FROM GSM TO LTE-ADVANCED: AN INTRODUCTION TO MOBILE NETWORKS AND MOBILE BROADBAND

3. UNIVERSAL MOBILE TELECOMMUNICATIONS SYSTEM (UMTS) AND HIGH-SPEED PACKET ACCESS (HSPA)

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- **Universal Mobile Telecommunications System (UMTS)**
  - a third generation wireless telecommunication system, which follows in the footsteps of GSM and GPRS
  - combines the properties of both **circuit-switched voice network** and **packet-switched data network**
  - offers a multitude of **new possibilities** compared to earlier systems
- UMTS **radio network** system has been significantly enhanced and offers **broadband speeds**, which is referred to as **High-Speed Packet Access (HSPA)**

3.1 OVERVIEW, HISTORY AND FUTURE

- While **UMTS Terrestrial Radio Access Network (UTRAN)** was a completely **new** development, many components of GSM **core network** were **reused**, with only a **few changes**, for the **first step** of UMTS
- New **core** and **radio network** enhancements were then specified in **subsequent steps**
- The process continued up to not only with UMTS but also with **Long-Term Evolution (LTE)** and **LTE-Advanced radio access networks**
- These developments, together with the **evolved packet core (EPC)**
- **Third Generation Partnership Project (3GPP)** is responsible for evolving GSM, UMTS and LTE standards and refers to different versions as '**Releases**'

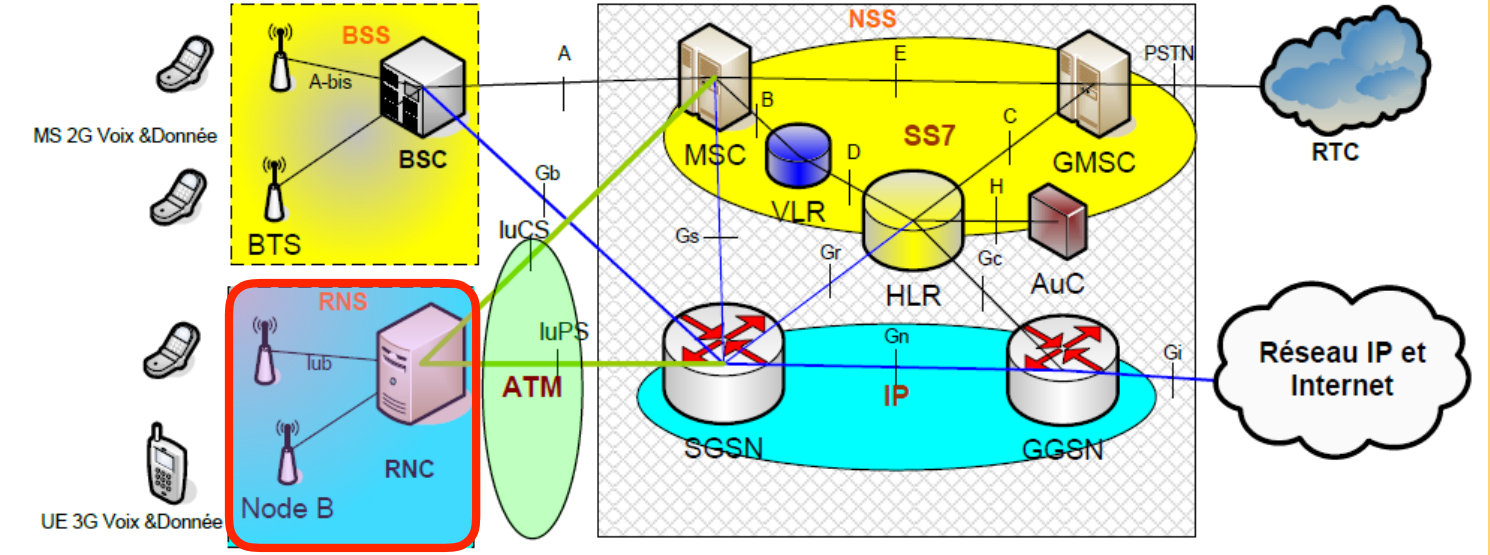
Phase 1	1992	GSM Features
Phase 2	1995	GSM Features, EFR Codec,
Release 96	1997 Q1	GSM Features, 14.4 kbit/s User Data Rate,
Release 97	1998 Q1	GSM Features, GPRS
Release 98	1999 Q1	GSM Features, AMR, EDGE, GPRS for PCS1900

Release 99	2000 Q1	Specified the first UMTS 3G networks, incorporating a CDMA air interface[9]
Release 4	2001 Q2	Originally called the **Release 2000** - added features including an all-IP Core Network[10]
Release 5	2002 Q1	Introduced IMS and HSDPA[11]
Release 6	2004 Q4	Integrated operation with Wireless LAN networks and adds HSUPA, MBMS, enhancements to IMS such as Push to Talk over Cellular (PoC), GAN[12]
Release 7	2007 Q4	Focuses on decreasing latency, improvements to QoS and real-time applications such as VoIP.[13] This specification also focus on HSPA+ (High Speed Packet Access Evolution), SIM high-speed protocol and contactless front-end interface (Near Field Communication enabling operators to deliver contactless services like Mobile Payments), EDGE Evolution.

Release 8	2008 Q4	First **LTE** release. All-IP Network (SAE). New OFDMA, FDE and MIMO based radio interface, not backwards compatible with previous CDMA interfaces. Dual-Cell HSDPA. UMTS HNB.
Release 9	2009 Q4	SAES Enhancements, WiMAX and LTE/UMTS Interoperability. Dual-Cell HSDPA with MIMO, Dual-Cell HSUPA. LTE HeNB.
Release 10	2011 Q1	**LTE Advanced** fulfilling IMT Advanced 4G requirements. Backwards compatible with release 8 (LTE). Multi-Cell HSDPA (4 carriers).
Release 11	2012 Q3	Advanced IP Interconnection of Services. Service layer interconnection between national operators/carriers as well as third party application providers. Heterogeneous networks (HetNet) improvements, Coordinated Multi-Point operation (CoMP). In-device Co-existence (IDC).
Release 12	2015 Q1	Enhanced Small Cells (higher order modulation, dual connectivity, cell discovery, self configuration), Carrier Aggregation (2 uplink carriers, 3 downlink carriers, FDD/TDD carrier aggregation), MIMO (3D channel modeling, elevation beamforming, massive MIMO), New and Enhanced Services (cost and range of MTC, D2D communication, eMBMS enhancements)[14]
Release 13	Planned to March 2016	LTE in unlicensed, LTE enhancements for Machine-Type Communication. Elevation Beamforming / Full-Dimension MIMO, Indoor positioning[15]
Release 14	Planned for June 2017	Energy Efficiency, Location Services (LCS), Mission Critical Data over LTE, Mission Critical Video over LTE, Flexible Mobile Service Steering (FMSS), Multimedia Broadcast Supplement for Public Warning System (MBSP), enhancement for TV service, massive Internet of Things, Cell Broadcast Service (CBS), Cell Broadcast Service (CBS)[16]
Release 15	Planned for Sept 2018	Support for 5G Vehicle-to-x service,IP Multimedia Core Network Subsystem (IMS), Future Railway Mobile Communication System[17]

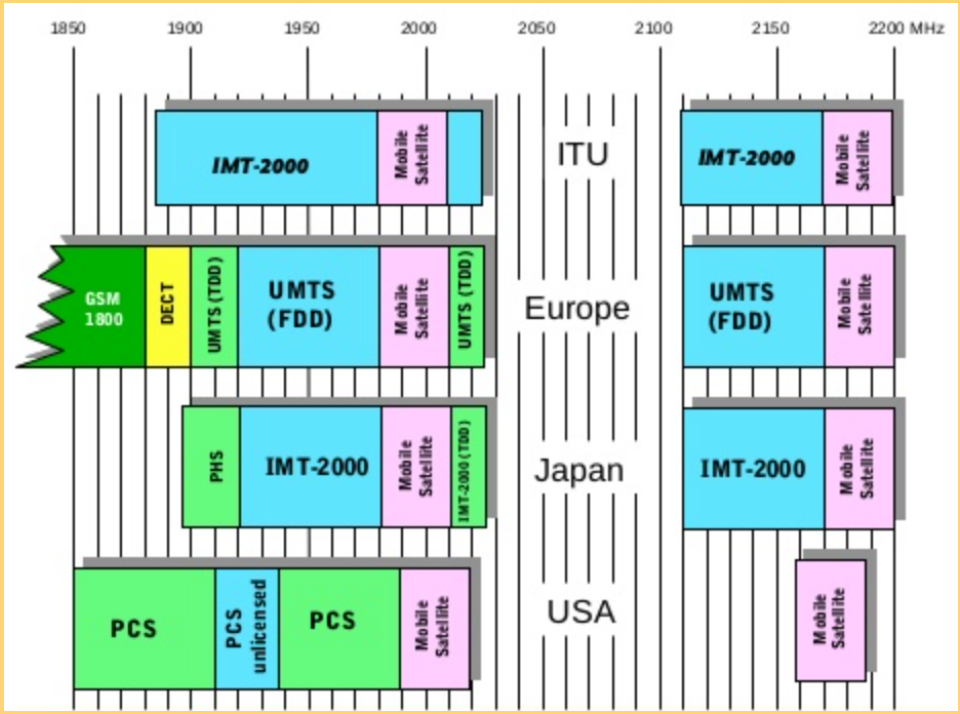
3.1.1 3GPP RELEASE 99: THE FIRST UMTS ACCESS NETWORK IMPLEMENTATION

- Release 99 contains all the specifications for the first release of UMTS
- The main improvement was the completely redesigned radio access network, which the UMTS standards refer to as UMTS Terrestrial Radio Access Network (UTRAN)

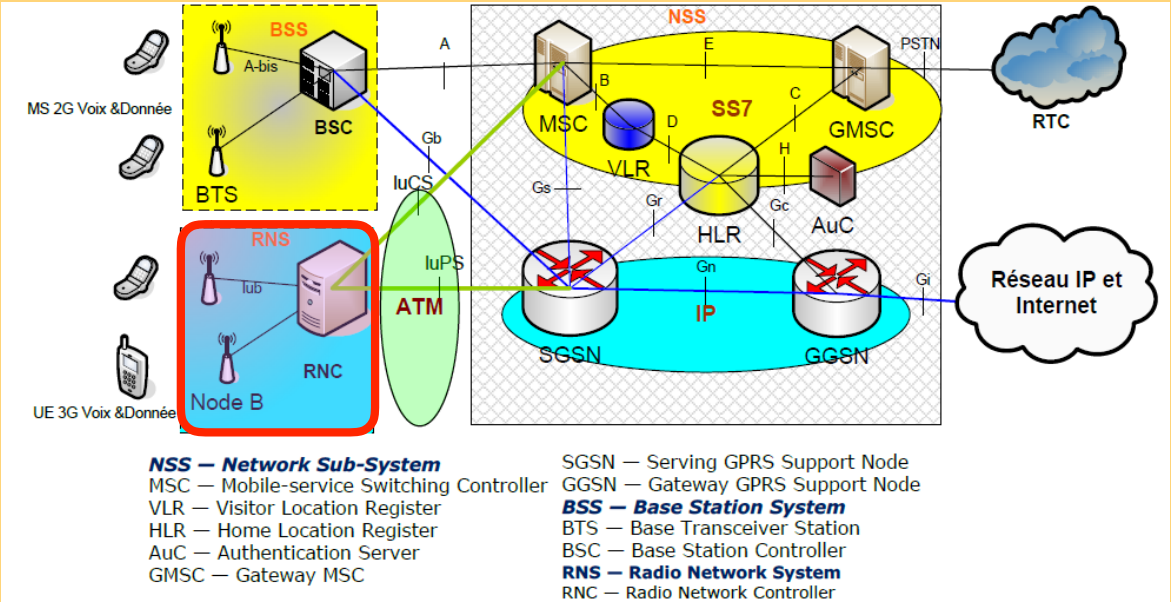


- A new method of air interface called Wideband Code Division Multiple Access (WCDMA) was introduced
  - In WCDMA, users are no longer separated from each other by timeslots and frequencies but are assigned a unique code
- The bandwidth of a single carrier was significantly increased, enabling a much faster data transfer
- Release 99 UTRAN is able to send data with a speed of
  - up to 384 kbps per user in downlink direction
  - also up to 384 kbps in uplink direction
- The base station and base station controller in UTRAN network are called Node-B and Radio Network Controller (RNC)
- The mobile station is referred to as User Equipment (UE)

- **Frequency allocation** in Europe and Asia
  - For the **uplink direction**, 12 blocks of 5 MHz each have been assigned in the frequency range between **1920** and **1980 MHz**
  - For the **downlink direction**, another 12 blocks of 5 MHz each have been assigned in the frequency range between **2110** and **2170 MHz**
- **Frequency allocation** in North America
  - Initially, UMTS networks shared the frequency band between **1850** and **1910 MHz** in the **uplink** direction and between **1930** and **1990 MHz** in the **downlink** direction with 2G networks such as GSM and CDMA networks
  - Later, **additional spectrum** has been assigned for 3G in the range of **1710–1755 MHz** in **uplink** direction and **2110–2155 MHz** in **downlink** direction



- The technology for GSM **circuit-switched core network** was chosen as the basis for **voice** and **video calls** in UMTS
- The **changes** in the **circuit core network** to support UMTS Release 99 were mainly **software enhancements** to support the **Iu(cs)** interface between **Mobile Switching Center (MSC)** and **UTRAN**
- While the **Iu(cs) interface** is quite similar to **GSM A-Interface** on the **upper layers**, the **lower layers** were **completely redesigned** and were based on **ATM**
- **Home Location Register (HLR)** and **Authentication Center (AuC)** software were enhanced to support new UMTS features



- No major changes were necessary in the core network
- It is possible to connect UMTS radio access network (UTRAN) to a GSM and GPRS core network, MSCs and SGSNs only required a software update and new interface cards to support Iu(cs) and Iu(ps) interfaces
- The network elements of a combined GSM and UMTS network is as follows.

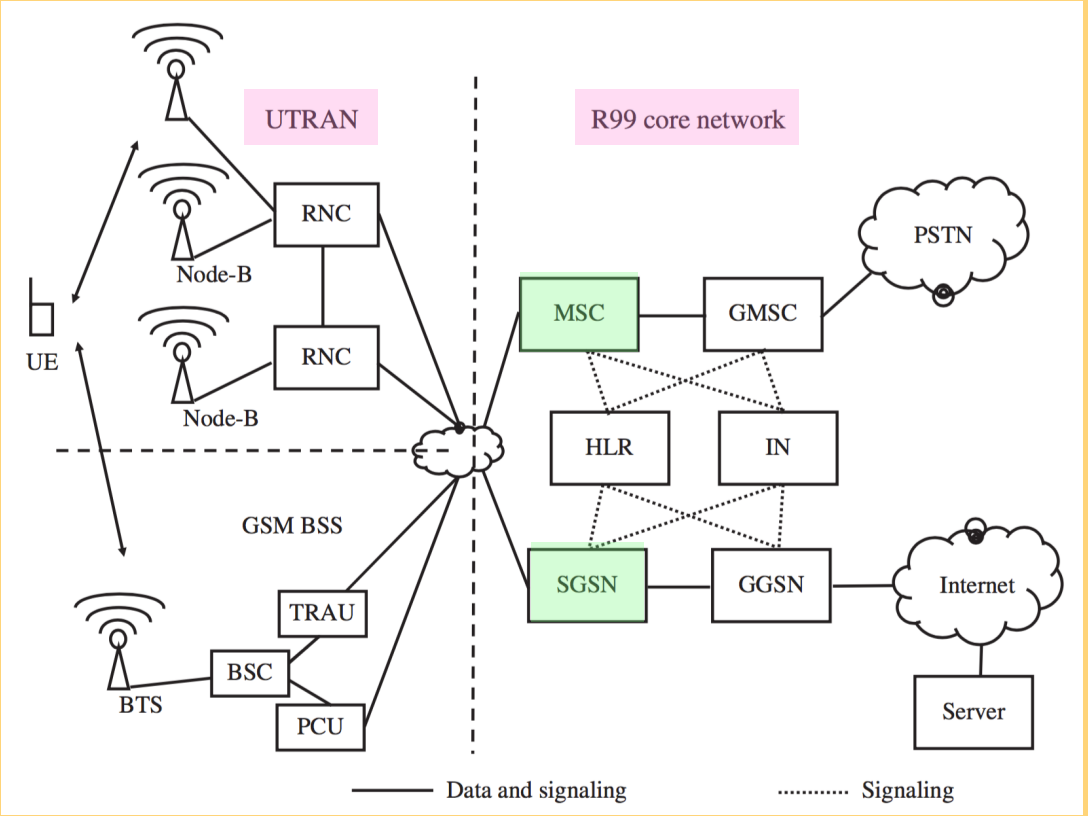


Figure 3.1 Common GSM/UMTS network: Release 99.

- Seamless roaming from UMTS to GSM and vice versa requires dual mode mobile devices that
  - Seamlessly handover ongoing voice calls from UMTS to GSM if a user leaves UMTS coverage area
  - Similar mechanisms were implemented for data sessions
- The main goal of the new radio access technology of UMTS networks was the introduction of fast packet data services
- Release 99 networks could achieve maximum downlink speeds of 384 kbps and 128 kbps in uplink direction

3.1.2 3GPP RELEASE 4: ENHANCEMENTS FOR CIRCUIT-SWITCHED CORE NETWORK

- The most important enhancement of **Release 4** was a concept called **Bearer-Independent Core Network (BICN)**
- Instead of using circuit-switched 64 kbps timeslots, **traffic** is now carried inside **Internet Protocol (IP) packets**
- **MSC** is split into
  - an **MSC-Server (MSC-S)** for **Call Control (CC)** and **Mobility Management (MM)**
  - a **Media Gateway (MG)** for handling **actual bearer (user traffic)**

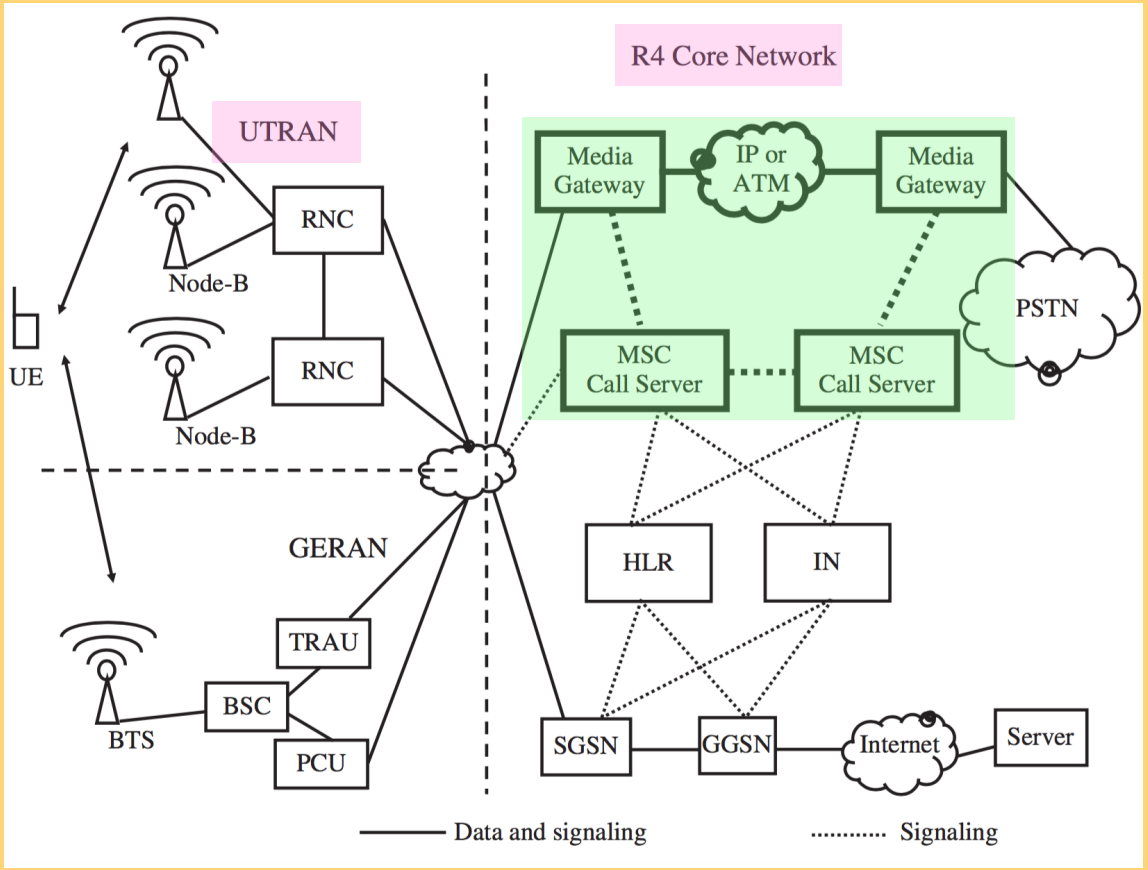
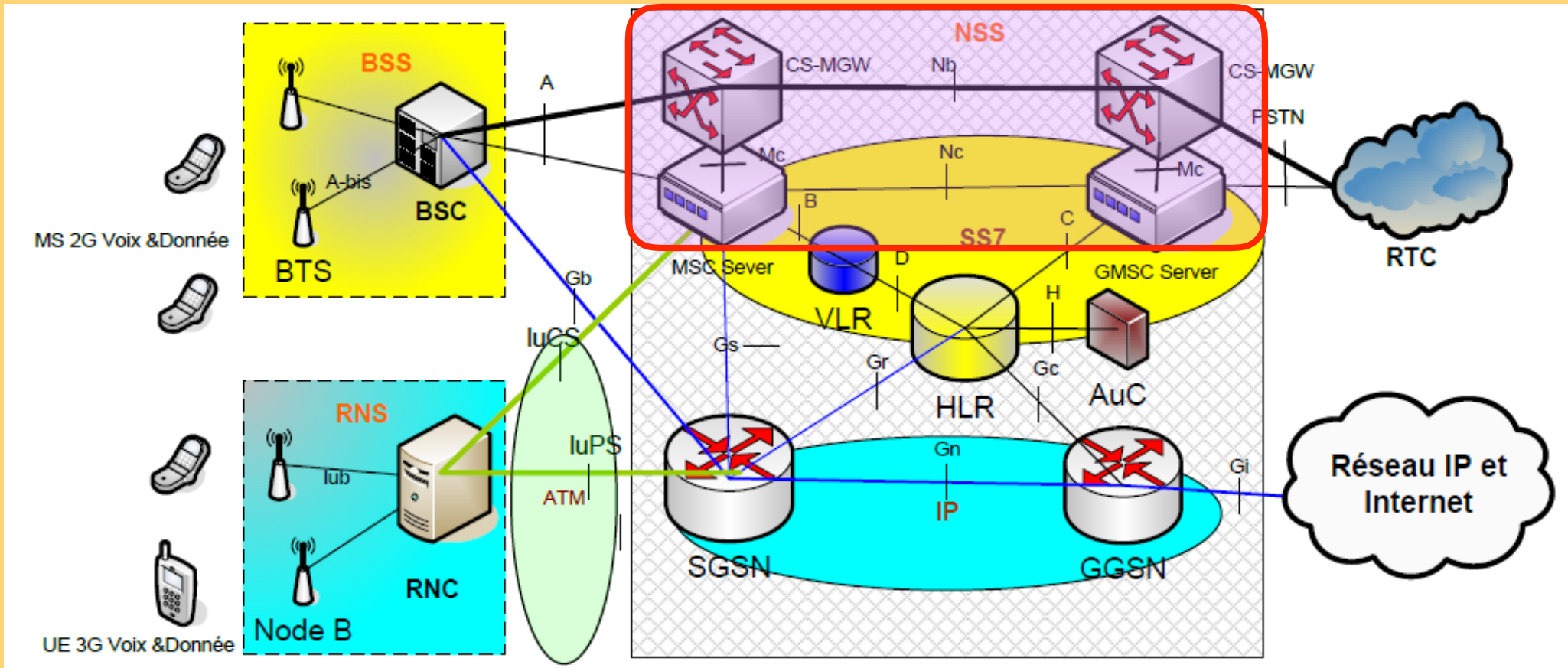


Figure 3.2 UMTS Release 4 (Bearer-Independent Core Network).



