A Tour of Mobile Data Technology Evolution

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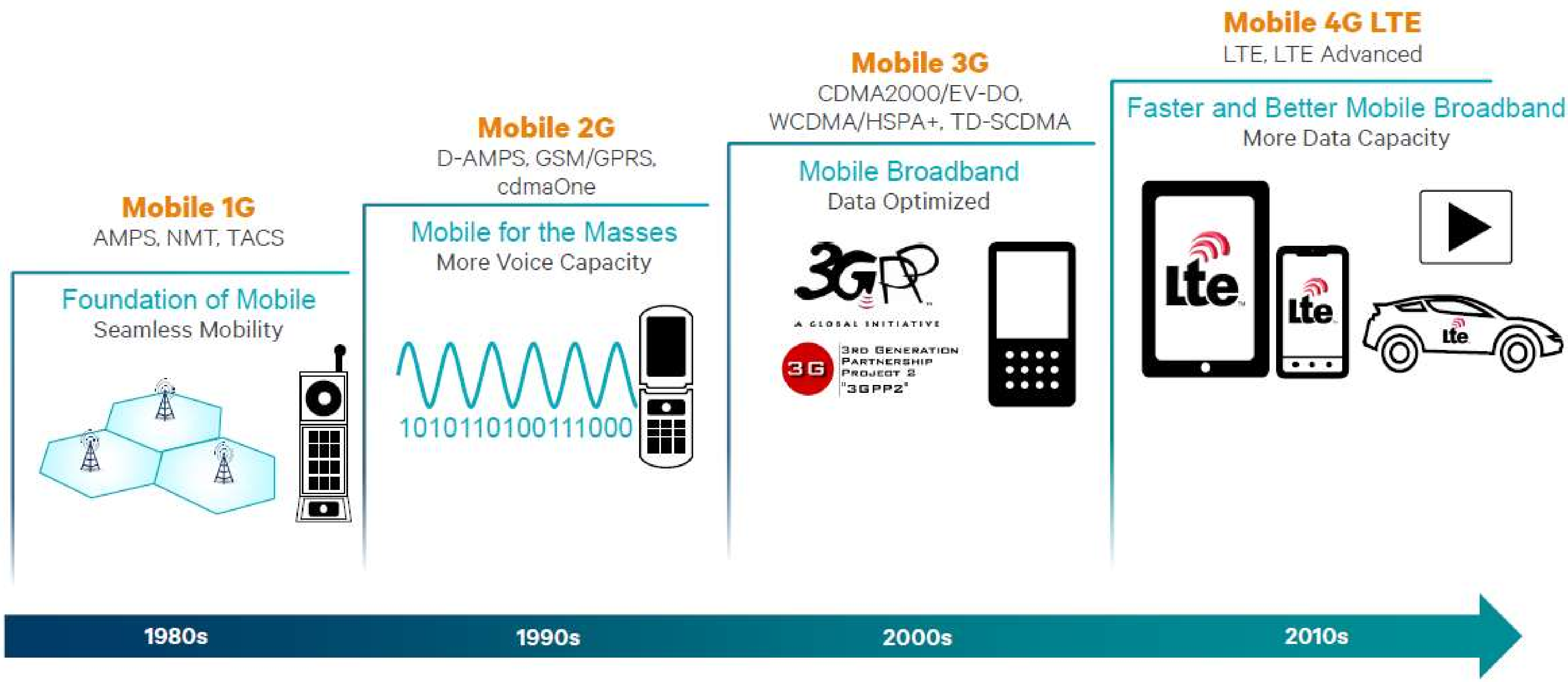
From old days to now



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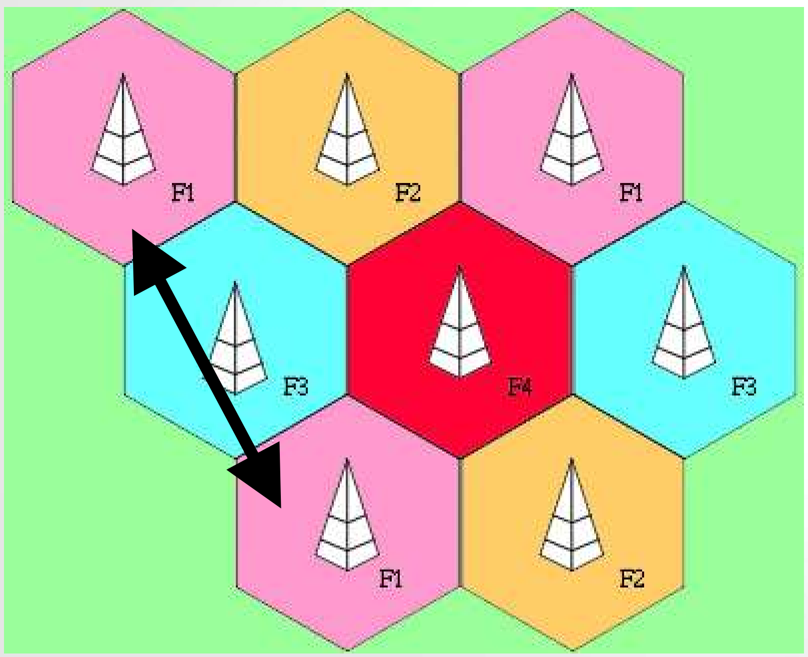
Mobile 1G – Invention of Public Mobile

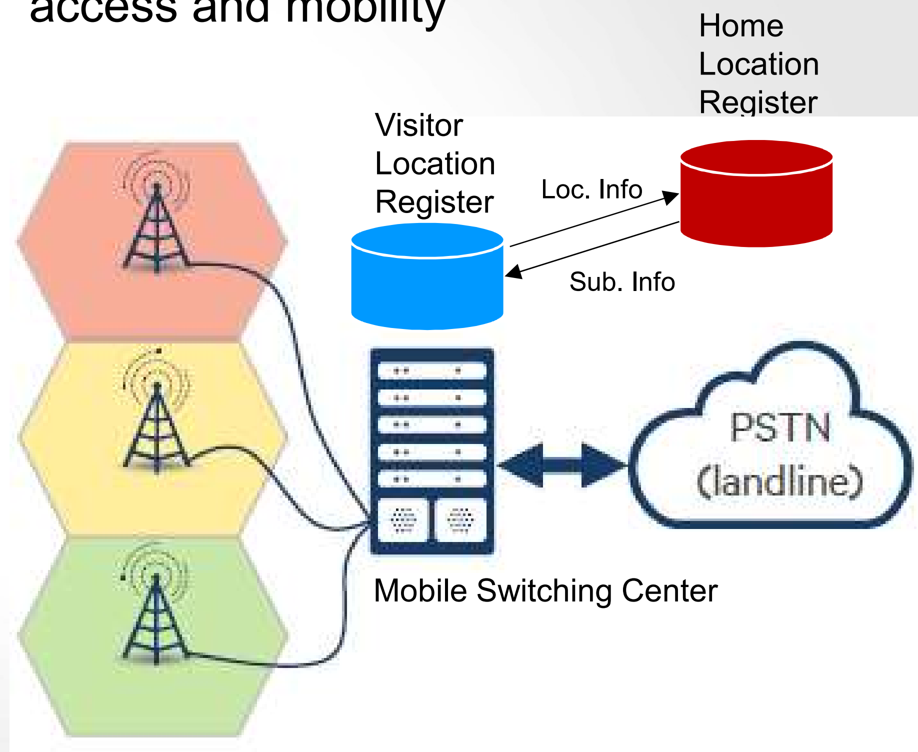
Frequency re-use of licensed spectrum

Reusing frequencies without interference through geographical separation



Mobile Network

Co-ordinated network for seamless access and mobility



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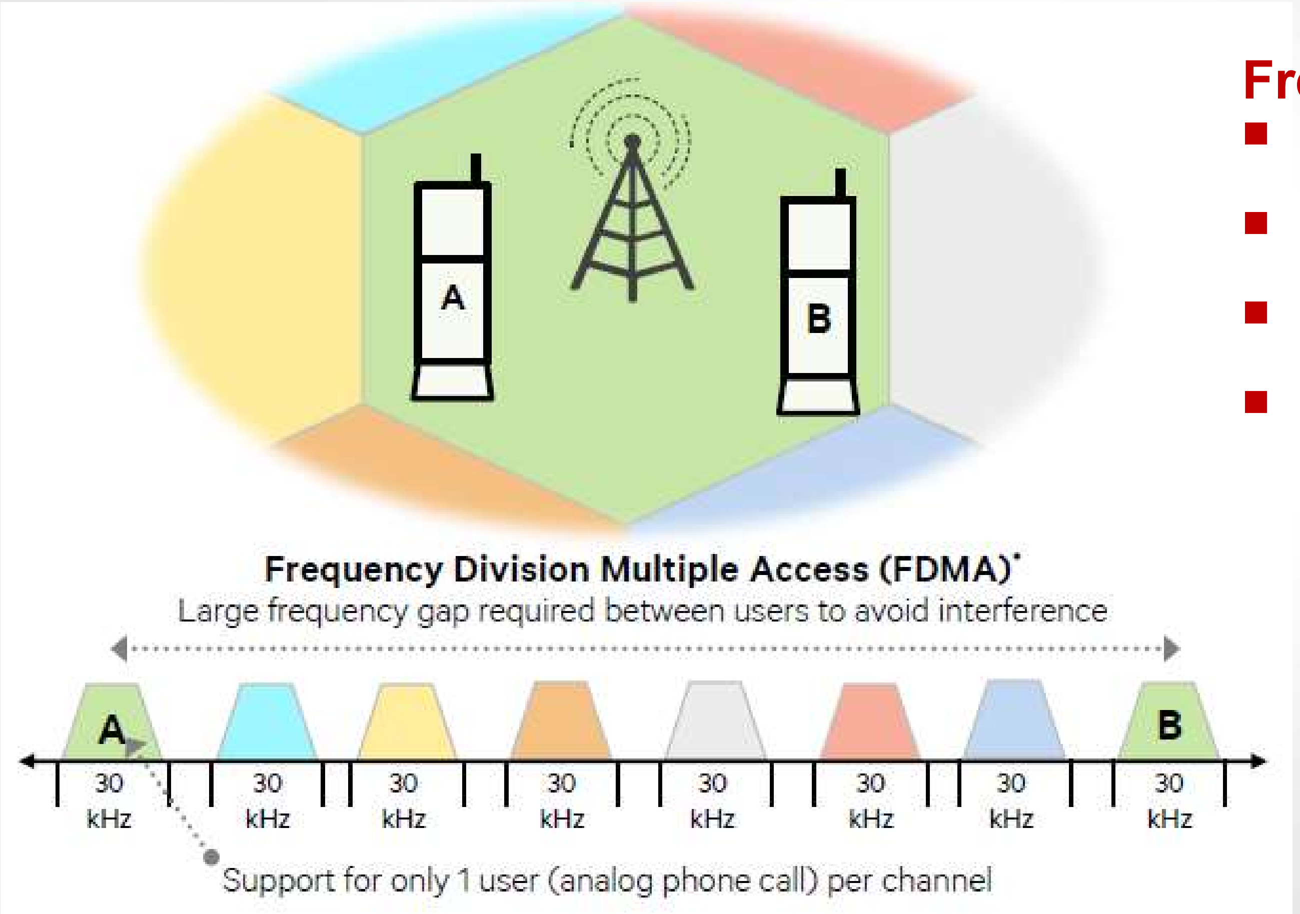
Limitations of Analog Modulation Technology

Single channel carries single voice signal ➔ Narrowband channel ➔ More band gaps ➔ Low spectral utilization



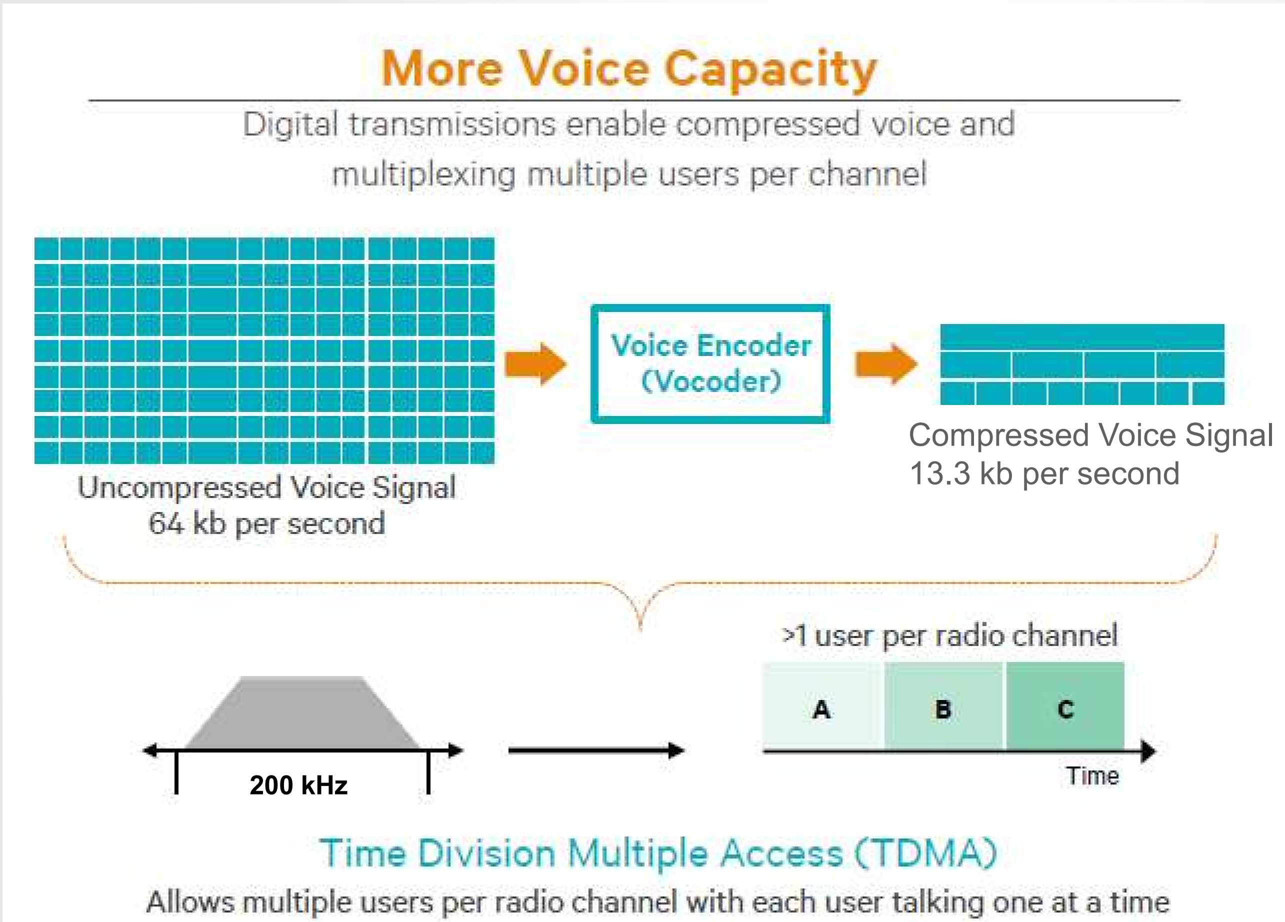
Frequency Modulation

- Voice quality is worse than fixed network
- Limited service – analog phone call only
- No data capability built in the system
- Similar to PSTN, audio coupling modem required for low rate data communication

* AMPS

Mobile 2G – Digitization for Massive Users

Digitized voice gives better quality & allows compression & time-sharing of a channel ➔ Wider channel BW for better spectral utilization



On top of Frequency Division Multiple Access (FDMA)

VAS services

- SIM: subscription separated from phone
- International roaming
- Short Message
- Circuit Switch Data
- Supplementary services

