LTE/EPC Fundamentals

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Agenda

- *LTE Overview*
- *LTE/EPC Network Architecture*
- *LTE/EPC Network Elements*
- *LTE/EPC Mobility & Session Management*
- *LTE/EPC Procedure*
- *LTE/EPS overview*

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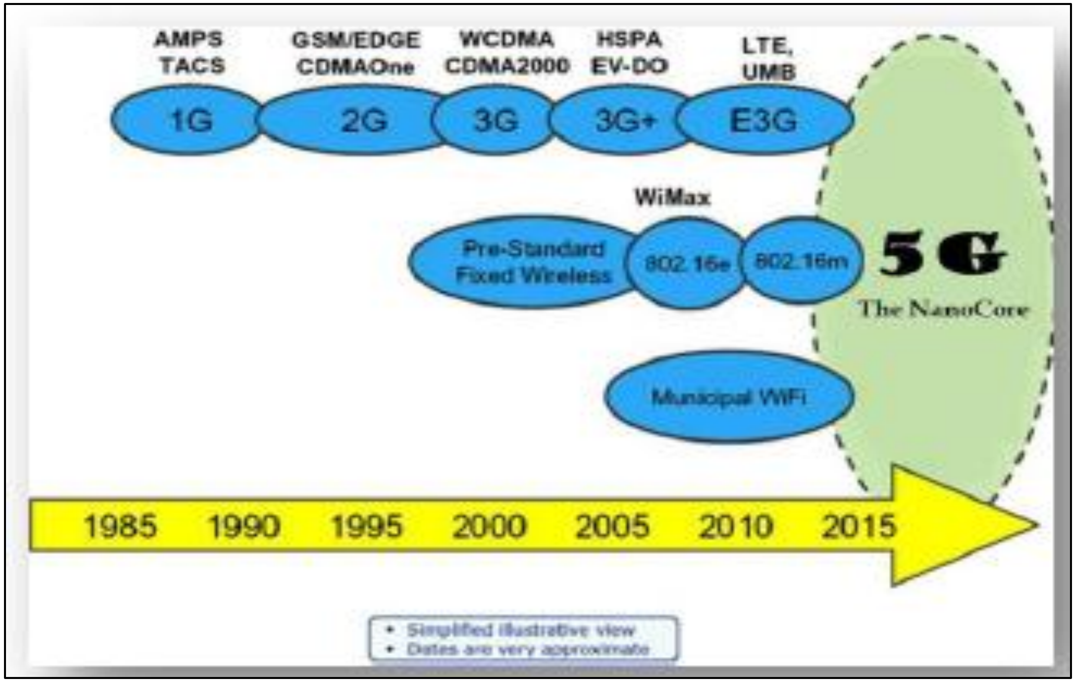
Agenda

- *Air Interface Protocols*
- *LTE Radio Channels*
- *Transport Channels and Procedure*
- *LTE Physical Channels and Procedure*
- *LTE Radio Resource Management*
- *MIMO for LTE*

LTE Overview

Cellular Generations

- There are different generations as far as mobile communication is concerned:
  - First Generation (1G)
  - Second Generation (2G)
  - 2.5 Generation (2.5G)
  - Third Generation (3G)
  - E3G (4G)
  - Fifth Generation(5G)



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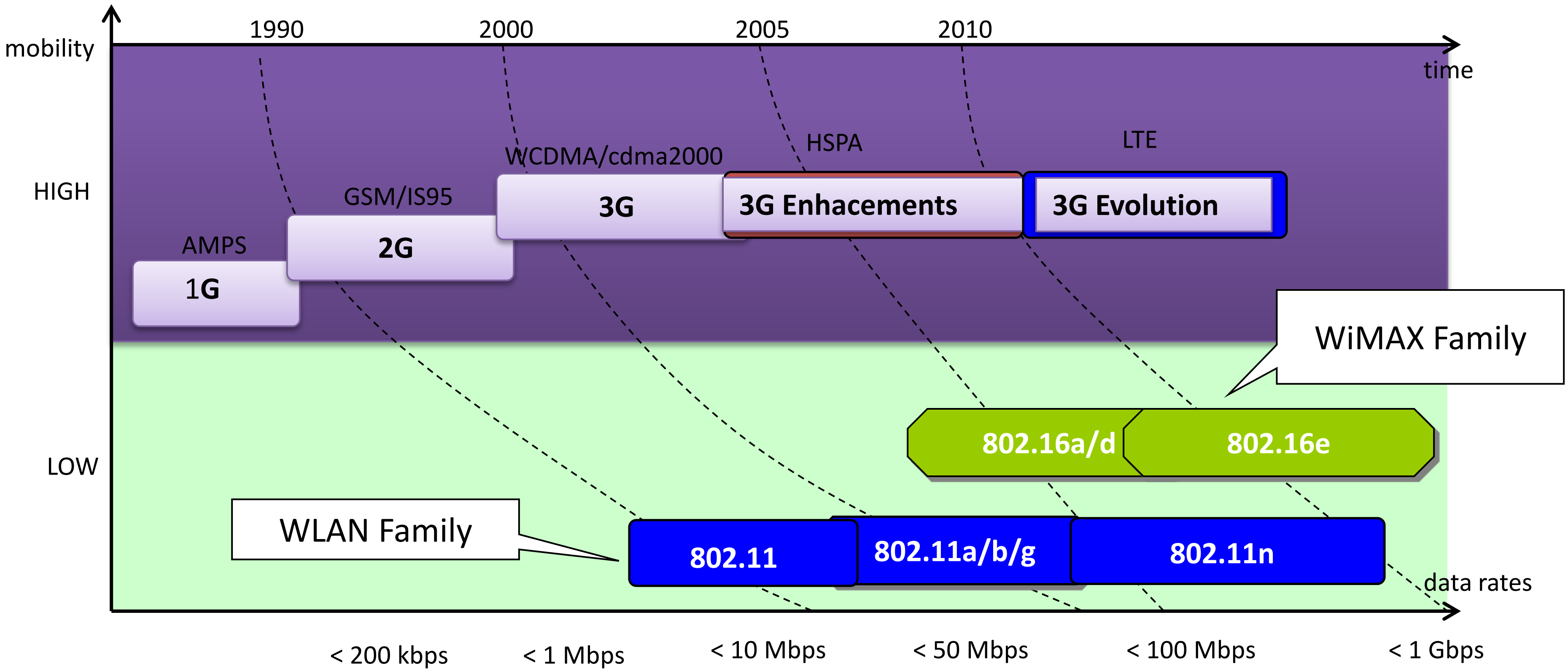
History and Future of Wireless



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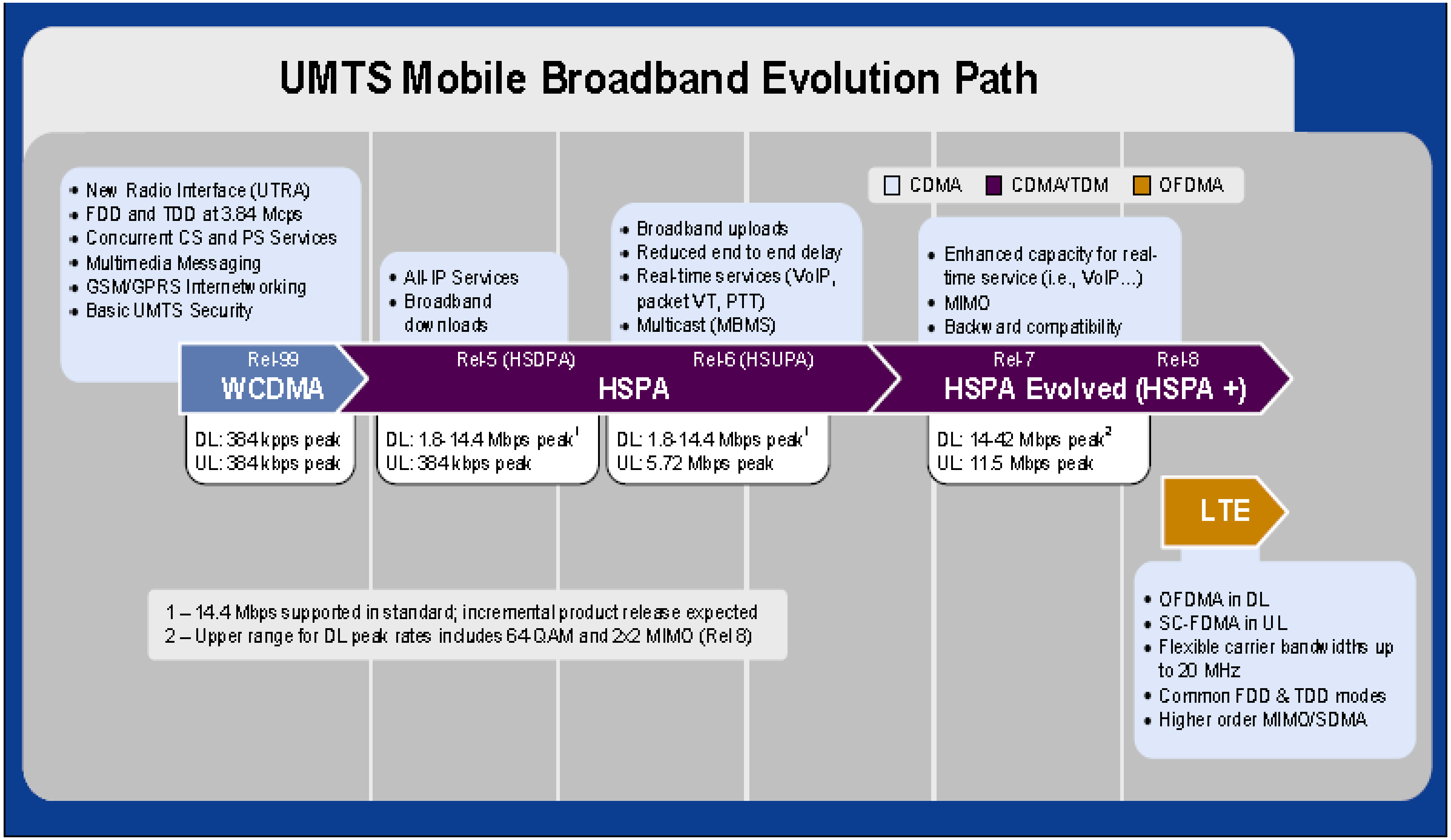
3GPP Releases & Features



Main LTE Requirements

- **Peak data rates** of uplink/downlink **50/100 Mbps**
- **Reduced Latency:**
  - Enables round trip time **<10 ms**
- Ensure good level of **mobility and security**
  - Optimized for low mobile speed but also support high mobile speed
- **Frequency flexibility and bandwidth scalability:**
  - with **1.25, 2.5, 5, 10, 15 and 20 MHz** allocations
- Improved **Spectrum Efficiency**:
  - Capacity 2-4 times higher than with Release 6 HSPA
- Efficient support of the various types of services, especially from the PS domain
  - **Packet switched optimized**
- Operation in **FDD and TDD modes**
- Improved terminal **power efficiency**
- Support for **inter-working** with existing **3GPP** system and **non-3GPP** specified systems

What is new in LTE?

- **New radio transmission schemes:**
  - OFDMA in downlink
  - SC-FDMA in uplink
  - MIMO Multiple Antenna Technology

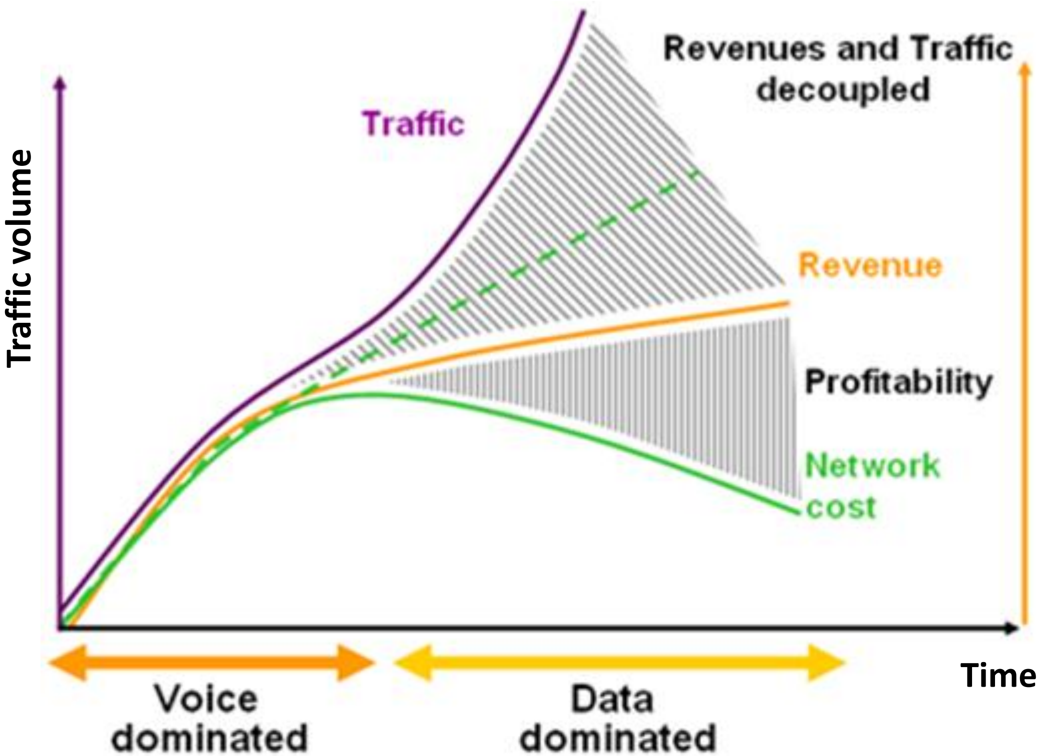
- **New radio protocol architecture:**
  - Complexity reduction
  - Focus on shared channel operation, no dedicated channels anymore

- **New network architecture: flat architecture:**
  - More functionality in the base station (eNodeB)
  - Focus on packet switched domain

What is new in LTE?

- Important for Radio Planning:
  - Frequency Reuse 1
    - No need for Frequency Planning
    - Importance of interference control
  - No need to define neighbour lists in LTE
  - LTE requires Physical Layer Cell Identity planning (504 physical layer cell IDs organised into 168 groups of 3)
  - Additional areas need to be planned like PRACH parameters, PUCCH and PDCCH capacity and UL Demodulation Reference Signal

Reasons for changes



New technology, interfaces, protocols

Quick time2market for new chipsets

Simple low-cost architecture, seamless transition from old technologies (smooth coexistence)

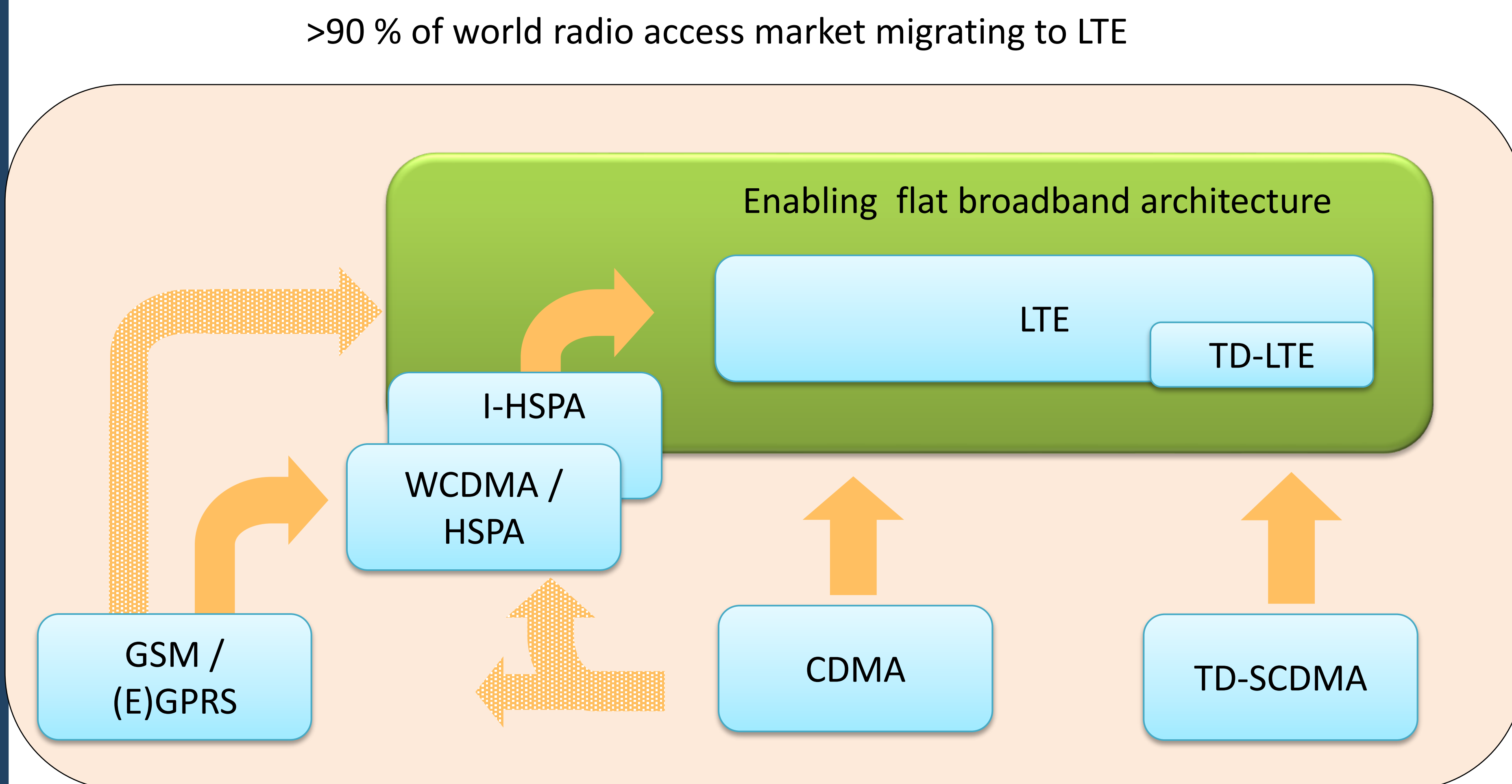
OFDM, MIMO, large bandwidth, scalable PHY/RRM

Cooperation with chipset vendors

Flat LTE/SAE, co-location and migration concept

Evolution Path to LTE

- Operator migration paths to LTE



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LTE/EPC Network Architecture

LTE/SAE Key Features – EUTRAN

Evolved NodeB

- No RNC is provided anymore
- The evolved Node Bs take over all radio management functionality.
- This will make radio management faster and hopefully the network architecture simpler

IP transport layer

- EUTRAN exclusively uses IP as transport layer

UL/DL resource scheduling

- In UMTS physical resources are either shared or dedicated
- Evolved Node B handles all physical resource via a scheduler and assigns them dynamically to users and channels
- This provides greater flexibility than the older system

LTE/SAE Key Features – EUTRAN

QoS awareness

- The scheduler must handle and distinguish different quality of service classes
- Otherwise real time services would not be possible via EUTRAN
- The system provides the possibility for differentiated service

Self configuration

- Currently under investigation
- Possibility to let Evolved Node Bs configure themselves
- It will not completely substitute the manual configuration and optimization.

Evolution of Network Architecture

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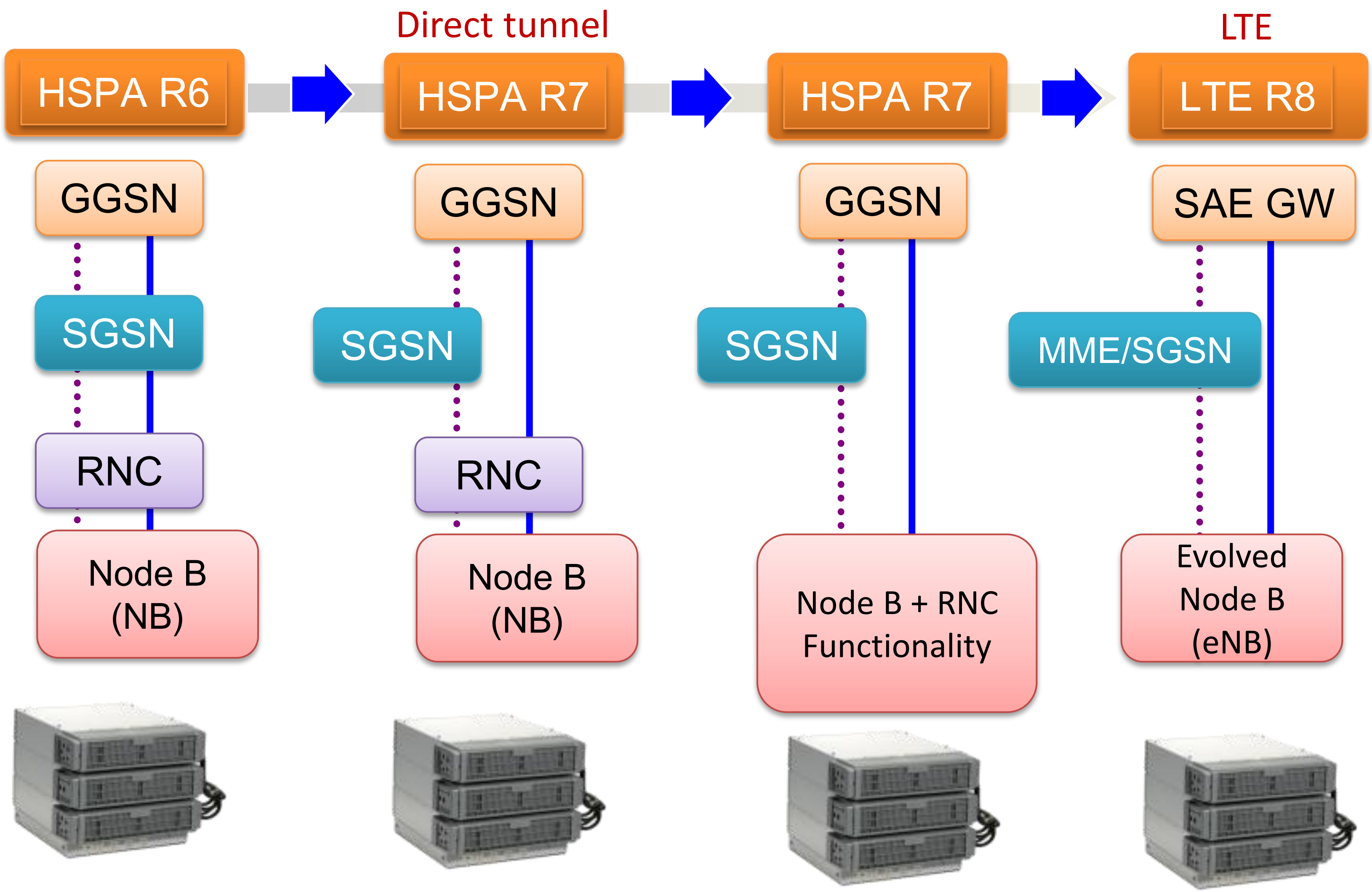
Evolution of Network Architecture



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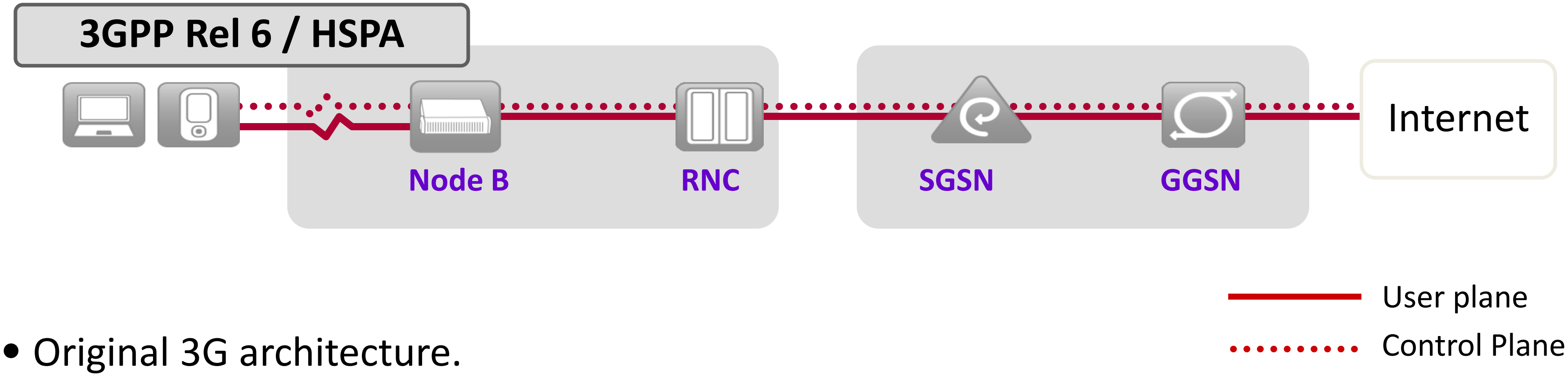
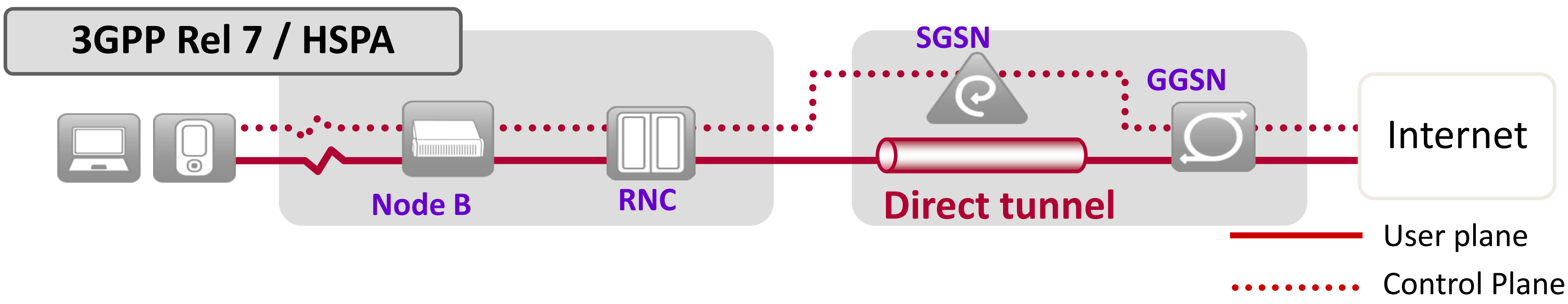
LTE Network Architecture Evolution



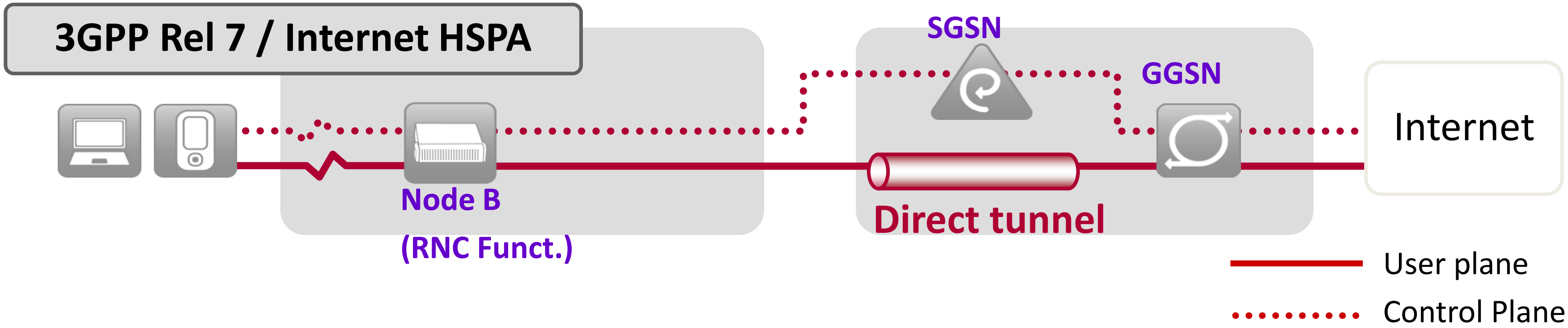
- Original 3G architecture.
- 2 nodes in the RAN.
- 2 nodes in the PS Core Network.
- Every Node introduces additional delay.
- Common path for User plane and Control plane data.
- Air interface based on WCDMA.
- RAN interfaces based on ATM.
- Option for Iu-PS interface to be based on IP

LTE Network Architecture Evolution



- Separated path for Control Plane and User Plane data in the PS Core Network.
- Direct GTP tunnel from the GGSN to the RNC for User plane data: simplifies the Core Network and reduces signaling.
- First step towards a flat network Architecture.
- 30% core network OPEX and CAPEX savings with Direct Tunnel.
- The SGSN still controls traffic plane handling, performs session and mobility management, and manages paging.
- Still 2 nodes in the RAN.

LTE Network Architecture Evolution



- I-HSPA introduces the first true flat architecture to WCDMA.
- Standardized in 3GPP Release 7 as Direct Tunnel with collapsed RNC.
- Most part of the RNC functionalities are moved to the Node B.
- Direct Tunnels runs now from the GGSN to the Node B.
- Solution for cost-efficient broadband wireless access.
- Improves the delay performance (less node in RAN).
- Deployable with existing WCDMA base stations.
- Transmission savings

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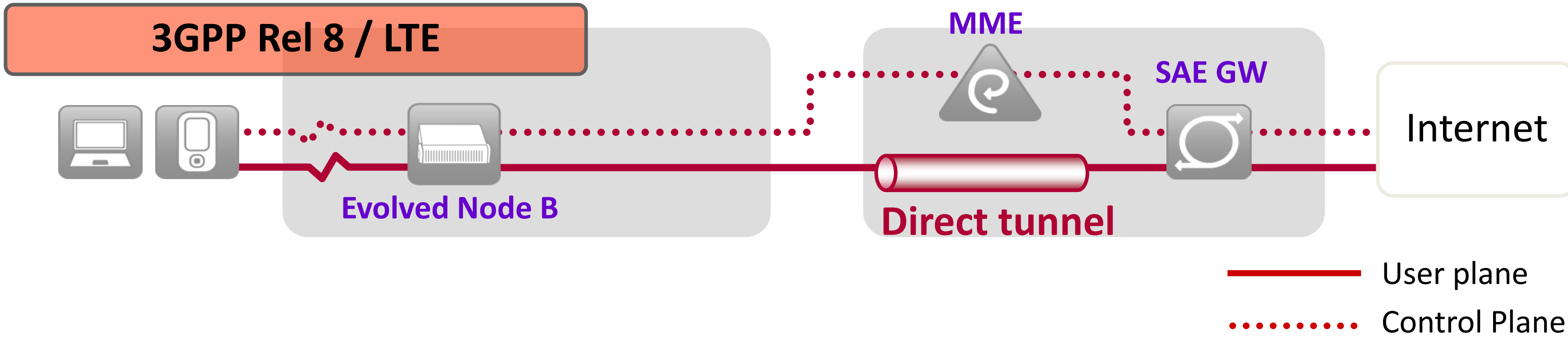
LTE Network Architecture Evolution



- LTE takes the same Flat architecture from Internet HSPA.
- Air interface based on OFDMA.
- All-IP network.
- New spectrum allocation (i.e 2600 MHz band)
- Possibility to reuse spectrum (i.e. 900 MHZ)

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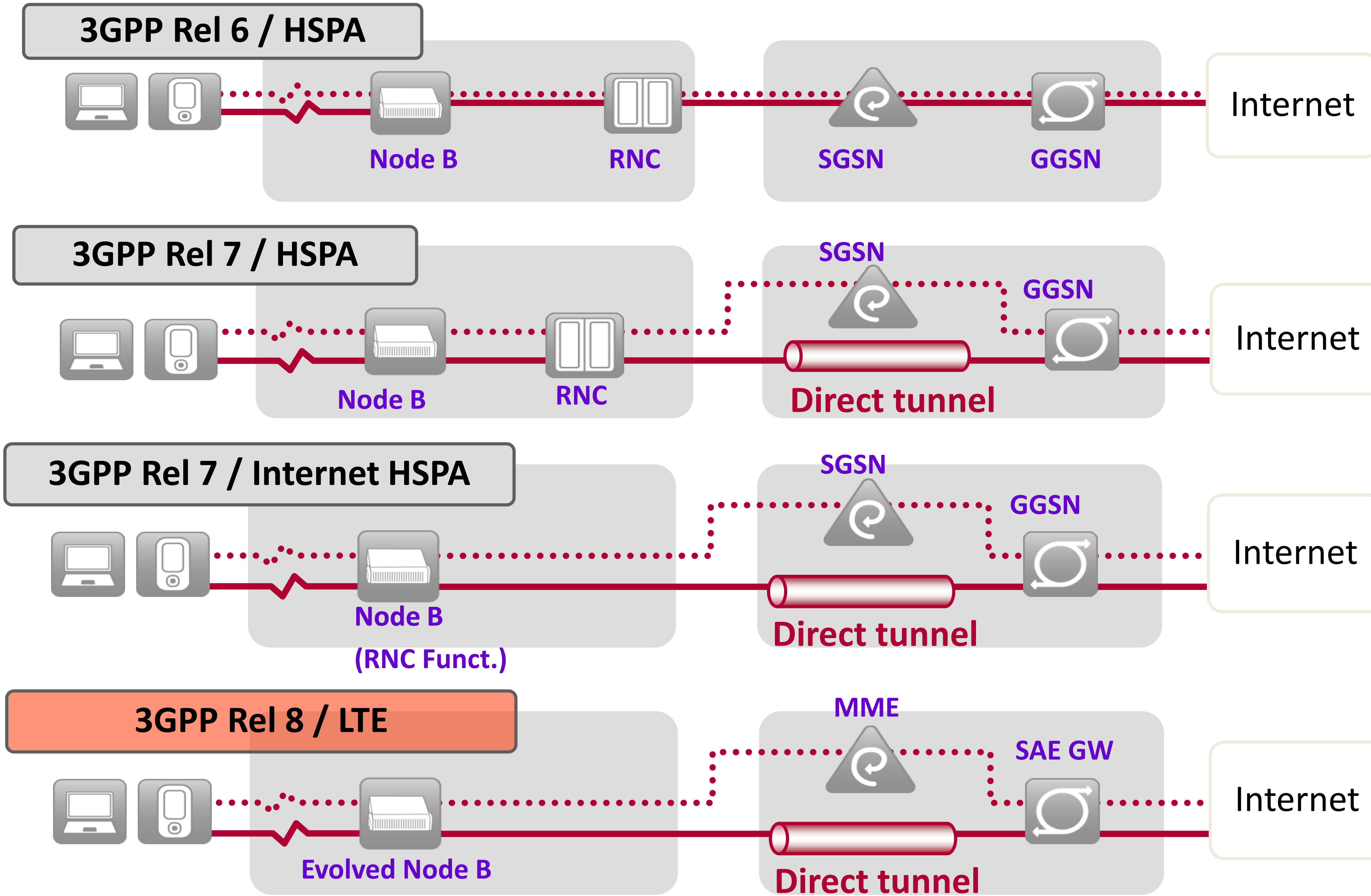
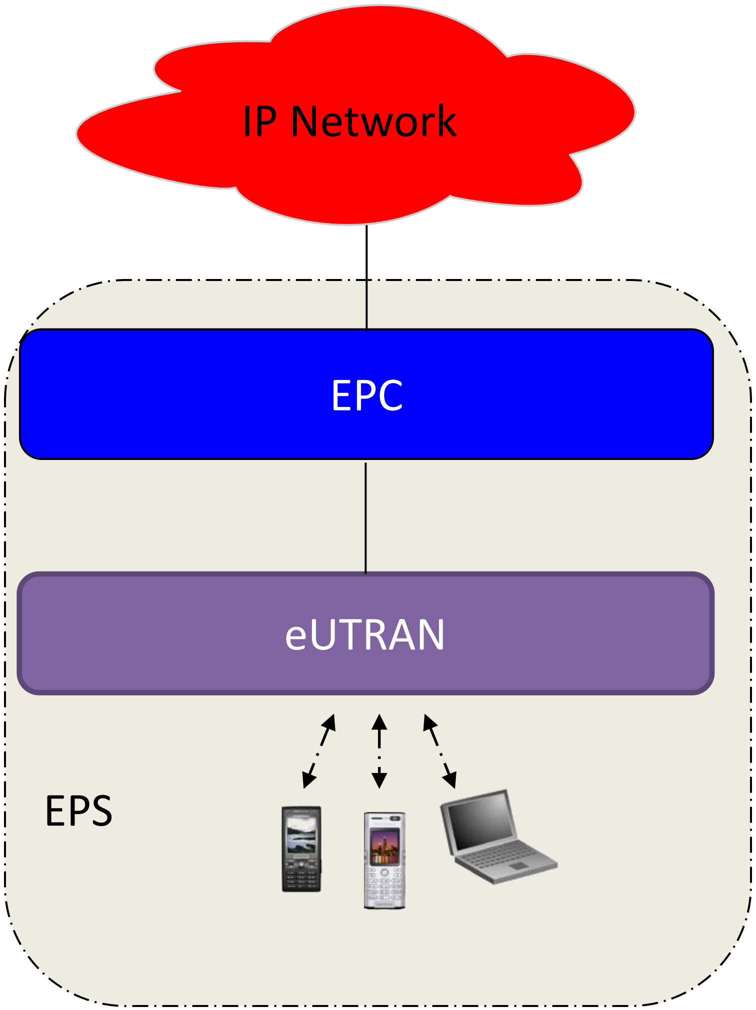
LTE Network Architecture Evolution - Summary



Terminology



EPC - Evolved Packet Core

SAE - System Architecture Evolution

eUTRAN - Evolved UTRAN

LTE - Long Term Evolution

EPS – Evolved Packet System

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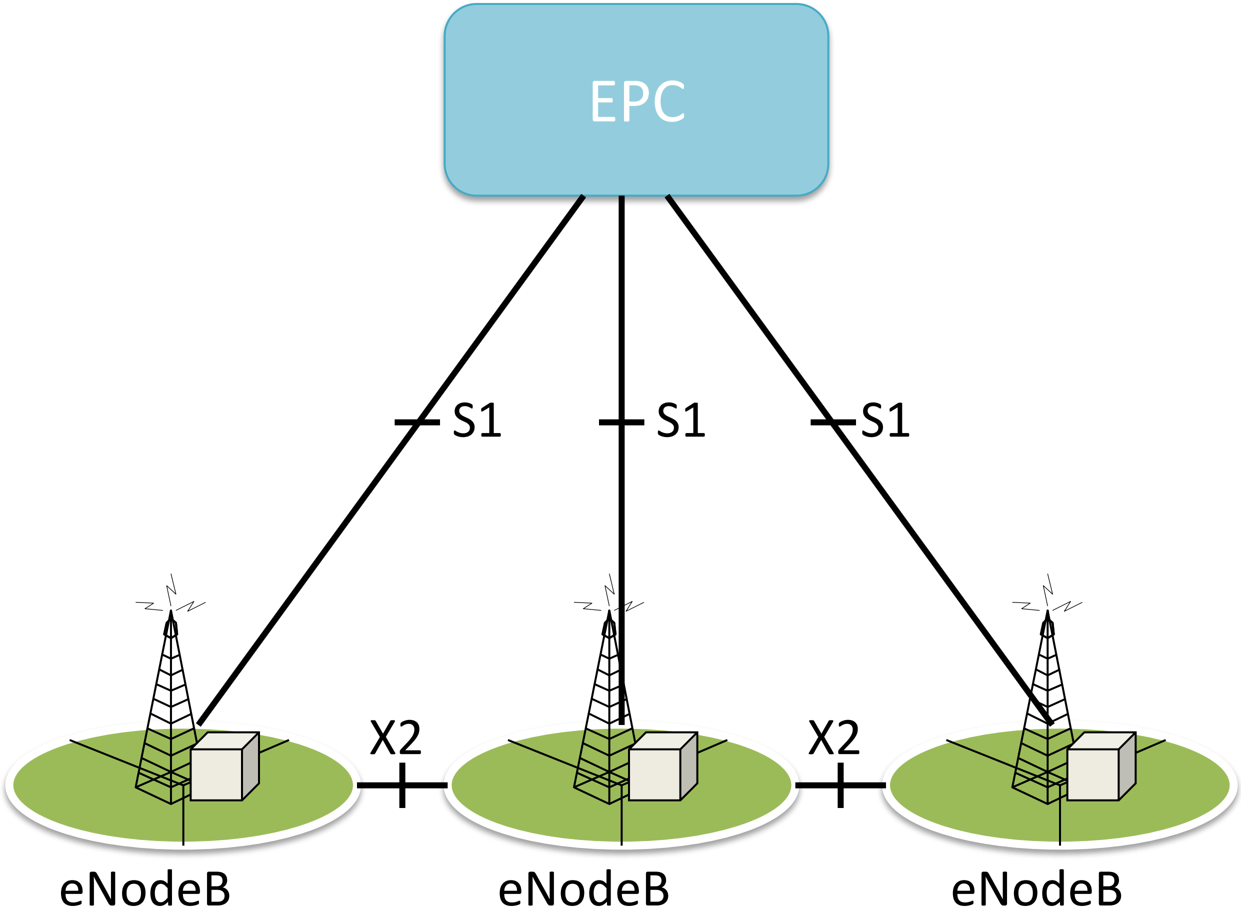
Terminology – Interfaces----Logical view