NSS — Network Sub-System
MSC — Mobile-service Switching Controller
VLR — Visitor Location Register
HLR — Home Location Register
AuC — Authentication Server
GMSC — Gateway MSC

SGSN — Serving GPRS Support Node
GGSN — Gateway GPRS Support Node

BSS — Base Station System
BTS — Base Transceiver Station
BSC — Base Station Controller

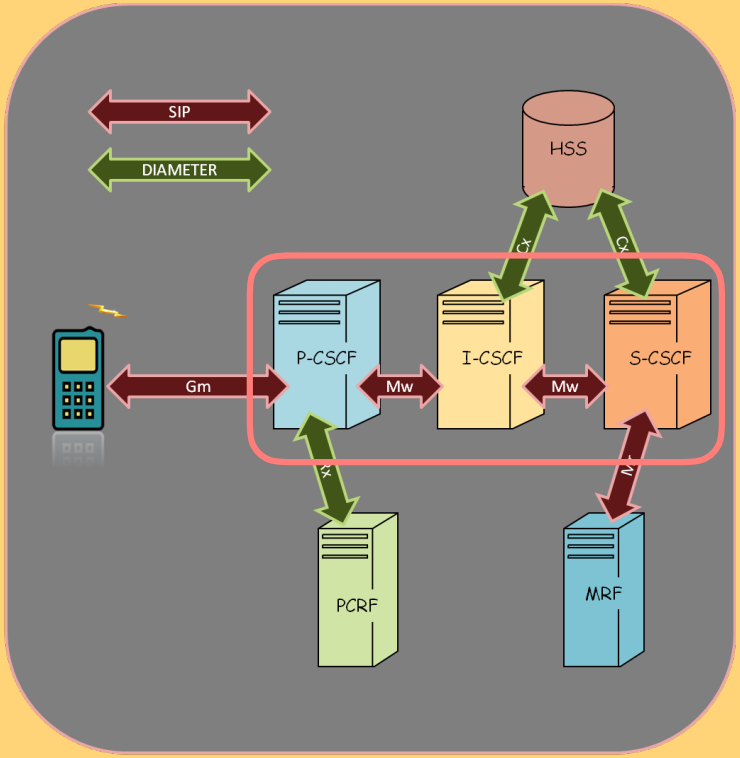
RNS — Radio Network System
RNC — Radio Network Controller

- MG is also responsible for **transcoding** of **user data** for different transmission methods
  - Example: receive **voice calls** via **GSM A-Interface via E-1 64 kbps timeslots** at MSC MG, which will then **convert** the **digital voice data stream** onto a **packet-switched IP connection** toward another MG in the network
  - The **remote MG** will then again **convert** the incoming **user data packets** to send it to
    - a remote party via **UMTS radio access network (Iu(cs) interface)** or
    - back to a **circuit-switched E-1 timeslot** in case a connection is established to **fixed-line telephone network**

Transcoding is the direct **analog-to-analog** or **digital-to-digital conversion** of one encoding to another, such as for movie data files (e.g., PAL, SECAM, NTSC), audio files (e.g., MP3, WAV), or character encoding (e.g., UTF-8, ISO/IEC 8859)

3.1.3 3GPP RELEASE 5: IMS AND HIGH-SPEED DOWNLINK PACKET ACCESS

- A further step toward an **all IP wireless network** is **IP Multimedia Subsystem (IMS)** specified in 3GPP **Release 5**
- IMS handles **voice calls** and other services via the **packet-switched** part of network
- The **core** of **IMS** consists of a number of nodes that form **Call Session Control Function (CSCF)**
  - CSCF is basically a **Session Initiation Protocol (SIP)** architecture that was initially developed for fixed-line world and is one of the core protocols for most **Voice over Internet Protocol (VoIP) telephony services**
  - CSCF takes the concept one step further and enhances the SIP standard with a number of functionalities necessary for **mobile networks**
  - This way, IMS can **transport voice calls over IP** not only in the core network but **from end to end** (from mobile device to mobile device)
  - While the CSCF is responsible for **call setup** and **call control**, the user data packets which, e.g., include **voice** or **video conversations**, are directly exchanged between end-user devices



- As the IMS is an **IP-based system** it cannot directly communicate with circuit-switched telephony systems
  - Nevertheless, it has to be ensured that **every user can talk to every other user** regardless of the kind of telephony architecture that is in use at each end
  - This is achieved by using **MGs**, which convert between **IMS VoIP**, **BICN**, and the **classic circuit-switched timeslot transmission**

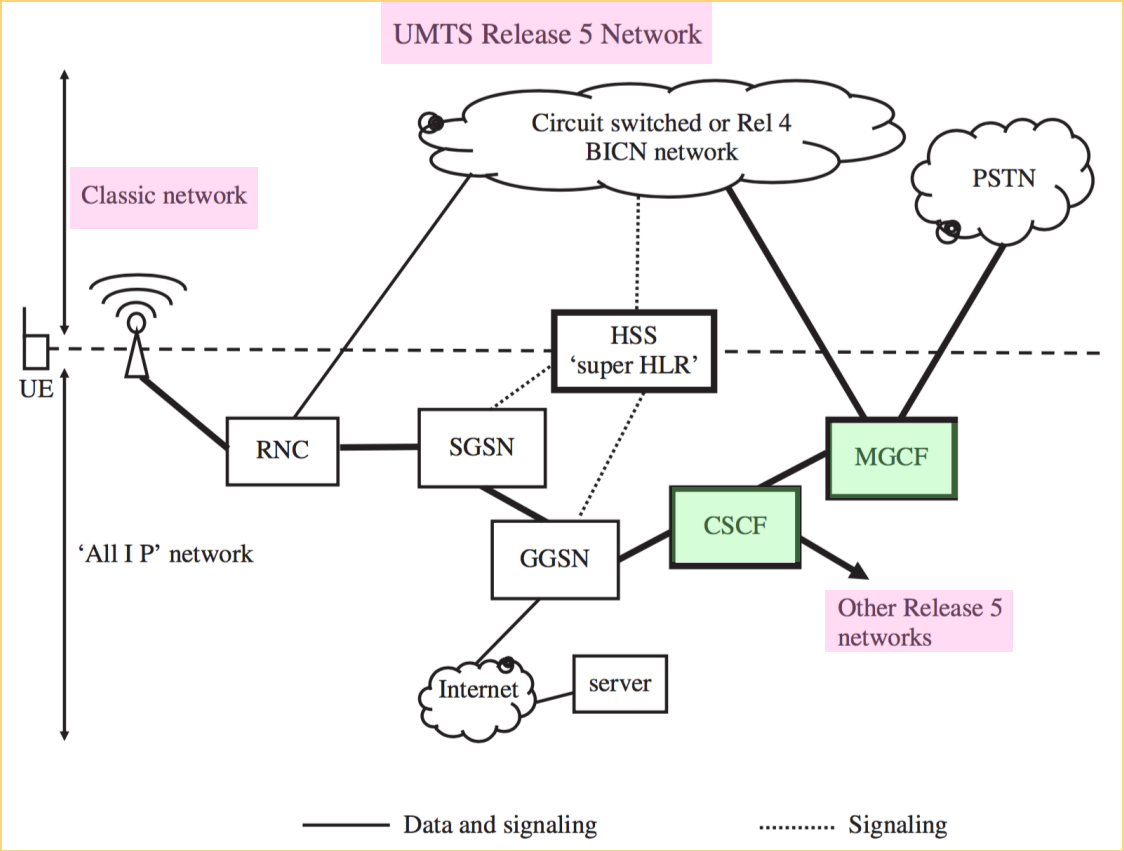
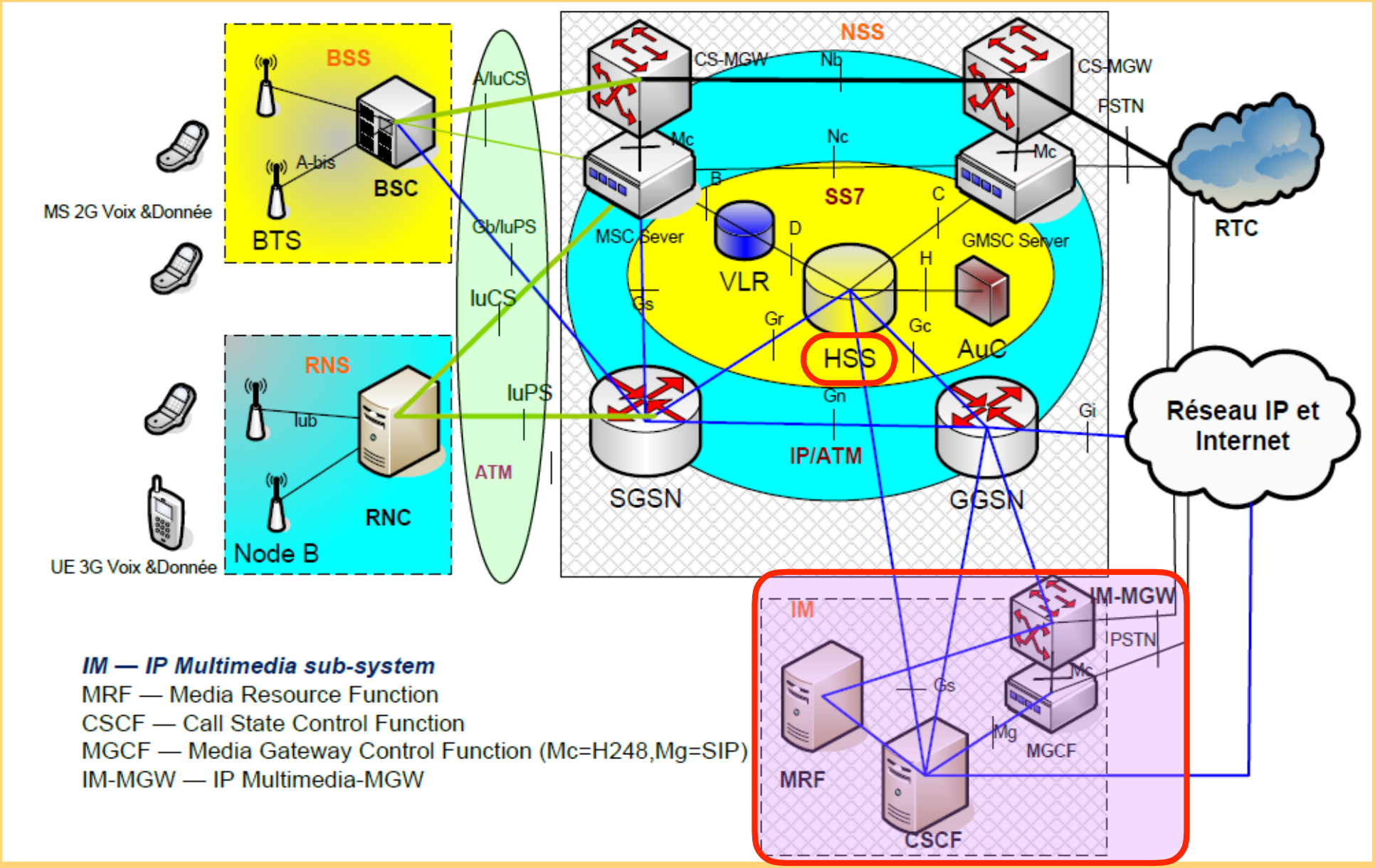


Figure 3.3 UMTS Release 5 IMS architecture.



IM — IP Multimedia sub-system

MRF — Media Resource Function

CSCF — Call State Control Function

MGCF — Media Gateway Control Function (Mc=H248,Mg=SIP)

IM-MGW — IP Multimedia-MGW

- IMS is the basis for **Voice over LTE (VoLTE)** system
- As LTE supports only **IP-based data traffic** in the core and access network, a significant effort is underway to make VoLTE to **remove** the need for an LTE-capable device to **fall back** to **UMTS** or **GSM** for **voice calls**
- The most important new functionality introduced with 3GPP Release 5 was a **new data transmission scheme** called **High-Speed Downlink Packet Access (HSDPA)** to increase data transmission speeds from network to user
- While **384 kbps** was the maximum speed in **Release 99**, **HSDPA** increased speeds per user, under ordinary conditions, to **several megabits per second**

- **Top speeds** are highly dependent on a number of conditions
  - The **maximum throughput capability** of mobile device
  - The **sophistication** of the **receiver** and **antenna** of mobile device
  - The **capability** of **network**
  - The **radio conditions** at the place of use
    - the **signal level received** from a BS
    - the **interference** of **neighbor cell transmissions** on the **same frequency**
  - The **bandwidth** of the **backhaul link** between BS and the rest of network
  - The **number** of **other users** in the cell that are actively exchanging data at the same time
- In an **ideal radio environment** speeds up to **14.4 Mbps** can be reached if supported by network and mobile device

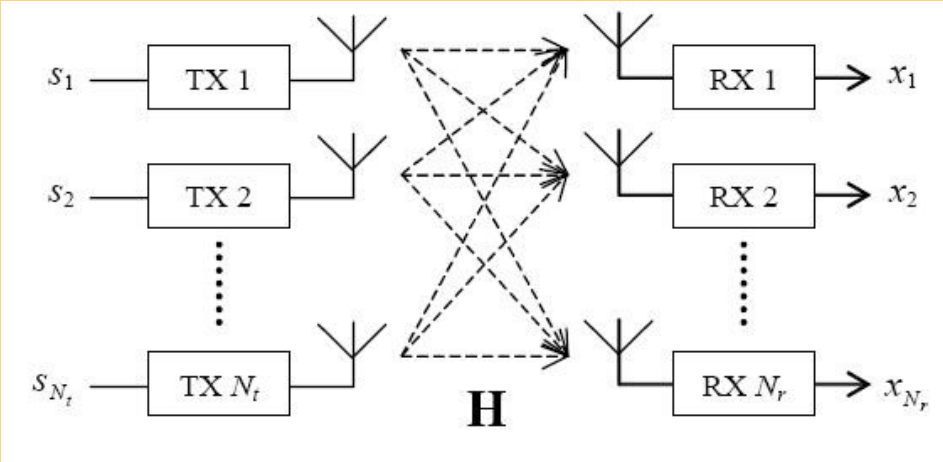
3.1.4 3GPP RELEASE 6: HIGH-SPEED UPLINK PACKET ACCESS (HSUPA)

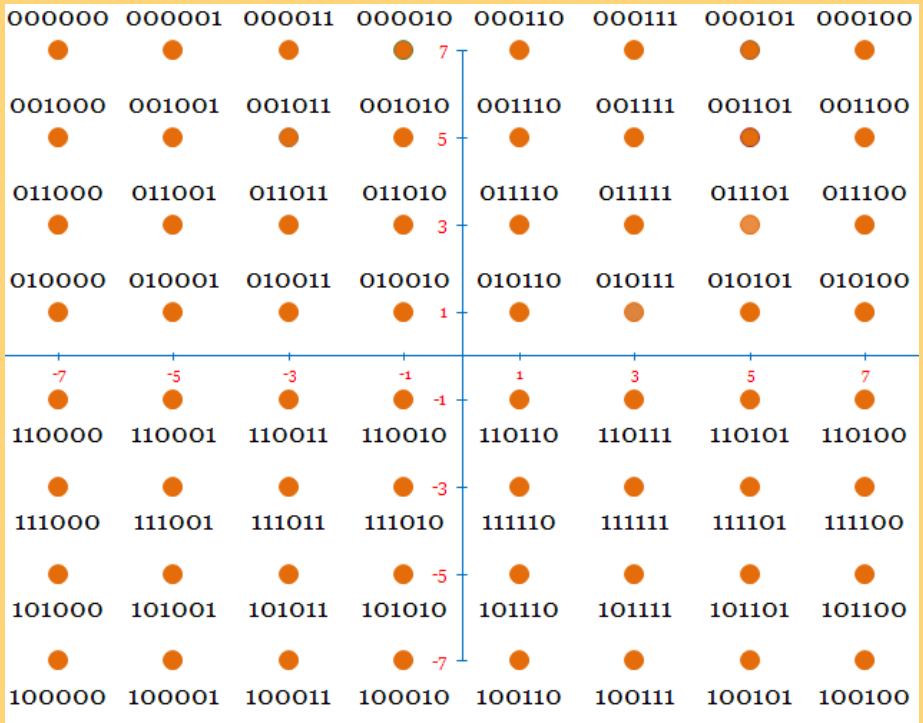
- This revision of specification introduces methods to increase **uplink** speeds
- This feature set, referred to as **High-Speed Uplink Packet Access (HSUPA)** in public, enables **uplink** datarates of **2–3Mbps** for a single user under ideal conditions
- HSUPA also increases the **maximum number of users** that can **simultaneously send data** via the **same cell** and thus further **reduces** the **overall cost** of the network
- The combination of HSDPA and HSUPA is sometimes also referred to as **HSPA**

3.1.5 3GPP RELEASE 7: EVEN FASTER HSPA AND CONTINUED PACKET CONNECTIVITY

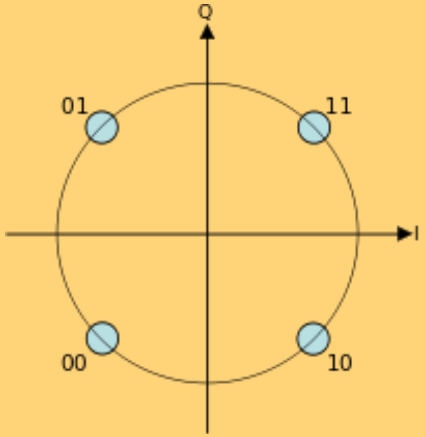
- One of the shortcomings of UMTS and HSPA compared to GSM is high power consumption during transmission gaps, e.g., between downloads of two web pages
  - Even though no user data is transmitted or received during this time, a significant amount of energy is required to send control information to keep the link established and to scan for new incoming data
  - Only after some time, usually in the order of 5–15 secs, does the system put the connection into a more power-efficient state
  - But even this state still requires a significant amount of power and the battery continues to be drained until the point where the network finally puts the air interface connection into a sleep state. In a typical setup, this happens after an additional 10–60 secs
  - It then takes around 1–3 secs to wake up from this state, which the user notices, e.g., when he clicks on a link on a web page after the air interface connection gets into sleep mode
- Reducing power consumption and a fast return to full active state have been the goals of Release 7 feature package referred to as Continuous Packet Connectivity (CPC)

- In addition, 3GPP Release 7 increased the **maximum possible data transfer speeds** in downlink direction with the introduction of
  - Use of several antennas and **Multiple Input Multiple Output (MIMO)** transmission schemes
  - 64 Quadrature Amplitude Modulation (**64-QAM**)
- The **maximum speeds** reached with these enhancements under ideal signal conditions are
  - **21 Mbps** with **64 QAM** modulation
  - **28 Mbps** with **MIMO**

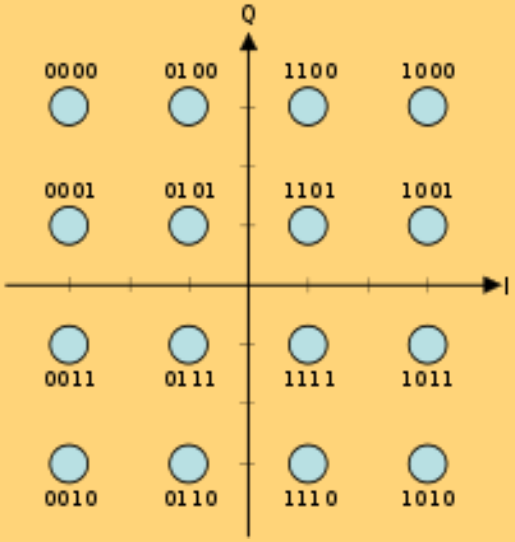




- In the uplink direction, the **HSUPA** functionality was also extended in this release
  - In addition to **Quadrature Phase Shift Keying (QPSK)** modulation scheme, **16-QAM** is now also specified for **uplink** operation, which further increases peak datarates to **11.5 Mbps** under very good signal conditions



QPSK

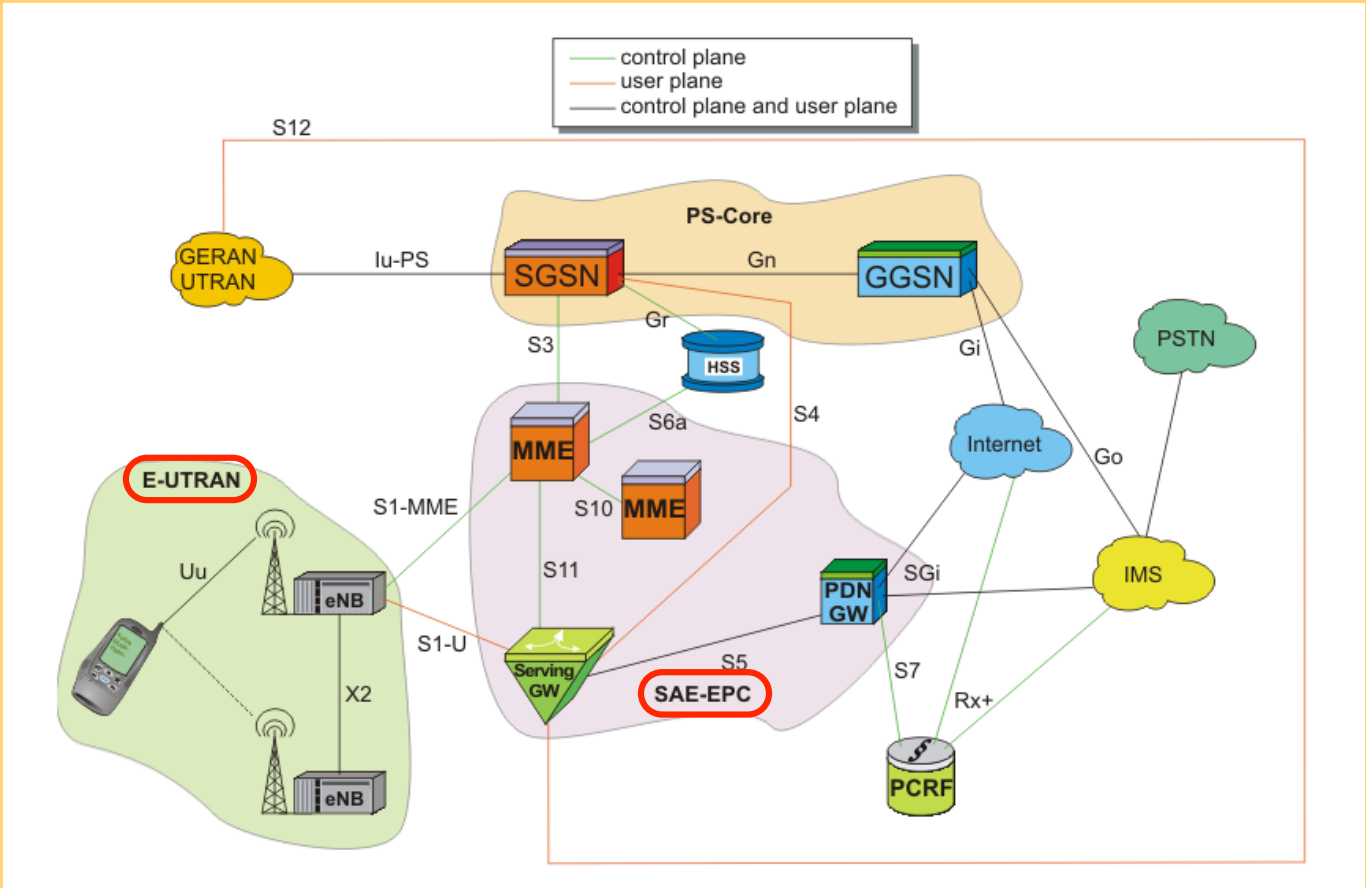


16-QAM

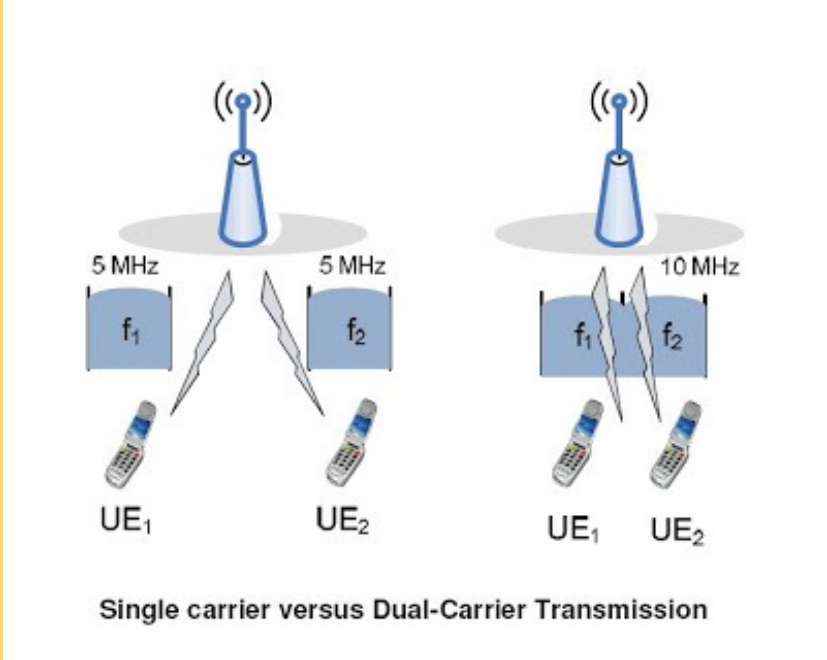
- In **cities**, UMTS cells usually cover an area with a diameter of **less than 1 km**
  - This is due to the **higher frequencies** used compared to GSM and because of the **high population density** in such areas
- In some countries, e.g., Australia, where the **population density** is **very low** in **rural areas**, UMTS is used by some operators in the **850 MHz band**, which allows for **very large coverage areas**
  - However, the **maximum cell range** of **60 km** is no longer sufficient, so that in **Release 7** the 3GPP standards were extended to allow for cell ranges of up to **180 km**