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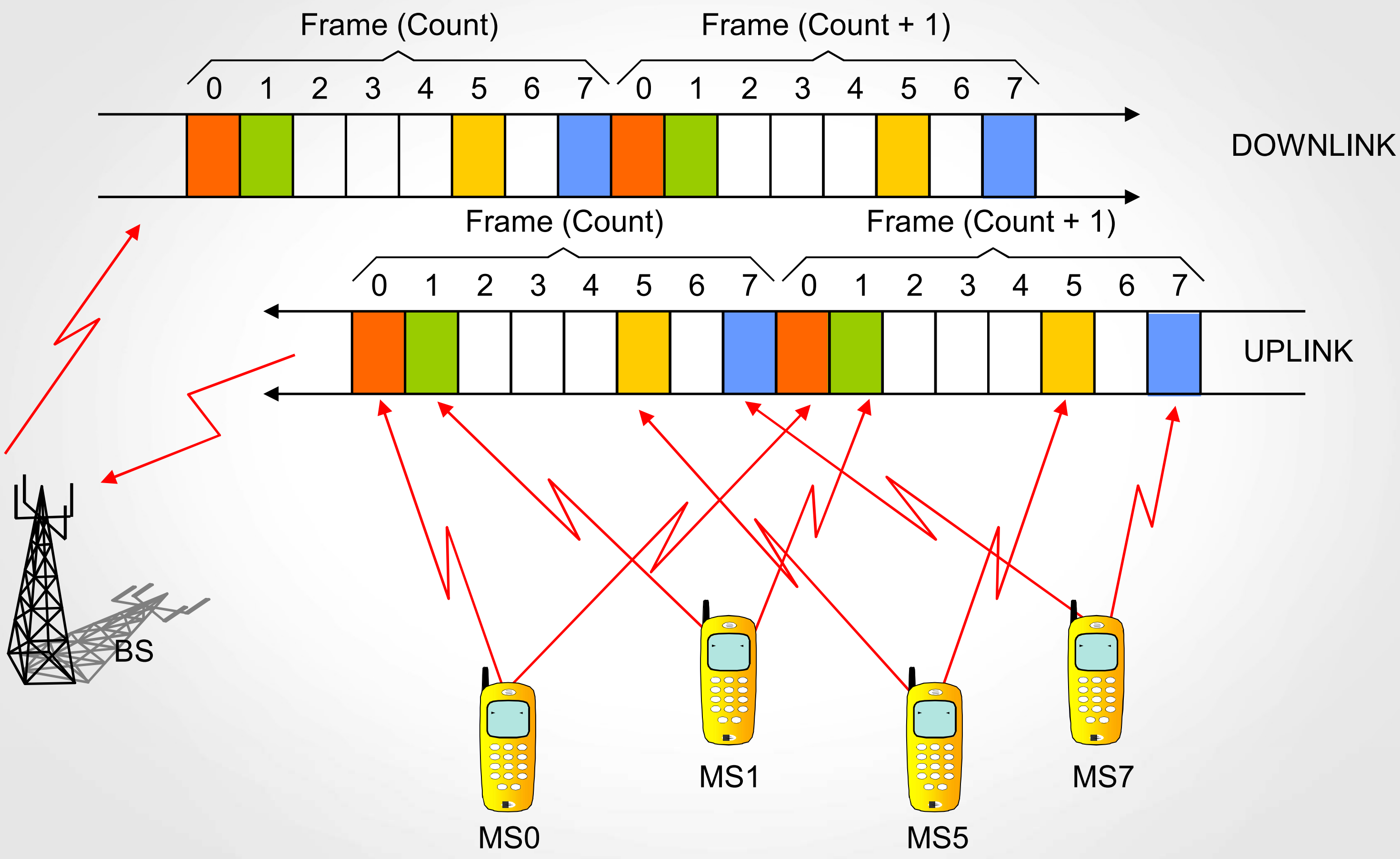
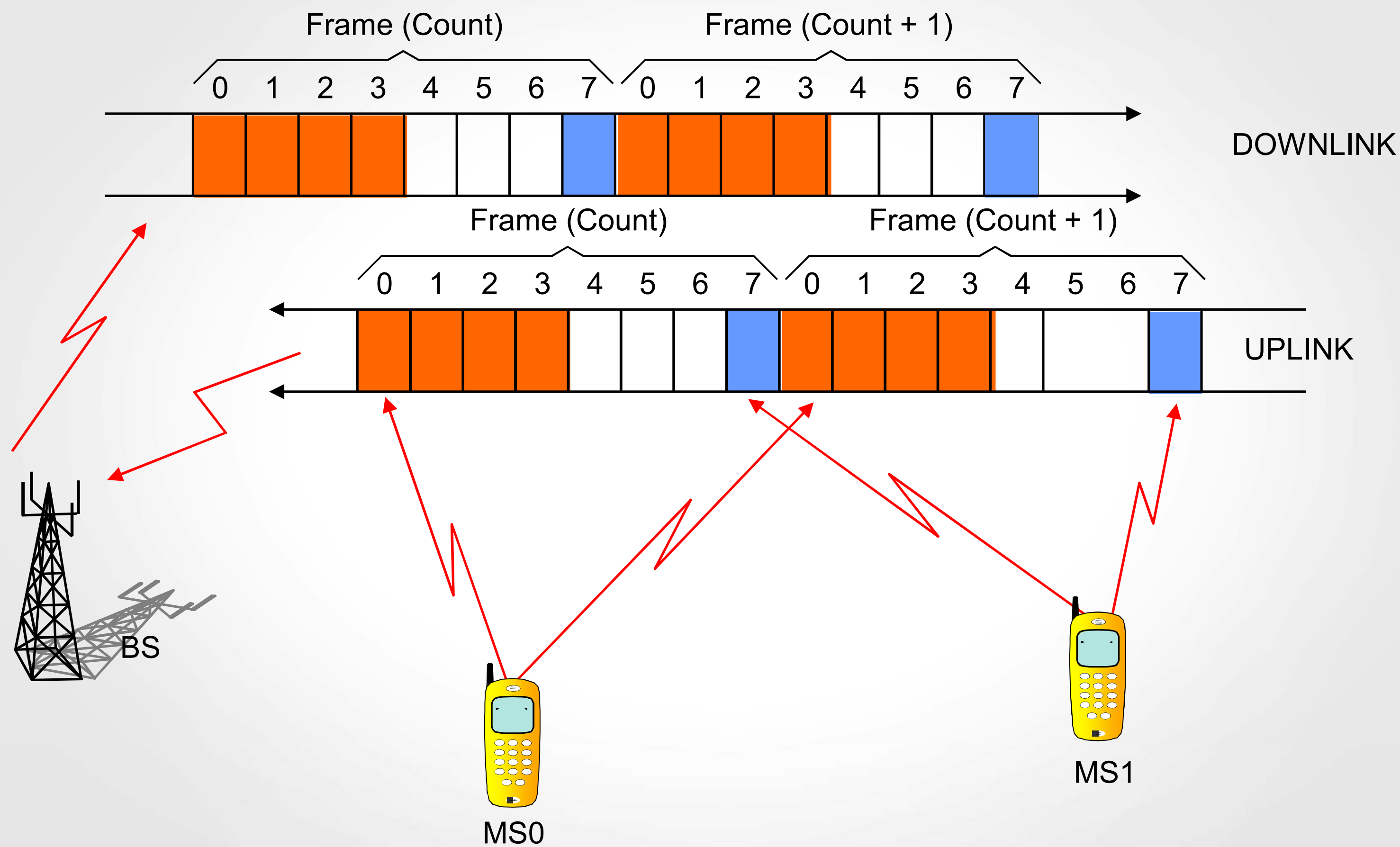
Mobile 2G – Circuit Switched Data Services



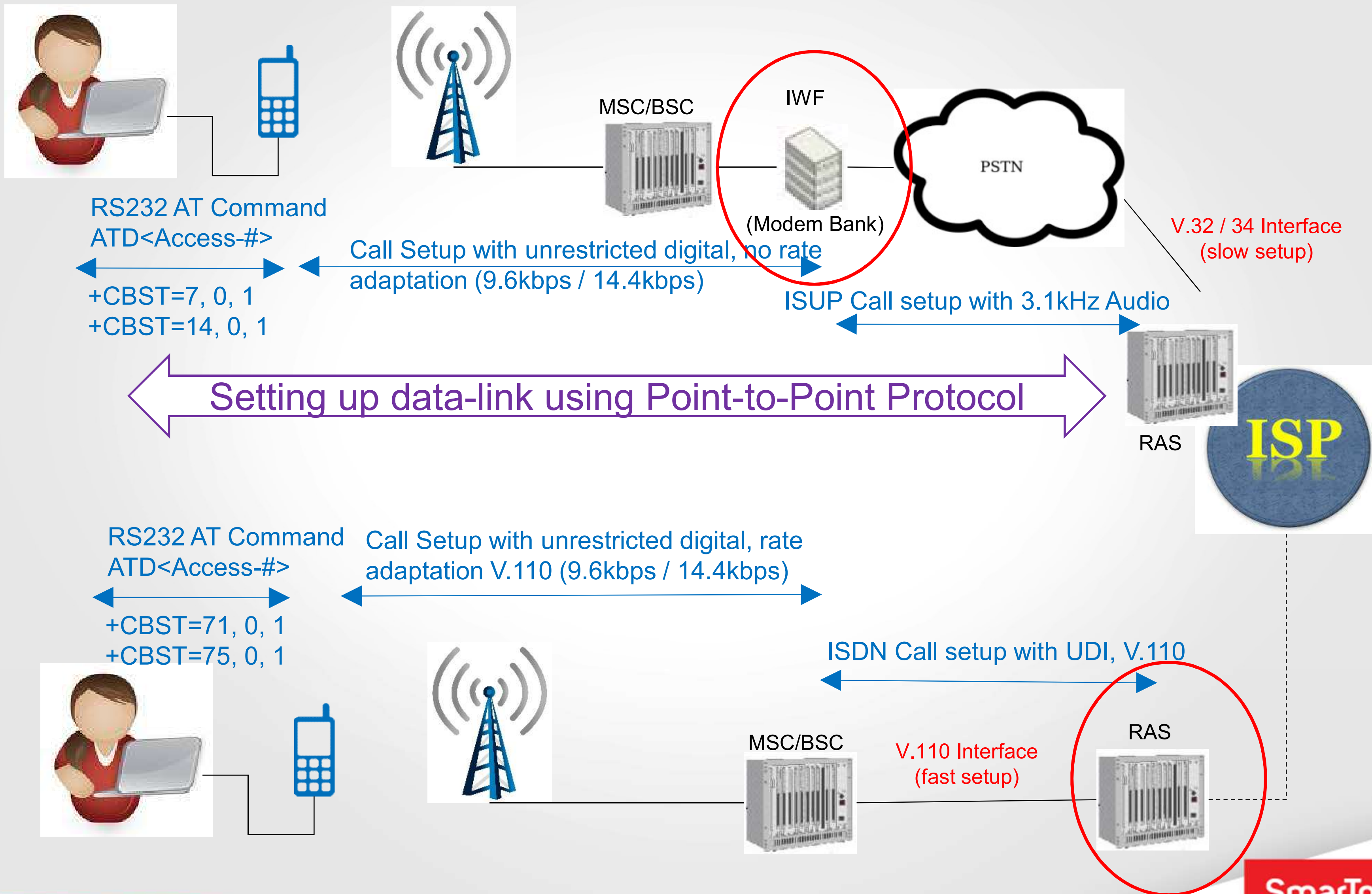
GSM CSD:9.6kbps / Timeslot

High Speed Circuit Switched Data (HSCSD)



GSM HSCSD: 14.4kbps / TS x 4 TS = 57.6kbps

Two Access Methods to ISP via Mobile CSD



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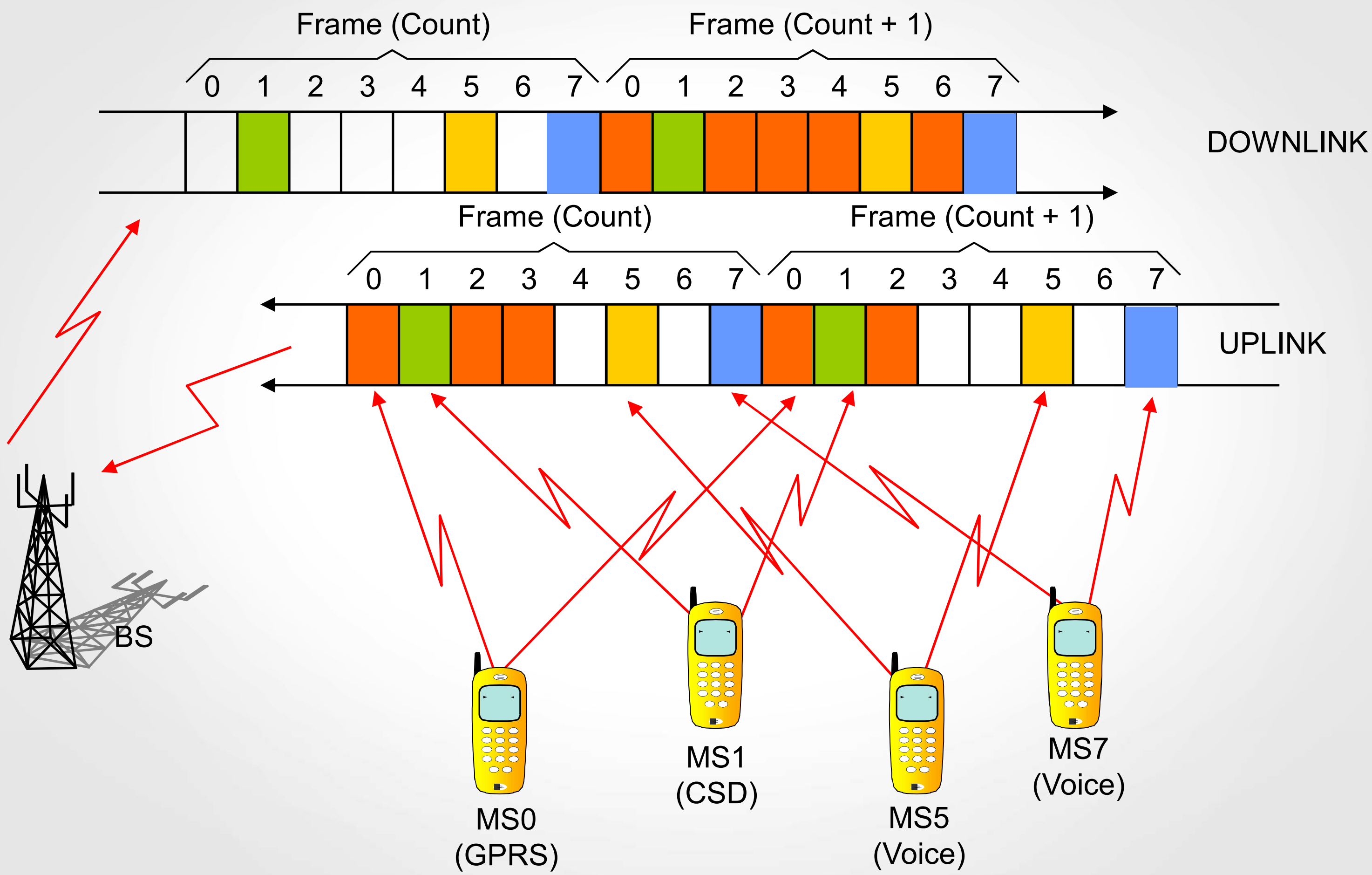
General Packet Radio Services (GPRS)

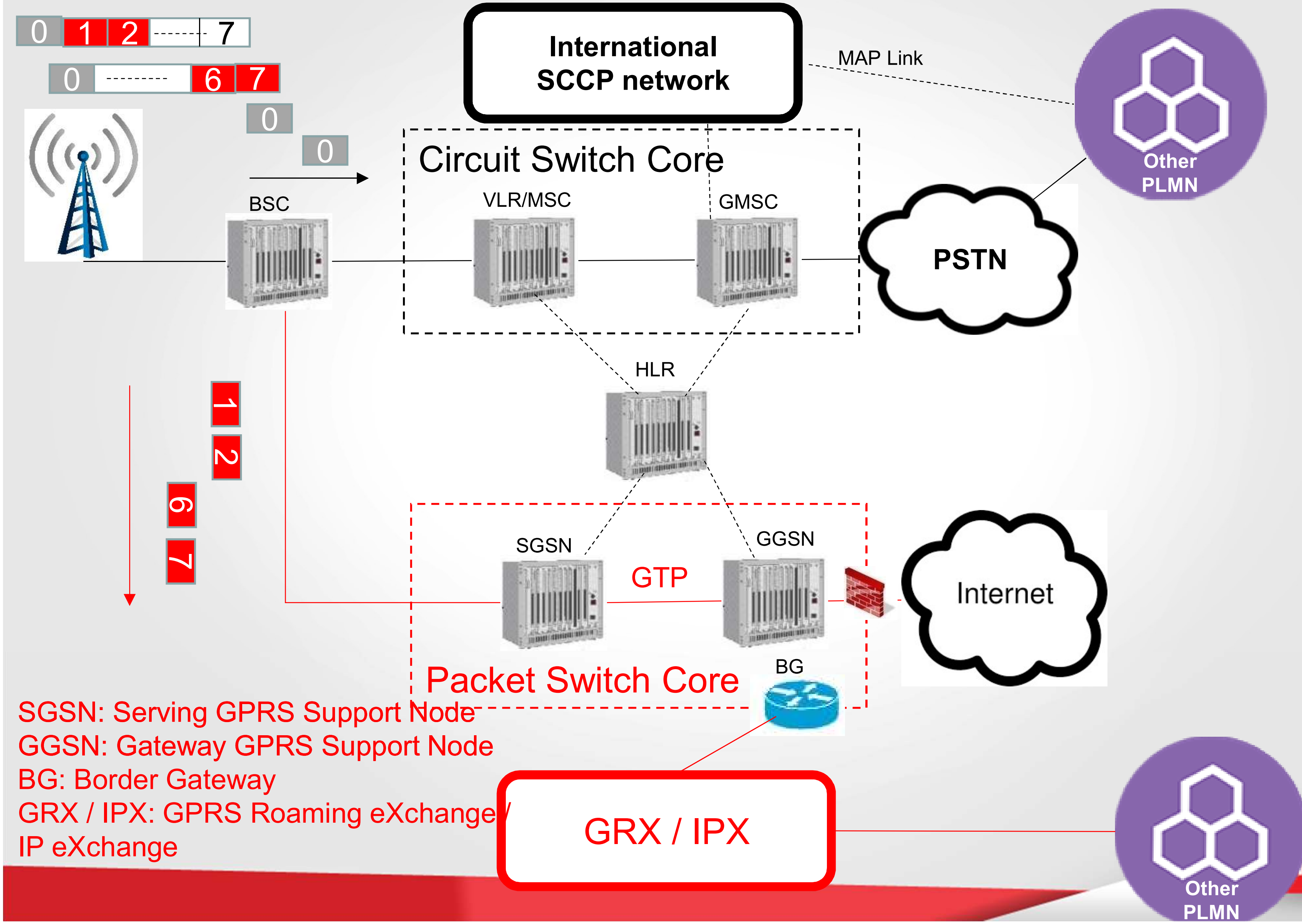


GPRS: Traffic is bursty & asymmetric over UL & DL → Timeslots are allocated on-demand basis

