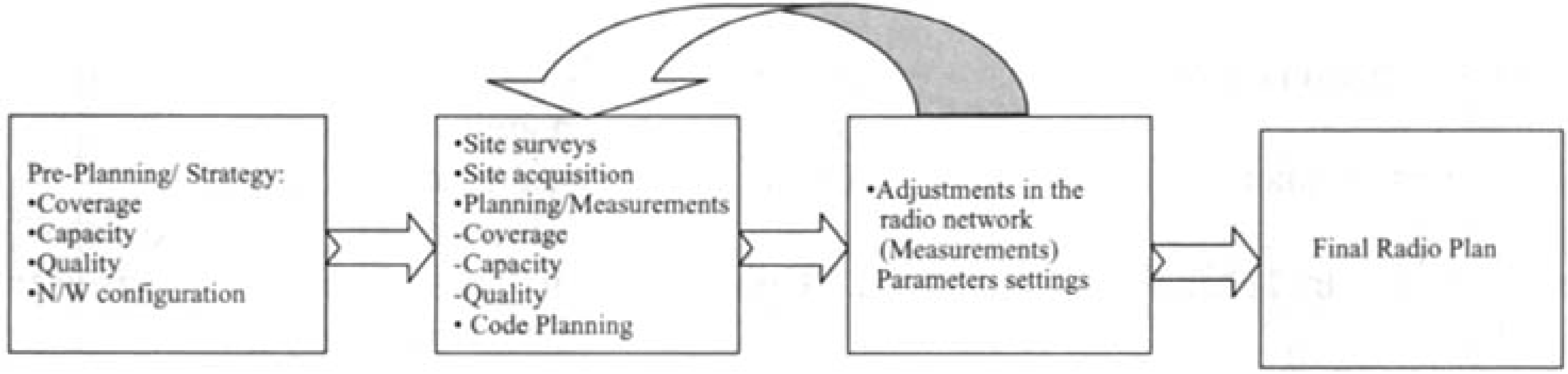


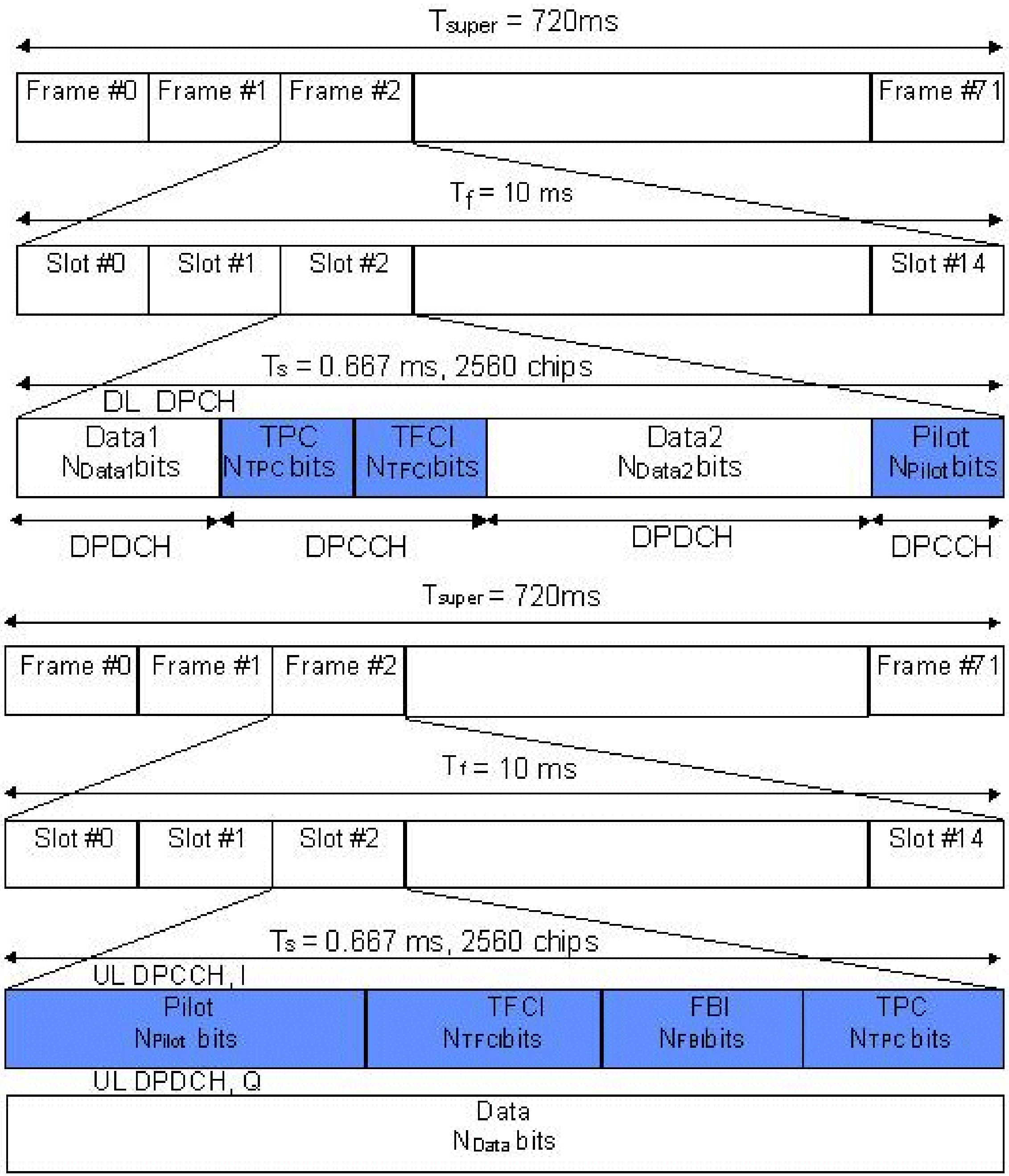
RAKE overcome multi-finger interference， improve receive capability