3.1.6 3GPP RELEASE 8: LTE, FURTHER HSPA ENHANCEMENTS AND FEMTOCELLS

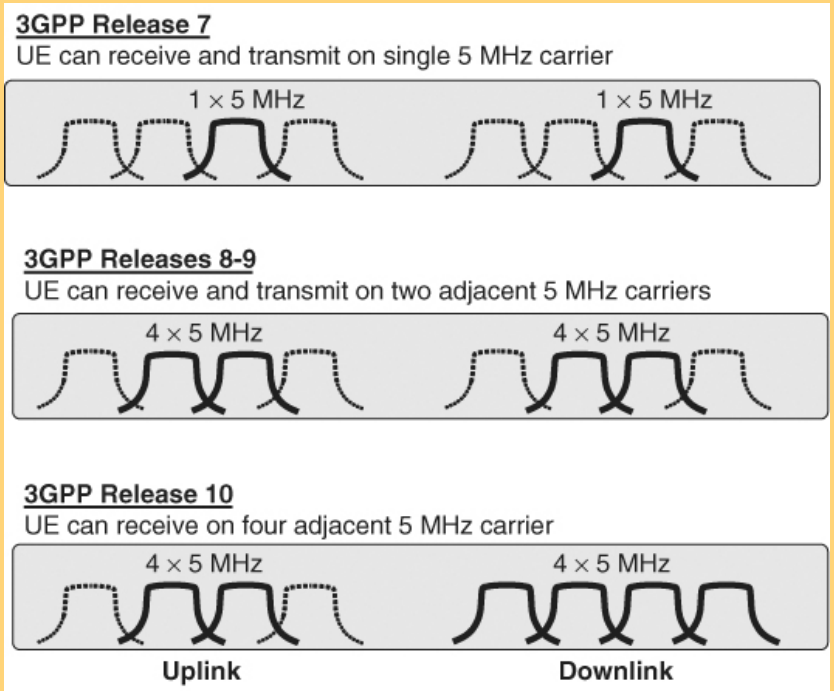
- 3GPP Release 8 introduced
  - **EUTRAN**: the successor of UMTS radio network
  - **EPC**: the successor architecture of the core network

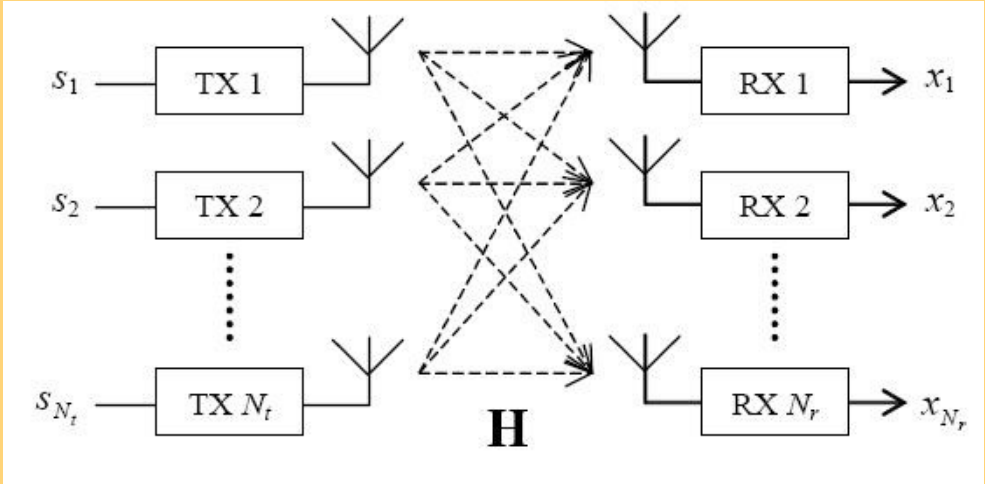


- To reach even **higher data speeds**, it is now possible to **aggregate two adjacent UMTS carriers** to get a total bandwidth of **10 MHz**. This is referred to as **Dual-Cell** or **Dual-Carrier** operation
- Also, simultaneous use of **64-QAM** and **MIMO** has entered the standards for **single carrier operation**
- Under ideal radio conditions, a peak throughput of **42 Mbps** in **downlink** direction can be reached

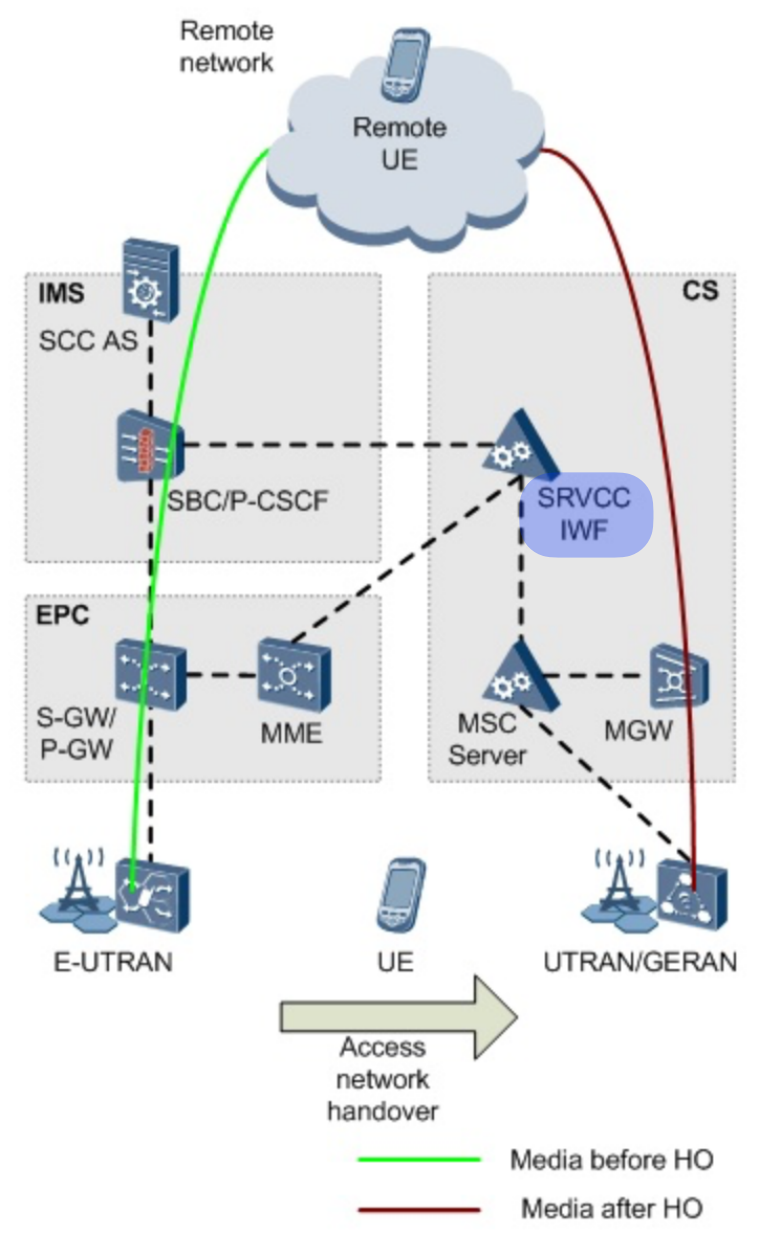


Single carrier versus Dual-Carrier Transmission

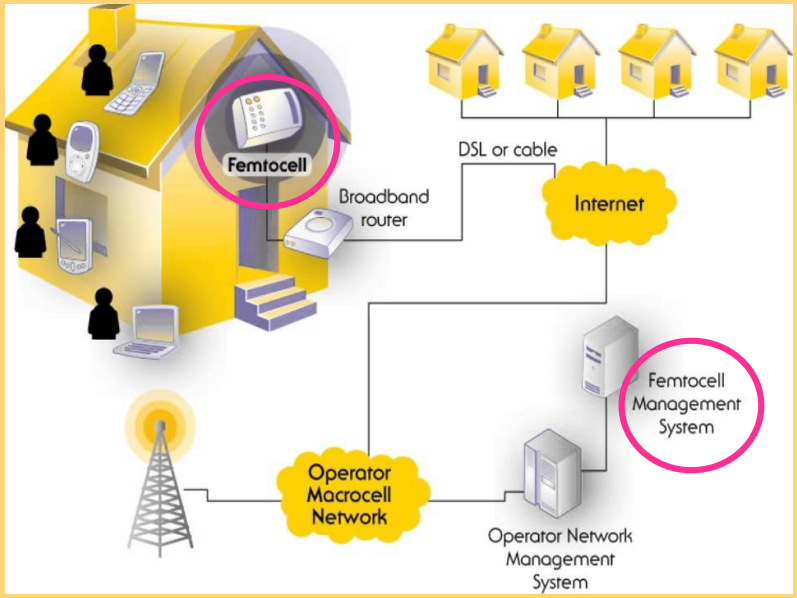




- For **VoIP** applications, an **enhancement** has been specified that allows the network to prepare a **circuit-switched channel in GSM** in order to make **handover** of a **packet-switched VoIP call** when the user **roams out** of UMTS or LTE coverage area
- As such devices **do not exist** in practice the **Single Radio Voice Call Continuity (SR-VCC)** feature, which was introduced in **Voice over LTE (VoLTE)**
- **SR-VCC:** provides **handover** functionality from **IMS PS** domain with **VoIP technology** to **CS domain** using **one single radio signal** at a time



- Furthermore, 3GPP Release 8 laid the groundwork for **Femtocells management**, referred to as **Home Node-Bs** in the standard and **Self-Organizing Network (SON)** functionality, to **ease deployment** and **maintenance** of BSs





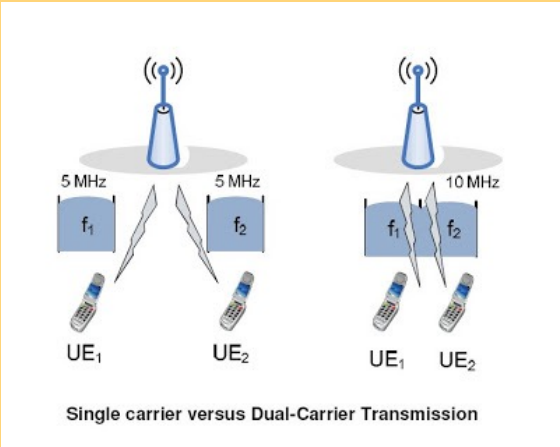
- Self-Organizing Network (SON)
  - Self-configuration functions
    - Strives towards"plug-and-play" paradigm in the way that new BSs shall automatically be configured and integrated into the network
    - Both connectivity establishment and download of configuration parameters are software
    - When a new BS is introduced into the network and powered on, it gets immediately recognized and registered by the network
    - The neighboring BSs then automatically adjust their technical parameters (such as emission power, antenna tilt, etc.) in order to provide the required coverage and capacity, and, in the same time, avoid the interference

- **Self-optimization functions**
  - Every BS contains hundreds of **configuration parameters** that control various aspects of the cell site
  - Each of these can be altered to **change network behavior**, based on **observations** of both **BS** itself and **measurements** at the **MS** or **handset**
  - One of the first SON features **establishes neighbor relations automatically (ANR)** while others **optimize random access parameters** or **mobility robustness** in terms of **handover oscillations**
  - A very illustrative use case is the **automatic switch-off** of a percent of BSs during **night hours**
  - The **neighboring BS** would then **re-configure** their parameters in order to **keep the entire area covered by signal**
  - In case of a **sudden growth in connectivity demand** for any reason, the **"sleeping" BSs "wake up"** almost instantaneously. This mechanism leads to **significant energy savings** for operators

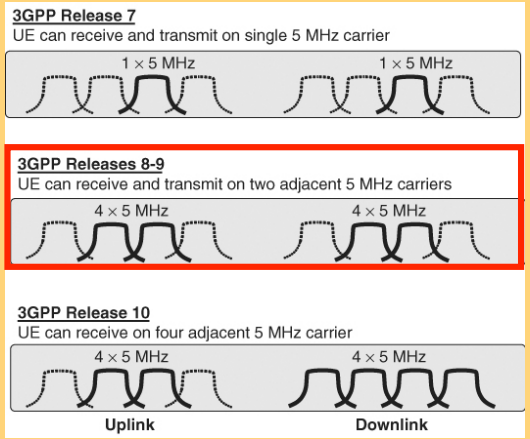
- **Self-healing functions**
  - When some nodes in the network become **inoperative**, self-healing mechanisms aim at **reducing** the impacts from **failure**, e.g., by **adjusting parameters** and **algorithms** in **adjacent cells** so that other nodes can support the users that were supported by the failing node
  - In legacy networks, the **failing BSs** are at times **hard to identify** and a significant amount of time and resources is required to fix it
    - SON permits to **spot** such **failing BSs** immediately in order to take further **measures**, and **ensure no or insignificant degradation** of service for the users

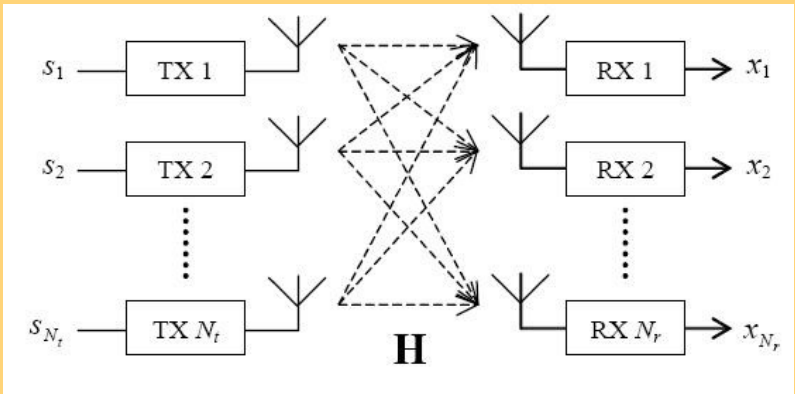
3.1.7 3GPP RELEASE 9: DIGITAL DIVIDEND AND DUAL CELL IMPROVEMENTS

- 3GPP Release 9 is mostly a **maintenance Release**
- The **SON** and **Femtocell architecture** (**Home Node-B** and **Home eNode-B**) specifications started in Release 8 have been continued in this release
- For UMTS, Release 9 brought a number of **further speed enhancements** in both **uplink** and **downlink** directions
- In the uplink direction, **aggregation** of **two adjacent 5 MHz carriers** has been specified in a similar way as in the **downlink** direction in the **previous release**
  - This in effect again **doubles the theoretical peak uplink datarate** to **over 20 Mbps**
- In the downlink direction, **dual-carrier operation** can now be combined with **MIMO** operation, increasing the peak throughput to **84 Mbps**

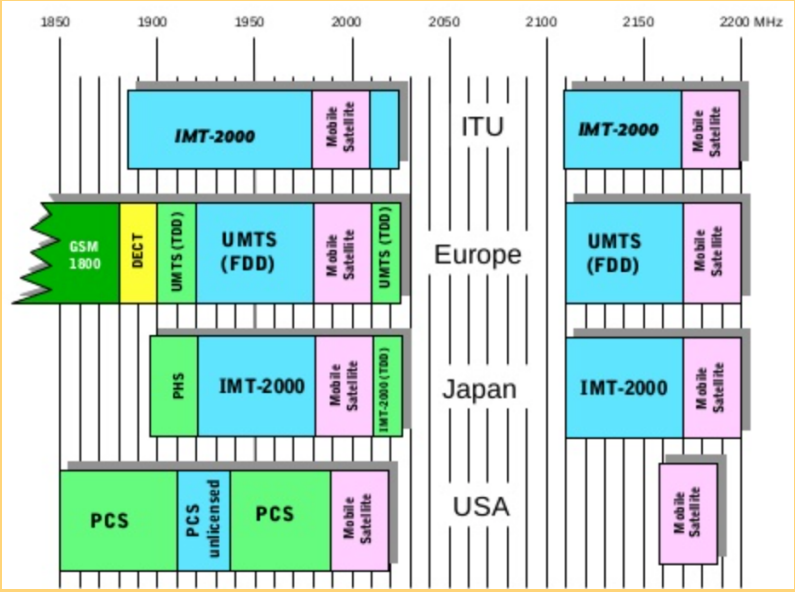


Single carrier versus Dual-Carrier Transmission





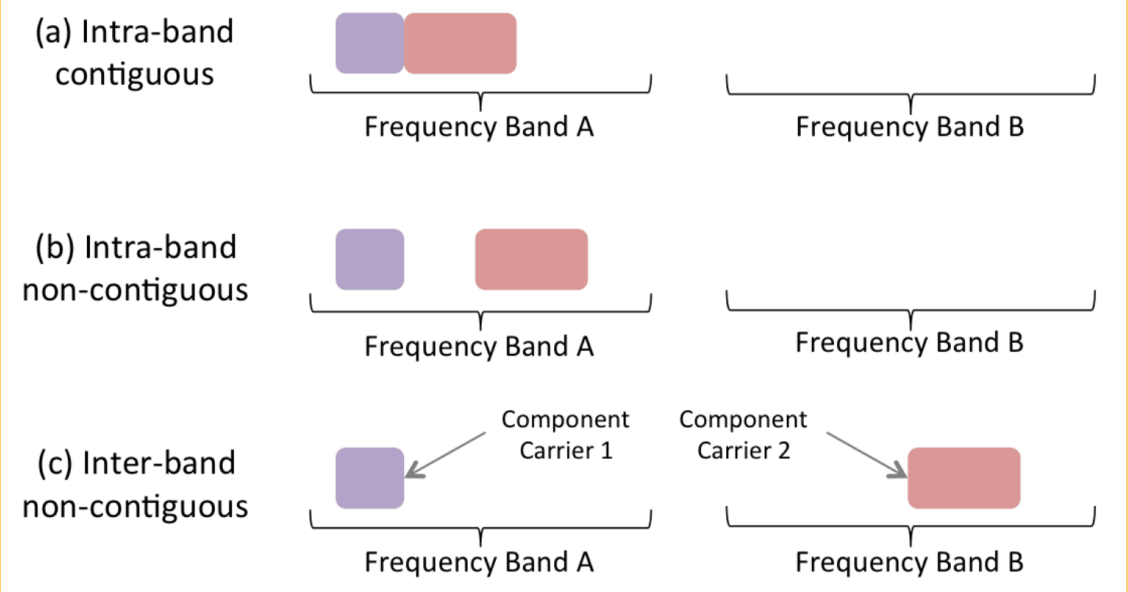
- In Europe, the operation bands are 900 and 2100 MHz
  - Mobility is allowed only in one of the two bands, i.e., neighbor cell measurements, and the decision to change cells is made with respect to one of the two bands
- In many parts of the world frequencies previously used for analog television have been freed up by introduction of digital standards
  - These frequency bands in the 700 MHz region in the United States and the 800 MHz region in Europe, respectively, which are sometimes also referred to as the digital dividend bands, have been reassigned for wireless broadband Internet use
  - Release 9 contains enhancements necessary for the use of LTE in the European digital dividend band



- Pre-Release 9 GSM and GPRS **security** mechanisms have **not been changed** in quite some time and vulnerabilities have been discovered
  - 3GPP Release 9 has added an **additional ciphering algorithm**, **A5/4**
  - Together with **doubling the ciphering key (CK) length** to **128 bits**, it is considered to be a major security upgrade

3.1.8 3GPP RELEASES 10 AND 11: LTE-ADVANCED

- To further increase the peak data rate of a device, 3GPP Release 10 introduced the aggregation of several carriers (Carrier Aggregation, CA) in the same or in different frequency bands
- From a European point of view, this feature would allow several 20-MHz carriers in different bands to be bundled together
  - This could, e.g., be a 20-MHz carrier in the 1800-MHz band and another 20-MHz carrier in the 2600-MHz band, respectively



Shannon's Theorem

$C = B * log2(1 + S/N)$

where C is the achievable channel capacity, B is the bandwidth of the line, S is the average signal power and N is the average noise power.

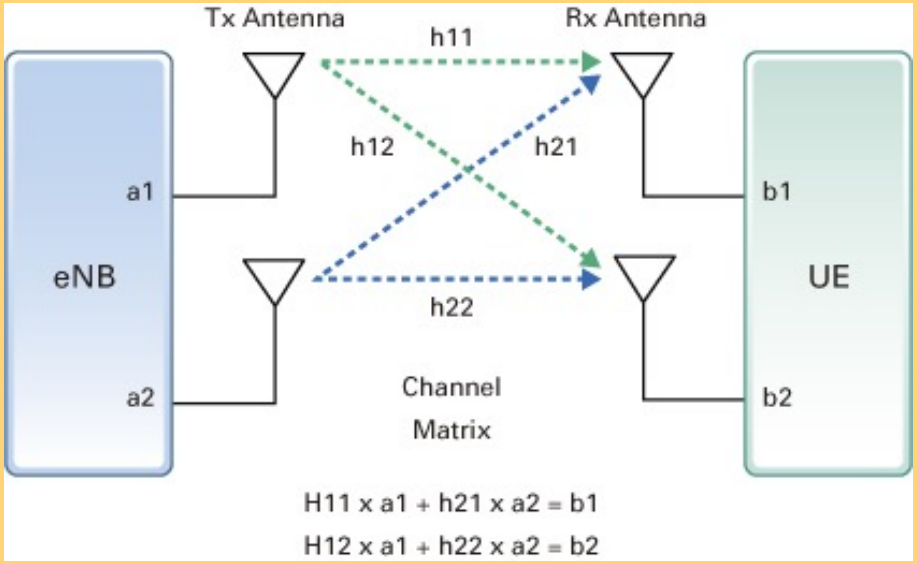
LTE Band Number	Uplink (MHz)	Downlink (MHz)	Width of Band (MHz)	Duplex Spacing (MHz)	Band Gap (MHz)
1	1920 - 1980	2110 - 2170	60	190	130
2	1850 - 1910	1930 - 1990	60	80	20
3	1710 - 1785	1805 -1880	75	95	20
4	1710 - 1755	2110 - 2155	45	400	355
5	824 - 849	869 - 894	25	45	20
6	830 - 840	875 - 885	10	35	25
7	2500 - 2570	2620 - 2690	70	120	50
8	880 - 915	925 - 960	35	45	10
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	60
10	1710 - 1770	2110 - 2170	60	400	340
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	28
12	698 - 716	728 - 746	18	30	12
13	777 - 787	746 - 756	10	-31	41
14	788 - 798	758 - 768	10	-30	40
15	1900 - 1920	2600 - 2620	20	700	680
16	2010 - 2025	2585 - 2600	15	575	560
17	704 - 716	734 - 746	12	30	18
18	815 - 830	860 - 875	15	45	30
19	830 - 845	875 - 890	15	45	30
20	832 - 862	791 - 821	30	-41	71
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	33
22	3410 - 3500	3510 - 3600	90	100	10
23	2000 - 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 - 1915	1930 - 1995	65	80	15

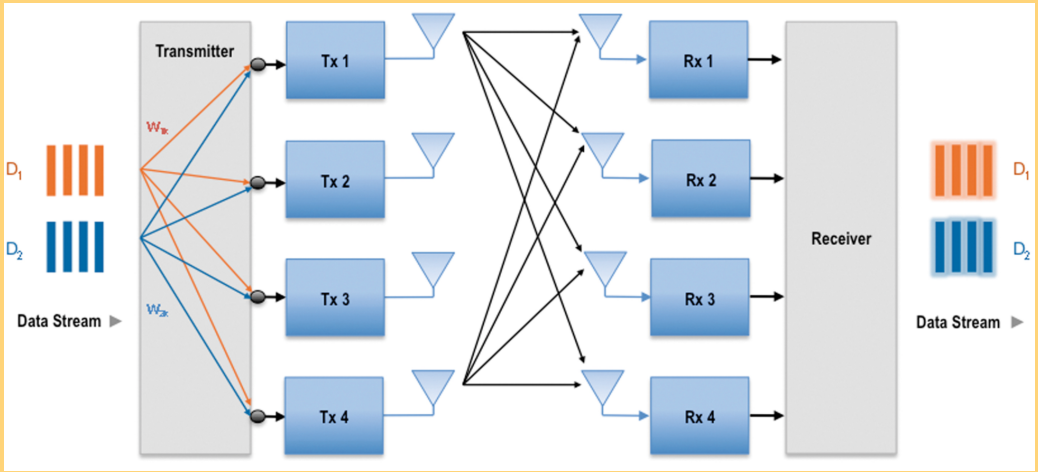
FDD LTE frequency band allocations

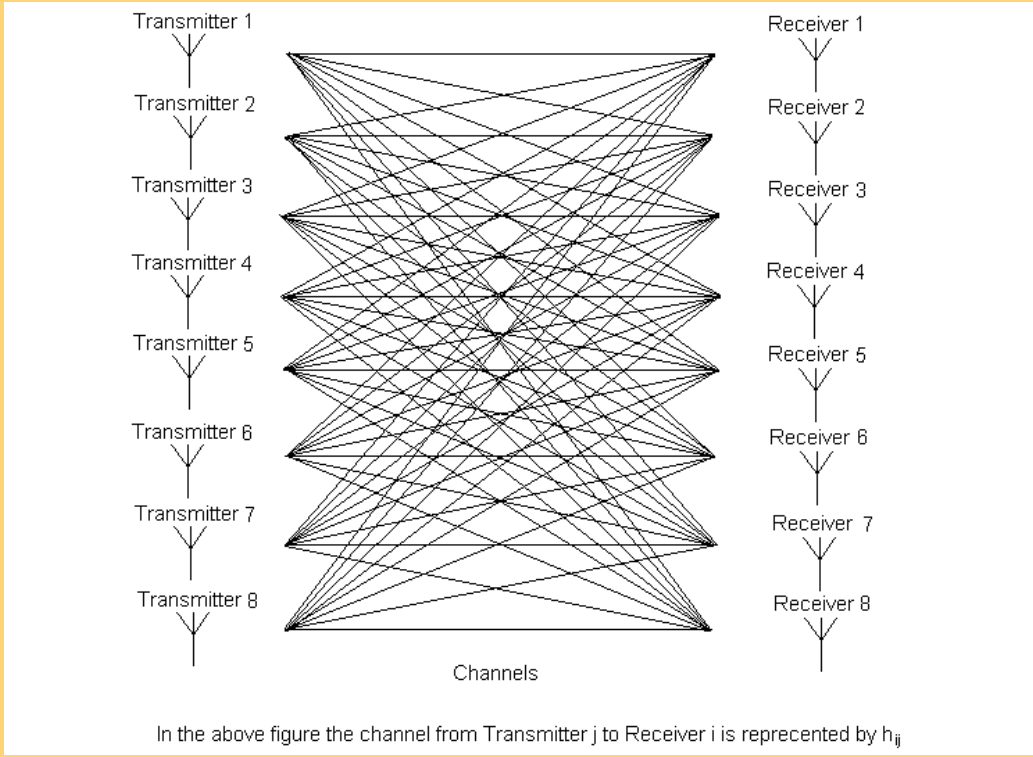
LTE Band Number	Allocation (MHz)	Width of Band (MHz)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 - 2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200