Mobile 2.5G – GPRS

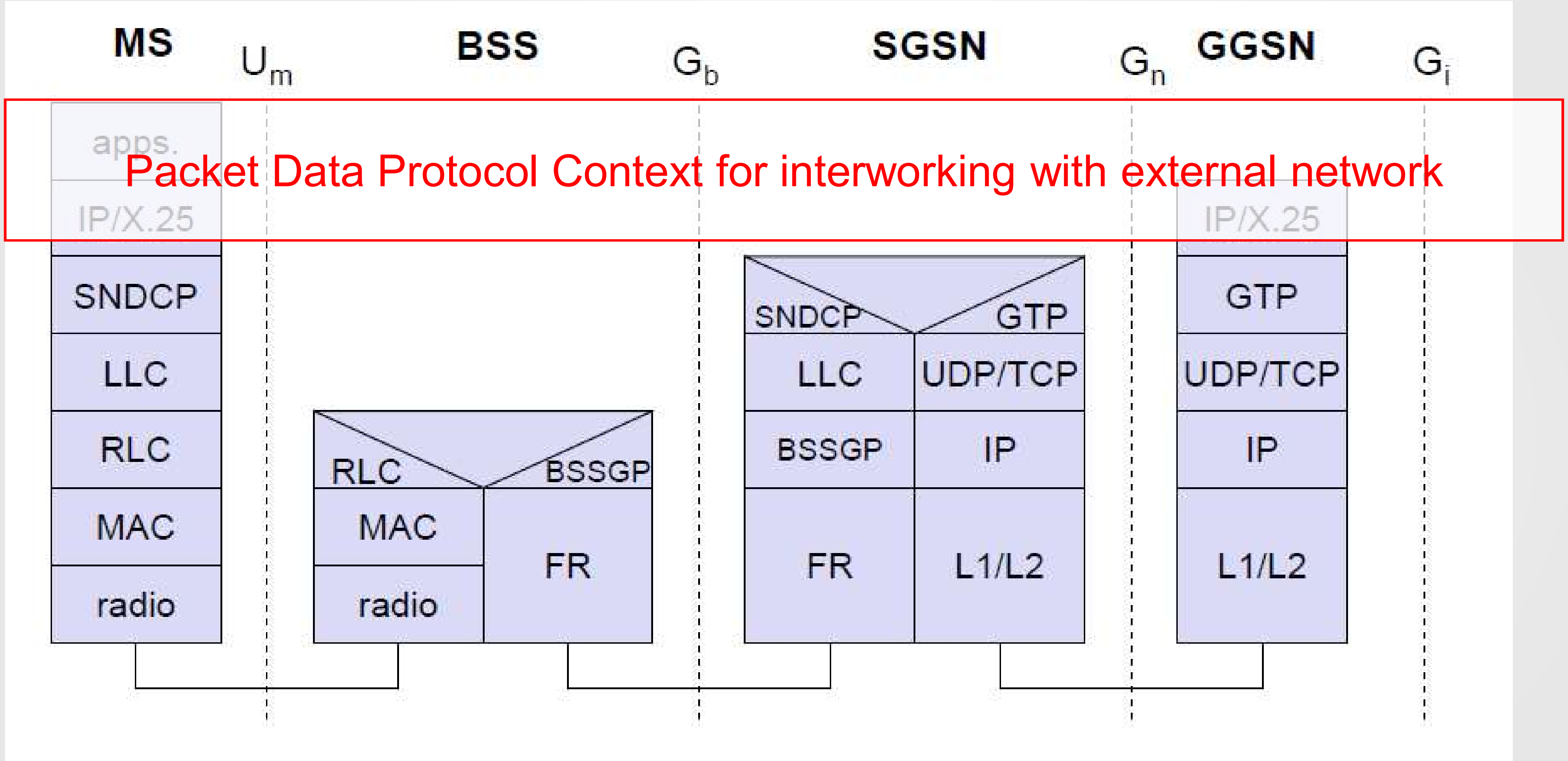
- Designed for bursty data traffic
  - Stays connected without wasting radio resources
  - Introduction of packet switching to the GSM network by overlaying a PS core network to CS network
  - Reuse of the GSM radio network infrastructure (logical packet data channels PDCHs)
  - Multi-slot combining traffic technology for bandwidth-on-demand (dynamically allocation of time-slots)
- Up to 4 (theoretically 8) timeslots for uplink and downlink
- 4 different channel coding schemes (CS) with different capabilities
  - Raw data rates from 9.05kbps (CS1), 13.4kbps (CS2), 15.6kbps (CS3) to 21.4kbps (CS4) / timeslot
  - User data rates of approx. 6, 9, 10 or 14kbps per timeslot
  - Theoretical maximum speed is 21.4 x 8 kbps (14 x 8) = 171.2kbps (112kbps)

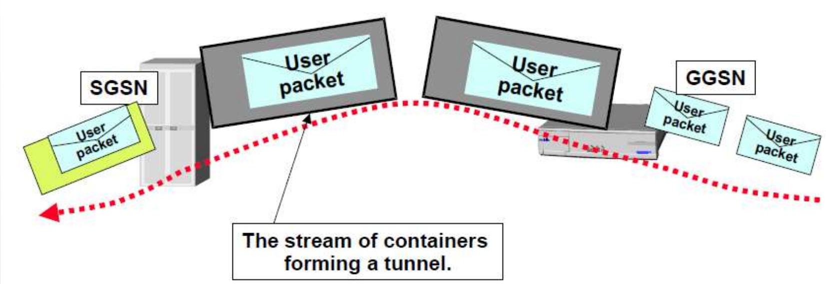
New Network Elements for Packet Switch



SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
BG: Border Gateway
GRX / IPX: GPRS Roaming eXchange / IP eXchange

GPRS Protocol Architecture





Functions of GPRS Support Nodes

- SGSN is a packet-switch core router between GGSN to Mobile Stations (MSs)
  - Handles PDP (Packet Data Protocol, eg. IP or X.25) contexts for MSs
  - Determines QoS assigned to the user
  - Mobility Management and Handover / Cell Change
  - Data segmentation and ciphering
  - Charging
- GGSN is a gateway to external packet data network
  - Based on the Access Point Name (APN) to identify the external packet data network that mobile user wants to communicate to; hence, it is acting as an Access Server
  - IP address allocation to the device corresponding to the APN by itself or help of DHCP or RADIUS server
  - Can support multiple SGSNs; anchor point that enables the mobility of the user terminal moving from one SGSN to another SGSN
  - Provide packet data buffer during changeover of SGSNs
  - Charging

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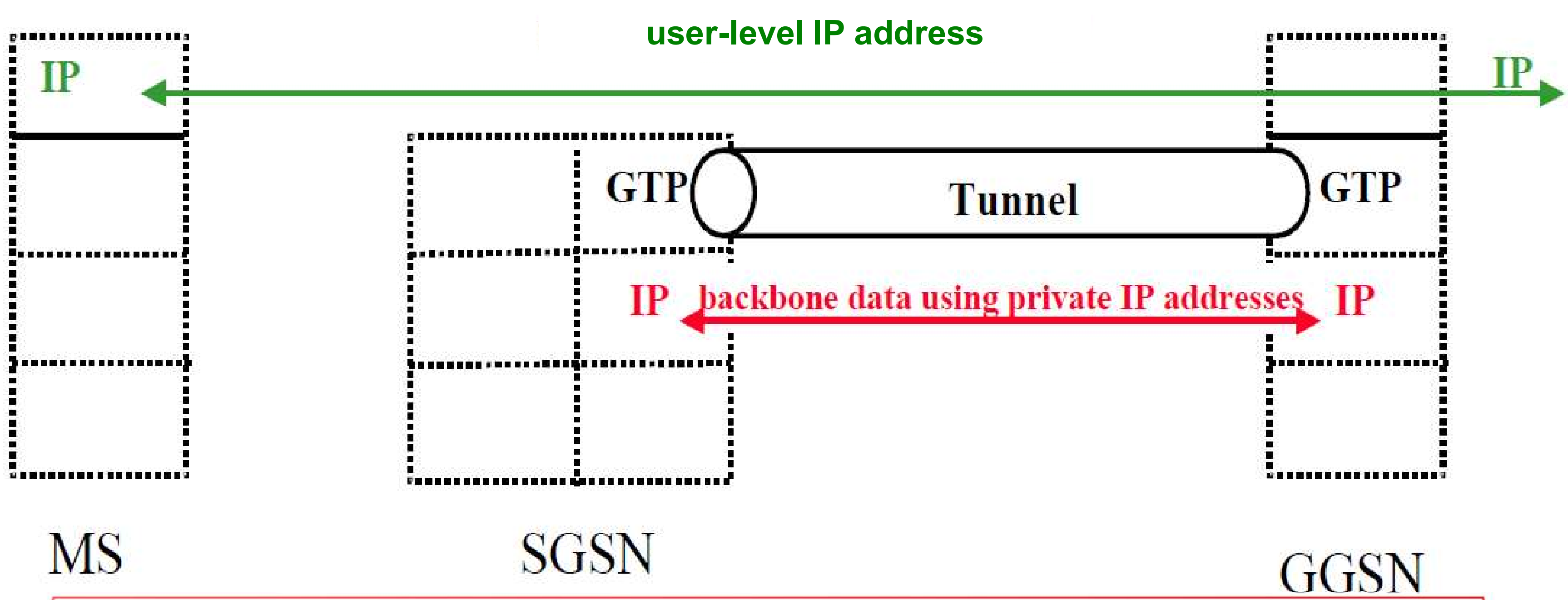
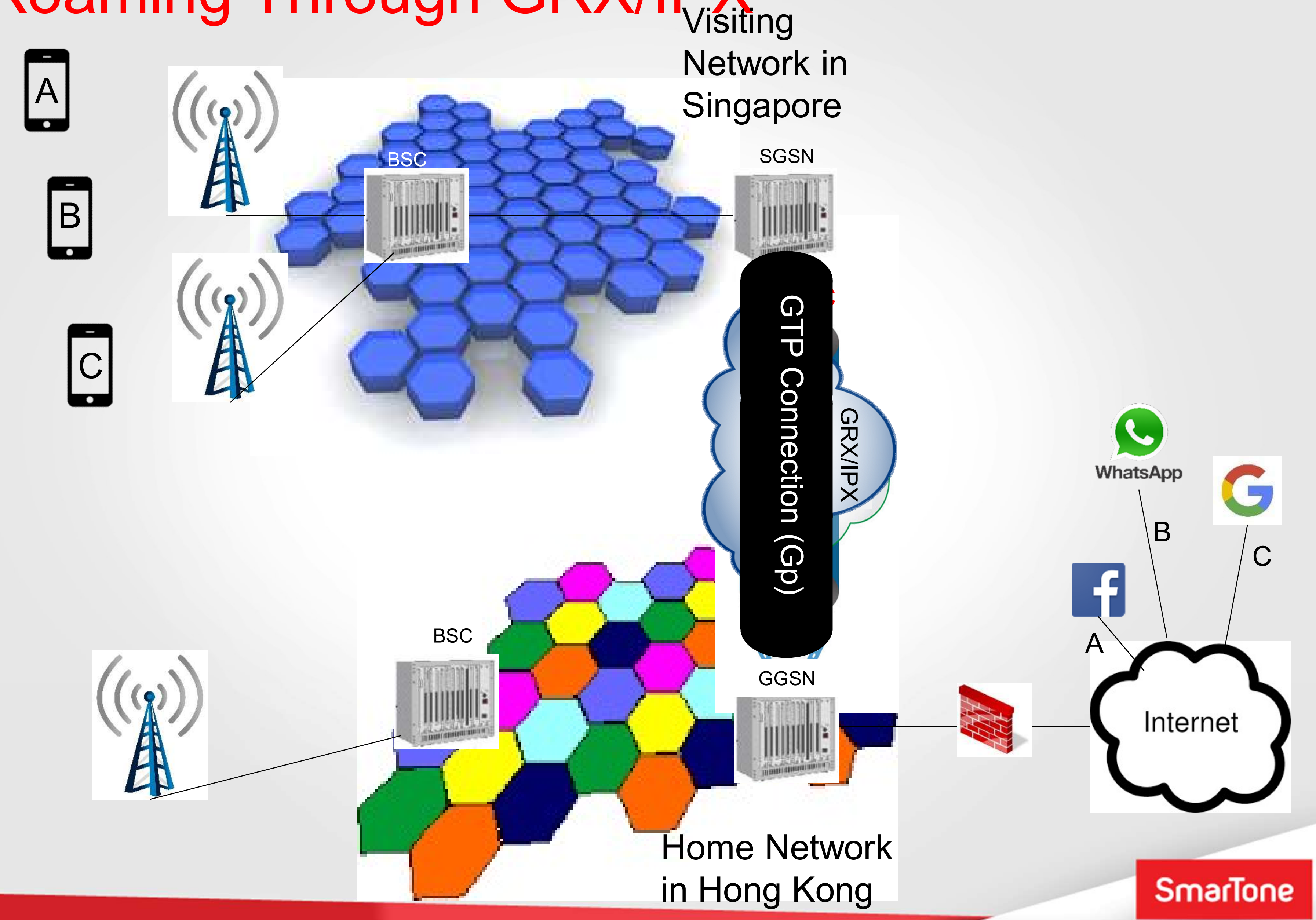
GTP hides network entities from user-level



GPRS Tunneling Protocol (GTP)

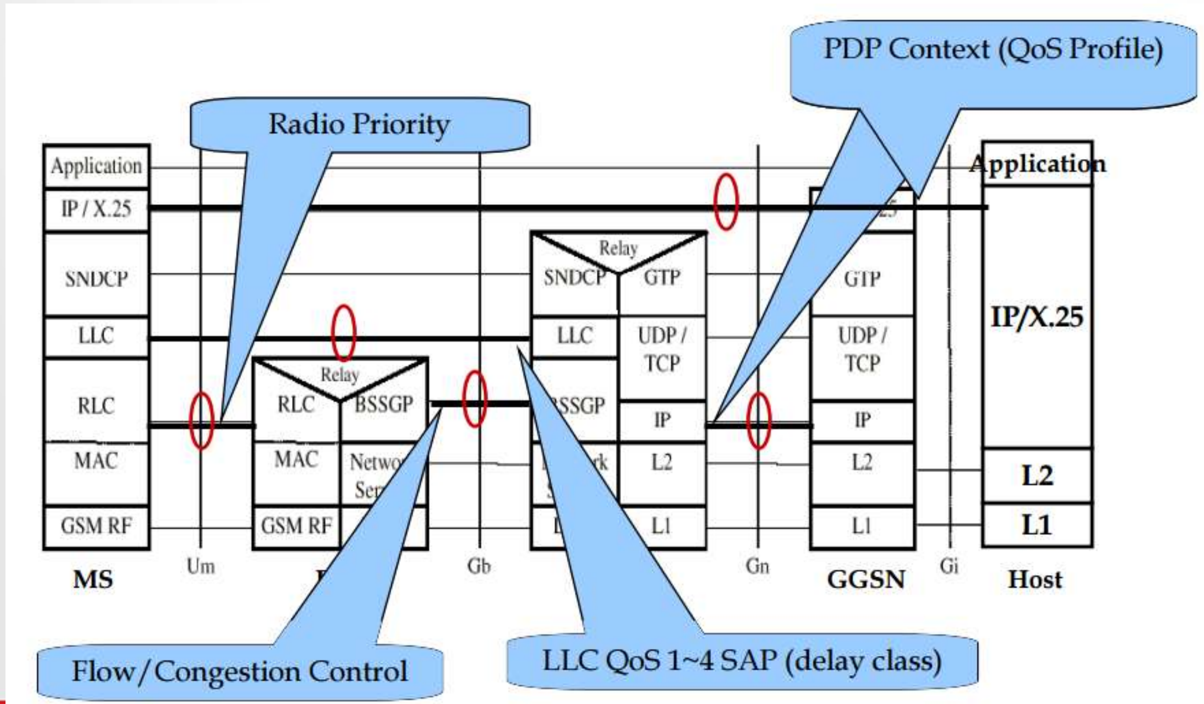
- It is an efficient network protocol (UDP basis) to transfer data over GPRS backbone;
- It makes invisible to user level by concept of tunneling;
- It provides mobility, i.e. User can move from one SGSN to other SGSN;
- It facilitates to route all packet data between visiting SGSN and home GGSN via node-to-node connection while roaming