RADIO NETWORK PLANNING PROCESS

The radio network planning process for WCDMA is nearly the same as for GSM networks.

- There are four different types of service classes and numerous different kinds of services in each class.
- Enough coverage, sufficient capacity and desired throughput will be key in the network configuration design to achieve the desired quality standards.





UMTS Time Slots

Example of DPCH (Dedicated Physical Channel) downlink and uplink time slot allocation.

TCP stands for Transmit Power Control,

Feedback Information (**FBI**) is used for closed loop transmission diversity.

Transport Format Combination Indicator (**TFCI**) contains the information relating to data rates.

Pilot bits are always the same and are used for channel synchronisation.

Power Control

- TX Power is adjusted regularly so that each connection is received with the required Eb/Nt of its service
  - Uplink: Avoid „Near-Far-Problem“
  - Downlink: Power share allocation

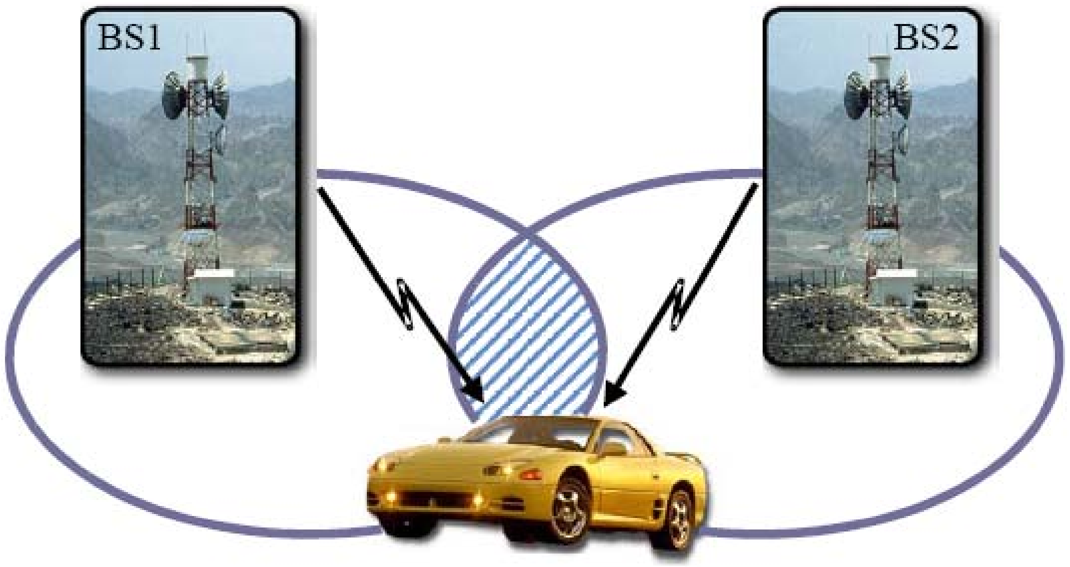
- Policy: “No one gets a higher quality (Eb/Nt) than he needs. Everyone gets exactly the required quality or is not served at all“
  - no unnecessary increase of interference for other mobiles
  - no waste of common power resource in the downlink

