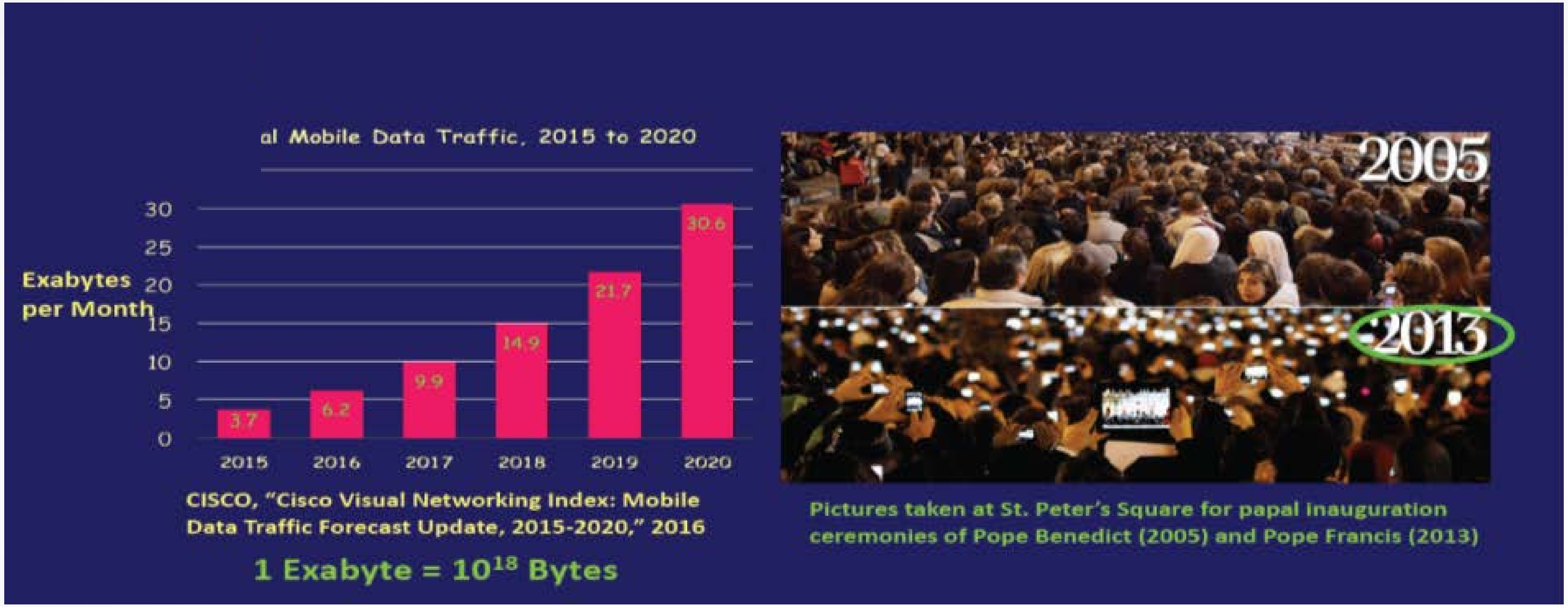
Wireless data communication

Joint master program Skoltech and CMC MSU

Prof. R. Smelyanskiy

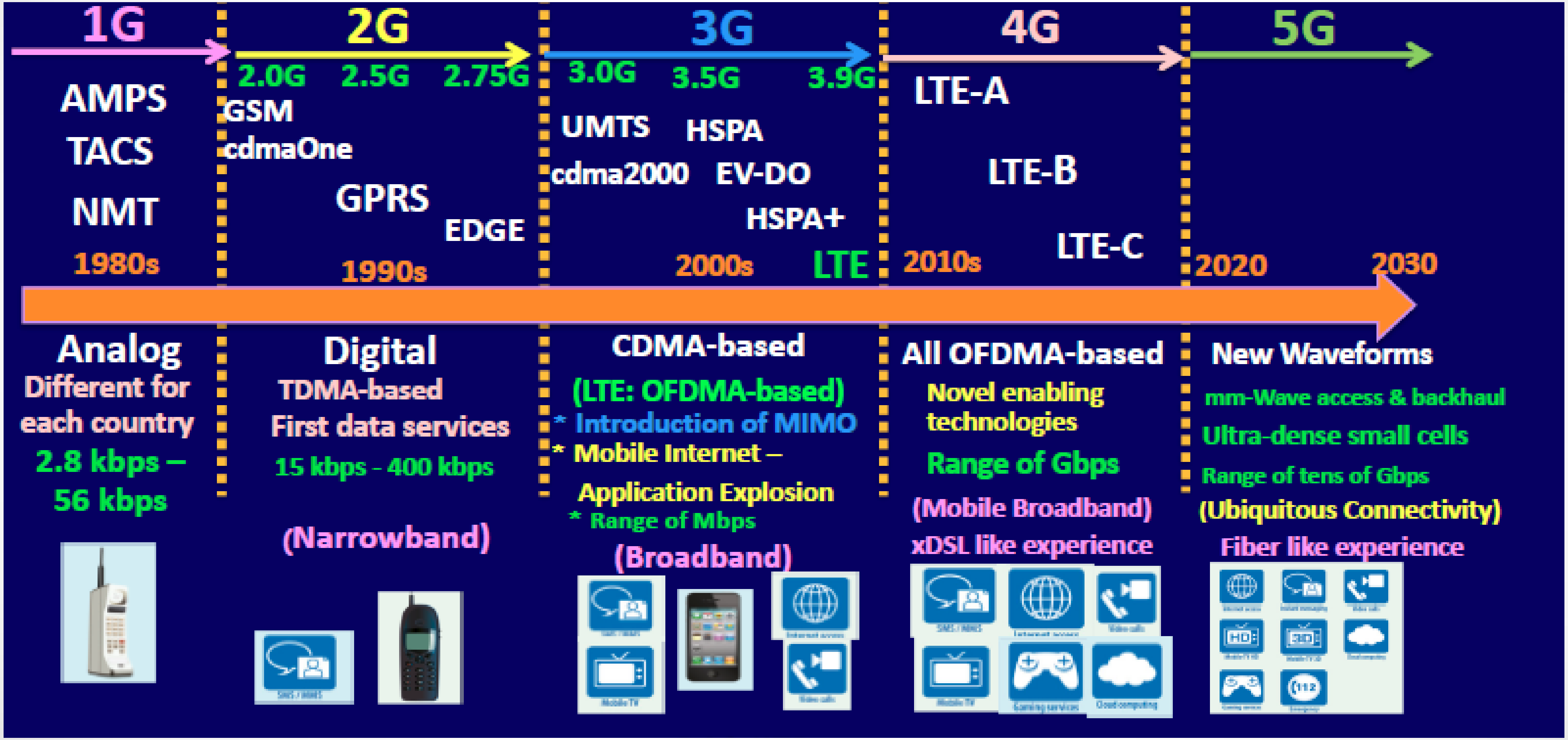
EVOLUTION OF WIRELESS SYSTEM



Akildiz Y. 10 key enabling technologies for 5G

Evolution of cellular systems

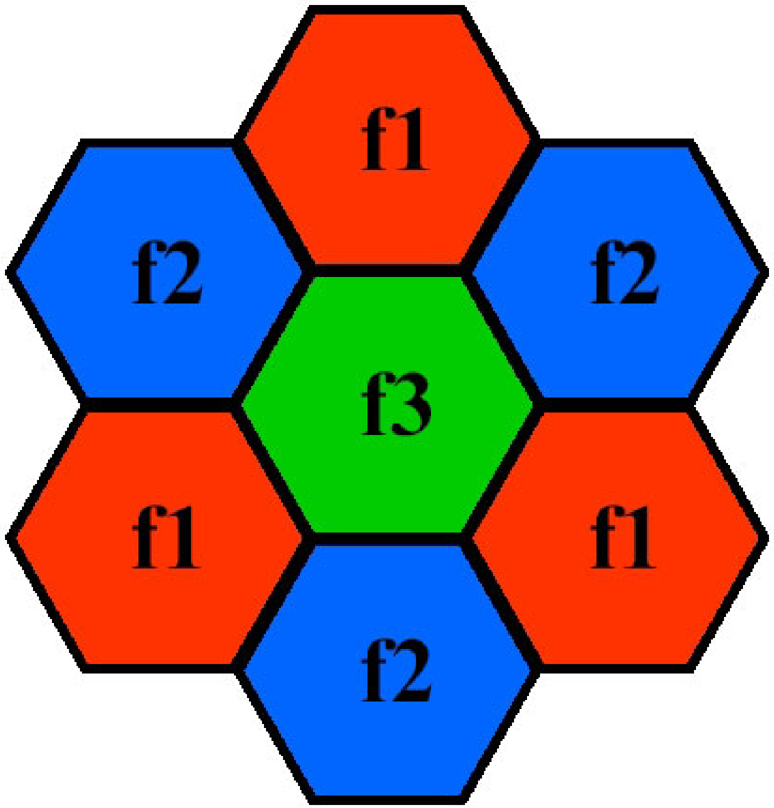
1982 – 1990 | 1991 – 1999 | 2000 – 2010 | 2010 – 2019 | 2020



Akildiz Y. 10 key enabling technologies for 5G

Cellular telecommunications

- Analog cellular communication
  - IMPS (1964 г.)
  - AMPS(1982 г.)



Advanced Mobil Telephone System – AMPS (1G)

- In 1982, Bell Labs introduced the AMPS (Advanced Mobil Telephone System)
- The principles of cellular communications
  - Bases (BS)
  - Mobile Switching Centers (MSC)
  - Move between cells
  - Channel allocation in cells
- AMPS uses the FDMA frequency separation technique. The entire frequency range of 824-894 MHz is divided into 832 duplex channels: 824 - 849 MHz for transmission and 869 - 894 MHz for reception. Each channel is 30 kHz wide. All channels are divided into four categories: Control, For messages, Settings for access and distribution of channels, Data - voice, data or fax.
- Button - Call management
- The main disadvantage is insecurity from eavesdropping

Digital Cellular Mobil Communication

Digital Cellular Mobil Communication

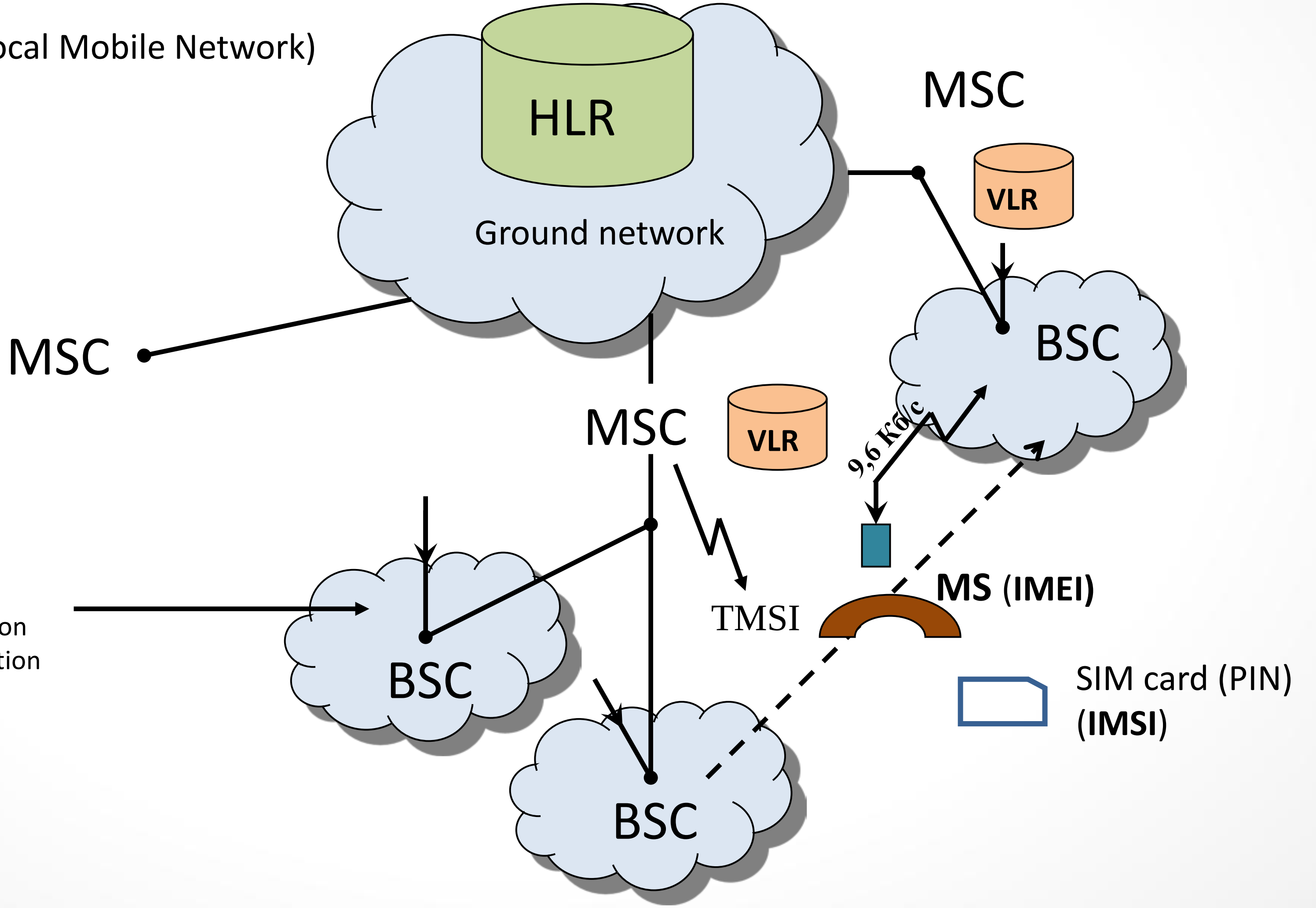
- GSM (Global System for Mobil communication)
- The main goal of the GSM standard was to provide people with the opportunity, easily moving as within a country as between countries, to communicate with any network subscribers.
- In each country there may be one or more networks in service.

1991 г. The first standard for digital cellular communications (GSM) was introduced.
1998 г. The number of mobile subscribers worldwide came over 200 million.

GSM network – General operation scheme

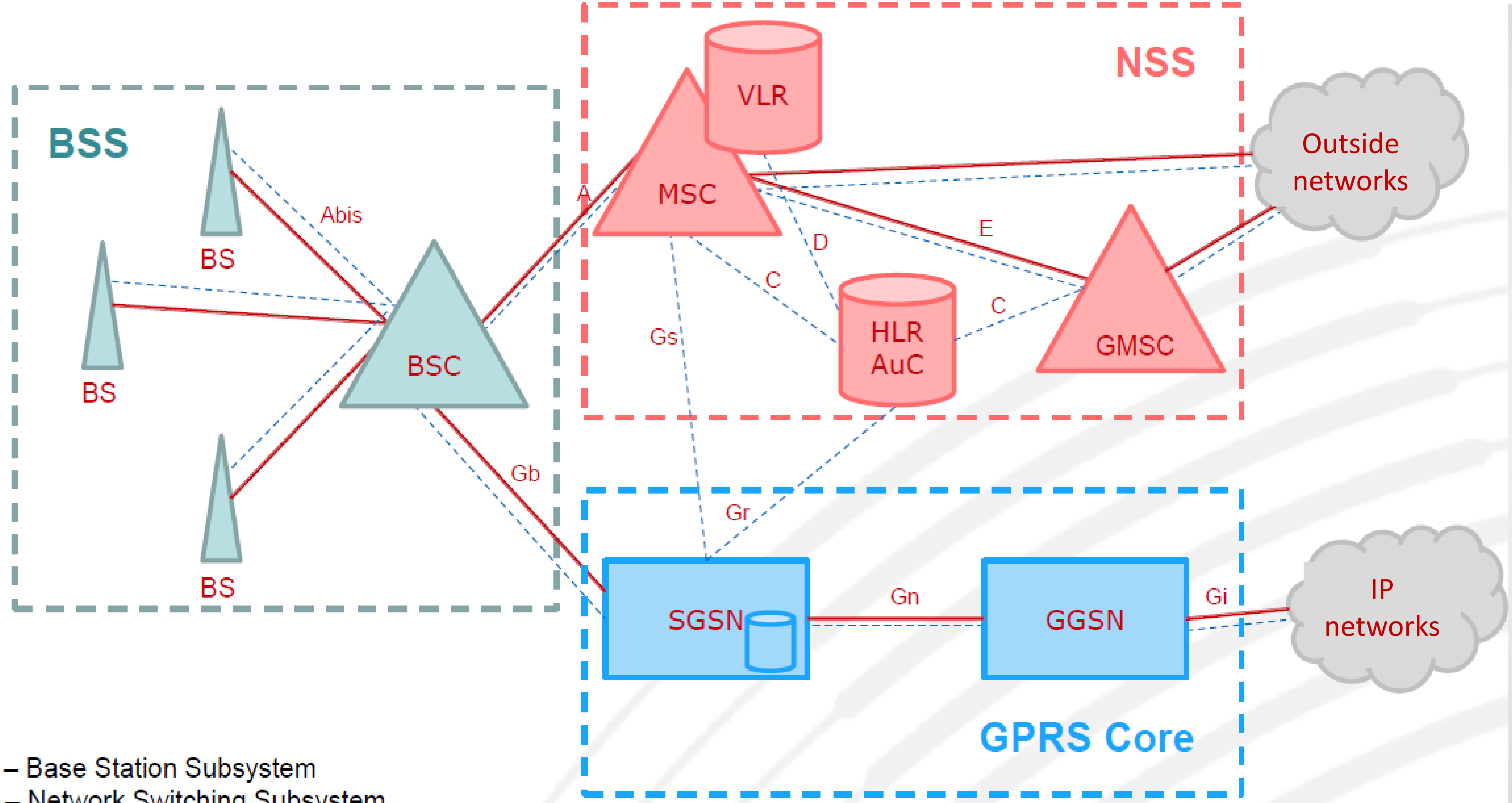
MSISDN-Mobile Subscriber ISDN, **IMSI, IMEI etc.**

PLMN
(Provider Local Mobile Network)



200 duplex channels
200 kHz channels in each direction
(124 channels – for communication
76 ones - reserve + service)

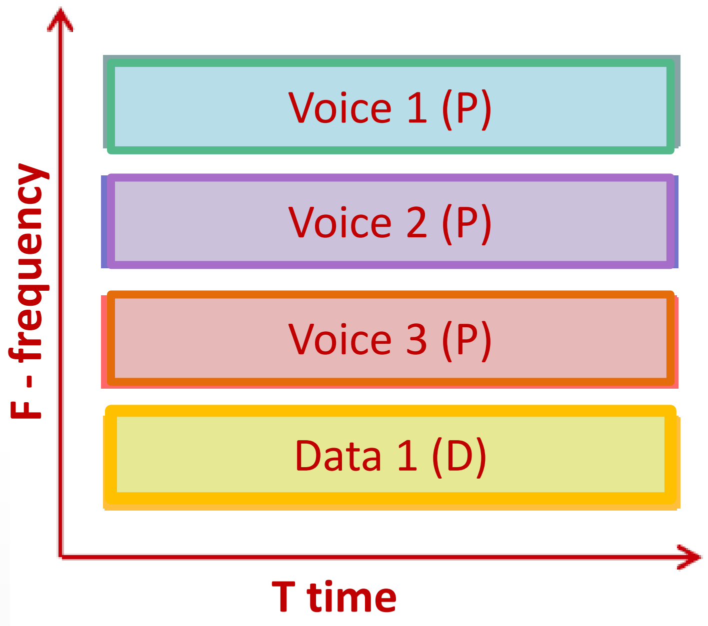
GSM (2G) – main subsystems



BSS – Base Station Subsystem
NSS – Network Switching Subsystem
GPRS Core – General Packet Radio Service Core

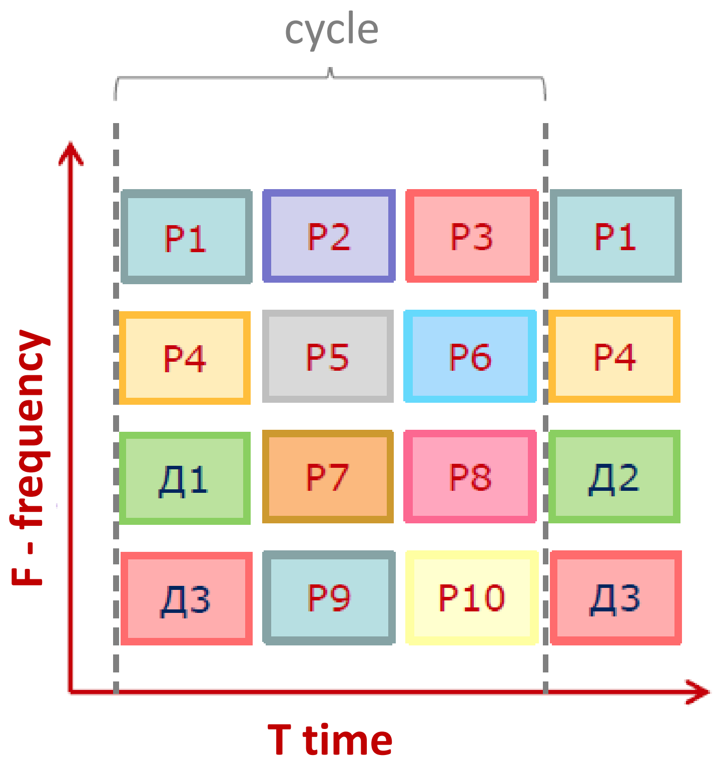
GSM - Multiplexing

FDMA
Frequency Division Multiple Access



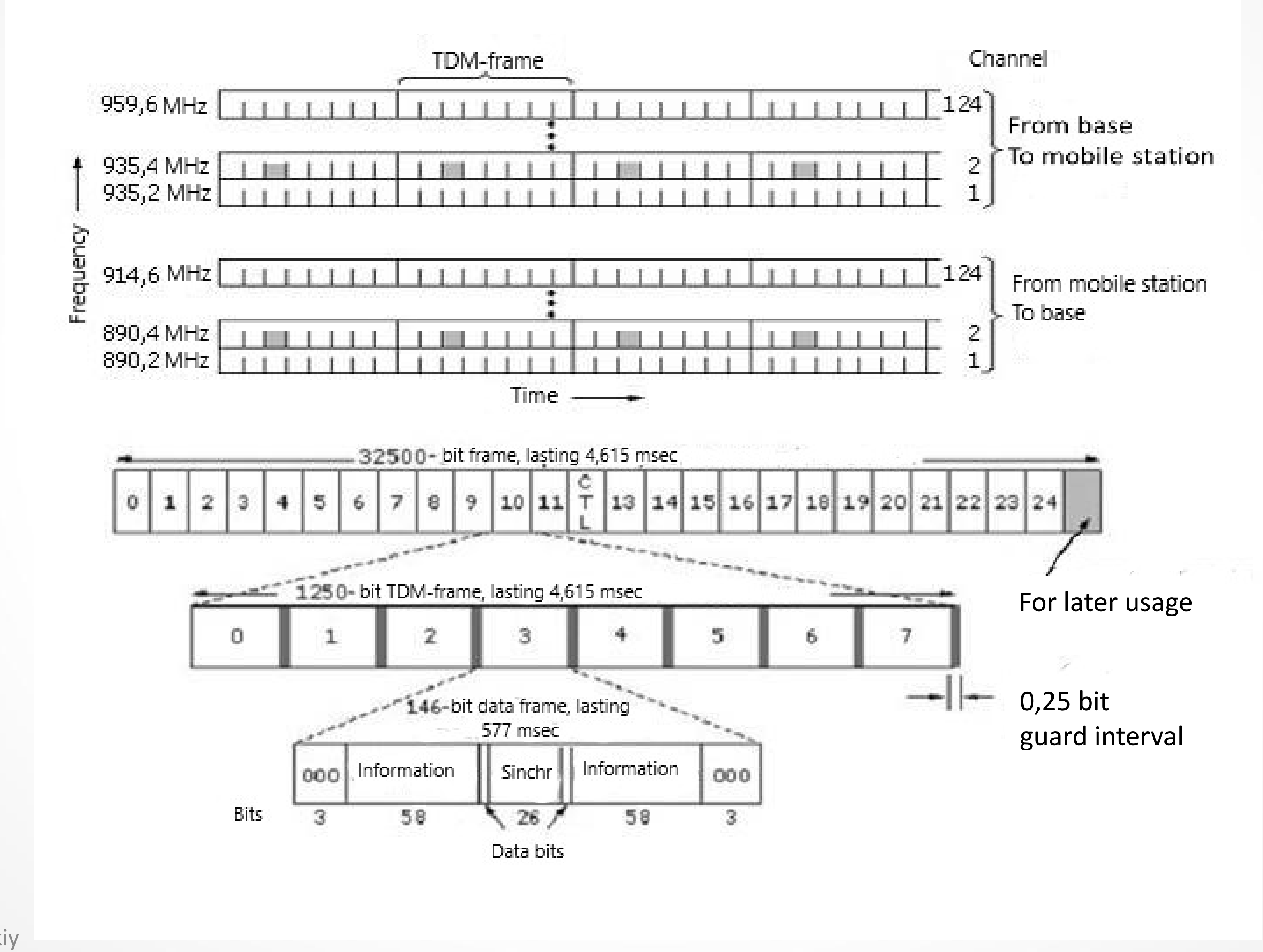
One conversation occupies the entire frequency band