TDD LTE frequency band allocations

- While LTE devices are usually equipped with **two antennas** for MIMO reception at the sender and receiver side (**2 × 2 MIMO**), the use of **four** and **eight antennas** on each side (**4 × 4** and **8 × 8 MIMO**) has also been specified

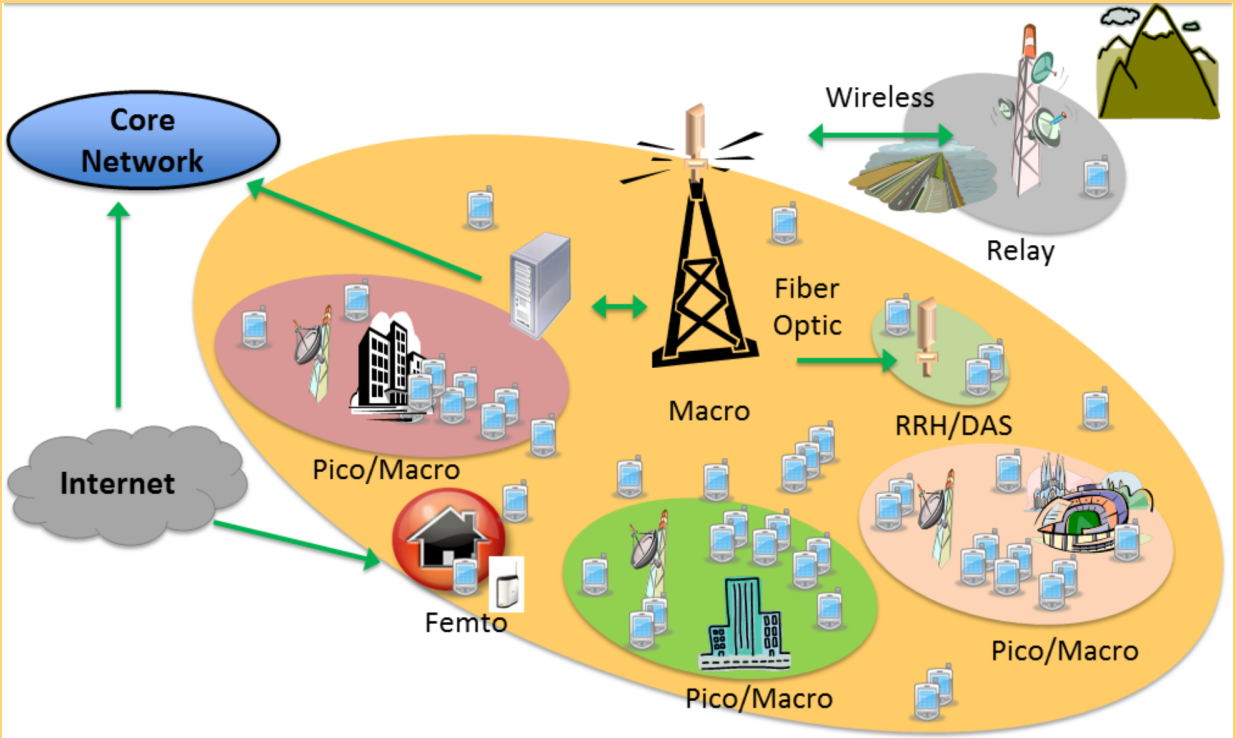


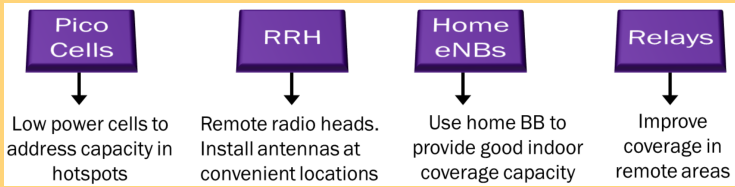




2x2 MIMO
4x4 MIMO
8x8 MIMO
750 Mbps
600 Mbps
450 Mbps
300 Mbps
150 Mbps
1.5 Gbps
1.2 Gbps
900 Mbps
600 Mbps
300 Mbps
3.0 Gbps
2.4 Gbps
1.8 Gbps
1.2 Gbps
600 Mbps
20 MHz
20 MHz
20 MHz
20 MHz
20 MHz
100 MHz
40 MHz
(Release 10)
LTE
LTE-Advanced

- Releases 10 and 11 have specified methods to add **further capacity** to networks by **complementing LTE macro cells** that cover areas in a radius of **several hundred meters** by **small** and **low-power cells** that only cover a fraction of this area
- This new network structure is referred to as a **heterogeneous network structure (HetNet)** as the coverage area of the **macro cells** and **local cells** overlap
- To **avoid** or **minimize** the **resulting interference**, a number of methods have been specified for these cells to **coordinate their transmissions** with each other or to be **controlled by a central BS**





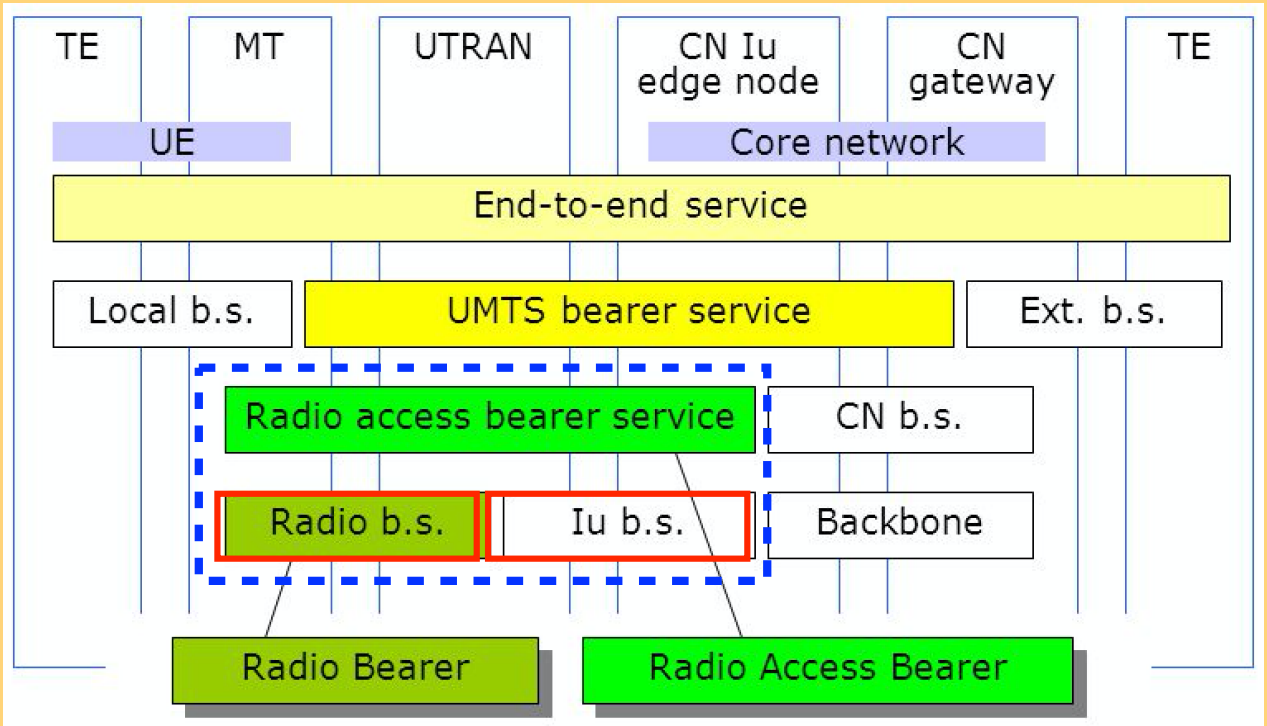
- Releases 10 and 11 also specify a number of **further carrier aggregation steps** for **HSPA** to bundle **four or eight 5-MHz carriers**
- Due to the quick adoption of LTE across the globe that can be observed today, it is **unlikely** that network operators are keen to further **develop their HSPA networks**

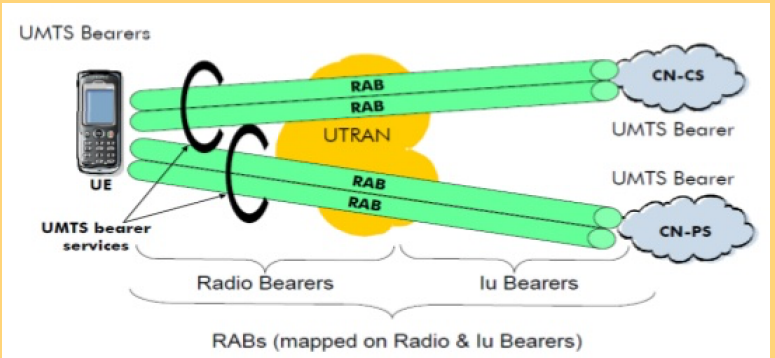
Release 8	2008 Q4	First **LTE** release. All-IP Network (SAE). New OFDMA, FDE and MIMO based radio interface, not backwards compatible with previous CDMA interfaces. Dual-Cell HSDPA. UMTS HNB.
Release 9	2009 Q4	SAES Enhancements, WiMAX and LTE/UMTS Interoperability. Dual-Cell HSDPA with MIMO, Dual-Cell HSUPA. LTE HeNB.
Release 10	2011 Q1	**LTE Advanced** fulfilling IMT Advanced 4G requirements. Backwards compatible with release 8 (LTE). Multi-Cell HSDPA (4 carriers).
Release 11	2012 Q3	Advanced IP Interconnection of Services. Service layer interconnection between national operators/carriers as well as third party application providers. Heterogeneous networks (HetNet) improvements, Coordinated Multi-Point operation (CoMP). In-device Co-existence (IDC).

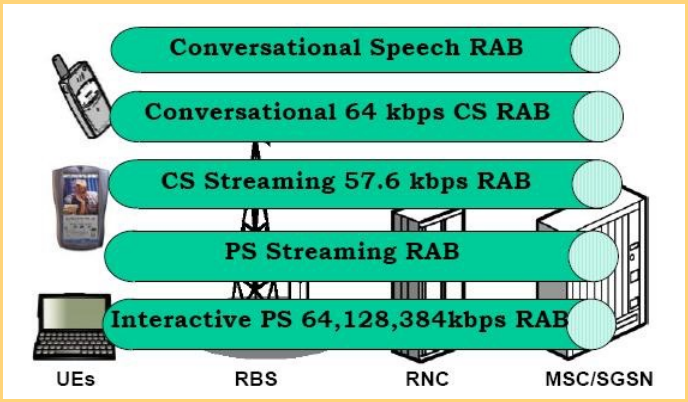
3.2 IMPORTANT NEW CONCEPTS OF UMTS

3.2.1 RADIO ACCESS BEARER (RAB)

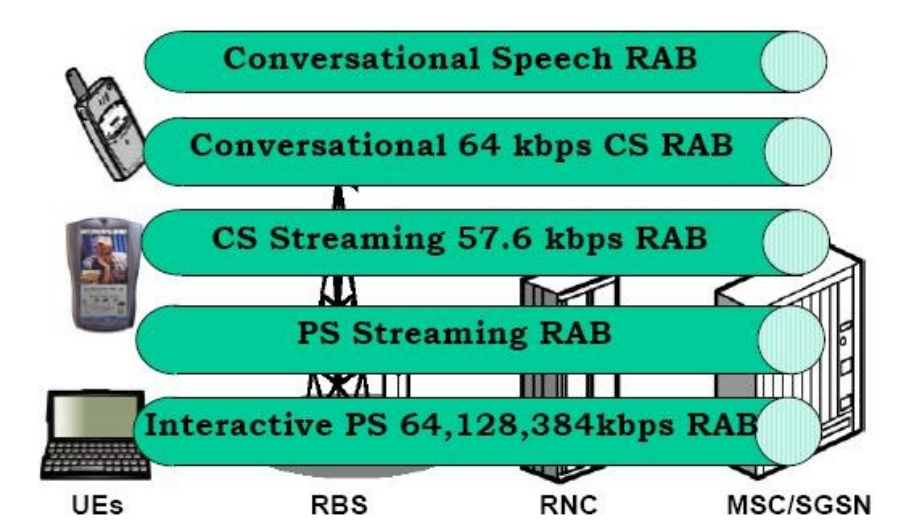
- An important new concept introduced with UMTS is **Radio Access Bearer (RAB)**, which is a **description of the transmission channel** between network and user
- RAB is divided into
  - **radio bearer** on **air interface**
  - **Iu bearer** in **radio network (UTRAN)**







- Before **data** can be **exchanged** between a user and network it is necessary to establish an **RAB** between them
  - This **channel** is then used for both **user** and **signaling data**
- An **RAB** is always established by **request** of **MSC** or **SGSN**
- **RAB establishment** requests contain only a **description** of the required **channel properties**
  - Service class (conversational, streaming, interactive or background)
  - Maximum speed
  - Guaranteed speed
  - Delay
  - Error probability



- UTRAN is then responsible for establishing an RAB that fits the description
- The properties have impact on
  - The bandwidth of the established RAB
  - Parameters like coding scheme, selection of a logical and physical transmission channel
  - The behavior of the network in the event of erroneous or missing frames on different layers of the protocol stack
    - For voice call (service class conversational) it does not make much sense to repeat lost frames
    - For web browsing, such behavior is beneficial as delay times are shorter if lost packets are only retransmitted in the radio network instead of end to end

3.2.2 ACCESS STRATUM AND NONACCESS STRATUM

- UMTS aims to **separate functionalities** of **core network** from **access network**, in order to be able to **independently evolve** the two parts of the network in the future
- UMTS strictly differentiates between functionalities of **Access Stratum (AS)** and **Nonaccess Stratum (NAS)**

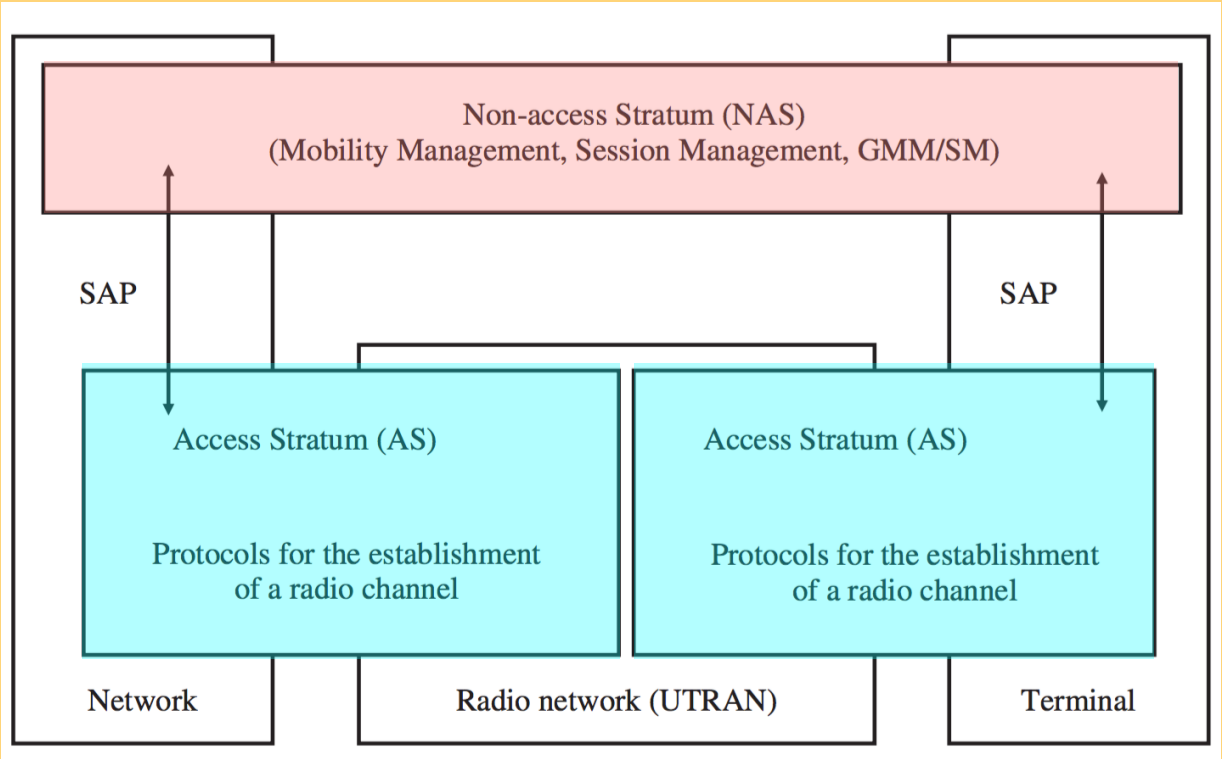
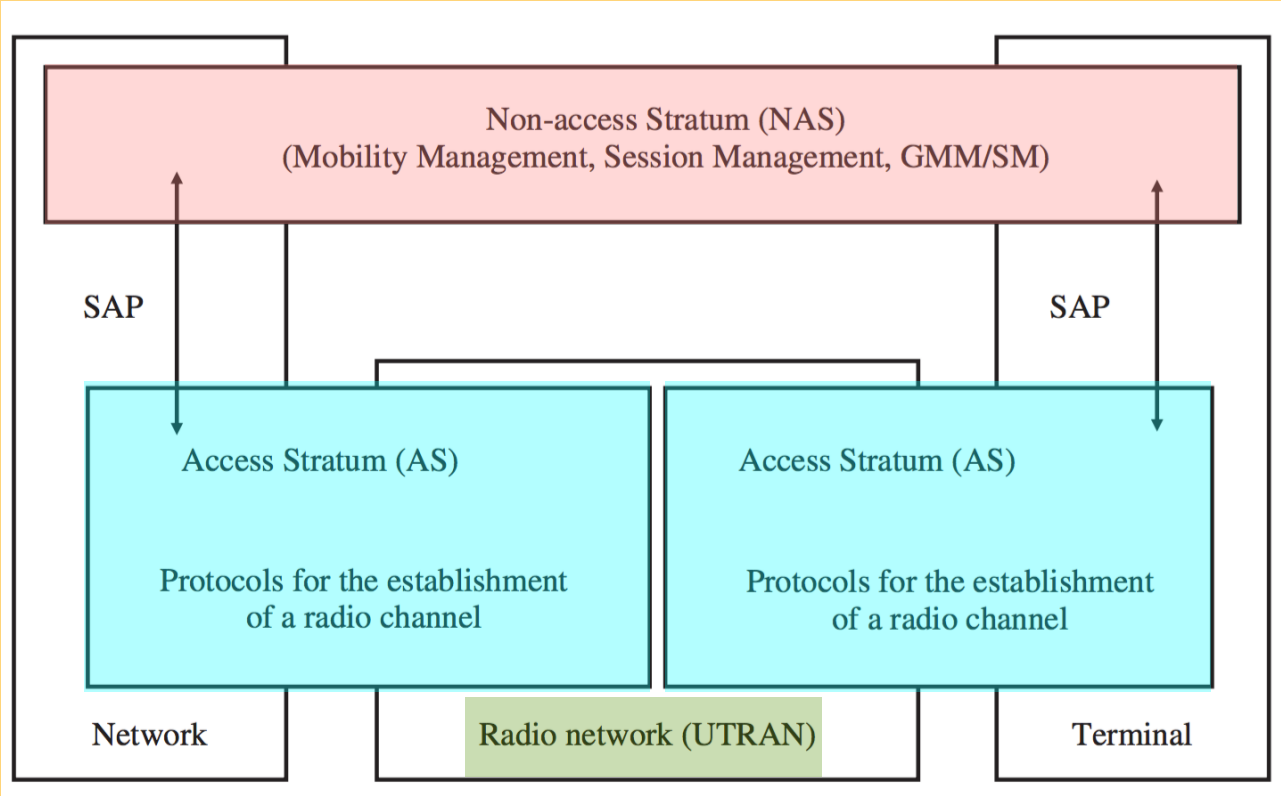
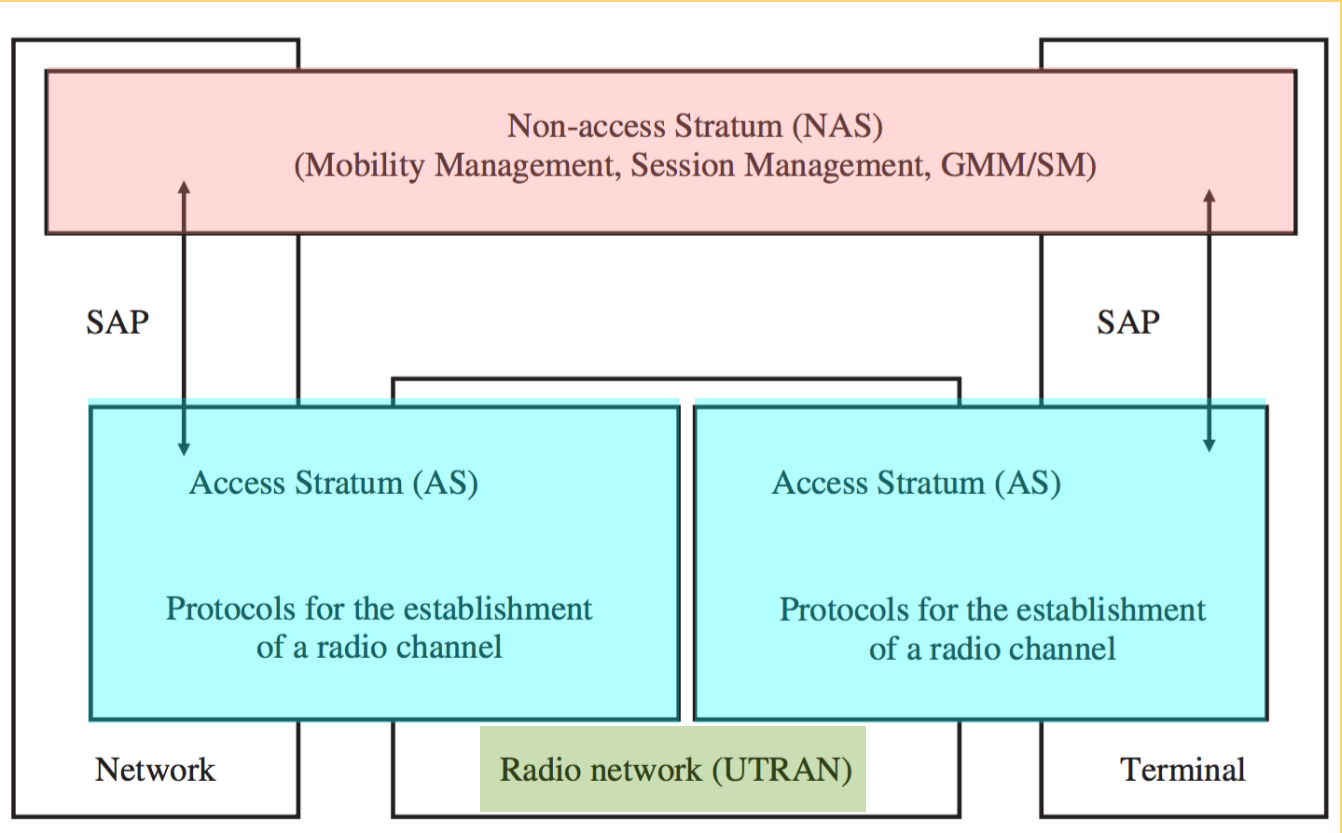