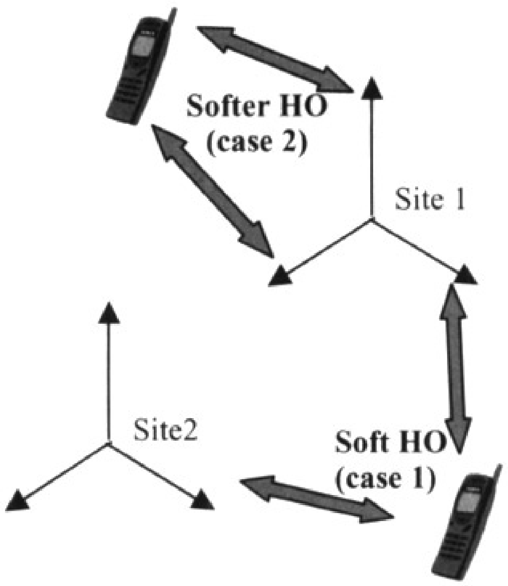
Soft/Softer Handover

Soft/softer handover is important for efficient power control. Without soft/softer handover there would be near-far scenarios of a UE penetrating from one cell deeply into an adjacent cell without being power controlled by the latter.

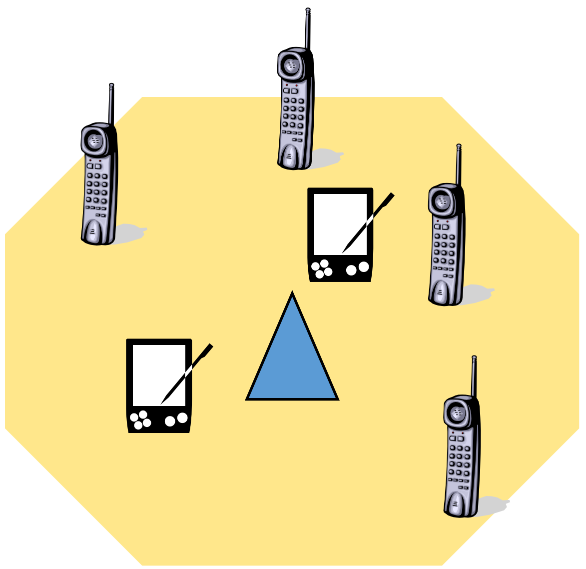
Soft Handover: UE connected to two or more RBSs at the same time