TDMA
Time Division Multiple Access

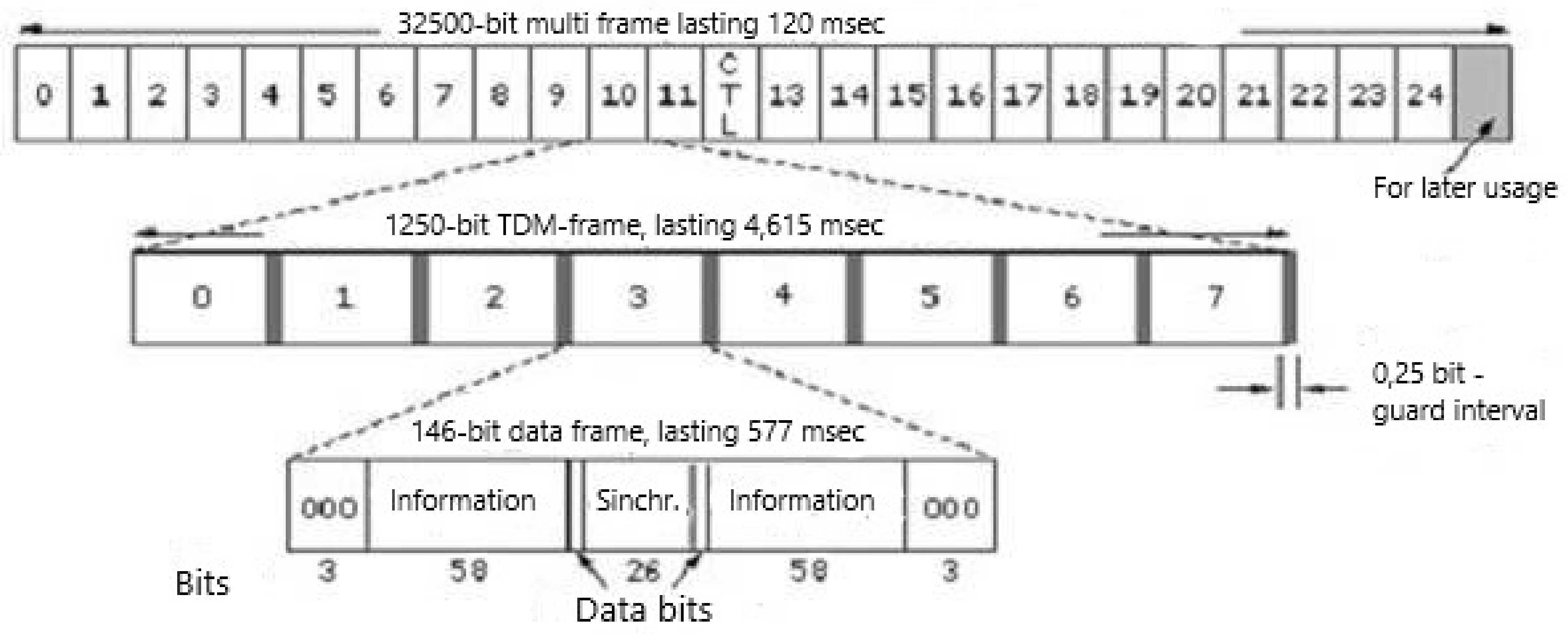


Multiplexing by dividing the frequency band into time slots

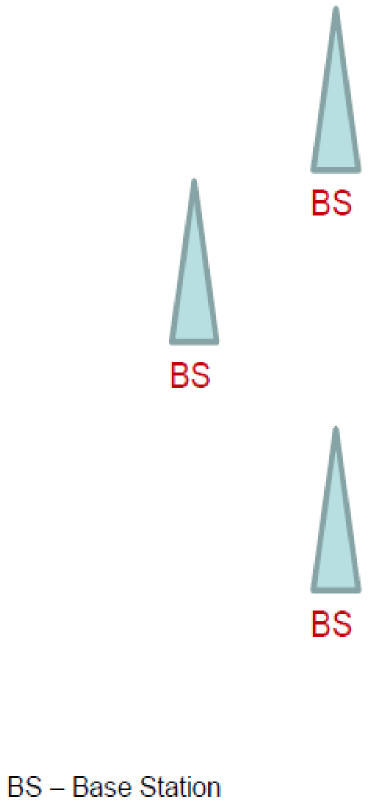
GSM – channel structure



GSM channel hierarchy

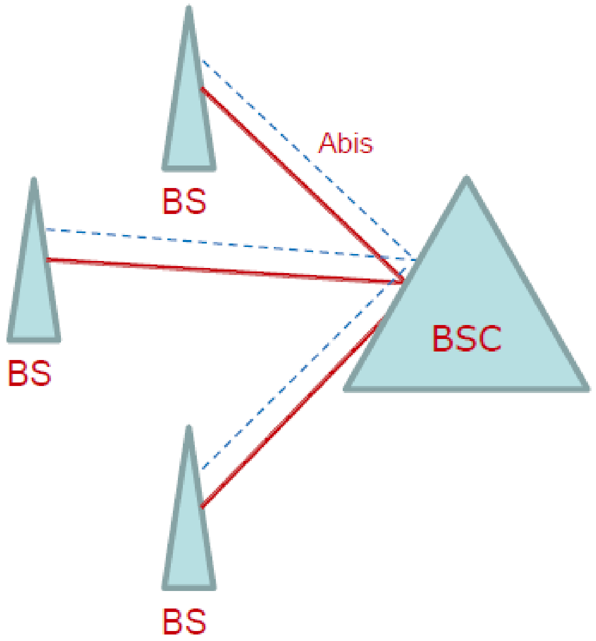


GSM – Base Station Purposes



- radio coverage development
- setting and maintaining a connection between a mobile terminal and a mobile network

GSM – Base Station Controller (BSC)



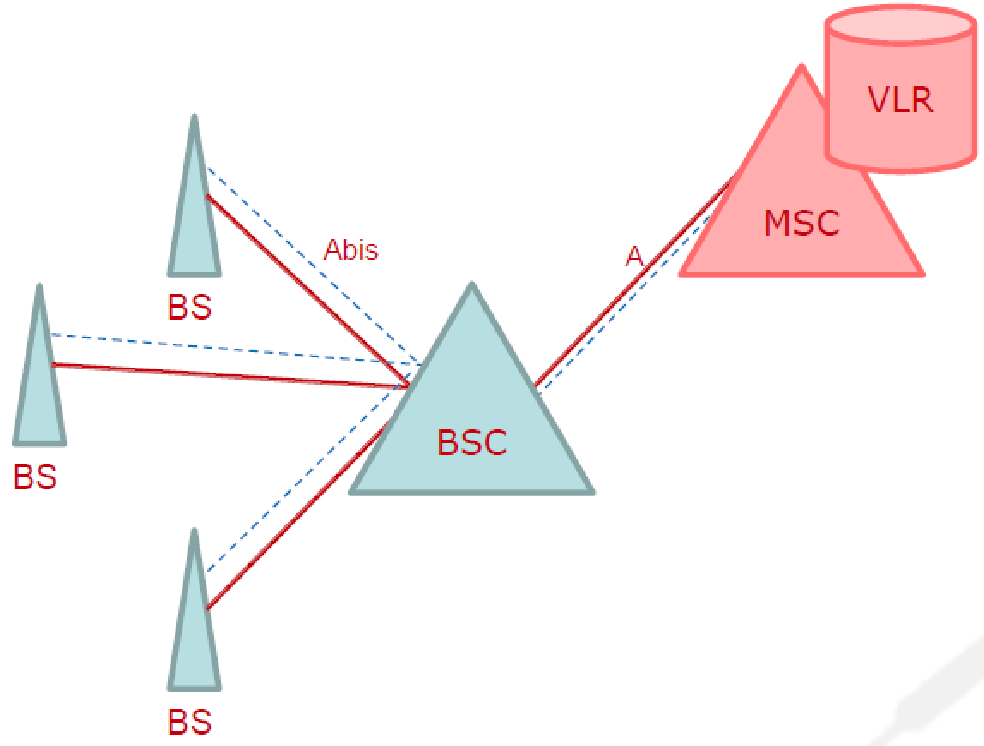
BS – Base Station
BSC – Base Station Controller

BSC functions

- radio channel management
- management of transport channels between BS and BSC
- management of transport channels between BSC and Channel Switching subsystem
- management of transport channels between BSC and Packet Switching subsystem
- management of Handover subsystem

Voice/Data
Signaling

GSM – Mobil Switching Center (MSC) and Visitors Location Register (VLR)



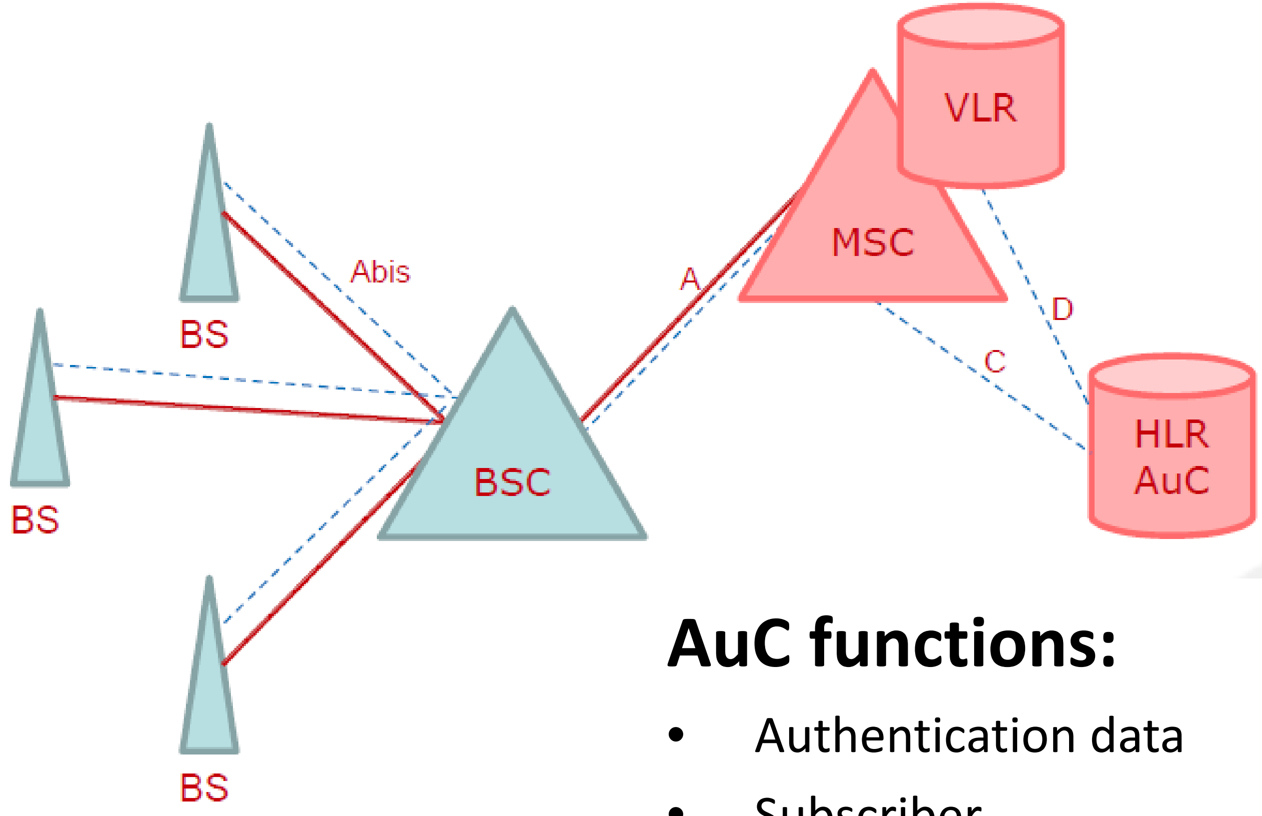
BS – Base Station
BSC – Base Station Controller
MSC – Mobile Switching Center
VLR – Visited Location Register

VLR Functions

- Storing information about active subscribers in MSC coverage area (allowed services, time, location etc.)
- Subscriber Authentication

Voice/Data
Signaling

GSM – Home Location Register (HLR) and Authentication Center (AuC)



BS – Base Station
BSC – Base Station Controller
MSC – Mobile Switching Center
VLR – Visited Location Register
AuC – Authentication Center

HLR – Home Loca

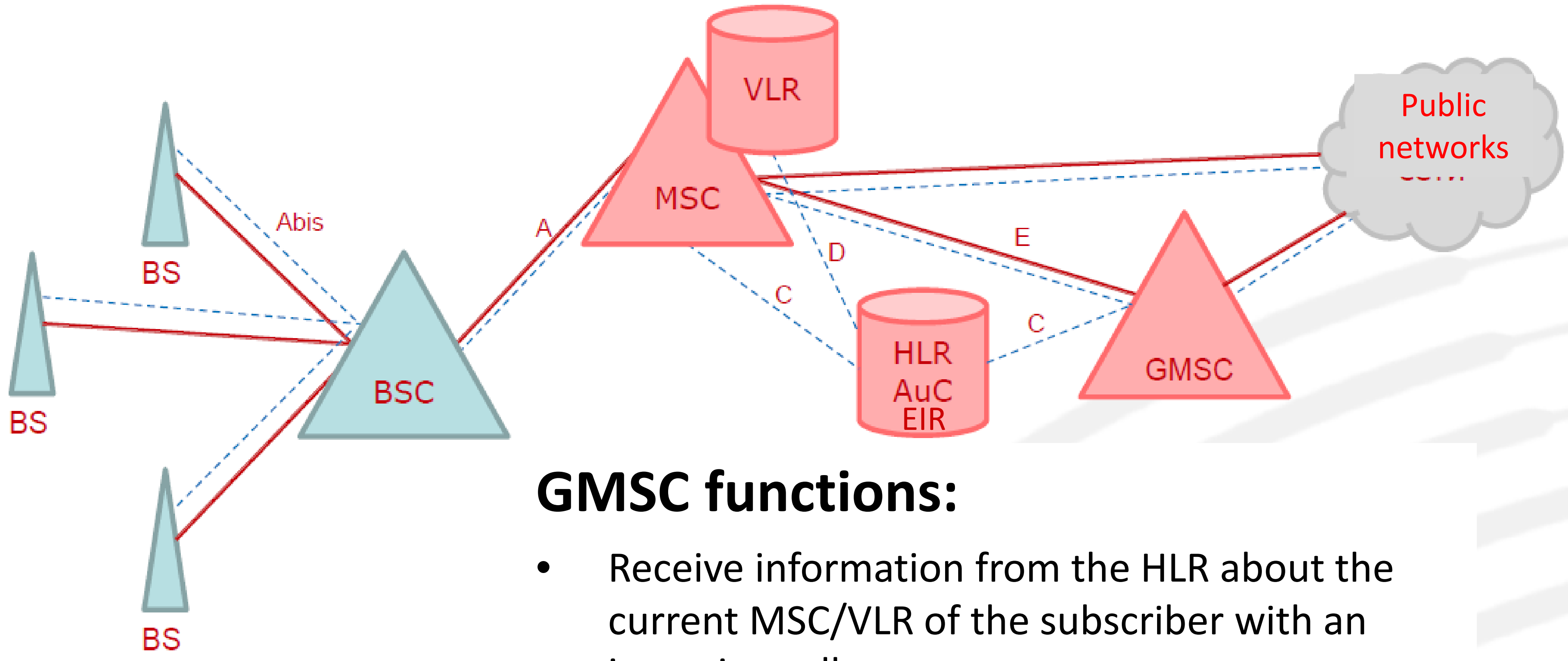
AuC functions:

- Authentication data
- Subscriber authentication support

HLR functions:

- Storing the data about all subscribers of certain network (available services, current MSC/VLR etc.)
- Supply to the caller MSC/VLR the information about the called party MSC/VLR
- Decides on the availability of services for the subscriber

GSM – Gateway Mobil Switching Center (GMSC)



GMSC functions:

- Receive information from the HLR about the current MSC/VLR of the subscriber with an incoming call
- Routing incoming calls to the appropriate MSC

BS – Base Station
BSC – Base Station Controller
MSC – Mobile Switching Center
VLR – Visited Location Register
AuC – Authentication Center
Equipment Identity Register (EIR)

HLR – Home Location Register
GMSC – Gateway MSC

Voice/Data
Signaling

GSM – GPRS service

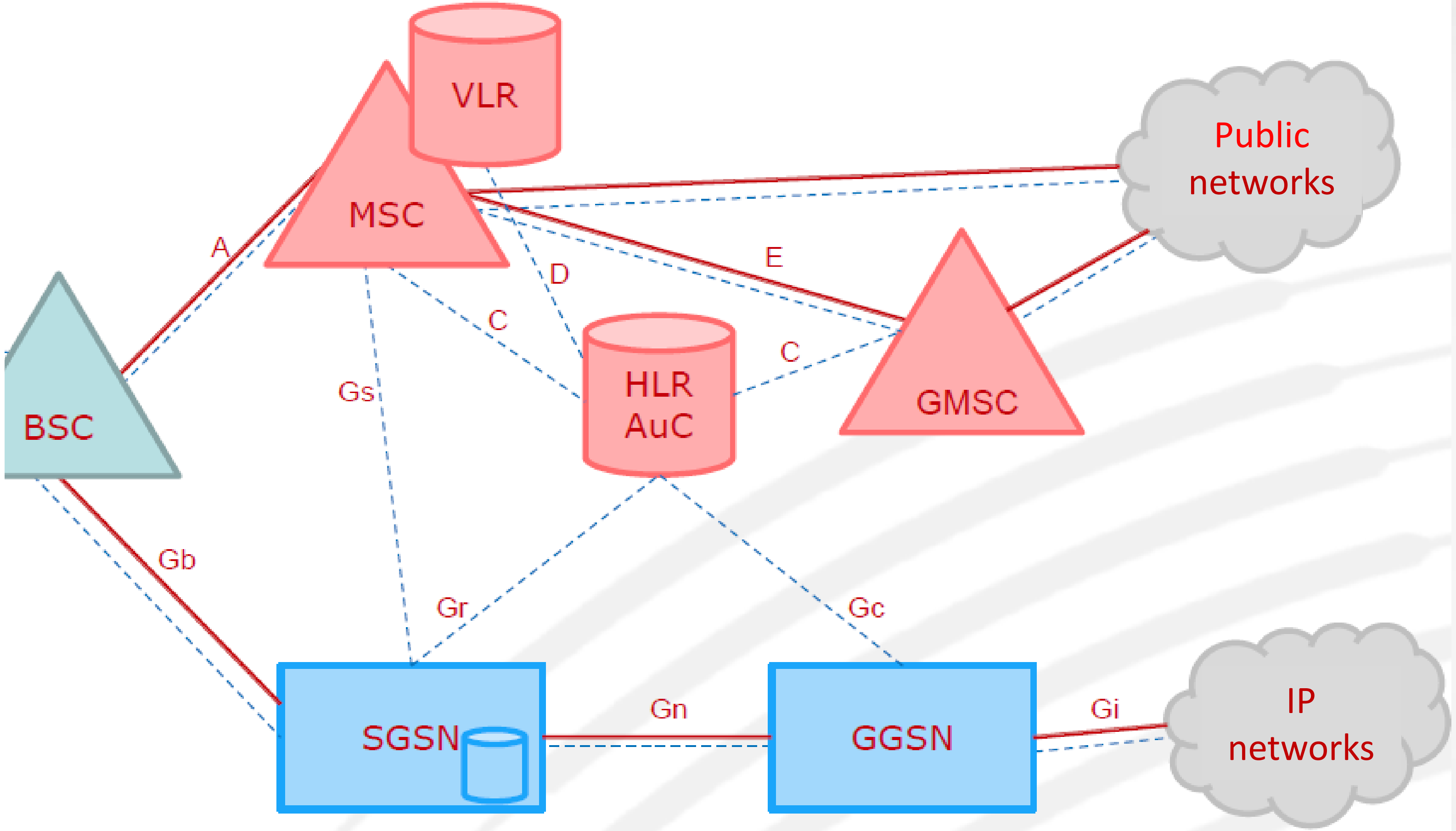
GPRS (General Packet Radio Service) is a packet data service over the air.