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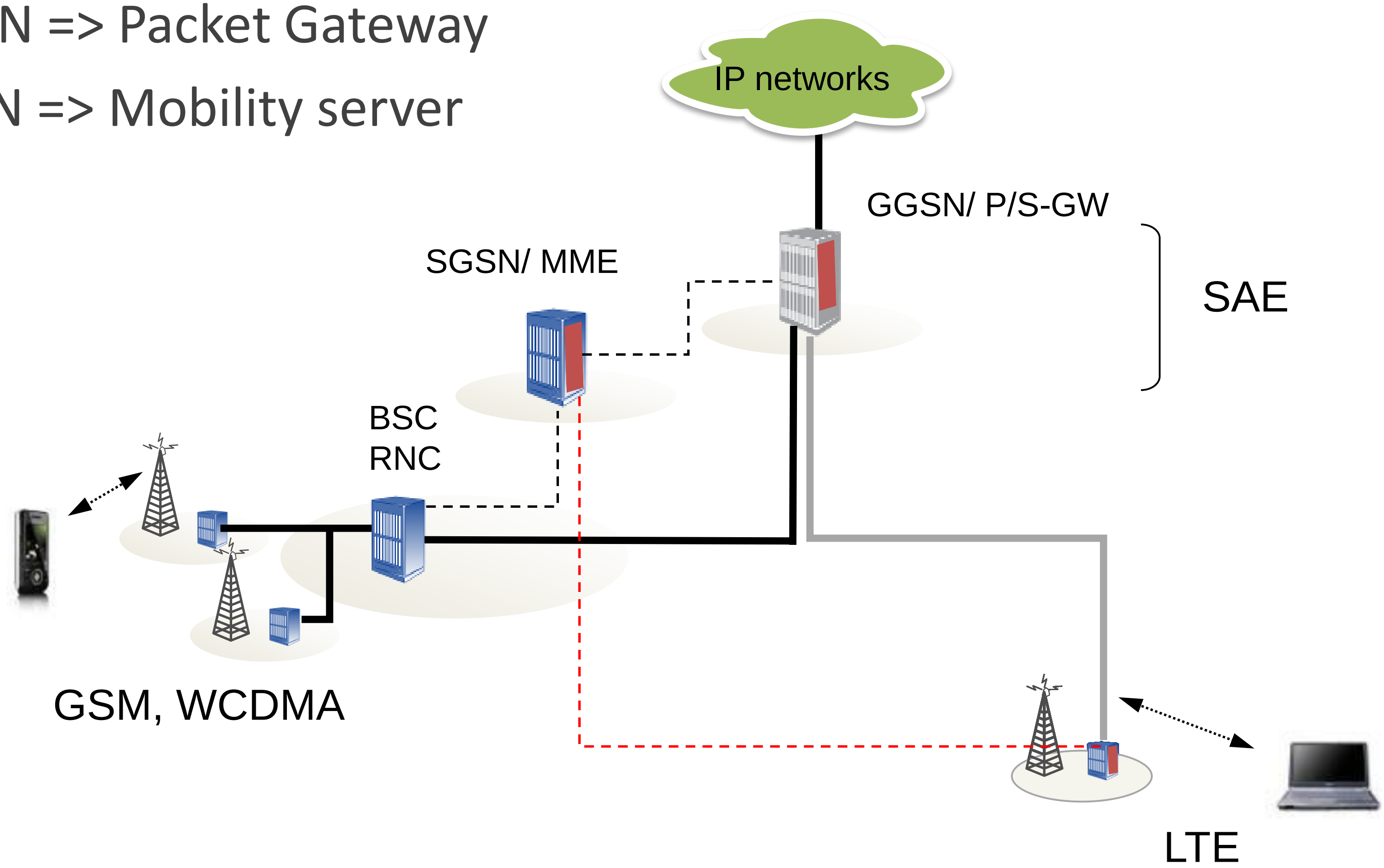
LTE/SAE Network Architecture

GGSN => Packet Gateway

SGSN => Mobility server

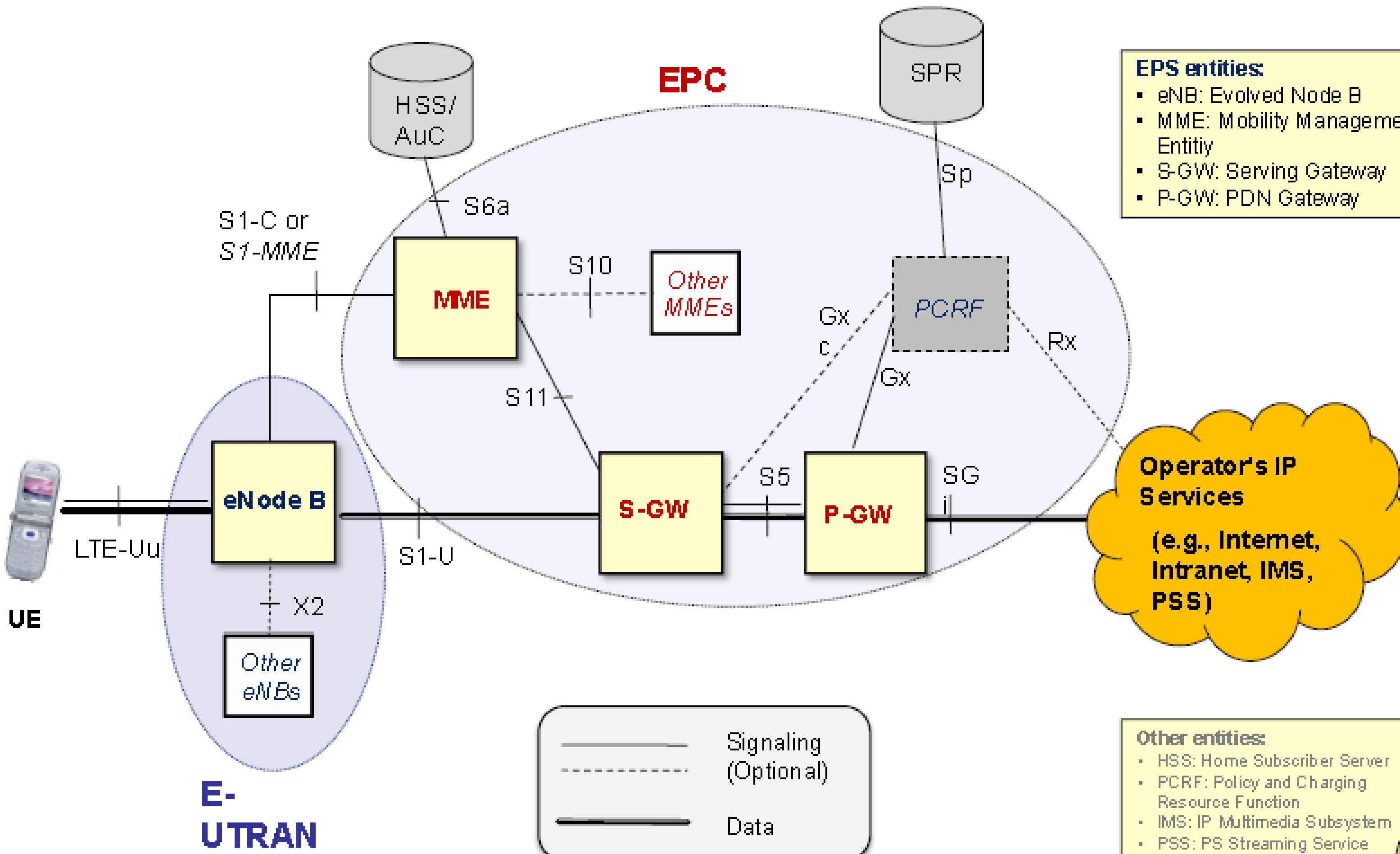


MME = Mobility Management Entity

P/S-GW = PDN/Serving gateway

Overall EPS Architecture

Basic EPS entities & interfaces



EPS entities:
- eNB: Evolved Node B
- MME: Mobility Management Entitiy
- S-GW: Serving Gateway
- P-GW: PDN Gateway

Other entities:
- HSS: Home Subscriber Server
- PCRF: Policy and Charging Resource Function
- IMS: IP Multimedia Subsystem
- PSS: PS Streaming Service

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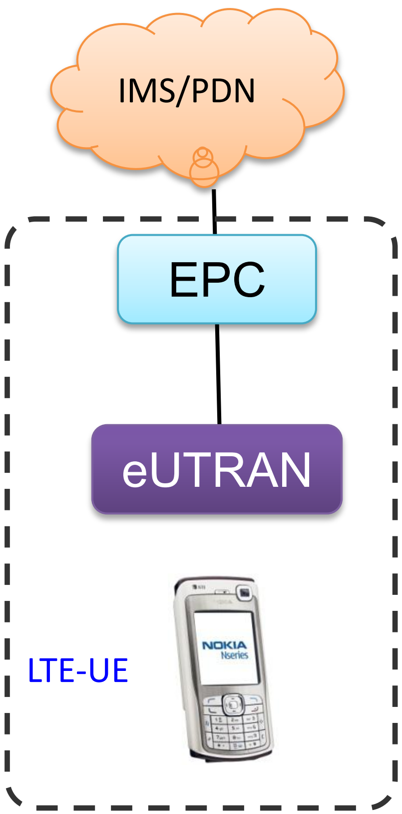
LTE/EPC Network Elements

LTE/SAE Network Architecture Subsystems

- LTE/SAE architecture is driven by the goal to optimize the system for packet data transfer.
- No circuit switched components
- New approach in the inter-connection between radio access network and core network



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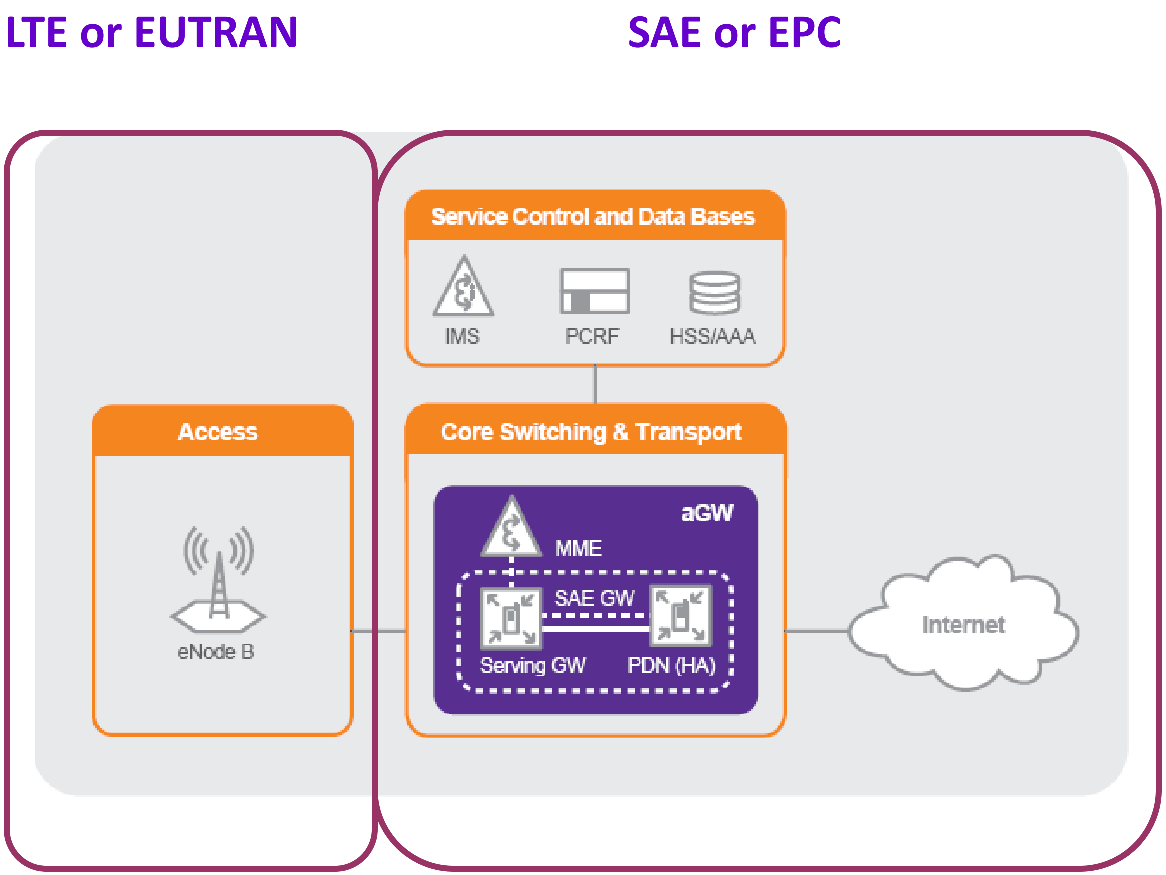
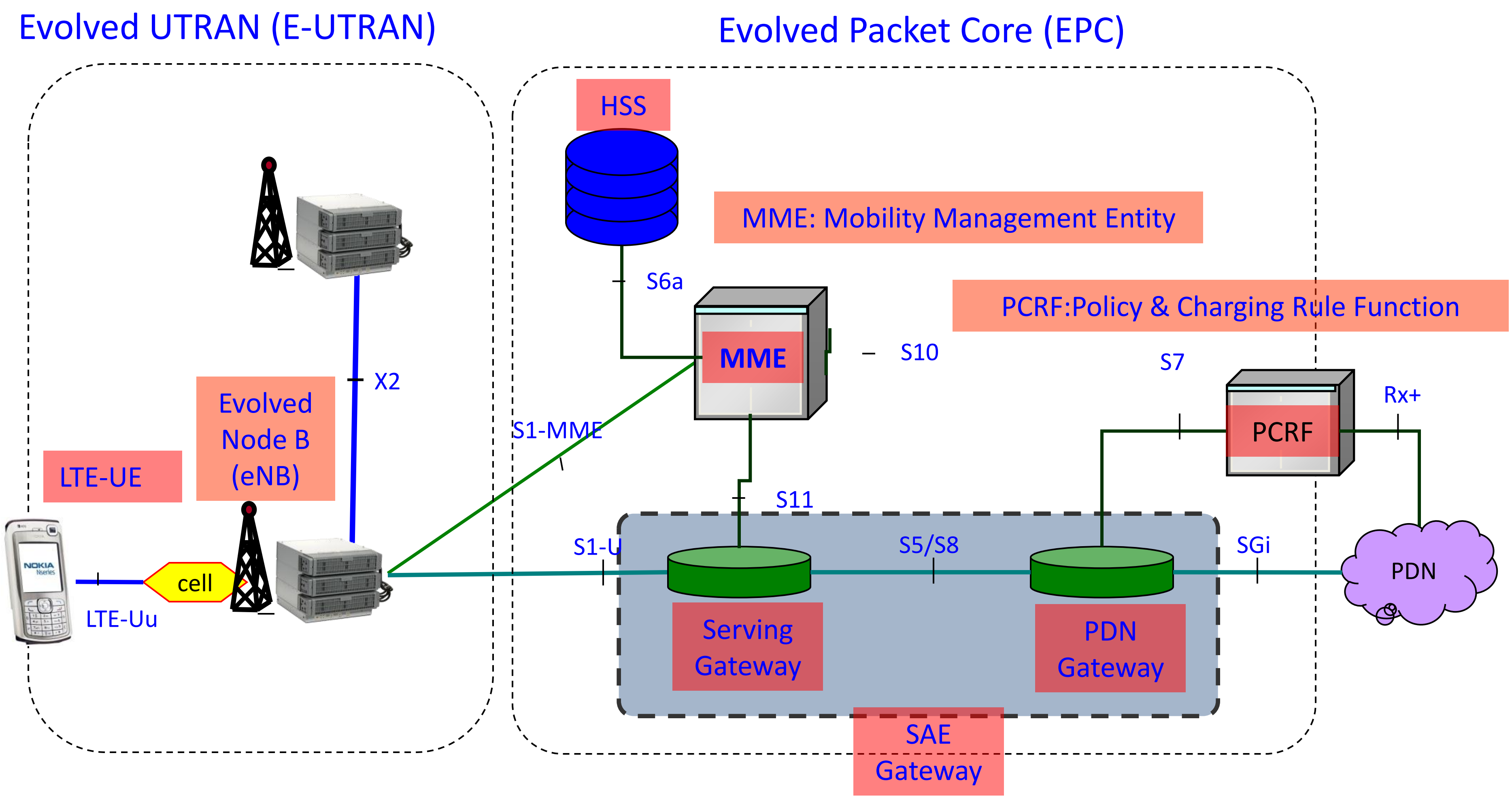
EPS Architecture - Subsystems

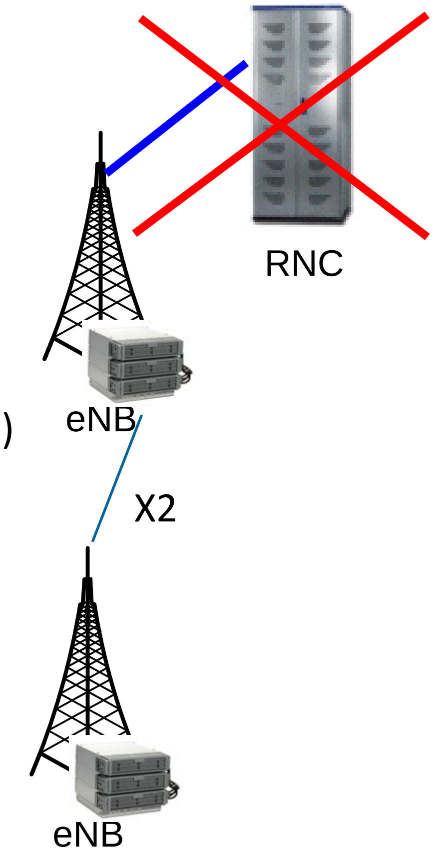


LTE/SAE Network Elements



Evolved Node B (eNB)

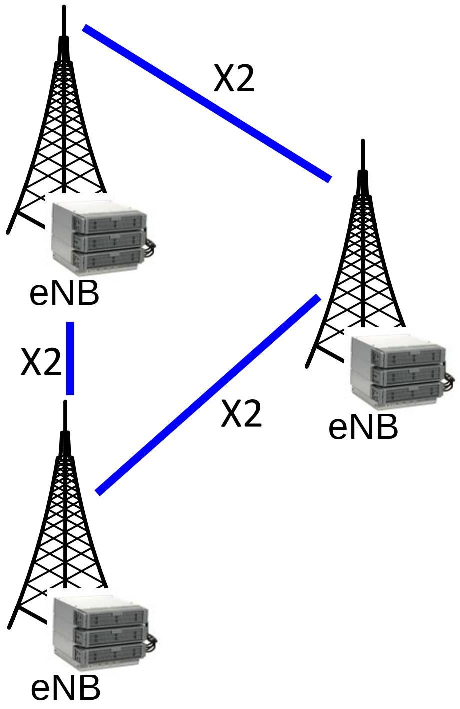
- RNC is not a part of E-UTRAN
  - Completely removed from the architecture
  - eNB is **the only one entity in E-UTRAN**
- eNB main functions:
  - Serving cell (or several cells)
  - Provisioning of radio interface to UEs (eUu)
  - Physical layer **(PHY)** and Radio Resource Management (**RRM**)
  - Exchange of crucial cell-specific data to other base stations (eNBs)



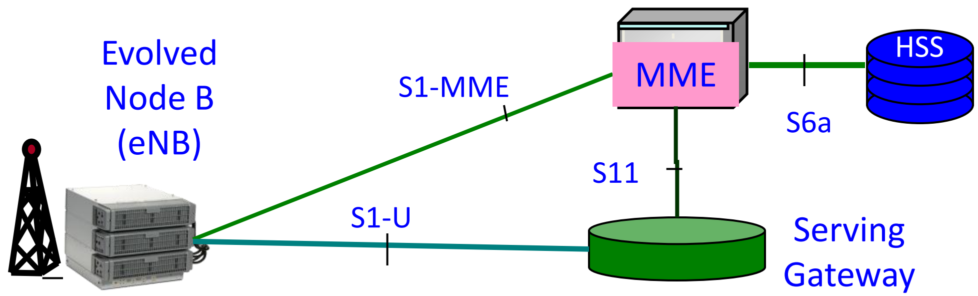
RRM (bearer control, mobility control, scheduling, etc.)
Collection and **evaluation of the measurements**
User Plane **data forwarding to SAE-GW**
MME selection when no info provided from UE
ROHC (Robust Header Compression)
Ciphering and integrity protection for the air interface
Transmission of messages coming from MME (i.e. broadcast, paging, NAS)

X2 interface

- Newly introduced E-UTRAN interface
  - **Inter eNB** interface
- X2 main functions:
  - **Provisioning of inter eNB direct connection**
  - **Handover (HO) coordination without EPC involvement**
    - Data packets buffered or coming from SAE-GW to the source eNB are forwarded to the target eNB
    - Improved HO performance (e.g. delay, packet loss ratio)
  - **Load balancing**
    - Exchange of Load Indicator (LI) messages between eNBs to adjust RRM parameters and/or manage Inter Cell Interference Cancellation (ICIC)
- X2 interface is not required
  - **Inter eNB HO can be managed by MME**
    - Source eNB <-> target eNB tunnel is established using MME



Mobility Management Entity (MME)

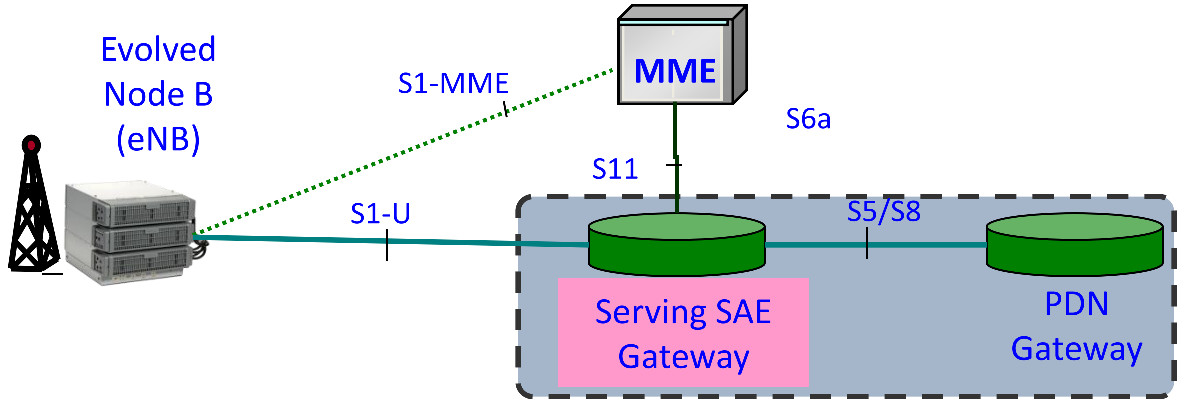


- It is a pure signaling entity inside the EPC.
- SAE uses tracking areas to track the position of idle UEs. The basic principle is identical to location or routing areas from 2G/3G.
- MME handles attaches and detaches to the SAE system, as well as tracking area updates
- Therefore it possesses an interface towards the HSS (home subscriber server) which stores the subscription relevant information and the currently assigned MME in its permanent data base.
- A second functionality of the MME is the signaling coordination to setup transport bearers (SAE bearers) through the EPC for a UE.
- MMEs can be interconnected via the S10 interface

MME Functions

- Control plane NE in EPC
- Non-Access-Stratum (NAS) Security (Authentication, integrity Protection)
- Idle State Mobility Handling
- Tracking Area updates
- Subscriber attach/detach
- Signalling coordination for SAE Bearer Setup/Release
- Radio Security Control
- Trigger and distribution of Paging Messages to eNB
- Roaming Control (S6a interface to HSS)
- Inter-CN Node Signaling (S10 interface), allows efficient inter-MME tracking area updates and attaches

Serving SAE Gateway



- The serving gateway is a network element that manages the user data path (SAE bearers) within EPC.
- It therefore connects via the S1-U interface towards eNB and receives uplink packet data from here and transmits downlink packet data on it.
- Thus the serving gateway is some kind of distribution and packet data anchoring function within EPC.
- It relays the packet data within EPC via the S5/S8 interface to or from the PDN gateway.
- A serving gateway is controlled by one or more MMEs via S11 interface.

Serving Gateway Functions

- Local mobility anchor point: Switching the user plane path to a new eNB in case of Handover
- Mobility anchoring for inter-3GPP mobility. This is sometimes referred to as the 3GPP Anchor function
- Idle Mode Packet Buffering and notification to MME
- Packet Routing/Forwarding between eNB, PDN GW and SGSN
- Lawful Interception support

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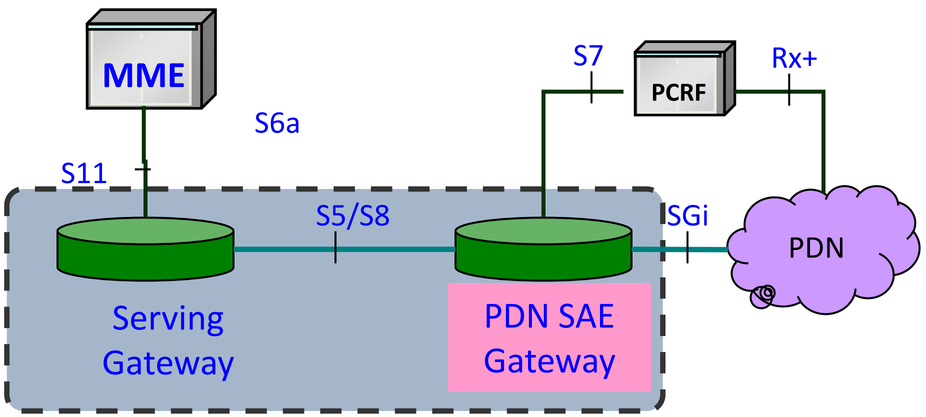
Packet Data Network (PDN) SAE Gateway

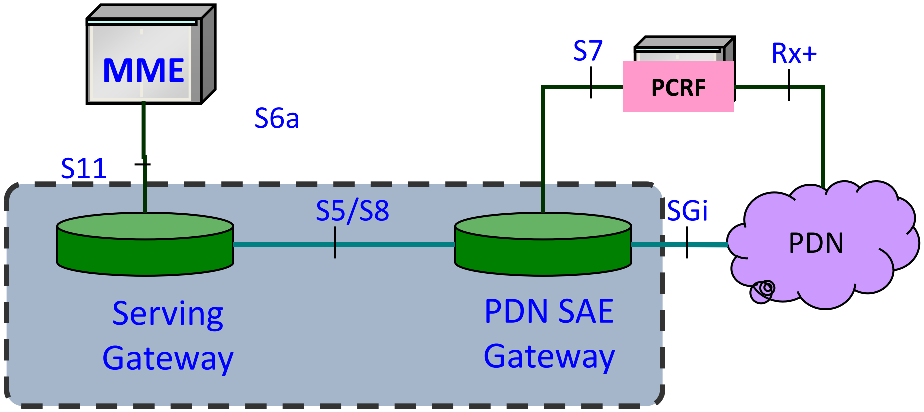


- The PDN gateway provides the connection between EPC and a number of external data networks.
- Thus it is comparable to GGSN in 2G/3G networks.
- A major functionality provided by a PDN gateway is the QoS coordination between the external PDN and EPC.
- Therefore the PDN gateway can be connected via S7 to a PCRF (Policy and Charging Rule Function).

PDN Gateway Functions

- Mobility anchor for mobility between 3GPP access systems and non-3GPP access systems. This is sometimes referred to as the SAE Anchor function
- Policy Enforcement (PCEF)
- Per User based Packet Filtering (i.e. deep packet inspection)
- Charging & Lawful Interception support
- IP Address Allocation for UE
- Packet Routing/Forwarding between Serving GW and external Data Network
- Packet screening (firewall functionality)

Policy and Charging Rule Function (PCRF)



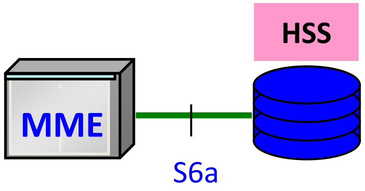
- The PCRF major functionality is the Quality of Service (QoS) coordination between the external PDN and EPC.
- Therefore the PCRF is connected via Rx+ interface to the external Data network (PDN)
- This function can be used to check and modify the QoS associated with a SAE bearer setup from SAE or to request the setup of a SAE bearer from the PDN.
- This QoS management resembles the policy and charging control framework introduced for IMS with UMTS release 6.

PCRF: Policy & Charging Rule Function

QoS policy negotiation with PDN

Charging Policy: determines how packets should be accounted

Home Subscriber Server (HSS)

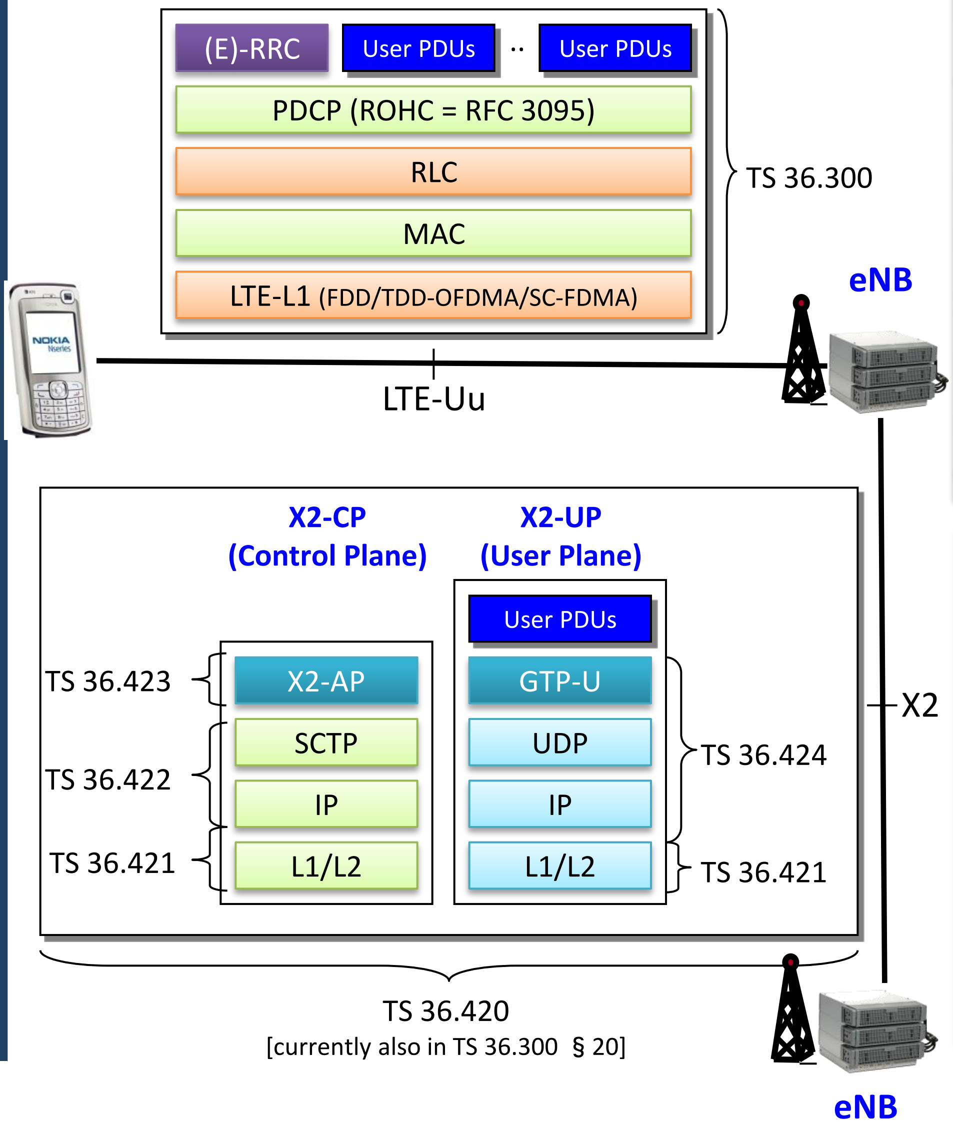


- The HSS is already introduced by UMTS release 5.
- With LTE/SAE the HSS will get additionally data per subscriber for SAE mobility and service handling.
- Some changes in the database as well as in the HSS protocol (DIAMETER) will be necessary to enable HSS for LTE/SAE.
- The HSS can be accessed by the MME via S6a interface.

<u>HSS Functions</u>

- Permanent and central subscriber database
- Stores mobility and service data for every subscriber
- Contains the Authentication Center (AuC) functionality.

LTE Radio Interface and the X2 Interface



LTE-Uu

Air interface of EUTRAN

Based on OFDMA in downlink and SC-FDMA in uplink

FDD and TDD duplex methods

Scalable bandwidth 1.4MHz to currently 20 MHz

Data rates up to 100 Mbps in DL

MIMO (Multiple Input Multiple Output) is a major component although optional.

X2

Inter eNB interface

Handover coordination without involving the EPC

X2AP: special signalling protocol

During HO, Source eNB can use the X2 interface to forward downlink packets still buffered or arriving from the serving gateway to the target eNB.

This will avoid loss of a huge amount of packets during inter-eNB handover.

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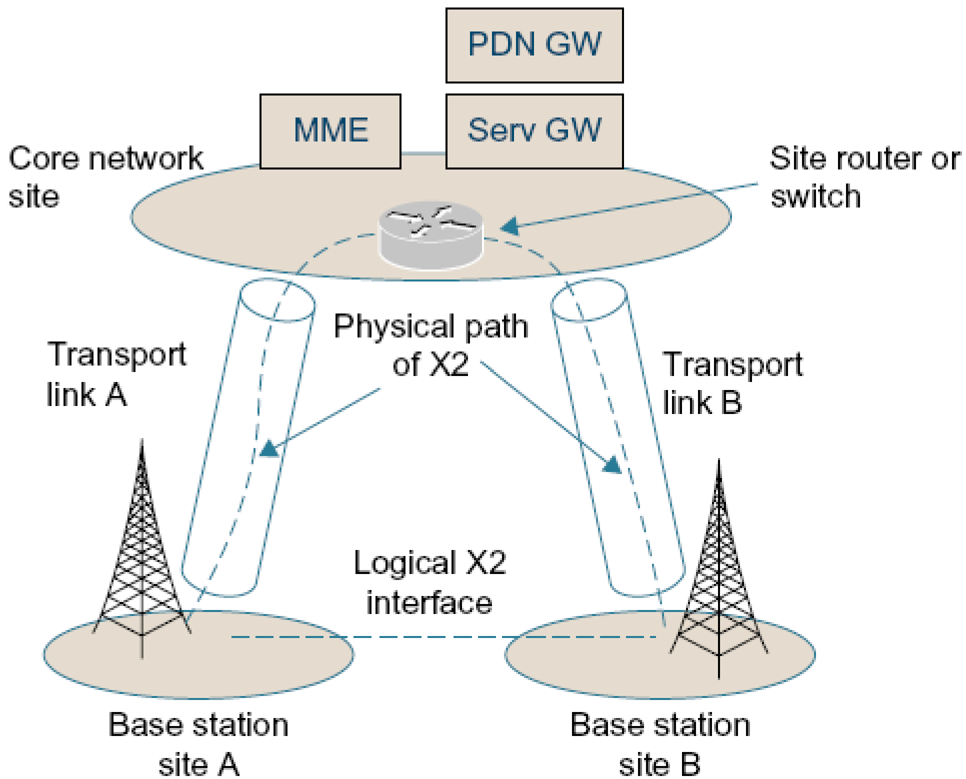
X2 Handover



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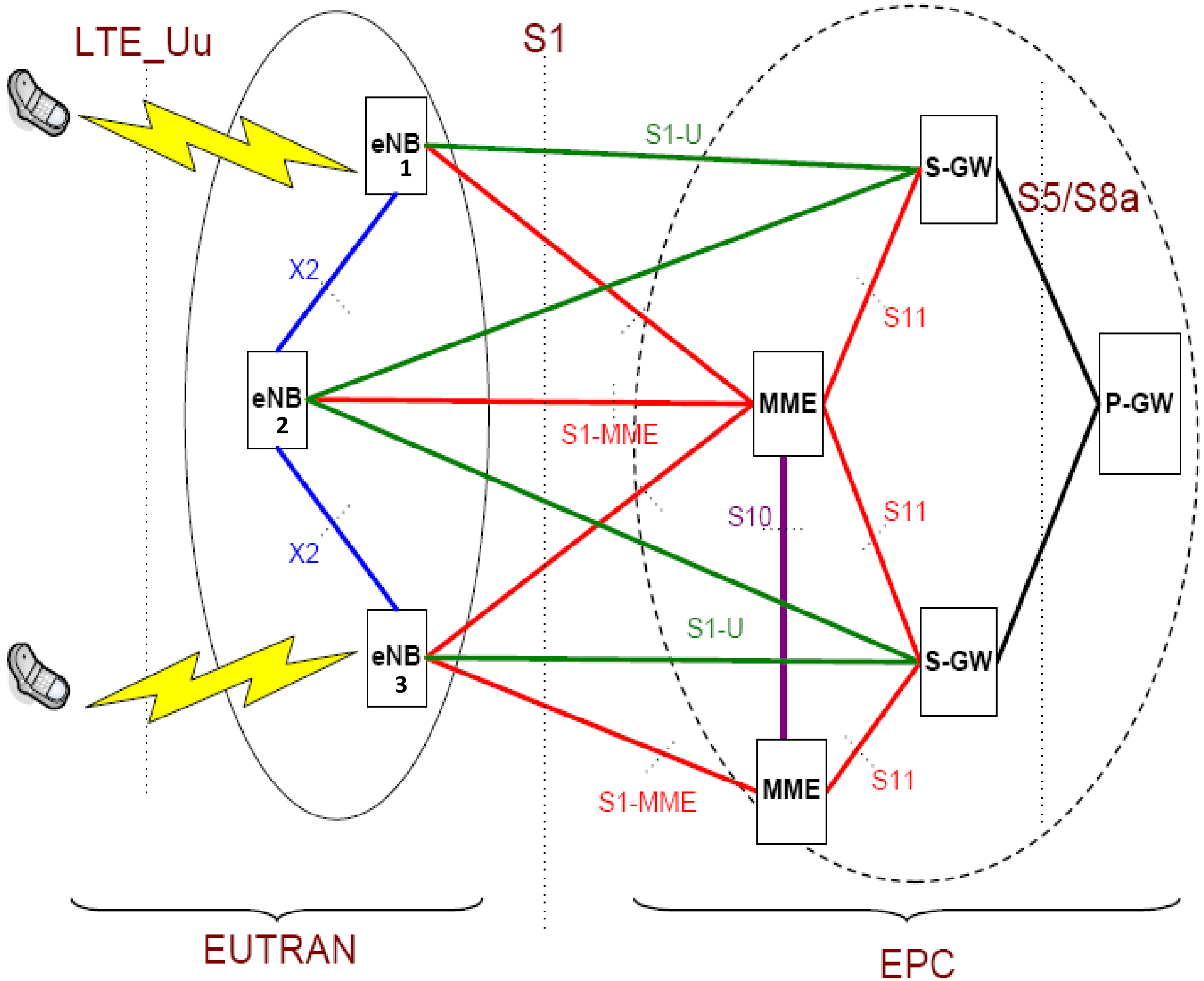
EUTRAN & EPC connected with S1-flex



Several cases

eNB 1 Single S1-MME
Single S1-U

eNB 2 Single S1-MME
Multiple S1-U→S1Flex-U

eNB 3 Multiple S1-ME→
S1Flex Single S1-U

LTE/EPC Mobility & Session Management

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LTE/SAE Mobility Areas

•Two areas are defined for handling of mobility in LTE/SAE:

•**The Cell**

•identified by the Cell Identity. The format is not standardized yet.

•**Tracking Area (TA)**

•It is the successor of location and routing areas from 2G/3G.