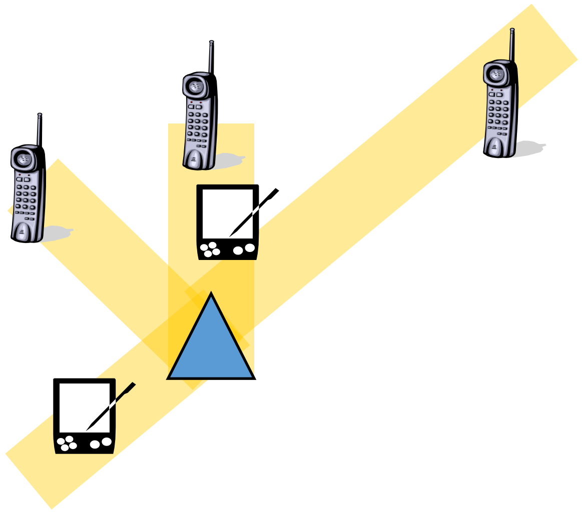
Softer Handover: UE connected to two or more sector of the same RBS/BTS

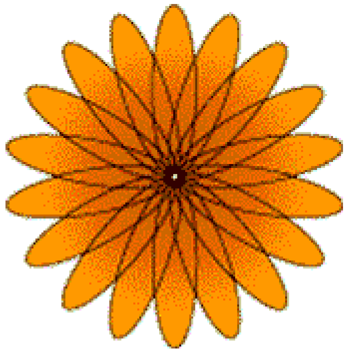




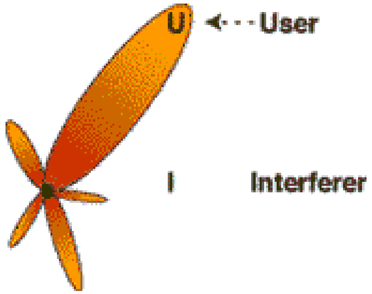
- Radio Interface
  - Smart Antenna
    - Increase the quality of the signals
    - Only installed at the BS, not the handset
    - Increase the usage of the BS
      - Increased frequency reuse







Switched Beam



Adaptive Array Antenna

Coverage Planning

- **Link Budget: The** main procedures of UMTS are very similar to that of GSM, and the coverage and capacity planning play also important roles in the whole radio network planning.
- **Eb/No:** Eb/No is the ratio of the received bit energy to the thermal noise
- **Soft Handover Gain:** The soft handover phenomenon gives an additional gain against the fast fading that takes place in the network
- **Power Control Headroom:** This is commonly known as the fast fading margin. It is the fade margin needed to maintain the closed-loop power control in action.
- **Loading Effect:** Interference from neighboring cells has an impact on the cell's performance. This is also known as cell loading, and the parameter to describe this is the loading factor. Theoretically, the parameter a may vary from zero to 100%, but practically it is in the range 40-50%.

- **Capacity Planning:** The downlink coverage decreases with an increase in the number of mobile subscribers and their transmission rates.
- **Adaptive Multi-rate:** in GSM, where speech codecs are fixed - e.g. FR (full rate) or HR (half rate). in WCDMA radio networks the process of AMR is used to make it possible to adapt speech and channel coding rates according to the quality of the radio channel. This improves the error protection and channel quality.
- The codec basically has one single integrated speech codec with eight source rates. This is controlled by the radio resource management functions of the RAN. These eight source rates are 12.2, 10.20, 7.95, 7.40, 6.70, 5.90, 5.15 and 4.75 kbps. The speech frames in the AMR coder are of 20 ms, so if the sampling rate is 8000/s, 160 samples are processed.

UL/DL LINK BUDGET

$$L_p\,(dB) = P_t\,(dBm) + G_t\,(dBi) - P_r\,(dBm) + G_r\,(dBi)$$
$$= EIRP\,(dBm) - P_r\,(dBm) + G_r\,(dBi)$$

EIRP depends on the UL or DL.

Uplink (UL)	**Downlink (DL)**
$EIRP\,(dBm) =$ $P_{Tx}\,(dBm) - L_u\,(dB) + G_t\,(dBi)$	$EIRP\,(dBm) =$ $P_{Tx}\,(dBm) - L_c\,(dB) + G_t\,(dBi)$
P_{Tx}: transmission power, G_t: antenna gain, L_u: body loss (voice: [3, 10], data: [0, 3]).	P_{Tx}: transmission power, G_t: antenna gain, L_c: *feeder* losses.