- speed increase (maximum in 2G was 48 Kbps),
- when using the GPRS service, the payment are made in proportion to the amount of transmitted data, not the channel usage time.
- "packets" of data are transmitted simultaneously via many channels only in pauses - voice traffic has absolute priority over data.

GSM GPRS – SGSN/GGSN Functions

GGSN functions:

- Gateway to the outside networks
- Dynamic IP-addresses assigning
- Request generation to the RADIUS server
- Storing the DB of routing< addresses and filters information

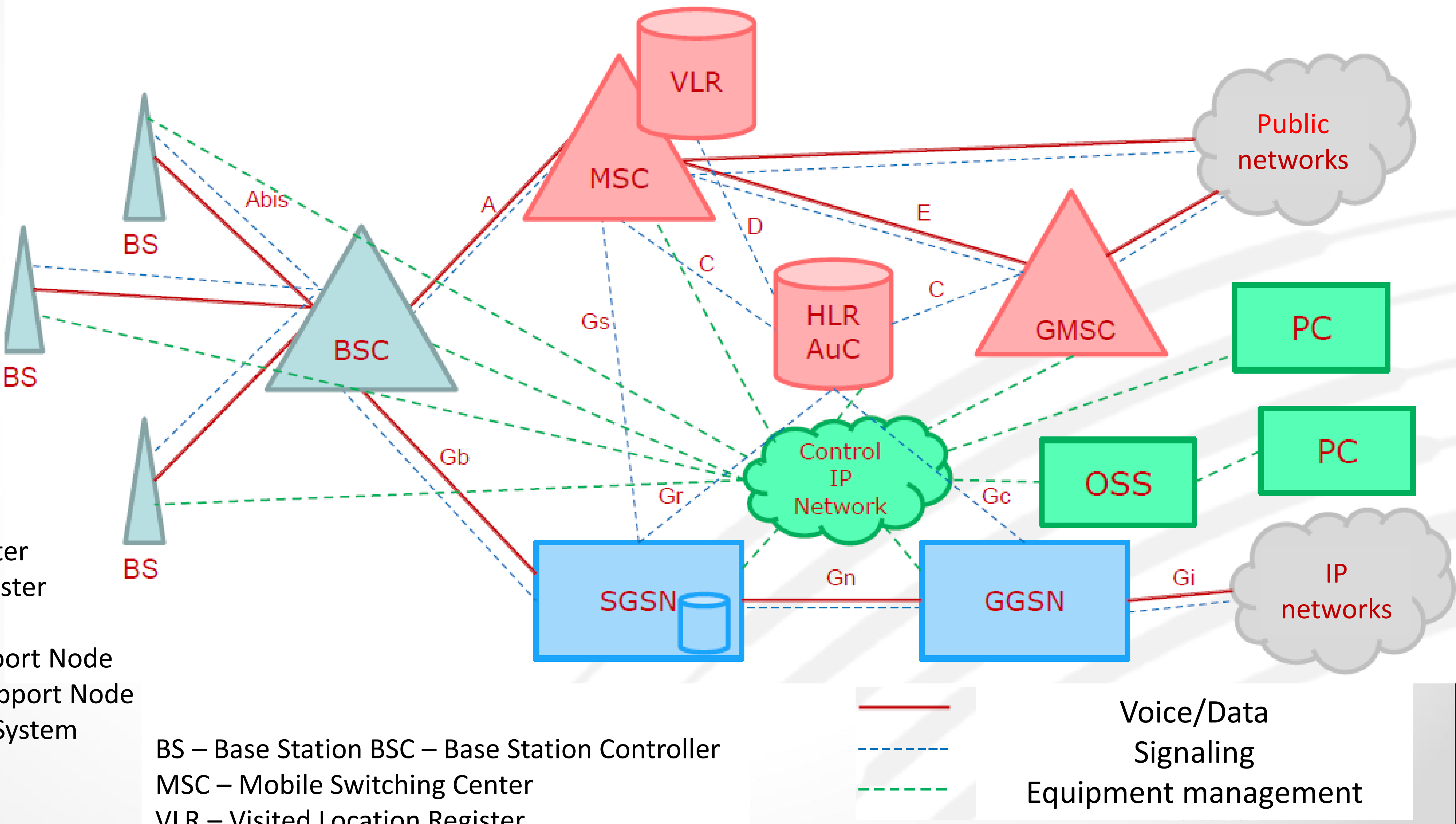


BS – Base Station
BSC – Base Station Controller
MSC – Mobile Switching Center
VLR – Visited Location Register
AuC – Authentication Center

HLR – Home Location Register
GMSC – Gateway MSC
SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node

Voice/Data
Signaling

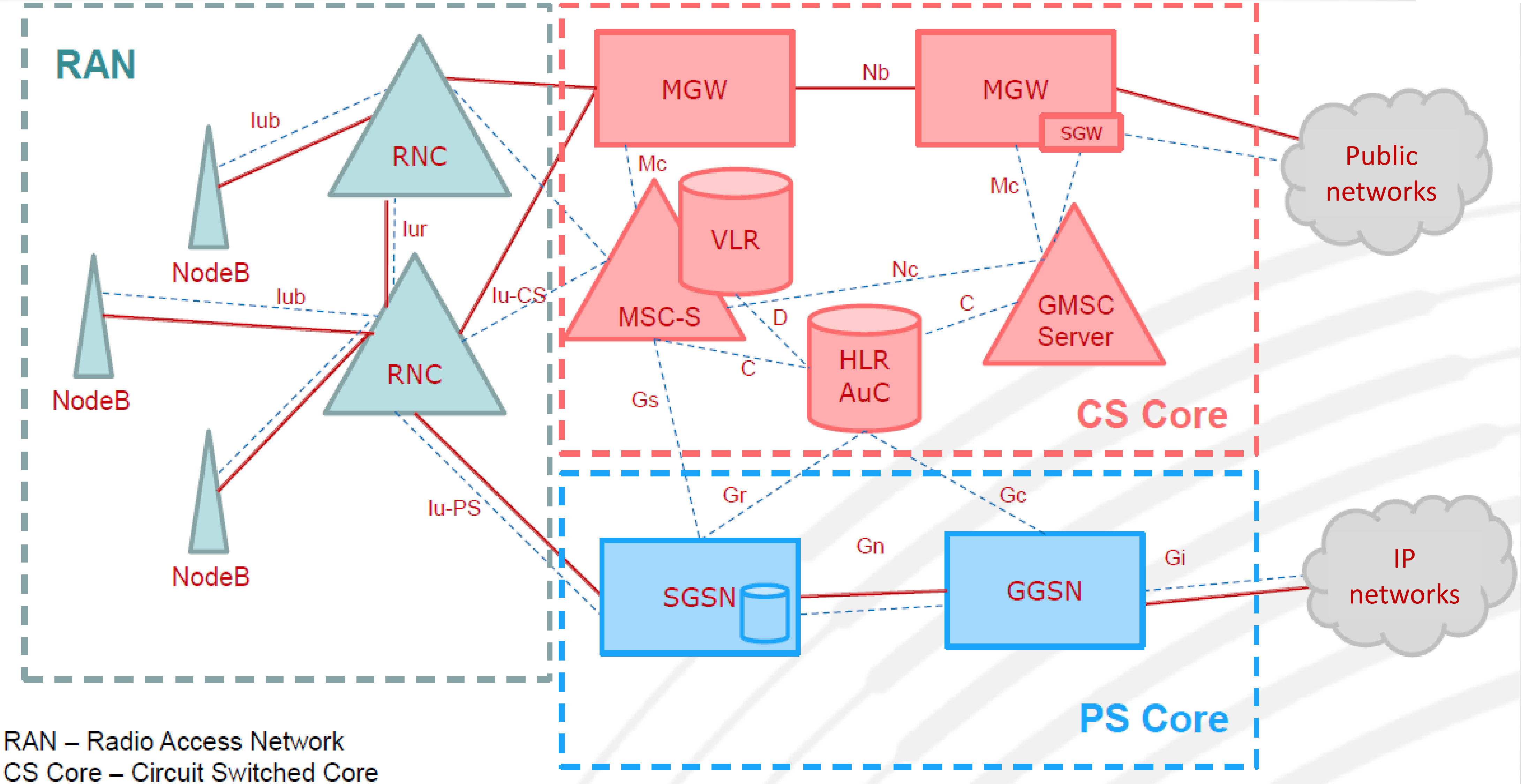
GSM – Control Support Subsystem



AuC – Authentication Center
HLR – Home Location Register
GMSC – Gateway MSC
SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node
OSS – Operation Support System

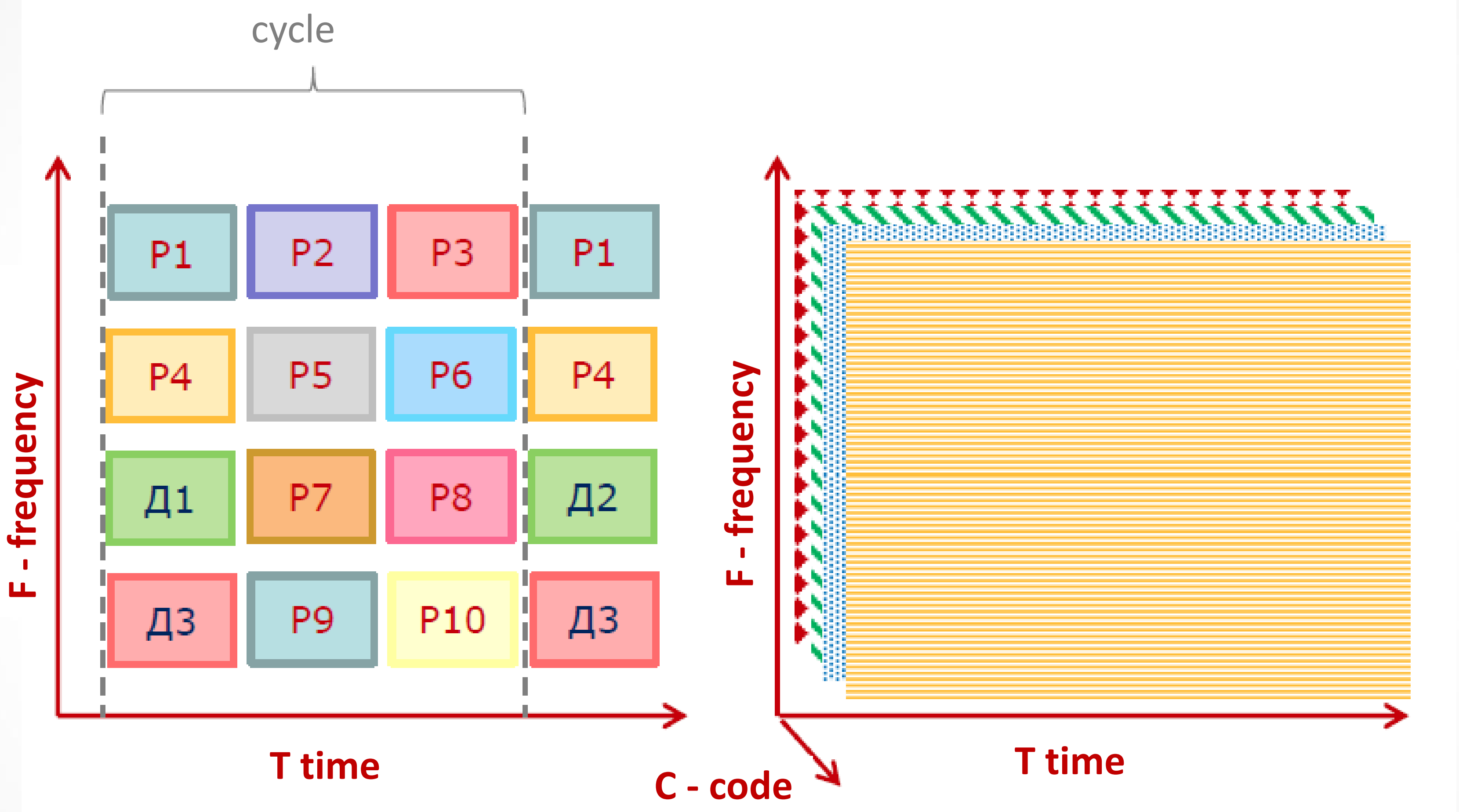
BS – Base Station BSC – Base Station Controller
MSC – Mobile Switching Center
VLR – Visited Location Register

3G (UMTS) – subsystems



RAN – Radio Access Network
CS Core – Circuit Switched Core
PS Core – Packet Switched Core

UMTS – modulation methods



TDMA Time Division Multiple Access

CDMA Code Division Multiple Access

Division of radio channels due to orthogonal codes is a resource that has no limit.

Walsh functions

$$wal_0(\theta) \equiv 1; \quad wal_i(\theta) = \prod^{n} [r_j(\theta)]^{i_j^{\Gamma}},$$ where

$$r_0(\theta) \equiv 1, \quad r_i(\theta) = \text{sign}[\sin(2^i \pi \theta)], \quad i = 1, 2, \ldots$$

where ***Θ = t/T*** **and** ***T*** **– function period,** ***0< Θ <1,*** r_i***(Θ) Rademacher function, signx*** **denotes**

$$\text{sign}x = \begin{cases} 1 & \textbf{when } x > 0, \\ -1 & \textbf{when } x < 0. \end{cases}$$

Gray code for *i* number $\quad i = a_n\, a_{n-1} \ldots a_2\, a_1,$

has a representation

$$i = b_n\, b_{n-1} \ldots b_2\, b_1,$$

where $b_1 = a_1 \oplus a_2,\ b_2 = a_2 \oplus a_3, \ldots, b_{n-1} = a_{n-1} \oplus a_n,\ b_n = a_n;$

$\oplus$ - summation modulo 2 $\quad (0 \oplus 0=0;\ 0 \oplus 1=1;\ 1 \oplus 0=1;\ 1 \oplus 1=0).$

Properties of Walsh Functions

1. Walsh functions are orthogonal and normalized

$$\int_0^1 wal_i(\theta)\, wal_j(\theta)\, d\theta = \begin{cases} 1 & \textbf{when } i = j, \\ 0 & \textbf{when } i \neq j. \end{cases}$$

2. The average value of the Walsh functions for all $i \neq 0$ **is 0**

$$\int_0^1 wal_i(\theta)\, d\theta = 0, \quad i = 1, 2, \ldots, N-1.$$

3. The product of two Walsh functions is the Walsh function

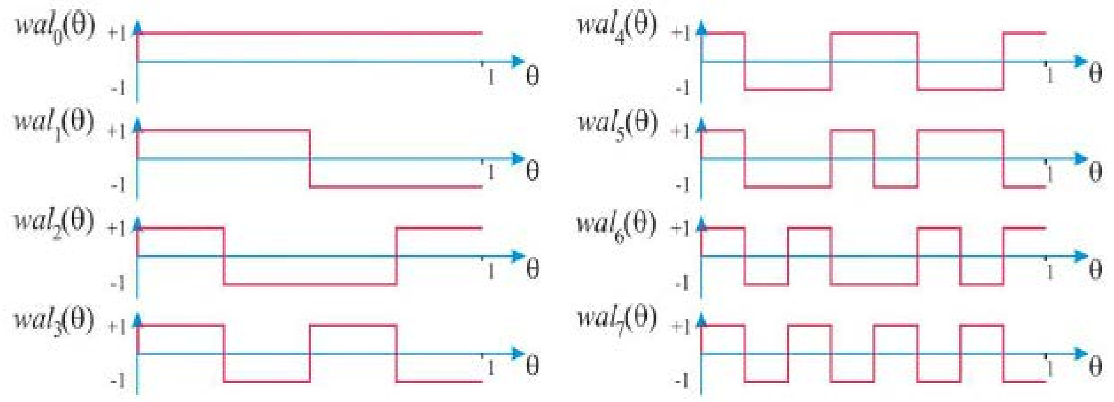
$$wal_i(\theta) \oplus wal_j(\theta) = wal_k(\theta),$$

where $k = i \oplus j$, $\oplus$ – **modulo two bitwise summation symbol** $1 \oplus 1 = 0$, $1 \oplus 0 = 1$, $0 \oplus 1 = 1$, $0 \oplus 0 = 0$.

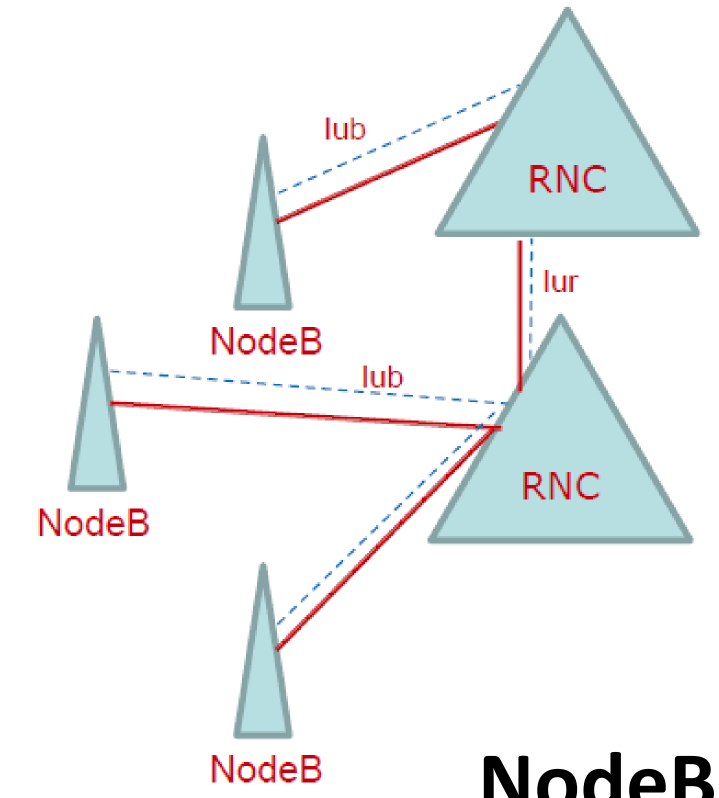
4. Even relative to the middle of the interval $(\theta = 0.5)$ **functions correspond to even values *i*, and vice versa**

Expansion in the Walsh functions

Function number	Binary representation number i	Gray code for number i	Walsh function representation
0	000	000	$wal_0(\theta) = 1$
1	001	001	$wal_1(\theta) = r_1(\theta)$
2	010	011	$wal_2(\theta) = r_1(\theta) r_2(\theta)$
3	011	010	$wal_3(\theta) = r_2(\theta)$
4	100	110	$wal_4(\theta) = r_2(\theta) r_3(\theta)$
5	101	111	$wal_5(\theta) = r_1(\theta) r_2(\theta) r_3(\theta)$
6	110	101	$wal_6(\theta) = r_1(\theta) r_3(\theta)$
7	111	100	$wal_7(\theta) = r_3(\theta)$



UMTS – Radio Network Controller (RNC)



NodeB – 3G Base Station
RNC – Radio Network Controller

Voice/Data
Signaling

RNC Functions:

- Radio Channel Management
- Managing transport channels between NodeB and RNC
- Managing transport channels between NodeB and Core Network
- Manage seamless connection transfer between NodeB during a conversation or Internet session

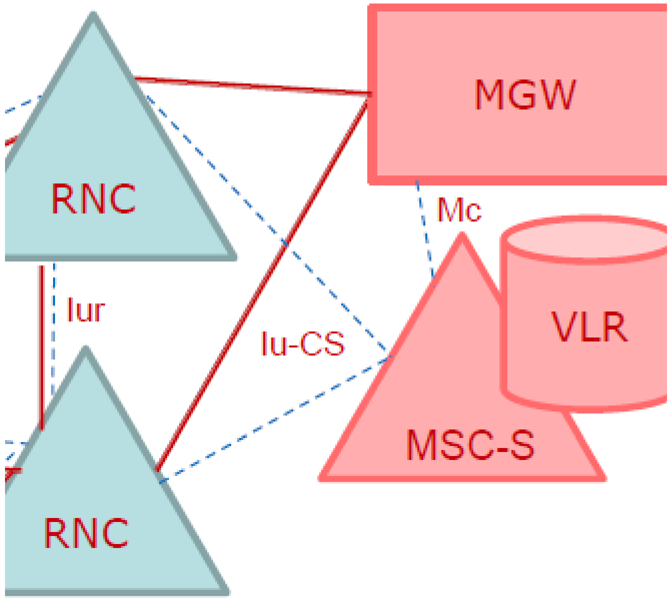
NodeB Functions:

- Radio coverage
- Setting and support of the connection between the mobile terminal and mobile communication system

UMTS – Distributed Switching Center

VLR Functions

- Storing information about active subscribers in MSC-S coverage area (allowed services, time, location etc.)
- Subscriber Authentication



Voice/Data
Signaling

NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay

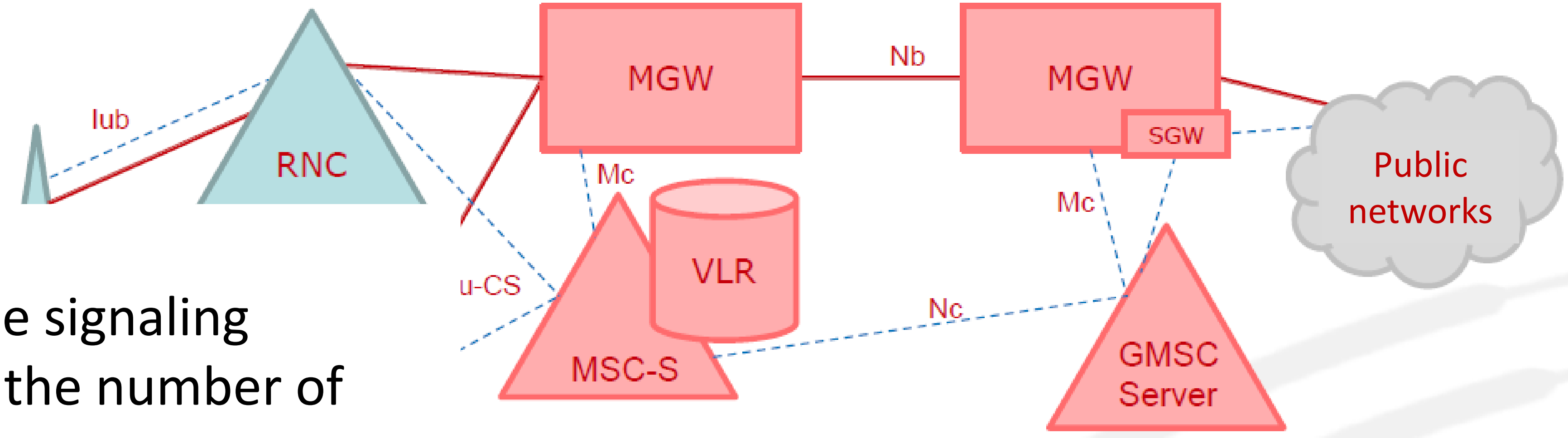
MSC-Server Functions:

- Signaling and Connection settings
- Managing Media Gateway (MGW)
- Handover Managing between RNCs, MSCs
- Signaling conversions between two telecommunication systems

MGM Functions:

- Voice channels under MSC-S management

UMTS – Distributed Mobil Switching Center



SGW Functions:

- Transparent routing the signaling information to reduce the number of external connections
- Converts signaling between two telecommunications systems

NodeB

NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay
GMSC – Gateway MSC

SGW – Signaling GateWay

Voice/Data
Signaling

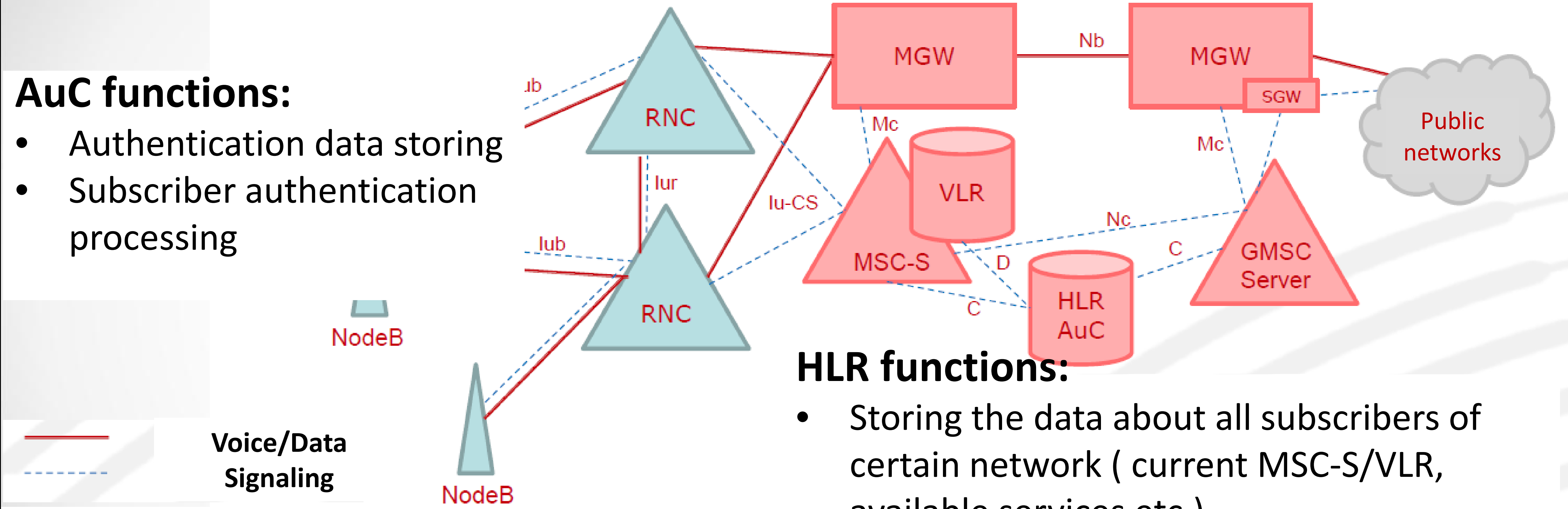
GMSC-Server Functions:

- Getting from the HLR information about the current user MSC-S/VLR of an incoming call
- Routing incoming calls to the appropriate MSC-Server
- Media Gateway management (MGW)

UMTS – Subscribers Home Register (HLR) and Authentication Center (AuC)

AuC functions:

- Authentication data storing
- Subscriber authentication processing

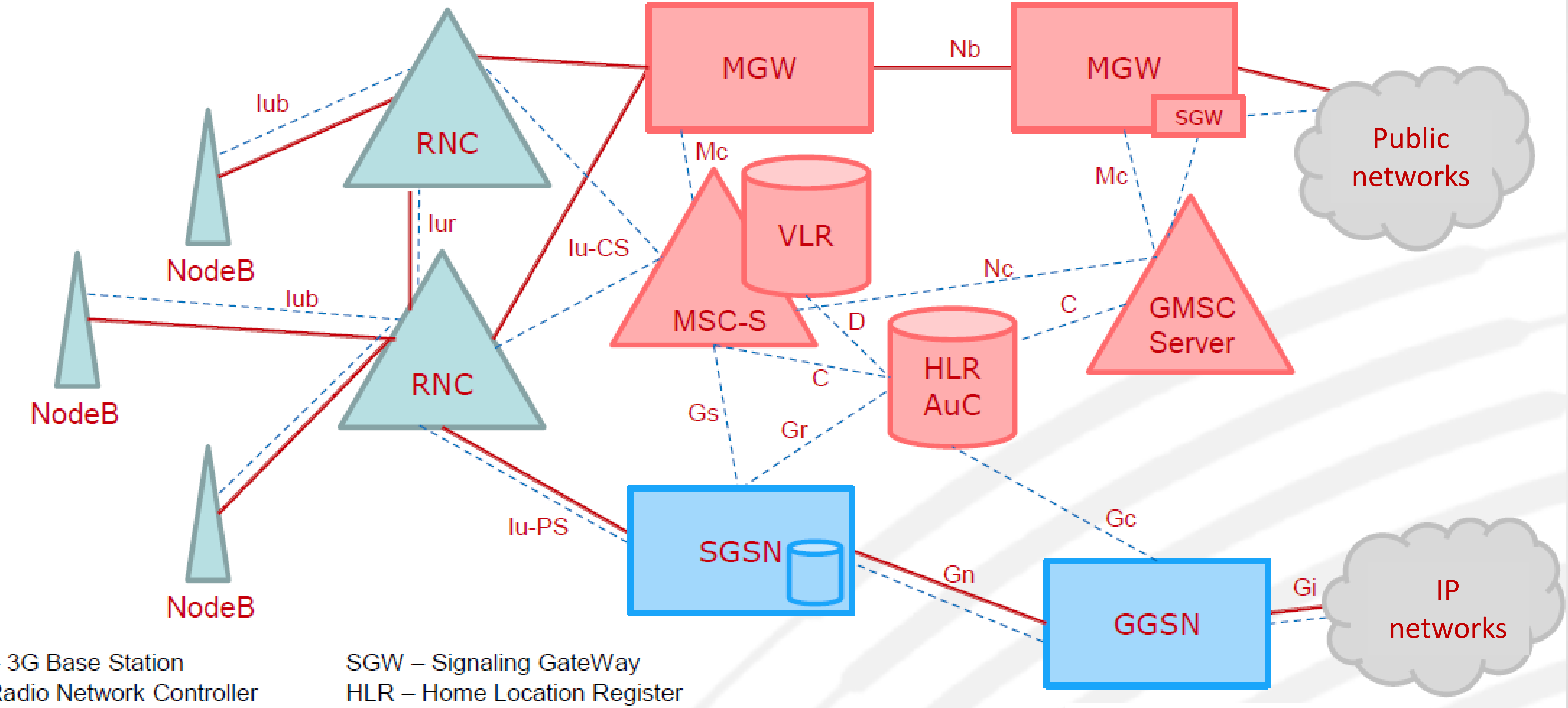


NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay
GMSC – Gateway MSC
SGW – Signaling GateWay
HLR – Home Location Register
AuC – Authentication Center

HLR functions:

- Storing the data about all subscribers of certain network (current MSC-S/VLR, available services etc.)
- Supply the information about current MSC-S/VLR of the called party to the caller
- Decides on the availability of services for the subscriber

UMTS – Packet Switching Subsystem



NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay
GMSC – Gateway MSC

SGW – Signaling GateWay
HLR – Home Location Register
AuC – Authentication Center
SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node

Voice/Data
Signaling

UMTS – Packet Switching Subsystem

SGSN Functions:

- Packets routing between BS network and outside networks
- Video communication routing
- Mobility of subscribers during package services (Internet, MMC, video)
- Subscriber authentication support
- Subscriber registration for GPRS services
- Processing of primary billing information and its transfer to the billing center

GGSN Functions:

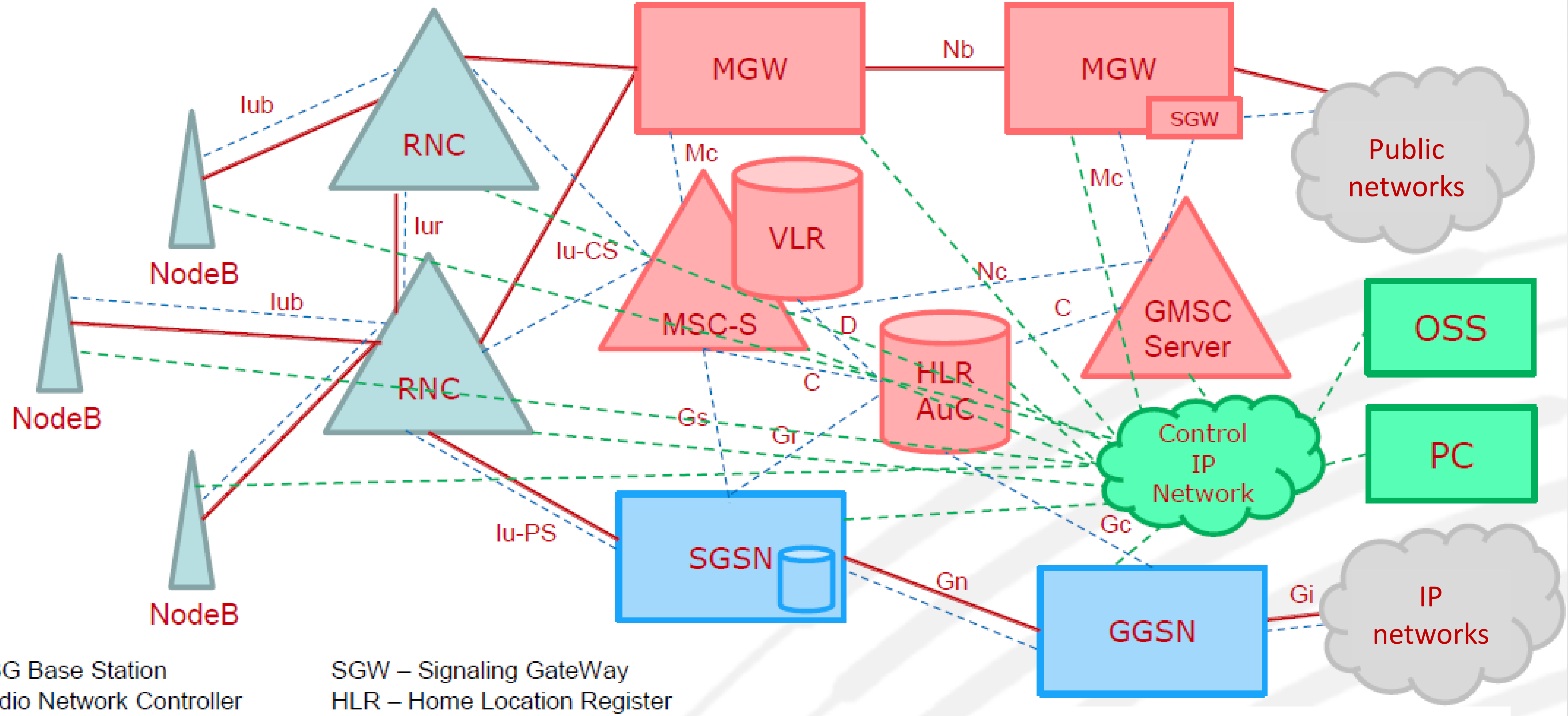
- Gateway to outside networks
- Dynamic assigning of IP addresses
- Authentication support by request to RADIUS server
- Routing DB support
- Routing incoming video calls to the appropriate SGSN
- Receive from the HLR information about the current SGSN of the subscriber with an incoming video call

NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay
GMSC – Gateway MSC

SGW – Signaling GateWay
HLR – Home Location Register
AuC – Authentication Center
SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node

Voice/Data
Signaling

UMTS – Network Control and Management

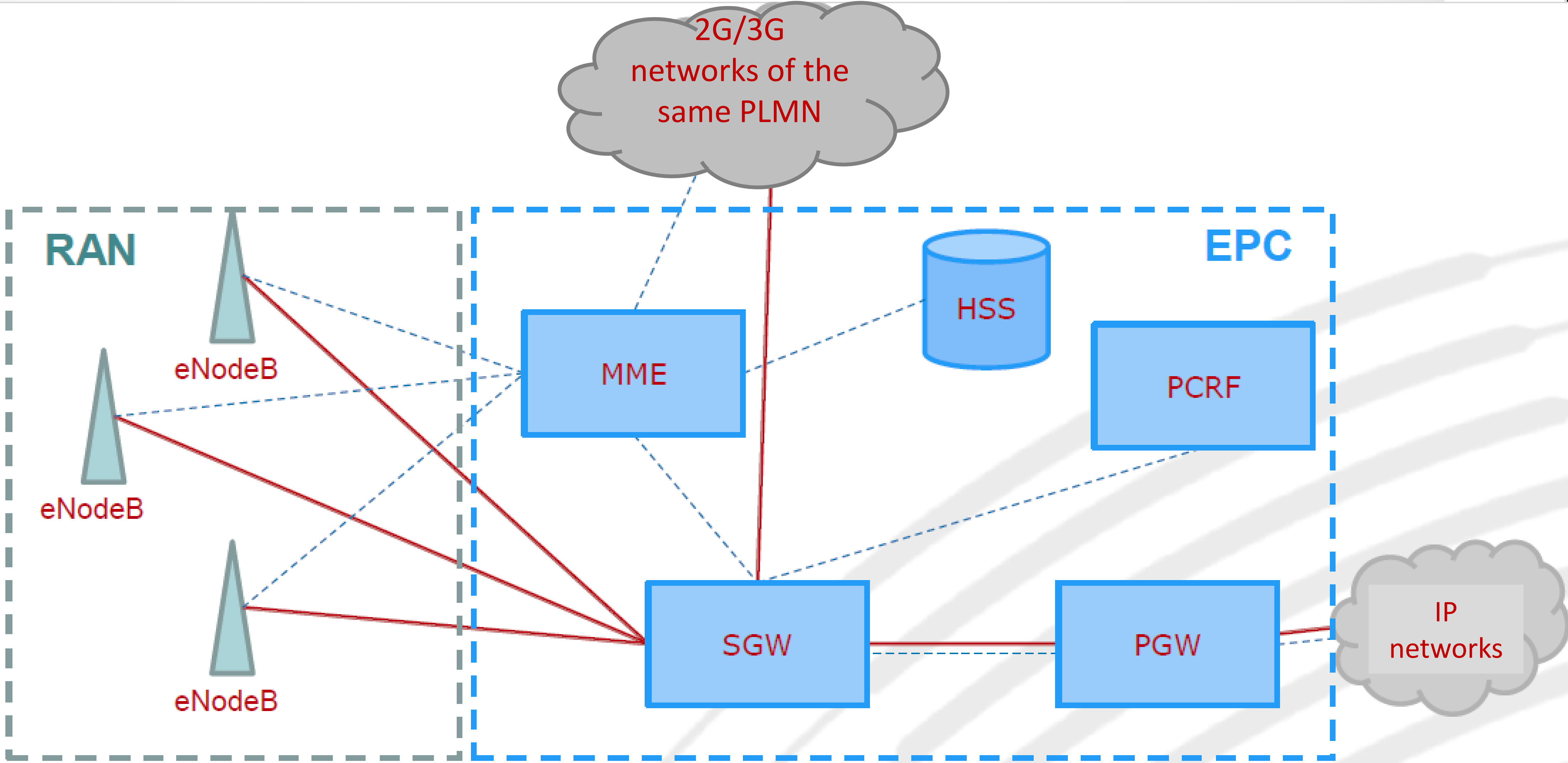


NodeB – 3G Base Station
RNC – Radio Network Controller
MSC-S – MSC Server
VLR – Visited Location Register
MGW – Media GateWay
GMSC – Gateway MSC

SGW – Signaling GateWay
HLR – Home Location Register
AuC – Authentication Center
SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node
OSS – Operation Support System

Voice/Data
Signaling
Equipment management

LTE – main subsystems

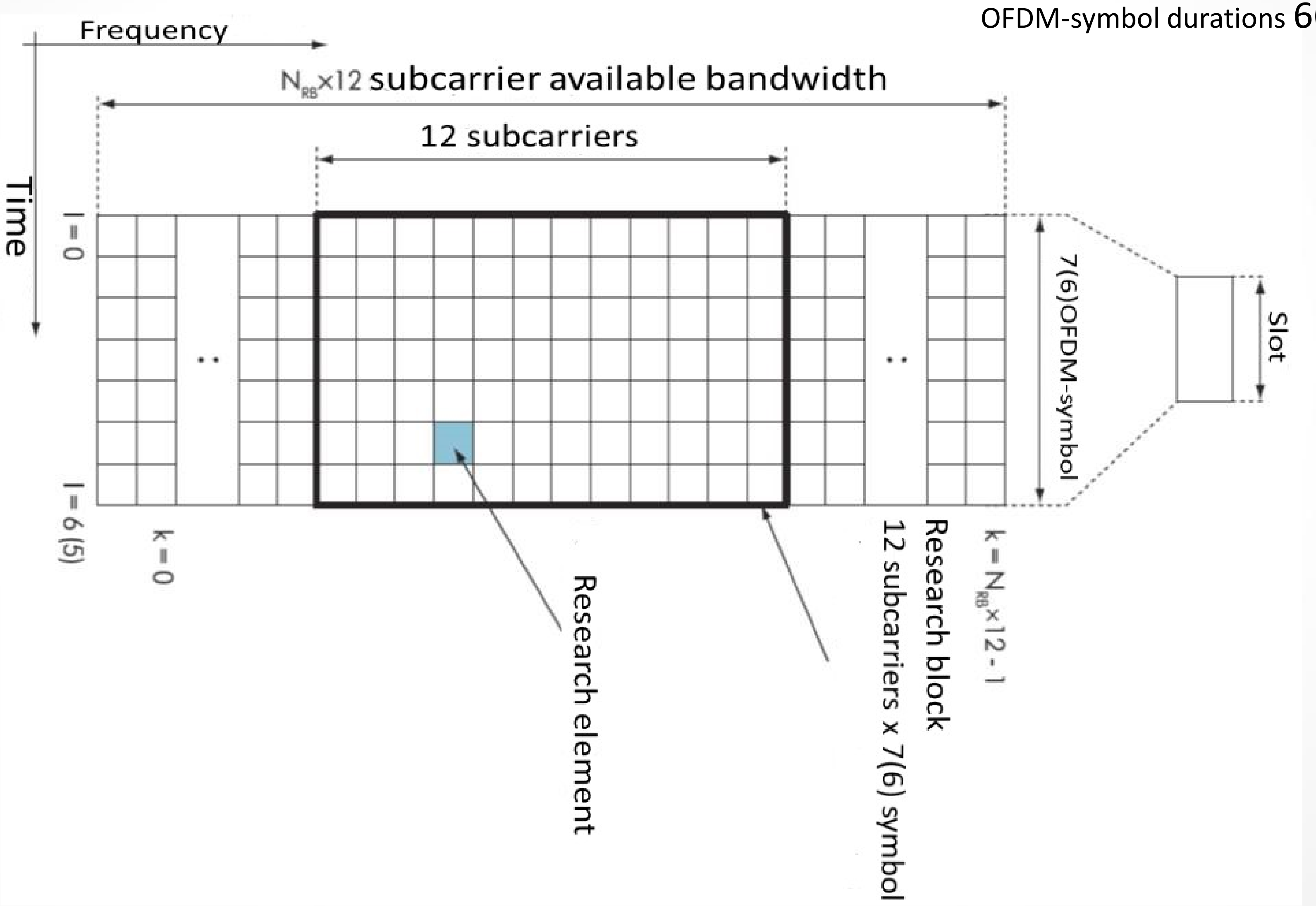


RAN – Radio Access Network
EPC – Evolved Packet Core

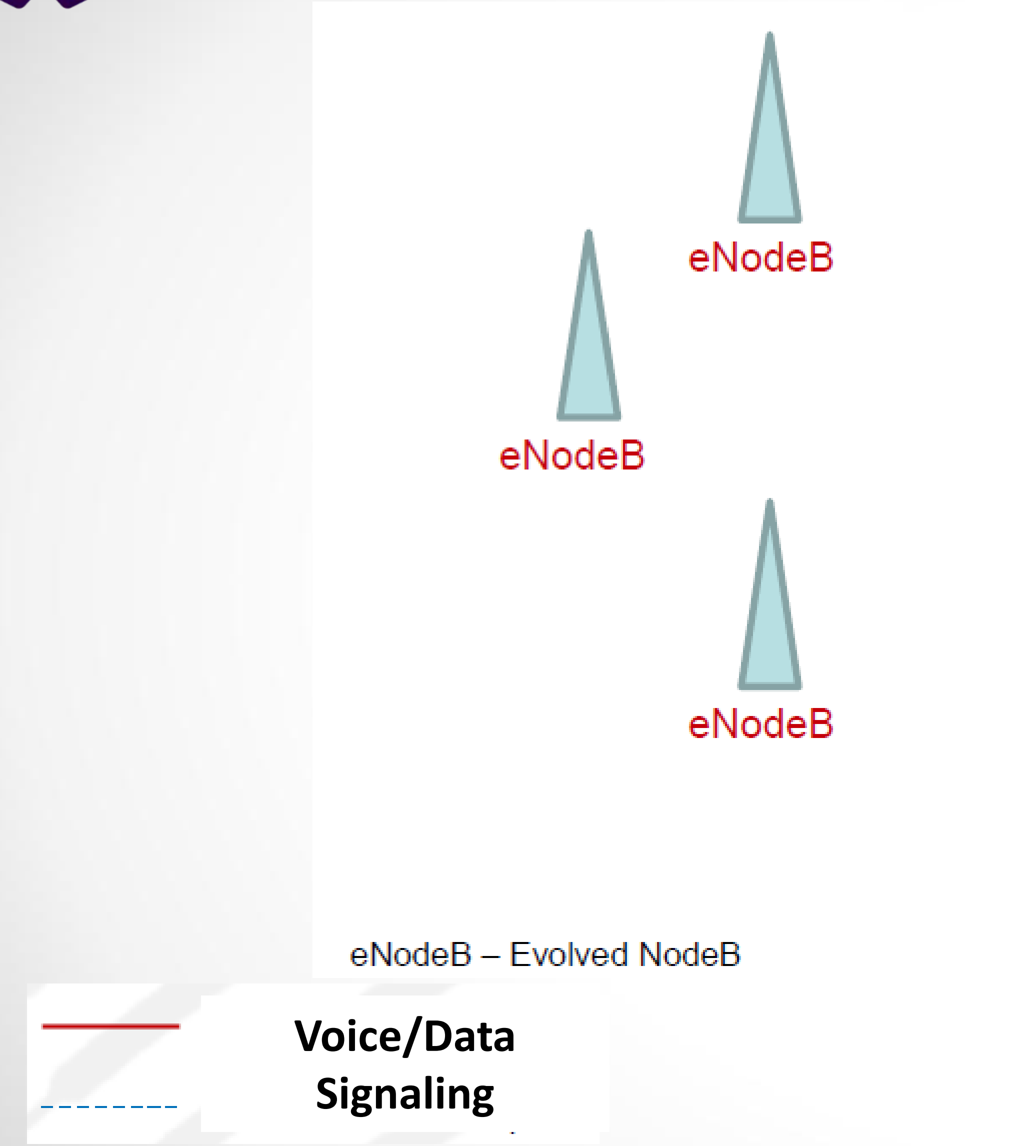
All subsystems communicate via IP network