Figure 3.4 Separation of protocols between the core and radio network into Access Stratum (AS) and Nonaccess Stratum (NAS)

- **AS**
  - Contains all functionalities that are associated with
    - **Radio network** (‘the **access**’)
    - **Control** of **active connections** between a user and radio network
  - The **handover control**, e.g., for which the **RNC** is responsible in the UTRAN, is part of the **AS**



- **NAS**
  - Contains all functionalities and protocols that are used directly between **mobile device (UE)** and **core network**
  - Functionalities like **call control**, **mobility**, and **session management** as well as **supplementary services** (e.g. **SMS**), which are controlled via **MSC** and **SGSN**, are considered NAS functionalities



3.3 CODE DIVISION MULTIPLE ACCESS (CDMA)

- UMTS introduced **code multiplexing** (**Code Division Multiple Access, CDMA**) to allow a single BS to communicate with many users at the same time
  - Before transmission, a **user's data** is **multiplied** by a **code** that can be **distinguished** from codes used by other users
  - As the **data** of **all users** is **sent at the same time**, the **signals add up** on the transmission path to the BS
  - The BS uses the **inverse** of the mathematical approach that was used by mobile device, as the **BS knows the code of each user**

- This principle can also be described within certain **boundaries** with the following analogy
  - Communication during a lecture
    - Usually there is only **one person** speaking at a time while many people in the room are just listening
    - The **bandwidth** of the '**transmission channel**' is **high** as it is only used by a single person
    - At the same time, however, the **whispering** of the students creates a **slight background noise** that has **no impact on the transmission** (of the speaker) due to its **low volume**

- Communication during a party
  - Again, there are many people in a room but this time they are all talking to each other
  - Although the conversations add up in the air the human ear is still able to distinguish the different conversations from each other
  - Most conversations are filtered out by the ear as unwanted background noise
  - The more people that speak at the same time, the higher the perceived background noise for the listeners
  - To be understood, the speakers have to reduce their talking speed
  - Alternatively, speakers could increase their volume to be able to be heard over the background noise
  - This, however, means that the background noise for others would increase substantially
- Communication in a disco
  - In this scenario, the background noise, that is, the music is very loud and no other communication is possible

- Operation of CDMA is as follows
  - If only a few users communicate with a BS at the same time, each user will experience only low interference on the transmission channel
    - The transmission power can be quite low and the BS will still be able to distinguish the signal from other sources
    - The available bandwidth per user is high and can be used if necessary to increase the transmission speed
    - If data is sent faster, the signal power needs to be increased to get a more favorable signal to noise ratio (SNR)
    - As only a few users are using the transmission channel in this scenario, increasing the transmission speed is no problem as all others are able to compensate

- If many users communicate with a BS at the same time, all users will experience a high background noise
  - All users have to send at a higher power to overcome the background noise
  - As each user in this scenario can still increase the power level, the system remains stable
  - This means that the transmission speed is not only limited by the 5-MHz bandwidth of the transmission channel but also by the noise generated by other users of the cell
  - Even though the system is still stable, it might not be possible to increase the data transmission speed for some users who are farther away from BS as they cannot increase their transmission power anymore and thus cannot reach the signal-to-noise ratio required for a higher transmission speed

- From a mathematical point of view, CDMA works as follows
  - The user **data bits** of the individual users are first **multiplied** with a **vector**, which, e.g., has a length of **128**
    - The **elements** of the **resulting vector** are called **chips**
    - A vector with a length of 128 has the **same number of chips**
  - Instead of transmitting a single bit over the air interface, **128 chips** are transmitted
    - This is called '**spreading**' as more information, in this example, **128 times more**, is sent over the air interface compared to the transmission of the single bit
  - On the **receiver side** the **multiplication** can be **reversed** and the 128 chips are used to **deduce** if the sent bit represents a **0** or **1**
  - Figure 3.7 shows the mathematical operations for **two mobile devices** that transmit data to **a single receiver (BS)**

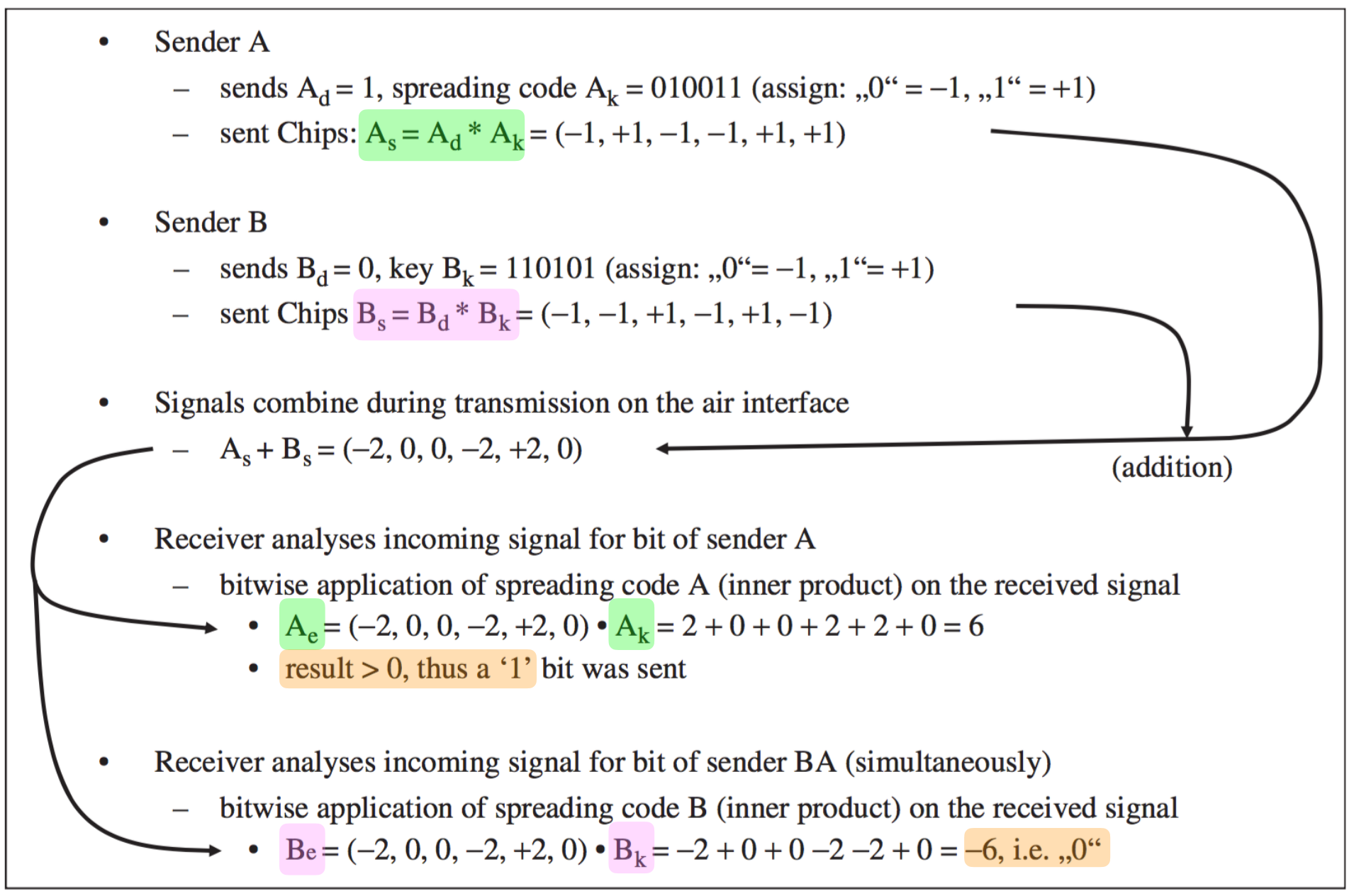
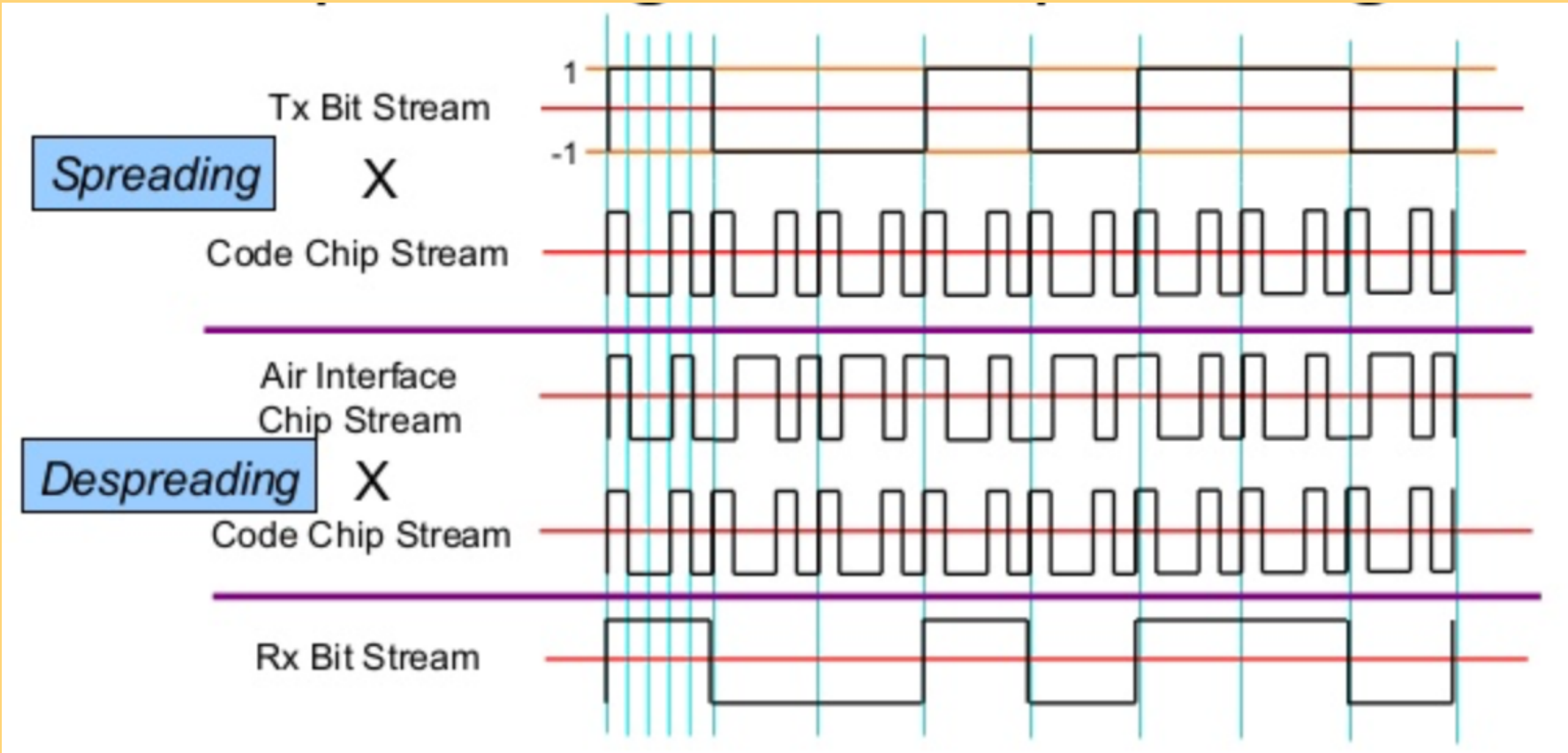


Figure 3.7 Simultaneous conversation of two users with a single BS and spreading of the data stream.

- **Disadvantage**
  - sending 128 chips instead of a single bit
- **Advantages**
  - **Transmission errors** that change the values of some of the 128 chips while being sent over the air interface can **easily be detected** and **corrected**. Even if **several chips** are **changed** because of interference, the probability of **correctly identifying the original bit** is still very **high**
  - As there are **many 128-chip vectors**, each user can be **assigned a unique vector** that allows calculation of the **original bit** out of the chips at the receiver side, not only for a single user but also for **multiple users** at the same time

3.3.1 SPREADING FACTOR, CHIP RATE AND PROCESS GAIN

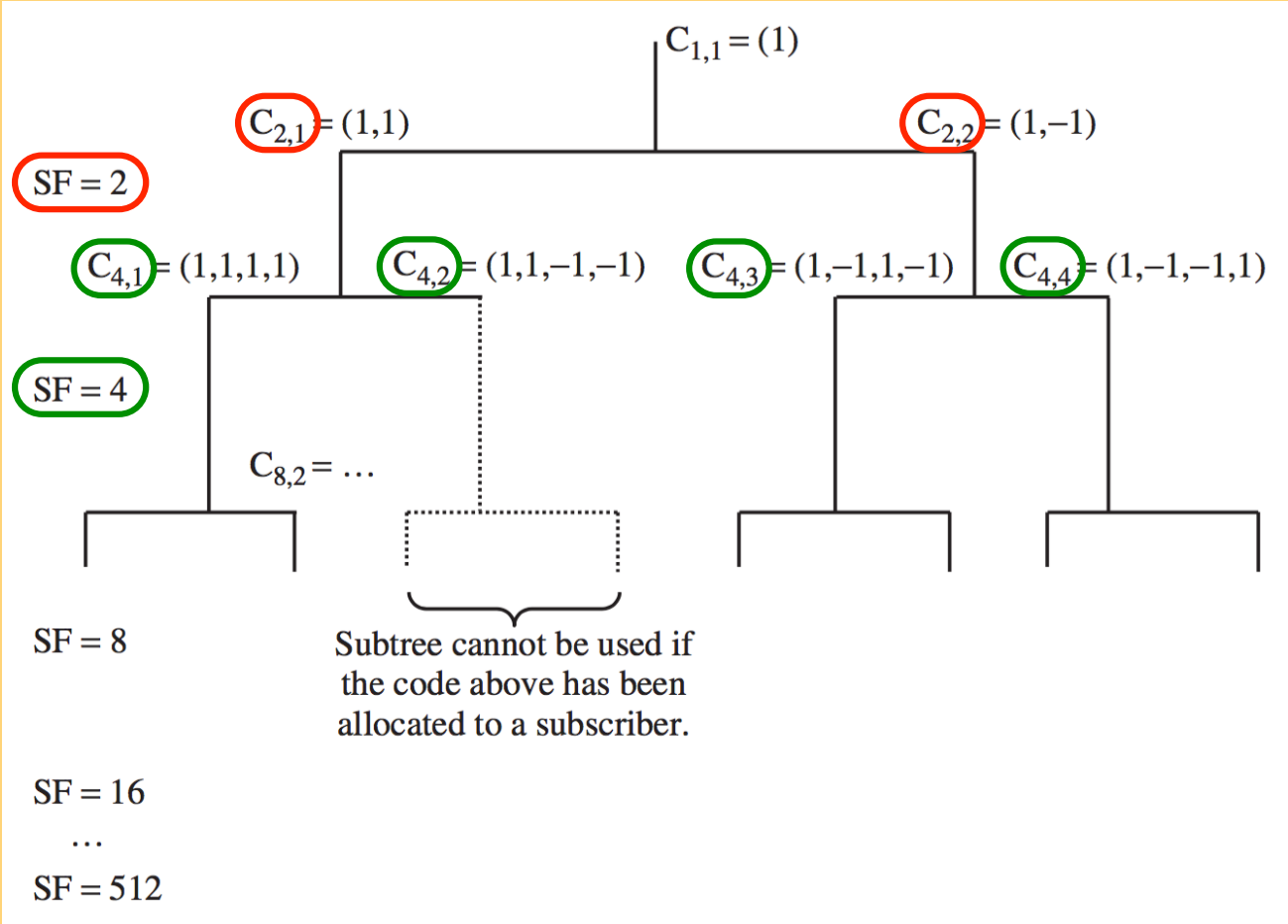
- The process of encoding a bit into several chips is called spreading
- The spreading factor for this operation defines the number of chips used to encode a single bit
- The speed with which the chips are transferred over the UMTS air interface is called the chip rate and is 3.84 Mchips/s, independent of the spreading factor
- As the chip rate is constant, increasing the spreading factor for a user means that his data rate decreases



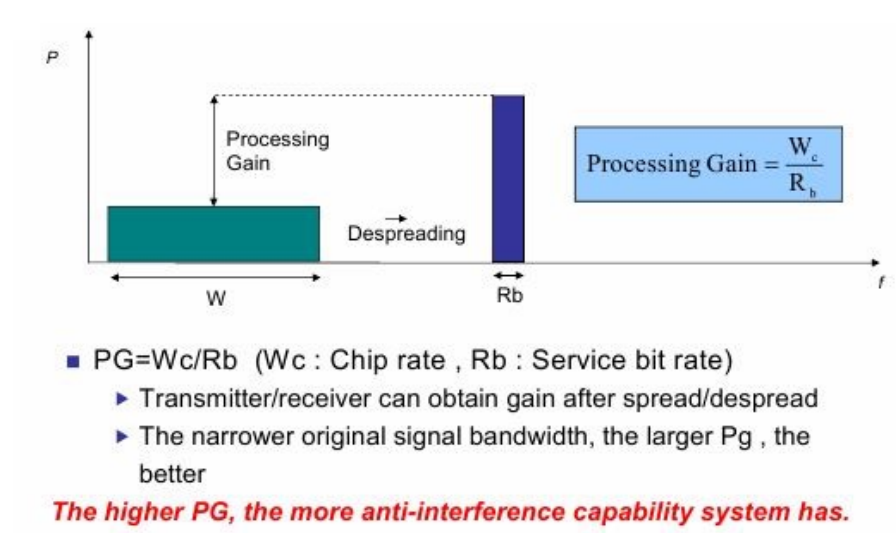
A	B	$Y = A \oplus B$	$Y = \overline{A \oplus B}$
0	0	0	**1**
0	1	1	**0**
1	0	1	**0**
1	1	0	**1**

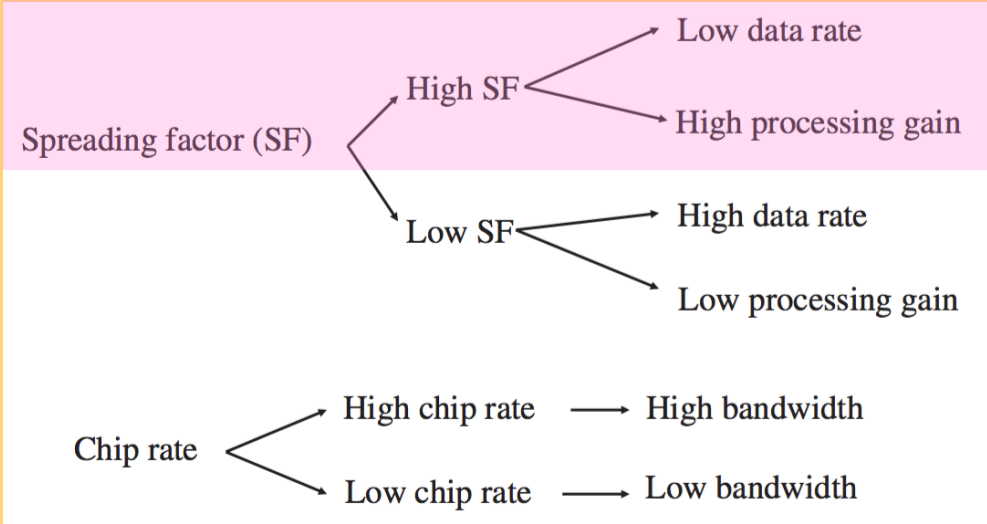
XNOR : logical complement of the exclusive OR (XOR)

- Besides a **higher robustness against errors**, there are a number of other **advantages of a higher spreading factor**
  - The **longer the code**, the **more codes** exist that are **orthogonal** to each other
    - This means that more users can **simultaneously use the transmission channel**



- As more users generate more noise, it is likely that the error rate increases at the receiver side
  - However, as more chips are used per bit, a higher error rate can be accepted
  - This means that a lower signal-to-noise ratio is required for a proper reception and thus, the transmission power can be reduced if the number of users in a cell is low
  - As less power is required for a slower transmission, it can also be said that a higher spreading factor increases the gain of the spreading process (processing gain)



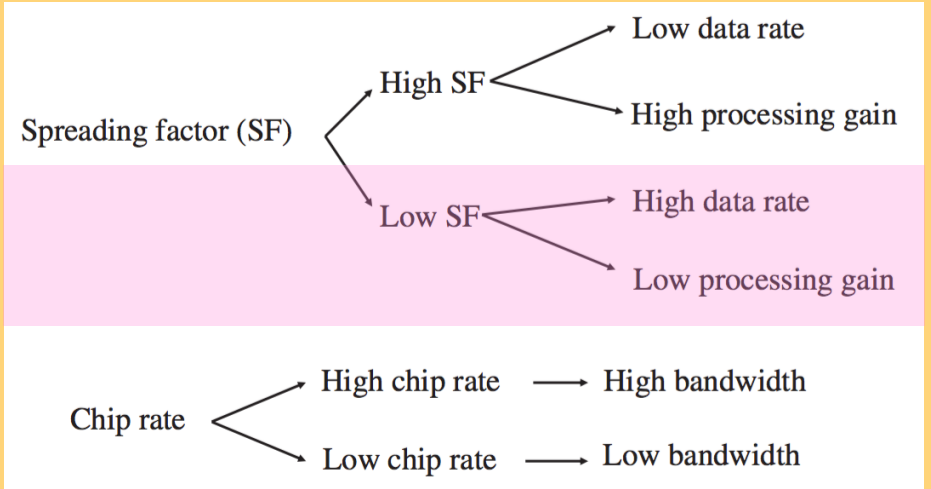


In a spread spectrum system, the processing gain is the ratio of the spread bandwidth to the unspread (or baseband) bandwidth. It is usually expressed in decibels (dB).

$$10 \log_{10}\left(\frac{P}{P_0}\right) \text{ dB}$$

P is the measured power, and P_0 is the reference power.