UL power budget (example for 144 kb/s data service)

	Value	*Formula*
Transmitter		
P: MS Tx Power (dBm)	23	
MAG: MS Tx Antenna Gain (dBi)	0	
BL: Body Loss (dB)	3	
PIRE: MS EIRP (dBm)	20	EIRP= P+MAG-BL
Receiver		
FM: Fade Margin (dB)	5,4	FM = 0,675*SD (RC=90%, SD=8dB)
IM: Interference Margin (dB)	3	IM = 10log(1/1-loading)
PL: Pathloss (dB)	0	Dense Urban = 20 dB
BAG: BTS Antenna Gain (dBi)	16	
BCL: BTS Cable Loss (dB)	3	
SHG: Soft HO Gain (dB)	2	
TM: Total Margin (dB)	-6,6	TM=FM+IM+PL-BAG+BCL-SHG
S: BTS Rx Sensitivity (dBm)	-115	
UL_PL: UpLink Path Loss (dB)	141,6	UP_PL = EIRP-TM-S

DL link budget

	Value	*Formula*
Transmitter		
P: BTS Tx Power (dBm)	29	Power allocated to the pilot channel
BAG: BTS Tx Antenna Gain (dBi)	16	
BCL: BTS Cable Loss (dB)	3	
PIRE: BTS EIRP (dBm)	42	PIRE = P+BAG-BCL
Receiver		
FM: Fade Margin (dB)	5,4	FM = 0,675*SD (RC=90%, SD=8dB)
IM: Interference Margin (dB)	3	IM = 10log(1/1-loading)
PL: penetration loss (dB)	0	Dense urban = 20 dB
MAG: MS Antenna Gain (dBi)	0	
SHG: Soft HO Gain (dB)	2	
TM: Total Margin (dB)	9,4	TM=FM+IM+PL-MAG+BL-SHG
S: MS Rx Sensitivity (dBm)	-110	
DL_PL: DownLink Path Loss (dB)	142,6	UP_PL = PIRE-TM-S