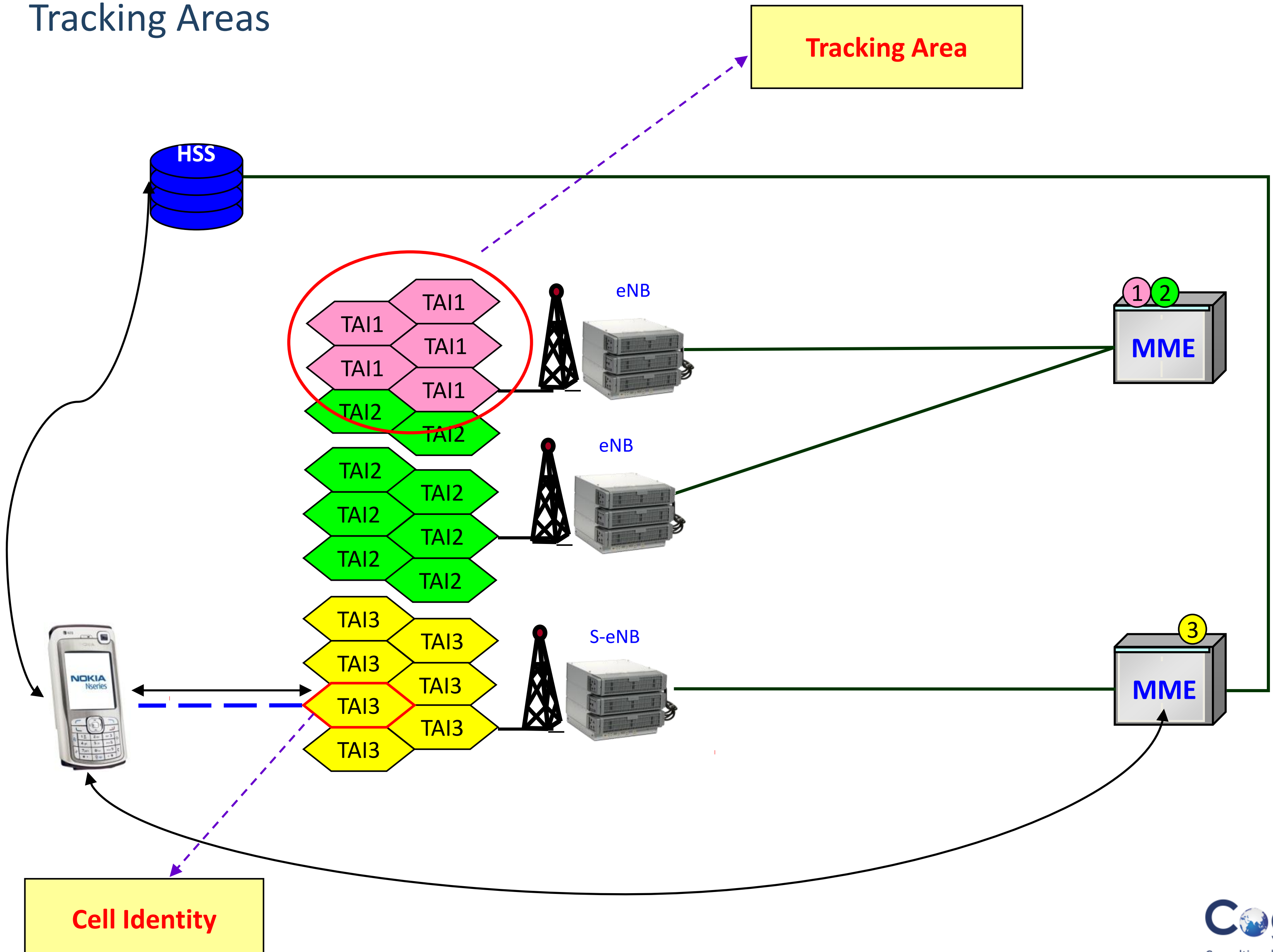
•When a UE is attached to the network, the MME will know the UE's position on tracking area level.

•In case the UE has to be paged, this will be done in the full tracking area.

•Tracking areas are identified by a **Tracking Area Identity (TAI).**

LTE/SAE Mobility Areas

- Tracking Areas



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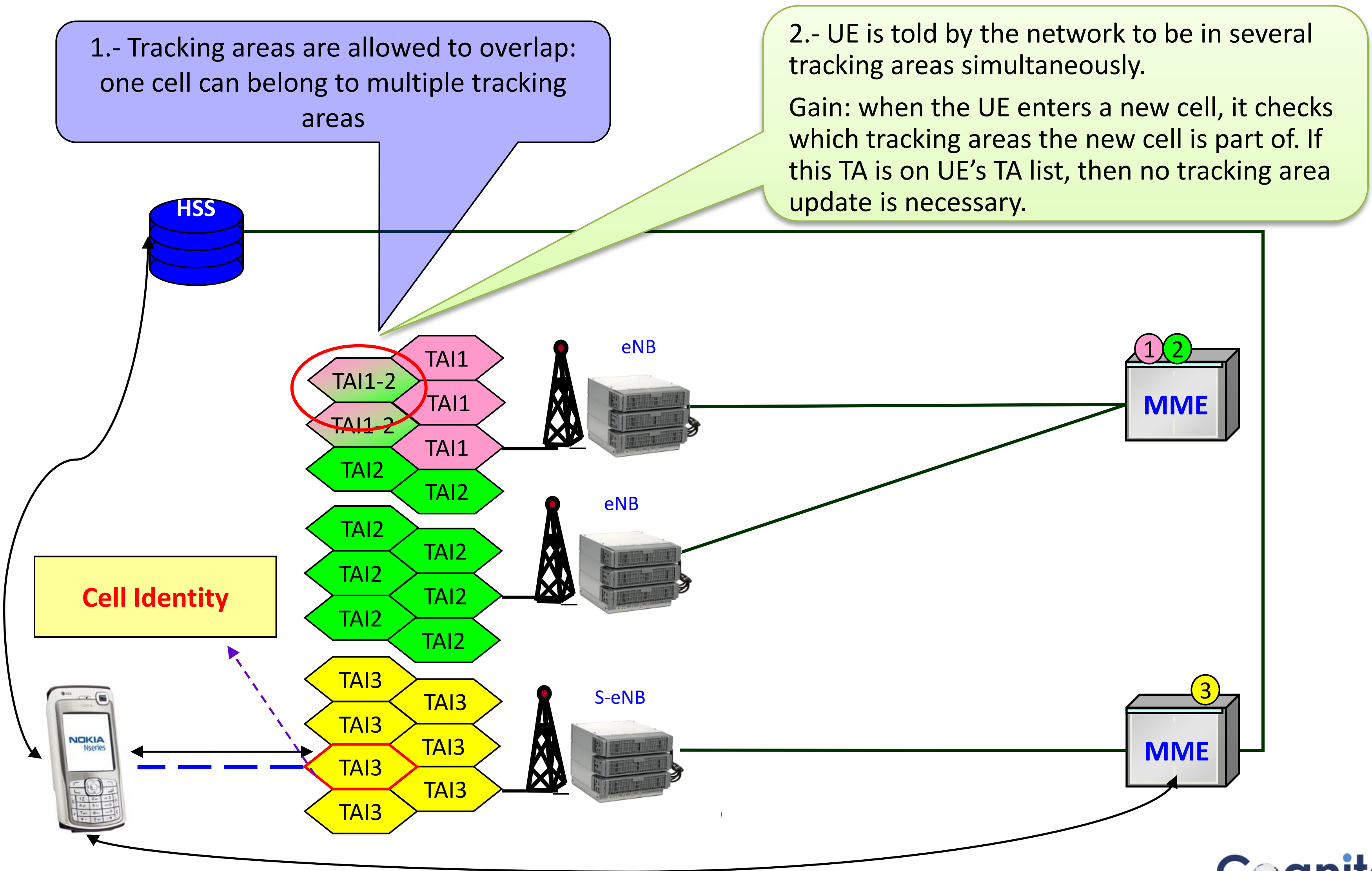
Tracking Areas Overlapping



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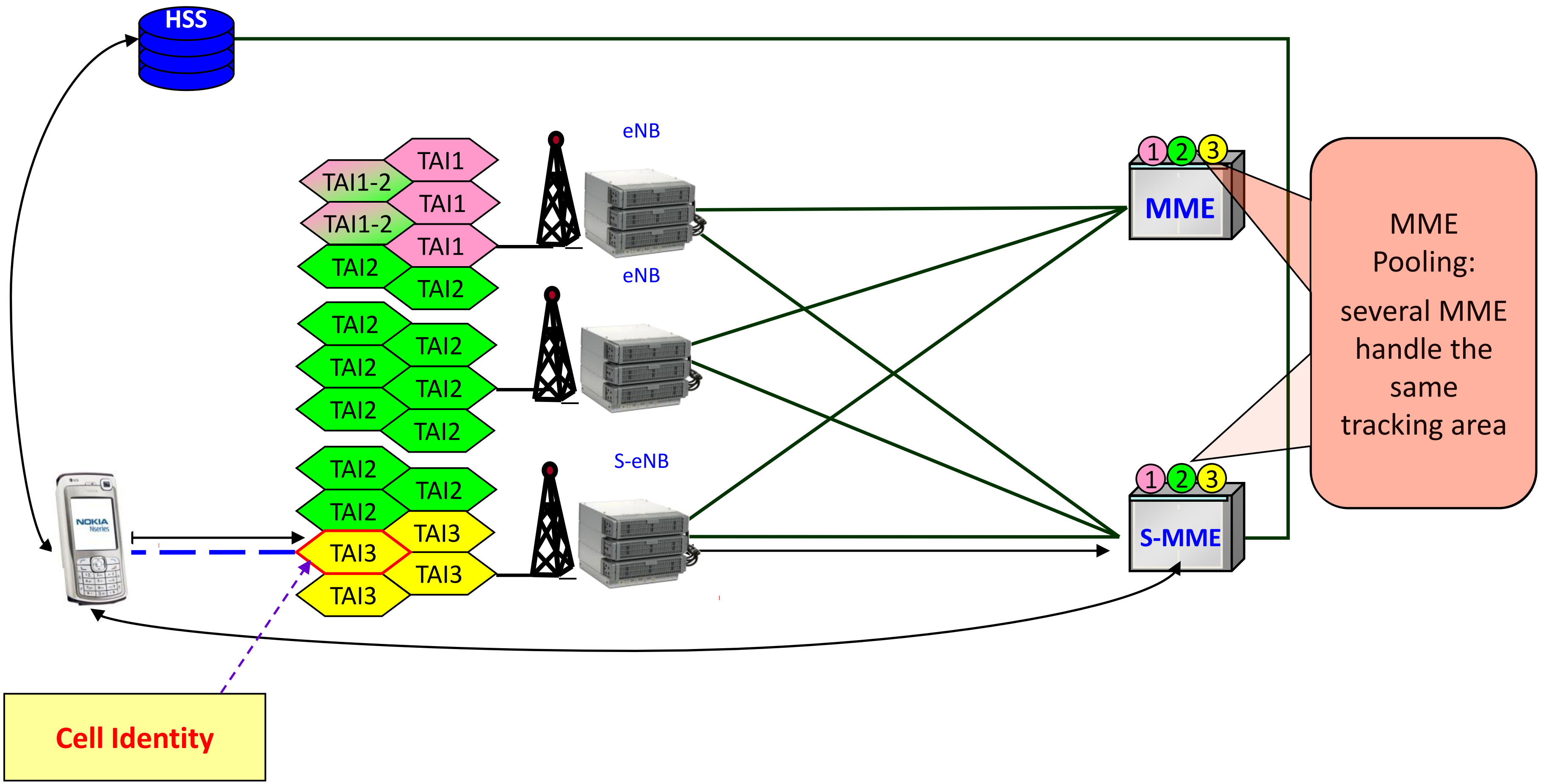
Tracking Areas: Use of S1-flex Interface



UE Identifications

- IMSI: International Mobile Subscriber Identity
- S-TMSI: SAE Temporary Mobile Subscriber Identity
- C-RNTI: Cell Radio Network Temporary Identity
- S1-AP UE ID: S1 Application Protocol User Equipment Identity

UE Identifications: IMSI

- **IMSI:**
  - International Mobile Subscriber Identity.

- Used in SAE to uniquely identify a subscriber world-wide.

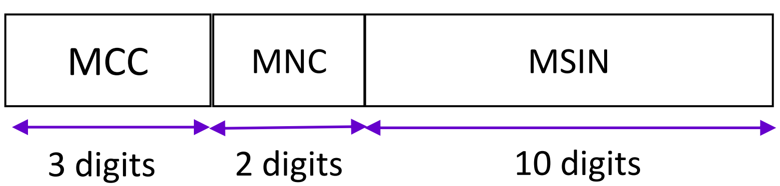
- Its structure is kept in form of MCC+MNC+MSIN:

  MCC: mobile country code
  MNC: mobile network code
  MSIN: mobile subscriber identification number

- A subscriber can use the same IMSI for 2G, 3G and SAE access.

- MME uses the IMSI to locate the HSS holding the subscribers permanent registration data for tracking area updates and attaches.

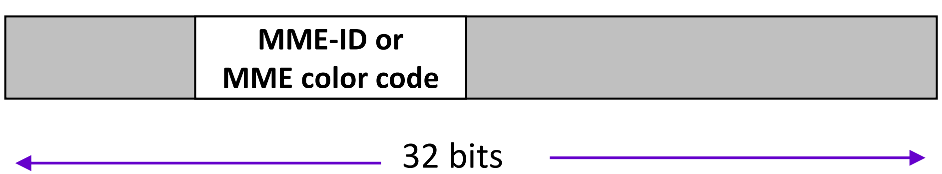
IMSI



UE Identification: S-TMSI

- **S-TMSI:**
- SAE Temporary Mobile Subscriber Identity
- It is dynamically allocated by the serving MME (S-MME).
- Its main purpose is to avoid usage of IMSI on air.
- Internally the allocating MME can translate S-TMSI into IMSI and vice versa.
- Whether the S-TMSI is unique per MME.
- In case the S1flex interface option is used, then the eNB must select the right MME for a UE. This is done by using some bits of the S-TMSI to identify the serving MME of the UE. This identifier might be a unique MME ID or a form of MME color code. Under investigation

S-TMSI

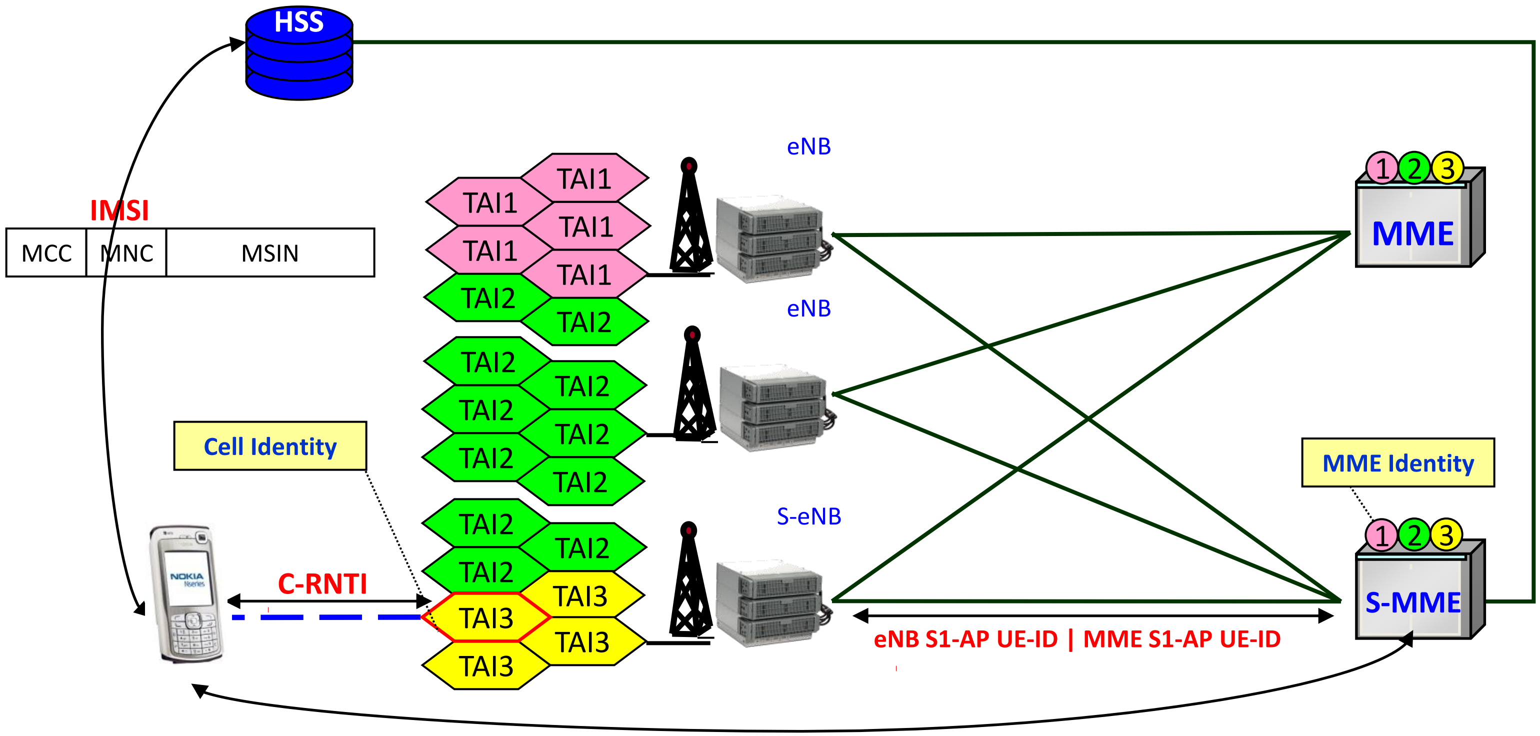


UE Identifications: C-RNTI

C-RNTI:

- Cell Radio Network Temporary Identity
- C-RNTI is allocated by the eNB serving a UE when it is in active mode (RRC_CONNECTED)
- This is a temporary identity for the user only valid within the serving cell of the UE.
- It is exclusively used for radio management procedures.
- X-RNTI identifications under investigation.

UE Identifications Summary



IMSI	International Mobile Subscriber Identity
S-TMSI	S-Temporary Mobile Subscriber Identity
C-RNTI	Cell Radio Network Temporary Identity
S-MME	Serving MME
S-eNB	Serving E-Node B
TAI	Tracking Area Identity (MCC+MNC+TAC)

S-TMSI

	MME-ID or MME color code	

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Terminology for 3G & LTE: Connection & Mobility Management

3G	LTE
Connection Management	
GPRS Attached	EMM Registered
PDP Context	EPS Bearer
Radio Access Bearer	Radio Bearer + S1 Bearer
Mobility Management	
Location Area	Not Relevant (no CS core)
Routing Area	Tracking Area
Handovers (DCH) and Cell reselections (PCH) when RRC connected	Handover when RRC connected
RNC hides mobility from core network	Core Network sees every handover

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LTE Mobility & Connection States

- There are two sets of states defined for the UE based on the information held by the MME.

- These are:
  - EPS* Mobility Management (EMM) states
  - EPS* Connection Management (ECM) states

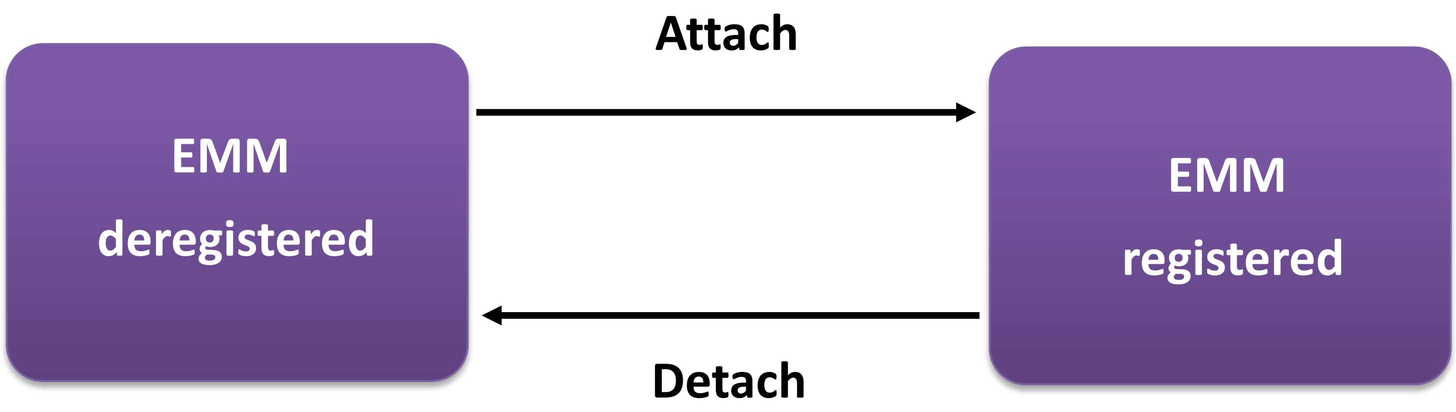
*EPS: Evolved Packet System

EPS Mobility Management (EMM) states

- **EMM-DEREGISTERED:**
- In this state the MME holds no valid location information about the UE
- MME may keep some UE context when the UE moves to this state (e.g. to avoid the need for Authentication and Key Agreement (AKA) during every attach procedure)
- Successful Attach and Tracking Area Update (TAU) procedures lead to transition to EMM-REGISTERED

- **EMM-REGISTERED:**
- In this state the MME holds location information for the UE at least to the accuracy of a tracking area
- In this state the UE performs TAU procedures, responds to paging messages and performs the service request procedure if there is uplink data to be sent.

EPS Mobility Management (EMM) states



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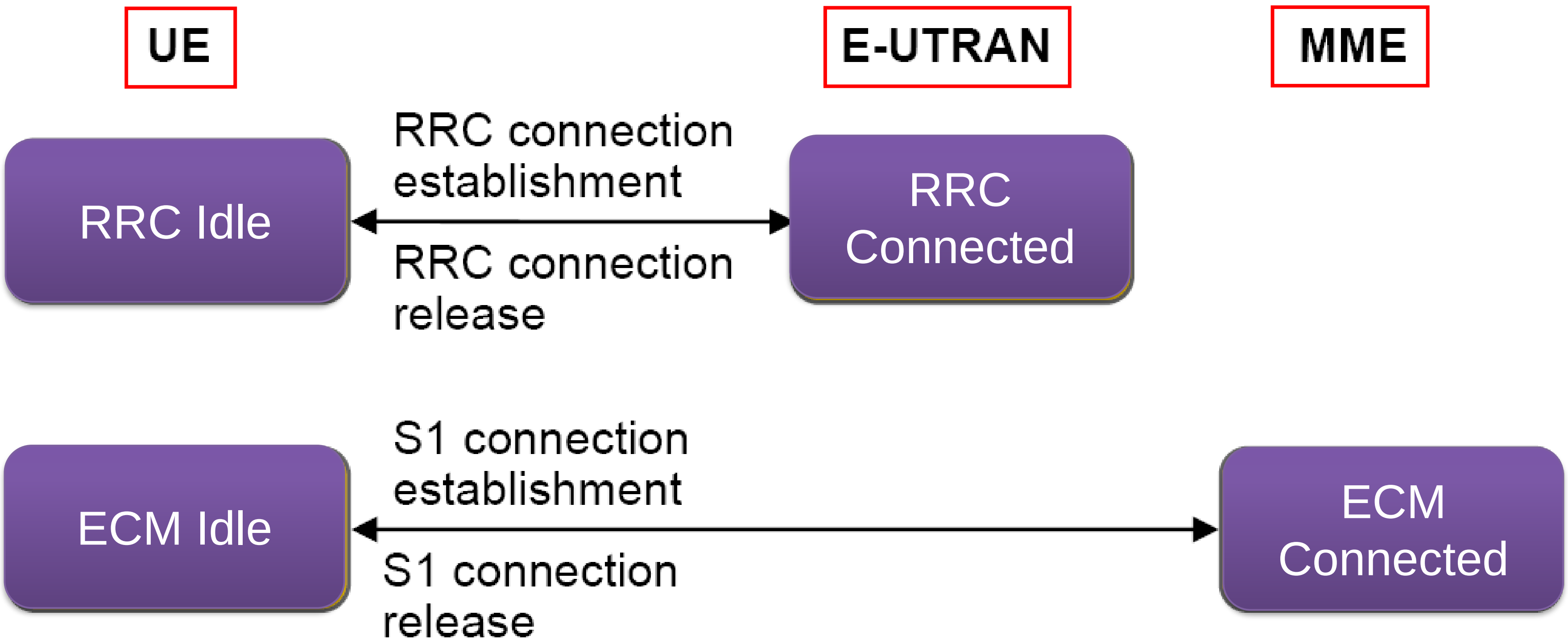
EPS Connection Management (ECM) and LTE Radio Resource Control States

- UE and MME enter ECM-CONNECTED state when the signalling connection is established between UE and MME
- UE and E-UTRAN enter RRC-CONNECTED state when the signalling connection is established between UE and E-UTRAN



EPS Connection Management (ECM) states

- **ECM-IDLE:**

- In this state there is no NAS signalling connection between the UE and the network and there is no context for the UE held in the E-UTRAN.
- The location of the UE is known to within the accuracy of a tracking area
- Mobility is managed by tracking area updates.

- **ECM-CONNECTED:**

- In this state there is a signalling connection between the UE and the MME which is provided in the form of a Radio Resource Control (RRC) connection between the UE and the E-UTRAN and an S1 connection for the UE between the E-UTRAN and the MME.
- The location of the UE is known to within the accuracy of a cell.
- Mobility is managed by handovers.

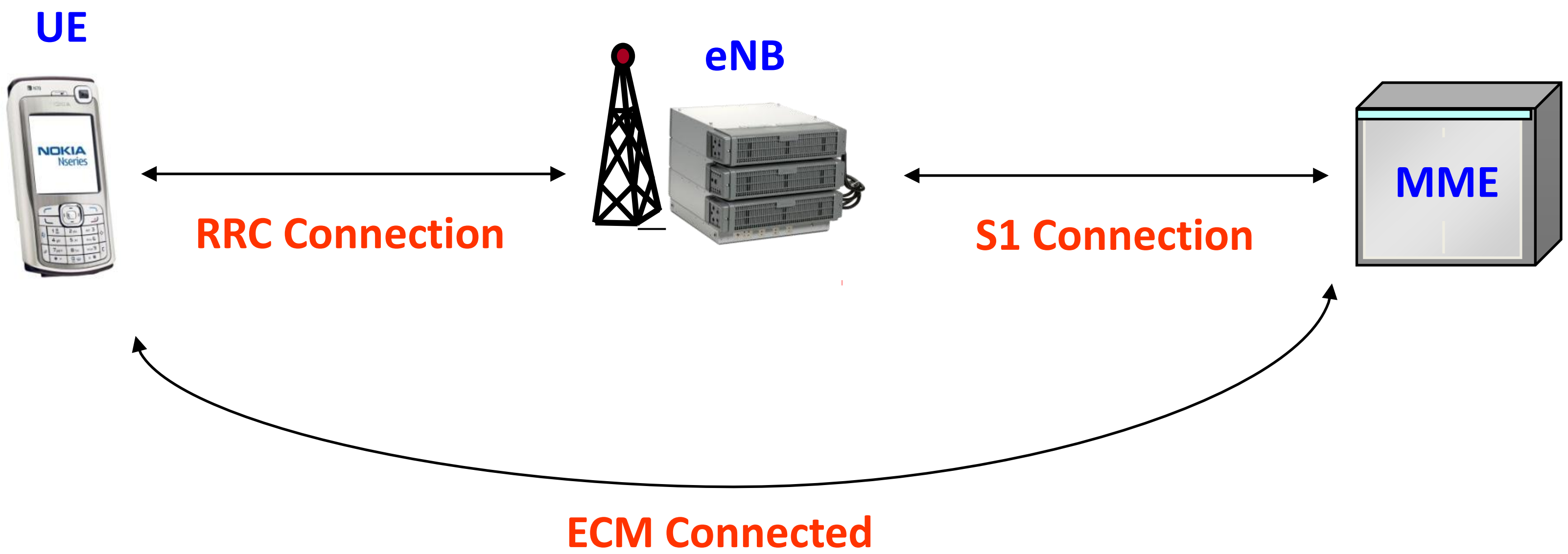
RRC States

- **RRC_IDLE**:
  - No signalling connection between the UE and the E-UTRAN, i.e. PLMN Selection.
  - UE Receives system information and listens for Paging.
  - Mobility based on Cell Re-selection performed by UE.
  - No RRC context stored in the eNB.
  - RACH procedure used on RRC connection establishment

- **RRC_CONNECTED**:
  - UE has an E-UTRAN RRC connection.
  - UE has context in E-UTRAN (C-RNTI allocated).
  - E-UTRAN knows the cell which the UE belongs to.
  - Network can transmit and/or receive data to/from UE.
  - Mobility based on handovers
  - UE reports neighbour cell measurements

EPS Connection Management

- **ECM Connected= RRC Connected + S1 Connection**



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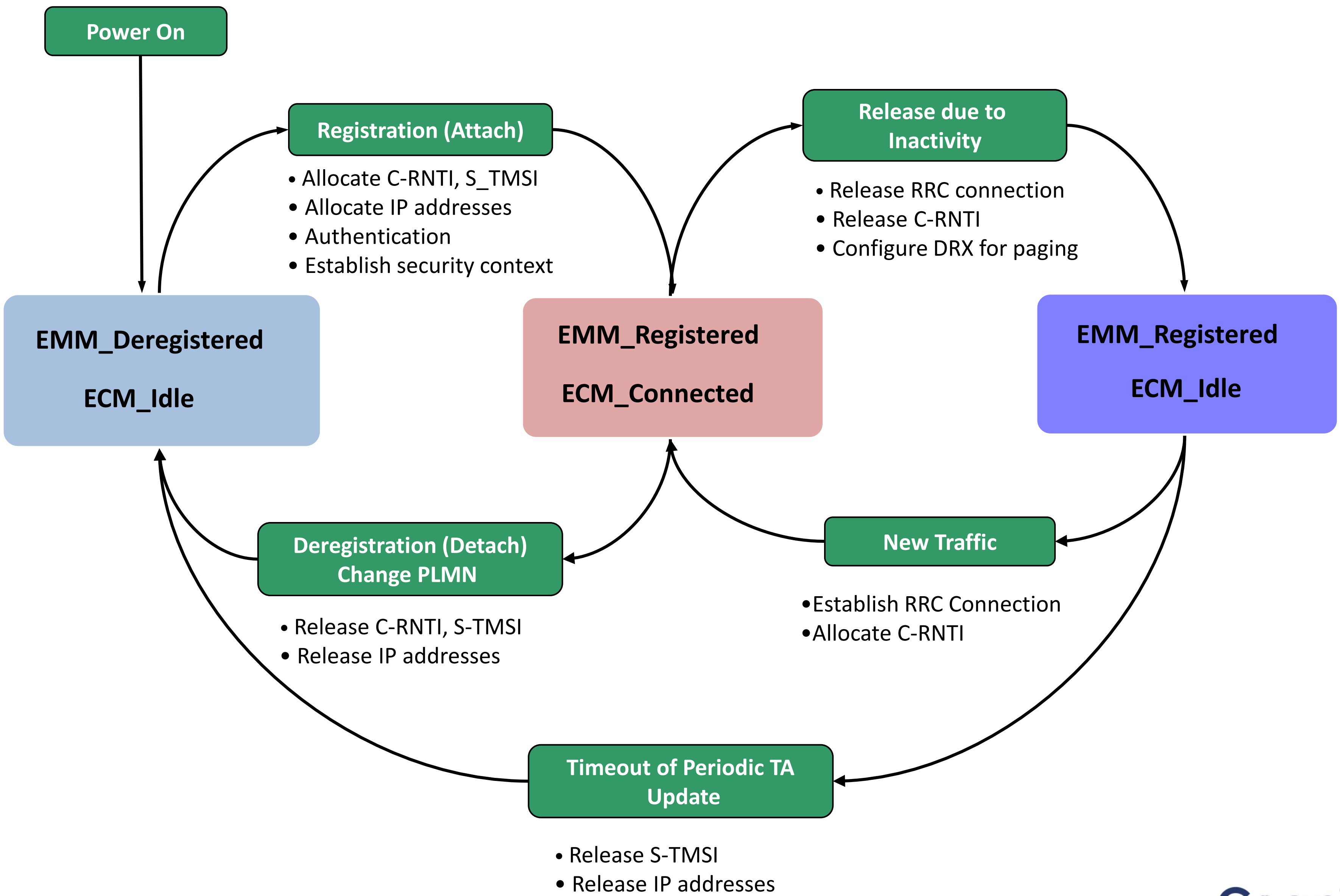
EMM & ECM States Transitions



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EMM & ECM States Summary

EMM_Deregistered
ECM_Idle

Network Context:
• no context exists

Allocated IDs:
• IMSI

UE Position:
• unknown to network

Mobility:
• PLMN/cell selection

UE Radio Activity:
• none

EMM_Registered
ECM_Connected

Network Context:
• all info for ongoing transmission/recepti on

Allocated IDs:
• IMSI, S-TMSI per TAI
• 1 or several IP addresses
• C-RNTI

UE Position:
• known on cell level

Mobility:
• NW controlled handover

EMM_Registered
ECM_Idle

Network Context:
• security keys
• enable fast transition to ECM_CONNECTED

Allocated IDs:
• IMSI, S-TMSI per TAI
• 1or several IP addresses

UE Position:
• known on TA level (TA list)

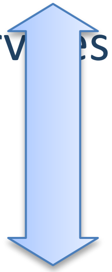
Mobility:
• cell reselection

LTE/SAE Bearer

- The main function of every mobile radio telecommunication network is to provide subscribers with transport bearers for their user data.

- In circuit switched networks users get a fixed assigned por ’s bandwidth.

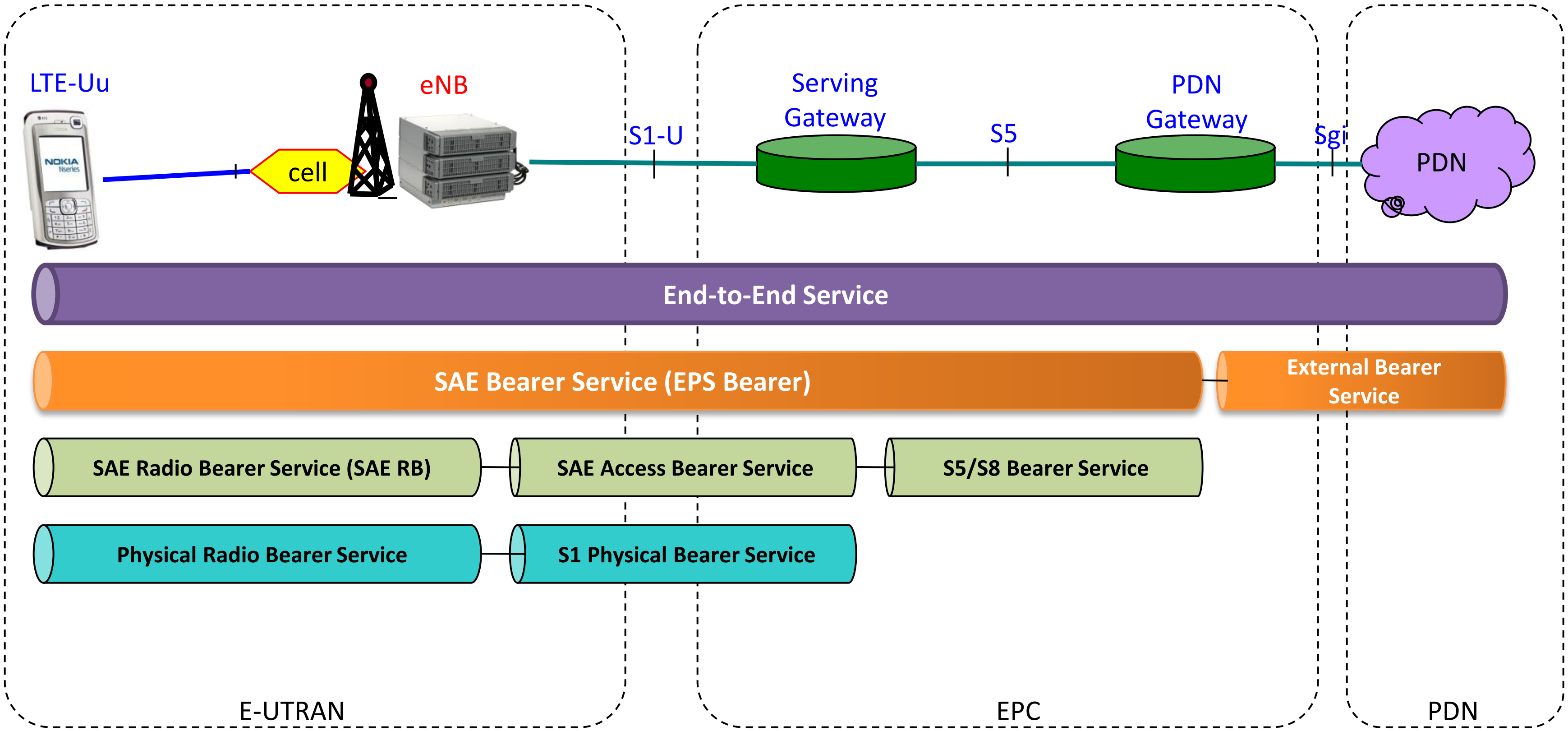
- In packet networks users get a bearer with a certain quality of service (QoS) ranging from fixed guaranteed bandwidth down to best effort serv es without any guarantee.



- LTE/SAE is a packet oriented system

SAE Bearer Architecture

- **SAE Bearer** spans the complete network, from UE over EUTRAN and EPS up to the connector of the external PDN.
- The SAE bearer is associated with a quality of service (QoS) usually expressed by a **label** or **QoS Class Identifier (QCI).**



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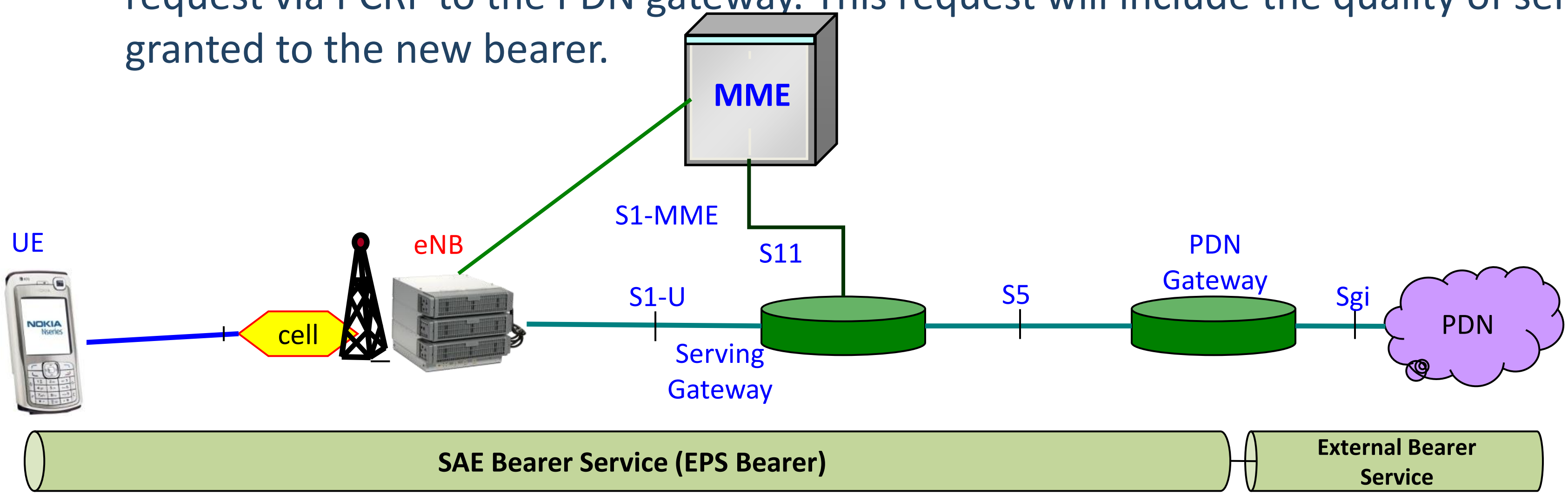
SAE Bearer Establishment

- It can be establish by MME or P-GW
- MME:
  - This happens typically during the attach procedure of an UE. Depending on the information coming from HSS, the MME will set up an initial SAE bearer, also known as the default SAE bearer. This SAE bearer provides the initial connectivity of the UE with its external data network.
- PDN Gateway:
  - The external data network can request the setup of a SAE bearer by issuing this request via PCRF to the PDN gateway. This request will include the quality of service granted to the new bearer.