- If shorter codes are used, i.e., fewer chips per bit, the transmission speed per user increases. However, there are two disadvantages to this
  - Owing to the shorter codes, fewer people can communicate with a single BS at the same time
    - With a code length of eight (spreading factor 8), which corresponds to a user data rate of 384 kbit/s in the downlink direction, only eight users can communicate at this speed
    - With a code length of 256 on the other hand, 256 users can communicate at the same time with BS although the transmission speed is a lot slower
  - Owing to the shorter spreading code, the processing gain also decreases
    - This means that the power level of each user has to increase to minimize transmission errors



3.3.2 OVSF CODE TREE

- UMTS air interface uses a **constant chip rate** of **3.84 Mchips/s**
- If the **spreading factor** was also **constant**, all users of a cell would have to communicate with the network at the **same speed**
  - This is **not desirable**, as a **single cell** has to support **many users** with many **different applications** simultaneously
  - While some users may want to simply make **voice calls**, which require only a **small bandwidth**, other users might want to place **video calls**, watch some **mobile TV** (**video streaming**) or start a **web surfing** session
  - All these services require **much higher bandwidths**, and thus using the **same spreading factor** for all connections is **not practicable**
- The **solution** to this problem is called **Orthogonal Variable Spreading Factors (OVSF)**

- It is possible to assign **different code lengths** to **different users** at the same time
- As the codes of **different lengths** also have to be **orthogonal to each other**, the codes need to fulfill the condition shown in the following

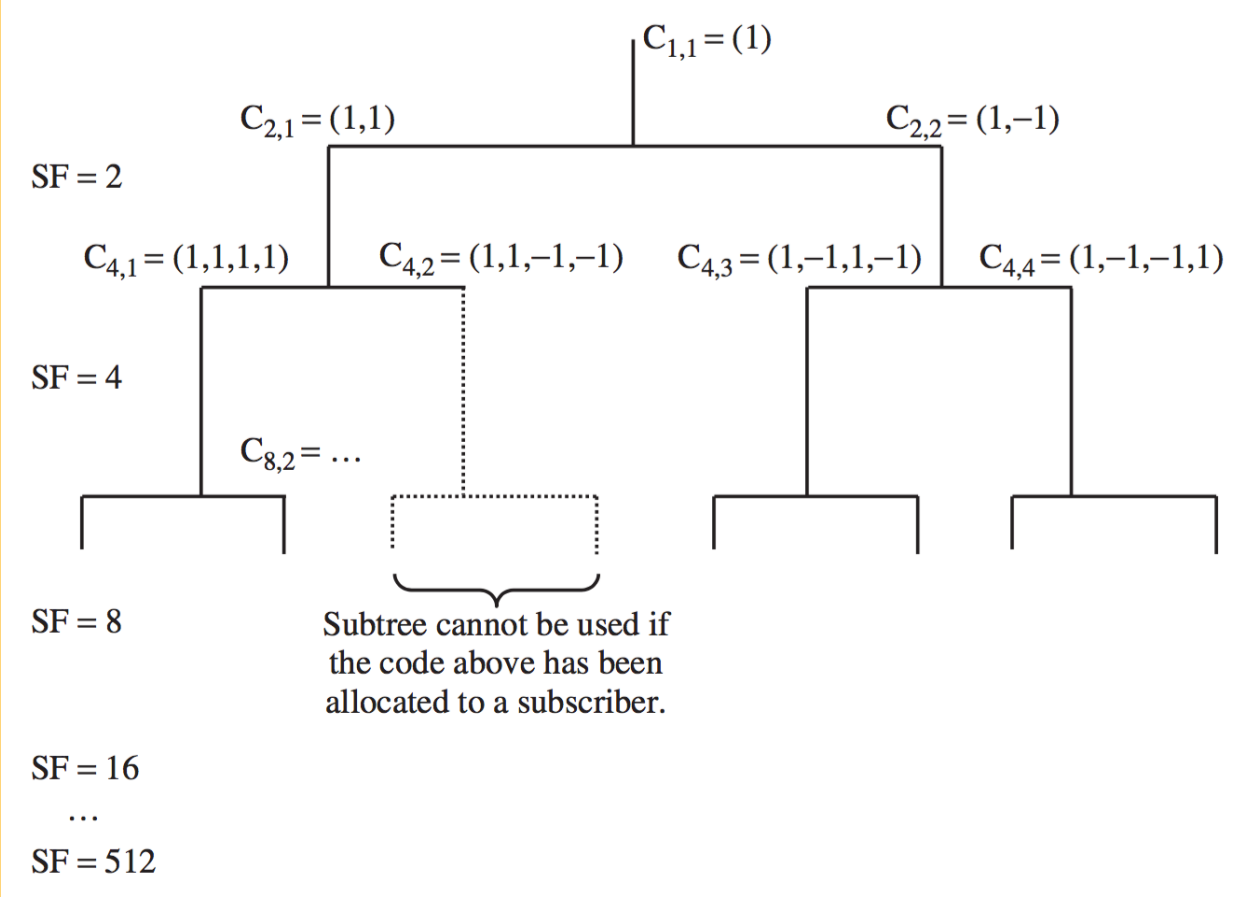


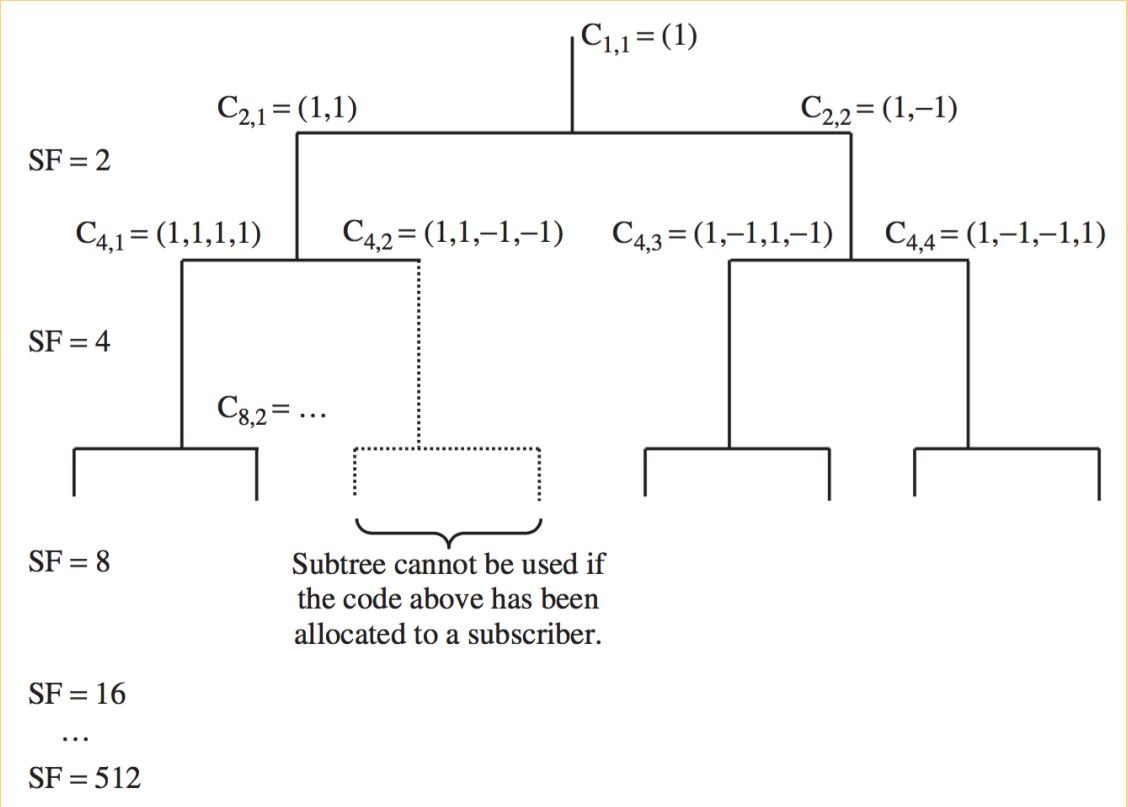
Figure 3.9 OVSF code tree

OVSF Code Generator ：

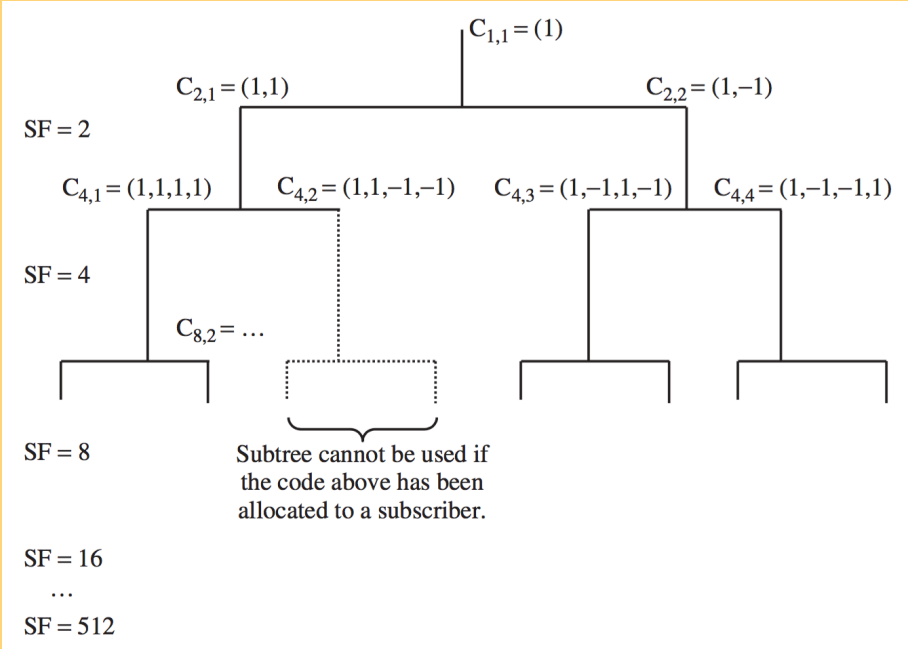
(IEEE) 15-12-0687-00-004k-document-for-dsss-ovsf-specification

https://www.google.com.tw/search?client=safari&rls=en&q=OVSF+Code+Generator&oq=OVSF+Code+Generator&gs_l=serp.3..0i19k1j0i8i30i19k1.131370.131370.0.132440.1.1.0.0.0.0.43.43.1.1.0....0...1c.2.64.serp..0.1.43.c6JD61QFy8g

- In the simplest case ($C_{1,1}$), the vector is **one dimensional**
- On the next level, with **two chips**, four vectors are possible of which **two are orthogonal to each other** ($C_{2,1}$ and $C_{2,2}$)
- On the **third level**, with four chips, there are 16 possible vector combinations and **four** that are **orthogonal to each other**
- The tree, which continues to grow for **SF 8, 16, 32, 64**, and so on shows that **the higher the spreading factor the more the number of subscribers** who can communicate with a cell at the same time



- If a mobile device, e.g., uses a spreading factor of **eight**, **all longer codes** of the **same branch cannot be used** anymore
  - This is due to the codes below not being orthogonal to the code on the higher level
  - As the tree offers **seven** other **SF 8 spreading factors**, it is still possible for other users to have codes with **higher spreading factors** from one of the other vertical branches of the code tree
  - It is up to the **network** to decide **how many codes are used** from **each level** of the tree
  - Thus, the network has the ability to **react dynamically** to **different usage scenarios**



- Table 3.1 shows the **spreading factors** in the **downlink** direction (from Node-B to mobile device) as they are used in a real system
  - **Raw data rate** is the number of **bits** transferred per second
  - **User data rate** results from the raw data rate after **removal of the extra bits** that are used for **channel coding**, which is necessary for **error detection** and **correction**, **signaling data** and **channel control**

Spreading Factor (Downlink)	Raw datarate (kbit/s)	User datarate (kbit/s)	Application
8	960	**384**	Packet data
16	480	**128**	Packet data
32	240	**64**	Packet data and video telephony
64	120	**32**	Packet data
128	60	**12.2**	Voice, packet data, location updates, SMS
256	30	**5.15**	Voice

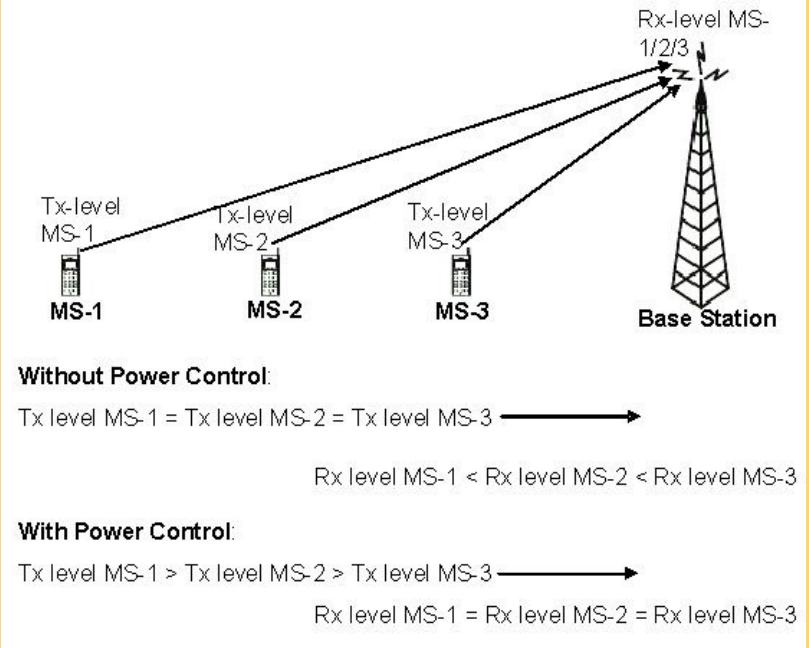
Table 3.1 Spreading factors and data rates

3.3.4 UMTS FREQUENCY AND CELL PLANNING

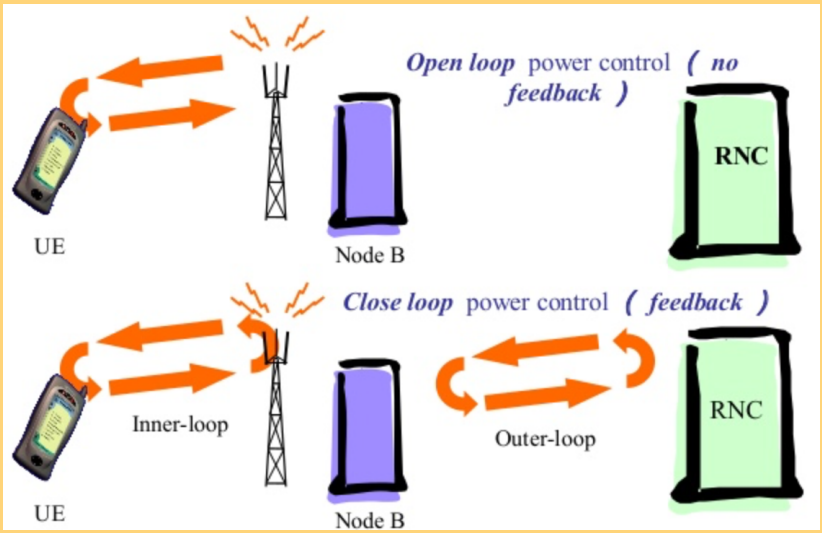
- As all cells in a UMTS radio network **can use the same frequency**, the **frequency plan** is greatly **simplified** compared to a GSM radio access network
- While it is of paramount importance in a **GSM** system to ensure that **neighboring cells use different frequencies**, it is quite the reverse in **UMTS**, as **all neighboring stations use the same frequency**
- This is possible because of the CDMA characteristics
- If a **new cell** is installed to **increase the bandwidth** in an area that is already covered by other cells, the most important task in a UMTS network is to **decrease the transmission power** of the **neighboring cells**
- Properly executed **cell changes** and **handovers** also improve the **overall capacity** of the system as they **minimize interference** of mobiles that stay in cells which are no longer suitable for them

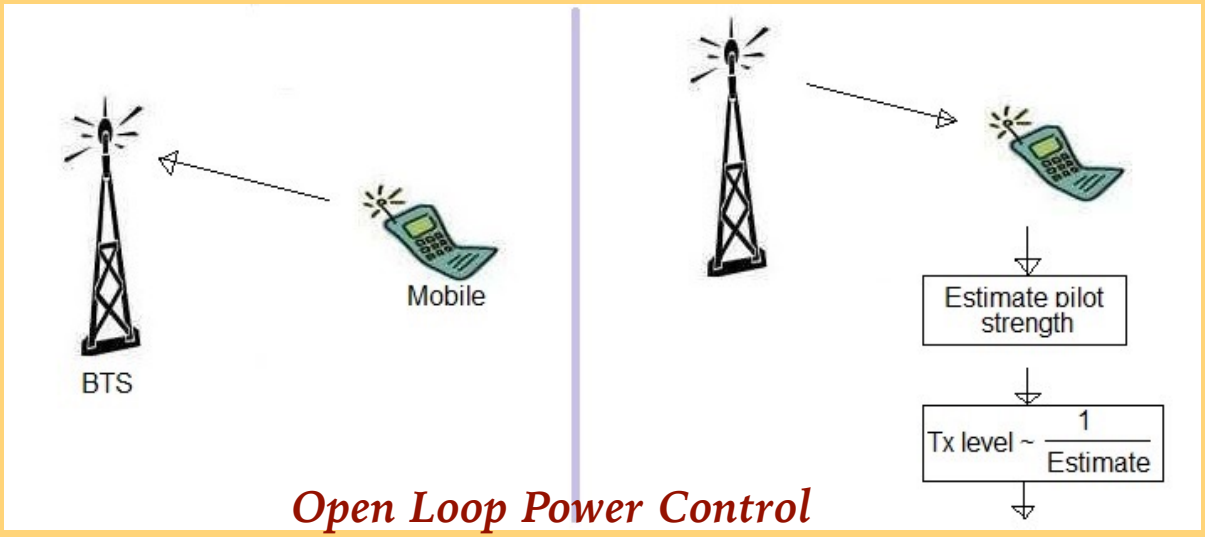
3.3.5 NEAR – FAR EFFECT AND CELL BREATHING

- As all users transmit on the **same frequency**, **interference** is the most **limiting factor** for UMTS radio network
- The following two phenomena are a direct result of the **interference problem**
  - To keep the **interference** at a **minimum**, it is important to have a **precise** and **fast power control**
  - Users that are **farther away** from BS have to send with **more power** than those **closer** to the BS, as the signal gets weaker the farther it has to travel
  - This is called **near–far effect**
  - Even **small changes** in the position of the user, like moving from a **free line of sight** to a BS to **behind a wall or tree**, has a **huge influence** on the necessary **transmission power**

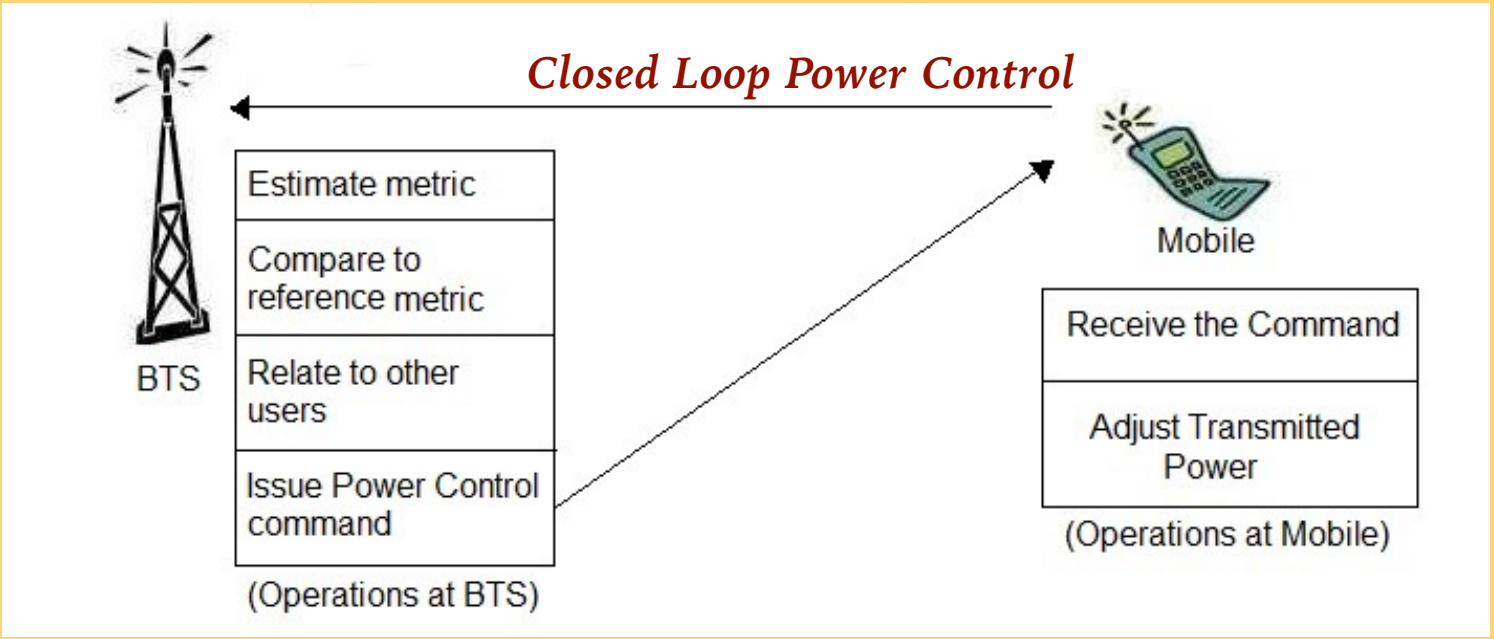


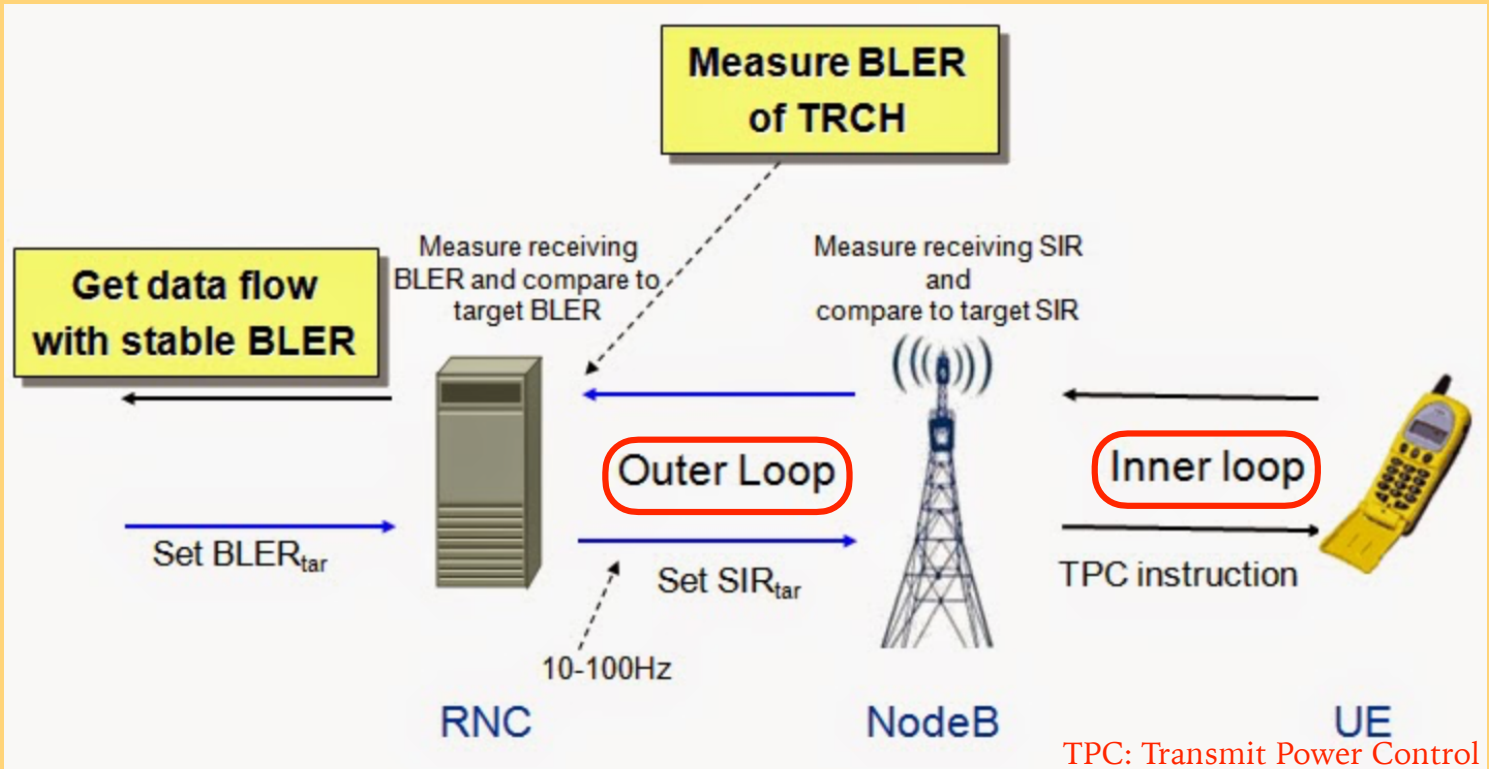
- The importance of **efficient power control** for UMTS is also shown by the fact that the network can **instruct** each handset **1500 times per second** to adapt its **transmission power**
- A **beneficial side effect** of this for the mobile device is an **increased operating time**, which is very important for most devices as the **battery capacity** is quite **limited**





Open Loop Power Control





TPC: Transmit Power Control

- The dependence on **low interference** for each user also creates another **unwanted side effect**
- Let us **assume** the following situation
  - There are a **high number of users** in the coverage area of a BS and the users are **dispersed** at various distances from the center of the cell
  - Because of **interference** the **most distant user** needs to transmit at the **highest possible power**
  - An **additional user** who is located at a **medium range** from the center of the cell **tries to establish a connection** to the network for a data transfer

- In this situation the following things can happen
  - If the network **accepts the connection request** the **interference level** for all users will **rise** in the cell. All users thus have to **increase** their **transmission power** accordingly
  - The user at the **border** of the cell, however, is already transmitting at his **maximum power** and thus **cannot increase the power level** anymore
  - As a result his **signal cannot be correctly decoded** anymore and the **connection is broken**
  - When seen from **outside** the system, this means that the **geographical area the cell can cover** is **reduced** as the most distant user **cannot** communicate with the cell anymore
  - This phenomenon is called **cell breathing** as the cell **expands** and **shrinks** like a human lung, which **increases** and **decreases** its size while breathing