Roaming Through GRX/IPX



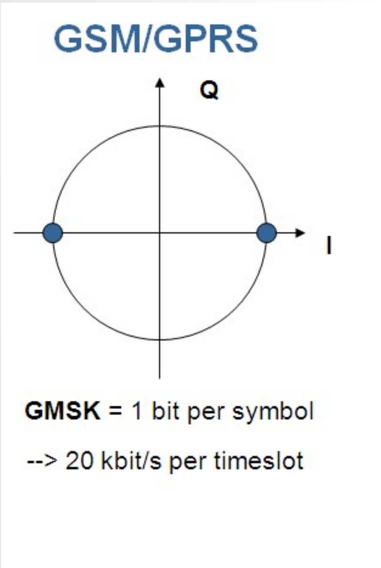
Mobile Quality of Service (QoS) Profile

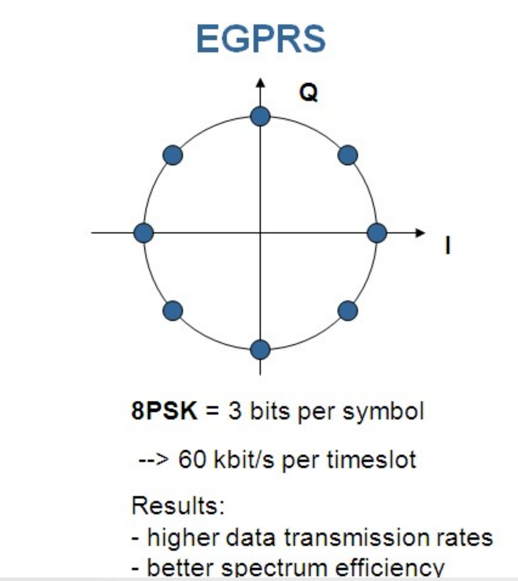
- GPRS QoS is classified at radio interface for timeslot allocation strategy
- It is negotiated per PDP context in GTP to meet different service requirements
- QoS Profile consists of:-
  - Service Precedence (high, normal, low)
  - Reliability
  - Delay (between mobile station and Gi interface)
  - Throughput (peak and mean bit rate)

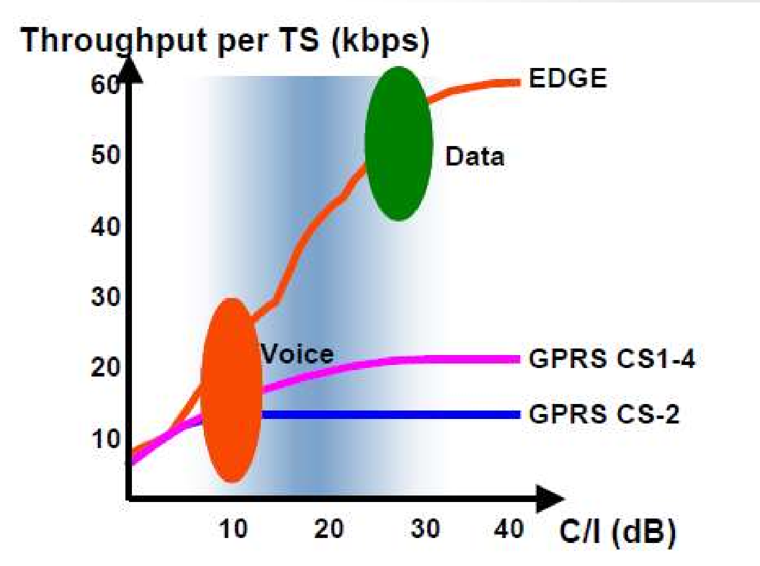


Mobile 2.75G – Enhanced Data rate for GSM Evolution

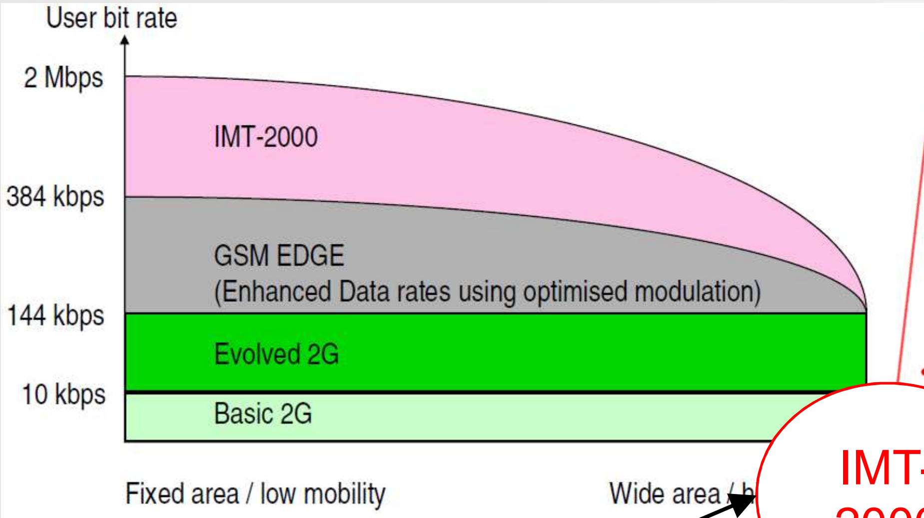
- Uses GSM / GPRS, but with higher-level modulation
  - Eight Phase Shift Keying (8-PSK) instead of Gaussian Minimum Shift Keying (GMSK)
  - Choice of 9 Modulation Schemes
  - Allows up to 48kbps per timeslot, 384kbps using 8 timeslot
  - More robust radio protocol
  - Link Quality Control for reliable link quality and efficient use of radio resources





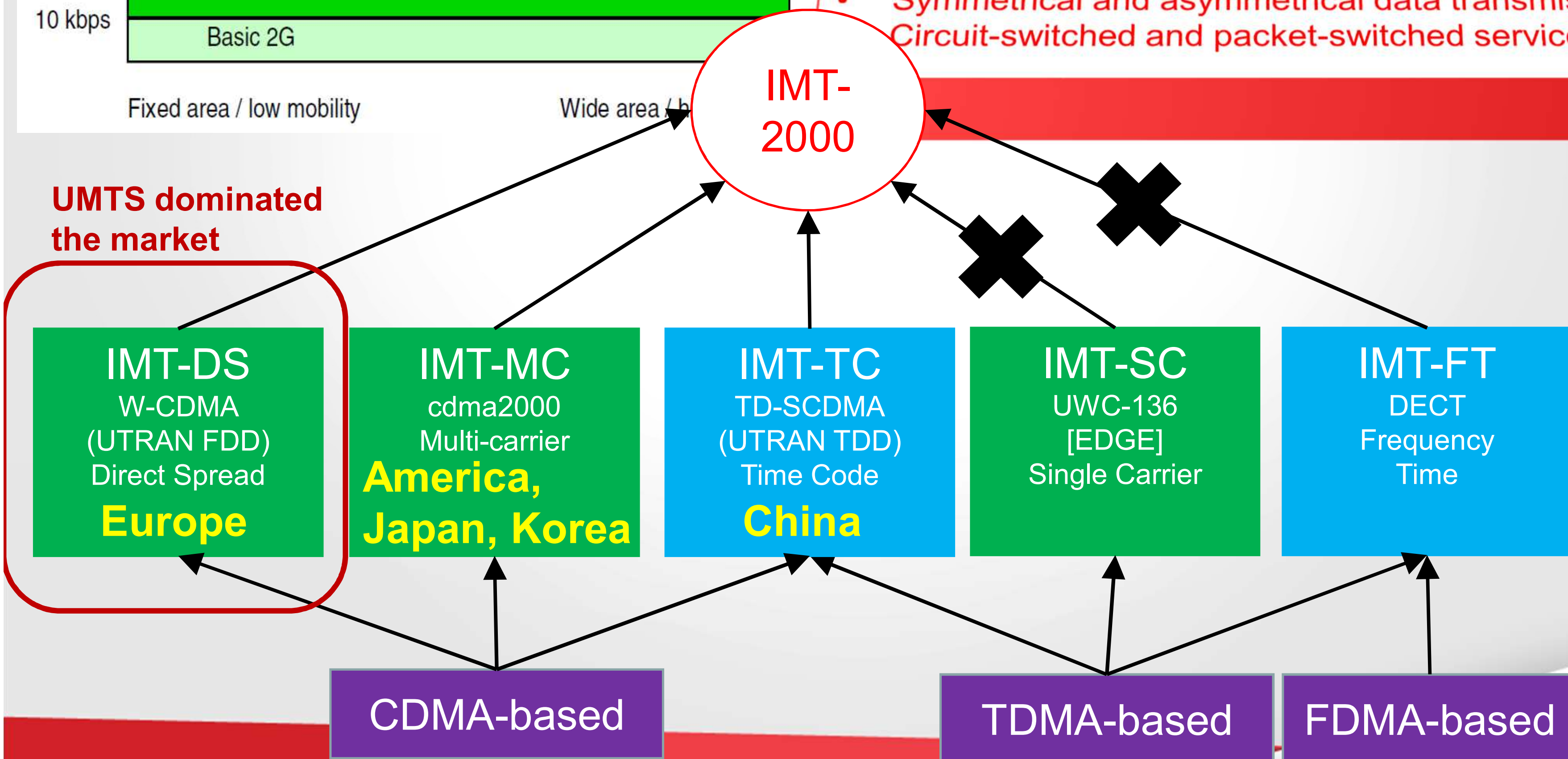


Mobile 3G – IMT-2000 / UMTS

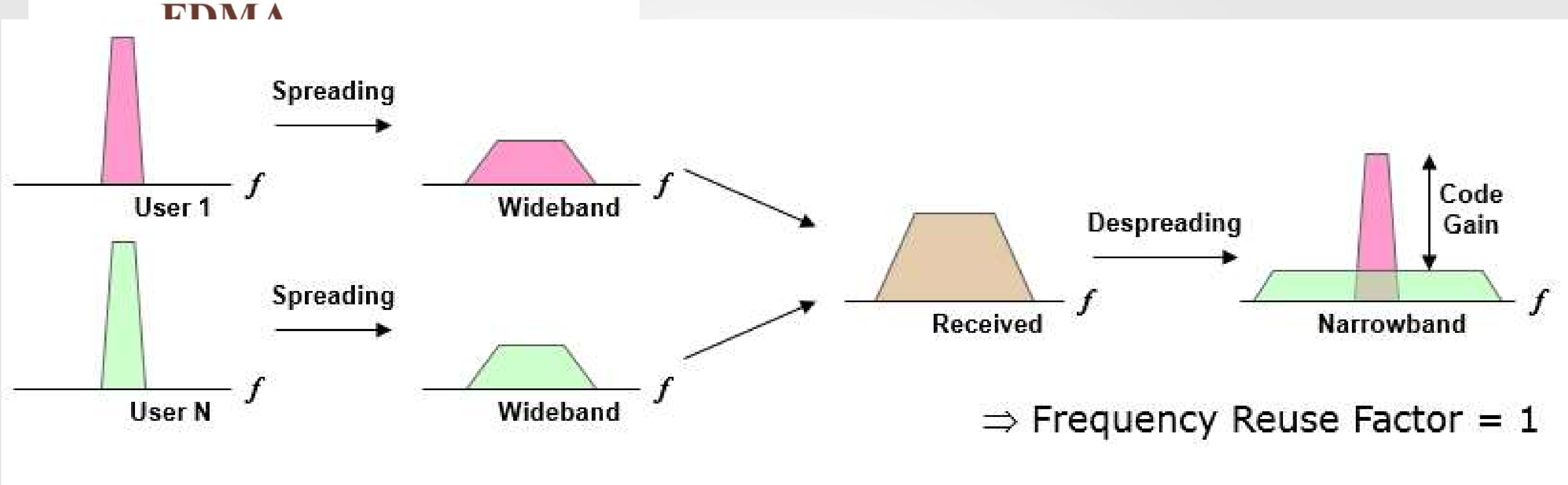


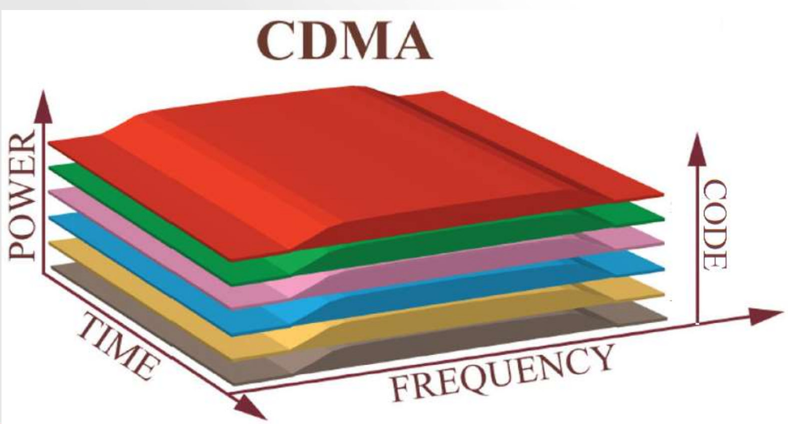
<u>IMT-2000 International Mobile Telecommunications</u>

- *ITU globally coordinated 3G covering key issues such as frequency spectrum use and technical standards;*
- *High transmission data rates for indoor and outdoor use;*
- *Multimedia services through high speed, high quality transmission with QoS classes*
- *Symmetrical and asymmetrical data transmission*
- *Circuit-switched and packet-switched services*



Code Division Multiple Access





A new dimension, "mathematical but not physical"
"Code" – A set of orthogonal codes such as Walsh Code is used for multiple users to share the same Frequency-Time space

Benefits of Wideband CDMA

- High capacity because of high frequency reuse factor
- More efficient use of spectrum resources
- Low power spectral density causes less interference to other systems
- Good anti-jam and significantly reduction of multi-path effects
- High data rate as wide band carrier (5MHz) and better SNR
- Better security with unknown pseudo random codes adopted in spreading
- Random access is possible as user can start their transmission at any arbitrary time
- Less call drop due to soft handoff is achievable

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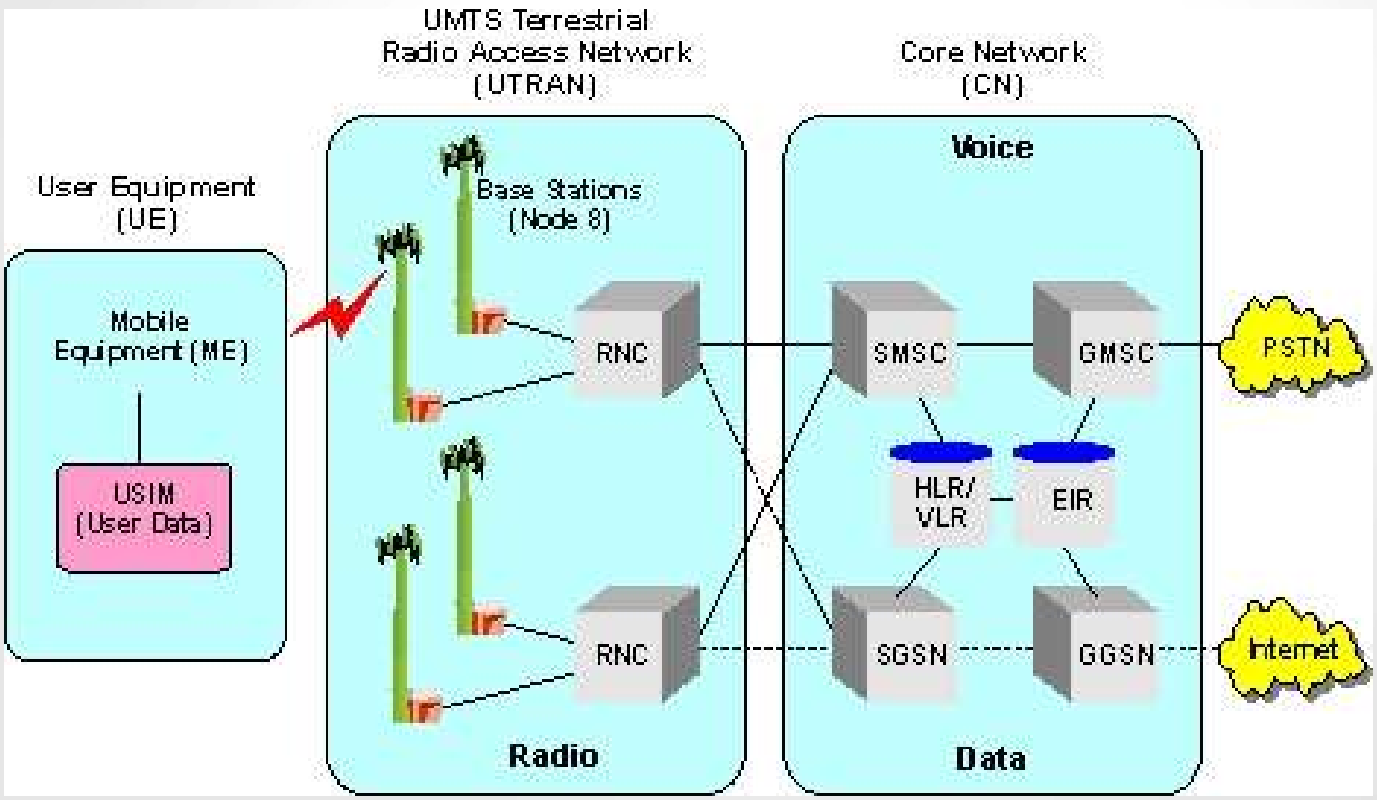
UMTS / W-CDMA – New Network Architecture

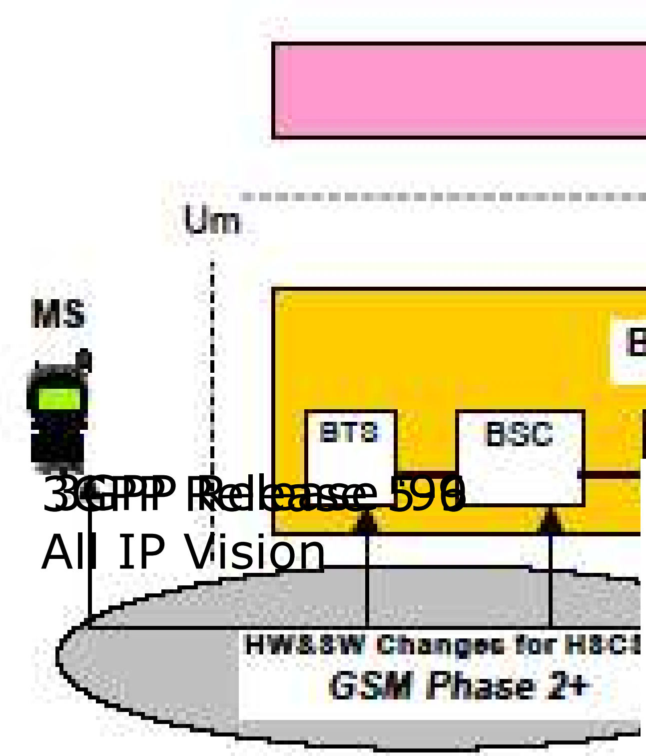
- Overall network classified into 3 domains
  - Core Network (CN), Radio Access Network (RAN) & User Equipment (UE)
  - Reuse of GSM/GPRS Core Network for smooth transition path