QoS Class Indentifier (QCI) Table in 3GPP

QCI	Guarantee	Priority	Delay budget	Loss rate	Application
1	GBR	2	100 ms	1e-2	VoIP
2	GBR	4	150 ms	1e-3	Video call
3	GBR	5	300 ms	1e-6	Streaming
4	GBR	3	50 ms	1e-3	Real time gaming
5	Non-GBR	1	100 ms	1e-6	IMS signalling
6	Non-GBR	7	100 ms	1e-3	Interactive gaming
7	Non-GBR	6	300 ms	1e-6	TCP protocols : browsing, email, file download
8	Non-GBR	8	300 ms	1e-6	
9	Non-GBR	9	300 ms	1e-6	

Operators can define more QCIs

Several bearers can be aggregated together if they have the same QCI

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LTE/EPC Procedures

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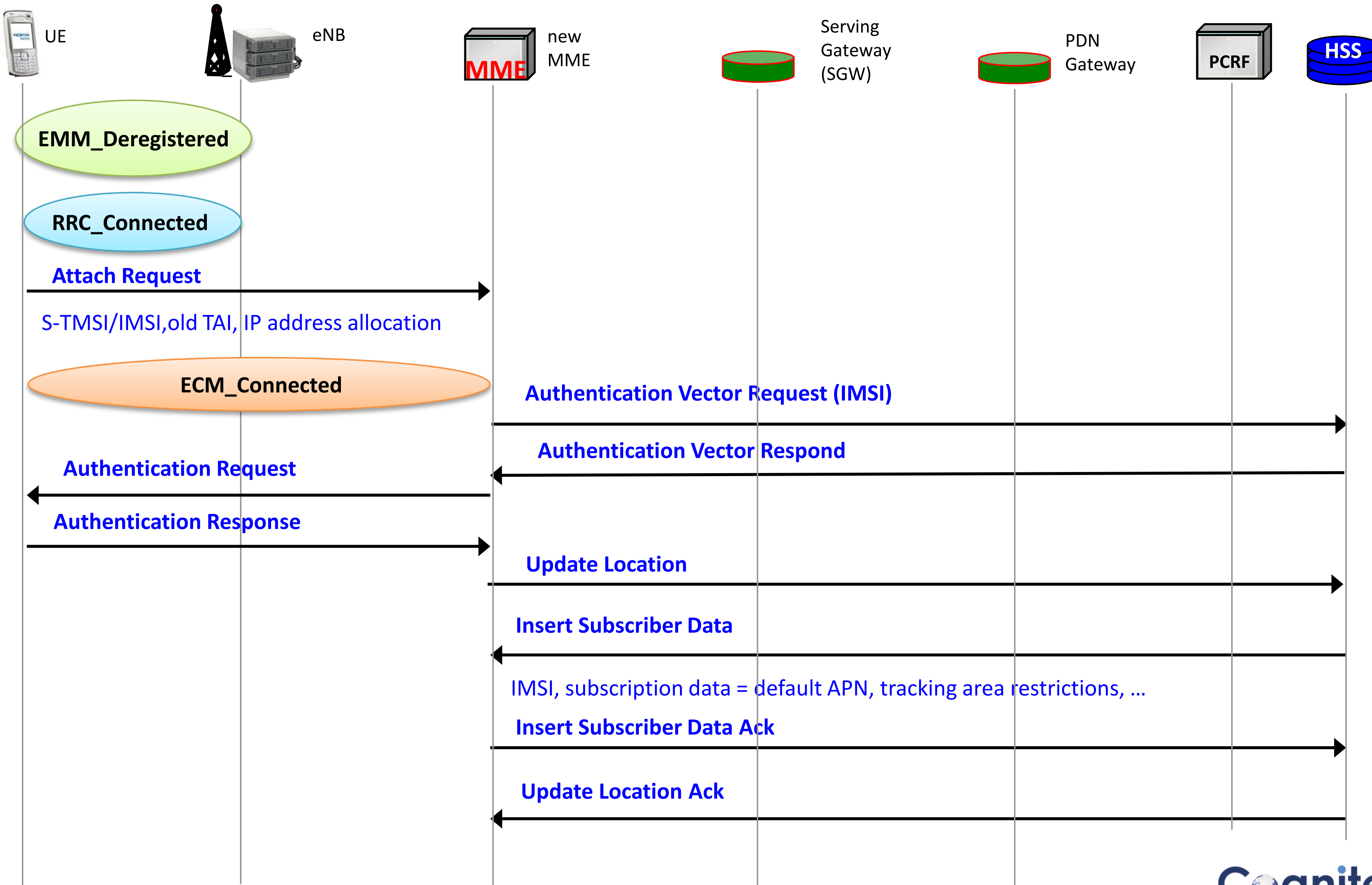
Attach



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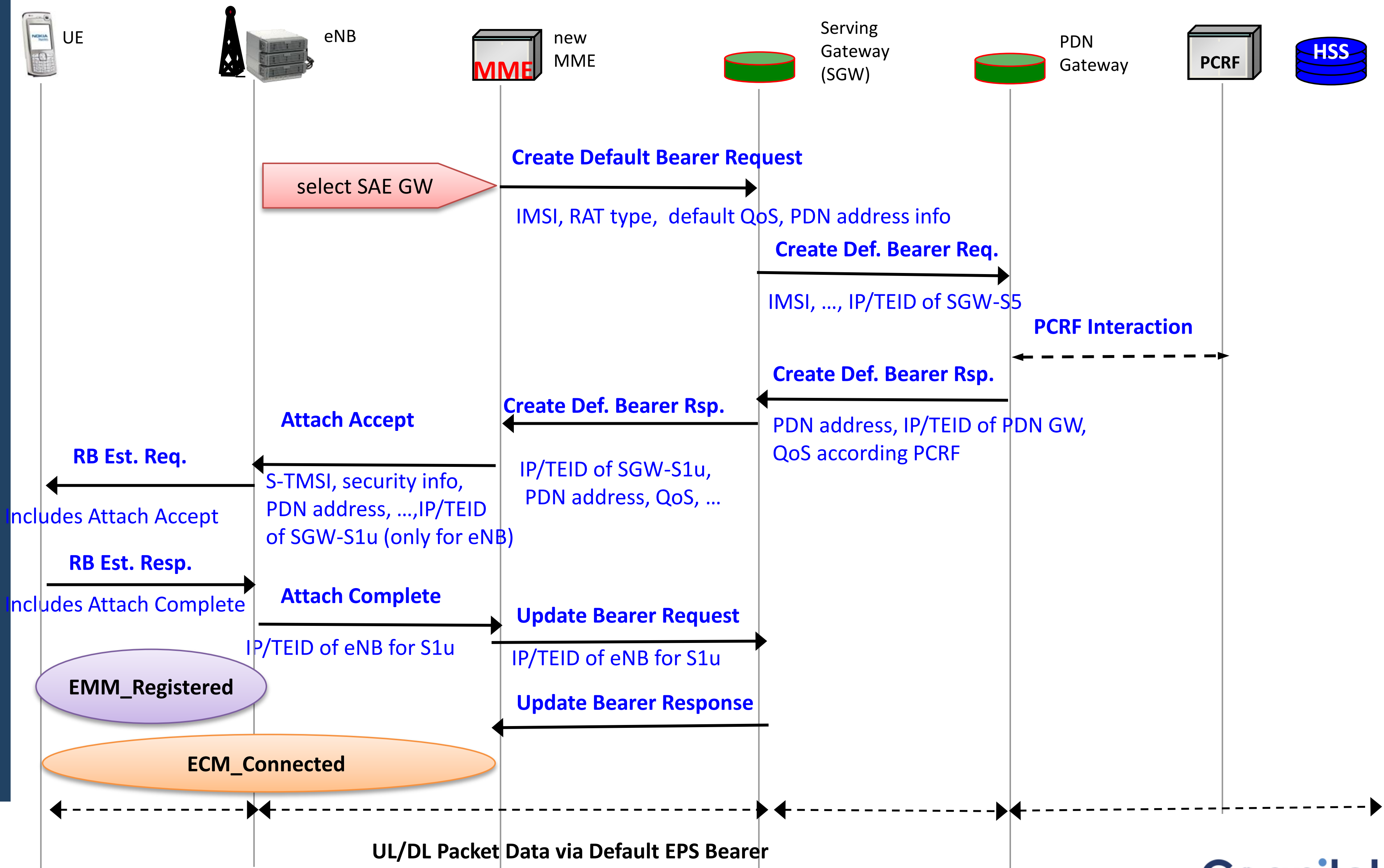
Attach cont....



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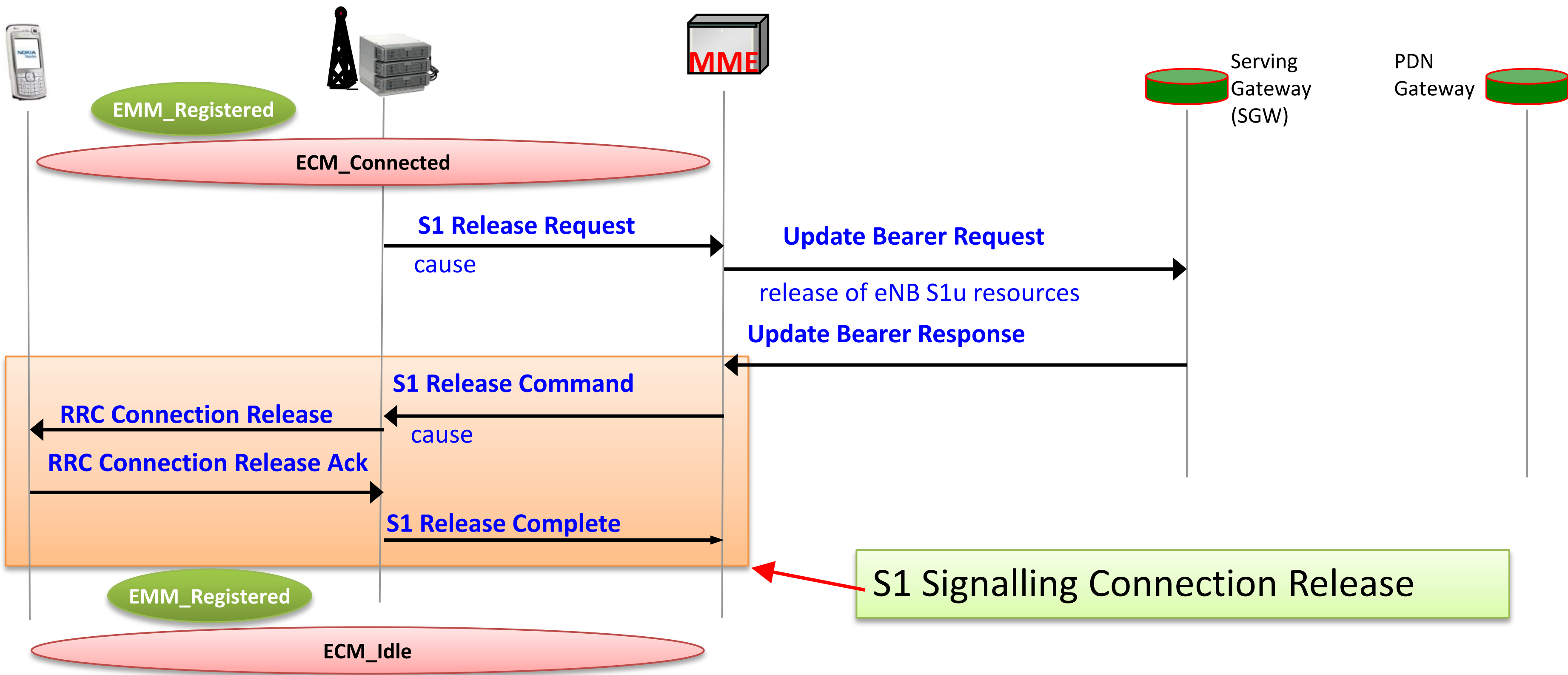
S1 Release

- After attach UE is in EMM Registered state.
- The default Bearer has been allocated (RRC connected + ECM connected) even it may not transmit or receive data
- If there is a longer period of inactivity by this UE, then we should free these admission control resources (RRC idle + ECM idle)
- The trigger for this procedure can come from eNB or from MME.



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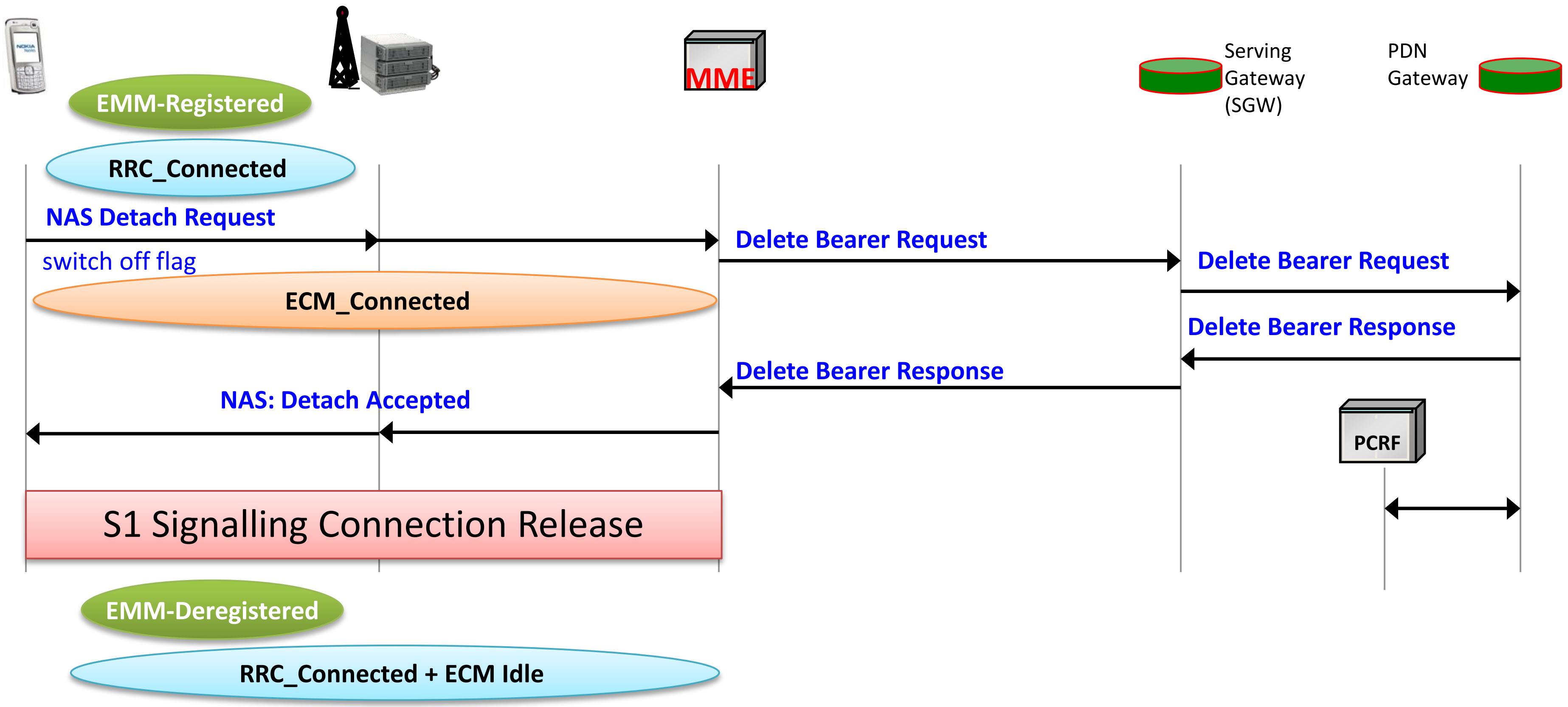
Detach

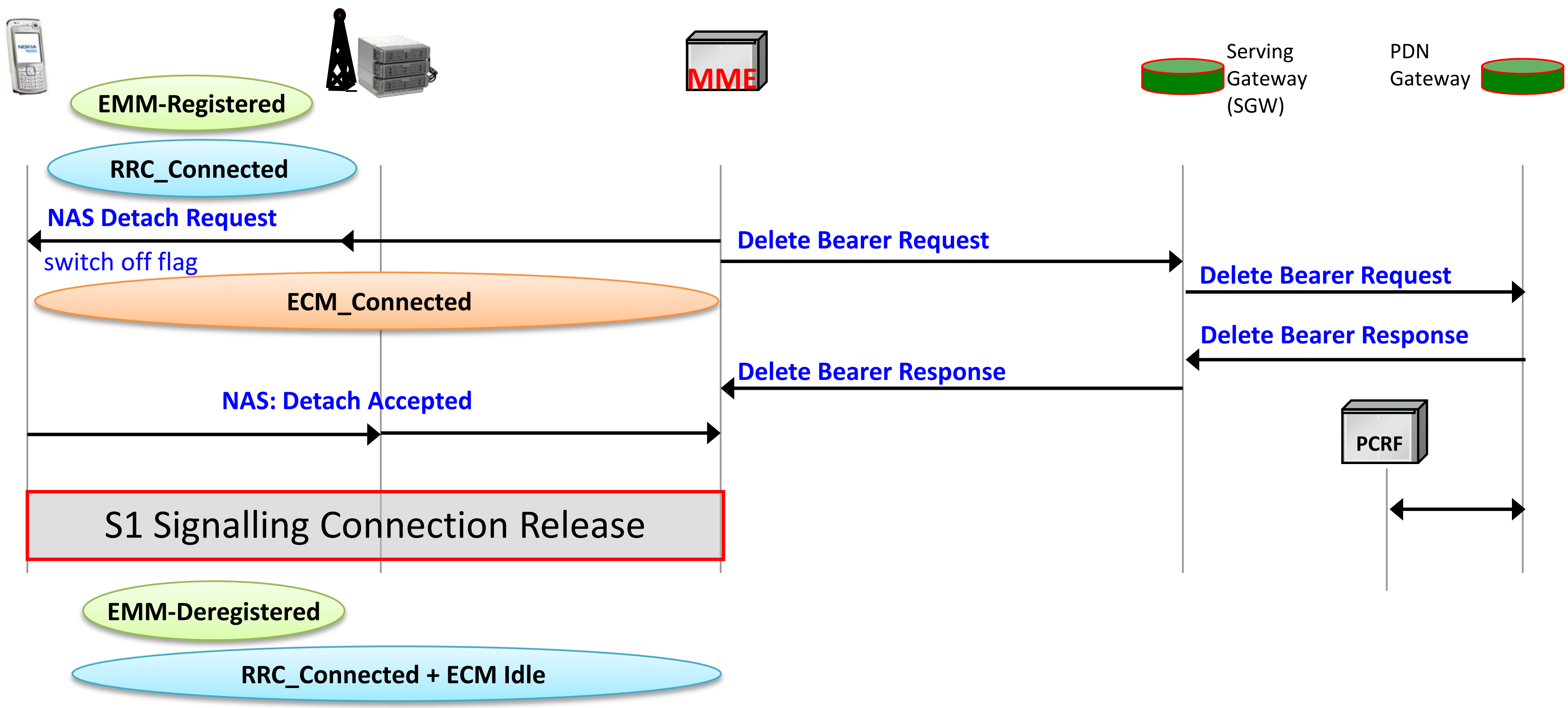
- Can be triggered by UE or by MME.
- During the detach procedure all SAE bearers with their associated tunnels and radio bearers will be deleted.



Note: Detach procedure initiated by UE.

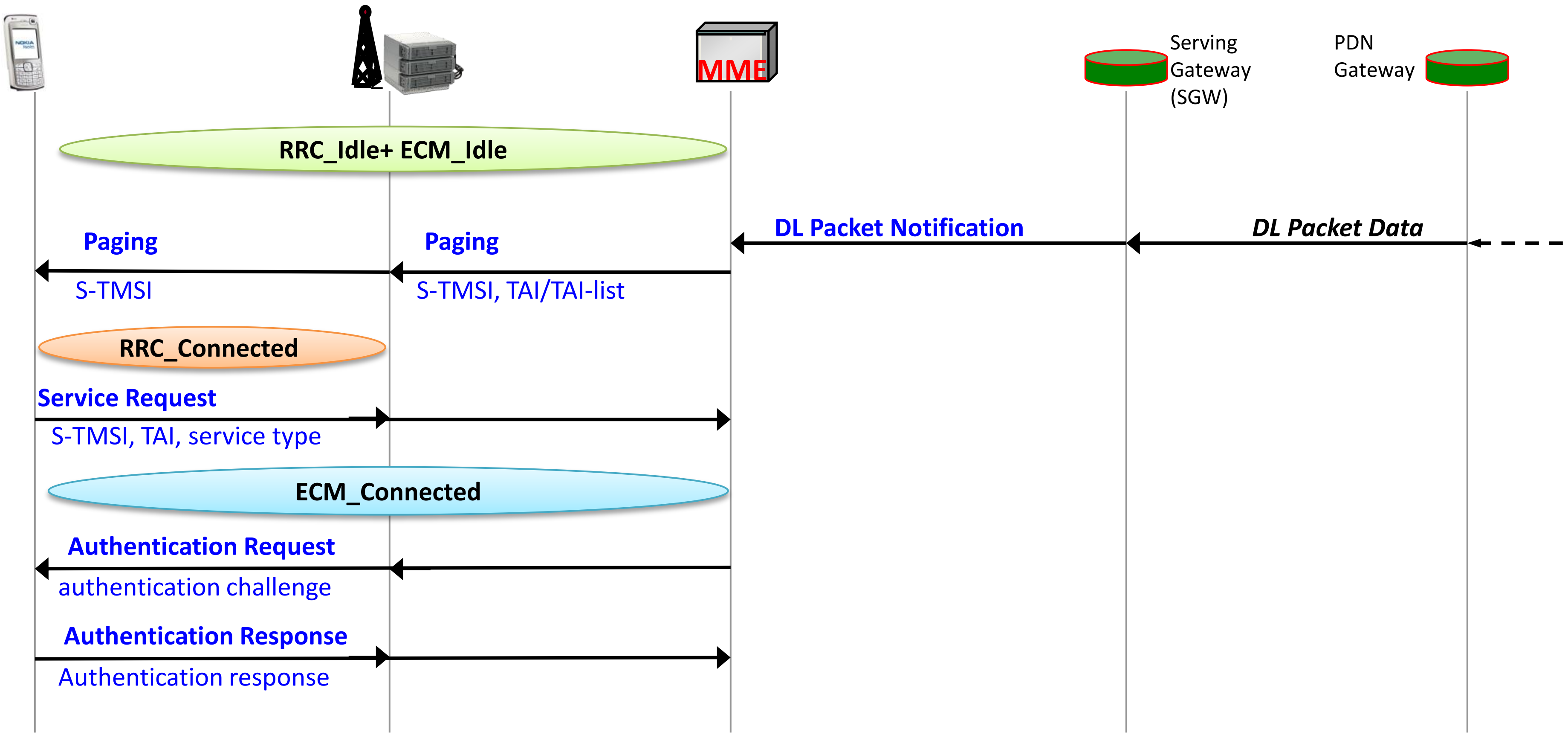
Detach

Note: Detach procedure initiated by MME.

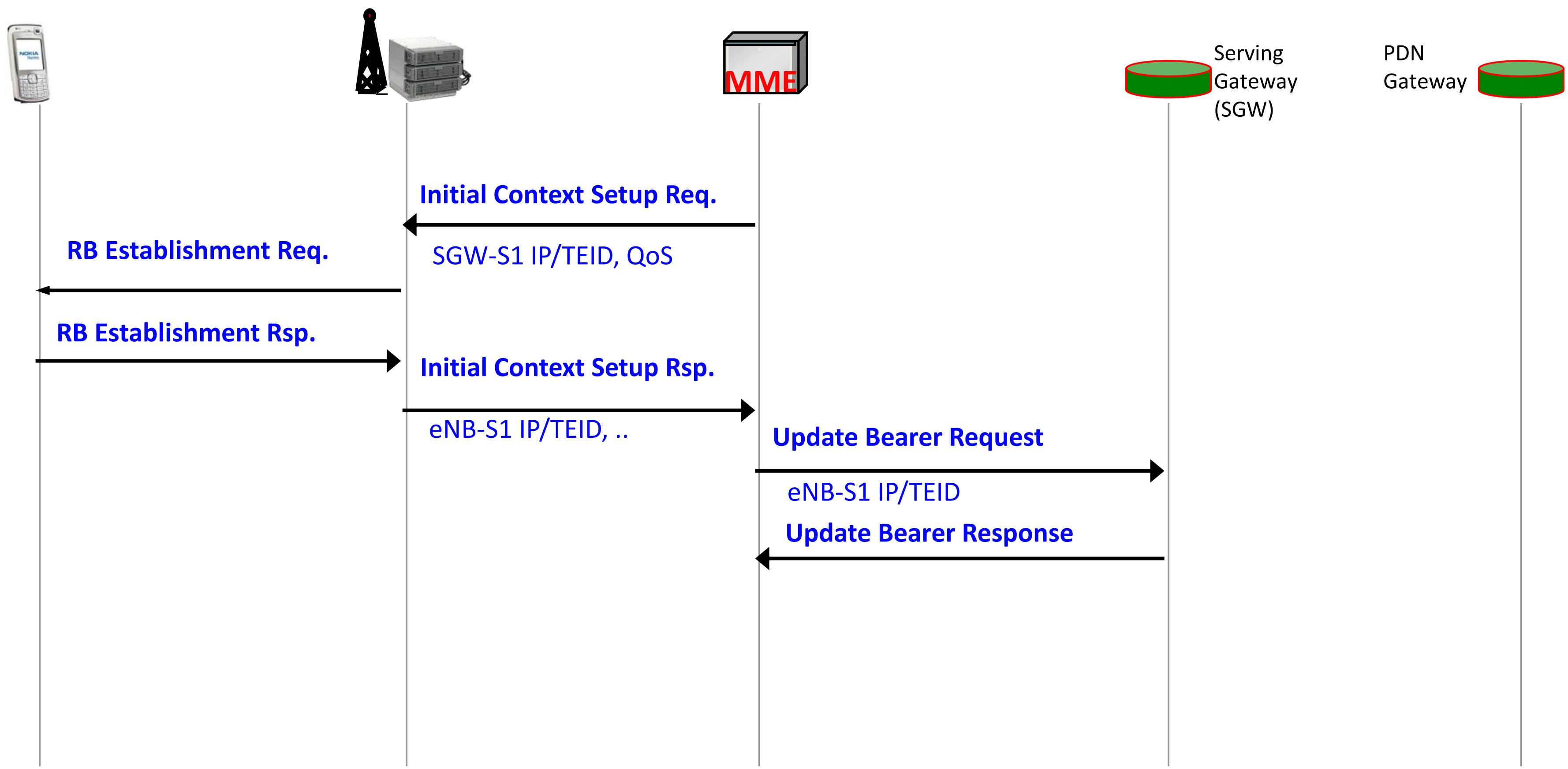


Service Request

- From time to time a UE must switch from ECM_Idle to ECM_connected
- The reasons for this might be UL data is available, UL signaling is pending (e.g. tracking area update, detach) or a paging from the network was received.

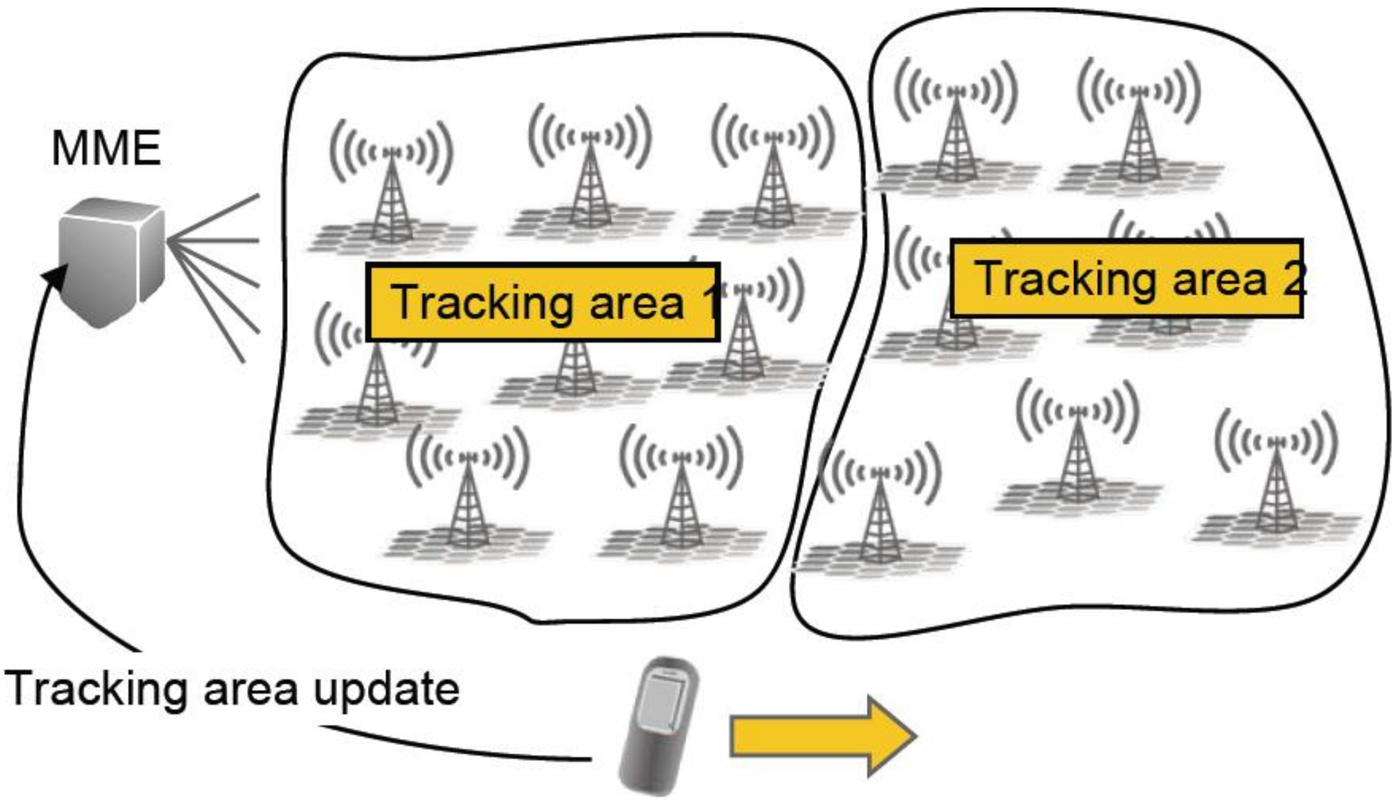


Service Request

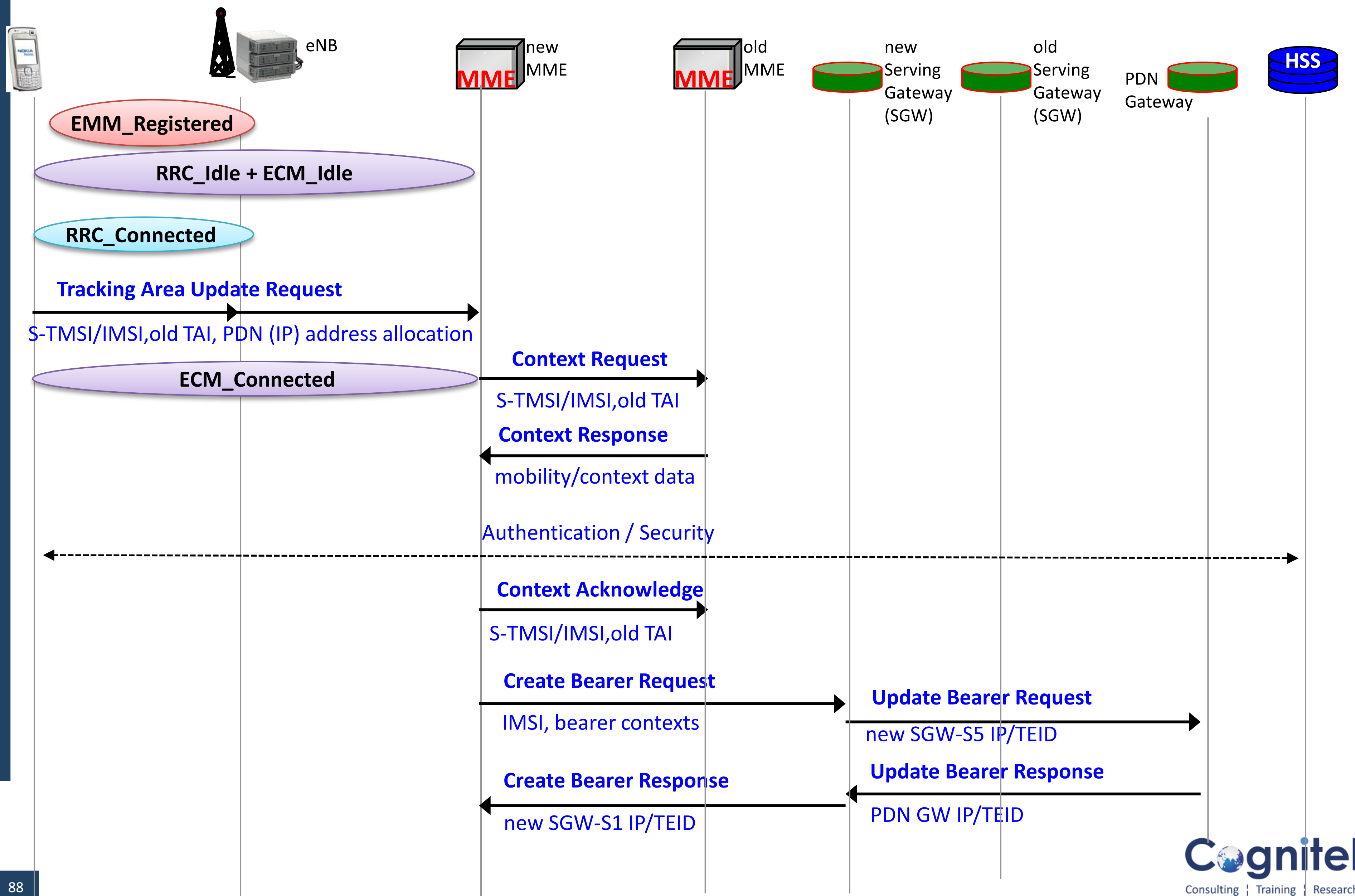


Tracking Area Update (TAU)

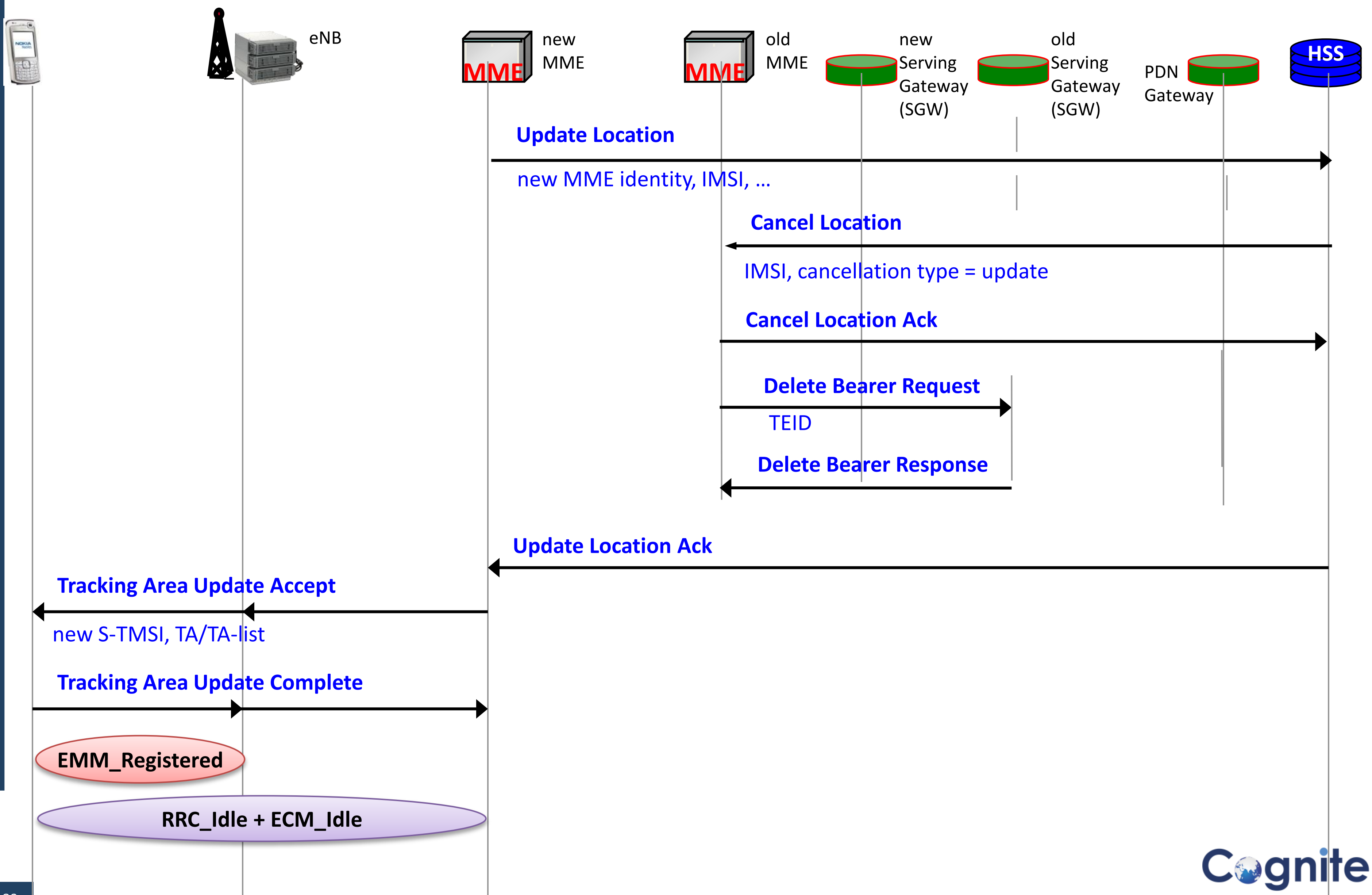
- Tracking area (TA) is similar to Location/Routing area in 2G/3G .
- Tracking Area Identity = MCC (Mobile Country Code), MNC (Mobile Network Code) and TAC (Tracking Area Code).
- When UE is in ECM-Idle, MME knows UE location with Tracking Area accuracy.