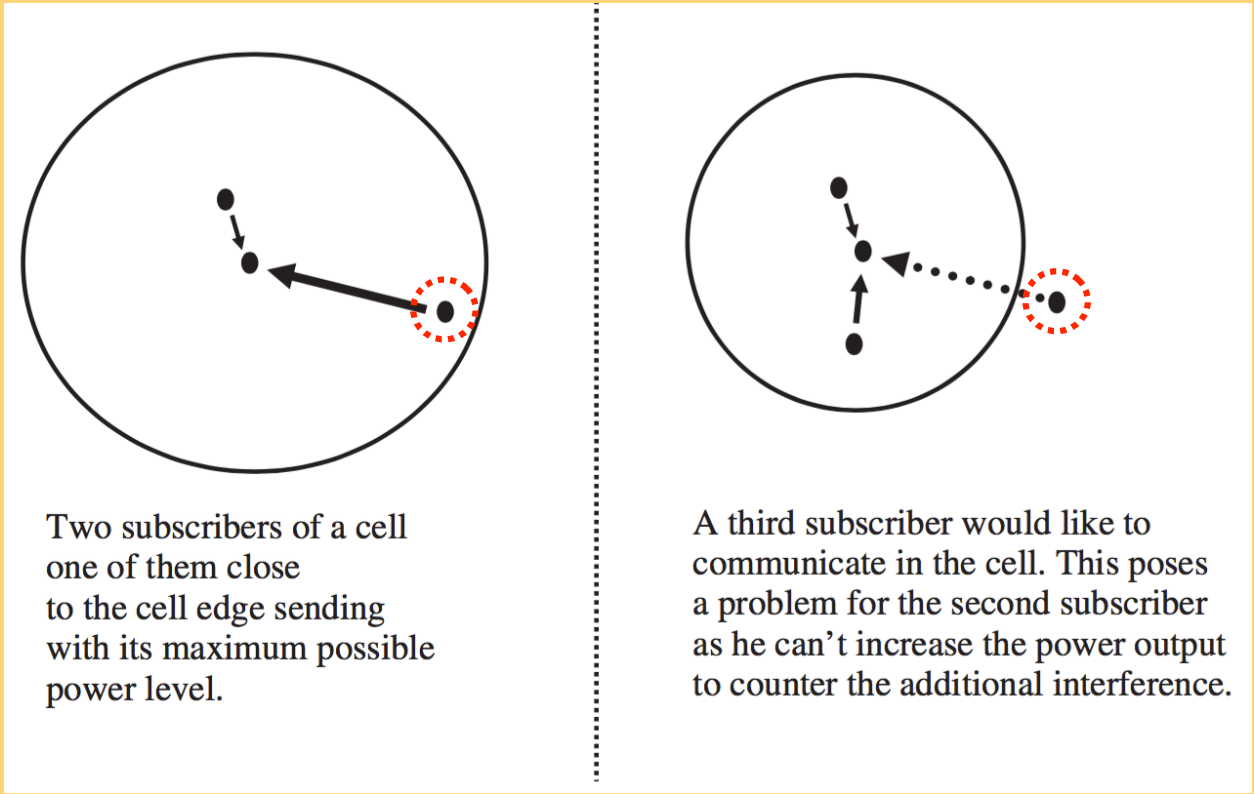
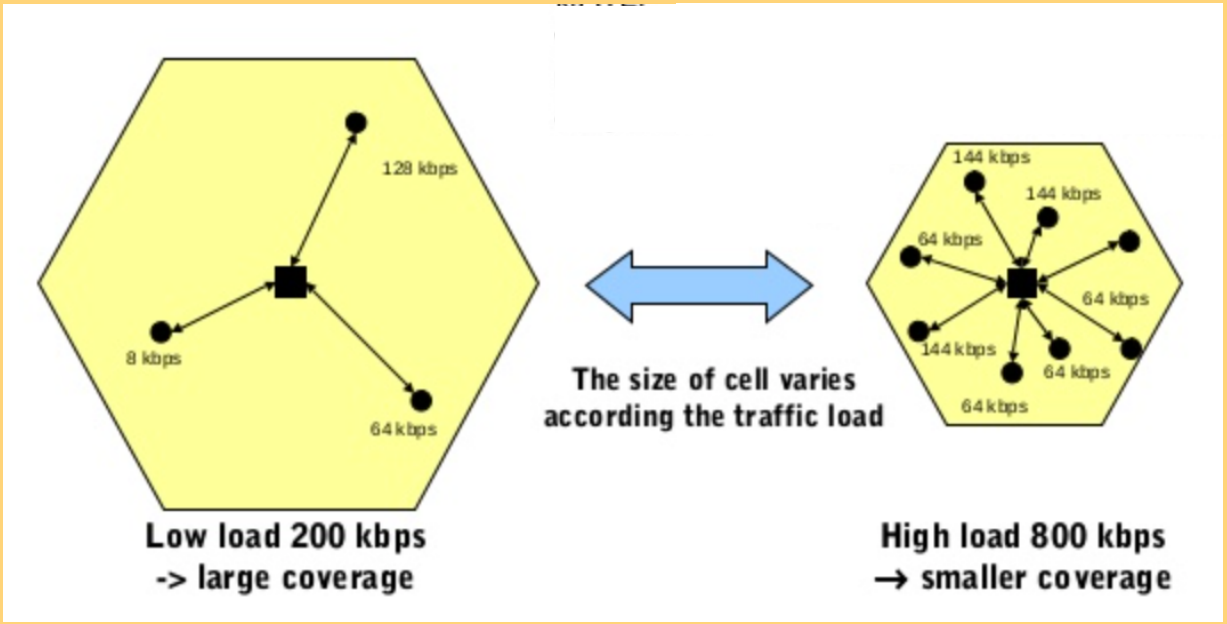


Figure 3.11 Cell breathing.



- To avoid this effect, the **network** constantly controls the **signal-to-noise ratio** of all active users
  - By **actively controlling** the **transmission power** of each user the network is aware of the **impact** an **additional user** would have on the overall situation of the cell
  - Therefore, the network has the possibility to **reject a new user** to protect the ongoing sessions

3.4 UMTS CHANNEL STRUCTURE ON THE AIR INTERFACE

3.4.1 USER PLANE AND CONTROL PLANE

- GSM, UMTS and other fixed and wireless communication systems differentiate between two kinds of data flows
  - In UMTS, these are referred to as user plane and data plane
- User plane
  - Is responsible for all data which is directly and transparently exchanged between the users of a connection like voice data or IP packets
- Control plane
  - Is responsible for all signaling data that is exchanged between users and network
  - Used for signaling data to exchange messages for call establishment or messages, e.g., for a location update

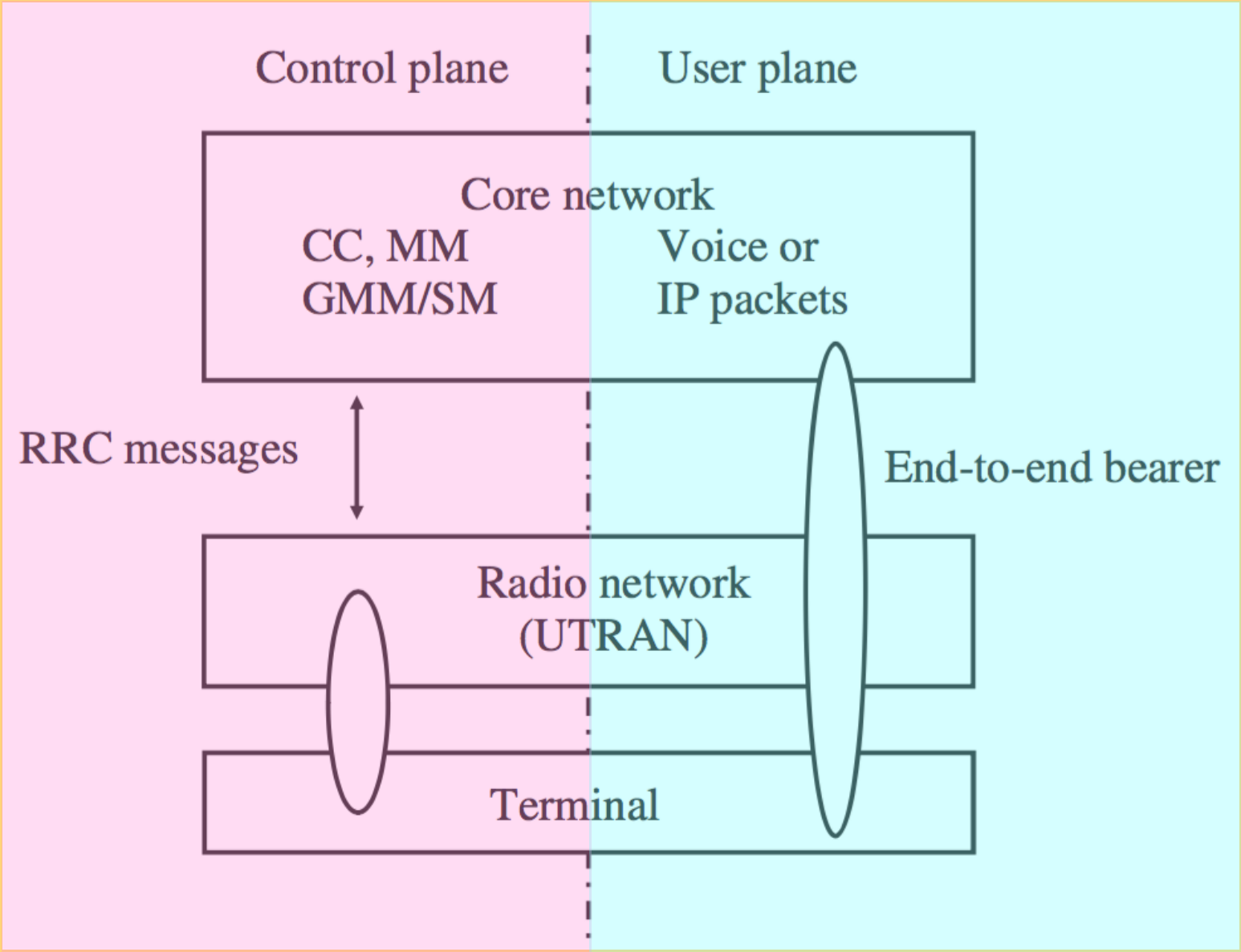


Figure 3.12 User and control planes.

RRC (RRC Connection)：*RRC*層主要負責的是有關無線資源的控管，透過*RRC*連線管理用戶端的無線電資源。*RRC*連線的狀態可能是閒置或是連線，差異在於是否有專屬於用戶端的無線承載*(Radio Bearer)*存在。在連線模式下，用戶端才能順暢的與基地台傳輸資料。此外基地台也才能根據用戶端的狀況，將*RRC*連線設定成最符合現狀需求的組態。

3.4.2 COMMON AND DEDICATED CHANNELS

- Both user plane data and control plane data are transferred over UMTS air interface in so-called 'channels'
- Three different kinds of channels exist
  - Dedicated channels
    - These channels transfer data for a single user
    - A dedicated channel is used for, e.g.,
      - Voice connection
      - IP packets between user and network
      - Location update message

- Common channels
  - Data transferred in common channels is destined for all users of a cell
  - Example: **broadcast channel**, which transmits general information about network to **all users** of a cell in order to inform them of, e.g.,
    - The **network** the cell belongs to
    - The **current state** of the network
    - etc.
  - Common channels can also be used by **several devices** for the **transfer of user data**
    - Each device **filters out** its packets from the stream broadcast over the common channel and only **forwards** these to **higher layers** of protocol stack

- Shared channels
  - Very similar to common channels
  - These channels are **not monitored by all devices** but **only by those that have been instructed by the network** to do so
  - Example: **High-Speed Downlink Shared Channel (HS-DSCH)** of **HSDPA**

3.4.3 LOGICAL, TRANSPORT AND PHYSICAL CHANNELS

- To separate the **physical properties** of the air interface from **logical data transmission**, UMTS design introduces three different channel layers
  - Logical channel
  - Transport channel
  - Physical channel

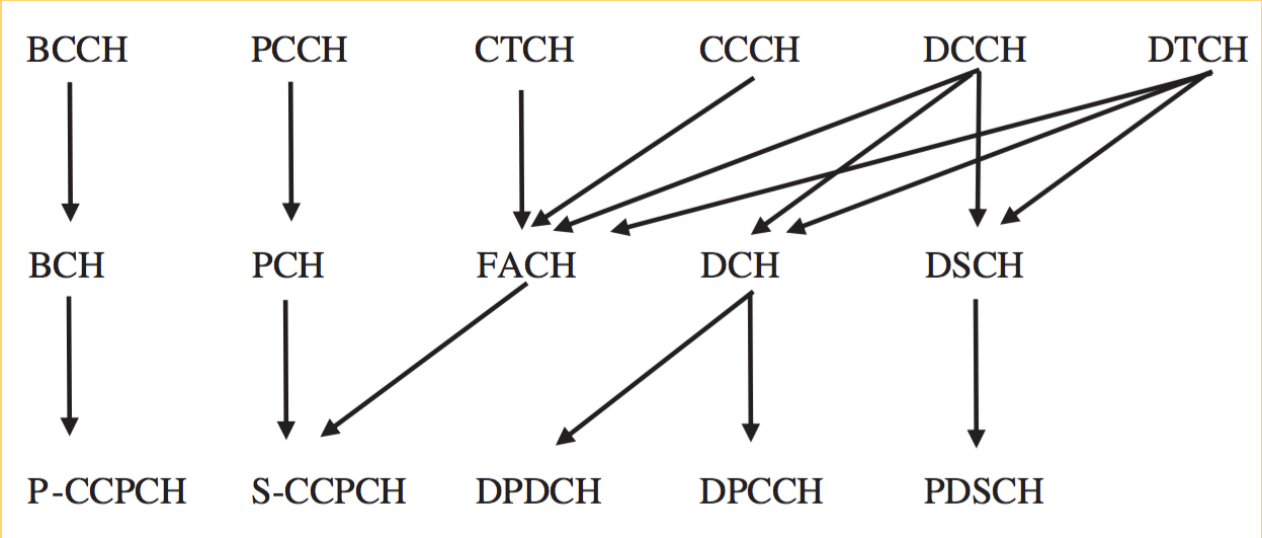


*Figure 3.13 Logical, transport and physical channels in **downlink** direction (without HSPA)*

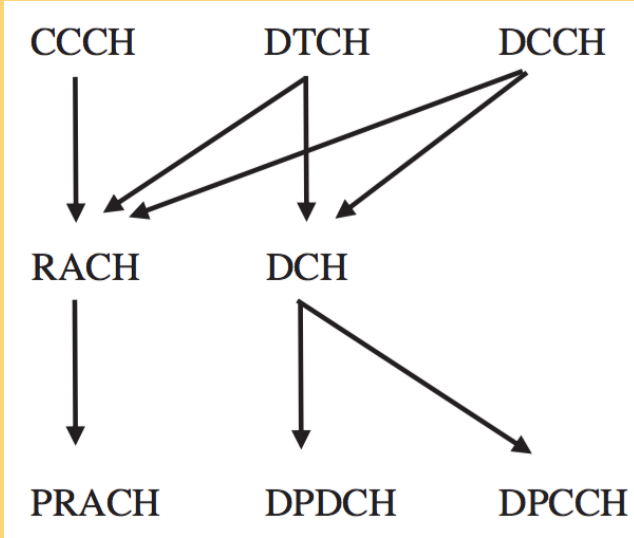
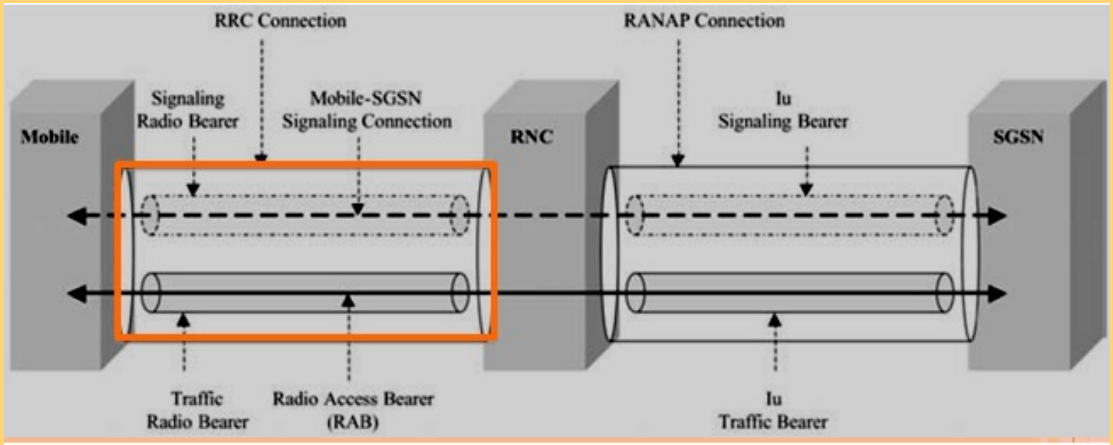


*Figure 3.14 Logical, transport and physical channels in **uplink** direction (without HSPA)*

- **Logical channels**
  - The **topmost channel layer** is formed by logical channels
  - Used to **separate different kinds of data flows** that have to be transferred over air interface
  - Contain **no information on how the data is later transmitted** over the air

- UMTS standards define the following **logical channels**
  - **Broadcast Control Channel (BCCH)**
    - Monitored by **all mobile devices** in **Idle state** to receive **general system information** from network
    - Information distributed via this channel, e.g.,
      - **How the network can be accessed**
      - **Which codes are used** by the neighboring cells
      - **LAC (Location Area Code)**
      - **Cell-ID**
      - **Many other parameters**
        - The parameters are further grouped into **System Information Block (SIB)** messages to help the mobile device to **decode the information** and to **save air interface bandwidth**

- Paging Control Channel (PCCH)
  - Inform users of **incoming calls** or **SMS messages**
  - **Paging messages** are also used for **packet-switched calls** if new data arrives from the network once all **physical resources** (**channels**) for a subscriber have been **released** owing to a **long period of inactivity**
  - If the mobile device receives a paging message it has to first **report** its **current serving cell** to the network
  - The network will then
    - **Reestablish a logical RRC (Radio Resource Control) connection** with the mobile device
    - The **data** waiting in the network is then **delivered** to the **mobile device**

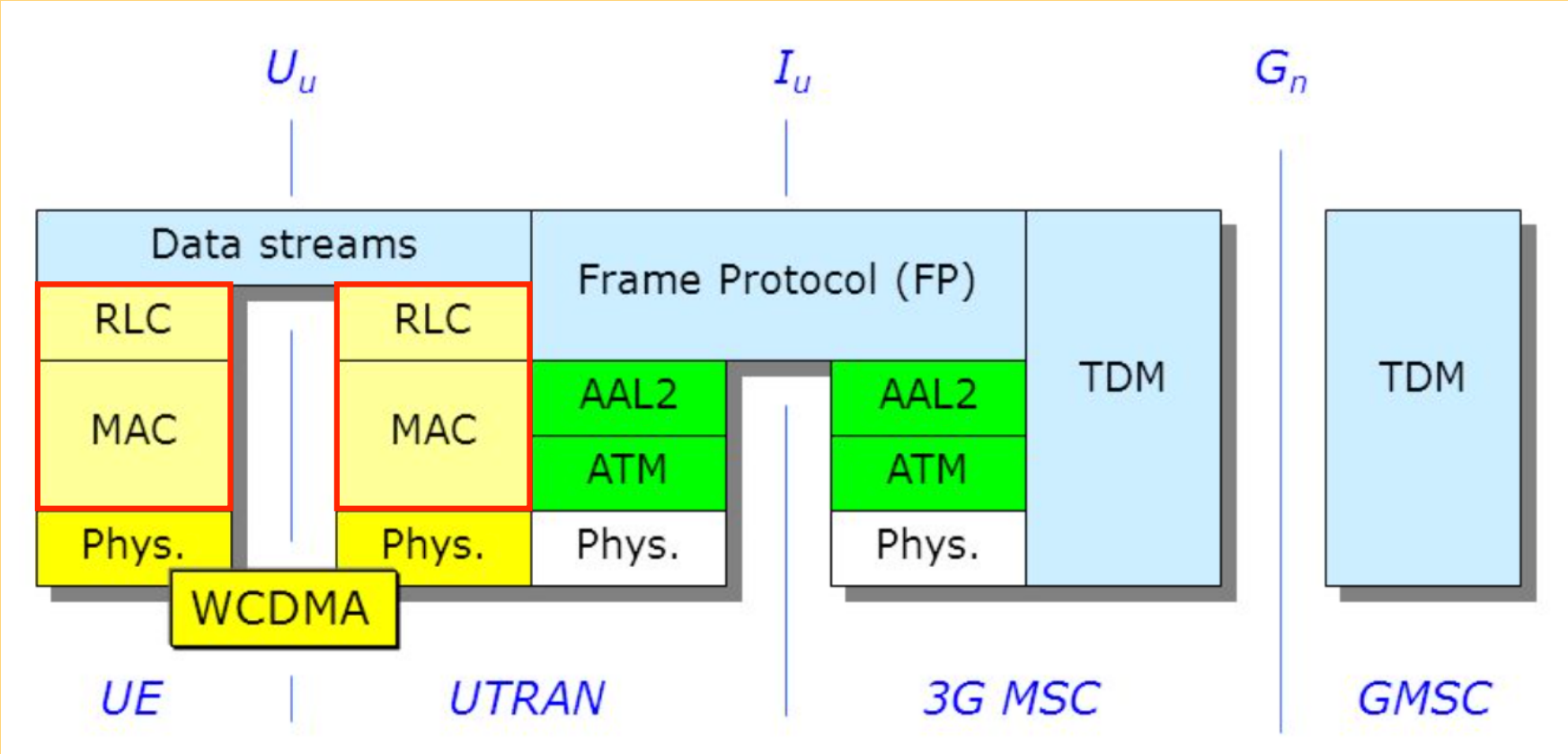


- Common Control Channel (CCCH)
  - Used for **all messages** from and to **individual mobile devices** (**bidirectional**) that want to establish a **new connection** with **network**
  - Example, if a user wants to
    - Make a **phone call**
    - Send an **SMS**
    - Establish a channel for **packet-switched data transmission**
- Dedicated Control Channel (DCCH)
  - Only transports data for a single subscriber
  - (CS) Transport messages for **MM (Mobility Management)** and **CC (Call Control)** protocols for **circuit-switched services**
  - (PS) Transport messages for **Packet Mobility Management (PMM)** and **SM** messages for **packet-switched services** from and to **MSC** and **SGSN**

- Dedicated Traffic Channel (DTCH)
  - Used for user data transfer between network and a single user
  - User data can be, e.g.
    - Digitized voice signal
    - IP packets of a packet-switched connection
  - If a dedicated logical channel carries a traditional voice call, the channel is mapped to a dedicated physical channel
  - If the dedicated logical channel carries packet-switched data, it is also possible mapped to a common or shared physical channel
    - In practice, a packet-switched connection is mapped to a common channel after some time of inactivity or if only little user data is transferred
    - The shared channel introduced with Release 99 was never used. Instead, it was replaced with the HSDSCH (High Speed Downlink Shared CHannel) introduced with HSDPA in Release 5

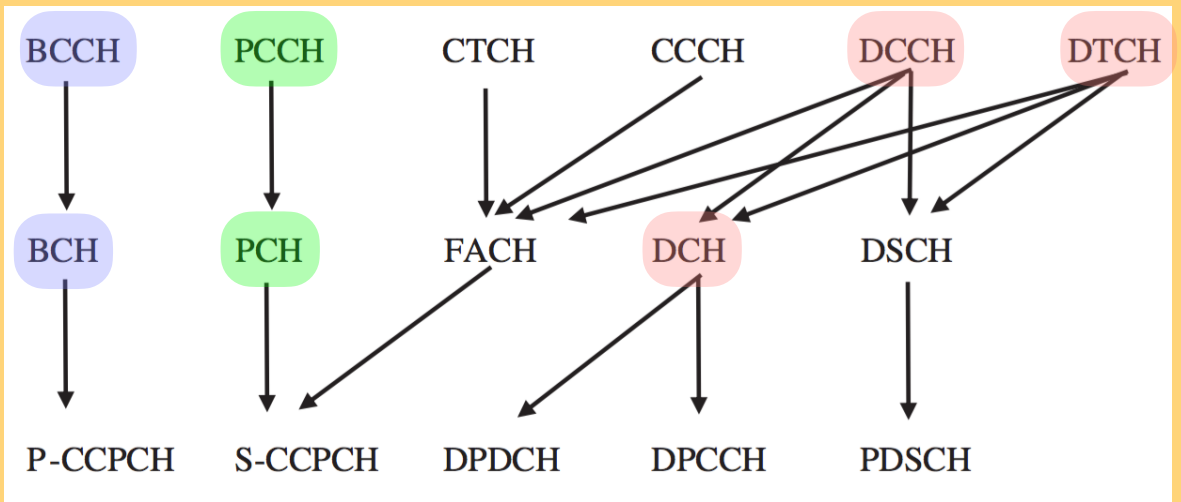
- **Common Traffic Channel (CTCH)**
  - Used for **cell broadcast information** that can be shown on the display of mobile devices
  - In practice, only few network operators make use of this
  - In a few countries such as Netherlands, **cell broadcast messages** are used for **public warning systems**

- **Transport channels**
  - **Prepare downlink data frames for transmission** over air interface by **splitting** them up into **smaller parts**, which are **encapsulated** into **RLC/MAC-frames** that are more suitable for transmission over air interface

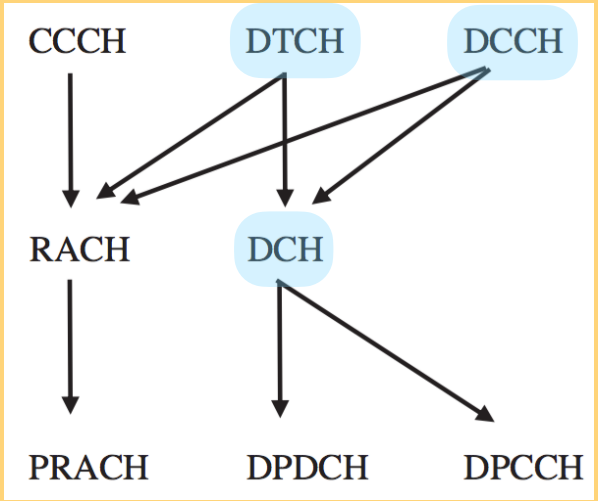


- The **RLC/MAC header** that is placed in front of each frame contains, among other things, the following information
  - **Length** of the **frame** (10, 20, 40 or 80 msec)
  - **Type** of **integrity checking mechanism** (**CRC checksum**)
  - **Channel coding format** for error detection and correction
  - **Rate matching** in case the **speed** of the physical channel and the layers above do not match
  - Control information for **detection** of **discontinuous transmission (DTX)** in case the other end has **no data** to send at a particular time
- All of these properties are combined into a so-called **transport format**