Table 7.5 Link budget calculation in WCDMA radio network

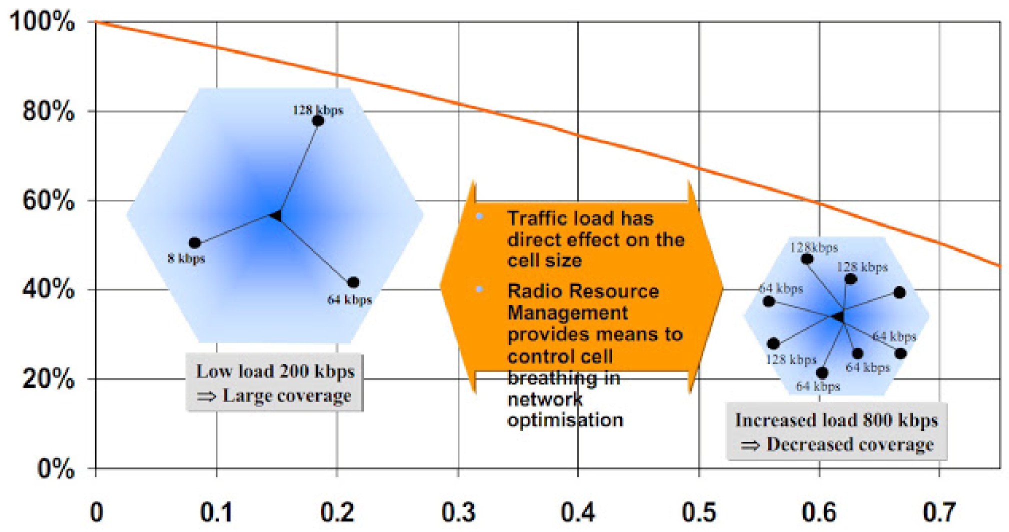
Link Budgets:		Voice		LCD		UDD		UDD		UDD	
Data rate (kb/s):		12.2	12.2	64	64	64	64	144	144	384	384
Load:		50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
		Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
RECEIVING END		Node B	UE	Node B	UE	Node B	UE	Node B	UE	Node B	UE
Thermal Noise Density	dBm/Hz	−174	−174	−174	−174	−174	−174	−174	−174	−174	−174
BTS Receiver Noise Figure	dB	3.00	8.00	3.00	8.00	3.00	8.00	3.00	8.00	3.00	8.00
BTS Receiver Noise Density	dBm/Hz	−171.00	−166.00	−171.00	−166.00	−171.00	−166.00	−171.00	−166.00	−171.00	−166.00
BTS Noise Power [NoW]	dBm	−105.16	−100.16	−105.16	−100.16	−105.16	−100.16	−105.16	−100.16	−105.16	−100.16
Reguired Eb/No	dB	4.00	6.50	2.00	5.50	2.00	5.50	1.50	5.00	1.00	4.50
Soft handover MDC gain	dB	0.00	1.20	0.00	1.20	0.00	1.20	0.00	1.20	0.00	1.20
Processing gain	dB	24.98	24.98	17.78	17.78	17.78	17.78	14.26	14.26	10.00	10.00
Interference margin (NR)	dB	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01
Required BTS Ec/Io [q]	dB	−17.97	−16.67	−12.77	−10.47	−12.77	−10.47	−9.75	−7.45	−5.99	−3.69
Required Signal Power [S]	dBm	−123.13	−116.83	−117.93	−110.63	−117.93	−110.63	−114.91	−107.61	−111.15	−103.85
Cable loss	dB	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Body loss	dB	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antenna gain RX	dBi	18.00	0.00	18.00	0.00	18.00	0.00	18.00	0.00	18.00	0.00
Soft handover gain	dB	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Power control headroom	dB	3.00	0.00	3.00	0.00	3.00	0.00	3.00	0.00	3.00	0.00
Sensitivity	dBm	−137.63	−111.33	−132.43	−110.13	−132.43	−110.13	−129.41	−107.11	−125.65	−103.35
TRANSMITTING END		UE	Node B	UE	Node B	UE	Node B	UE	Node B	UE	Node B
Power per connection	dBm	21.00	27.30	21.00	28.30	21.00	28.30	26.00	33.30	26.00	33.30
Maximum Power per connection	dBm	21.00	40.00	21.00	40.00	21.00	40.00	26.00	40.00	26.00	40.00
Cable loss	dB	0.00	3.00	0.00	3.00	0.00	3.00	0.00	3.00	0.00	3.00
Body loss	dB	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antenna gain TX	dBi	0.00	18.00	0.00	18.00	0.00	18.00	0.00	18.00	0.00	18.00
Peak EIRP	dBm	16.00	42.30	21.00	43.30	21.00	43.30	26.00	48.30	26.00	48.30
Maximum Isotropic path loss	dB	153.63	166.33	153.43	165.13	153.43	165.13	155.41	162.11	151.65	158.35
Isotropic path loss to the cell border			153.63		153.43		153.43		155.41		151.65

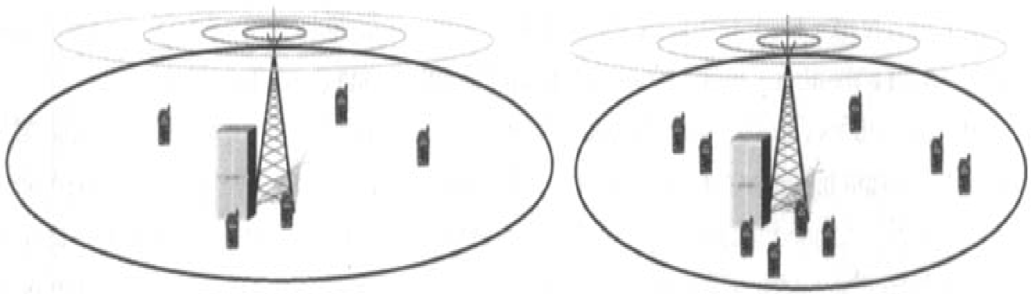
DETAILED PLANNING

- The frequency re-use factor is 1 in a WCDMA radio network, but code planning needs to done accurately.