Road to All IP Mobile Data Network

Introduction of GPRS / E-

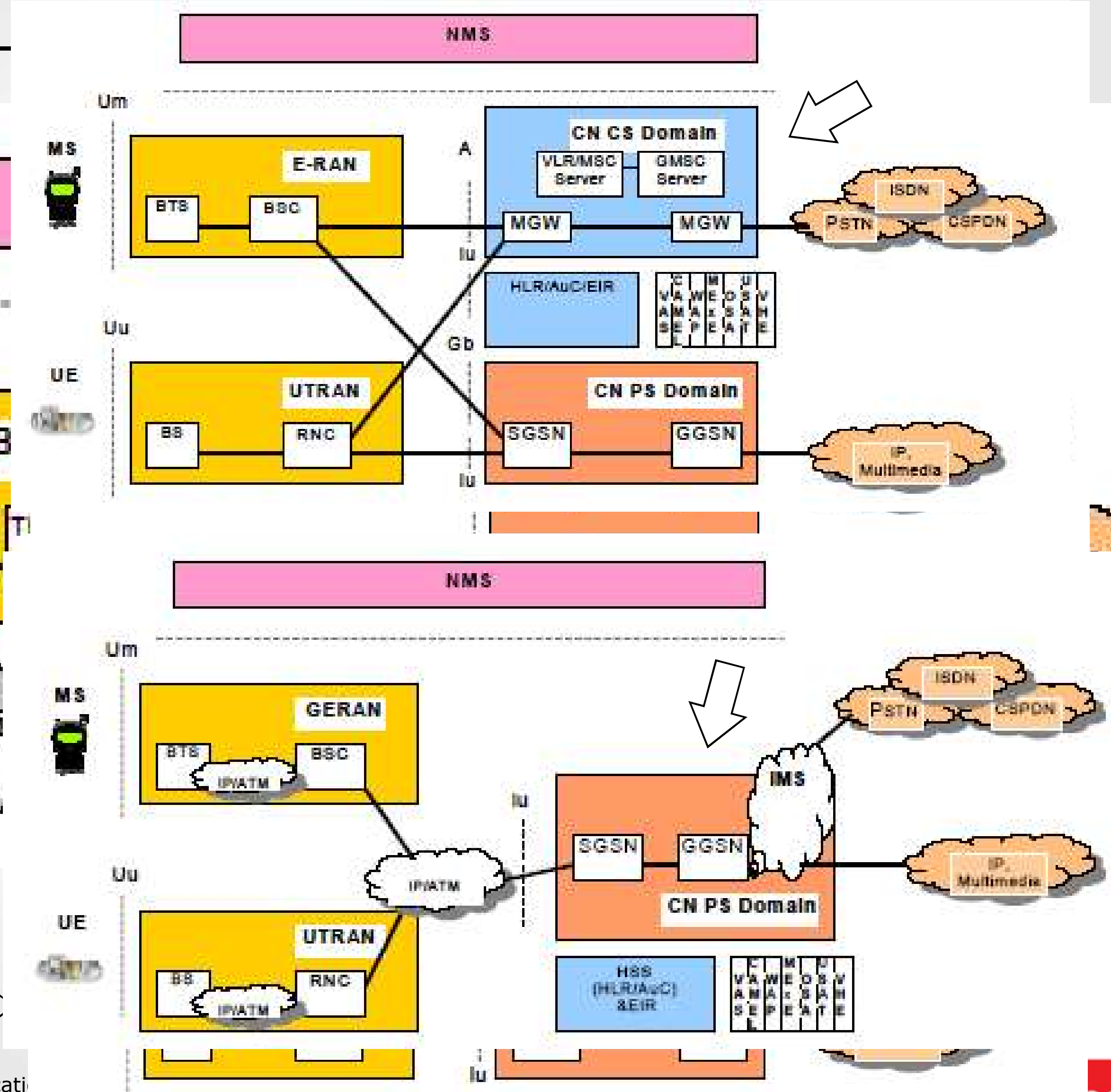
3GPP Release 4



3GPP Release 5

3GPP Release 6

All IP Vision



Source : Overview of UMTS, Guoyou He, Telecommunicati

Mobile 3.5G - High Speed Packet Access (HSPA)

- There were number of pushing forces to improve the packet data capabilities of WCDMA even further, e.g.
  - Growing interest towards rich calls, mobile-TV and music streaming in the wireless domain
  - Competitive technologies such as WIMAX (designed for 30-40 Mbps)
- HSPA evolution introduced in two phases
  - First for downlink called <u>High Speed Downlink Packet Access</u> (HSPDA) in Release 5; targeted to achieve <u>14.4Mbps at peak</u>
  - Then for uplink as <u>High Speed Uplink Packet Access</u> (HSPUA) in Release 6, targeted to achieve <u>5.8Mbps at peak</u>
- HSPA Properties
  - Adaptive & high order modulation (16/64 QAM much better than QPSK)
  - Smaller latency (from 200ms to 100ms or less, ~ 50ms)

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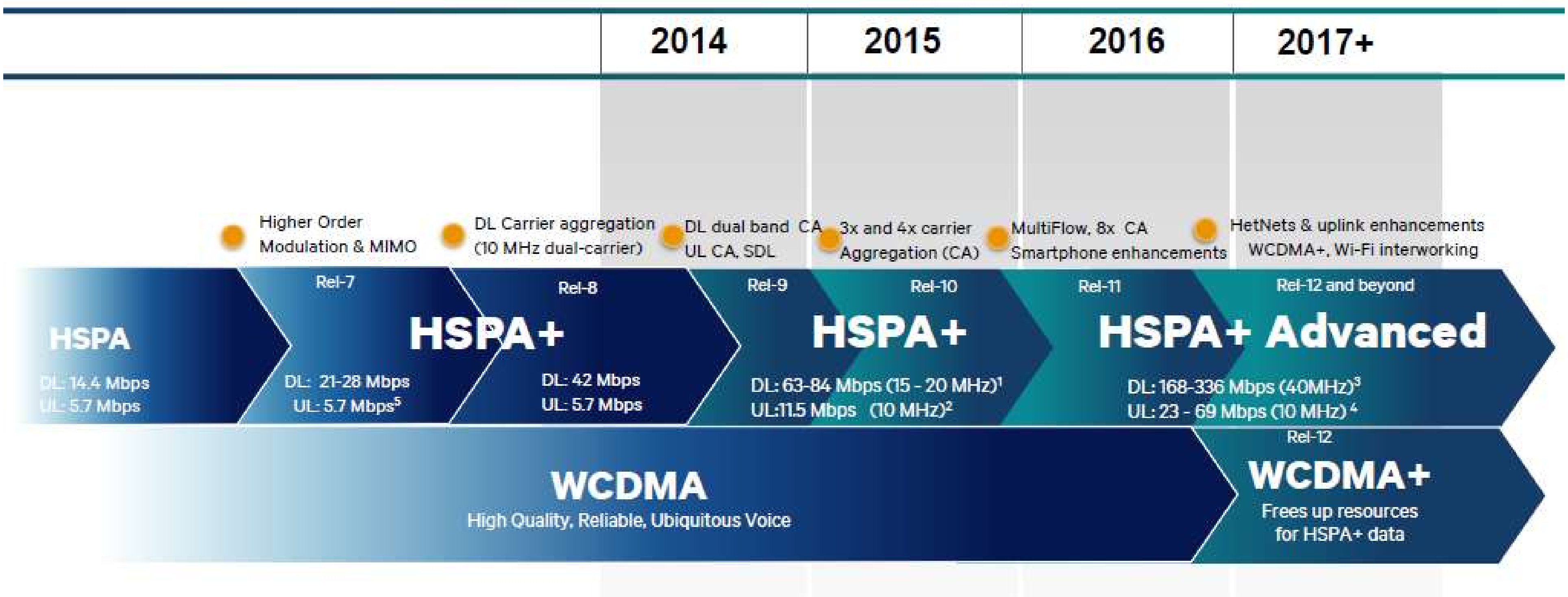
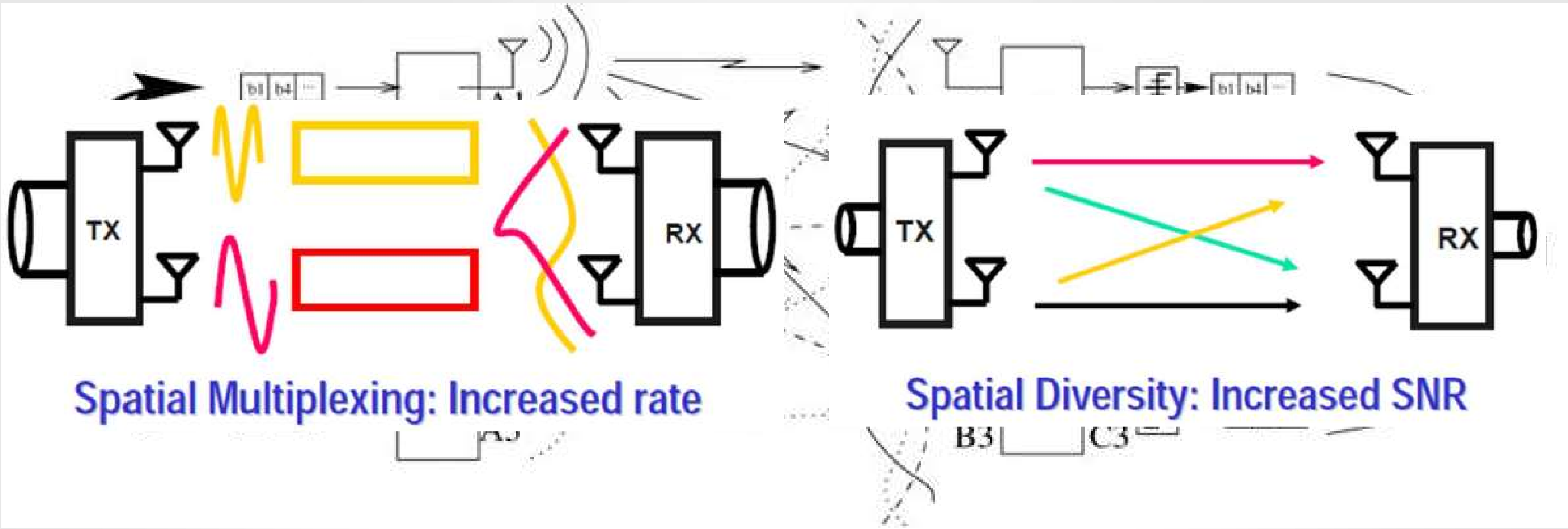
Mobile 3.75G – HSPA Evolution (HSPA+)

- Adopting the technologies to improve data rate further
  - Higher order modulation & Multiple-Input Multiple-Output (MIMO)
  - Carrier Aggregation
- UL: 5.8Mbps / DL: 14.4Mbps → UL: 5.9Mbps / DL: 42Mbps in Rel-8 or UL: 11Mbps / DL: 42Mbps in Rel-9 specified 2CC for both UL & DL



Multiple-Input Multiple-Output Concepts



- Multiple TX Antennae (Nt) & Multiple RX Antennae (Nr) system
- Core scheme of MIMO is “Space-Time” coding (STC) to resolve multipath issues
- Two main functions of STC: Spatial multiplexing & diversity
- Spatial Multiplexing provides multiple data links (min[Nt,Nr]) for higher data rate
- Spatial diversity provides better transmission quality (Lower Bit Error Rate)

Carrier Aggregation Concepts

- Carrier aggregation enhances broadband experience

4 CC: 84Mbps
Future

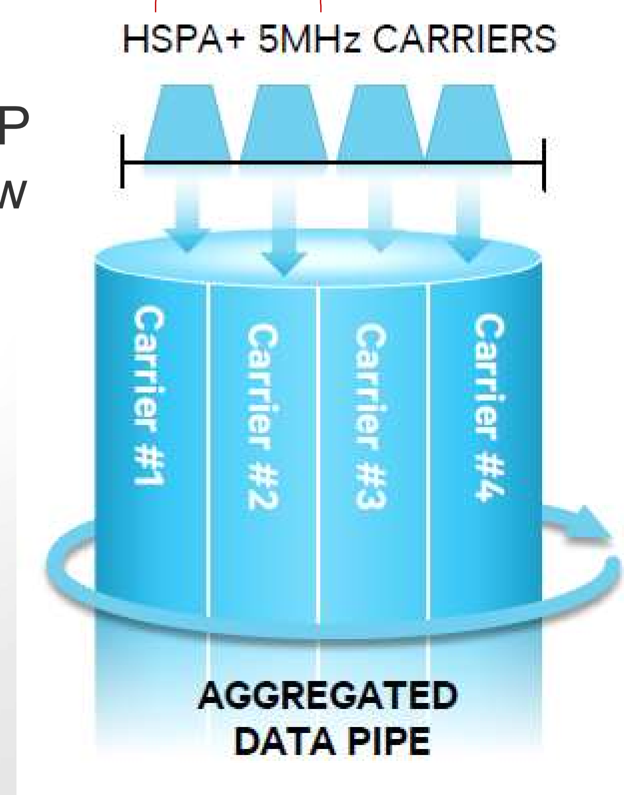
  - All users in the cell improved with higher data rates and lower latencies

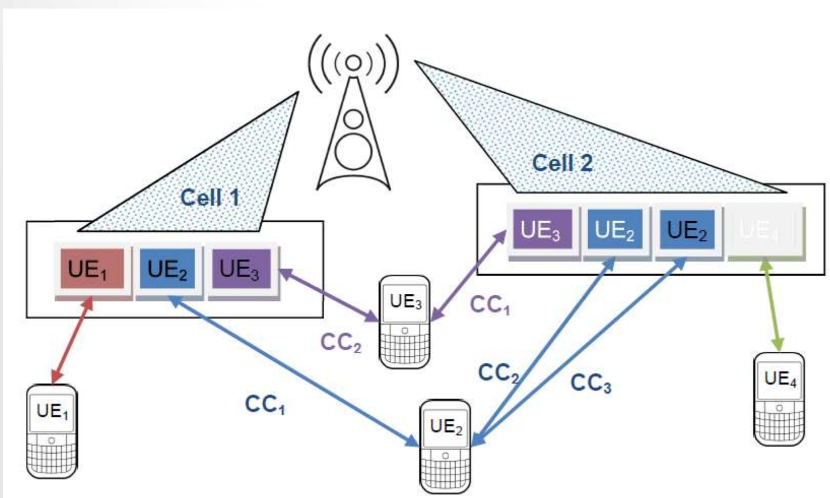
3 CC: 63Mbps
Commercial in use

- Evolving to leverage all spectrum assets

2 CC: 42Mbps
Commercial in use

  - Aggregation across bands, across carriers (multi-flow), more carriers, and uplink
- Benefits Heterogeneous Network (HetNet) / CoMP (across multiple cells) – even better with multi-flow because of less interference





Mobile 4G: 3GPP Long-Term Evolution (LTE)

- LTE is a convergent technology to evolve not only UMTS but also of CDMA2000, specified in Rel-8 in year 2008
- LTE introduced to get higher data rates, peak DL at 150Mbps and peak UL at 75Mbps by 20MHz DL & UL bandwidth
- LTE with low radio latency (<10ms) and high data rates for VoIP, streaming multimedia, video-conferencing
- All IP network with QoS to meet constant latency and bandwidth real-time services such as VoIP
- LTE supports flexible & scalable carrier bandwidth from 1.4MHz, 3MHz, 5MHz, 10MHz to 20MHz with paired (FDD) and unpaired (TDD) spectrum allocation on 2G, 3G or new spectrum to meet different network operators
- LTE provides better spectral efficiency than UMTS for higher capacity

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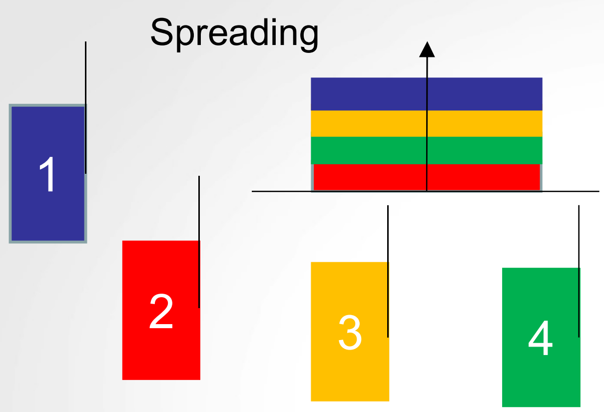
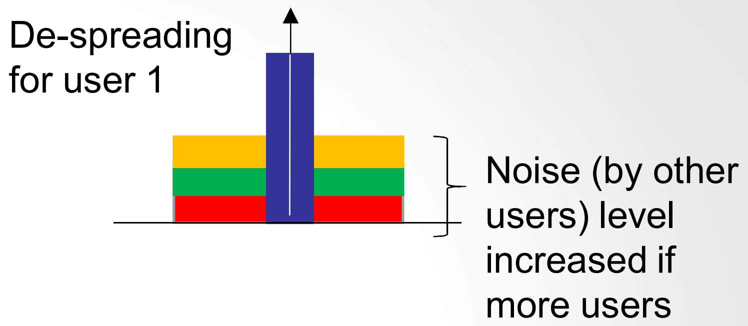
Disadvantages of WCDMA