- Logical channels are mapped to the following transport channels
  - Broadcast Channel (BCH)
    - Transport channel variant of the logical BCCH
  - Dedicated Channel (DCH)
    - This transport channel combines data from logical DTCH and logical DCCH
    - The channel exists in both uplink and downlink directions as data is exchanged in both directions
  - Paging Channel (PCH)
    - Transport channel variant of the logical PCCH

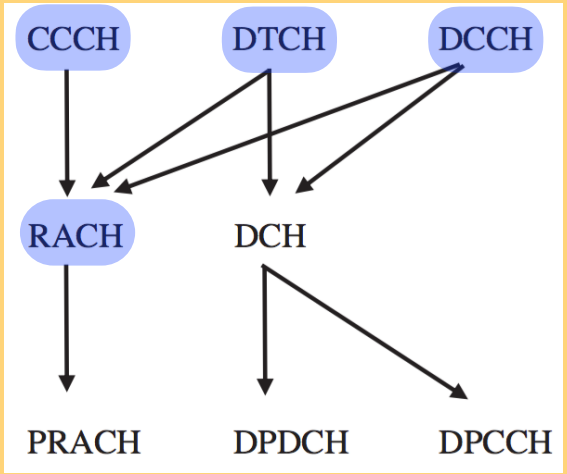


downlink



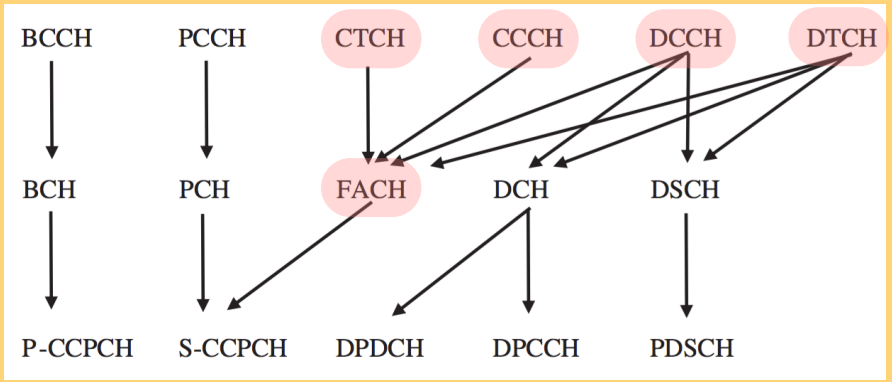
uplink

- **Random Access Channel (RACH)**
  - The bidirectional logical **CCCH** is called RACH on the transport layer in **uplink** direction
  - This channel is used by mobile devices to send **RRC Connection Request messages** to network if they wish to establish a **dedicated connection** with network (e.g., to establish a **voice call**)
  - The channel is used by mobile devices to send **user packet data** (in **Cell-FACH state**) if **no dedicated channel exists** between mobile device and network. It should be noted, however, that this channel is only suitable for **small amounts** of data



uplink

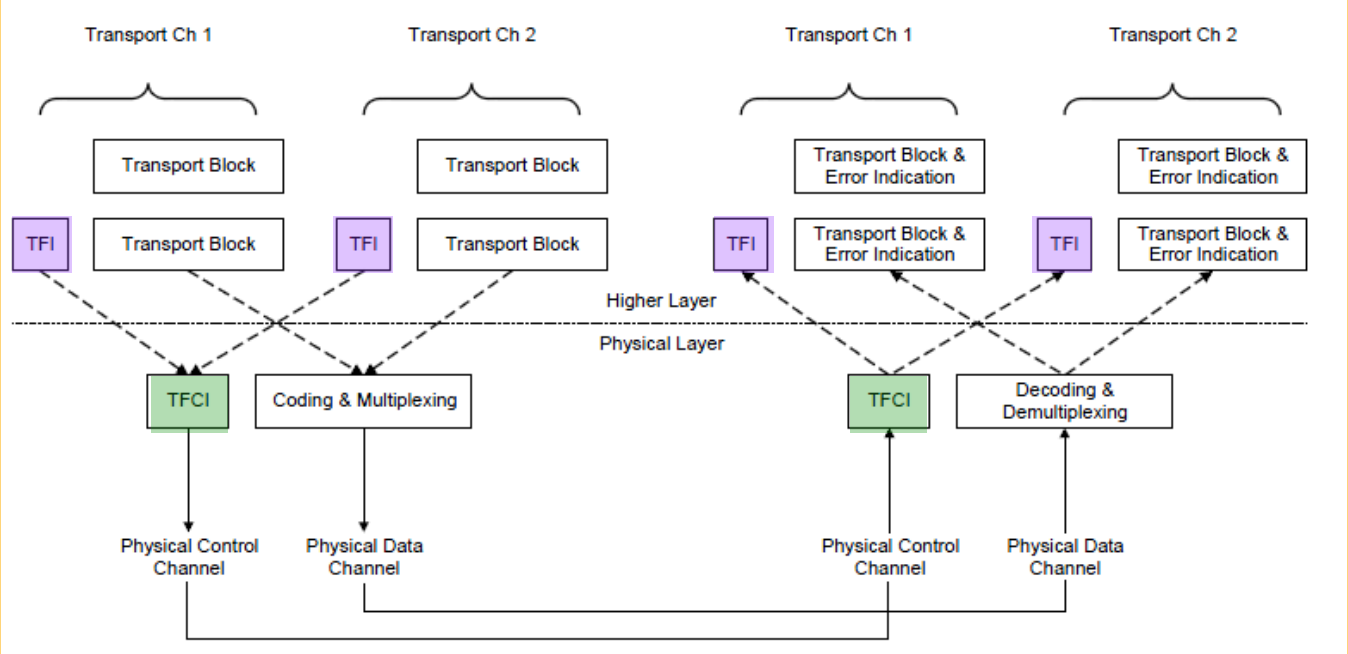
- **Forward Access Channel (FACH)**
  - This channel is used by **network** to send **RRC Connection Setup** messages to mobile devices, which have indicated via the RACH that they wish to establish a **connection** with network
  - The message contains information for mobile device on **how to access network**
  - If the network has assigned a **dedicated channel**, the message contains, e.g., information on **which spreading codes** will be used in uplink and downlink directions
  - The FACH can also be used by the network to send **user data** to a mobile device in case **no dedicated channel** has been allocated for a data transfer
  - The mobile device is then in the **Cell-FACH** state
  - A typical **channel capacity** of the FACH is **32 kbit/s**



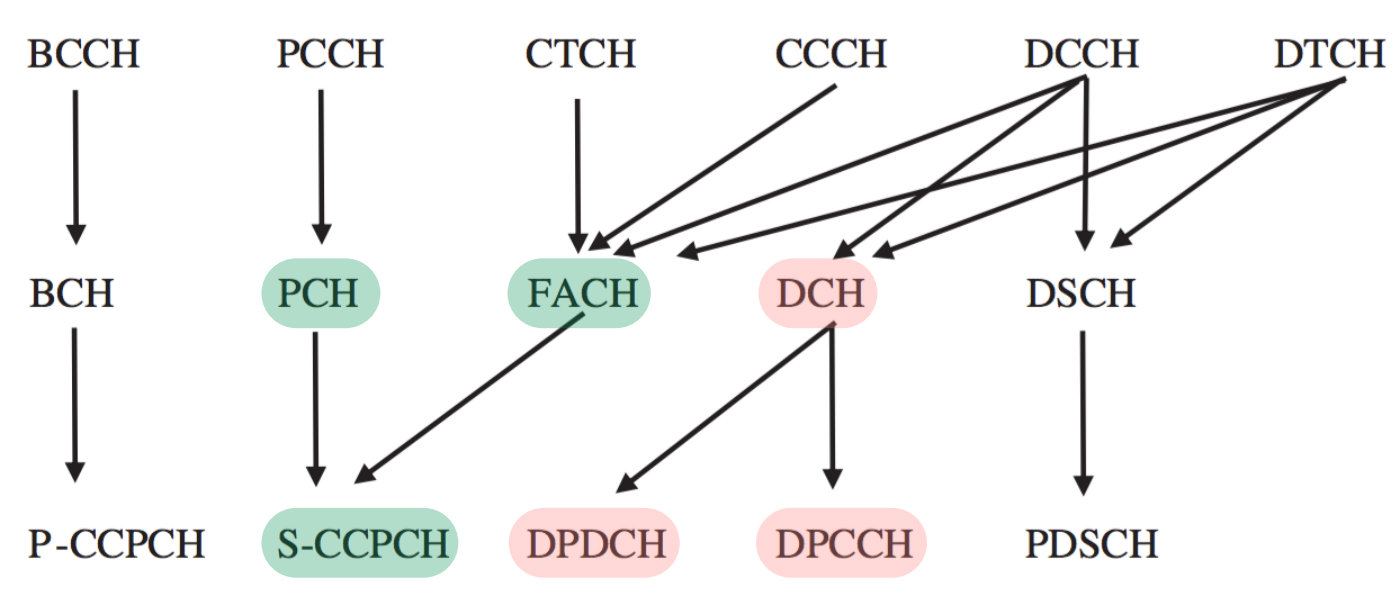
downlink

- **Physical channels**
  - Physical channels are responsible for **offering a physical transmission medium for one or more transport channels**
  - Physical channels are responsible for **channel coding**, that is, the addition of **redundancy** and **error detection bits** to the data stream
  - The **intermediate products** between transport channels and physical channels are called **Composite Coded Transport Channels (CCTrCh)** and are a **combination of several transport channels**, which are subsequently transmitted over one or more physical channels

- Each Transport Block has one TFI attached to it
  - TFI: Transport Format Indicator
- In physical layer, multiple transport blocks are combined into a large 'transmission frame'
  - This combined transmission frame is called Coded Composite Transport Channel (CCTrCh)
  - Each CCTrCH frame gets its own indicator which is called TFCI
    - TFCI: Transport Format Combination Indicator



- This **intermediate step** was introduced to
  - **Map several transport channels onto a single physical channel** (e.g. the **PCH** and **FACH** on the **S-CCPCH**)
  - **Map several physical channels onto a single transport channel** (e.g. the Dedicated Physical Data Channel (**DPDCH**) and Dedicated Physical Control Channel (**DPCCH**) onto the **DCH**)



- The following **physical channels** are used in a cell
  - **Primary Common Control Physical Channel (P-CCPCH)**
    - Used for **distributing broadcast information** in a cell
  - **Secondary Common Control Physical Channel (S-CCPCH)**
    - Used to **broadcast** PCH and FACH
  - **Physical Random Access Channel (PRACH)**
    - The physical implementation of RACH
  - **Acquisition Indication Channel (AICH)**
    - This channel is not shown in the channel overview figures as there is **no mapping** of this channel to a transport channel
    - The channel is used **exclusively together with PRACH** during **connection establishment** of a mobile device with the network

- **Dedicated Physical Data Channel (DPDCH)**
  - The physical counterpart of a **dedicated channel** to a **single** mobile device
  - The channel combines **user data** and **signaling messages** from (Packet) **MM**, **CC** and **SM**
- **Dedicated Physical Control Channel (DPCCH)**
  - Used in addition to a DPDCH in both **uplink** and **downlink** directions
  - It contains **layer 1 information** like **Transmit Power Control (TPC) bits** for adjusting the transmission power
  - The channel is also used to transmit the so-called **pilot bits**. These bits can be used by the **receiver** to generate a **channel estimation**, which is used to **decode** the **remaining bits** of **DPCCH** and **DPDCH**

- The following list summarizes the different kinds of channels and their main tasks
  - Logical Channels
    - Describe different flows of information like user data and signaling data
    - Contain no information about the characteristics of the transmission channel
  - Transport Channels
    - Prepare data packets that are received from logical channels for transmission over air interface
    - This layer defines which channel coding schemes (e.g., error correction methods) are to be applied on the physical layer
  - Physical Channels
    - Describe how data from transport channels is sent over the air interface and apply channel coding and decoding to the incoming data streams

3.5.4 RADIO RESOURCE CONTROL (RRC) STATES

- The activity of a subscriber determines **in which way data is transferred** over the air interface between mobile device and network
- In UMTS, a mobile device can therefore be in one of five RRC states

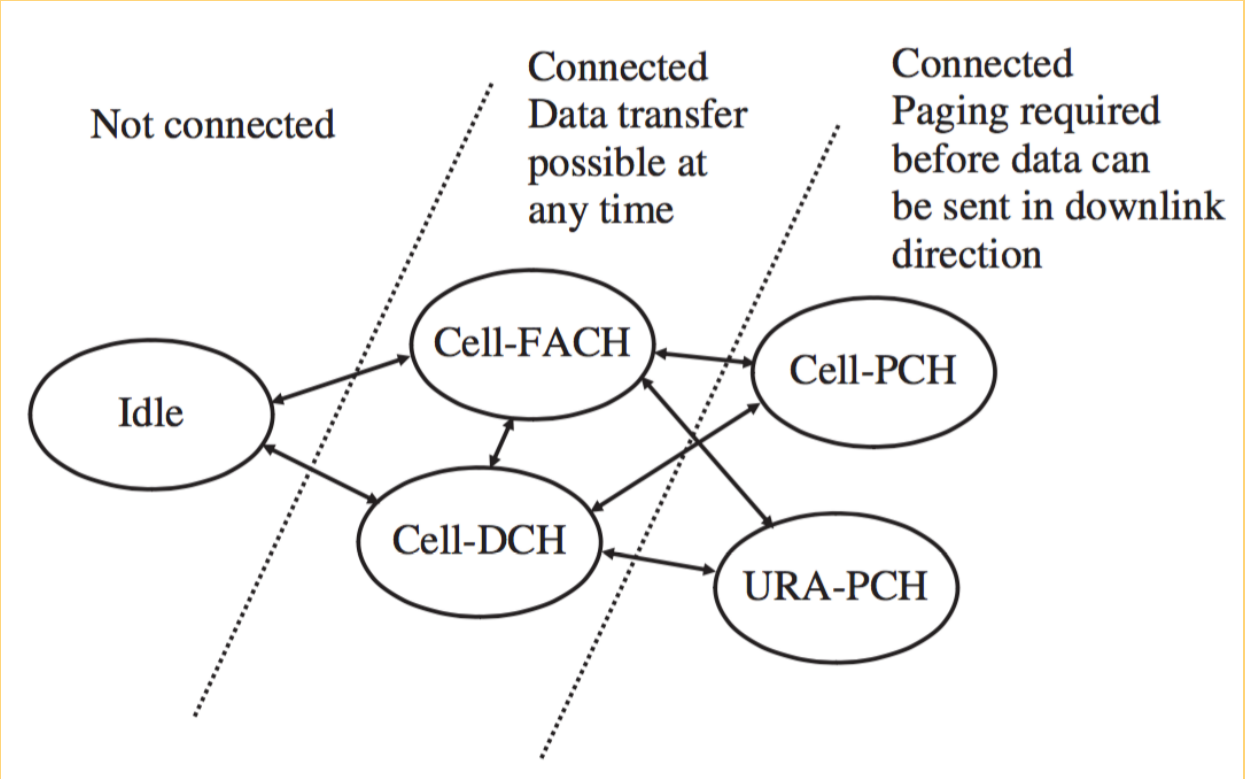
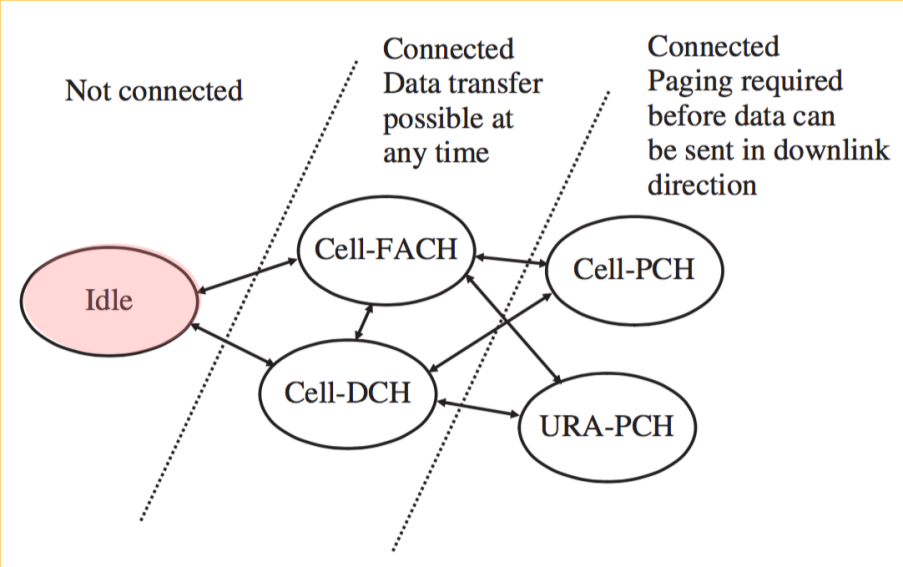
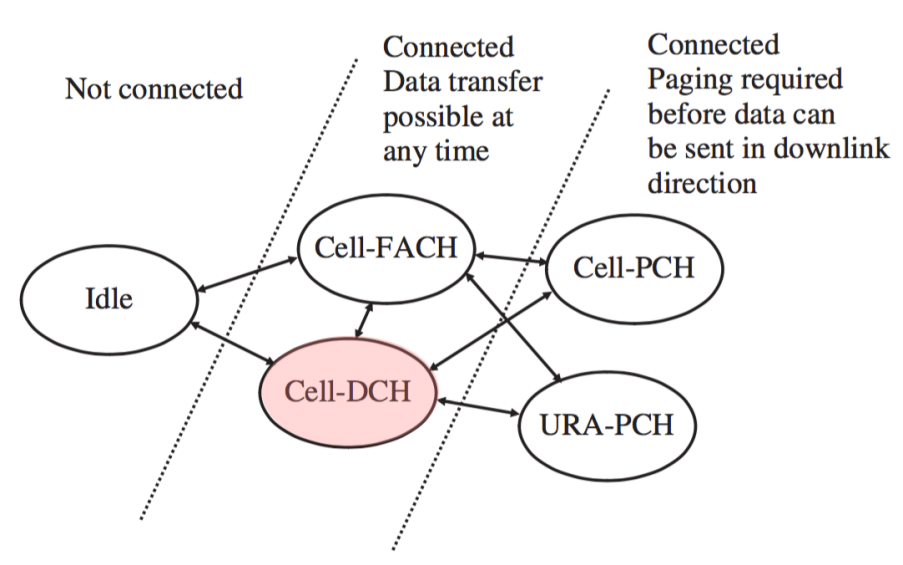


Figure 3.23 Radio Resource Control (RRC) states

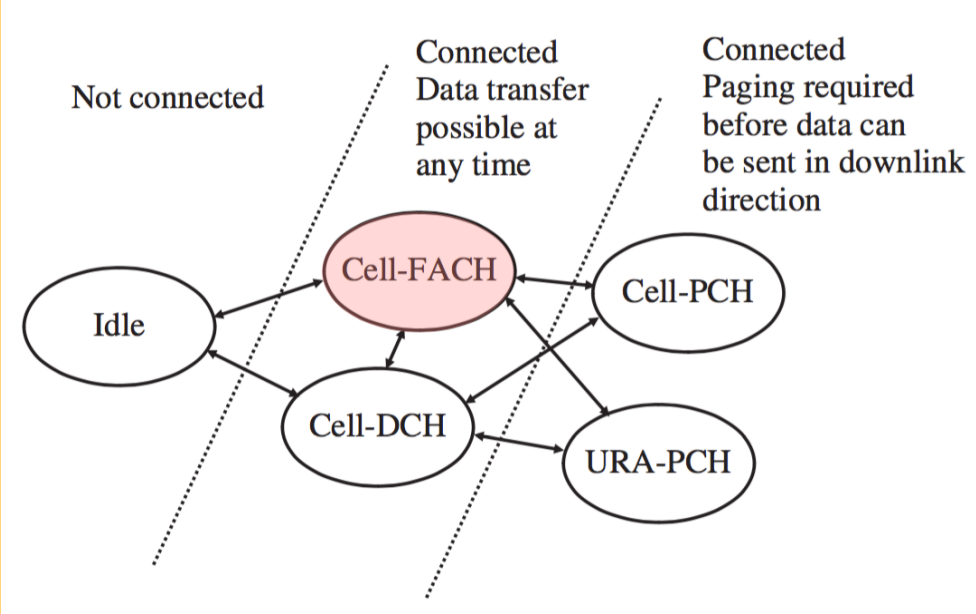
- **Idle State**
  - A mobile device is **attached** to the network but **does not have a physical or logical connection** with the radio network
    - The user is involved **neither** in a voice call nor in a data transfer
  - From the **packet-switched core network** point of view, the subscriber might still **have an active PDP context** (i.e., an **IP address**) even if **no radio resources are assigned** at the moment
  - Owing to the user's period of **inactivity**, the radio network has decided to **release the radio connection**
    - If the user wants to send some data again (e.g., request a new web page), the mobile device needs to **request the establishment** of a **new radio bearer**



- **Cell-DCH State**
  - While in this state, a **physical connection is established** between mobile device and network
  - In the UTRAN this means that the mobile device **has been assigned its own spreading code** in the **downlink** direction and its own **spreading** and **scrambling codes** in the **uplink** direction
    - By using **scrambling code** (both at the very low level of hardware)
      - NodeB can **separate signals** coming simultaneously from many different UEs and
      - UE can **separate signals** coming simultaneously from many different NodeB

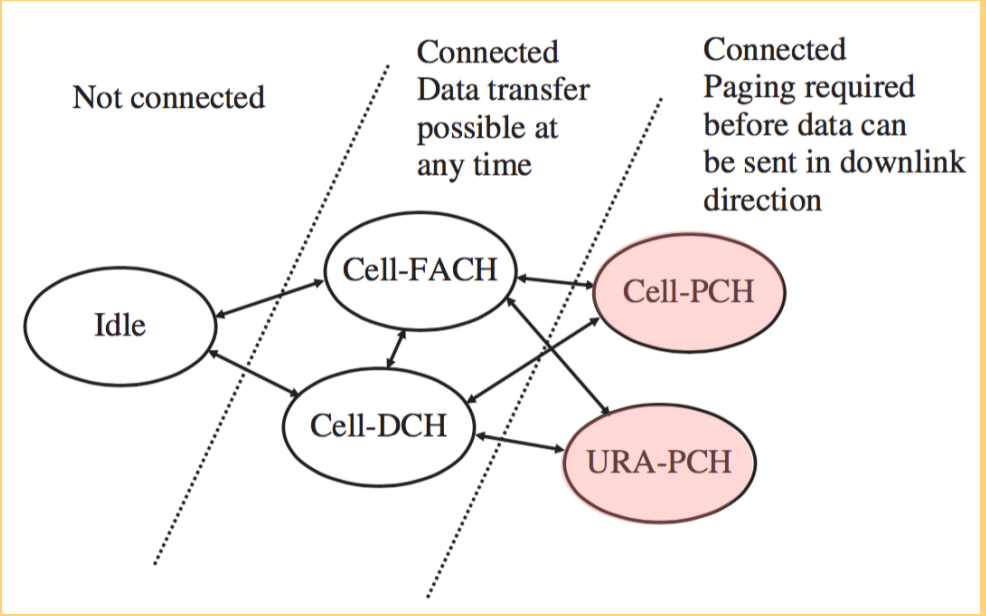


- **Cell-FACH State**
  - Mainly used when only a **small amount of data** needs to be transferred to or from a **subscriber**
  - In this mode, the subscriber **does not get a dedicated channel** but uses the FACH to **receive** data
  - FACH is also used for carrying **signaling data** such as **RRC connection setup messages** for devices that have requested access to the network via RACH



Cell-PCH and URA-PCH States

- The optional Cell-Paging Channel (Cell-PCH) RRC state and the UTRAN Registration Area – Paging Channel (URA-PCH) RRC state can be used to reduce the power consumption of the mobile device during extended times of inactivity
- Similar to the Idle state, no resources are assigned to the mobile device
- If data arrives for a subscriber from the network, the mobile device needs to be paged first. The mobile device then responds and implicitly changes back to Cell-FACH state



	RNC state	SGSN state
Idle	Not connected	Not connected
Cell-DCH	Connected, data is sent via the DCH or HS-DSCH	Connected
Cell-FACH	Connected, incoming data is sent immediately via the FACH (Common Channel)	Connected
Cell-PCH	Connected, but subscriber has to be paged and needs to reply before data can be forwarded. Once the answer to the paging has been received, the subscriber is put in either Cell-FACH or Cell-DCH state	Connected
URA-PCH	Same as Cell-PCH. Furthermore, the network only needs to be informed of a cell change in case the mobile device is moved into a cell, which is part of a different UTRAN Registration Area	Connected

Table 3.4 RNC and SGSN states