Cell breathing

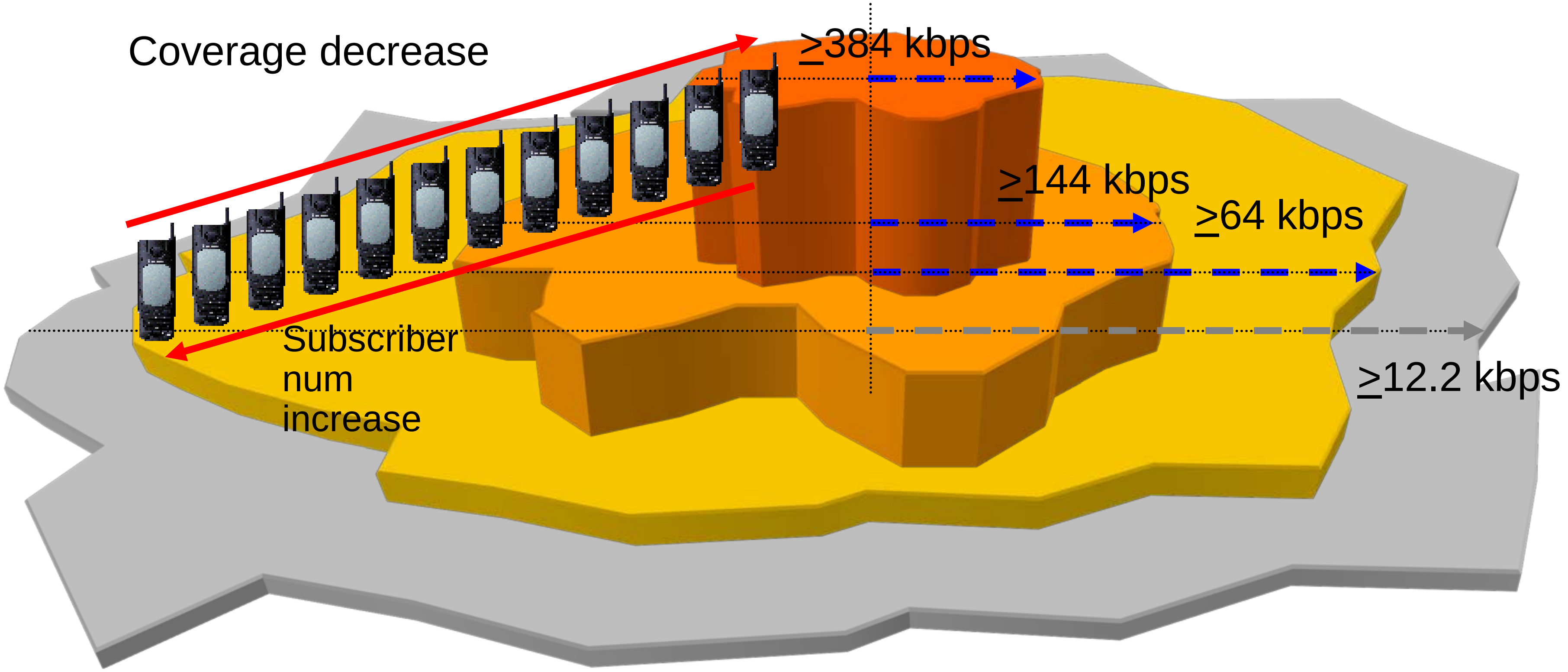
- If the number of subscribers using the cell increases, the area covered by the cell decreases. As the load decreases, the area increases.