LTE – Resource plane
(step between subcarriers Δf = 15 кHz)

OFDM-symbol durations 66,7 mks



LTE – eNodeB Base station



eNodeB Functions:

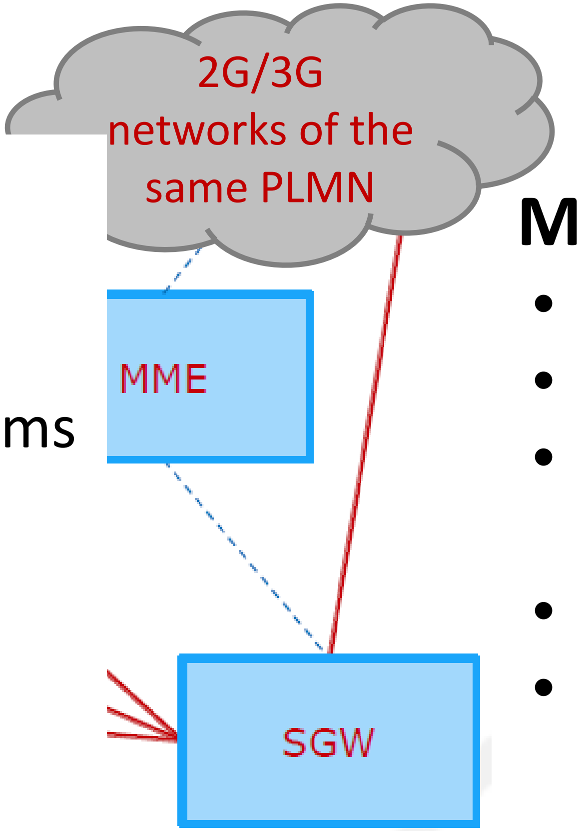
- Providing radio coverage.
- Setting up a connection between the mobile device and the mobile communication system.
- Management of radio channels.
- Management of transport channels between eNodeB and Core.
- Seamless transfer of the connection between the eNodeBs during a conversation or Internet session.

All subsystems communicate via IP network

LTE – Routing (SGW) and Mobility Management (MME)

SGW Functions:

- Packet Traffic Routing
- Handover between eNode
- Handover between access systems
- Collection of primary billing information and its transfer to PCRF



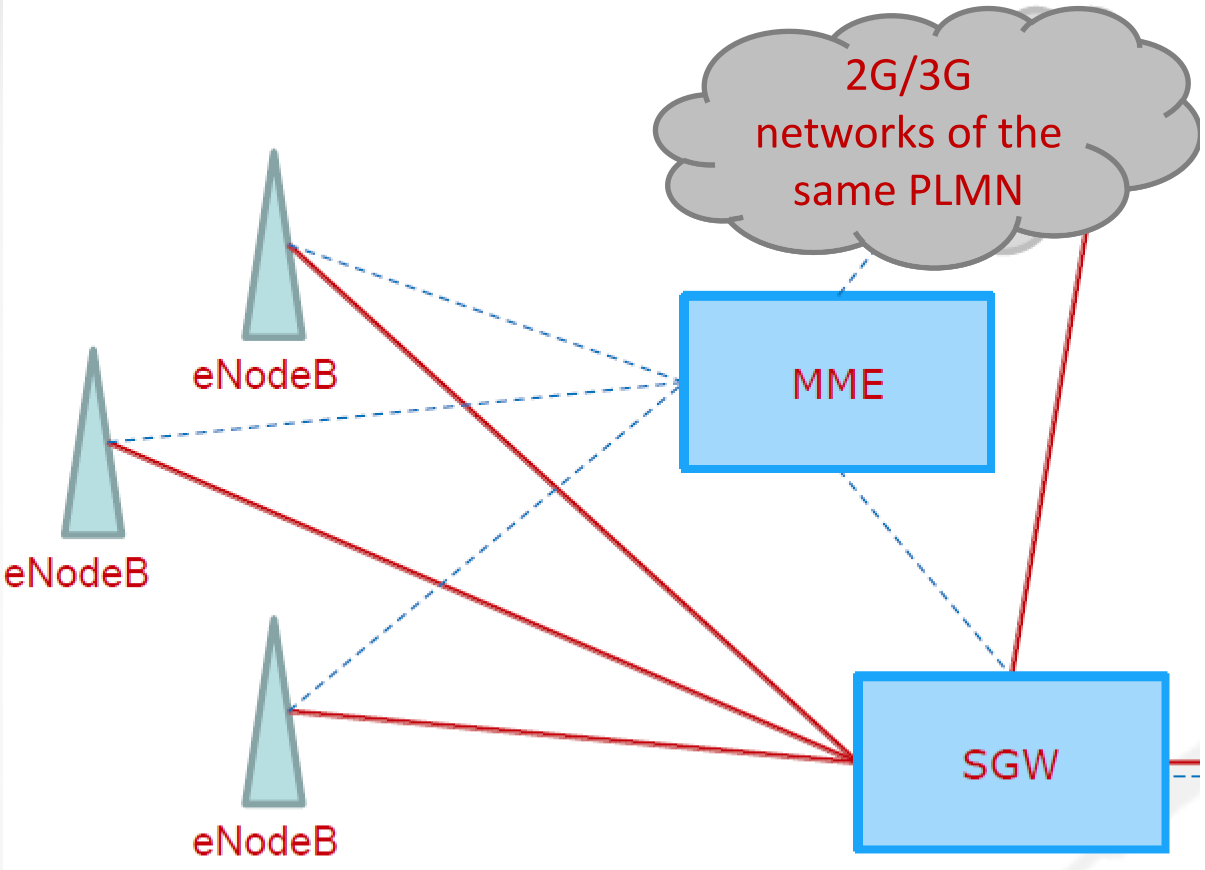
MME Functions:

- Management of subscriber mobility.
- Signaling processing.
- Handover management between access systems.
- Authentication.
- Selection of SGW and PGW.

Voice/Data
Signaling

All subsystems communicate via IP network

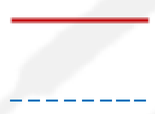
LTE – Gateway to Public Networks (PGW)



PGW Functions:

- Packet Traffic Routing to public networks
- Packets assigning to the subscribers
- IP addresses assigning to mobile terminals
- Bandwidth connection management

eNodeB – Evolved NodeB
MME – Mobility Management Entity
SGW – Serving GateWay
PGW – Public Data Network GateWay

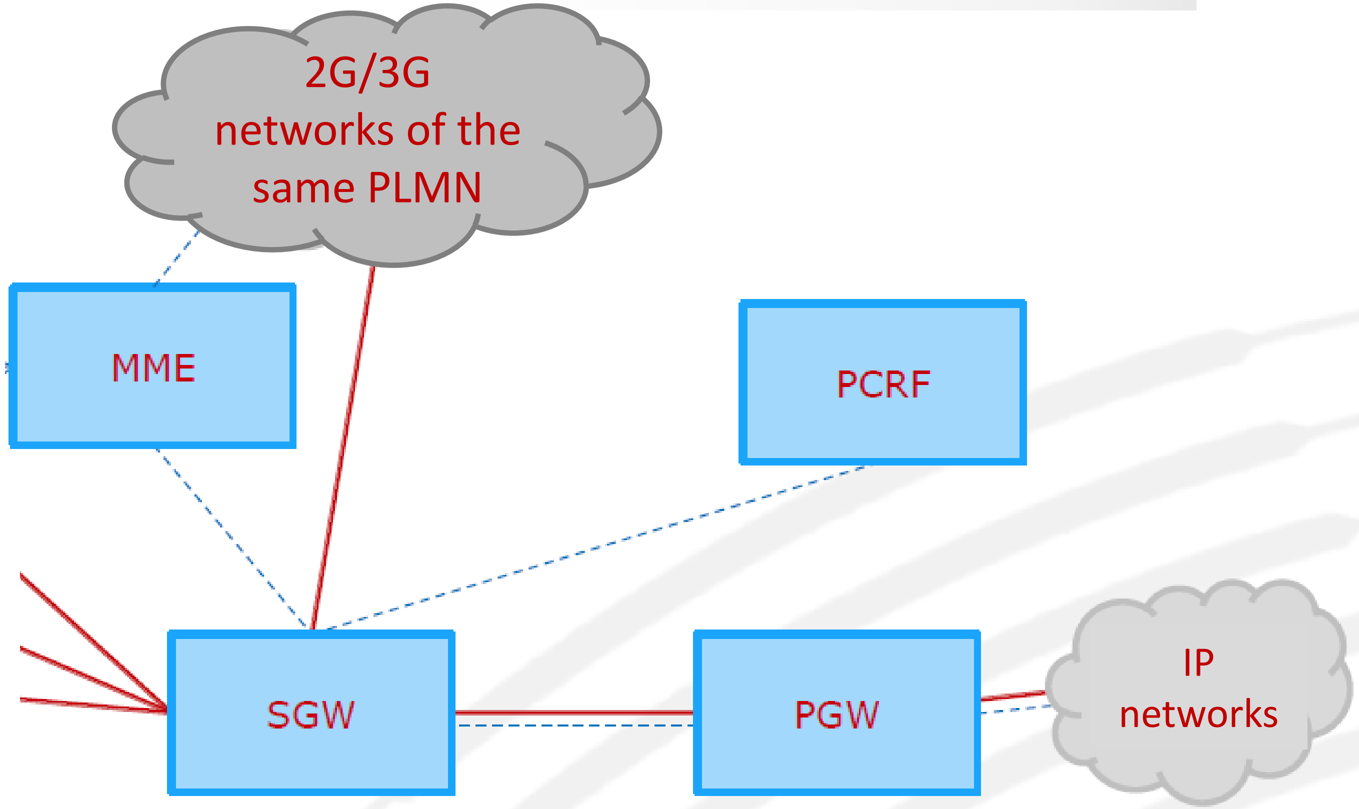


All subsystems communicate via IP network

LTE – Policy Enforcement and Charging (PCRF)

Payment Calculation Functions
- Online billing
- Tariffication of roaming subscribers
- Billing according to the volume of services provided
- Billing according to the time spent on services
- Tariffing upon the provision of services

Policy Enforcement Features
- Fixing the beginning and end of the services provided
- Timeliness and accuracy of determining the parameters of services and their possible changes
- Monitoring and maintaining the specified characteristics of services (quality of service - QoS)



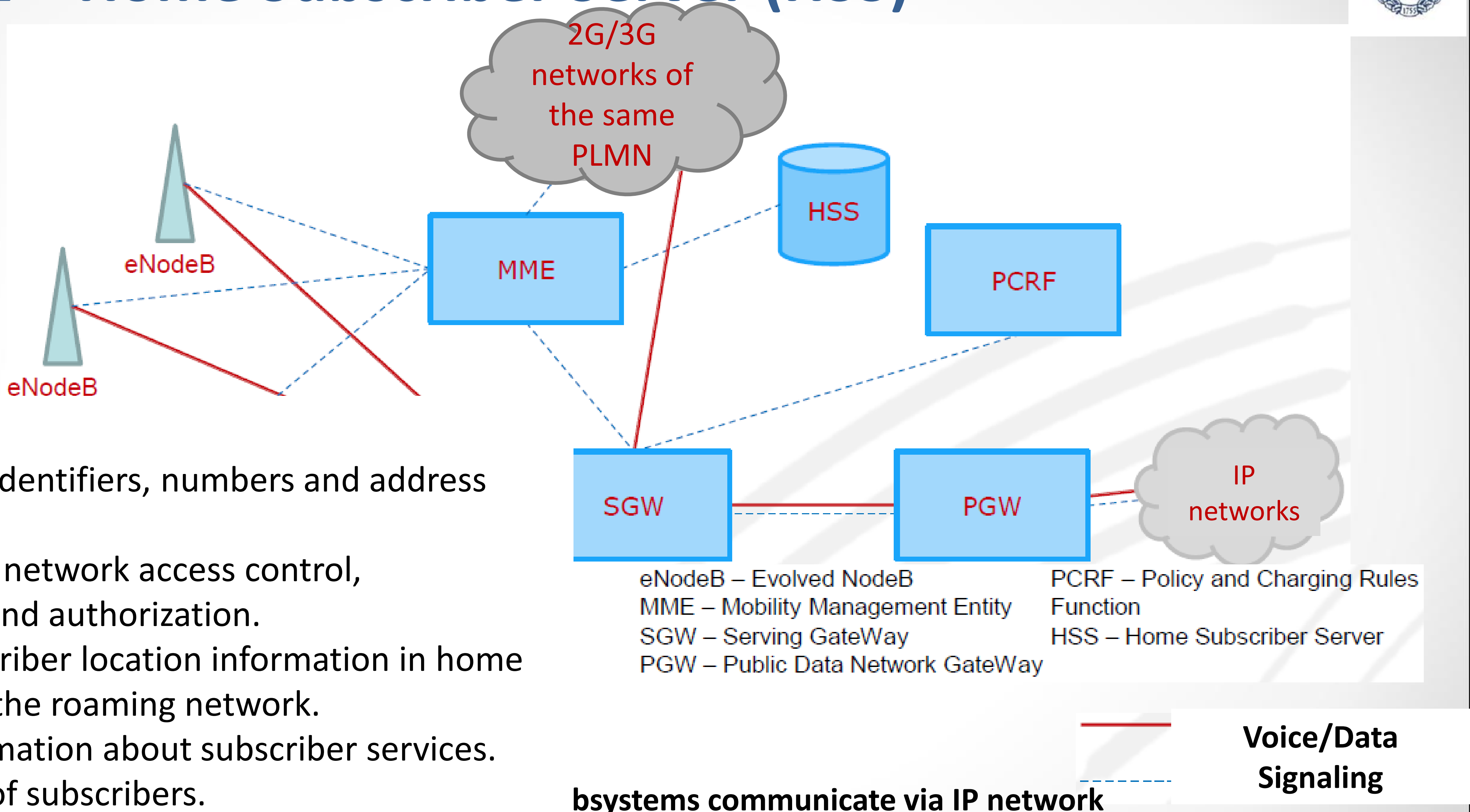
eNodeB – Evolved NodeB
MME – Mobility Management Entity
SGW – Serving GateWay
PGW – Public Data Network GateWay

PCRF – Policy and Charging Rules Function

Voice/Data
Signaling

All subsystems communicate via IP network

LTE – Home Subscriber Server (HSS)

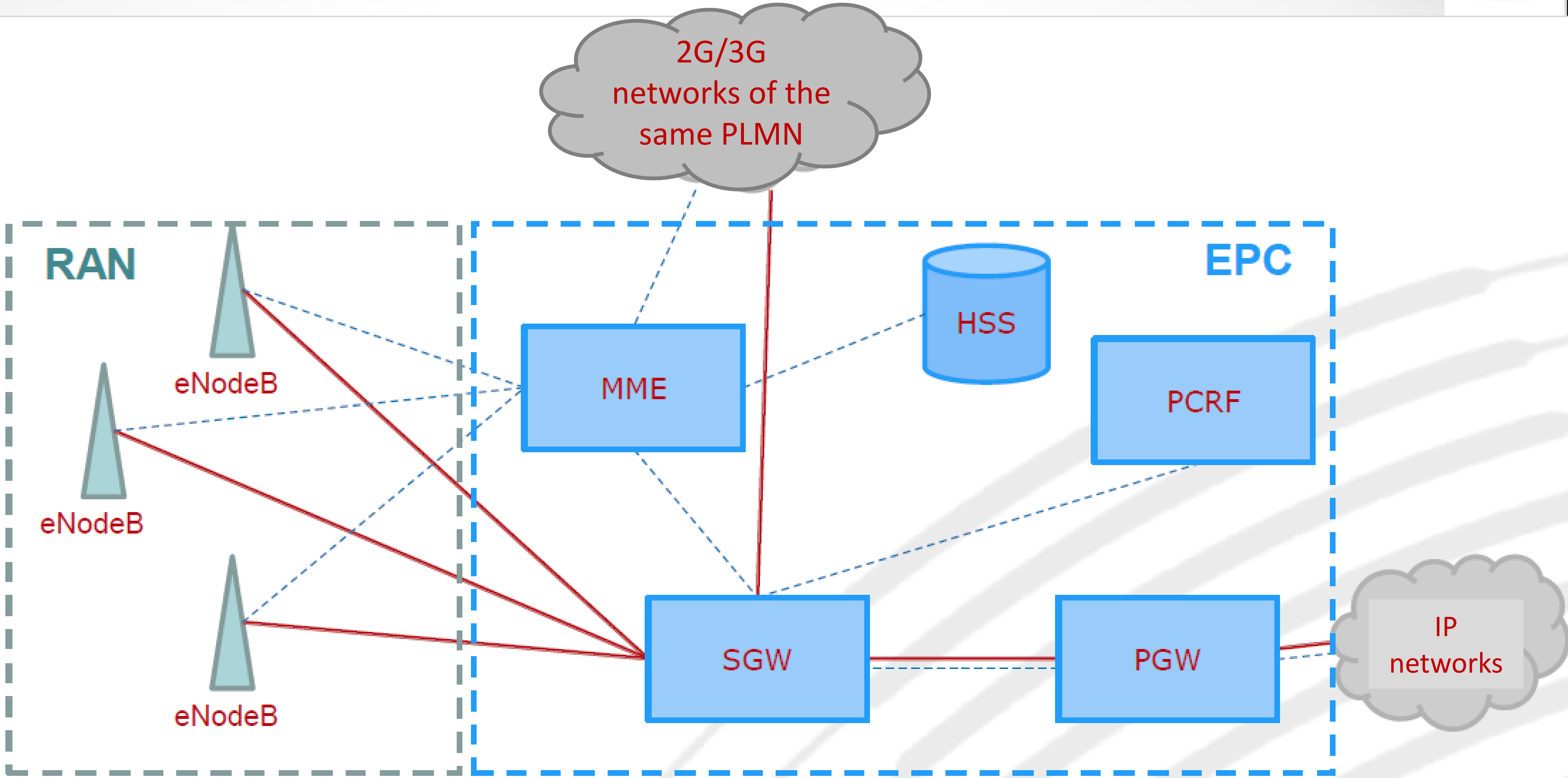


HSS Functions:

- Storage of user identifiers, numbers and address information.
- Data storage for network access control, authentication and authorization.
- Storage of subscriber location information in home network and at the roaming network.
- Storage of information about subscriber services.
- Authentication of subscribers.
- Data generation for traffic encryption.