Tracking Area Update (1/2)



Tracking Area Update cont…



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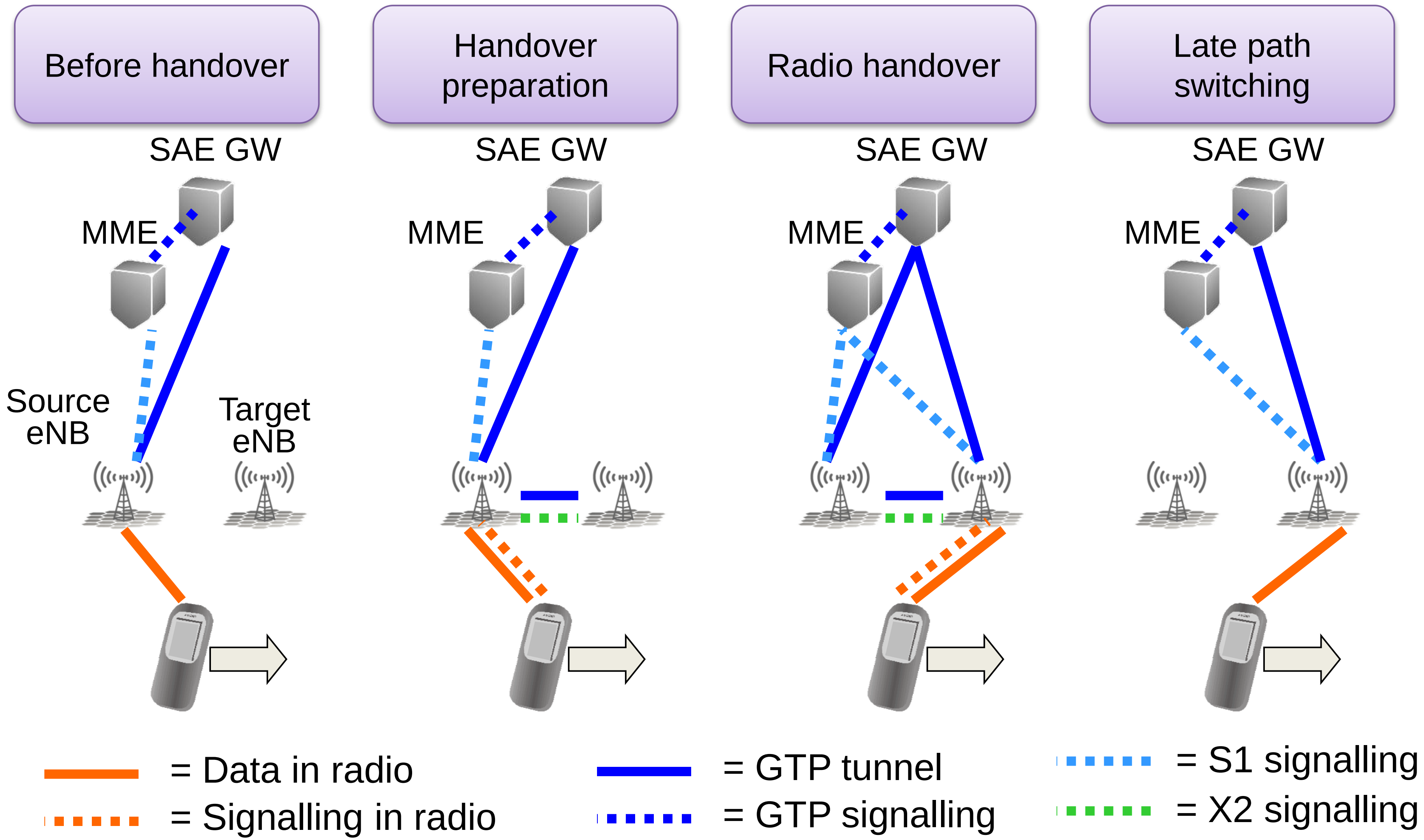
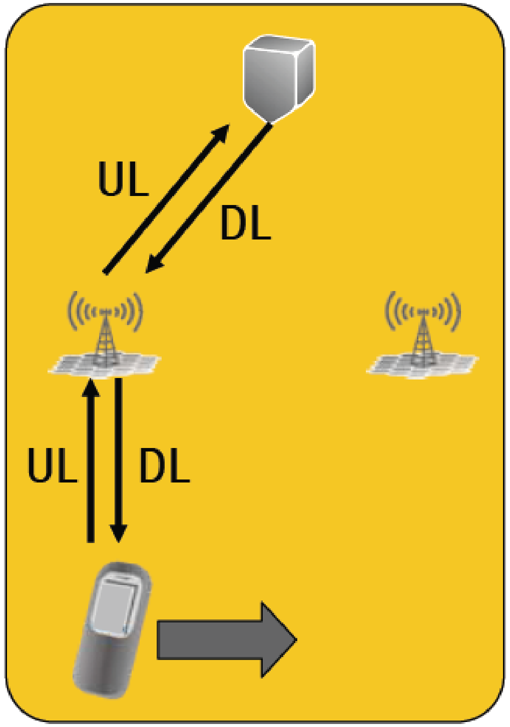
Handover Procedure



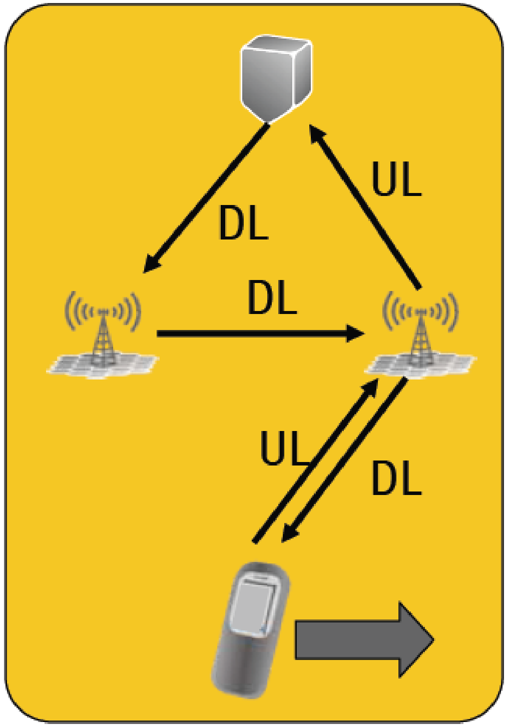
Note: Inter eNB Handover with X2 Interface and without CN Relocation

User plane switching in Handover

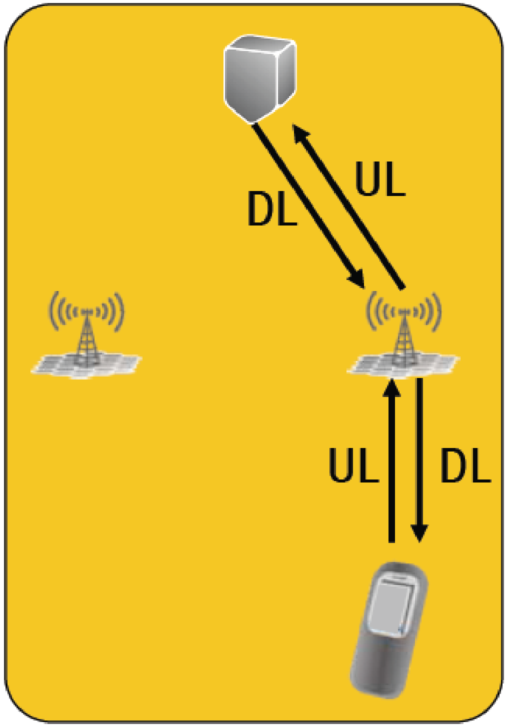
Before handover



Packet forwarding



Late path switching



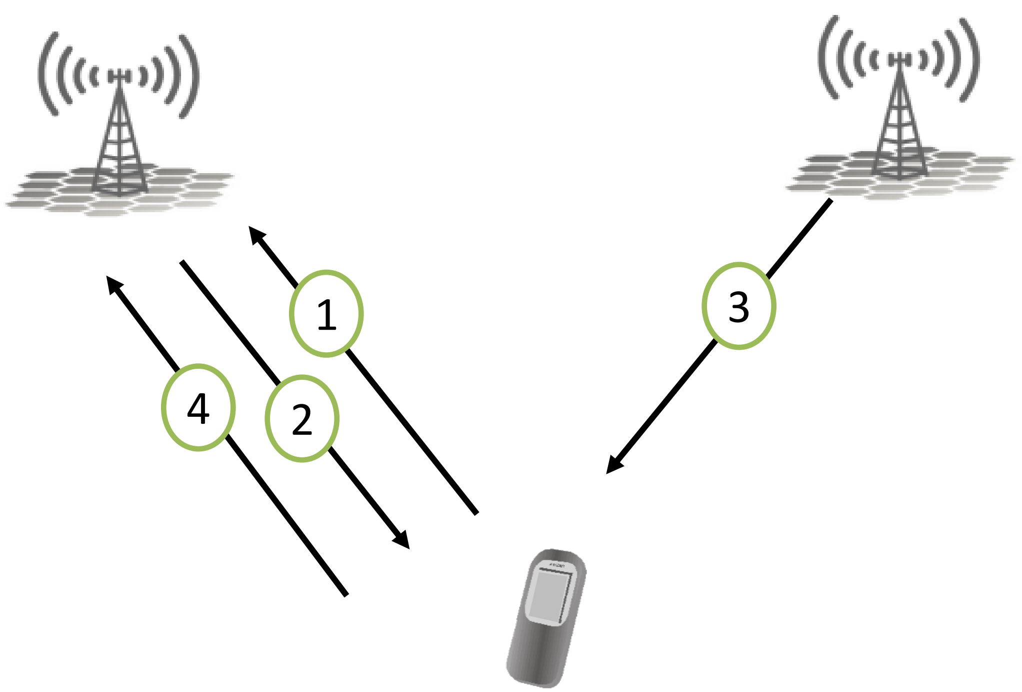
Automatic Neighbor Relations

1--UE reports neighbor cell signal including Physical Cell ID

2--Request for Global Cell ID reporting

3--UE reads Global Cell ID from BCH

4--UE reports Global Cell ID



LTE Air Interface

LTE Design Performance Targets

- **Scalable transmission bandwidth(up to 20 MHz)**

- **Improved Spectrum Efficiency**
  - Downlink (DL) spectrum efficiency should be 2-4 times Release 6 HSDPA.
    - Downlink target assumes 2x2 MIMO for E-UTRA and single Tx antenna with Type 1 receiver HSDPA.
  - Uplink (UL) spectrum efficiency should be 2-3 times Release 6 HSUPA.
    - Uplink target assumes 1 Tx antenna and 2 Rx antennas for both E-UTRA and Release 6 HSUPA.

- **Coverage**
  - Good performance up to 5 km
  - Slight degradation from 5 km to 30 km (up to 100 km not precluded)

- **Mobility**
  - Optimized for low mobile speed (< 15 km/h)
  - Maintained mobility support up to 350 km/h (possibly up to 500 km/h)

LTE Design Performance Targets

- **Advanced transmission schemes, multiple-antenna technologies**

- **Inter-working with existing 3G and non-3GPP systems**
  - Interruption time of real-time or non-real-time service handover between E-UTRAN and UTRAN/GERAN shall be less than 300 or 500 ms.

Air Interface Capabilities

- Bandwidth support
  - Flexible from 1.4 MHz to 20 MHz
- Waveform
  - OFDM in Downlink
  - SC-FDM in Uplink
- Duplexing mode
  - FDD: full-duplex (FD) and half-duplex (HD)
  - TDD
- Modulation orders for data channels
  - Downlink: QPSK, 16-QAM, 64-QAM
  - Uplink: QPSK, 16-QAM, 64-QAM
- MIMO support
  - Downlink: SU-MIMO and MU-MIMO (SDMA)
  - Uplink: SDMA

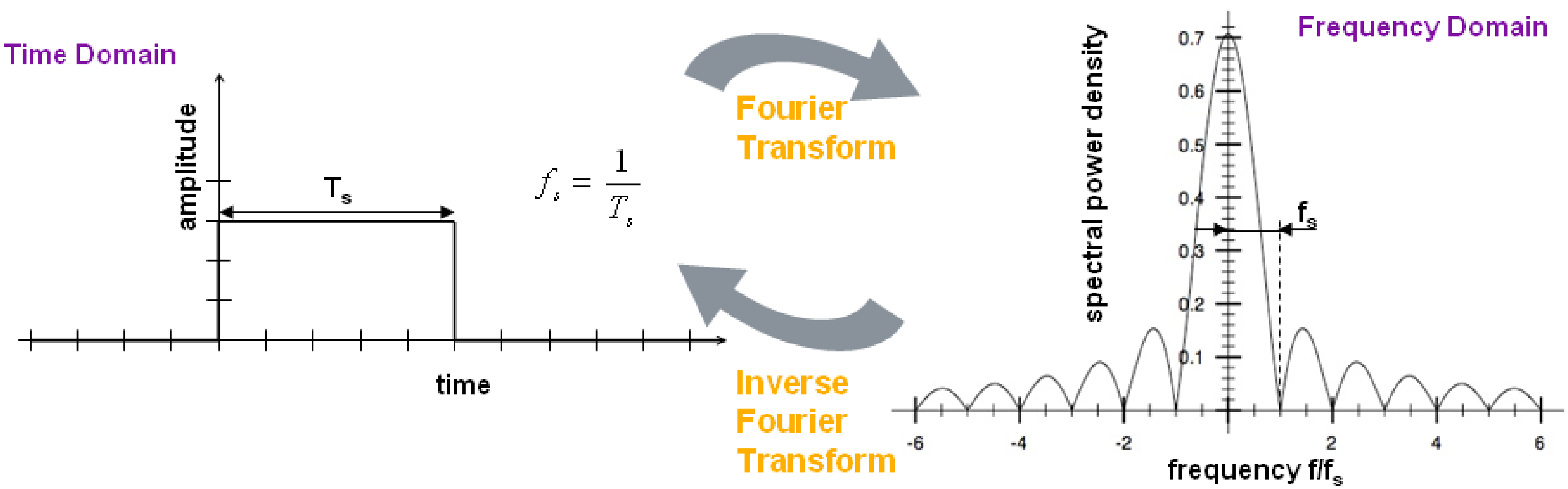
Downlink Air Interface-OFDMA

Fast Fourier Transform

- Two characteristics define a signal:
  - **Time domain:** represents how long the symbol lasts on air
  - **Frequency domain:** represents the spectrum needed in terms of bandwidth

- Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT) allow to move between time and frequency domain representation and it is a fundamental block in an OFDMA system

- OFDM signals are generated using the IFFT



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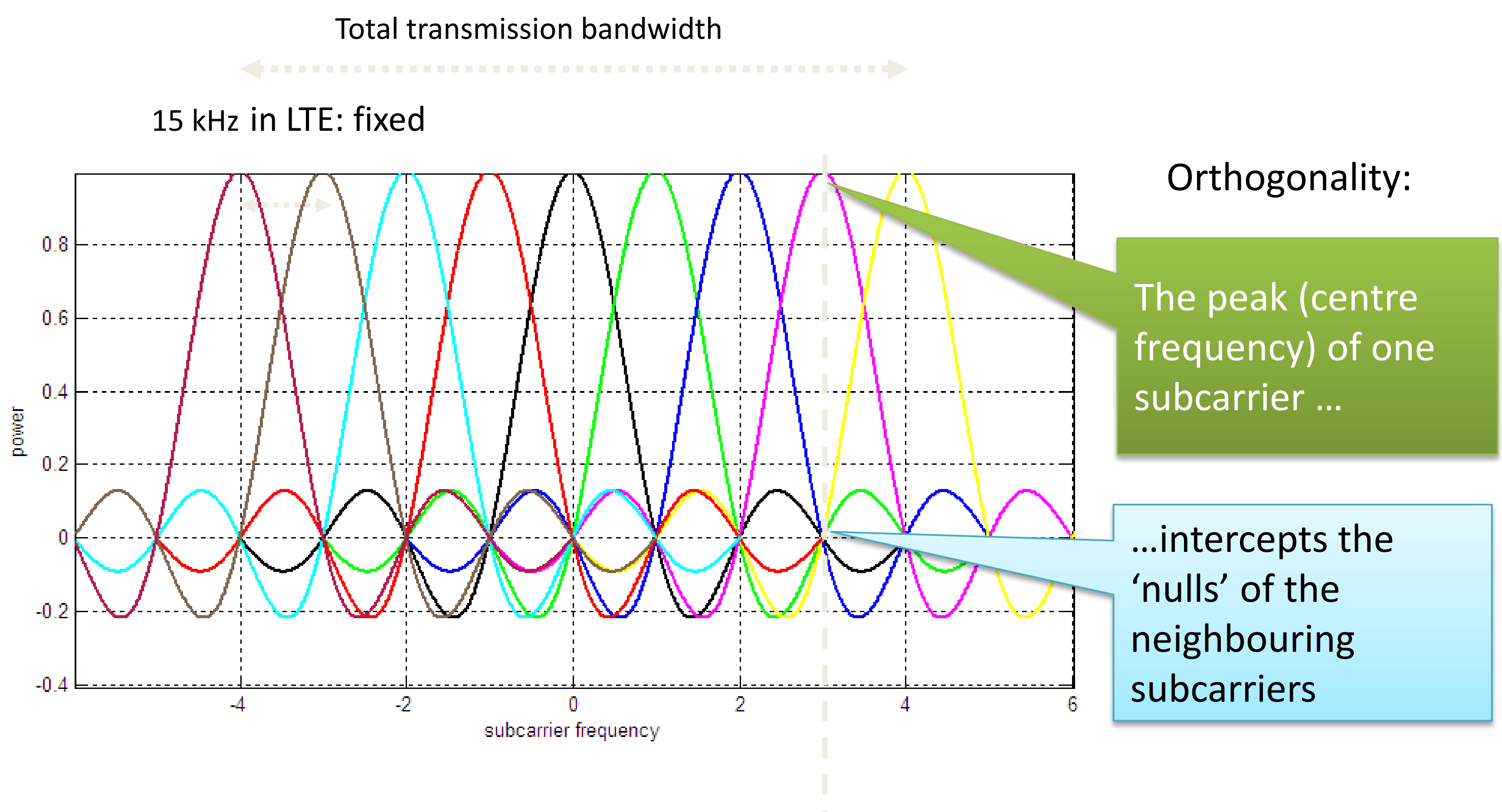
OFDM Basics

- Transmits hundreds or even thousands of separately modulated radio signals using **orthogonal subcarriers** spread across a wideband channel



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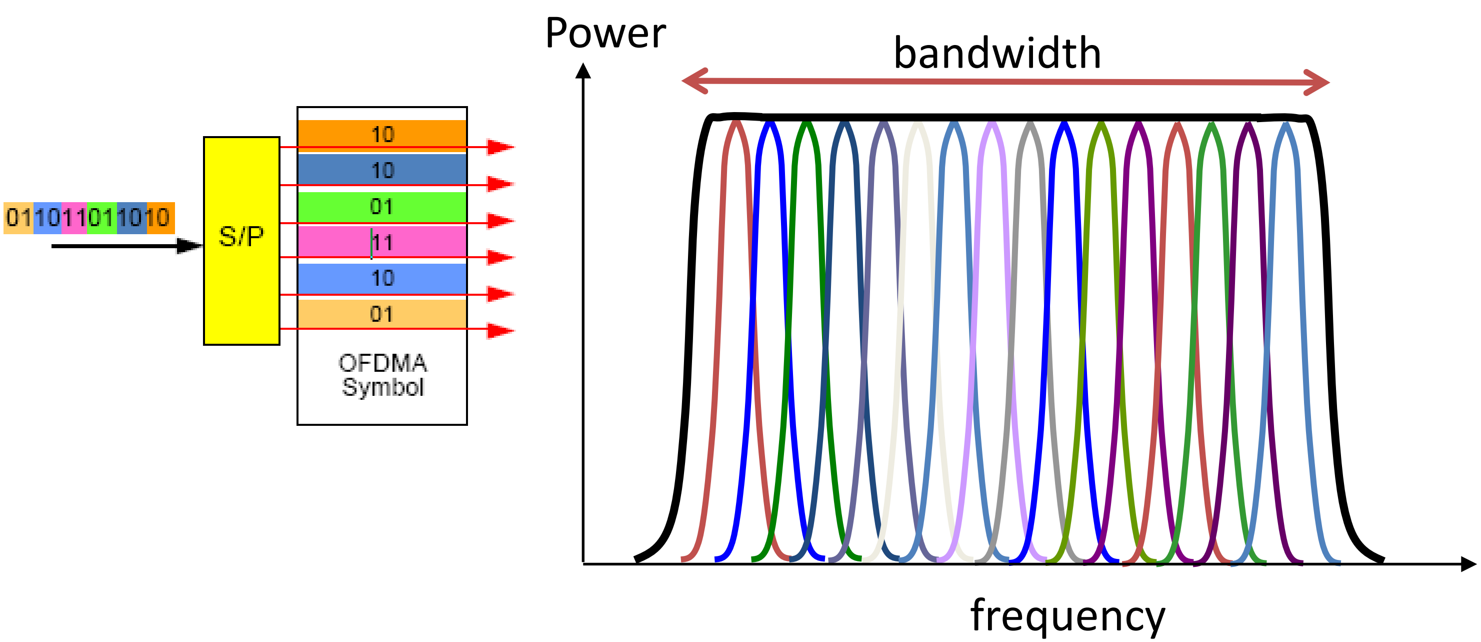
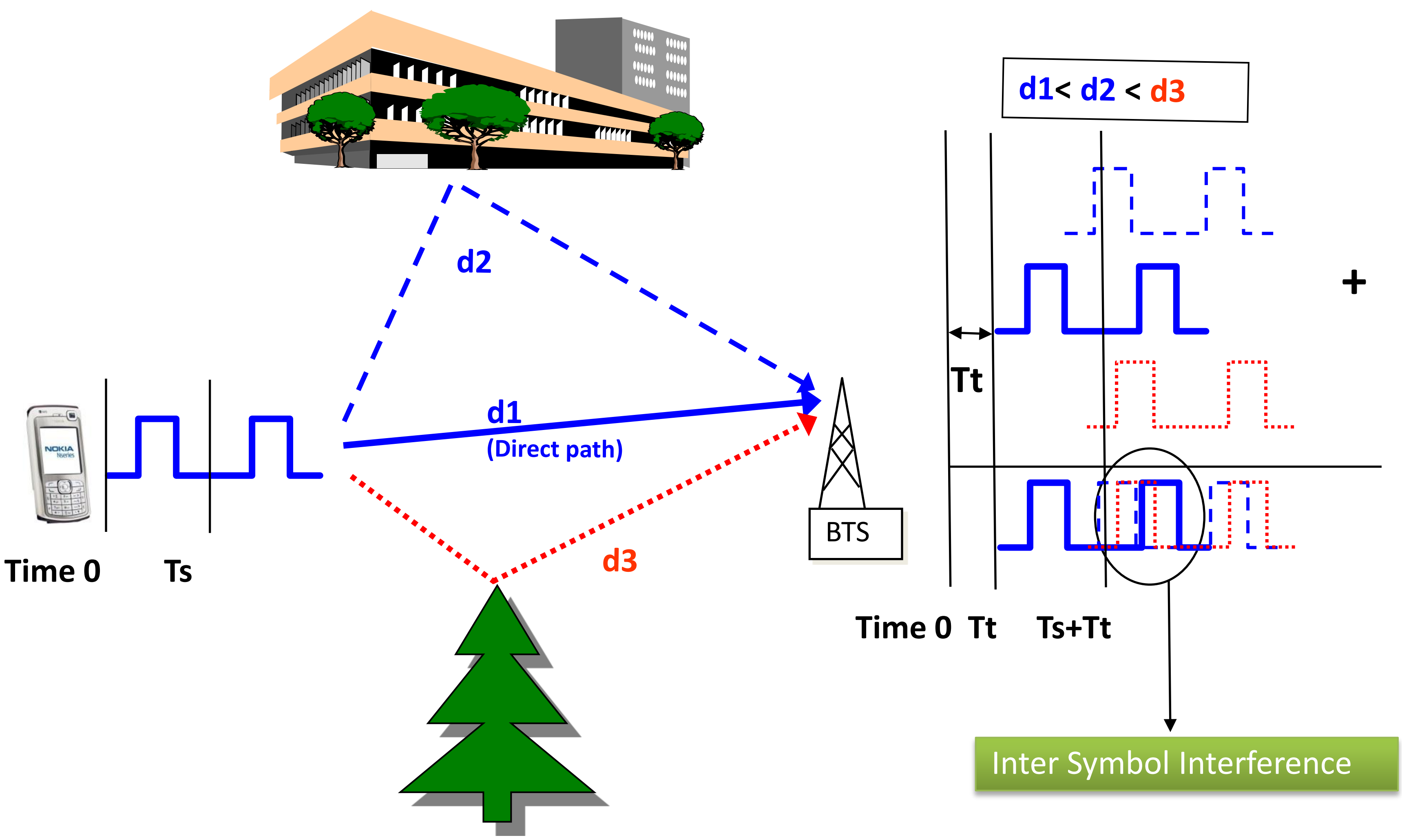
OFDM Basics

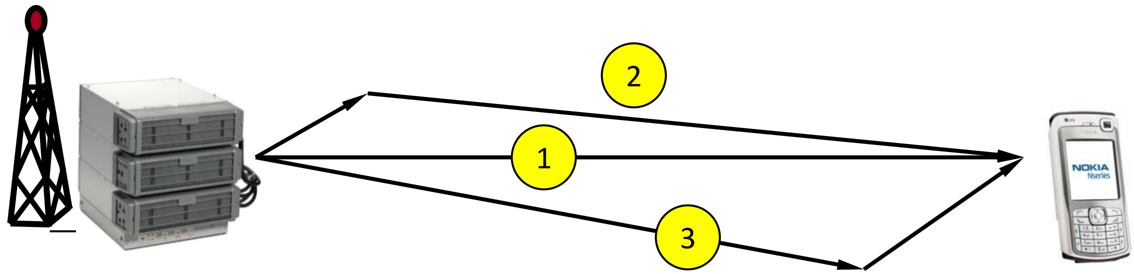
- Data is sent in parallel across the set of subcarriers, **each subcarrier only transports a part of the whole transmission**
- The throughput is the sum of the data rates of each individual (or used) subcarriers while the power is distributed to all subcarriers
- FFT (Fast Fourier Transform) is used to create the orthogonal subcarriers. The number of subcarriers is determined by the FFT size (by the bandwidth)
- In LTE, these subcarriers are separated 15kHZ

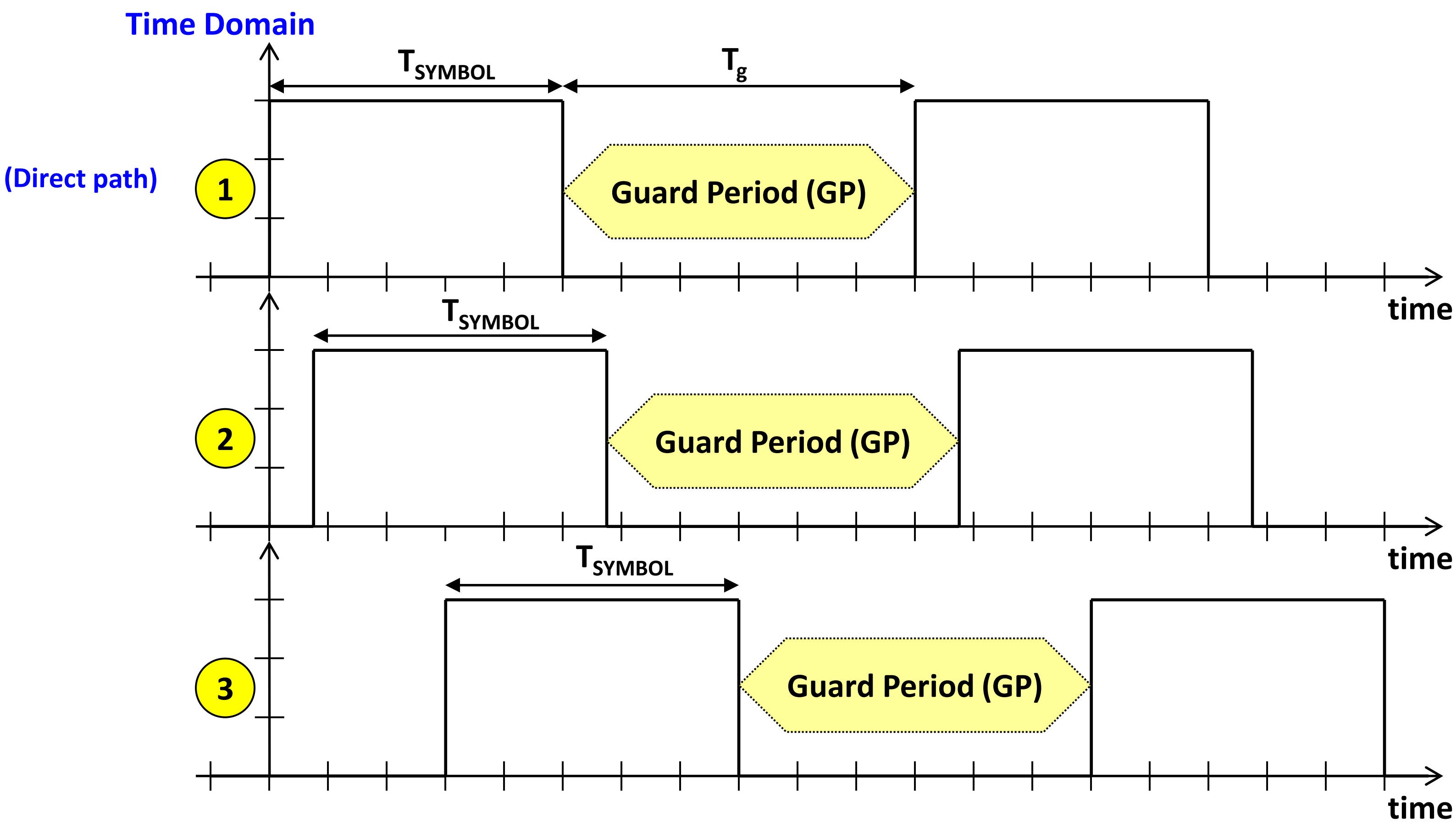


Multi-Path Propagation and Inter-Symbol Interference



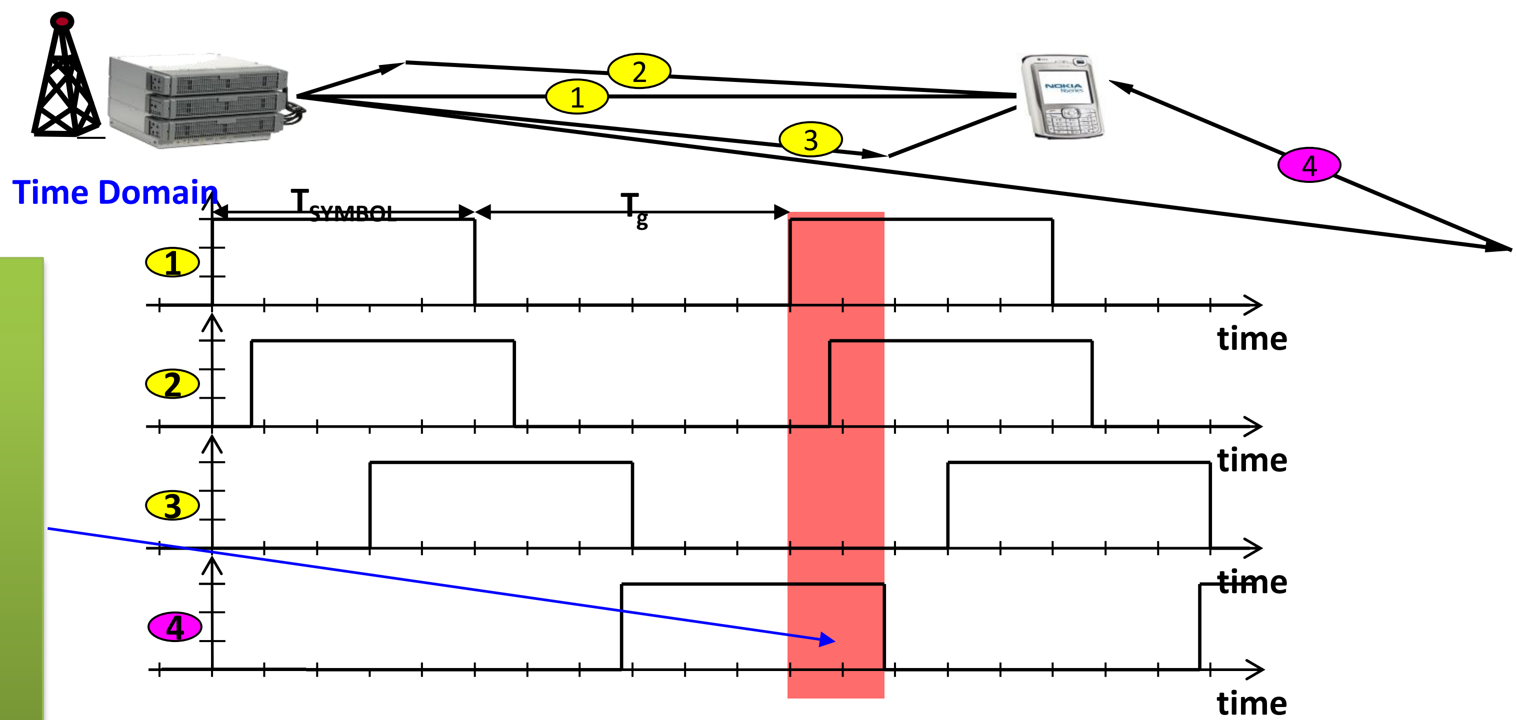
Multi-Path Propagation and the Guard Period





Propagation delay exceeding the Guard Period

- Multipath causes Inter Symbol Interference (ISI) which affects the subcarrier orthogonality due to phase distortion
- Solution to avoid ISI is to introduce a Guard Period (Tg) after the pulse
  - Tg needs to be long enough to capture all the delayed multipath signals
- To make use of that Tg (no transmission) Cyclic Prefix is transmitted



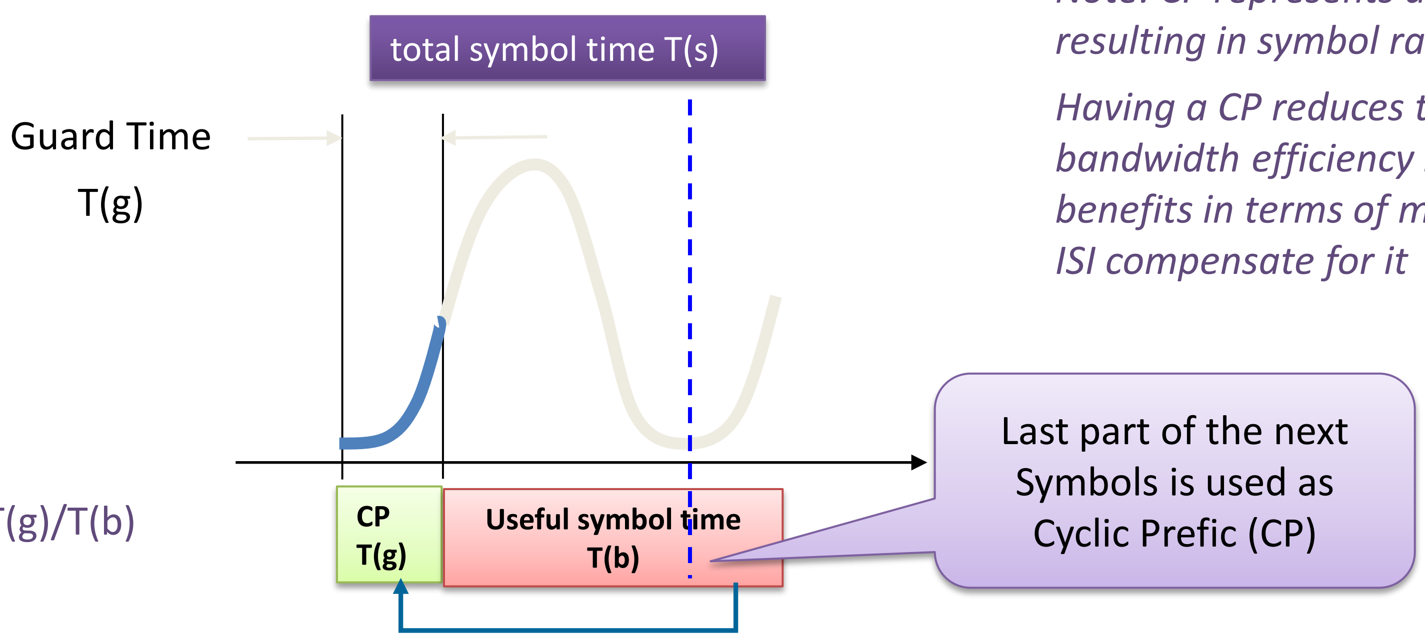
Obviously when the delay spread of the multi-path environment is greater than the guard period duration (Tg), then we encounter inter-symbol interference (ISI)

Cyclic Prefix (CP) and Guard Time

- Consists in copying the last part of a symbol shape for a duration of guard-time and attaching it in front of the symbol
- CP needs to be longer than the channel multipath delay spread.
- A receiver typically uses the high correlation between the Cyclic Prefix (CP) and the last part of the following symbol to locate the start of the symbol and begin then with decoding
- 2 CP options in LTE:
  - **Normal CP:** for small cells or with short multipath delay spread
  - **Extended CP:** designed for use with large cells or those with long delay profiles

Note: CP represents an overhead resulting in symbol rate reduction.

Having a CP reduces the bandwidth efficiency but the benefits in terms of minimizing the ISI compensate for it

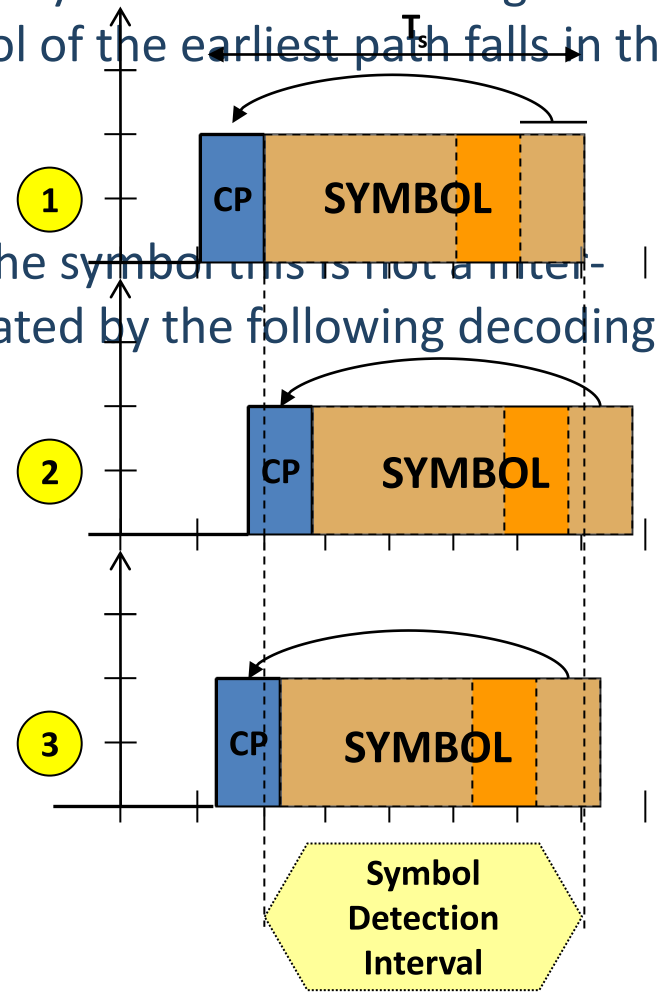


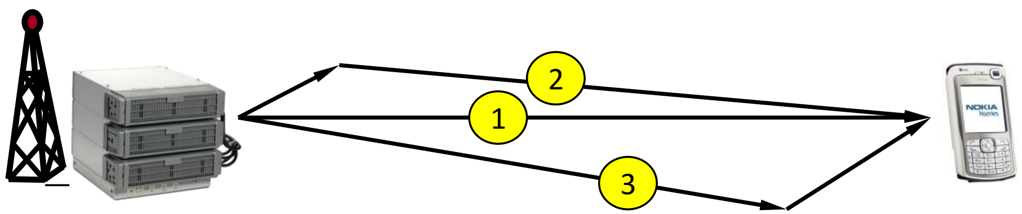
CP ratio = T(g)/T(b)

Cyclic Prefix

• In multi-path propagation environments the delayed versions of the signal arrive with a time offset, so that the start of the symbol of the earliest path falls in the cyclic prefixes of the delayed symbols.

• As the CP is simply a repetition of the end of the symbol this is not a inter-symbol interference and can be easily compensated by the following decoding based on discrete Fourier transform.