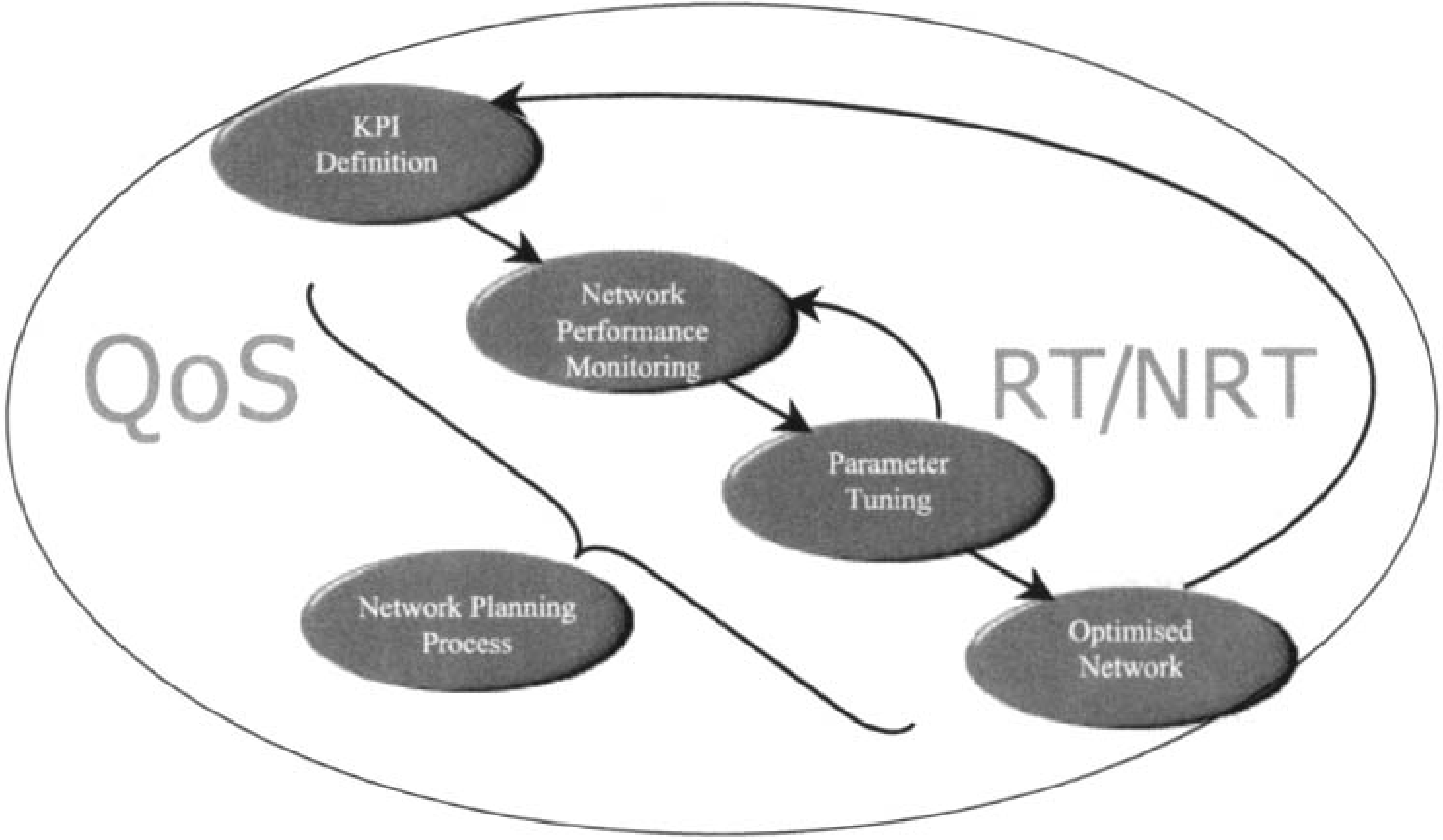


Coverage/capacity vs Data Rate

- Higher rate needs higher power
- High data rate transmission is only available nearby the station



WCDMA RADIO NETWORK OPTIMISATION



- The main KPIs may include call success/failure rate, dropped call rate, (soft) handover success rate, average throughput on uplink/downlink, and average throughput on various channels.
- The network's performance can be monitored through drive tests and the network management system (NMS).