- Signal-to-Noise Ratio gets worse when more users in the same cell





- Not efficiently use the spectrum because full bandwidth of carrier is used no matter how much user data rate to be served
  - Cannot benefit from scalability in using the radio resource in frequency and time domain

- Not flexible in carrier bandwidth because each carrier needs 5MHz bandwidth. By carrier aggregation, spectrum needs to be integer number of 5MHz

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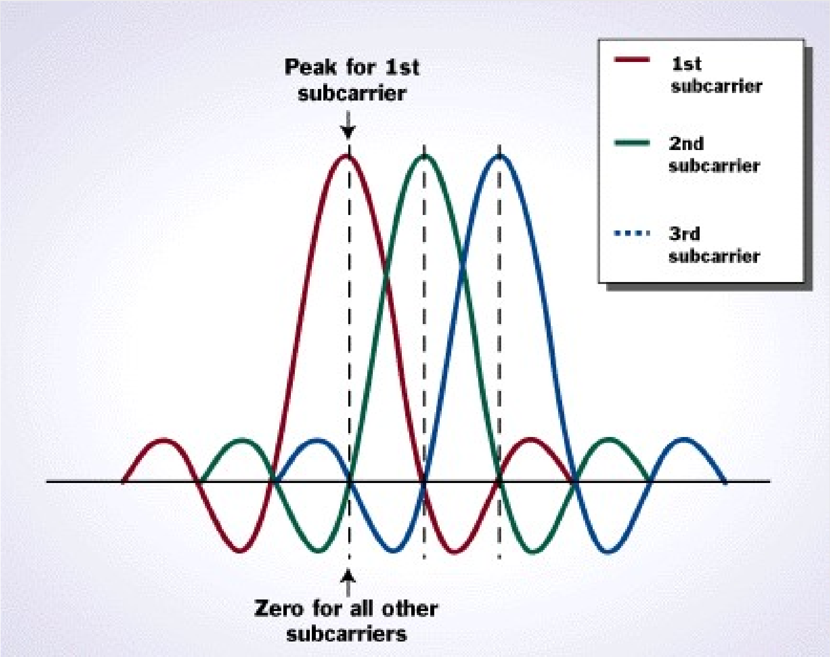
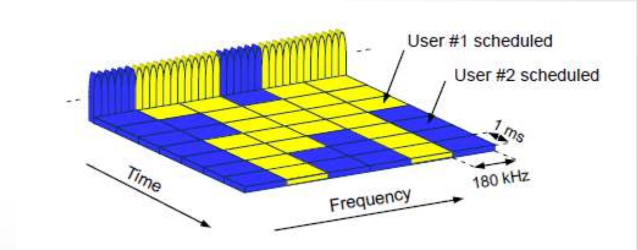
Orthogonal FDMA meets LTE requirements

- FDMA: data transmitted through a large number of bandwidth carriers (sub-carrier)
  - serial data stream transferred into parallel multiple streams for higher data rate but spectrum wasted by too many band gaps
- Sub-carriers created orthogonally not only remove band gaps but also further reduce total bandwidth by overlapping
- Similar to TDMA + FDMA, 1 TS on 12 sub-carriers are grouped as a resource block, a pool of resource blocks are shared by multi-users for better spectral utilization
- Grouping different # of resource blocks for different channel bandwidths
  - 6 channel bandwidths specified in LTE





Channel bandwidth $BW_{Channel}$ [MHz]	1.4	3	5	10	15	20
Number of resource blocks	6	15	25	50	75	100

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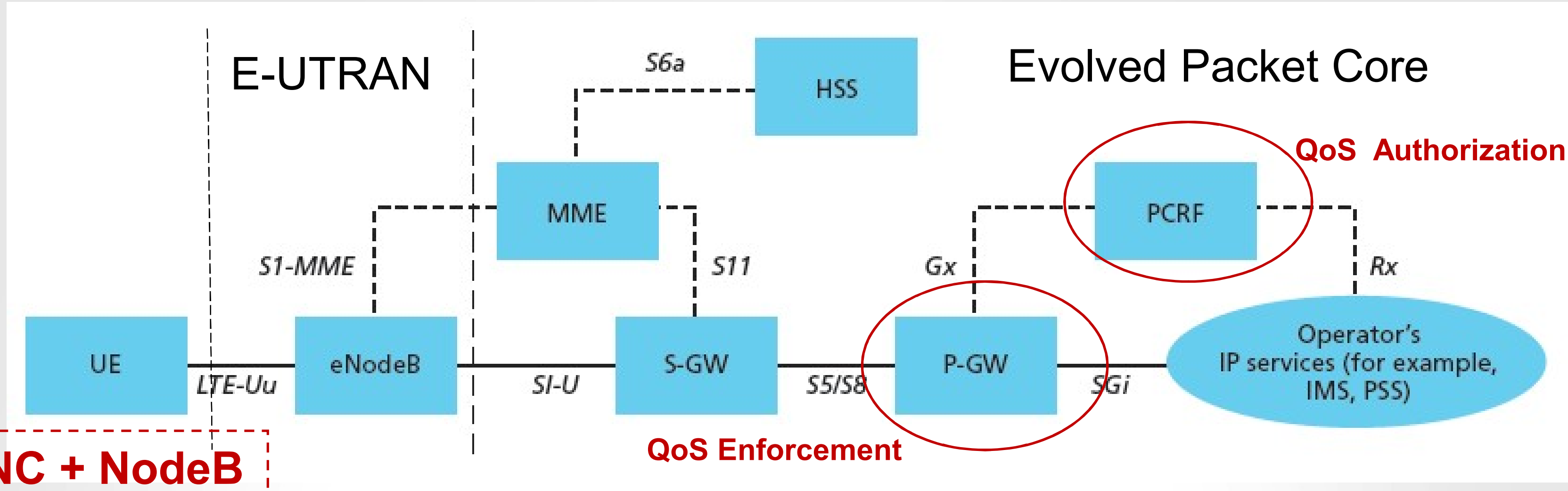
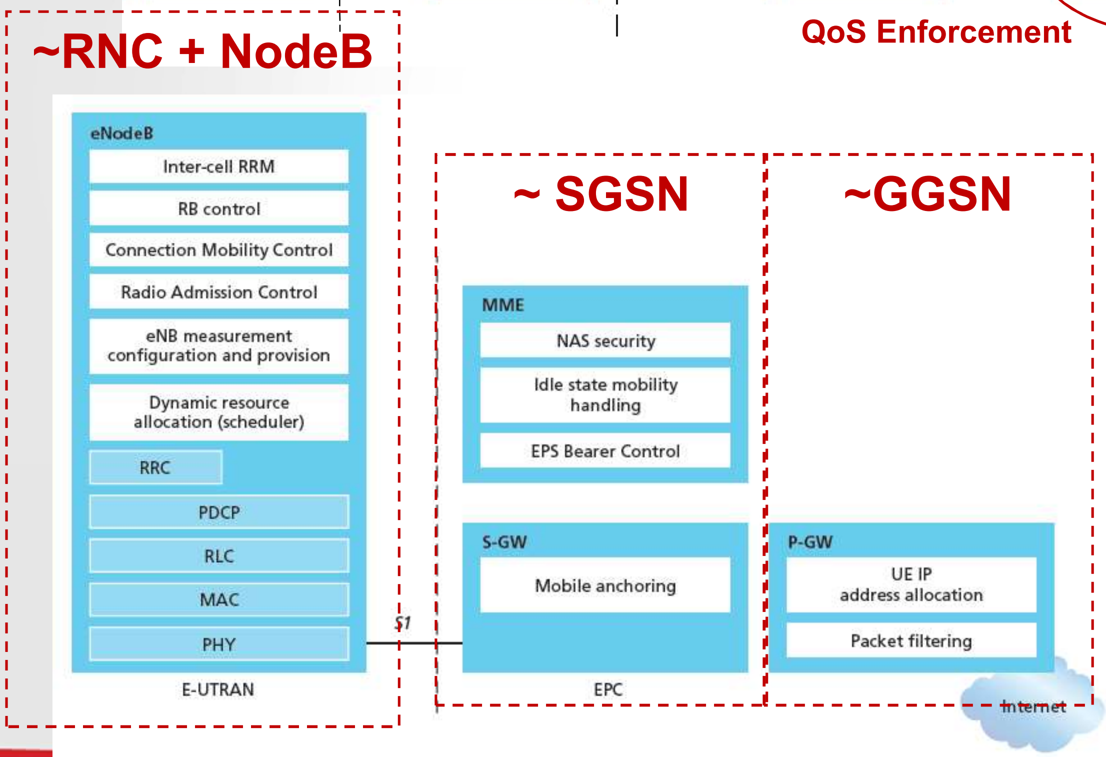
LTE IP Network Architecture





HSS: Home Subscriber Server

MME: Mobility Management Entity

P-GW: PDN Gateway

PCRF: Policy Control & Charging Rule Function

S-GW: Serving Gateway

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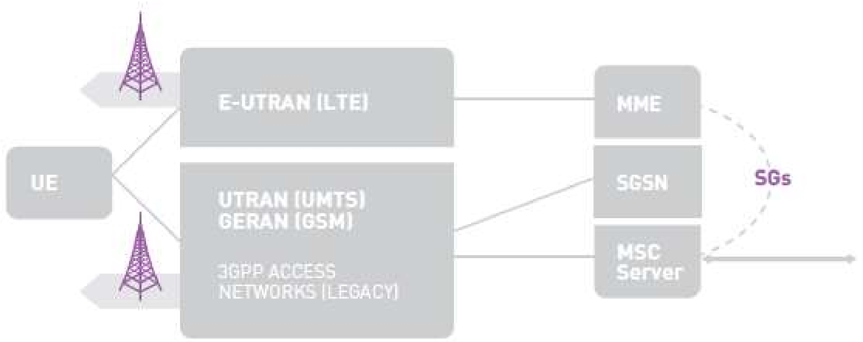
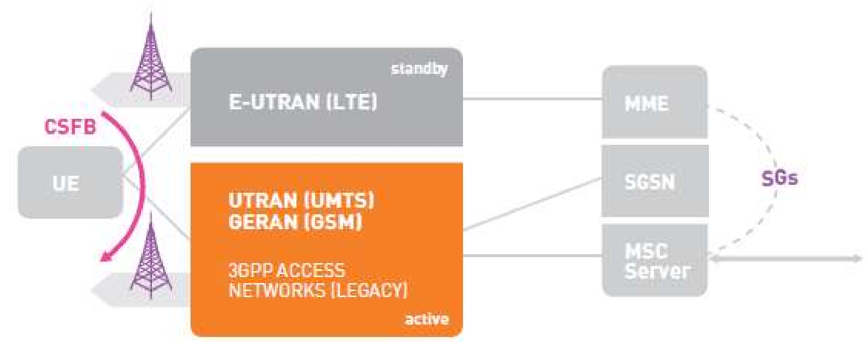
Circuit-switch Fallback – 1st Phase Voice Evolution over LTE

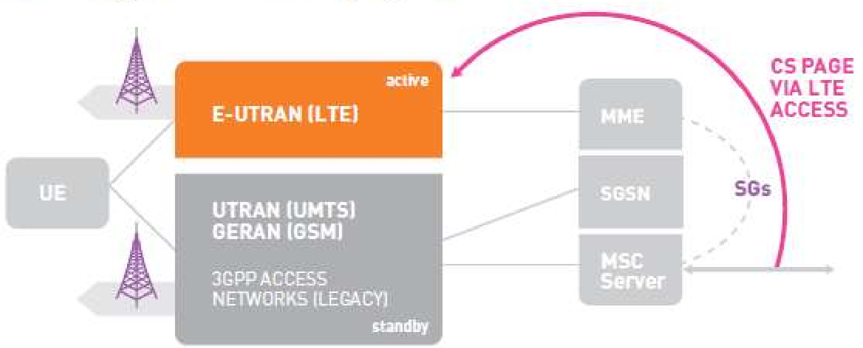
EPS and legacy 3GPP packet core networks.



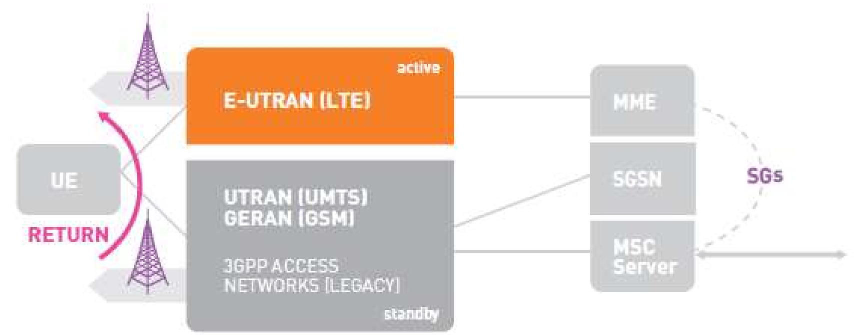
Circuit-switched fallback.



Incoming voice call: CS page via LTE.

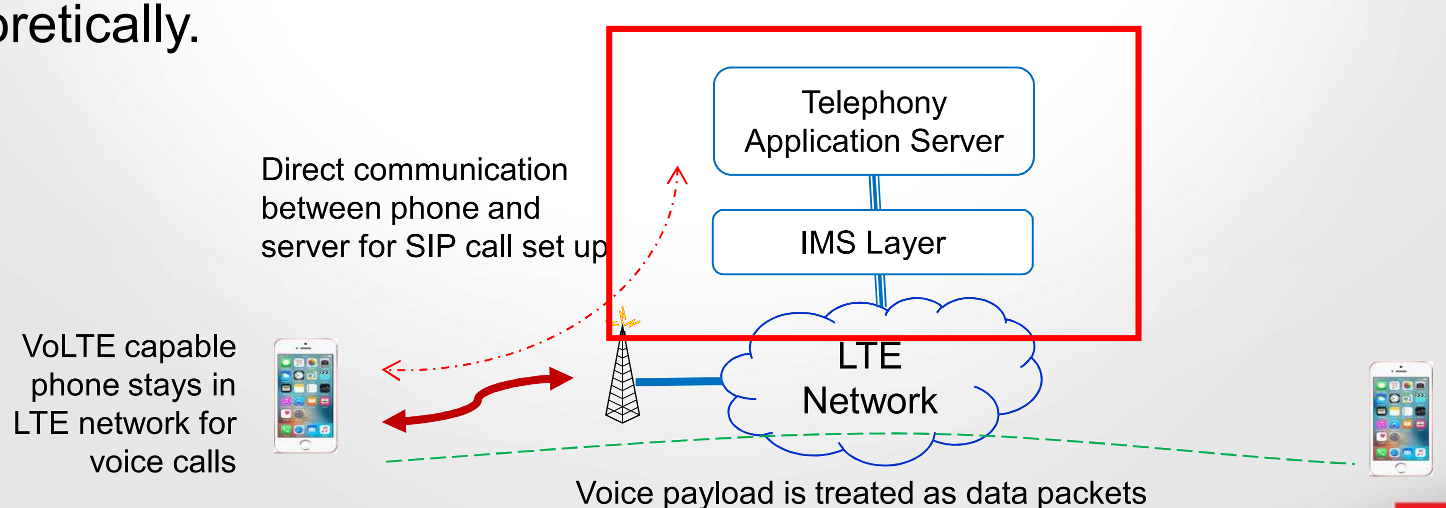


Return to LTE after voice call.



Voice over LTE – Pure IP network for voice

- Native client supported in mobile station
- IP Multimedia Subsystem (IMS, 3GPP TS23.228), an application layer on LTE network, enables SIP operation in the mobile packet domain
- With a telephony application server (TAS) running on SIP, voice over LTE (VoLTE) is made possible.
- Low latency and QoS control in LTE network result in a voice quality in par with a circuit-switched voice calls.
- Switching between LTE and 2/3G network is not required any more theoretically.