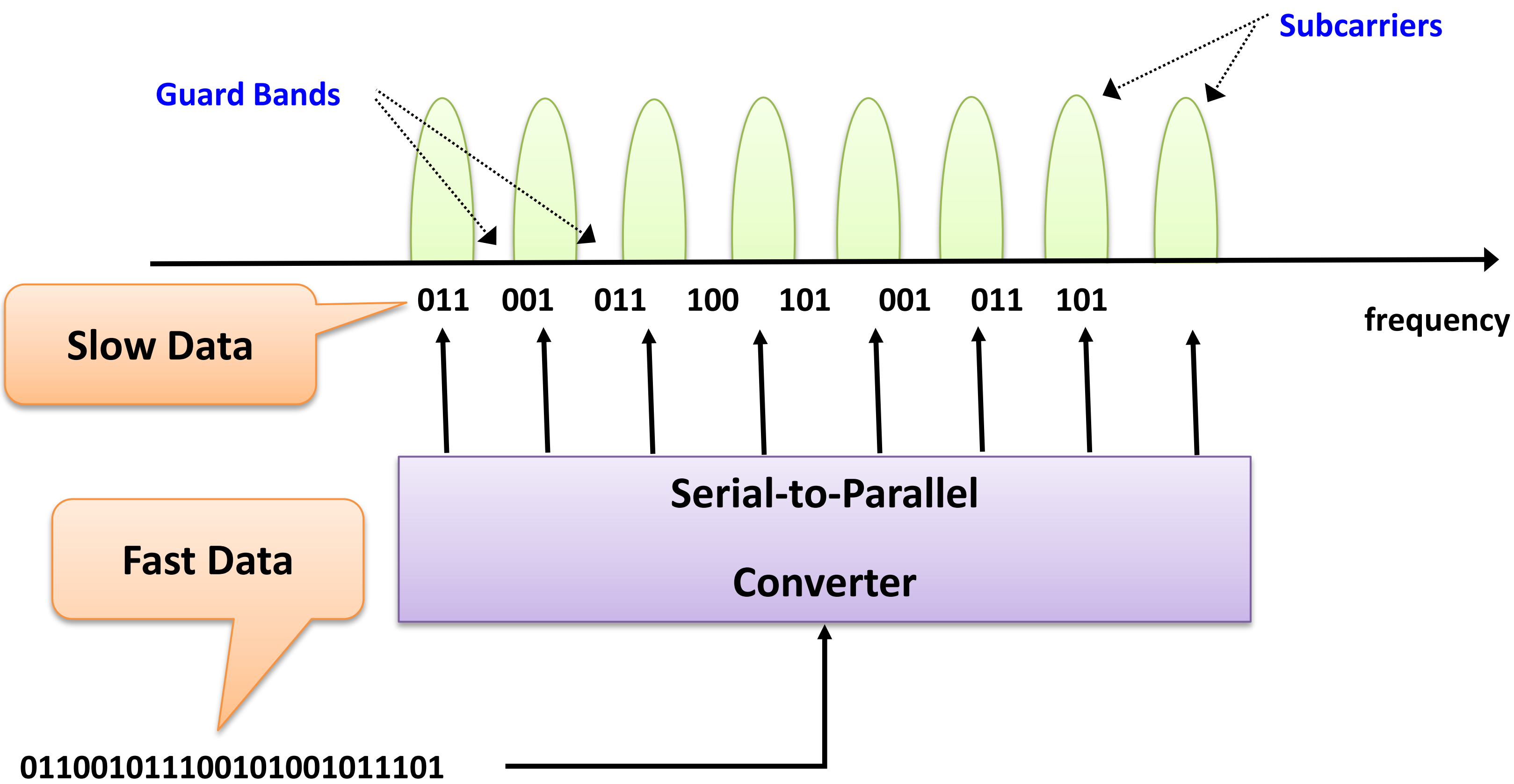




Multi-Carrier Modulation

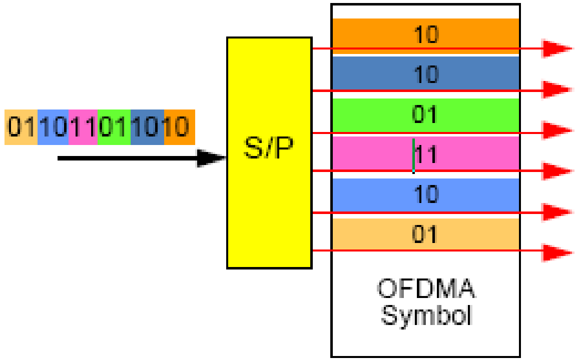
• One solution is to use multiple carriers in parallel (Subcarriers).

• This allows to increase the bit rate, but keeping the advantages of smaller carriers with simple inter-symbol interference handling via cyclic prefix and/or cyclic suffix.



OFDMA Symbol

- OFDMA is an extension of OFDM technique to allow multiple user transmissions and it is used in other systems like Wi-Fi, DVB and WiMAX
- OFDMA Symbol is the Time period occupied by the modulation symbols on all subcarriers. Represents **all the data being transferred in parallel** at a point in time



- OFDM symbol duration including CP is aprox. 71.4 µs (*)
  - Long duration when compared with 3.69µs for GSM and 0.26µs for WCDMA allowing a good CP duration
    - Robust for mobile radio channel with the use of guard internal/cyclic prefix
  - Symbol length without considering CP: 66.67µs (1/15kHz)

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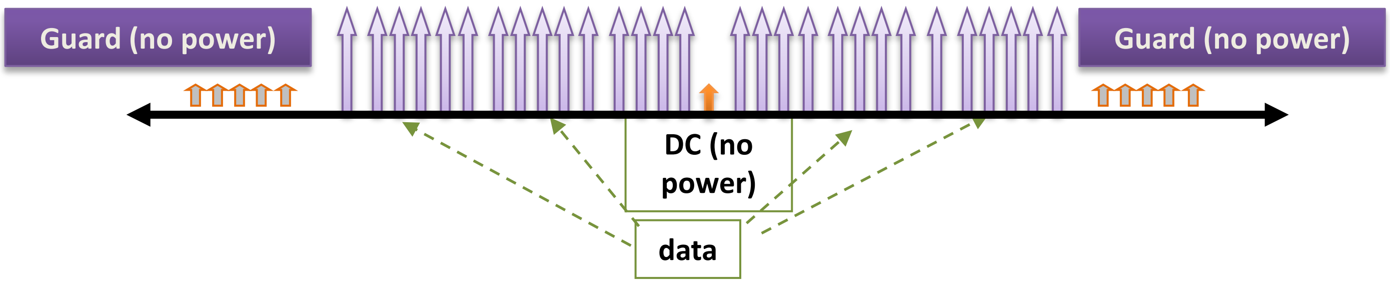
Subcarrier types

Data subcarriers: used for data transmission

- Reference Signals:
  - used for channel quality and signal strength estimates.
  - They don’t occupy a whole subcarrier but they are periodically embedded in the stream of data being carried on a data subcarrier.

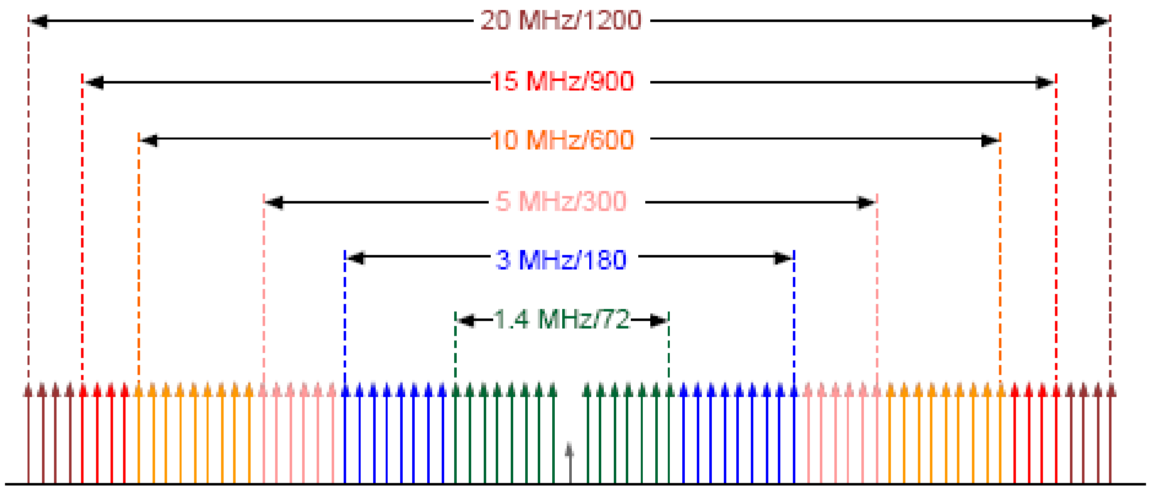
Null subcarriers (no transmission/power):

- DC (centre) subcarrier: 0Hz offset from the channel’s centre frequency
- Guard subcarriers: Separate top and bottom subcarriers from any adjacent channel interference and also limit the amount of interference caused by the channel. Guard band size has an impact on the data throughput of the channel.



OFDMA Parameters

- *Channel bandwidth*: Bandwidths ranging from 1.4 MHz to 20 MHz
- *Data subcarriers*: They vary with the bandwidth
  - 72 for 1.4MHz to 1200 for 20MHz



Channel bandwidths
(bandwidth/data subcarriers)

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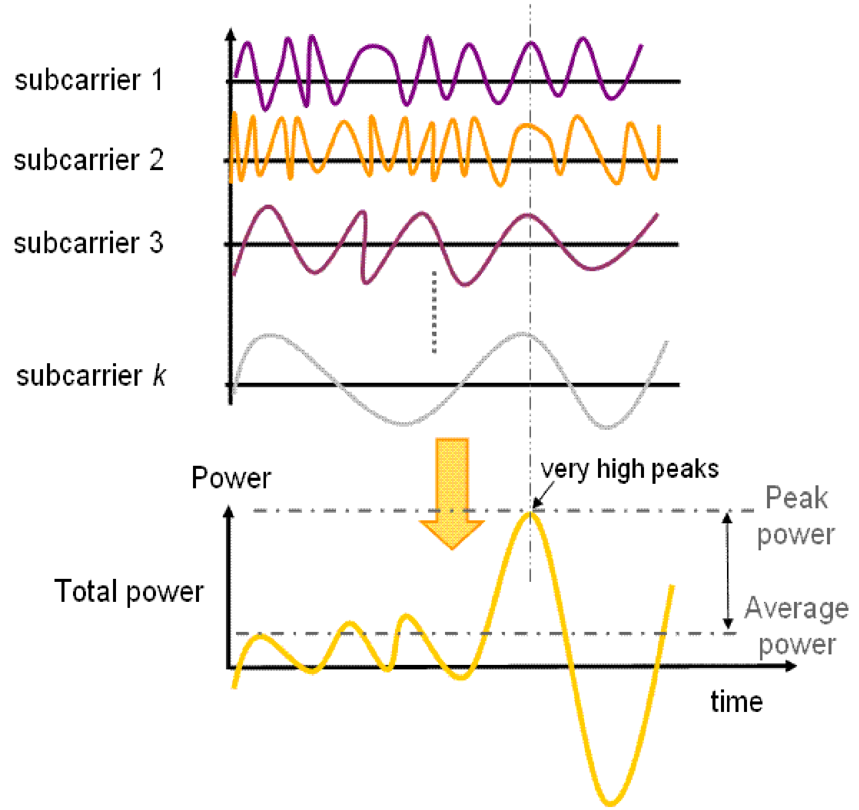
OFDMA Parameters

- **Frame duration:** 10ms created from slots and subframes
- **Subframe duration (TTI):** 1 ms (composed of 2x0.5ms slots)
- **Subcarrier spacing:** Fixed to 15kHz (7.5 kHz defined for MBMS)
- **Sampling Rate:** Varies with the bandwidth but always factor or multiple of 3.84 to ensure compatibility with WCDMA by using common clocking

	1.4MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Frame Duration	10ms					
Subcarrier Spacing	15 kHz					
Sampling Rate (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Data Subcarriers	72	180	300	600	900	1200
Symbols/slot	Normal CP=7, extended CP=6					
CP length	Normal CP=4.69/5.12 µsec, extended CP= 16.67µsec					

Peak-to-Average Power Ratio in OFDMA

- The transmitted power is the sum of the powers of all the subcarriers
  - Due to large number of subcarriers, the peak to average power ratio (PAPR) tends to have a large range
  - The higher the peaks, the greater the ra amplifier is required to work
  - Having a UE with such a PA that works o expensive
  - Not best suited for use with mobile (bat

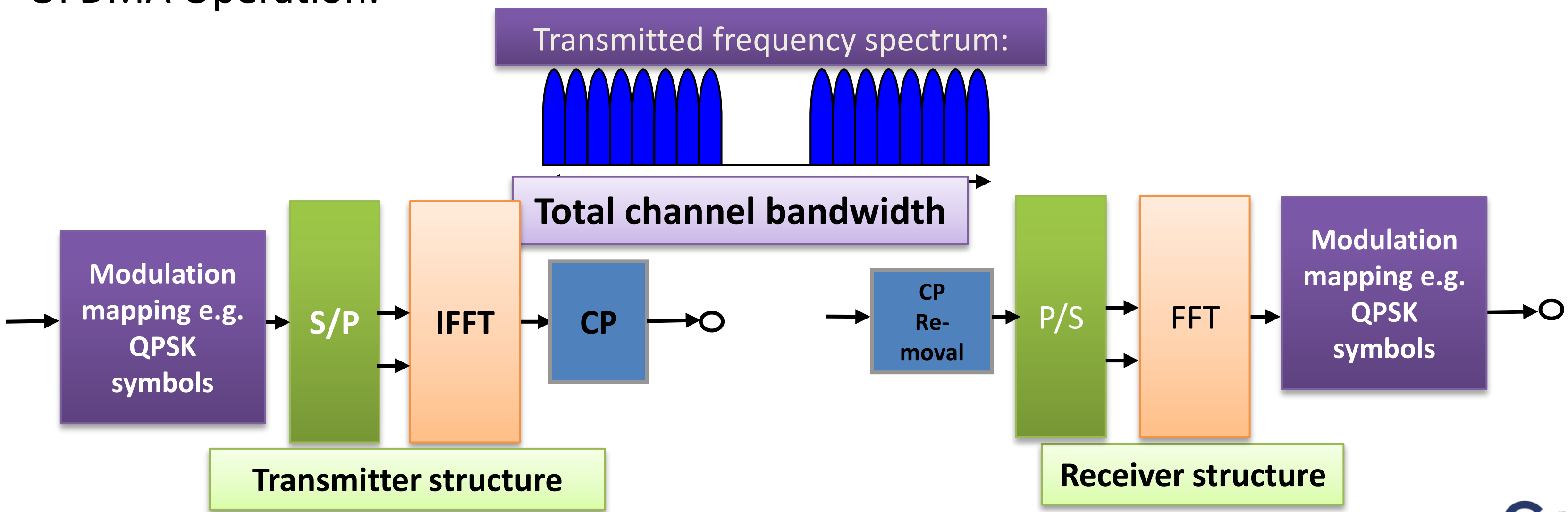


OFDM Wrap-up

- Pros:
  - High spectral efficiency and little interference between channels
  - Robust in multi-path environments thanks to Cyclic Prefix
  - Frequency domain scheduling offer high potential for throughput gain

- Cons:
  - Severe High PAPR (Peak to Average Power Ratio)
  - Small subcarrier spacing makes it more sensitive to frequency offset (subcarriers may interfere each others)

- OFDMA Operation:



Downlink Air Interface-SC-FDMA

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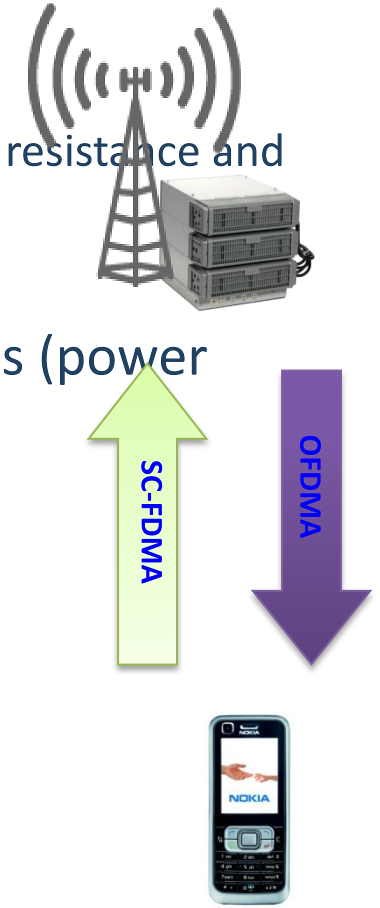
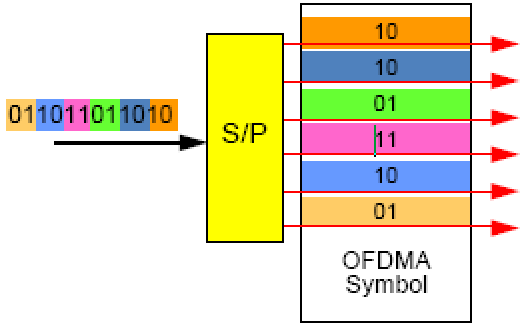
SC-FDMA in Uplink

- Single Carrier Frequency Division Multiple Access: Transmission technique used for Uplink
- Variant of OFDM that reduces the PAPR:
  - Combines the PAR of single-carrier system with the multipath resistance and flexible subcarrier frequency allocation offered by OFDM
  - It can reduce the PAPR between 6…9dB compared to OFDMA
  - Reduced PAPR means lower RF hardware requirements (power amplifier)

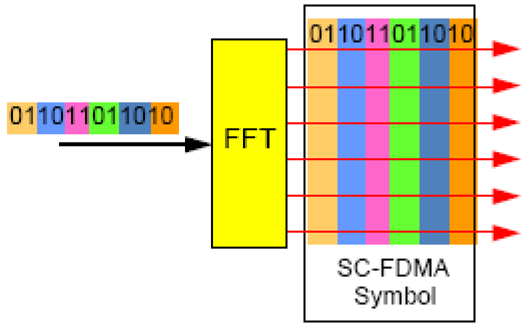


SC-FDMA and OFDMA Comparison

- OFDMA transmits data in parallel across multiple subcarriers
- SC-FDMA transmits data in series employing multiple subcarriers
- In the example:
  - OFDMA: 6 modulation symbols (01,10,11,01,10 and 10) are transmitted per OFDMA symbol, one on each subcarrier
  - SC-FDMA: 6 modulation symbols are transmitted per SC-FDMA symbol using all subcarriers per modulation symbol. The duration of each modulation symbol is 1/6th of the modulation symbol in OFDMA

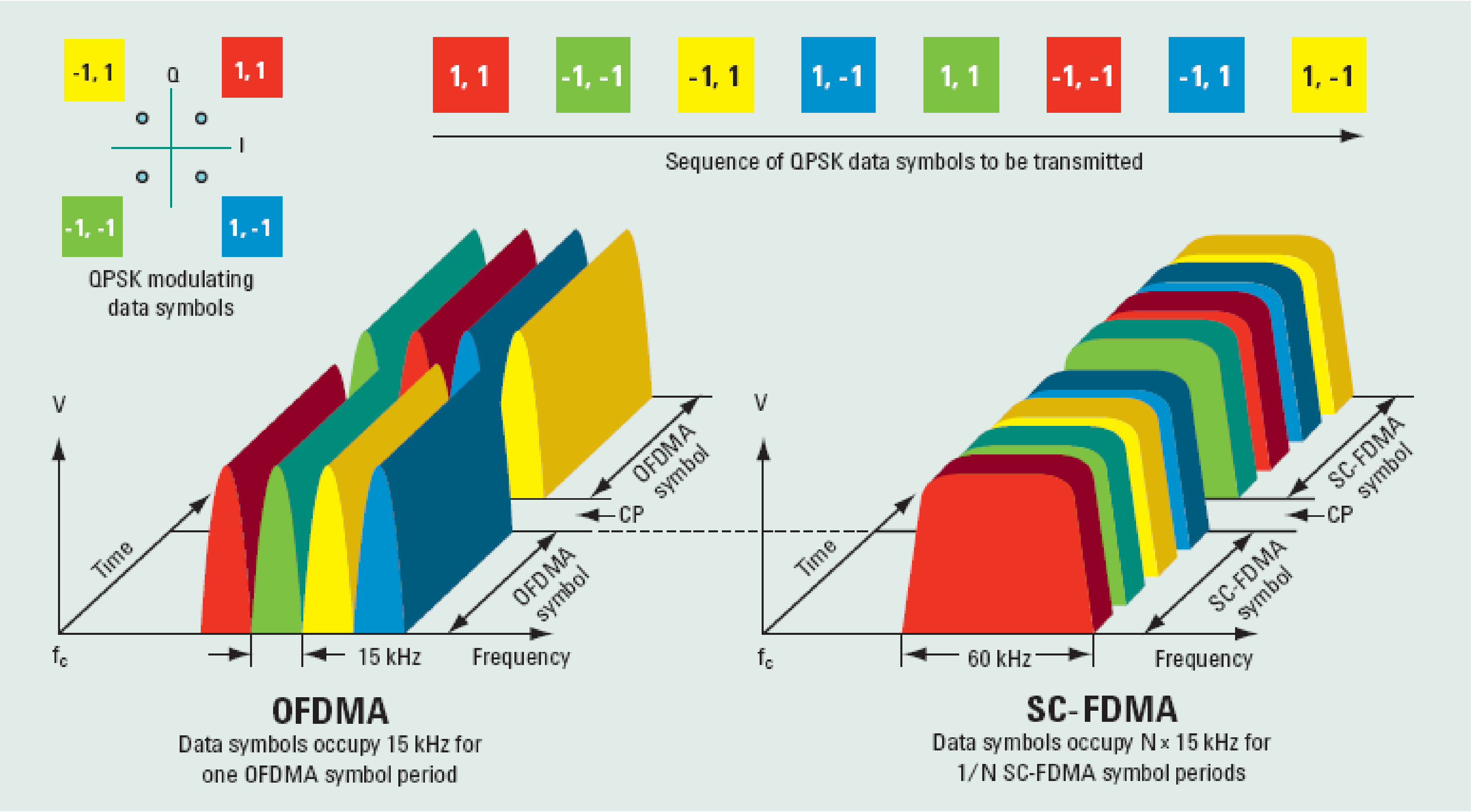


OFDMA



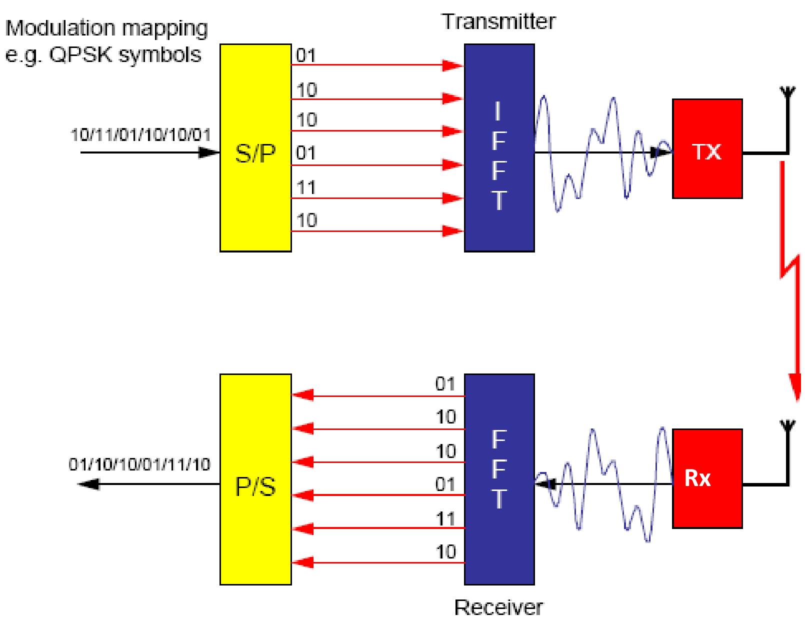
SC-FDMA

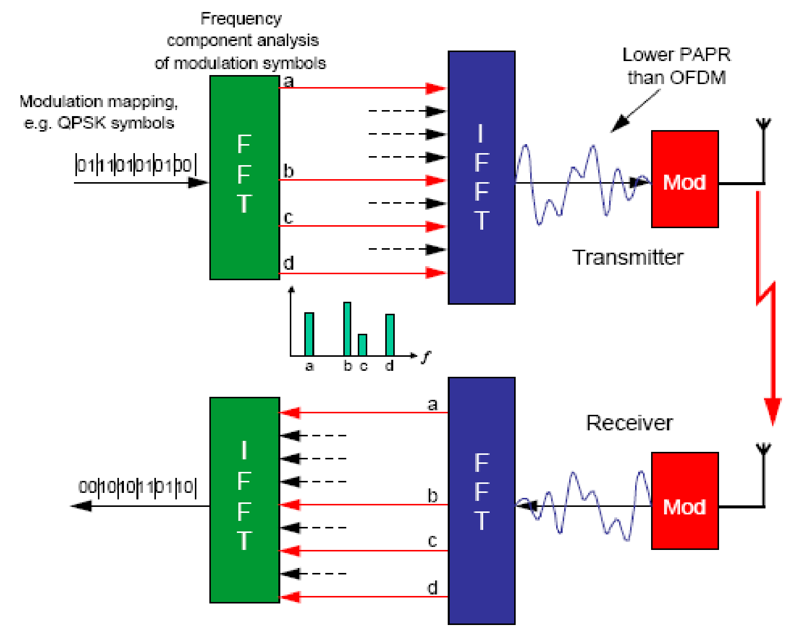
SC-FDMA and OFDMA Comparison



SC-FDMA Operation

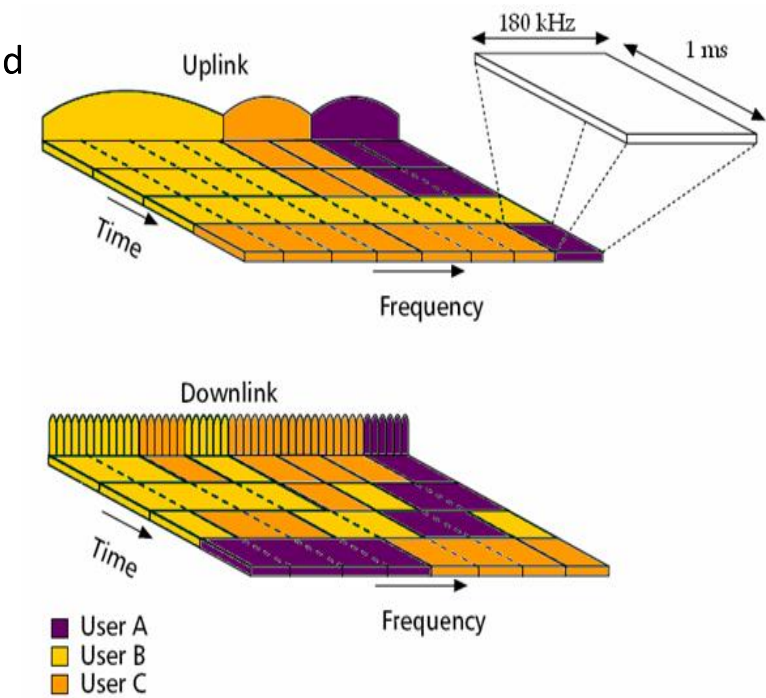
- The parallel transmission of multiple symbols in OFDMA creates high PAR
- SC-FDMA avoids this by additional processing before the IFFT: modulation symbols are presented to FFT. The output represents the frequency components of the modulation symbols.
- Subcarriers created by this process have a **set amplitude** that should remain nearly constant between one SC-FDMA symbol and the next for a given modulation scheme which results in little difference between the peak power and the average power radiated on a channel





Uplink Air Interface Technology-SC-FDMA

- User multiplexing in frequency domain, a user is allocated different bandwidths (multiples of 180kHz)
  - In OFDMA the user multiplexing is in sub-carrier d Blocks



- One user is always continuous in frequency
- Smallest uplink bandwidth, 12 subcarriers: 180 kHz
  - same for OFDMA in downlink
- Largest uplink bandwidth: 20 MHz
  - same for OFDMA in downlink
  - Terminals are required to be able to receive & transmit up to 20 MHz, depending on the frequency band though

Physical Layer

Physical Layer Structure and Channels

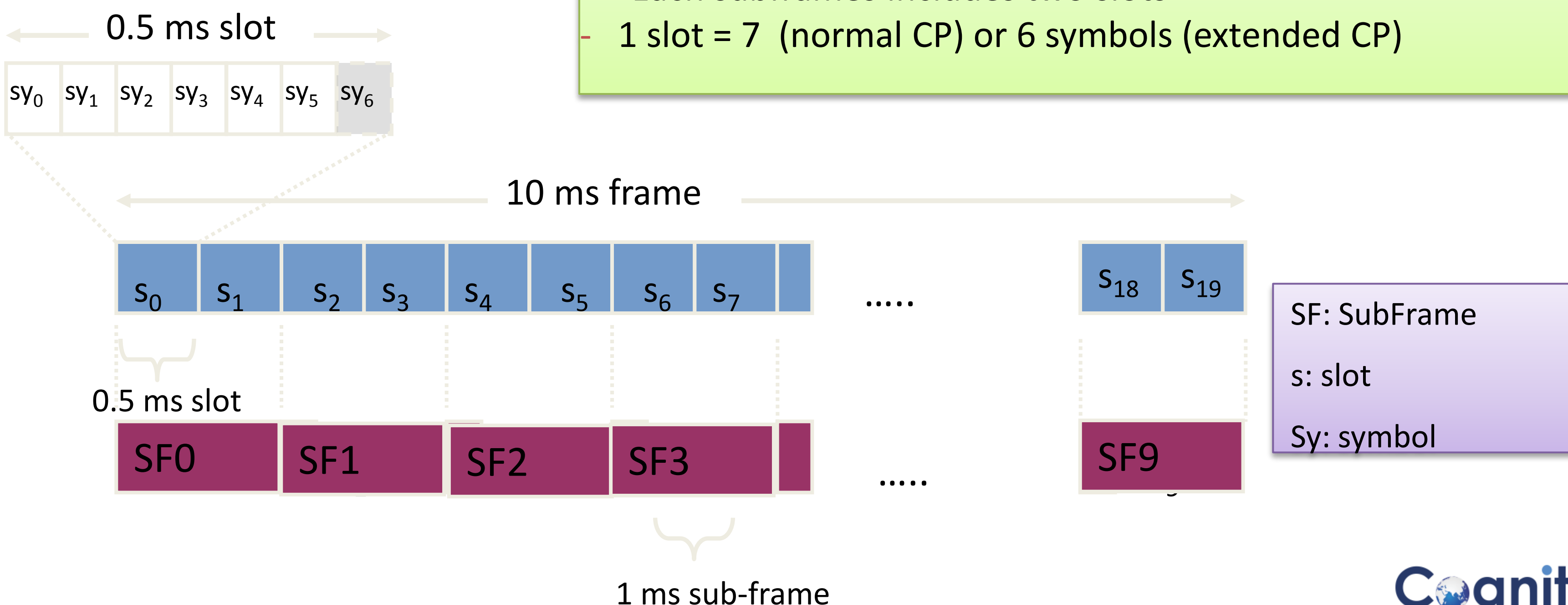
Introduction

- It provides the basic bit transmission functionality over air
- LTE physical layer based on OFDMA downlink and SC-FDMA in uplink direction
  - This is the same for both FDD and TDD mode of operation
- No need of RNC like functional element
  - Everything radio related can be terminated in the eNodeB
- System is reuse 1, single frequency network operation is feasible
  - No frequency planning required
- There are **no dedicated physical (neither transport) channels** anymore, as all resource mapping is dynamically driven by the scheduler

Frame Structure (FDD)

- FDD Frame structure (also called **Type 1 Frame**) is common to both uplink and downlink.
- Divided into 20 x 0.5ms slots
  - Structure has been designed to facilitate short round trip time

- Frame duration =10 ms (same as UMTS)
- FDD: 10 ms radio frame for UL and 10 ms radio frame for DL
- Radio frame includes 10 subframes
- 1 Subframe represents a Transmission Time Interval (TTI)
- Each subframes includes two slots
- 1 slot = 7 (normal CP) or 6 symbols (extended CP)



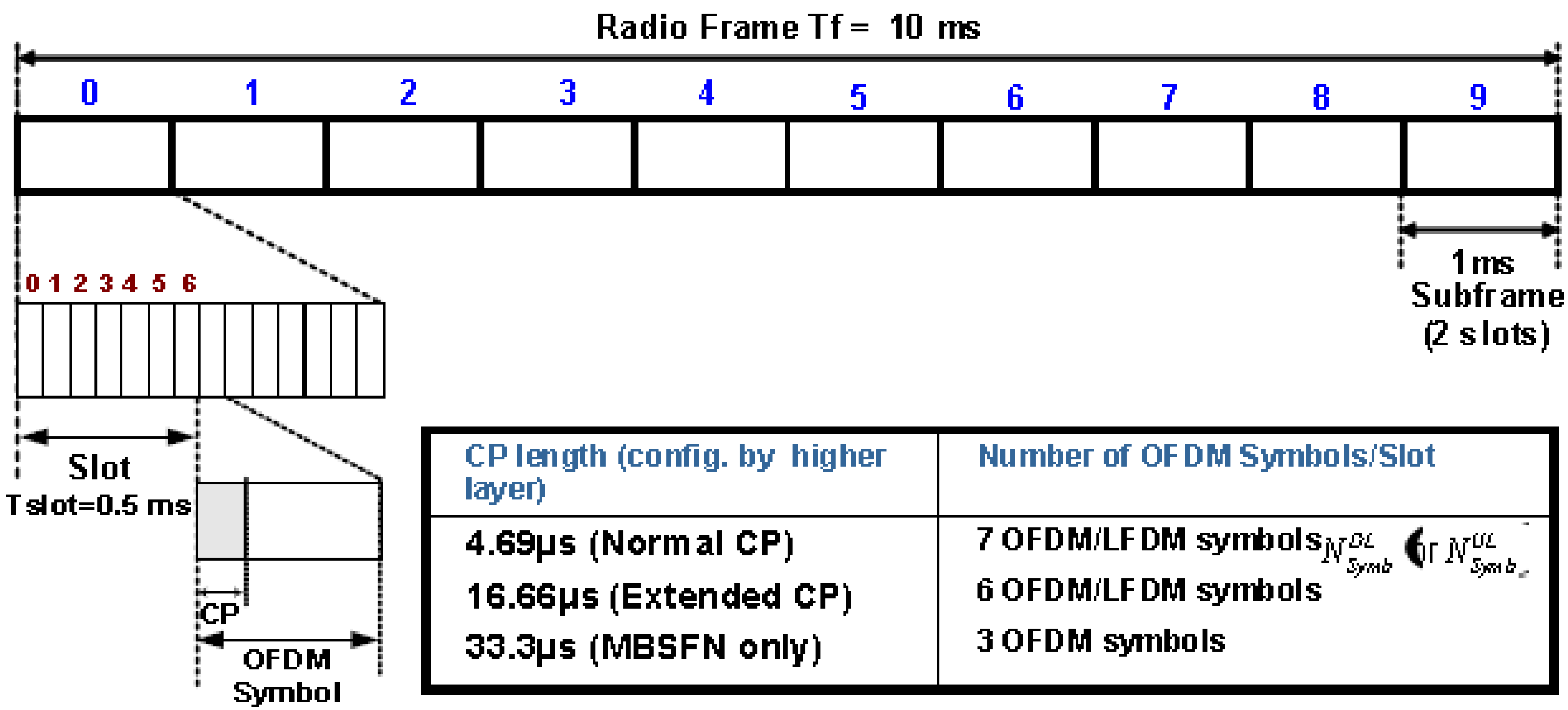
Frame Structure (FDD)

LTE Time Domain is organized as:

- Frame (10 ms)
- Subframe (1 ms)
- Slot (0.5 ms)
- Symbol (duration depending on configuration)

Radio Frame has 2 structures:

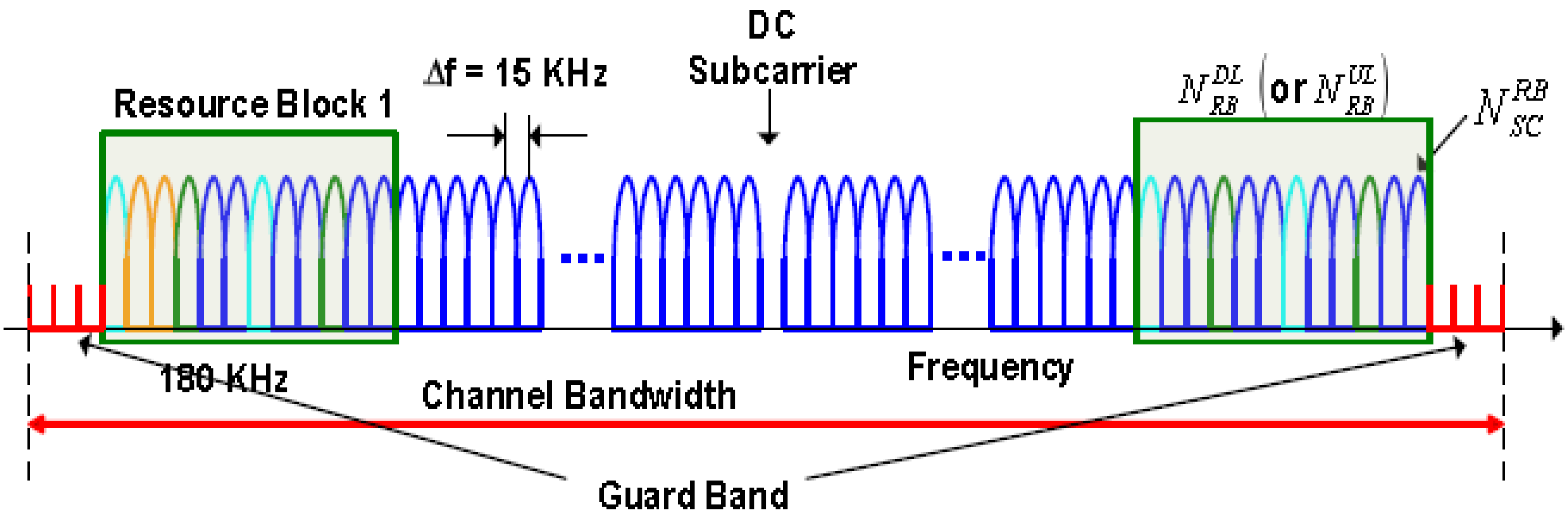
- Type 1 (FS1) for FDD DL/UL
- Type 2 (FS2) for TDD FS1 is considered in this presentation



CP length (config. by higher layer)	Number of OFDM Symbols/Slot
4.69µs (Normal CP)	7 OFDM/LFDM symbols N_{Symb}^{DL} or N_{Symb}^{UL}
16.66µs (Extended CP)	6 OFDM/LFDM symbols
33.3µs (MBSFN only)	3 OFDM symbols

Frequency Domain Organization

- LTE DL/UL air interface waveforms use several orthogonal subcarriers to send user traffic data, Reference Signals (Pilots), and Control Information.