bsystems communicate via IP network

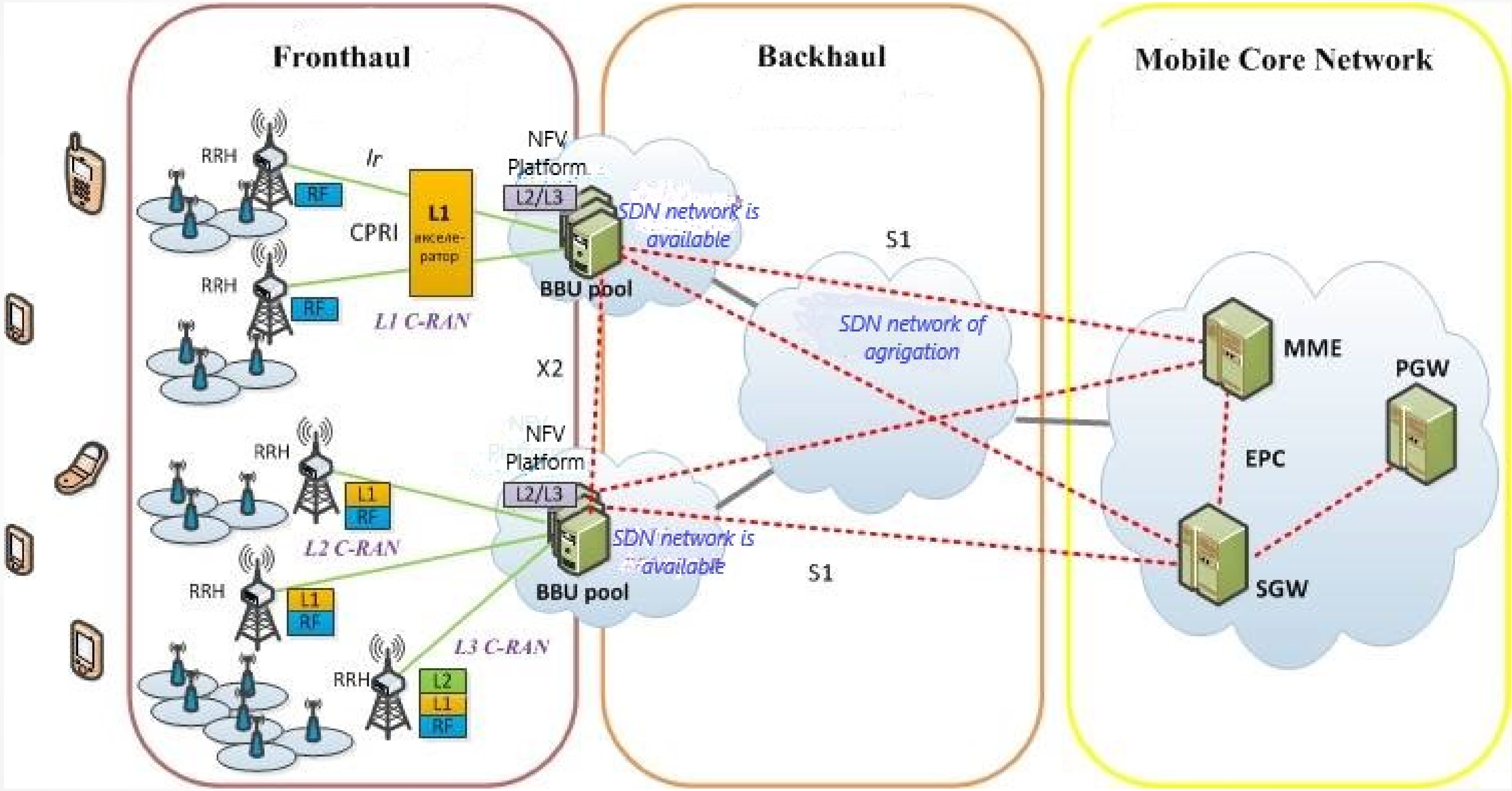
LTE – main subsystems



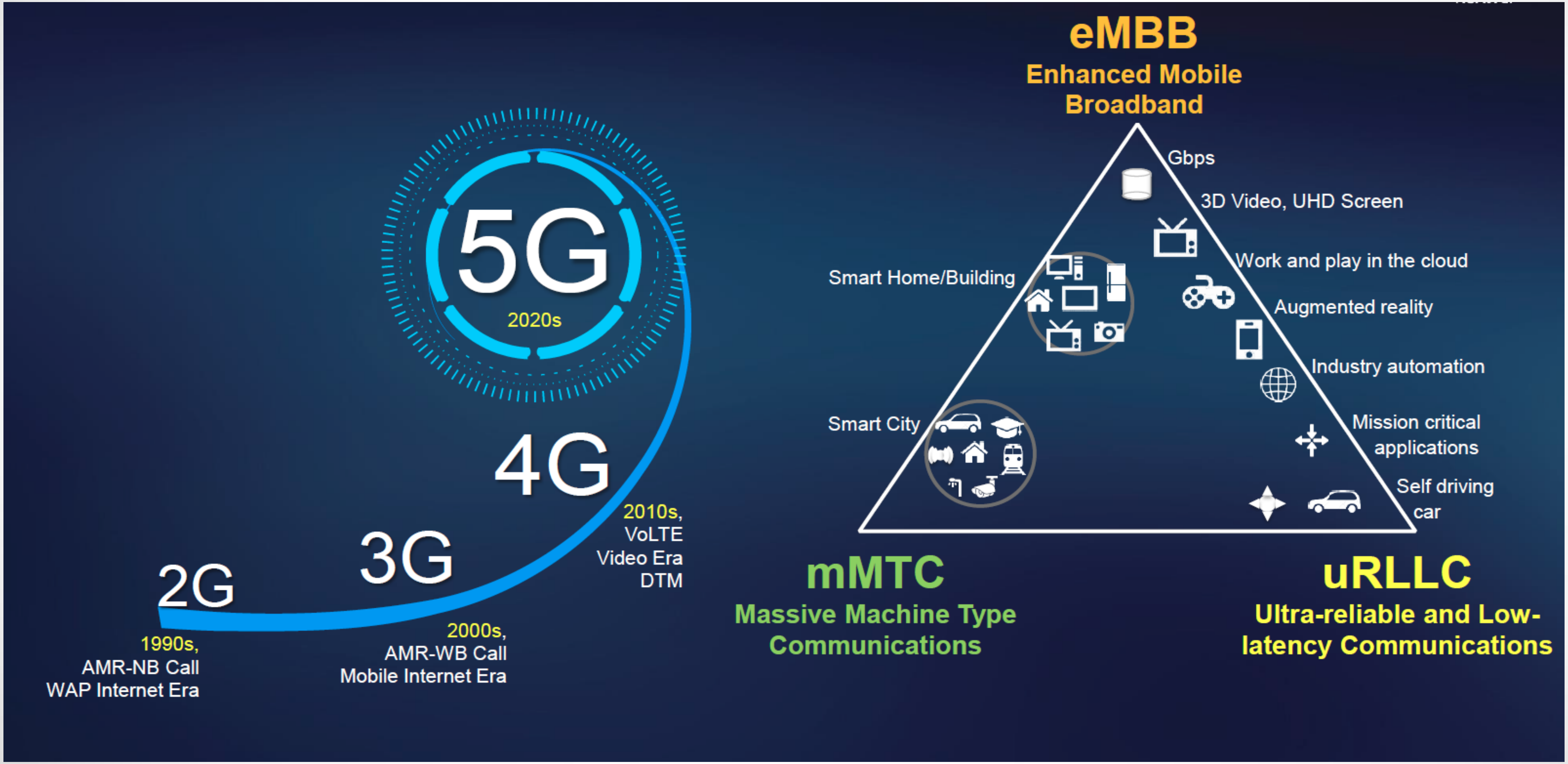
RAN – Radio Access Network
EPC – Evolved Packet Core

All subsystems communicate via IP network

Structure of 5G network

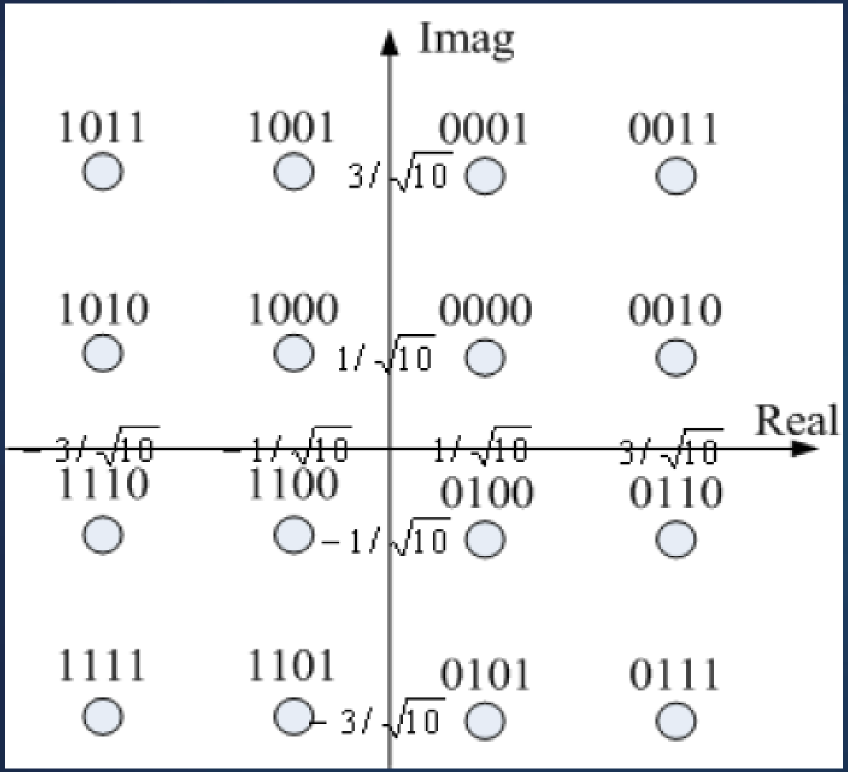


What is 5G?



5G
2020s
4G
2010s,
VoLTE
Video Era
DTM
3G
2000s,
AMR-WB Call
Mobile Internet Era
2G
1990s,
AMR-NB Call
WAP Internet Era
eMBB
Enhanced Mobile Broadband
Gbps
3D Video, UHD Screen
Work and play in the cloud
Augmented reality
Industry automation
Mission critical applications
Self driving car
Smart Home/Building
Smart City
mMTC
Massive Machine Type Communications
uRLLC
Ultra-reliable and Low-latency Communications

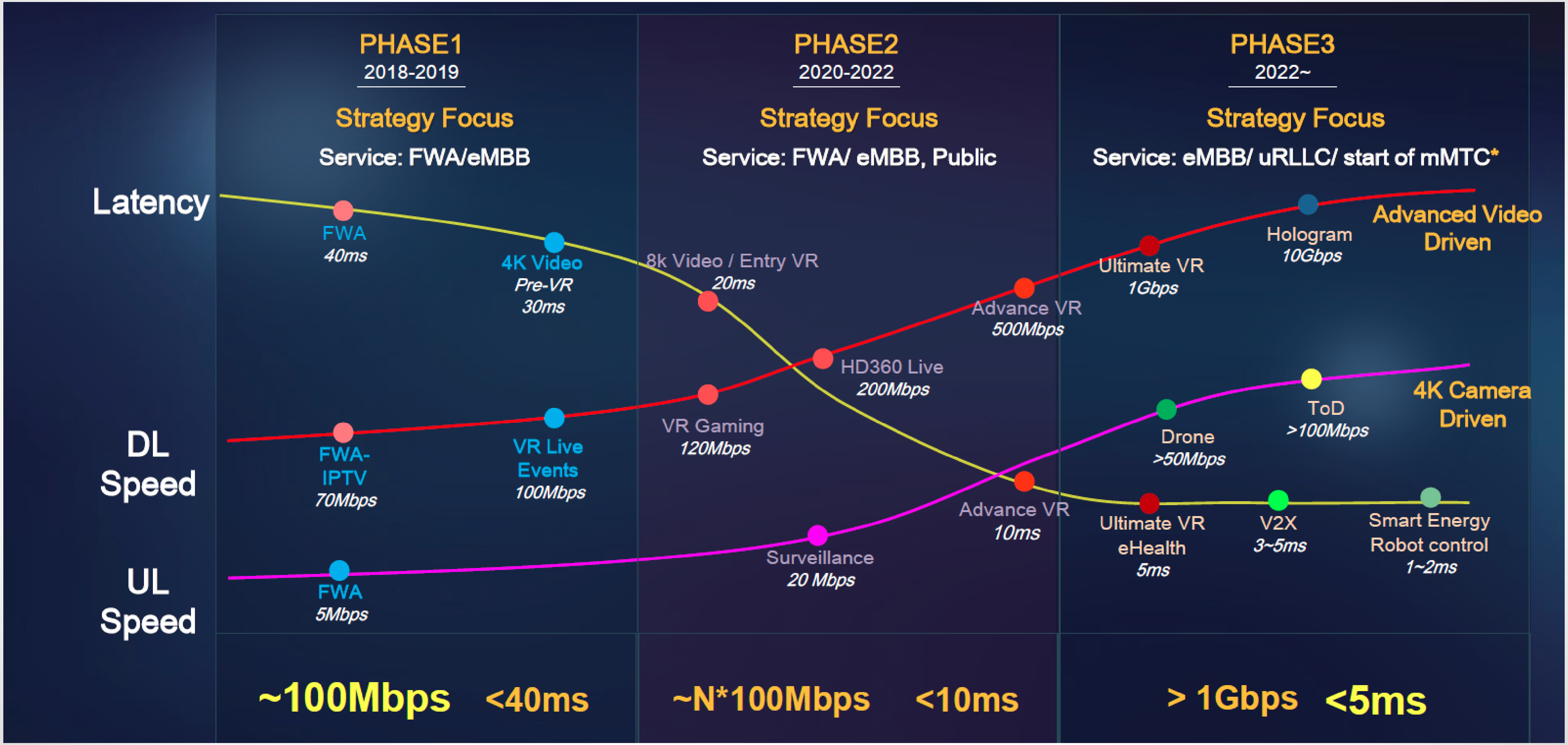
5G – new modulation methods



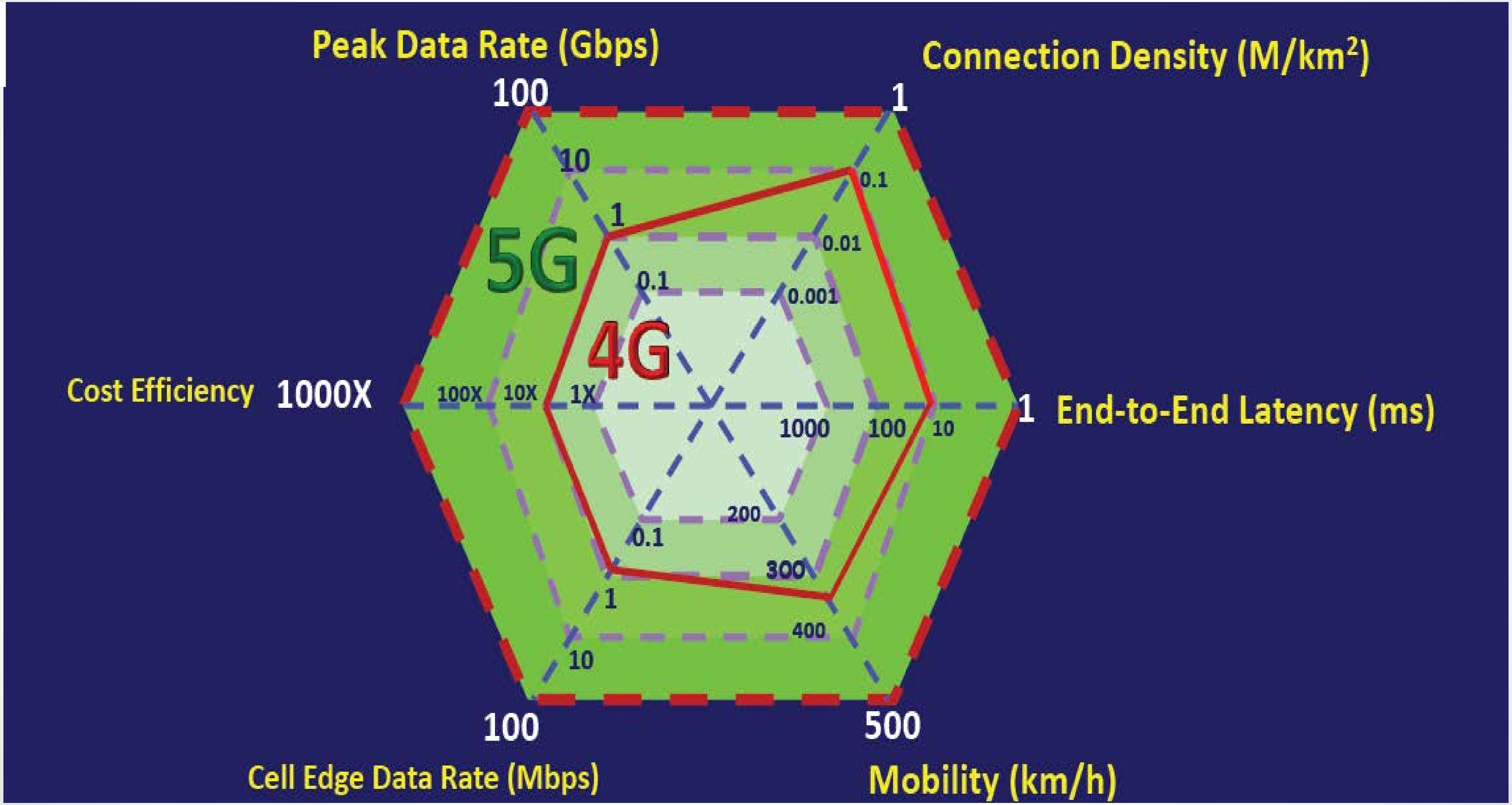
For instance. at 16 QAM 1 character can carry 4 bits

	LTE	5G
UL	QPSK 16QAM 64QAM	QPSK 16QAM 64QAM 256QAM
DL	QPSK 16QAM 64QAM 256QAM	QPSK 16QAM 64QAM 256QAM 1024QAM

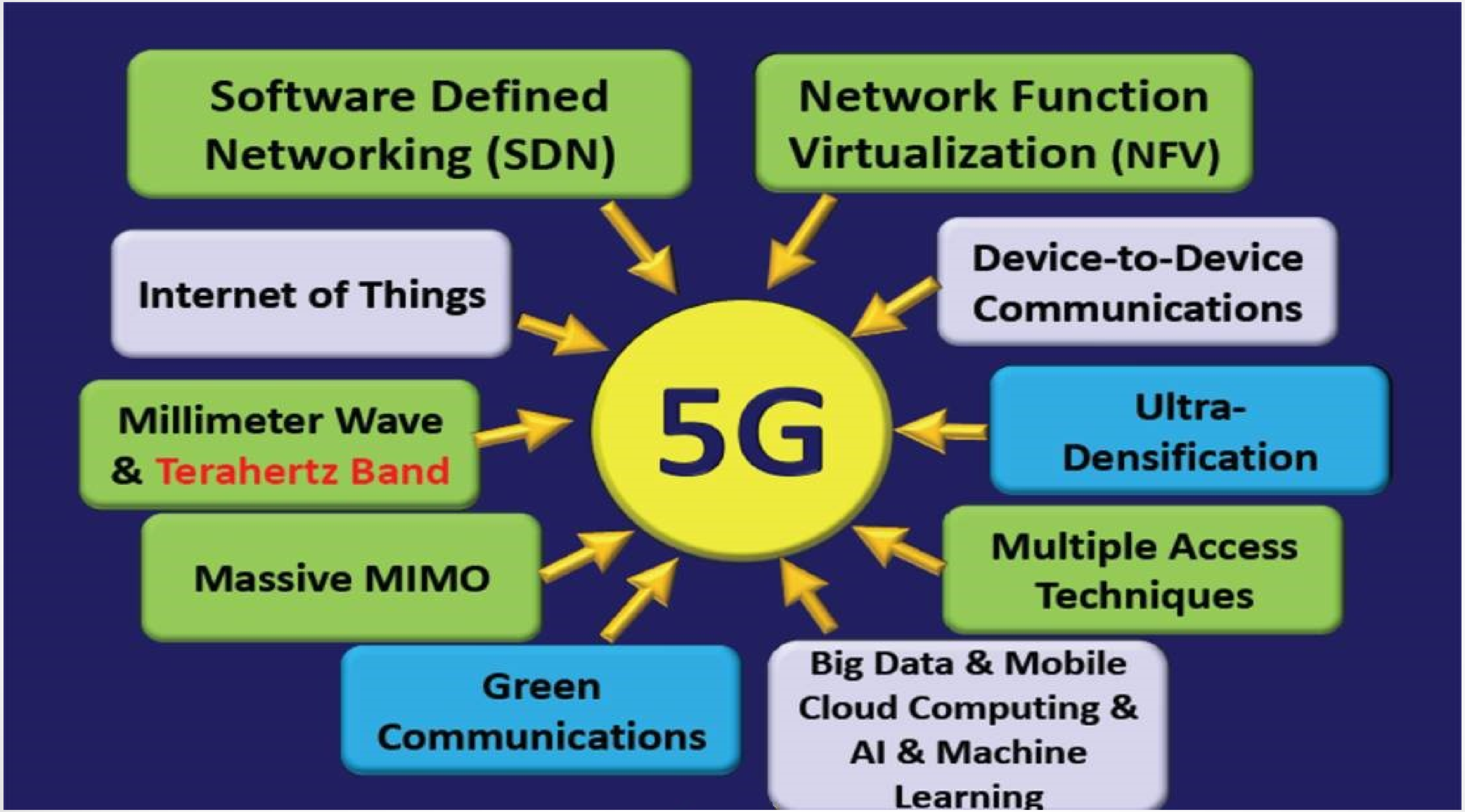
Service Experience Requirement Evolution