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Mobile WiFi Integration

- Offloading purpose in hotspots
- Emphasis on customer experience
  - Clientless, i.e. native support
  - Seamless authentication
  - Mobility across different access networks
  - Device driven vs. network driven
  - Service appearance
- 3GPP standardization
  - TS23.234 on 3GPP system to Wireless LAN interworking
  - Common core system for authentication, charging and policy
    - **EAP-AKA/SIM** based authentication and **S2a-based Mobility over GTP (SaMOG)**
    - **3GPP ANDSF** (network driven) complementary with the **Hotspot 2.0** (device driven)
  - Common services
  - WiFi/3G/4G mobility

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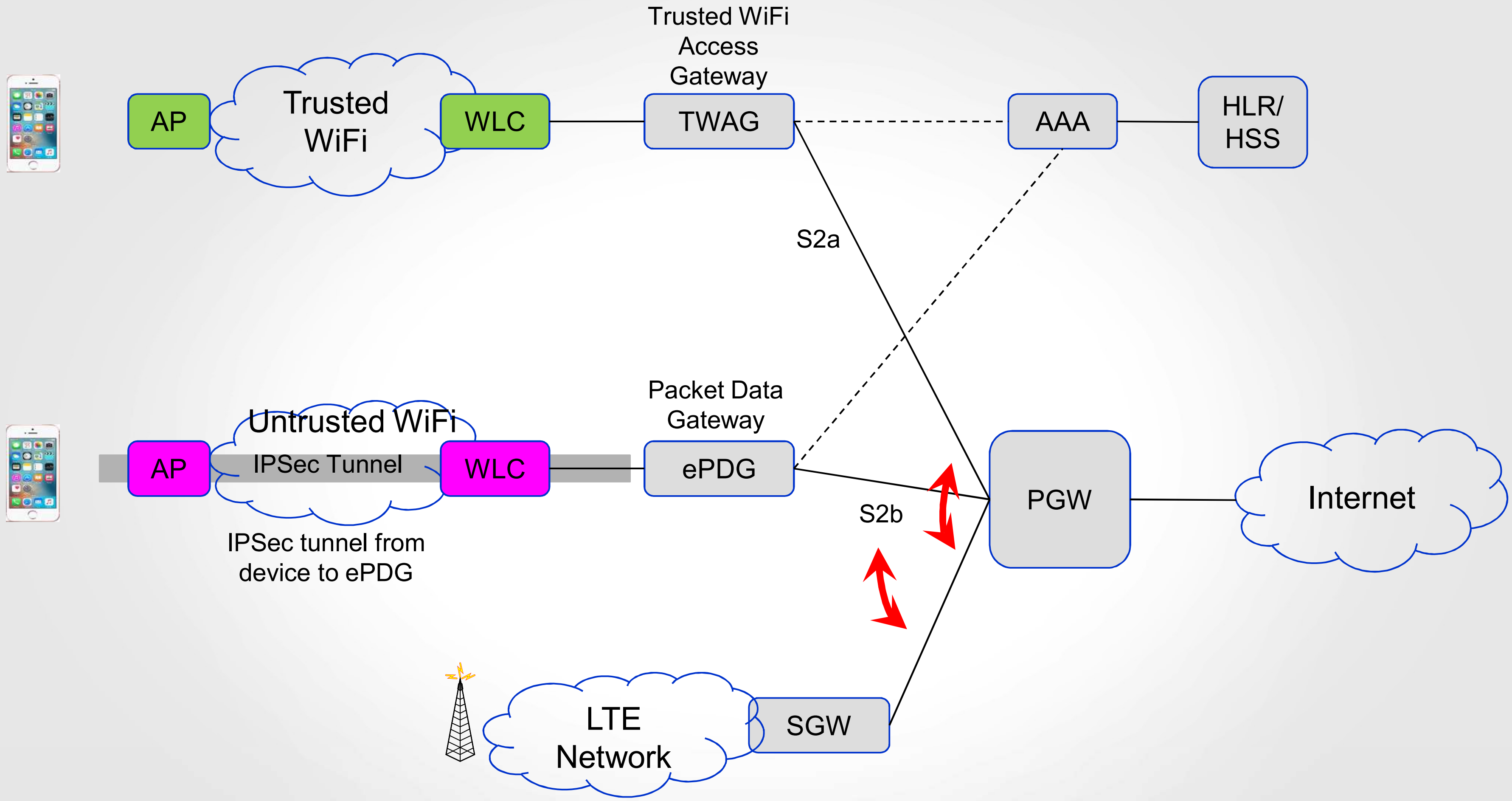
Different Integration Scenarios



3GPP defines the architecture to allow session continuity upon switchover between trusted/untrusted WiFi access and cellular access

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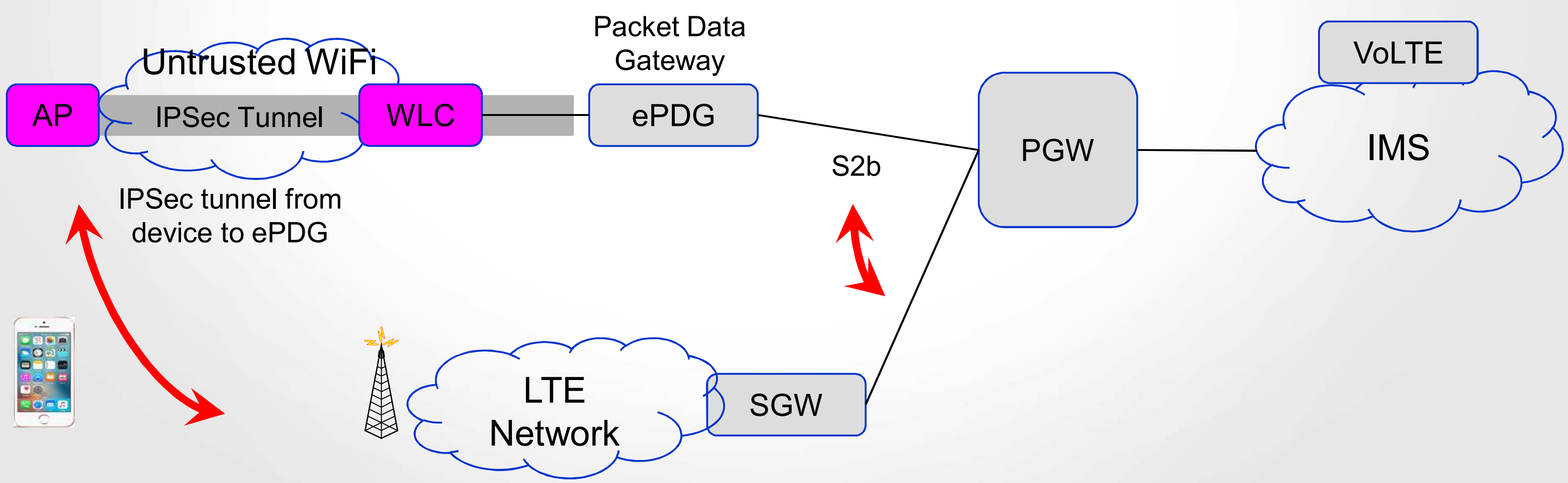
Voice over WiFi

- VoWiFi is the first application benefited from WLAN interworking with seamless handover
- VoWiFi and VoLTE together to provide a pure-IP voice services (mobile originating and terminating call) across different RAT with the same service appearance



Drivers to the use of IPv6 in Mobile Network

- IP address required for each connected device
- Increasing number of connected device in mobile network
  - Proliferation of smart devices and improved battery life meaning that always on become a fact of life, (3G – almost “always on”; 4G – must be “always on”
  - Non-SIM device attaching to mobile network through WiFi interworking
- Multiple PDN (Packet Data Network) connections are common
  - Standardization recommends a separate data connection for VoLTE in addition to that for data traffic
  - iOS devices: always on for device browsing, ad-hoc for tethering → Likely 2 IP addresses
- Depletion of IPv4 addresses earlier
  - Increasing need for device-to-device communications
  - Increasingly more applications not supporting private addresses
  - Emerging technologies and uptake of M2M and IoT applications
- Interworking with IPv6 world
  - Now possible through NAT 46/64 etc. but not efficient

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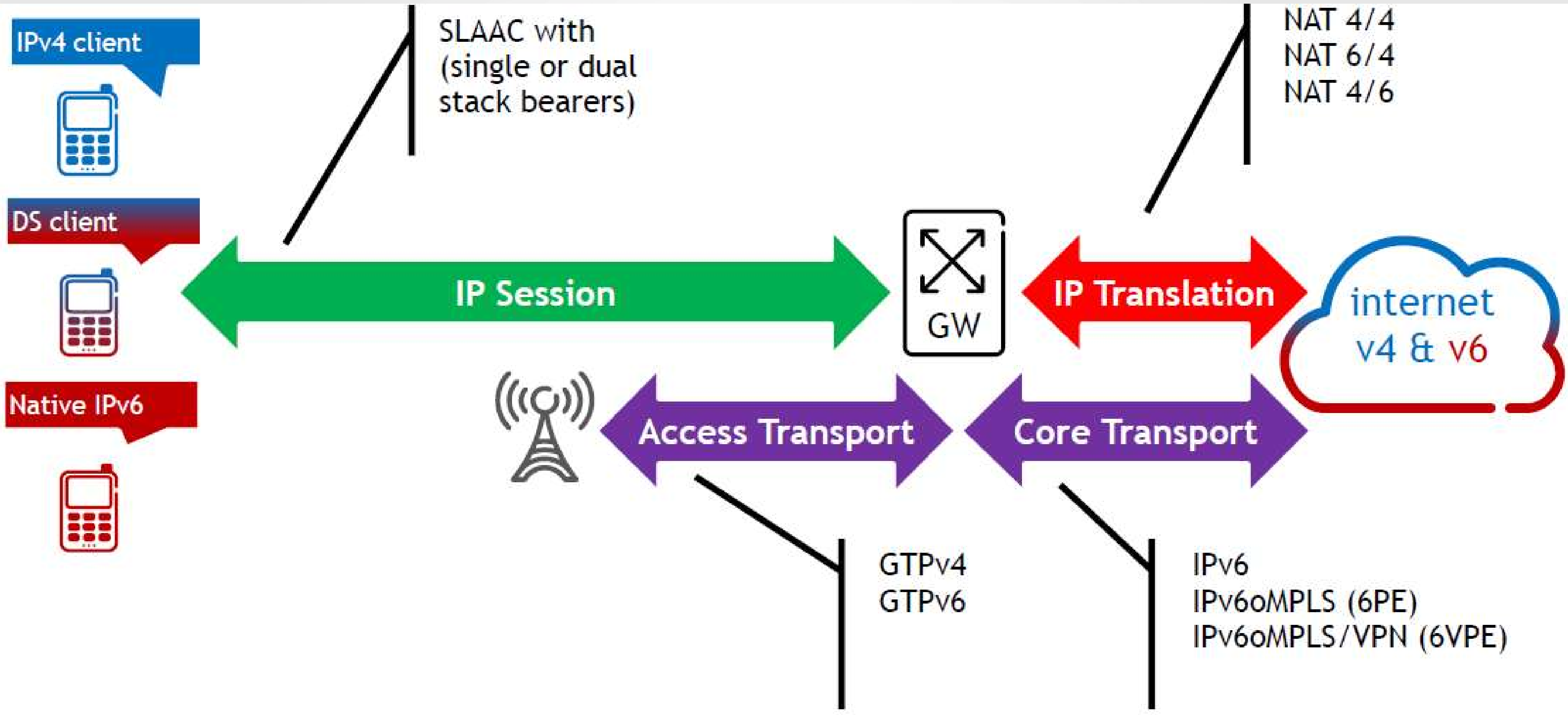
IP v4/v6 scenarios in Mobile Broadband



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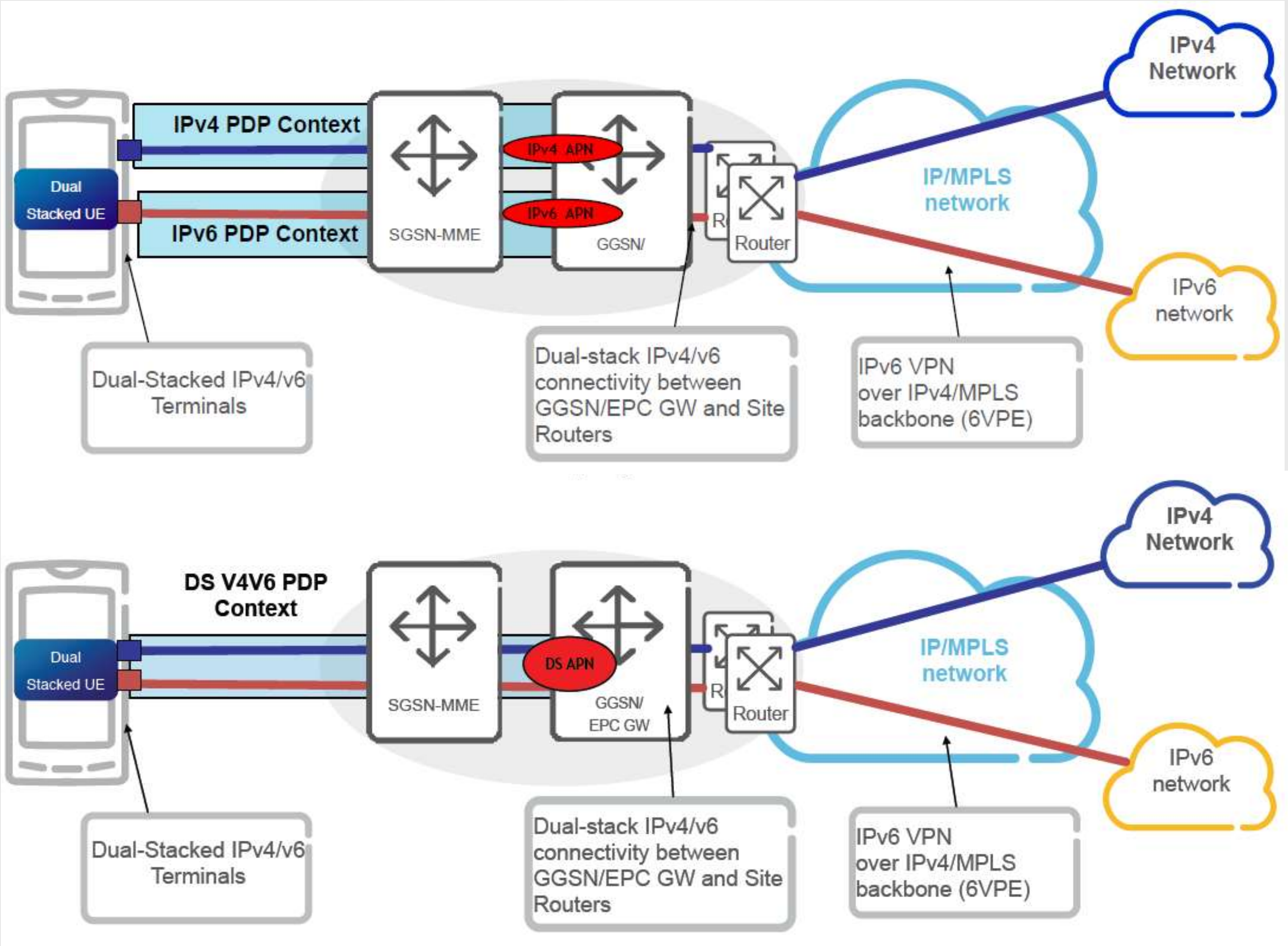
Dual-Stack Support in 3GPP



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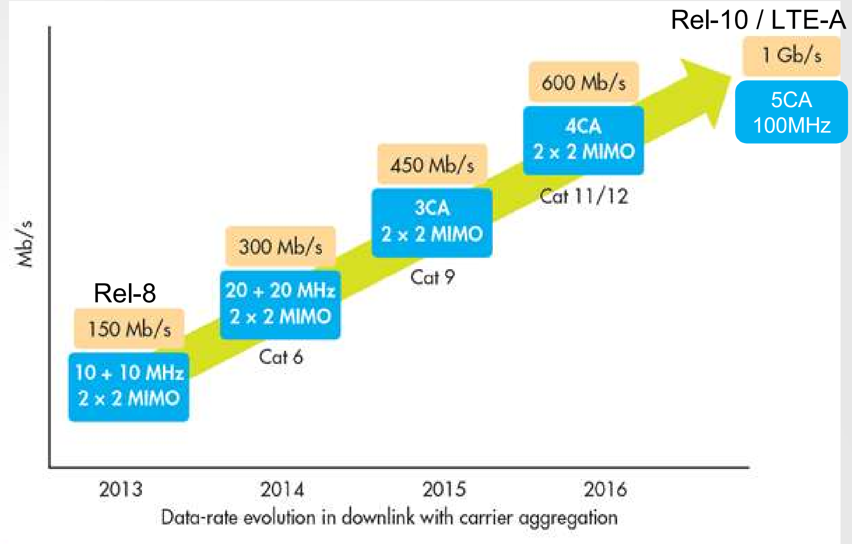
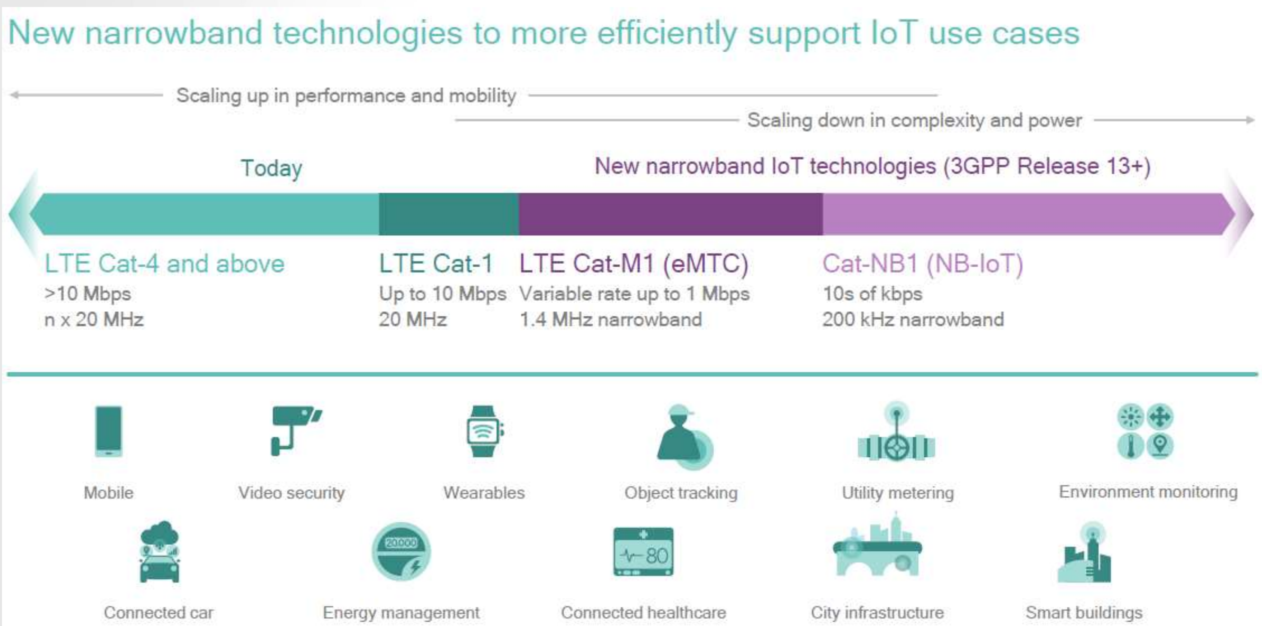
Opportunities for further evolution of LTE