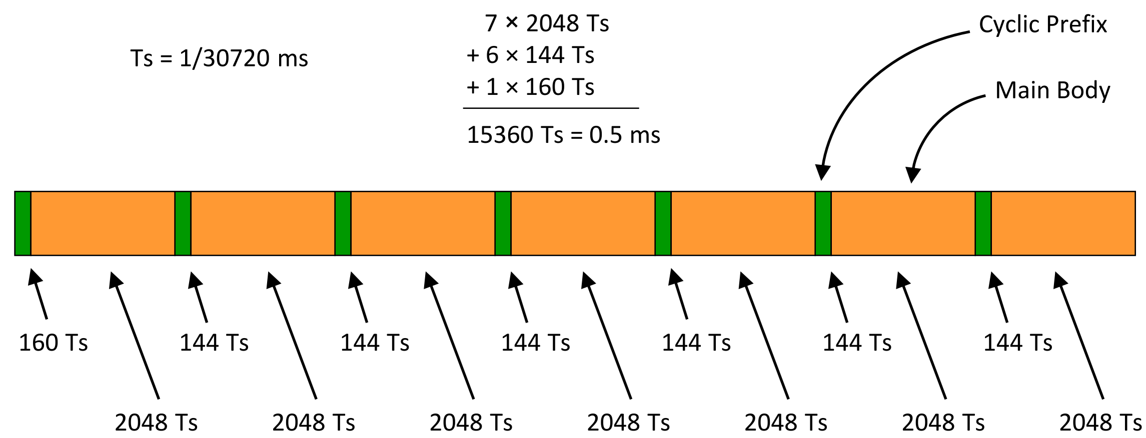


- DC Subcarrier: Direct Current subcarrier at center of frequency band
- Number of DL or UL Resource Blocks (groups of subcarriers)
- N_{RB}^{DL} / N_{RB}^{UL} mber of subcarriers within a Resource Block

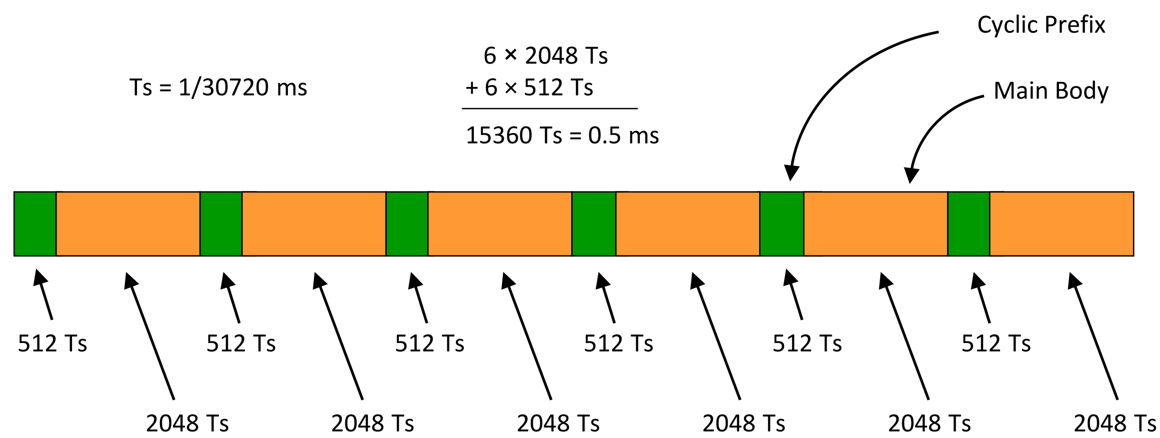
N_{SC}^{RB}

Normal and Extended Cyclic Prefix

Normal Cyclic Prefix



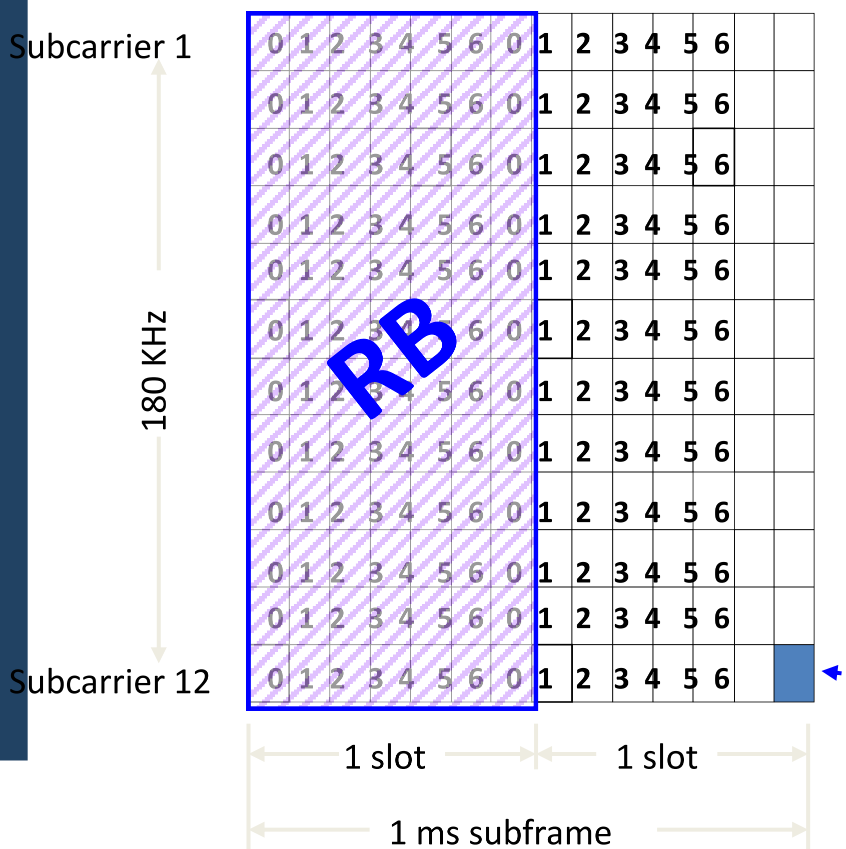
Extended Cyclic Prefix



Resource Block

- Physical Resource Block or Resource Block (PRB or RB):
  - 12 subcarriers in frequency domain (180kHz) x 1 slot period in time domain (0.5ms)

Capacity allocation is based on Resource Blocks

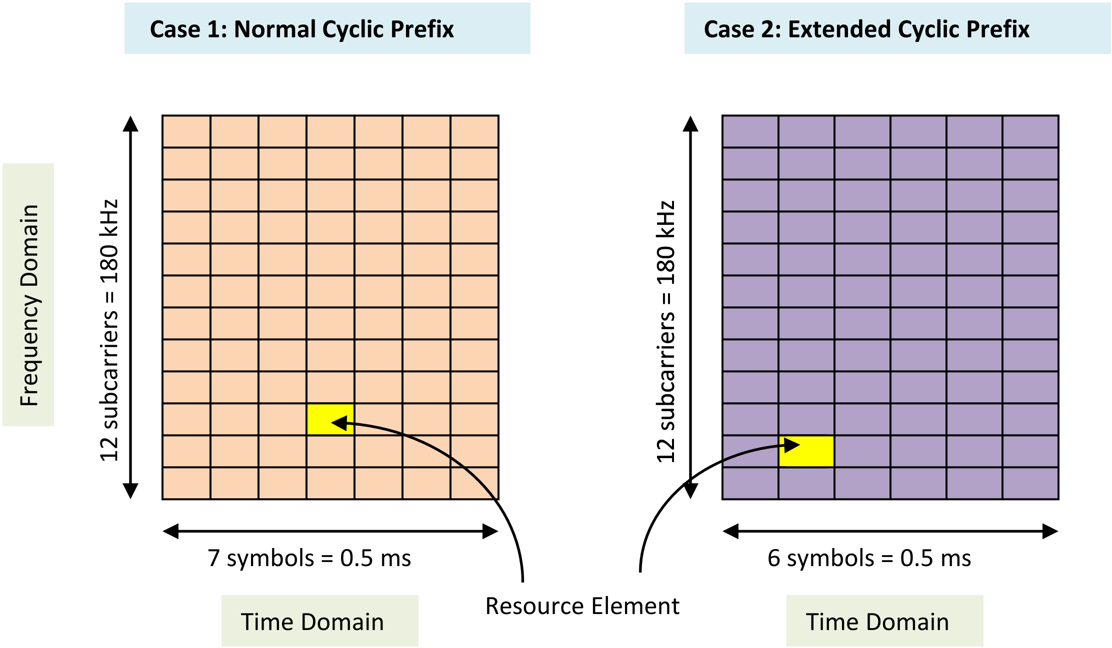


- Note: Although 3GPP definition of RB refers to 0.5ms, in some cases it is possible to found that RB refers to 12 subcarriers in frequency domain and 1ms in time domain. In particular, since the scheduler in the eNodeB works on TTI basis (1ms) RBs are considered to last 1ms in time domain. They can also be known as ‘scheduling resource blocks’

Resource Element

Resource Element

- Theoretical minimum capacity allocation unit
- Equivalent to one subcarrier x one symbol period
- 72 or 84 Resource Elements per Resource Block
- Each Resource Element can accommodate 1 modulation symbol, e.g. 2 bits for QPSK, 4 bits for 16QAM and 6 bits for 64 QAM
- Modulation symbol rate per Resource Block is 144 ksps or 168 ksps



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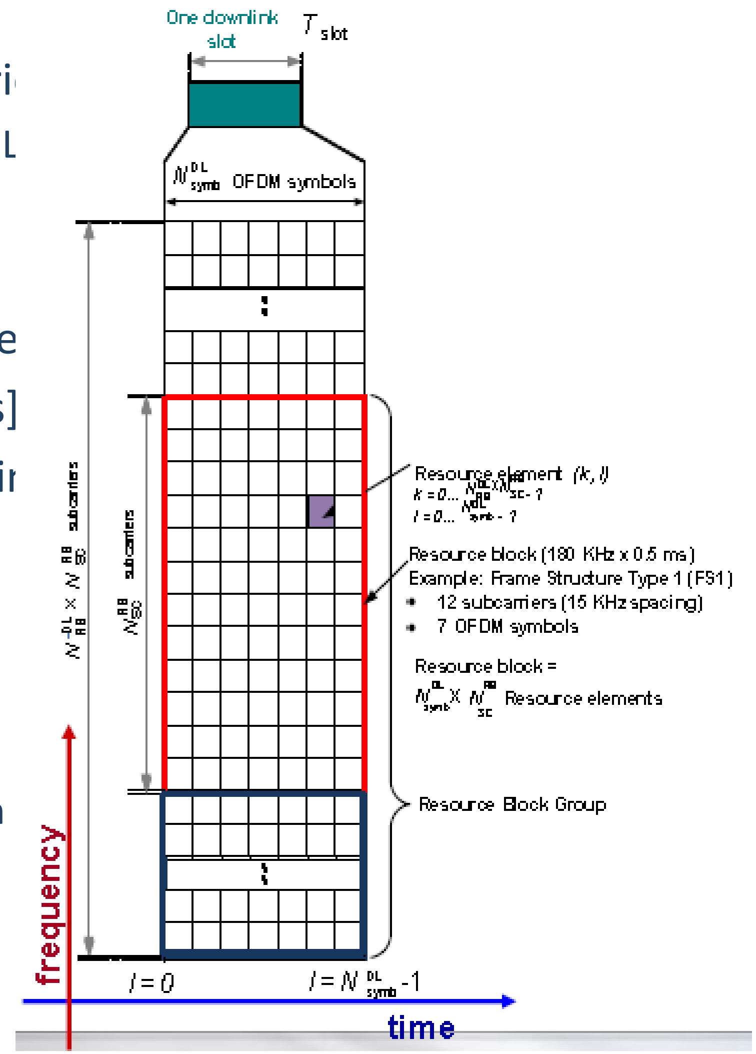
Resource Grid Definition-Ul/DL

- Resource Element (RE)
  - One element in the time/frequency resource gri
    - One subcarrier in one OFDM/LFDM symbol for DL resource assignment.
- Resource Block (RB)
  - Minimum scheduling size for DL/UL data channe
  - Physical Resource Block (PRB) [180 kHz x 0.5 ms]
  - Virtual Resource Block (VRB) [180 kHz x 0.5 ms ir
    - Localized VRB
    - Distributed VRB
- Resource Block Group (RBG)
  - Group of Resource Blocks
    - Size of RBG depends on the system bandwidth in



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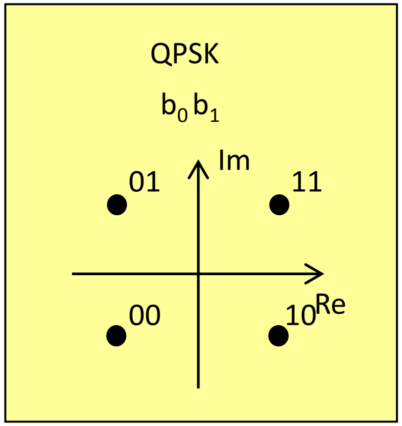
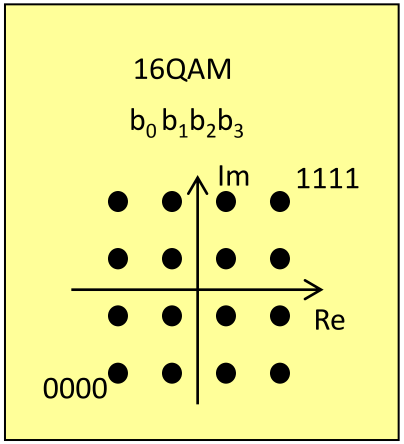
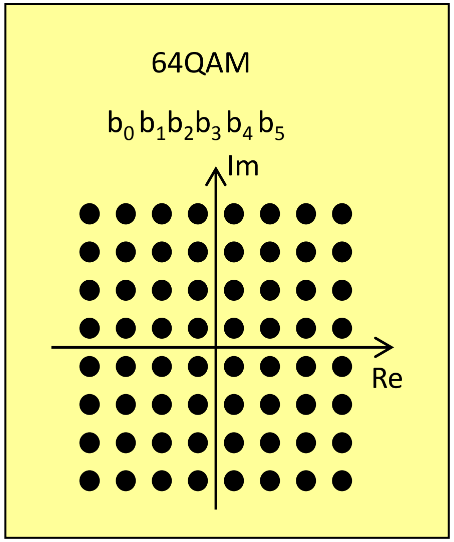
Modulation Schemes for LTE/EUTRAN

- Each OFDM symbol even within a resource block can have a different modulation scheme.
- EUTRAN defines the following options: QPSK, 16QAM, 64QAM.
- Not every physical channel will be allowed to use any modulation scheme: Control channels to be using mainly QPSK.
- In general it is the scheduler that decides which form to use depending on carrier quality feedback information from the UE.







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LTE Frequency Variants in 3GPP – FDD

	Total [MHz]	Uplink [MHz]	Downlink [MHz]	Europe	Japan	Americas	
1	2x60	1920-1980	2110-2170	●	●		UMTS core
2	2x60	1850-1910	1930-1990			●	US PCS
3	2x75	1710-1785	1805-1880	●			1800
4	2x45	1710-1755	2110-2155			●	US AWS
5	2x25	824-849	869-894			●	US 850
6	2x10	830-840	875-885		●		Japan 800
7	2x70	2500-2570	2620-2690	●			2600
8	2x35	880-915	925-960	●			900
9	2x35	1749.9-1784.9	1844.9-1879.9		●		Japan 1700
10	2x60	1710-1770	2110-2170			●	Extended AWS
11	2x25	1427.9-1452.9	1475.9-1500.9		●		Japan 1500
12	2x18	698-716	728-746			●	US700
13	2x10	777-787	746-756			●	US700
14	2x10	788-798	758-768			●	US700
xx	2x30?	790-820	832-862?	●			UHF (TV)

LTE Frequency Variants - TDD

	Total Spectrum	Frequency (MHz)	
33	1x20	1900-1920	UMTS TDD1
34	1x15	2010-2025	UMTS TDD2
35	1x60	1850-1910	US PCS
36	1x60	1930-1990	US PCS
37	1x20	1910-1930	US PCS
38	1x50	2570-2620	Euro middle gap 2600
39	1x40	1880-1920	China TDD
40	1x100	2300-2400	2.3 TDD

LTE Radio Interface LTE States

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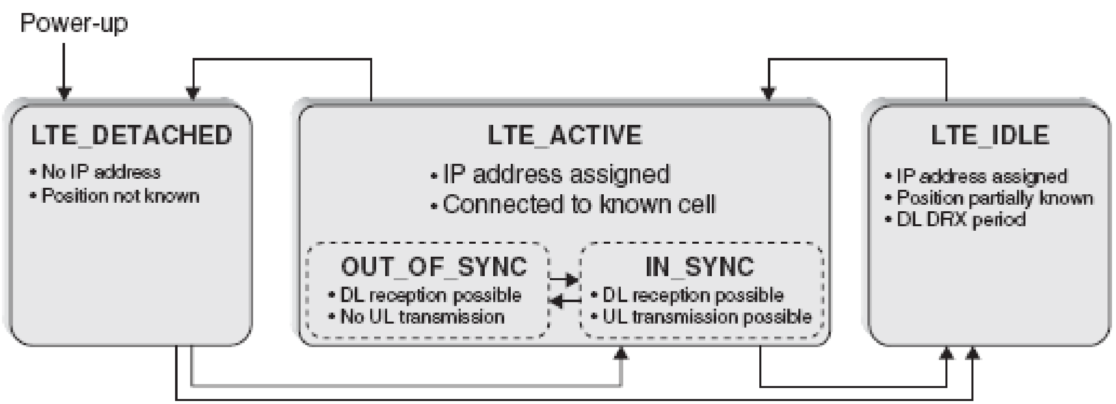
LTE Radio Interface LTE States

- LTE_DETACHED
  - Used @ power up when the mobile terminal is not known to the network.
  - Before any further communication, the mobile terminal need to register with the network using the random-access procedure.
- LTE_ACTIVE
  - Mobile terminal is active with transmitting and receiving data.
  - IN_SYNC
    - Uplink is synchronized with eNodeB
  - OUT_SYNC
    - Uplink is not synchronized with eNodeB.
    - Mobile terminal needs to perform a random-access procedure to restore uplink synchronization.



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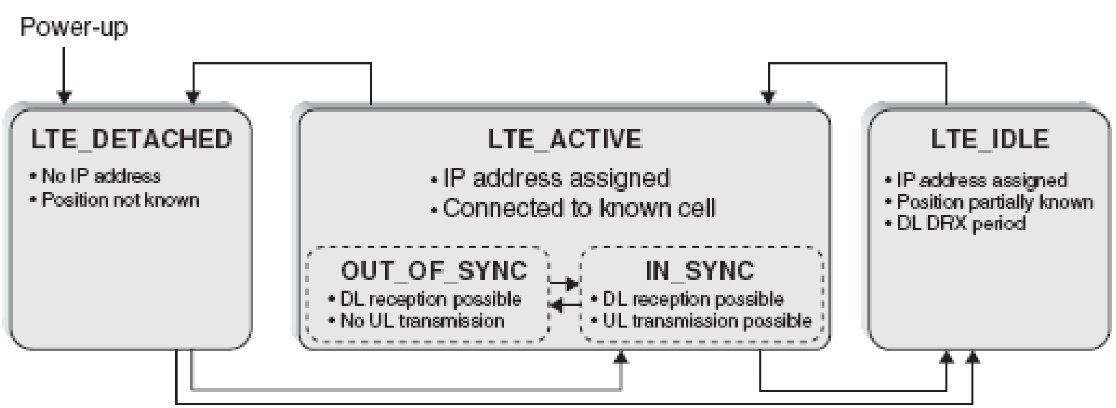
LTE Radio Interface LTE States

- LTE_IDLE
  - Low activity state to reduce battery consumption.
  - The only uplink transmission activity that may take place is random access to move to LTE_ACTIVE.
  - In the downlink, the mobile terminal can periodically wake up in order to be paged for incoming calls
  - The network knows at least the group of cells in which paging of the mobile terminal is to be done.



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Downlink Physical Signals and Channels

Downlink Physical Signals and Channels

- **Downlink Physical Signals**
  - Reference Signals
  - Synchronisation Signals

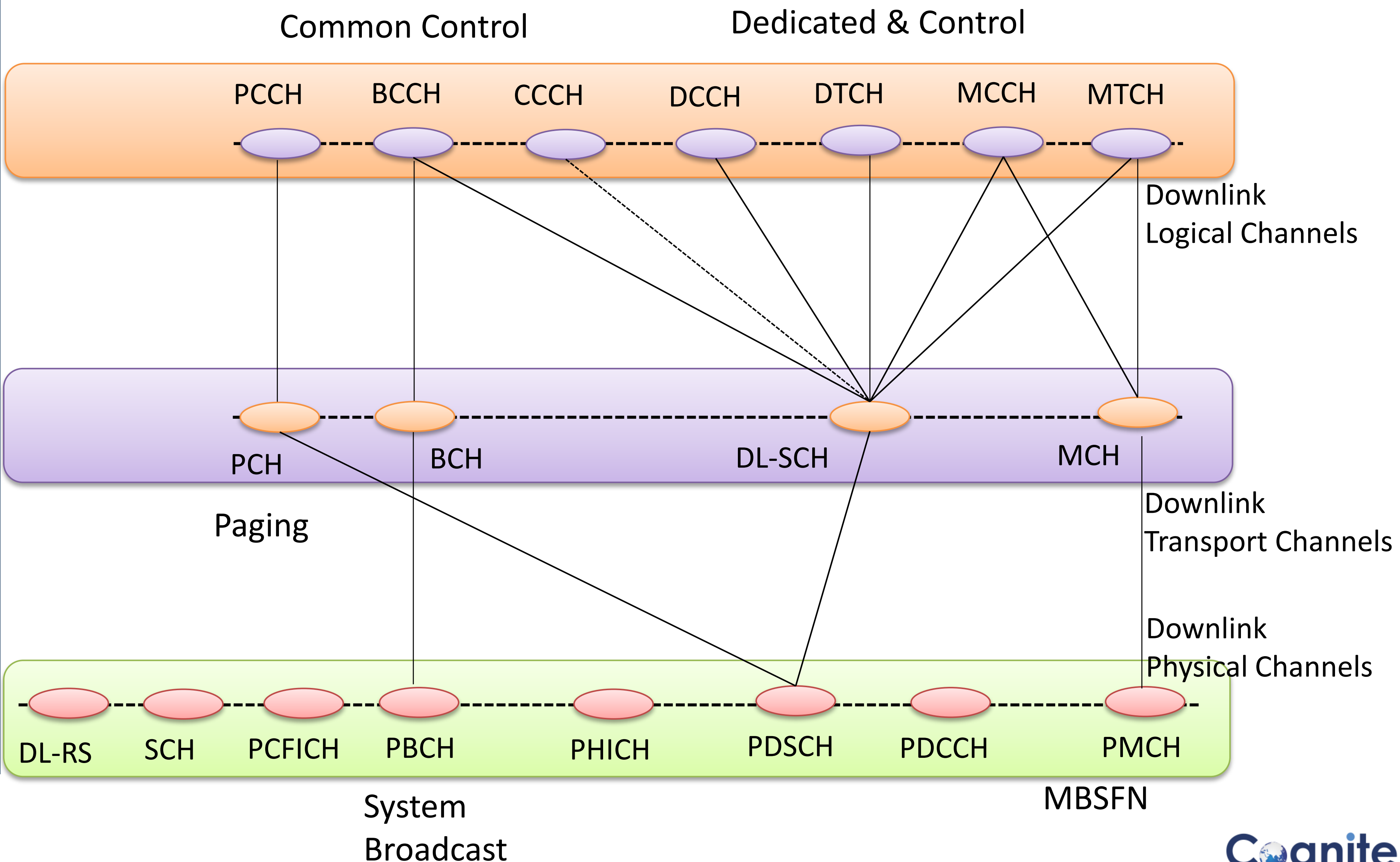
- **Downlink Physical Channels**
  - Physical Broadcast Channel (PBCH)
  - Physical Downlink Shared Channel (PDSCH)
  - Physical Downlink Control Channel (PDCCH)
  - Physical Control Format Indicator Channel (PCFICH)
  - Physical Hybrid-ARQ Indicator Channel (PHICH)
  - Physical Multicast Channel (PMCH)

DL Physical Channels

- PBCH:
  - To broadcast the MIB (Master Information Block), RACH parameters
- PDSCH:
  - Carries user data, paging data, SIBs (cell status, cell IDs, allowed services…)
- PMCH:
  - For multicast traffic as MBMS services
- PHICH:
  - Carries H-ARQ Ack/Nack messages from eNB to UE in response to UL transmission
- PCFICH:
  - Carries details of PDCCH format (e.g.# of symbols)
- PDCCH:
  - Carries the DCI (DL control information): schedule uplink resources on the PUSCH or downlink resources on the PDSCH. Alternatively, DCI transmits TPC commands for UL

Note:There are no dedicated channels in LTE, neither in UL nor DL

DL Channelization Hierarchy



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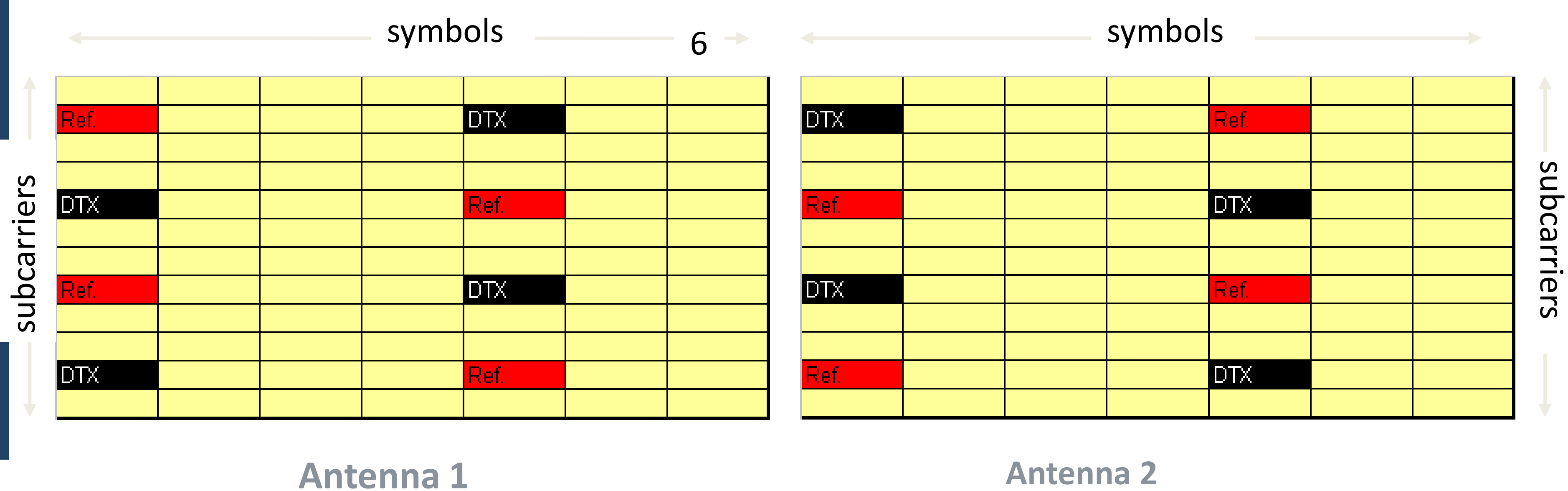
Reference Signals: OFDMA Channel Estimation

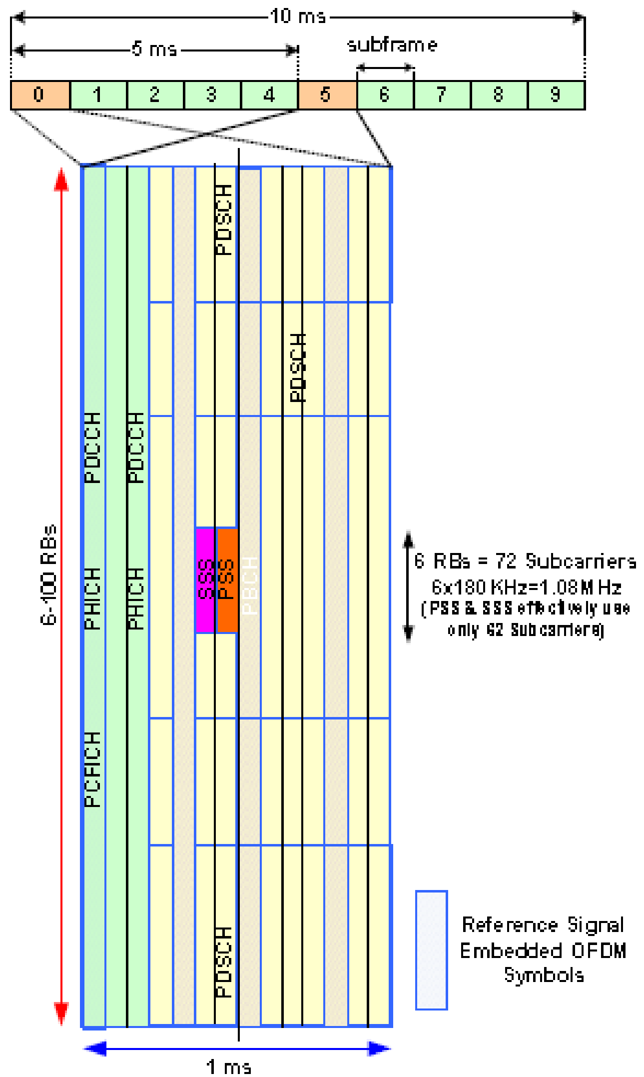
- Channel estimation in LTE is based on reference signals (like CPICH functionality in WCDMA)
- Reference signals position in time domain is fixed (0 and 4 for Type 1 Frame) whereas in frequency domain it depends on the Cell ID
- In case more than one antenna is used (e.g. MIMO) the Resource elements allocated to reference signals on one antenna are DTX on the other antennas
- Reference signals are modulated to identify the cell to which they belong.



Synchronization Signals (PSS & SSS)

- PSS and SSS Functions
  - Frequency and Time synchronization
    - Carrier frequency determination
    - OFDM symbol/subframe/frame timing determina
  - Physical Layer Cell ID determination
    - Determine 1 out of 504possibilities

- PSS and SSS resource allocation
  - Time: subframe0 and 5 of every Frame
  - Frequency: middle of bandwidth (6 RBs = 1.08 M



Synchronization Signals (PSS & SSS)

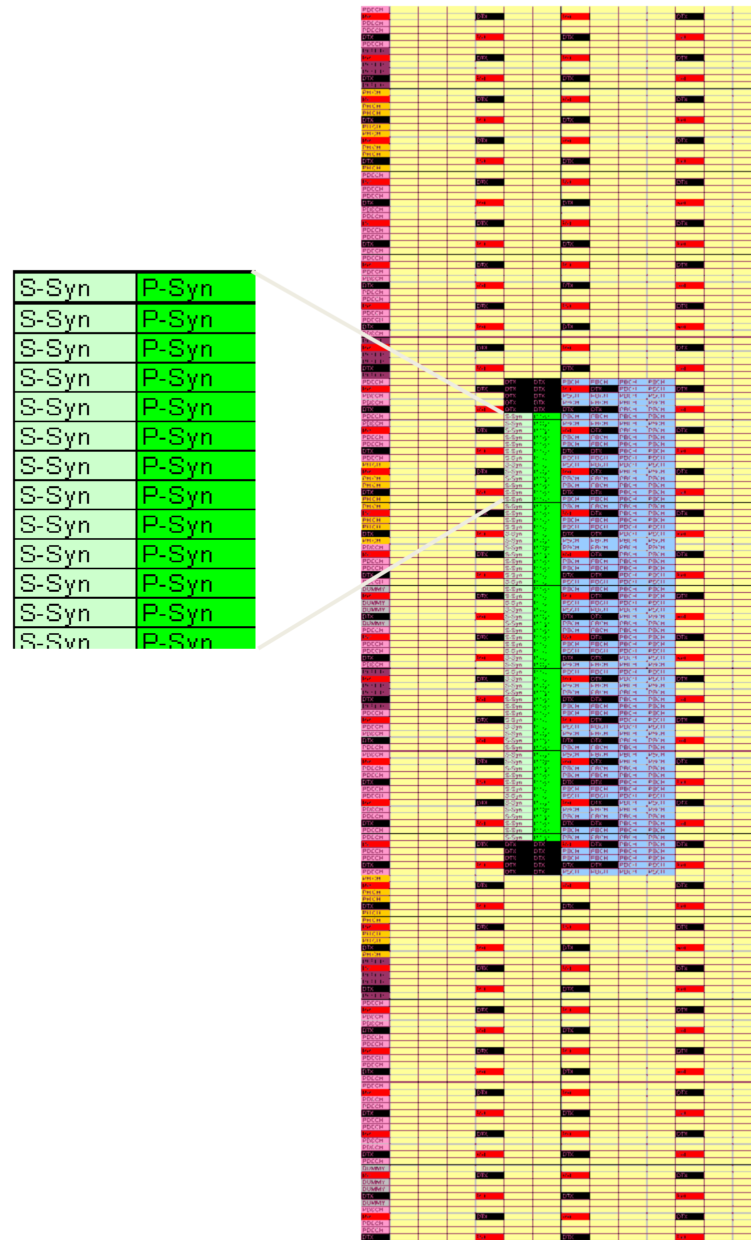
- Primary Synchronization Signals (PSS)
  - Assists subframe timing determination
  - Provides a unique Cell ID index (0, 1, or 2) within a Cell ID group

- Secondary Synchronization Signals (SSS)
  - Assists frame timing determination

    M-sequences with scrambling and different concatenation methods for SF0 and SF5)
  - Provides a unique Cell ID group number among 168 possible Cell ID groups

Synchronization Signals allocation (DL)

- Synchronization signals:
  - Transmitted during the 1st and 11th slots within a radio frame
  - Occupy the central 62 Subcarriers (around the DC subcarrier) to facilitate the cell search
  - 5 Subcarriers above and 5 Subcarriers below the synch. Signals are reserved and transmitted as DTx
  - Synchronisation Signal can indicate 504 (168 x 3) CellID different values and from those one can determine the location of cell specific reference symbols



Physical Broadcast Channel (PBCH)

PBCH Function

–Carries the primary Broadcast Transport Channel

–Carries the Master Information Block (MIB), which incl

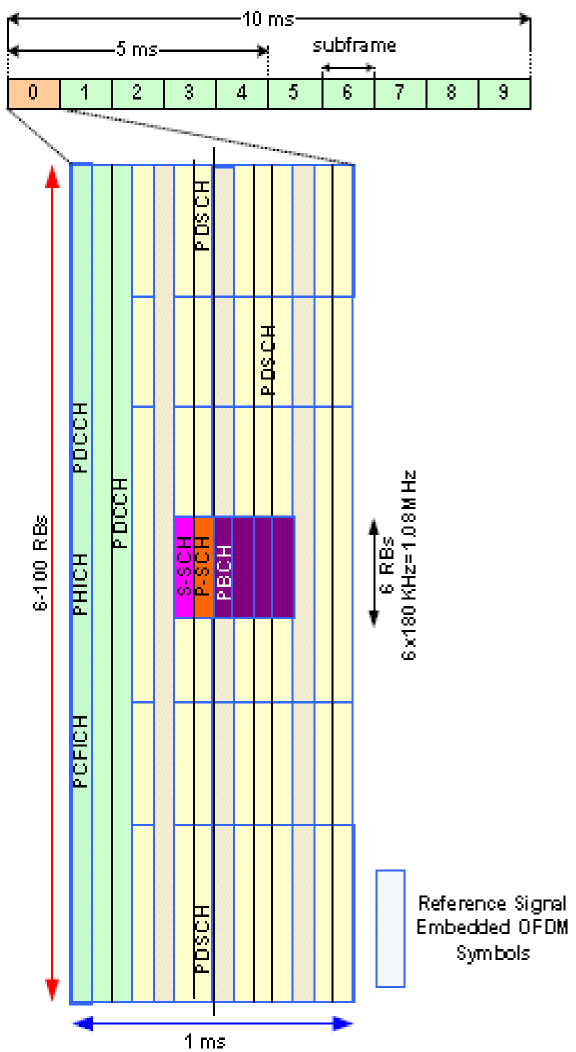
Overall DL transmission bandwidth

PHICH configuration in the cell

System Frame Number

Number of transmit antennas (implicit)

- **Transmitted in**
  - – **Time**: subframe 0 in every frame
  - – 4 OFDM symbols in the second slot of corresponding s
  - – **Frequency**: middle 1.08 MHz (6 RBs)



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Physical Broadcast Channel (PBCH)

- **TTI = 40 ms**
  - Transmitted in 4 bursts at a very low data rate
  - Same information is repeated in 4 subframes
  - Every 10 ms burst is self-decodable
  - CRC check uniquely determines the 40 ms PBCH TTI boundary

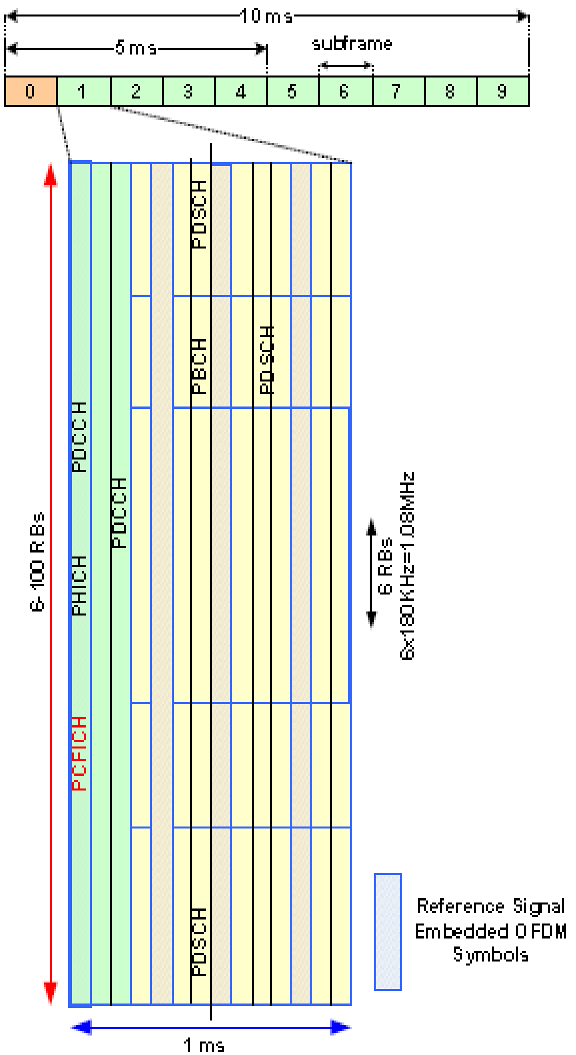
Last 2 bits of SFN is not transmitted

Physical Control Format Indicator Channel (PCFICH)

- **Carries the Control Format Indicator (CFI)**
- **Signals the number of OFDM symbols of PDCCH:**
  - 1, 2, or 3 OFDM symbols for system bandwidth > 10 RE
  - 2, 3, or 4 OFDM symbols for system bandwidth > 6-10
  - Control and data do **not occur in same OFDM symbol**
- **Transmitted in:**
  - Time: 1st OFDM symbol of all subframes
  - Frequency: spanning the entire system band

    4 REGs -> 16 REs

    Mapping depends on Cell ID
- **PCFICH in Multiple Antenna configuration**
  - 1 Tx: PCFICH is transmitted as is
  - 2Tx, 4Tx: PCFICH transmission uses Alamouti Code



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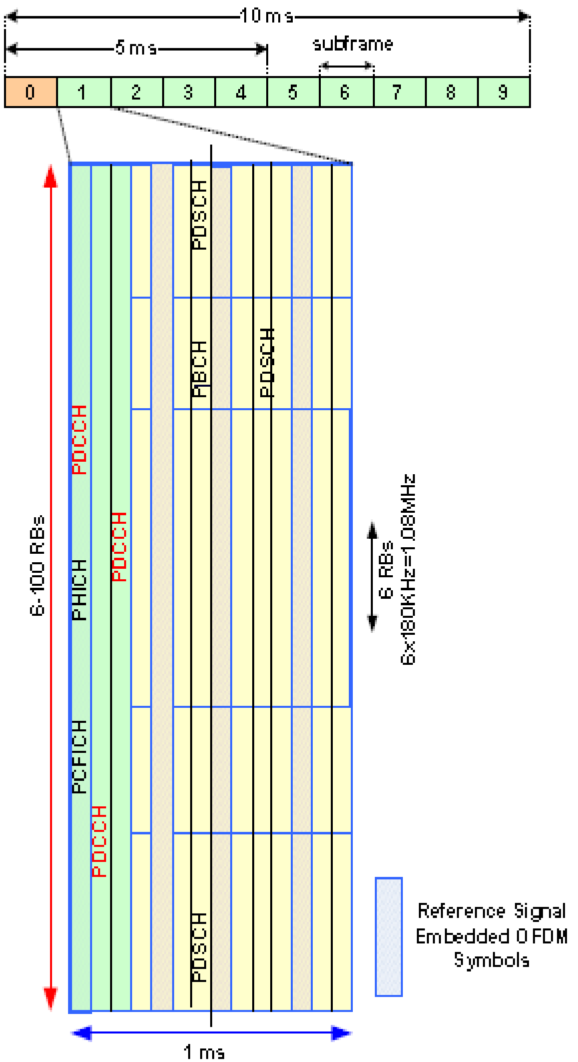
Physical Downlink Control Channel (PDCCH)

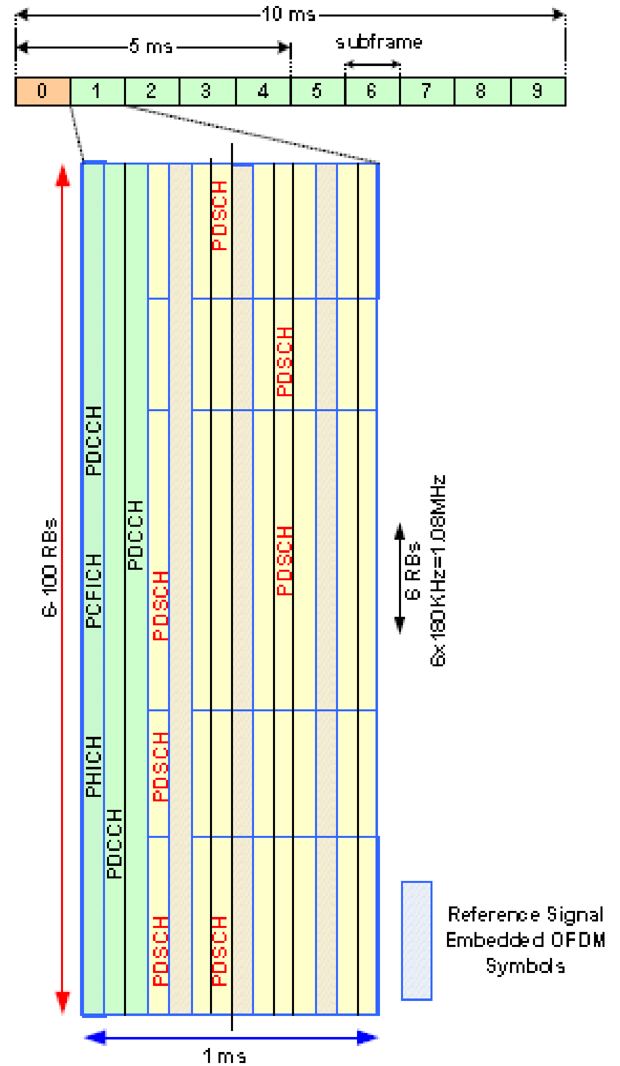
- **Used for:**
  - DL/UL resource assignments
  - Multi-user Transmit Power Control (TPC) commands
  - Paging indicators
- **CCEs are the building blocks for transmitting PDCCH**
  - 1 CCE = 9 REGs (36 REs) = 72 bits
  - The control region consists of a set of CCEs, numbered from 0 to N_CCE for each subframe
  - The control region is confined to 3 or 4 (maximum) OFDM symbols per subframe (depending on system bandwidth)
- **A PDCCH is an *aggregation of contiguous CCEs (1,2,4,8)***
  - Necessary for different PDCCH formats and coding rate protections
  - Effective supported PDCCH aggregation levels need to result in code rate < 0.75