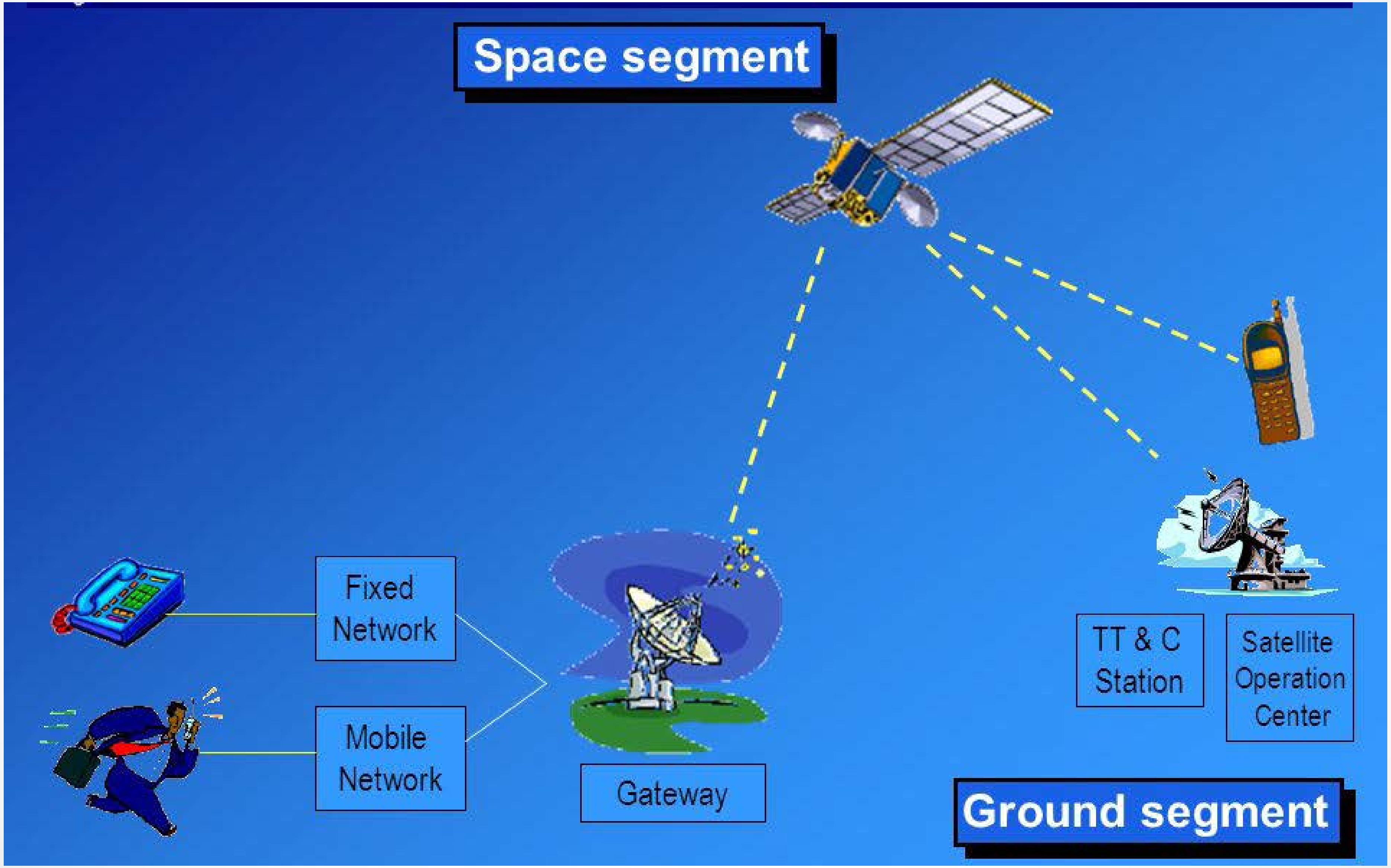
Evolution From 4G to 5G



10 Key Enabling Technologies for 5G



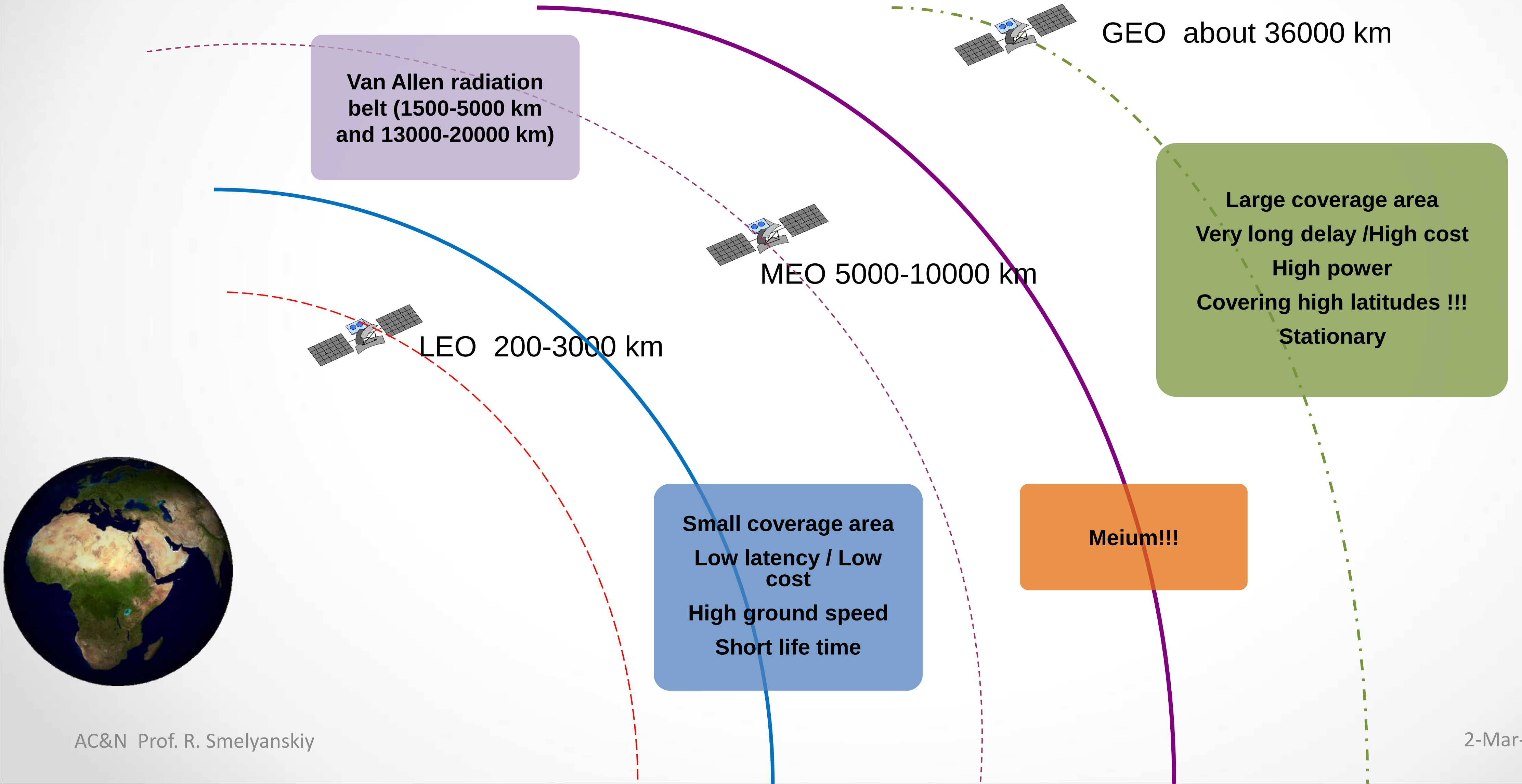
Satellite Communication System



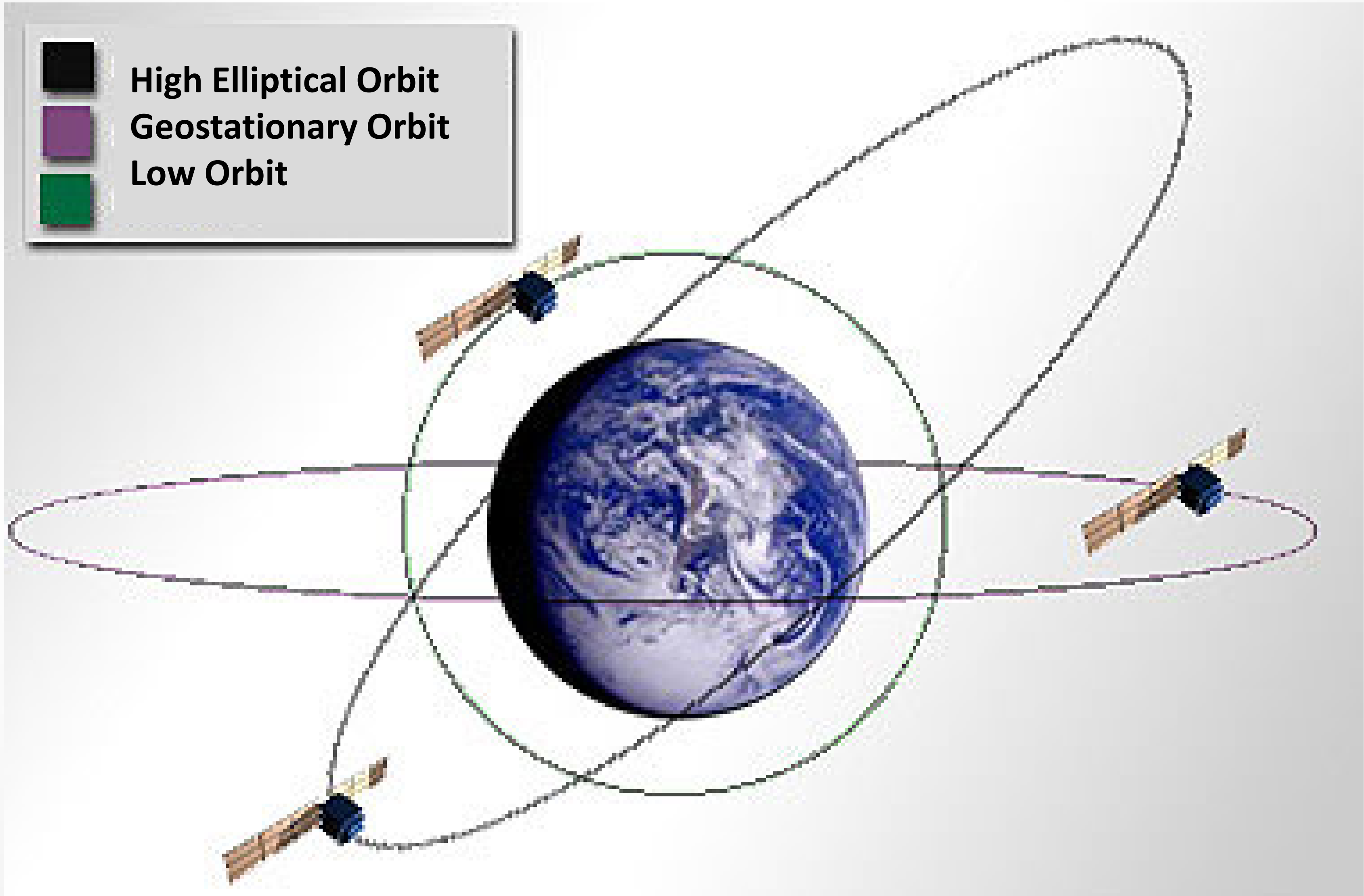
Satellite communication systems: taxonomy

- **By location**
  - Geostationary Satellites (GEO)
  - Medium Orbiting Satellites (MEO)
  - Low Orbit Satellites (LEO)
  - High Elliptical Orbits Satellites
- **By appointment**
  - Personal communication
  - Corporate VSAT systems
  - Television systems

Satellites


GEO about 36000 km
Van Allen radiation belt (1500-5000 km and 13000-20000 km)
Large coverage area
Very long delay /High cost
High power
Covering high latitudes !!!
Stationary
MEO 5000-10000 km
LEO 200-3000 km
Small coverage area
Low latency / Low cost
High ground speed
Short life time
Meium!!!

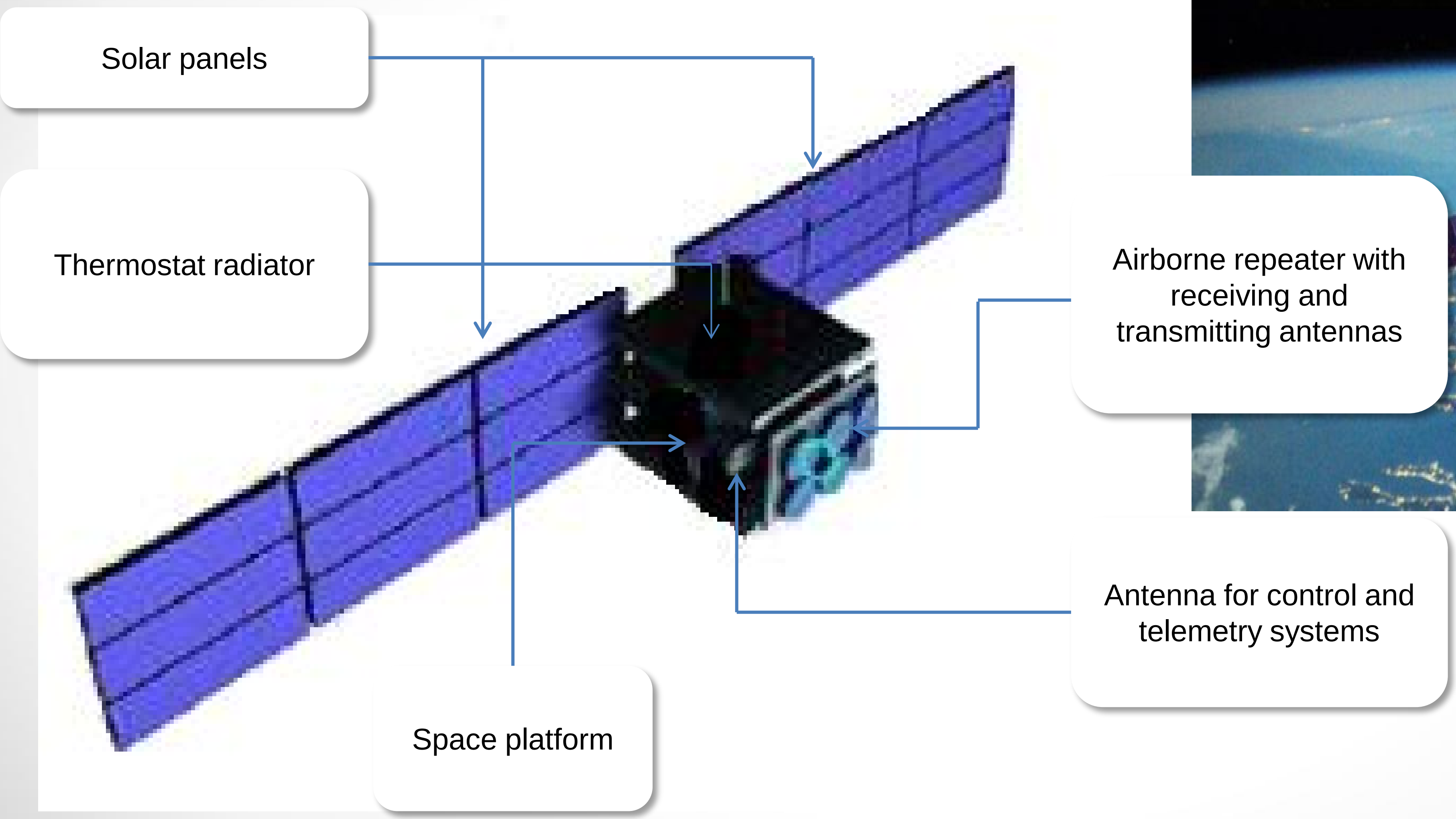
High Elliptical Orbits

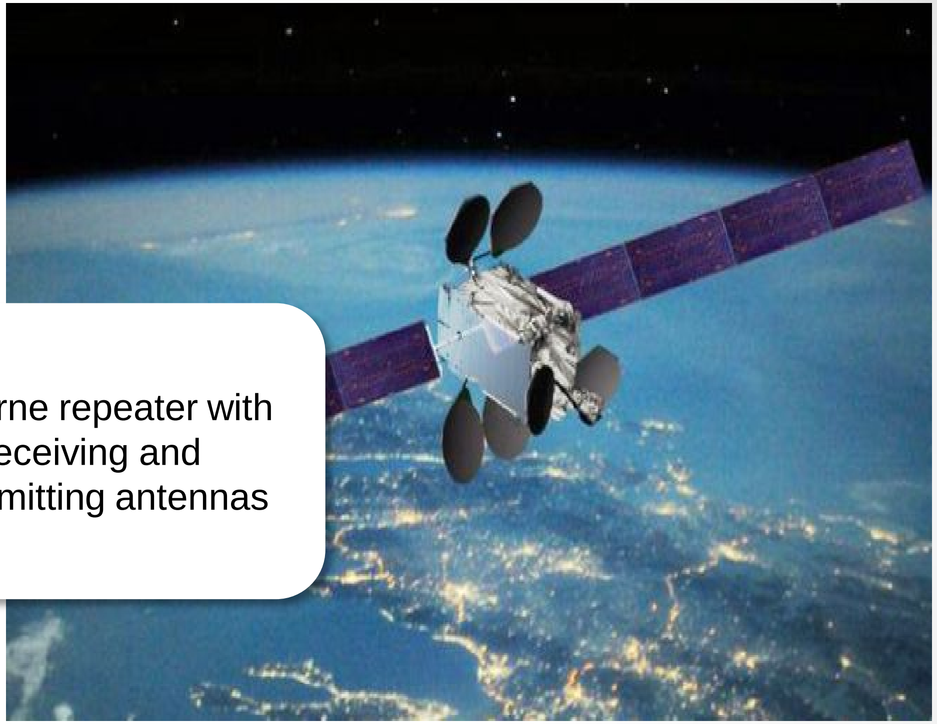


Geostationary satellites

- Principle of operation
- Satellite Device
  - antenna system
  - transponder system
- Frequency distribution

Communication Satellite Organization





The main satellite frequency bands

LEO sattelite

- Satellite Communications Systems (SCS) for individual use - relevance
- Principle of operation
- Iridium - 1990 Motorola
  - 77 satellites (later 66) per 750 km, 11 per meridian
  - inter-satellite communication
  - each satellite 48 spots on 174 duplex telephone channels (283 272 channels)

LEO Satellite communications systems

Satellite Communications Systems - SCS

- A large transmission delay is 250-300 ms, versus 3-5 μs / km on coaxial, optical fiber, etc.
- Satellite systems are fundamentally broadcast type. For some applications this is very important. The cost of transmission does not depend on how many recipients the message is intended. However, the security problem of the transmitted information here requires special attention - everyone hears everything that is transmitted. The solution to this problem is only encryption.
- The transmission cost is independent of distance.
- This transmission method has a very low transmission error rate.

SCS in Russia

- Specifics of the geographical position of Russia
- Peripheral Terrestrial Infrastructure
- SCS - ground segment development

Short list of Russian operators of satellite communication

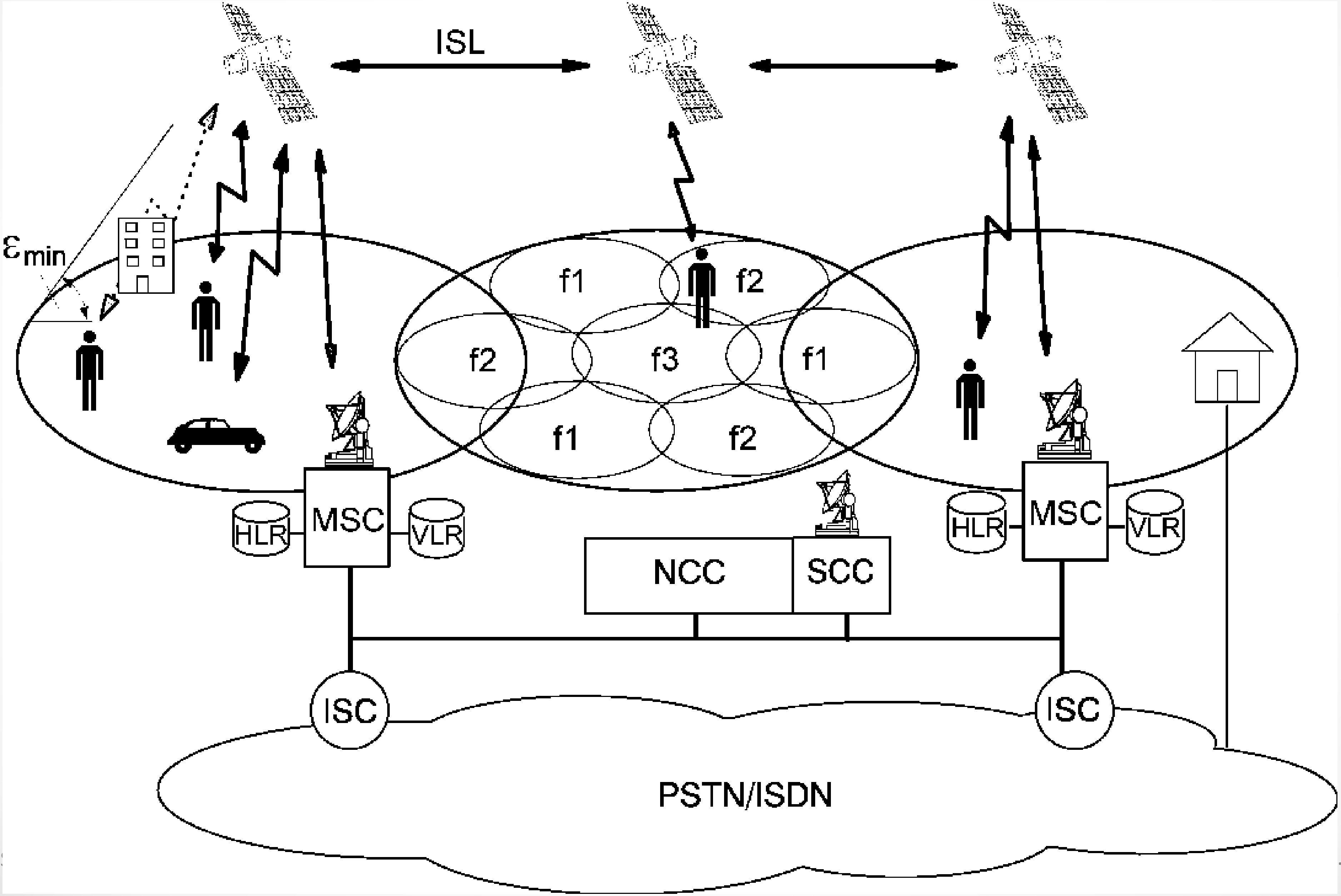
ФГУП «Космическая связь».
АО «Газпром Космические системы»
Группа компаний «АльтегроСкай»
Красноярская компания КБ «Искра».
ООО «РуСат»
ПАО «Ростелеком» АО «РТКомм.Ру»
ГК «АМТЭЛ-СВЯЗЬ»
ООО «СТЭК.КОМ»
ООО «Евтелсат Нетворкс»
ООО «ЕВРОКОМ»

ЗАО «Джи ТИ Эн ТИ»
ООО «ТелематикаНэт»
ООО «Оранж Бизнес Сервисез»
ООО «ТИС»
ФГУП «Морсвязьспутник»
ООО «Мобифон-2000»
Компания «Радуга-Интернет»
АО «Сатис ТЛ 94»
АО «СатисСвязь»
ООО «Телепорт»

Types of SCS

- Personal communication (Iridium, Inmarsat, Globalstar, ICO, Ellipso, Thuraya, OneWEB)
- VSAT corporate communications systems
- Television broadcasting systems

Satellite Personal Communication System



Satellite Personal Terminals

Satellite Personal Communication System

Iridium – 17.03.00 stop it function as a public system

Inmarsat - medium-orbital C3 serves 143 thousand ground terminals, speed 2.4 - 64 Kb / s

Globalstar - low orbit. system in the C range (March 2000)

48 satellites for 1414 km. + 4 reserve

Ground stations Moscow, Novosibirsk, Khabarovsk

Integrated in the Russian telephone network (954)

CDMA technology

Speed 1.2 - 9.6 Kb / s

ICO (Intermediate Circular Orbit) - separated from Inmarsat in 1995

The average orbital system of 10 satellites per 10 390 km.