- Possible to evolve LTE further by **MIMO/CoMP** & **CA** technologies for bandwidth-consumed applications;
- Upgrade LTE with NB-IoT to support IoT applications with LPWAN





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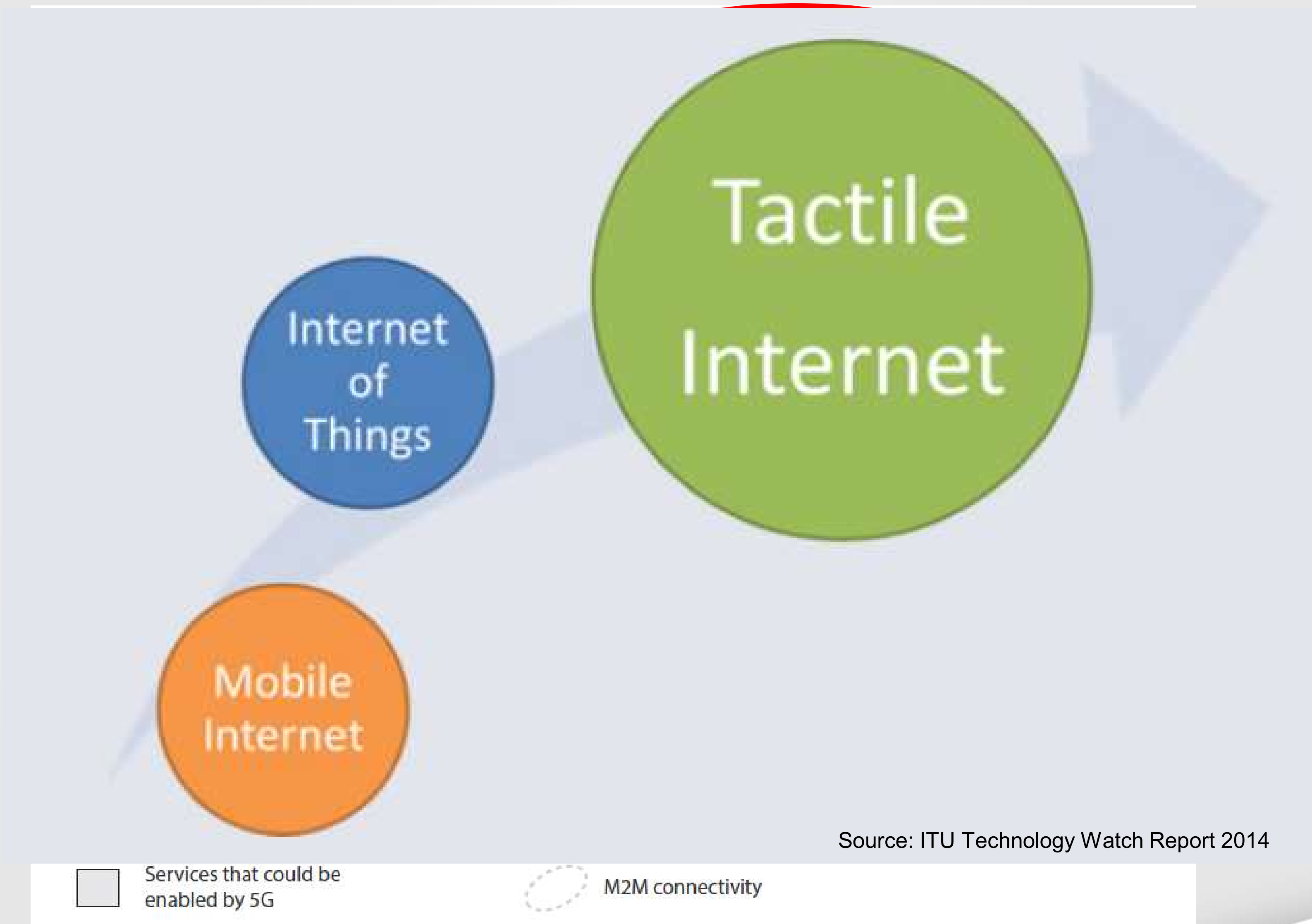
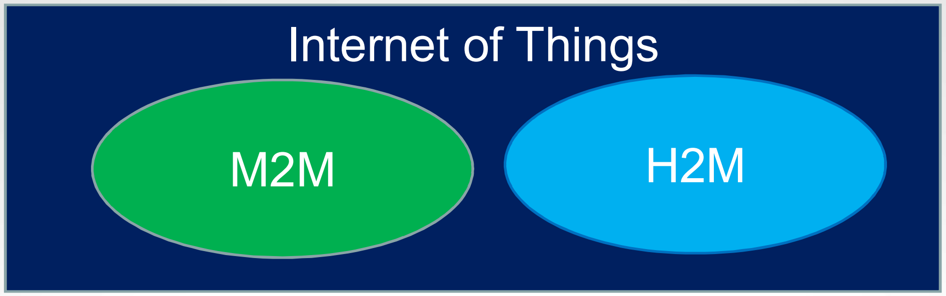
Drivers for Next Generation Mobile

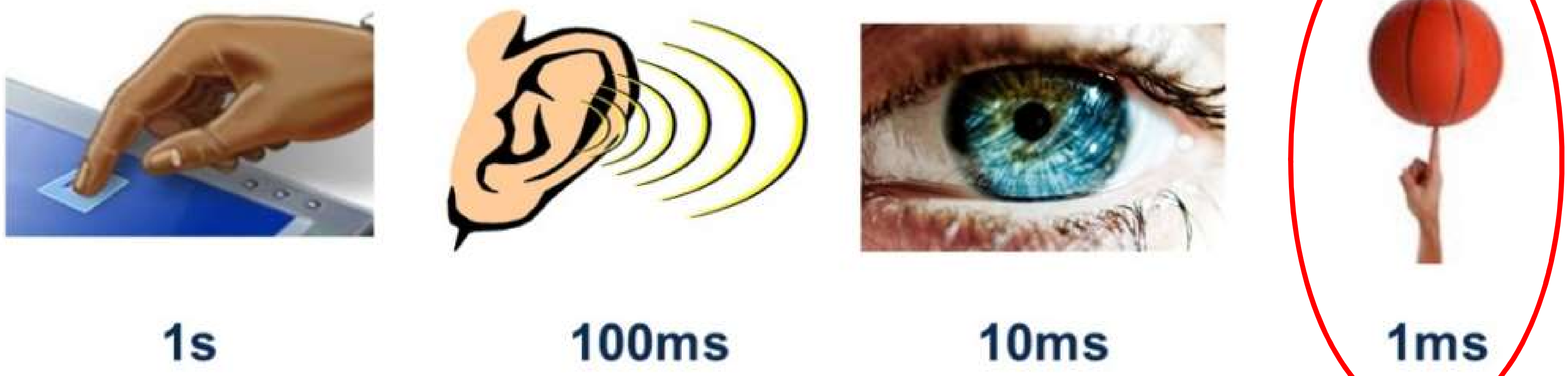


Source: ITU Technology Watch Report 2014

From Internet of Things to Tactile Internet



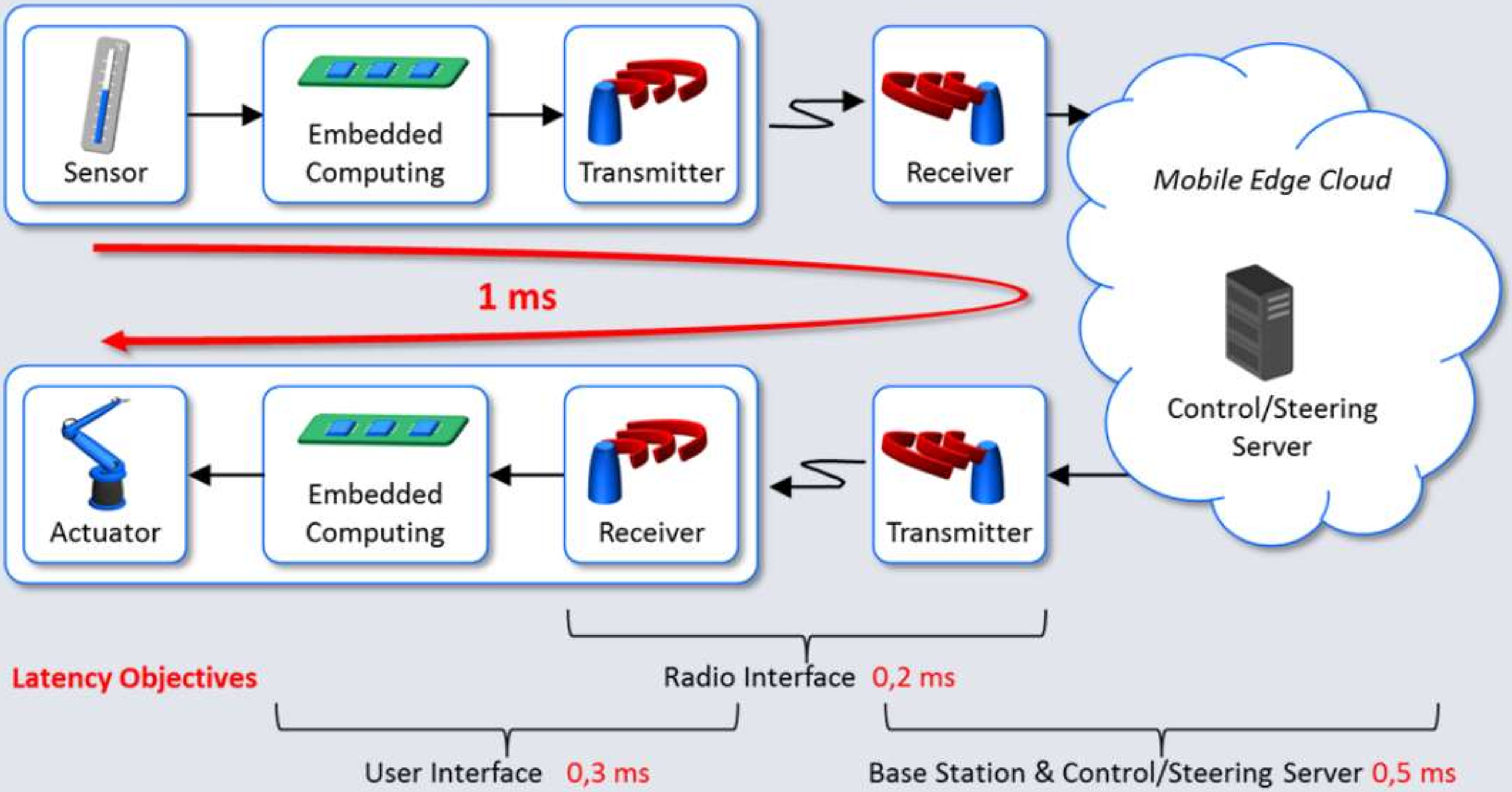
Order of magnitude of human reaction times



Extremely low latency in combination with high availability, reliability and security will define the character of the ***Tactile Internet***

Source: ITU Technology Watch Report 2014

Exemplary latency budget of a system of Tactile Internet



Source: ITU Technology Watch Report 2014

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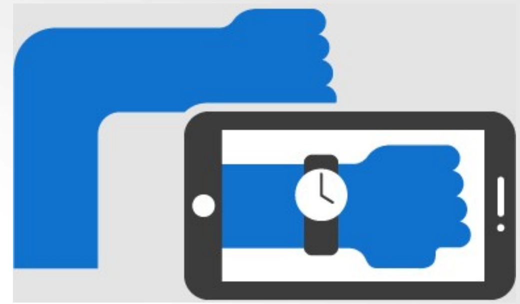
Online Application Fields - Examples

Robotic Industry

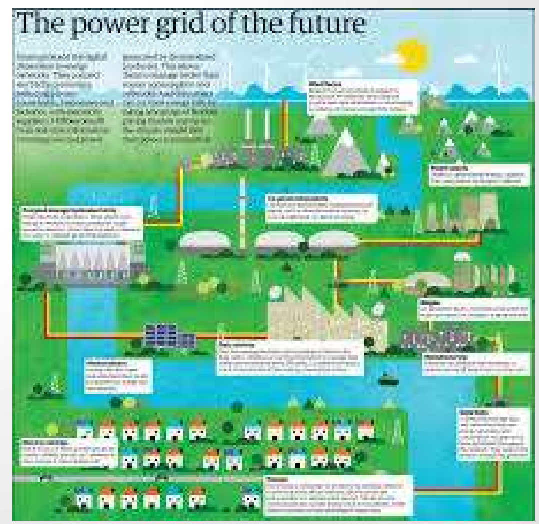
Video Reality



Augmented Reality

Autonomous vehicle

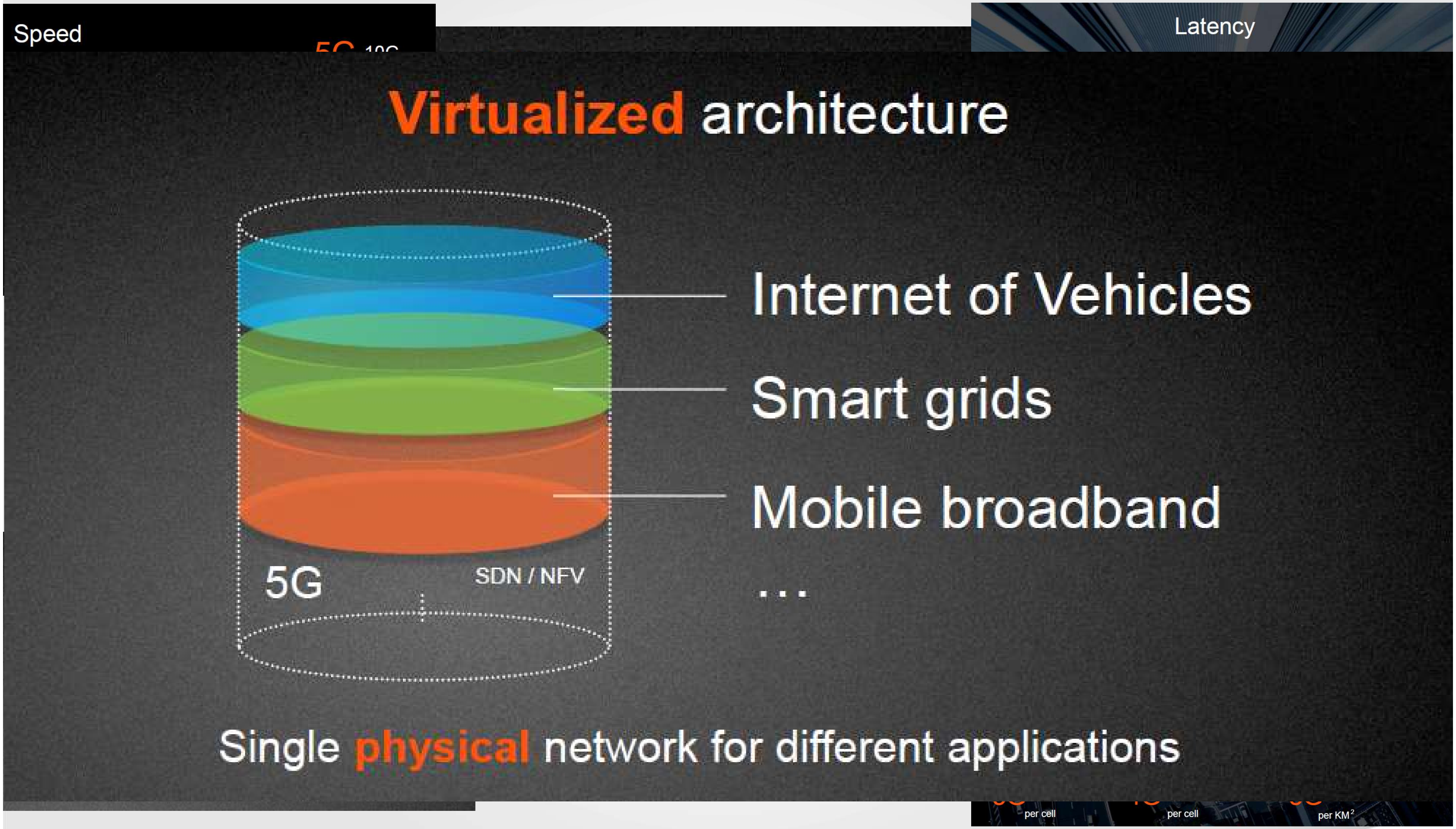
Tele-surgery



Intelligent Power Grid

Source: ITU Technology Watch Report 2014

Next Generation Mobile Data Technology



Thank You !

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