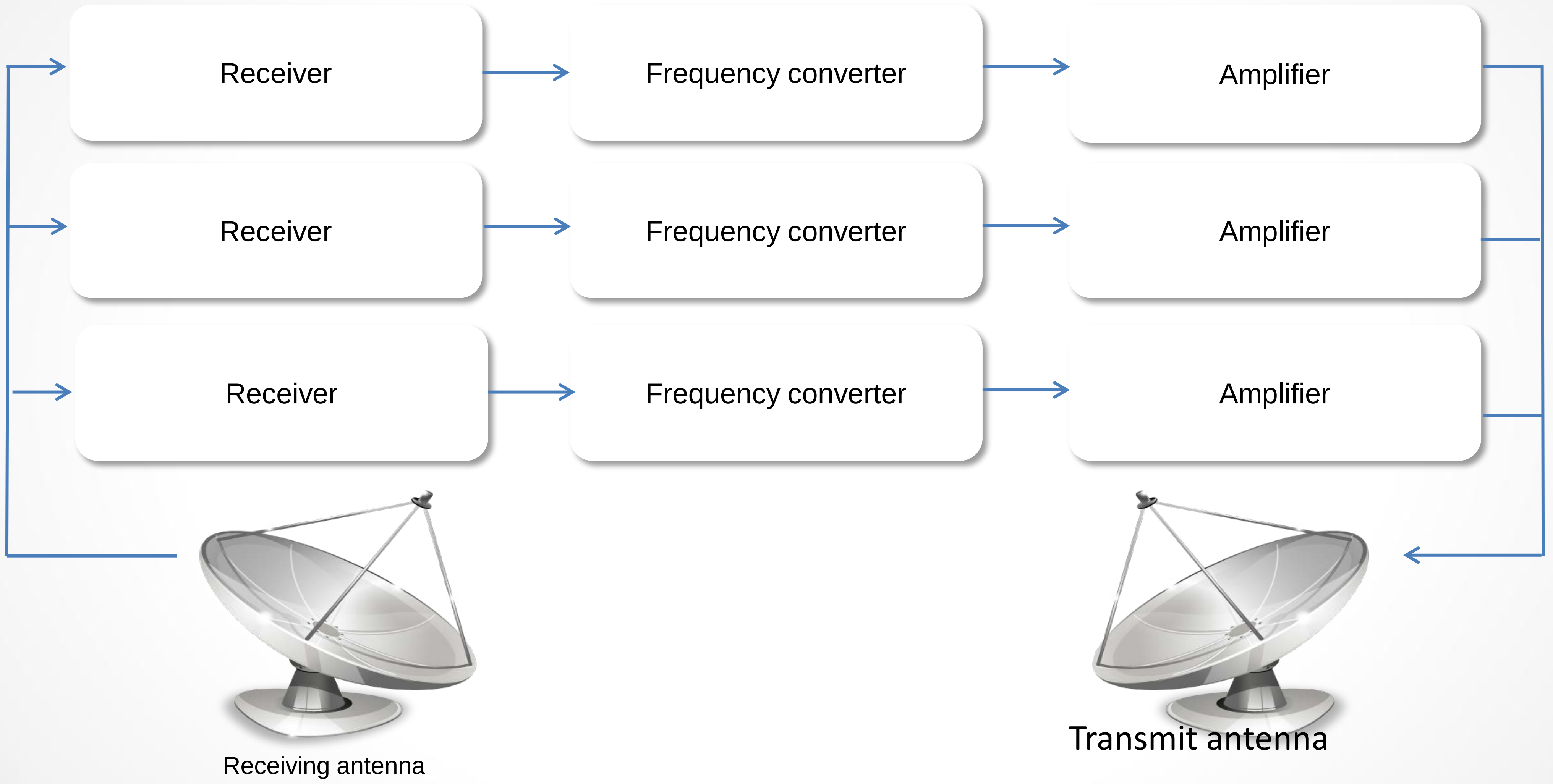
6 hours in the radio reception area

43 SAN stations

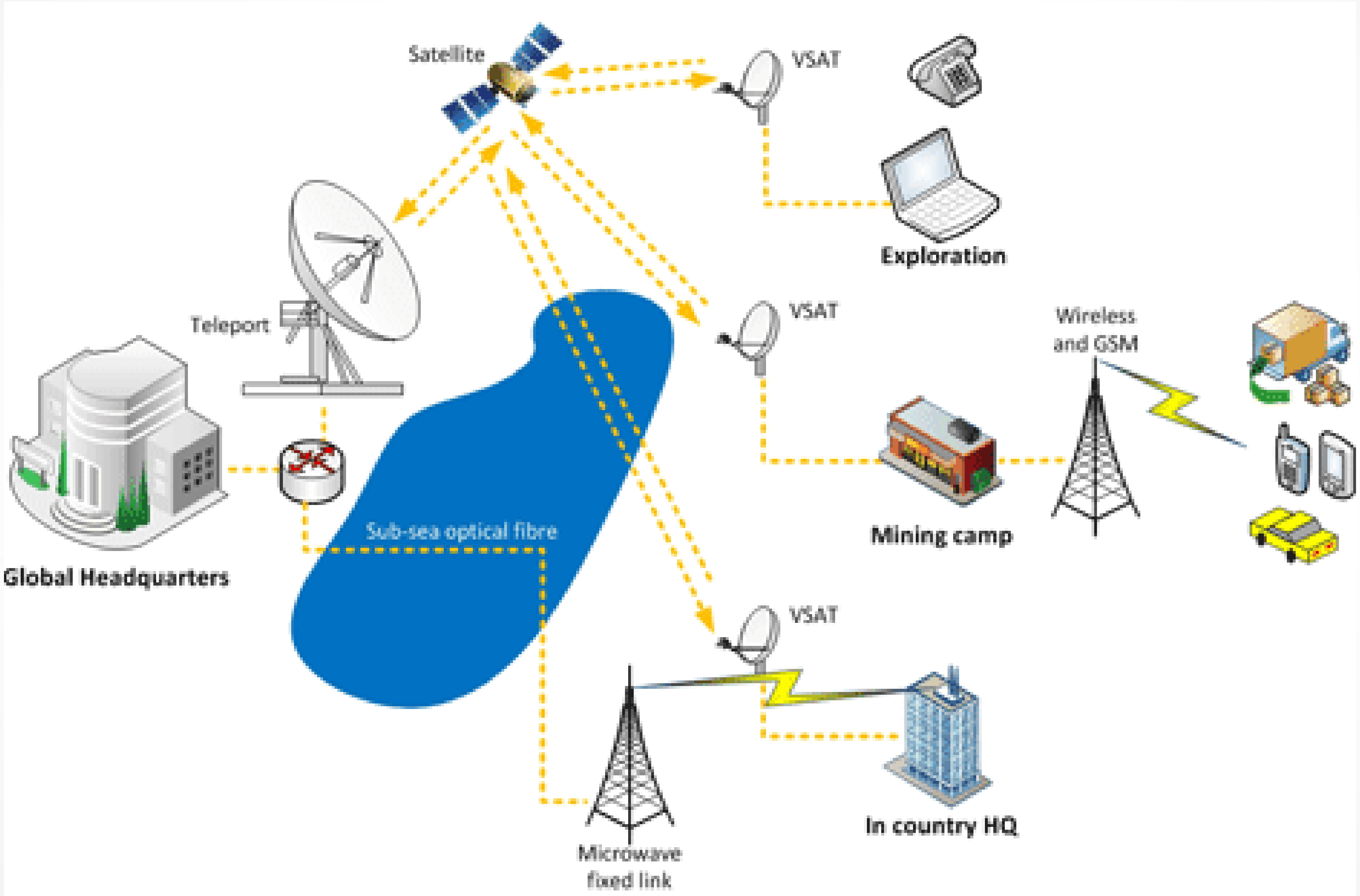
OneWEB - 650 satellites in circular orbits with an altitude of 1200 kilometers, 50 Mb / s

As the main customers, the company considers residents of hard-to-reach areas with poor or no internet connection, as well as transport such as ships and aircraft.

VSAT Satellite communication system organization



VSAT Satellite Communication System



High Speed Satellite Communication Systems

- Low orbit – One Web
- Geostationary
  - Astrolink, Spaceway , Cyberstar
  - Skybridge, Teledesic

Satellite based Network

- Organization of a satellite system: the main drawback is the large delay time in the channel (270 ms)ALOHA,
- FDM,
- TDM,
- CDMA

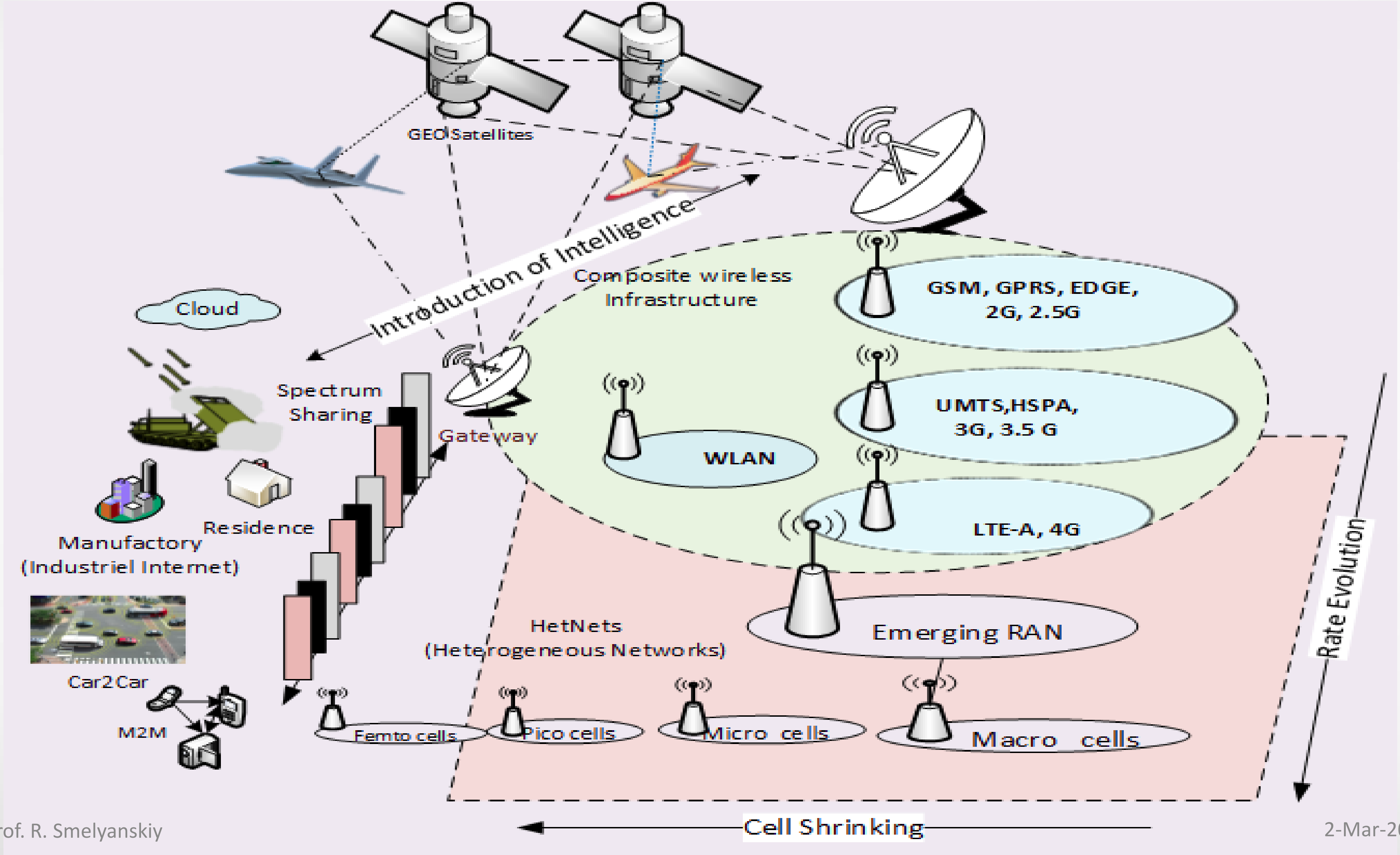
Some technical specifics of systems implementation

- Almost all of the announced systems operate in the Ka-frequency band (20/30 GHz)
- Presence of inter-satellite radio links (60 GHz)
- Multipath antennas (tens of beams) on geostationary systems
- Use of HEADLIGHTS on low-orbit systems
- Channel switching
  - Earth-KA - FDMA
  - KA-Earth - TDMA
- Brand new service

Advantages of Satellite Communication Systems

- It is **enough to install the antenna on the roof**, and you will have access to the entire satellite bandwidth.
- The satellite is almost **always available**.
- **Mobility.** Now people want to have a connection always: on a walk, traveling. The combination of cellular and fiber does not always solve this problem: what about a ship or plane?
- Where **broadcasting** is fundamentally necessary, the satellite is not replaceable.
- A satellite cannot be replaced where **geographical conditions** do **not allow** to create a developed **cable system** or to deploy a radio access network.
- The satellite is good wherever you need **to quickly deploy a data transmission** system. Where there is no time or money to create a cable infrastructure or radio access network.

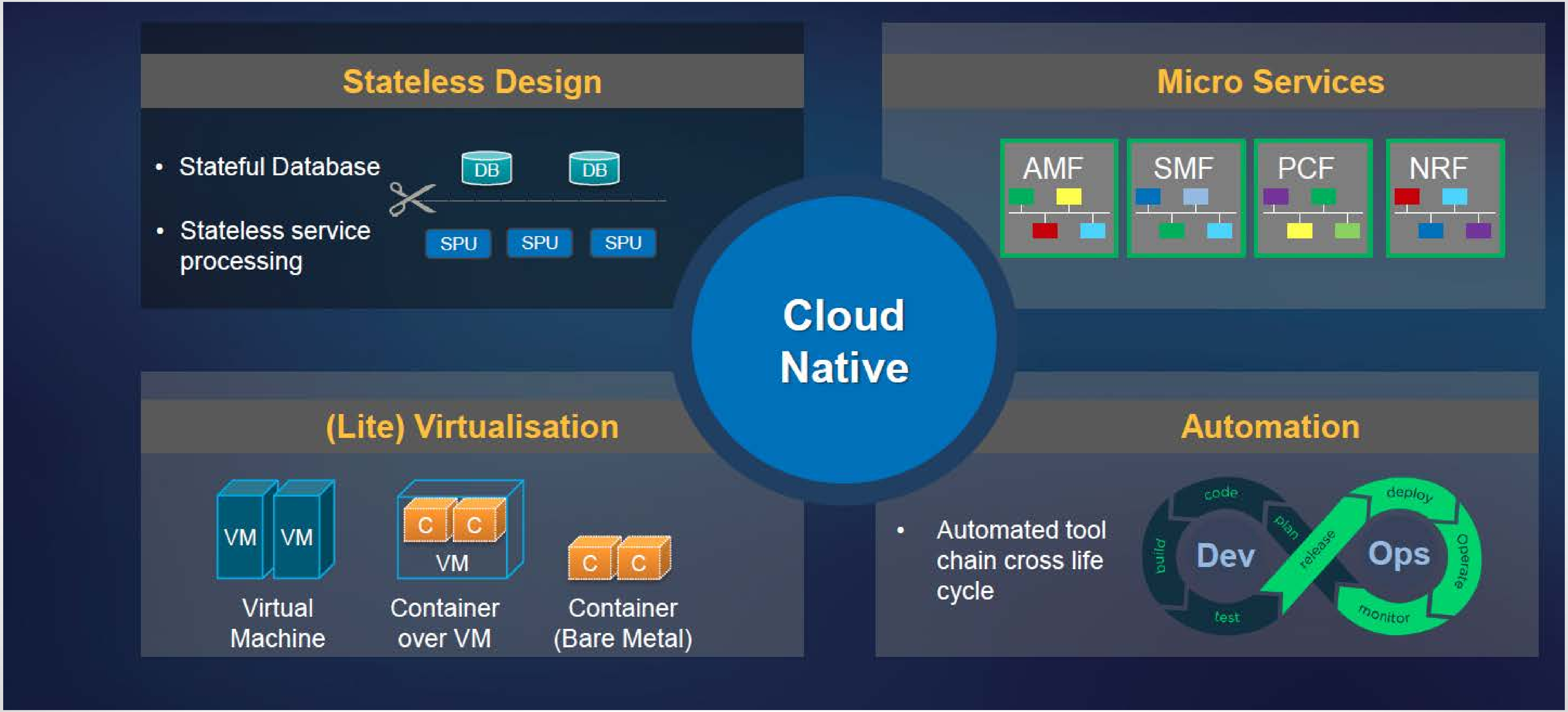
As the conclusions



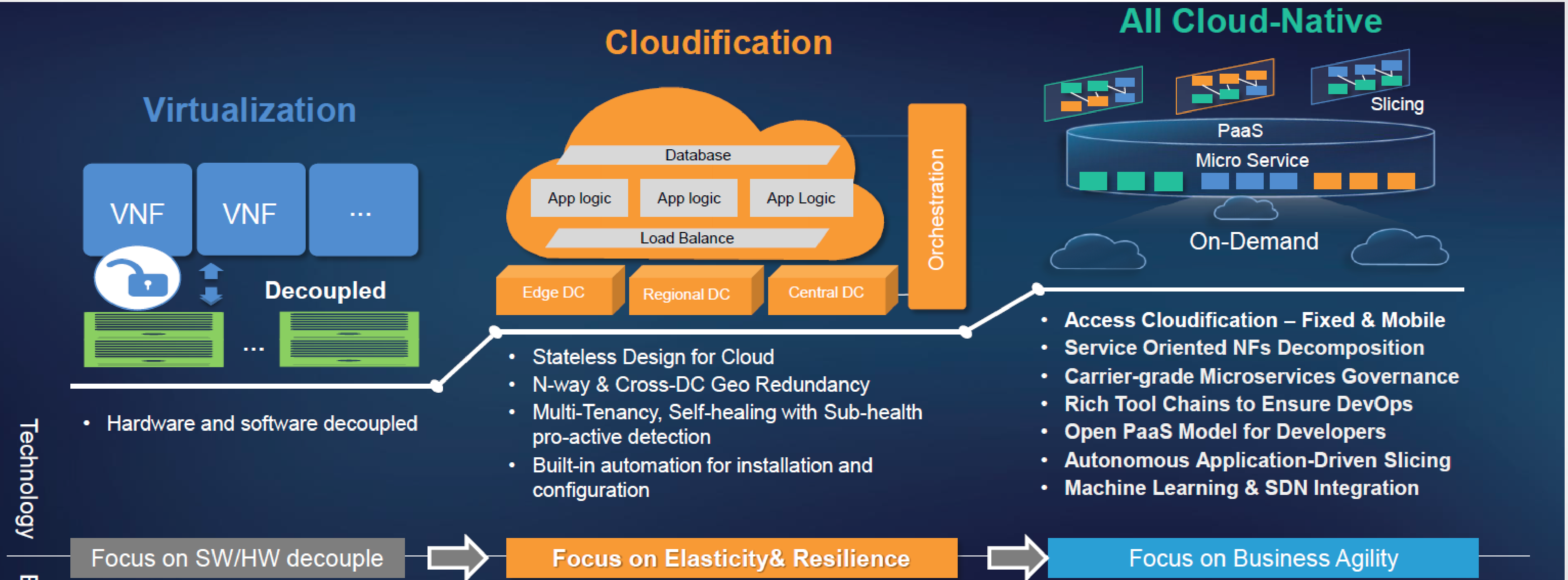
Thank You

Questions?

Cloud Native



Cloud Native - From NFV to NFC: Beyond Network Virtualization



- Hardware and software decoupled

- Stateless Design for Cloud
- N-way & Cross-DC Geo Redundancy
- Multi-Tenancy, Self-healing with Sub-health pro-active detection
- Built-in automation for installation and configuration

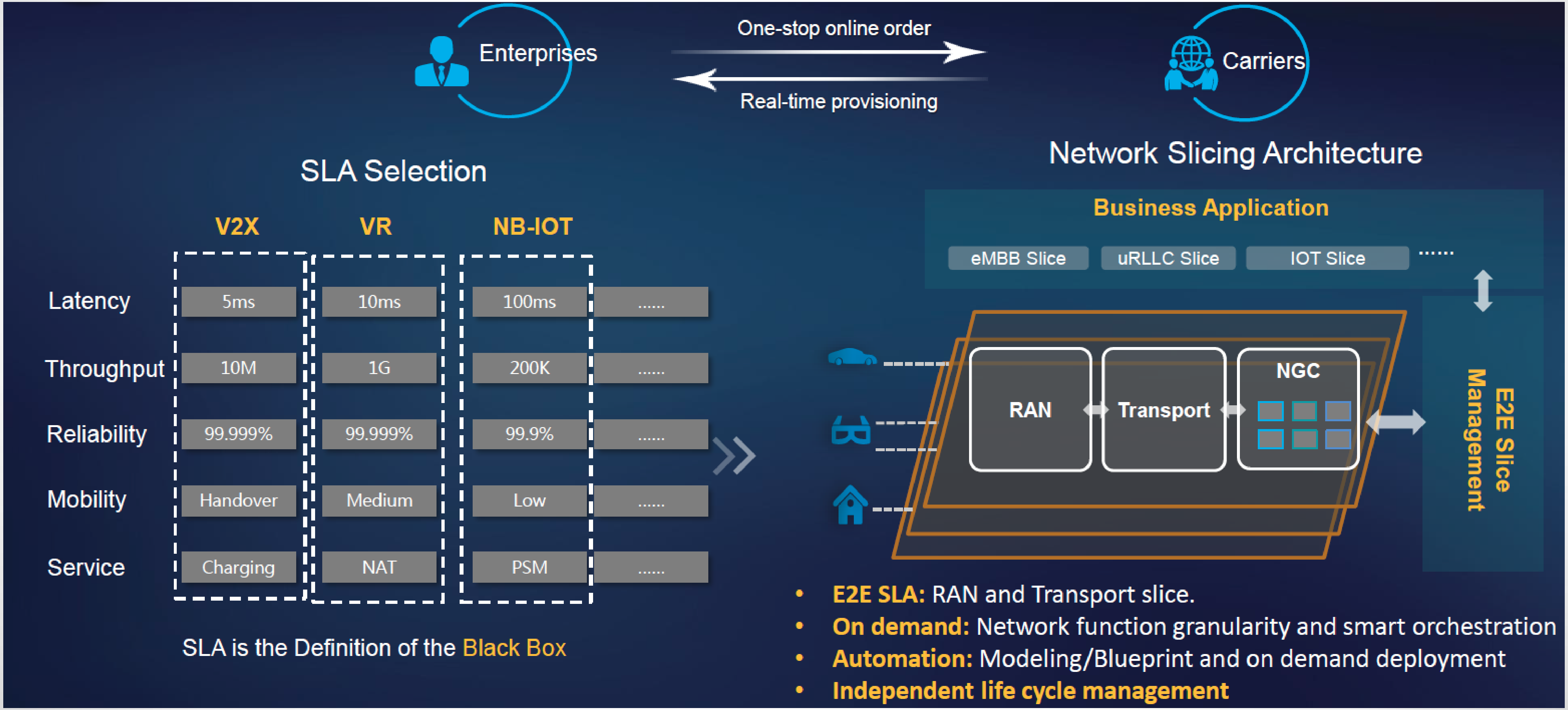
- **Access Cloudification – Fixed & Mobile**
- **Service Oriented NFs Decomposition**
- **Carrier-grade Microservices Governance**
- **Rich Tool Chains to Ensure DevOps**
- **Open PaaS Model for Developers**
- **Autonomous Application-Driven Slicing**
- **Machine Learning & SDN Integration**

- Mass market

- Virtualized Enterprise Services – CloudCPE/VPN/VAS
- Dedicated CloudCore for M2M/NB-IoT/Enterprise…
- Cloudified Gi-LAN, VoLTE/Wi-Fi Calling…..

- Dynamic Slicing: AR/VR, V2X, Industry 4.0
- Market place for millions of apps

Slicing – Network aaS: Redefine Service Provisioning to Tenant



Slicing – 5G slicing – Orchestration On-demand