Physical Downlink Shared Channel (PDSCH)

Transmits DL packet data

- One Transport Block transmission per UE's code wo
- A common MCS per code word per UE across all all
  - Independent MCS for two code words per UE
- 7 PDSCH Tx modes



Mapping to Resource Blocks (RBs)

- Mapping for a particular transmit antenna port sha
  - –First the frequency index,
  - –Then the time index, starting with the first slot ina sub

Physical HARQ Indicator Channel (PHICH)

Used for ACK/NAK of UL-SCH transmissions

Transmitted in:

Time

–Normal duration: 1stOFDM symbol

–Extended duration: Over 2 or 3 OFDM symb

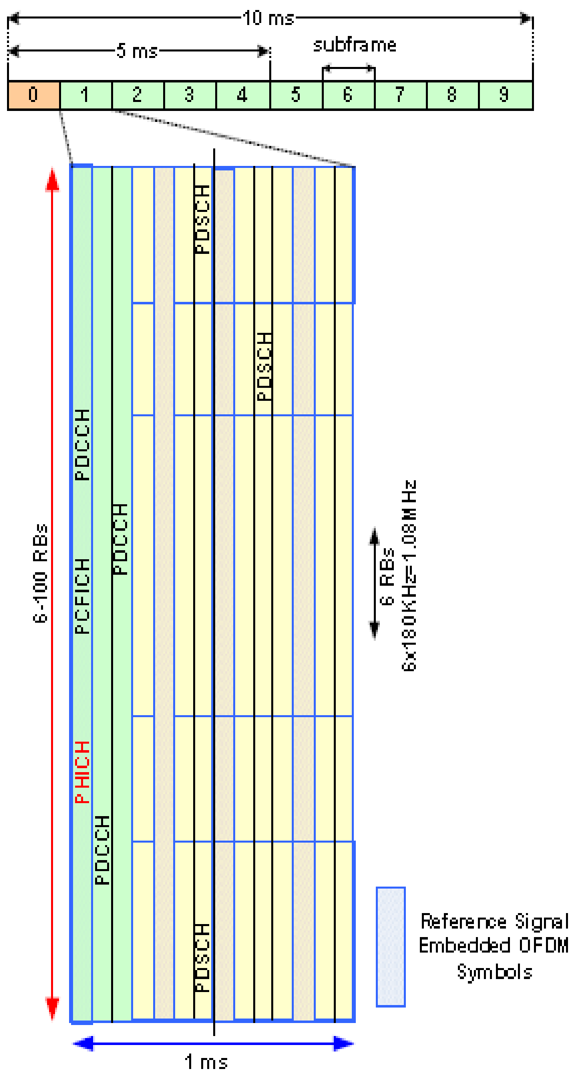
Frequency

–Spanning all system bandwidth

–Mapping depending on Cell ID

FDM multiplexed with other DL control channels

Support of CDM multiplexing of multiple PHICHs



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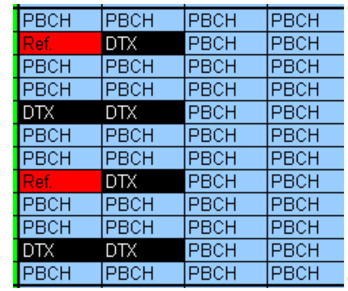
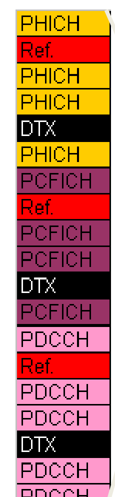
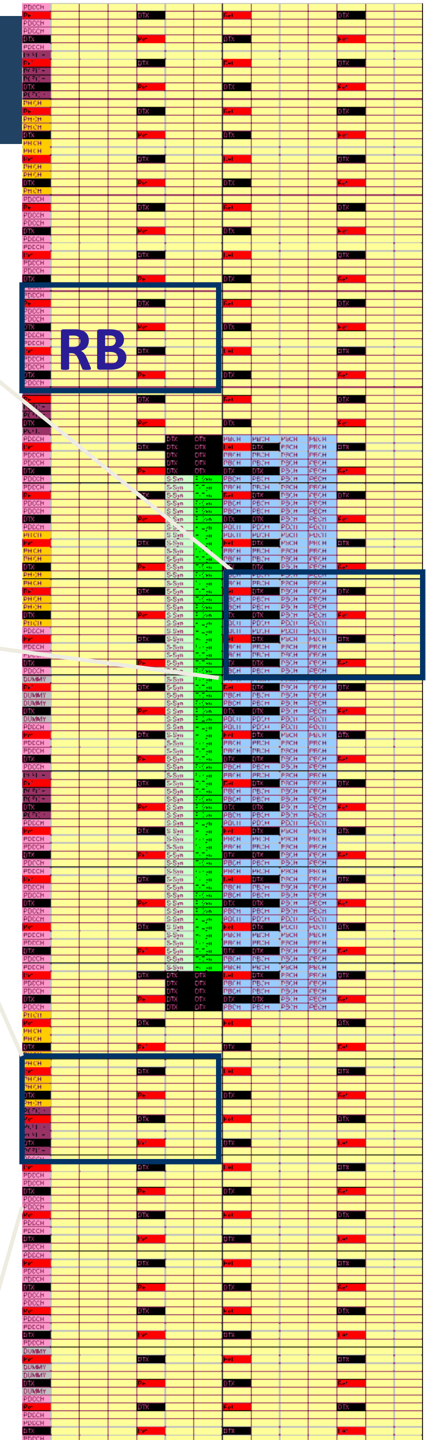
DL Physical Channels Allocation

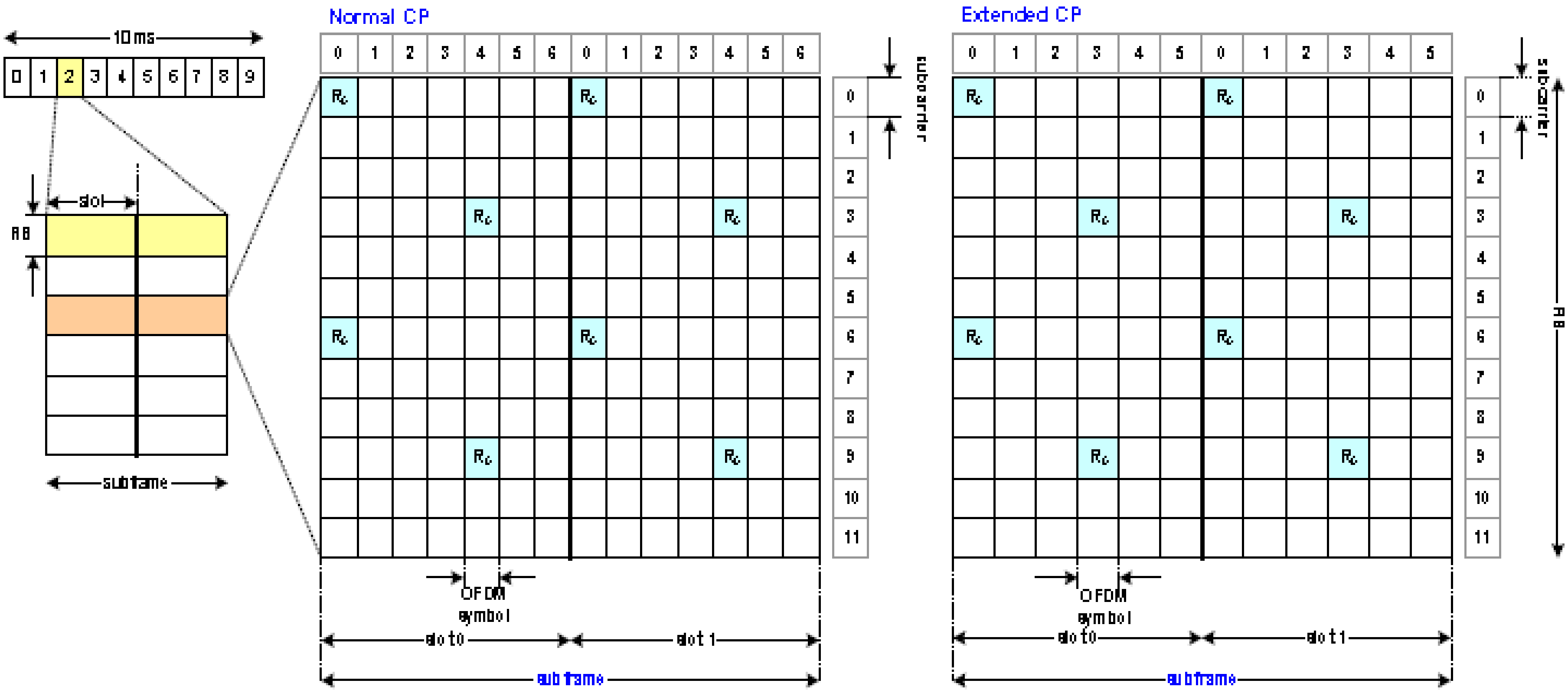
- **PBCH:**
  - Occupies the central 72 subcarriers across 4 symbols
  - Transmitted during second slot of each 10 ms radio frame on all antennas
- **PCFICH:**
  - Can be transmitted during the first 3 symbols of each TTI
  - Occupies up to 16 RE per TTI
- **PHICH:**
  - Normal CP: Tx during 1st symbol of each TTI
  - Extended CP: Tx during first 3 symbols of each TTI
  - Each PHCIH group occupies 12 RE
- **PDCCH:**
  - Occupies the RE left from PCFICH and PHICH within the first 3 symbols of each TTI
  - Minimum number of symbols are occupied. If PDCCH data is small then it only occupies the 1st symbol
- **PDSCH:**
  - Is allocated the RE not used by signals or other physical channels





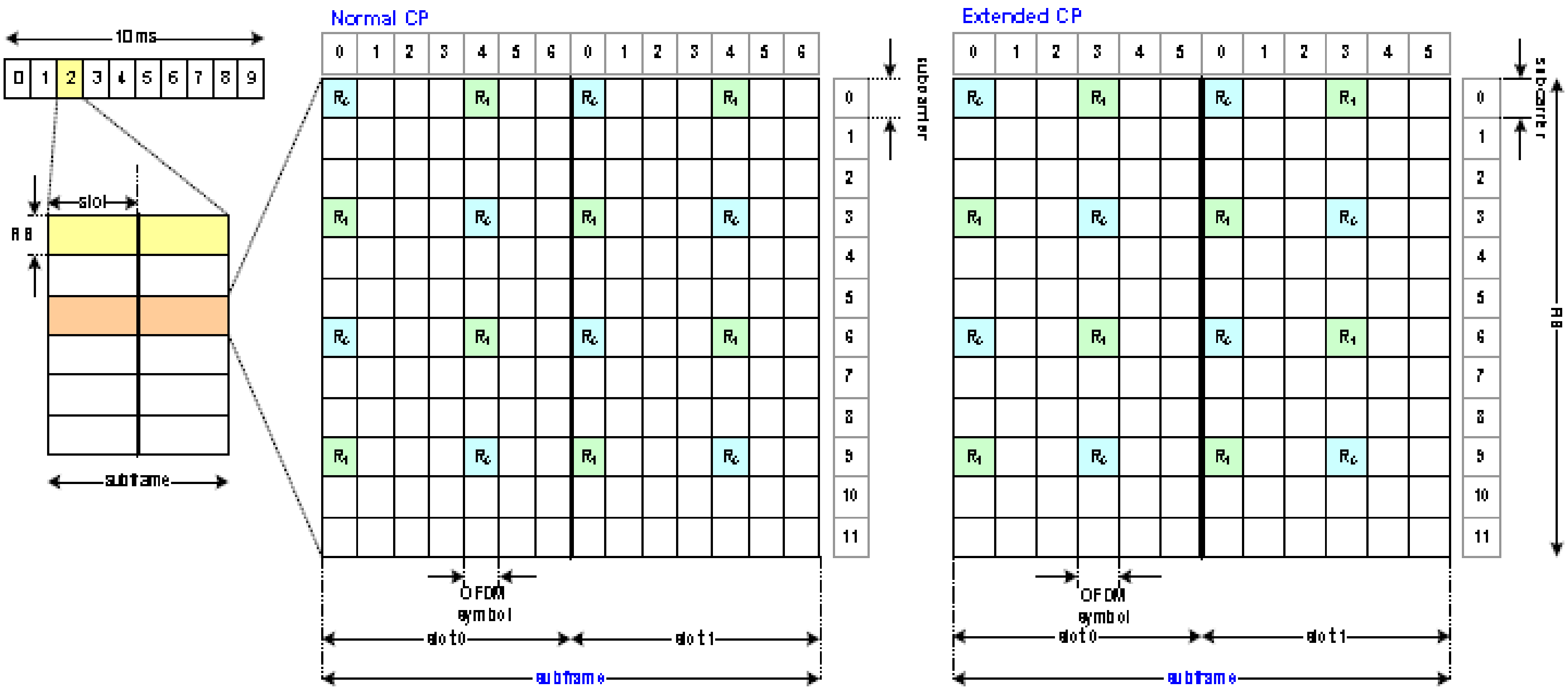


DL Reference Signals: 1 TxAntenna

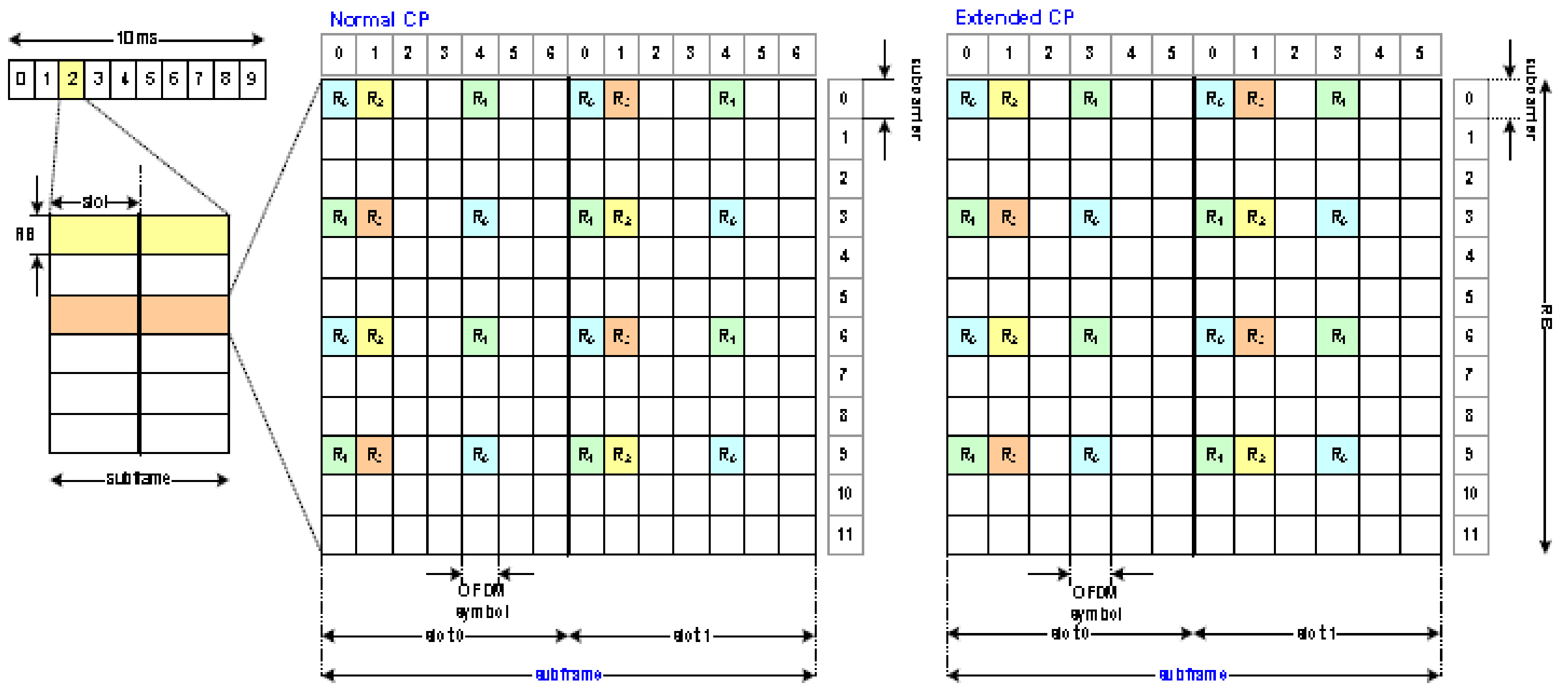


DL Reference Signals transmitted on 2 OFDM symbols every slot
6 subcarrier spacing

DL Reference Signals: 2 Tx Antenna



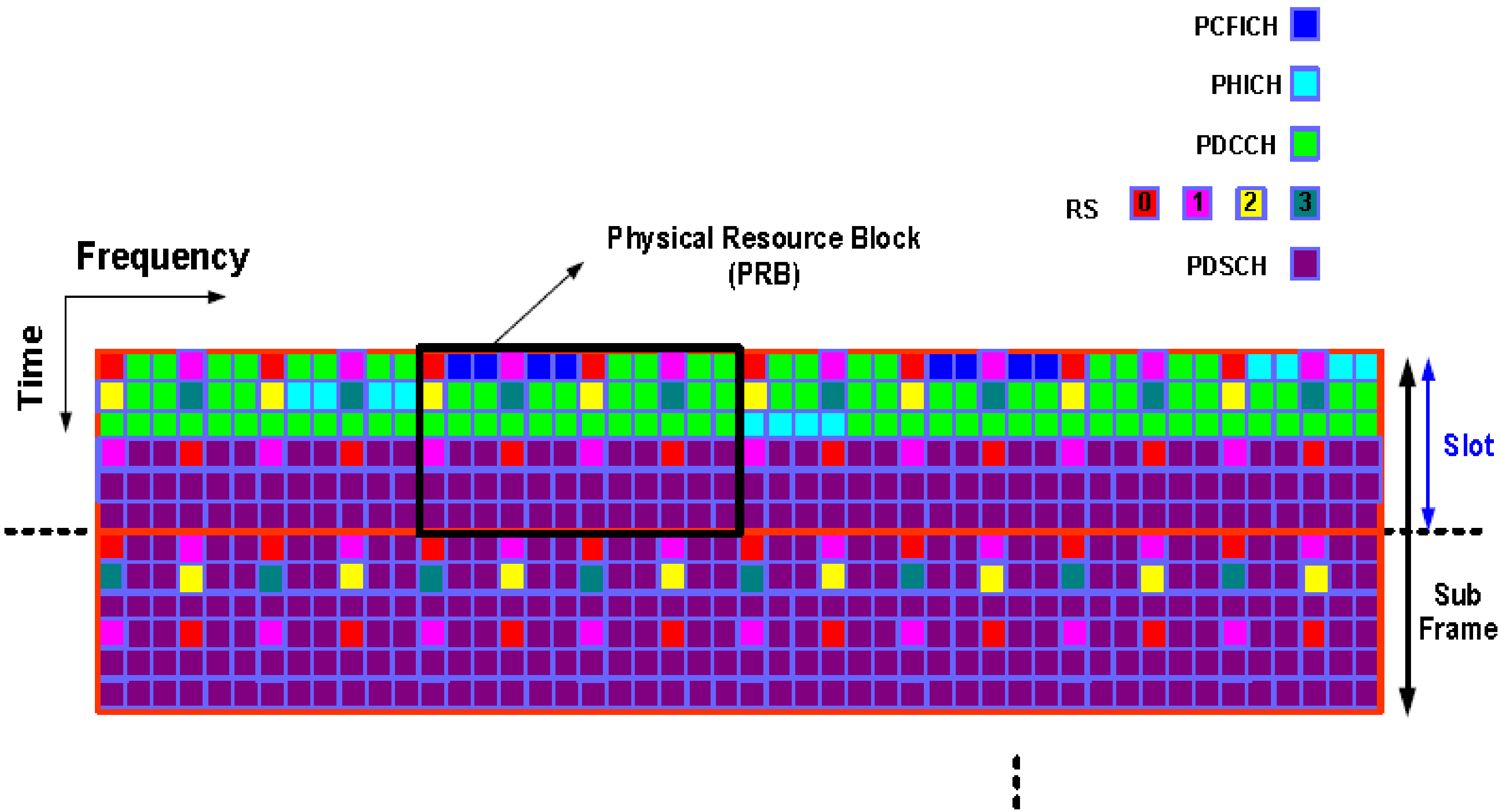
DL Reference Signals: 4 Tx Antenna



Overheads	Normal CP	Extended CP
1 TX Antenna	4.76%	5.56%
2 TX Antenna	9.52%	11.11%
4 TX Antenna	14.29%	15.87%

7Downlink Transmission –An Example

- **Example of Frame Structure Type 1 (extended CP) transmission**



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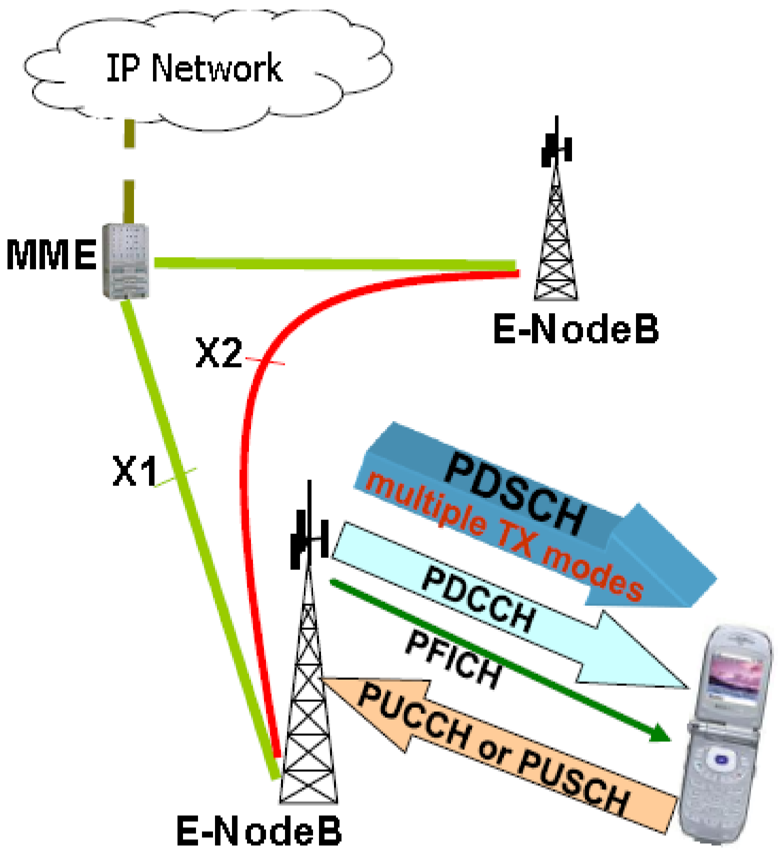
lDL Scheduled Operation Overview



PDSCH Physical Downlink Shared Channel
PDCCH Physical Downlink Control Channel
PFICH Physical Format Indicator Channel
PUCCH Physical Uplink Control Channel

1. UE reports CQI(Channel Quality Indicator), PMI(Precoding Matrix Index), and RI (Rank Indicator) in PUCCH (or PUSCH if there is UL traffic).

2. Scheduler at eNodeB dynamically allocates resources to UE:–UE readsPCFICH every subframe to discover the number of OFDM symbols occupied by PDCCH.–UE reads PDCCH to discover Tx Modeand assigned resources (PR BandMCS).

3. eNodeB sends user data in PDSCH.

4. UE attempts to decode the received packet and sends ACK/NACK using PUCCH(or PUSCH if there is UL traffic).

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Uplink Physical Signals and Channels

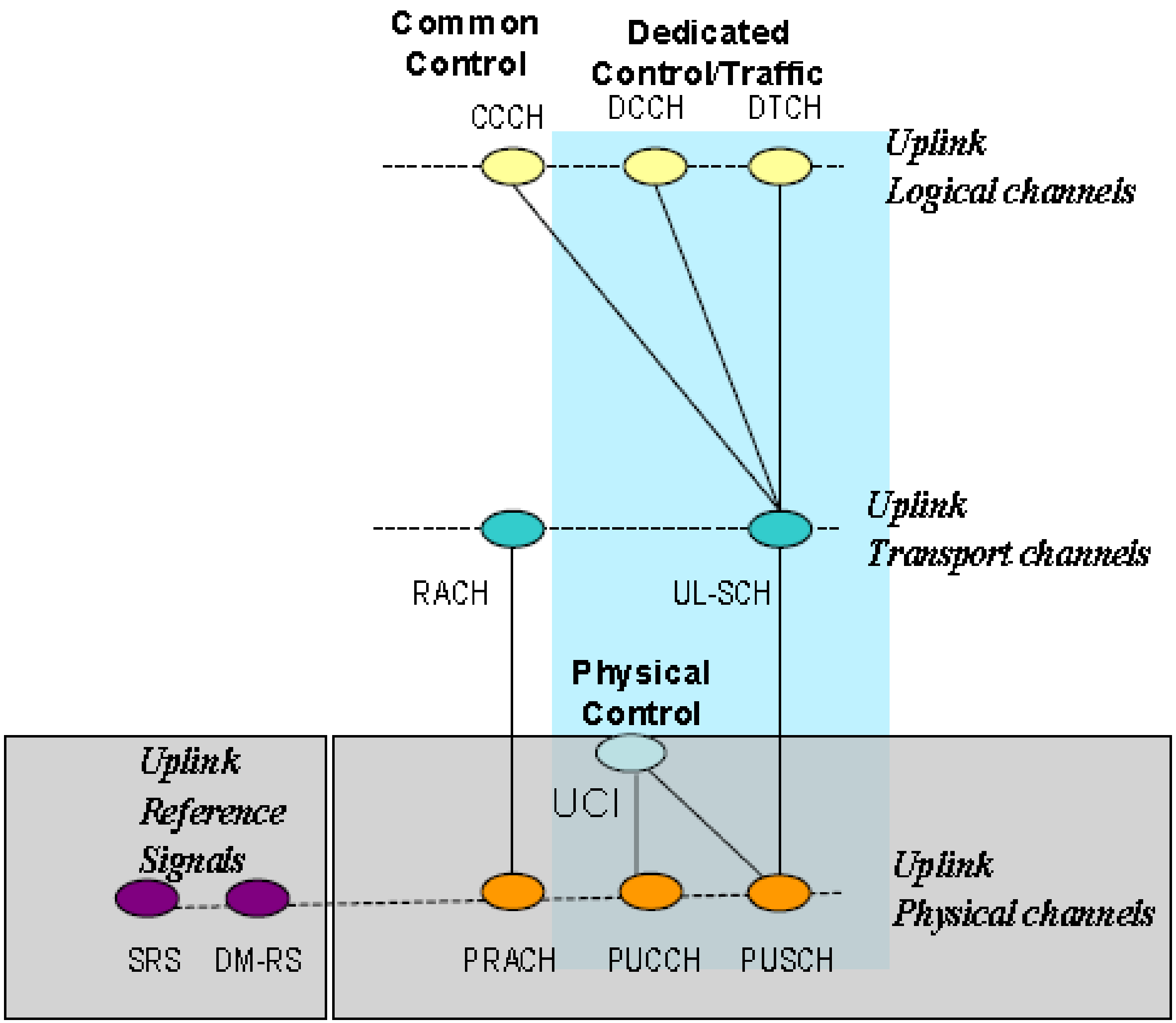
– **Uplink Physical Signals**
  - Demodulation Signals:
    – Used for channel estimation in the eNodeB receiver to demodulate control and data channels
    – Located in the 4th symbol (normal CP) of each slot and spans the same bandwidth as the allocated uplink data
  - Sounding Reference Signals:
    – Provides uplink channel quality estimation as basis for the UL scheduling decisions -> similar in use as the CQI in DL
    – Sent in different parts of the bandwidth where no uplink data transmission is available.
    – Not part of first NSNs implementations (UL channel aware scheduler in RL30)

– **Uplink Physical Channels**
  - Physical Uplink Shared Channel (PUSCH)
  - Physical Uplink Control Channel (PUCCH)
  - Physical Random Access Channel (PRACH)

UL Physical Channels

- **PUSCH: Physical Uplink Shared Channel**
  - Intended for the user data (carries traffic for multiple UEs)
- **PUCCH: Physical Uplink Control Channel**
  - Carries H-ARQ Ack/Nack indications, uplink scheduling request, CQIs and MIMO feedback
  - If control data is sent when traffic data is being transmitted, UE multiplexes both streams together
  - If there is only control data to be sent the UE uses Resources Elements at the edges of the channel with higher power
- **PRACH: Physical Random Access Channel**
  - For Random Access attempts. PDCCH indicates the Resource elements for PRACH use
  - PBCH contains a list of allowed preambles (max. 64 per cell in Type 1 frame) and the required length of the preamble

UL Channelization Hierarchy



No dedicated transport channels: Focus on “shared” transport channels.

E-UTRA Uplink Reference Signals

Two types of E-UTRA/LTE Uplink Reference Signals:

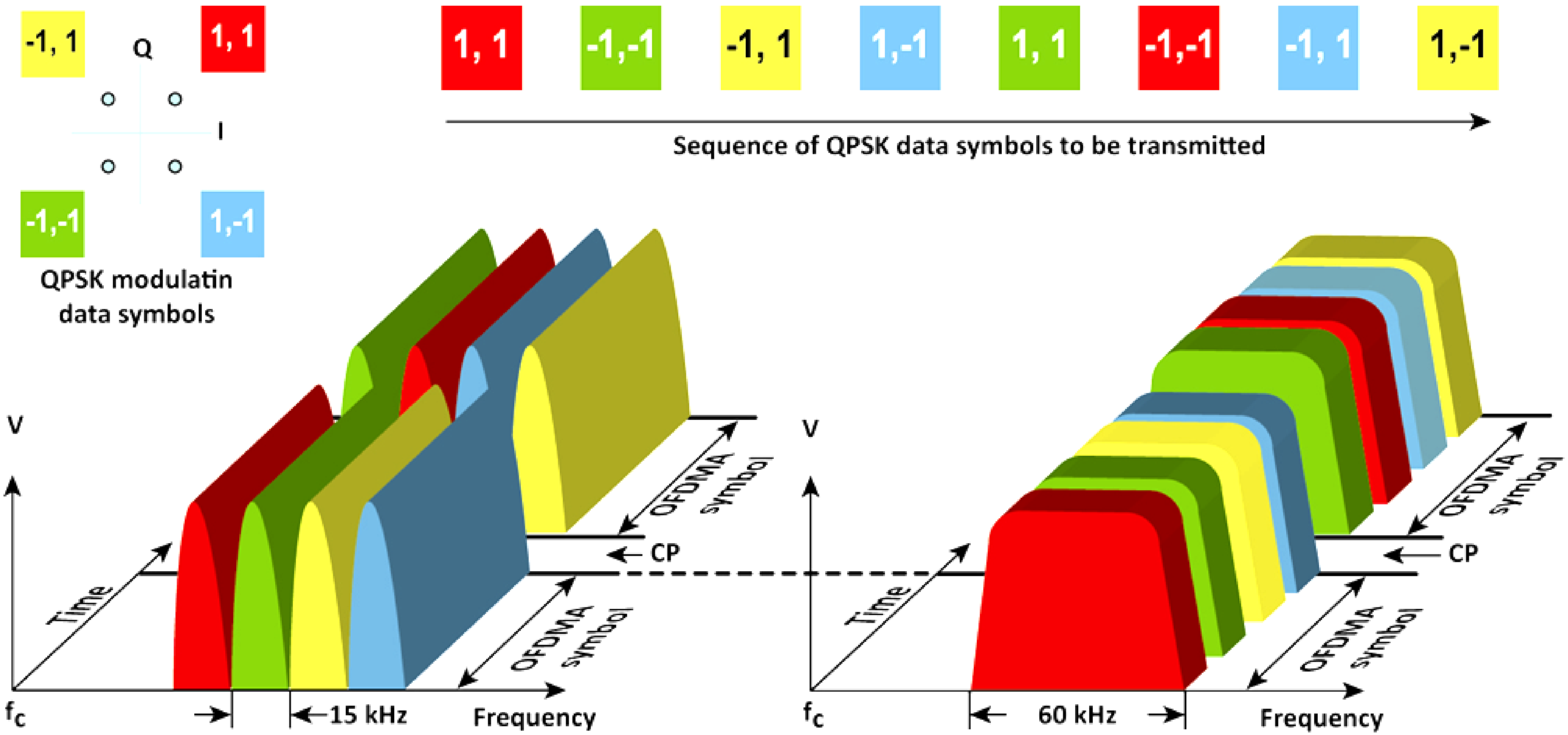
Demodulation reference signal

- Associated with transmission of PUSCH or PUCCH
- Purpose: Channel estimation for Uplink coherent demodulation/detection of the Uplink control and data channels
- Transmitted in time/frequency depending on the channel type (PUSCH/PUCCH), format, and cyclic prefix type

Sounding reference signal

- Not associated with transmission of PUSCH or PUCCH
- Purpose: Uplink channel quality estimation feedback to the Uplink scheduler (for Channel Dependent Scheduling) at the eNodeB
- Transmitted in time/frequency depending on the SRS bandwidth and the SRS bandwidth configuration (some rules apply if there is overlap with PUSCH and PUCCH)

OFDMA versus SC-FDMA



OFDMA

Data symbols occupy 15 kHz for one OFDMA symbol period

SC-FDMA

Data symbols occupy N x 15 kHz for 1/N SC-FCMA symbol periods

DivTypesOFDMA-SC-FDMA.ai

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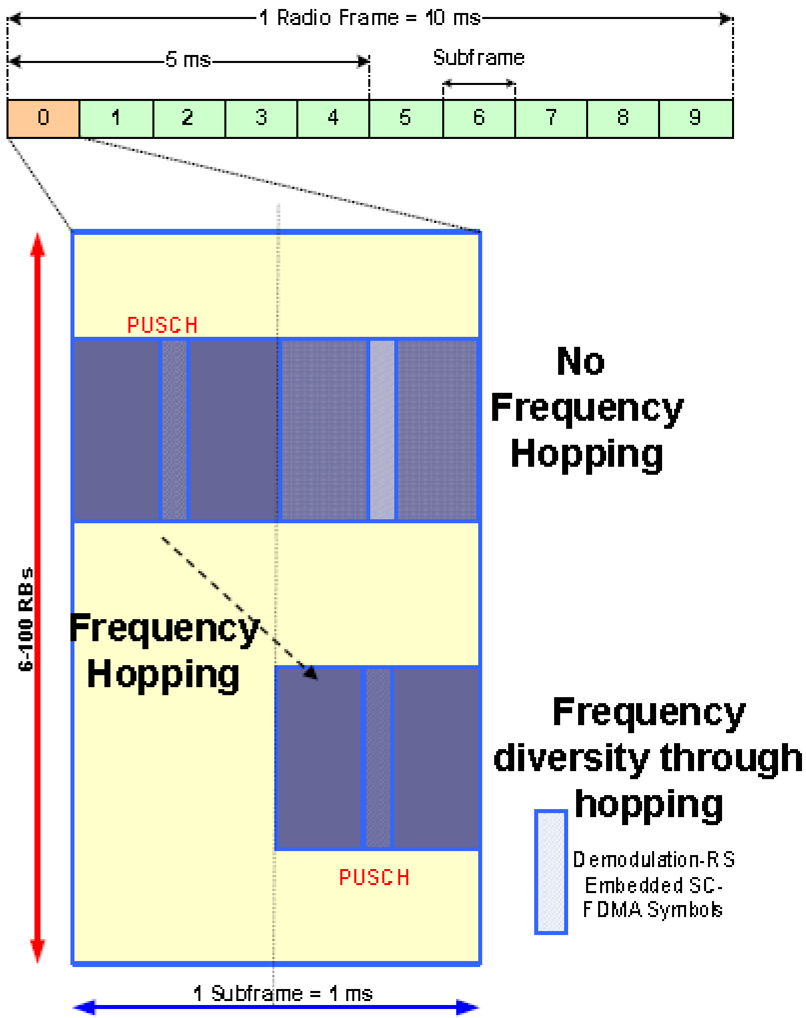
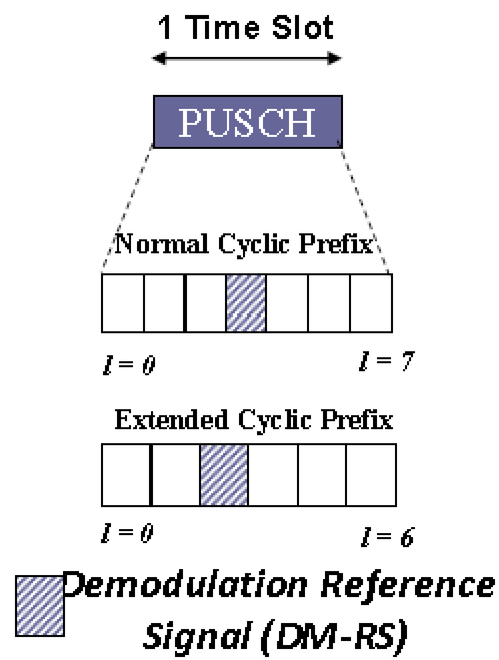
Physical Uplink Shared Channel (PUSCH)



PUSCH may carry:
- **UL Data**
- **ACK/NAK for DL data**
- **CQI/PMI/RI**



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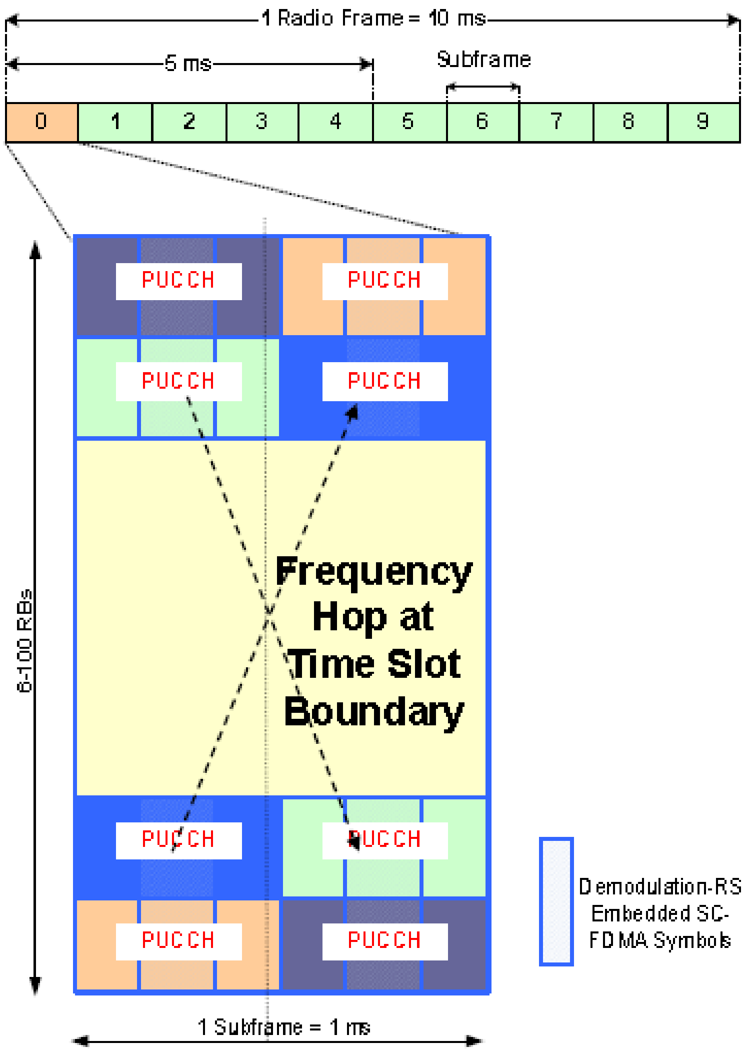
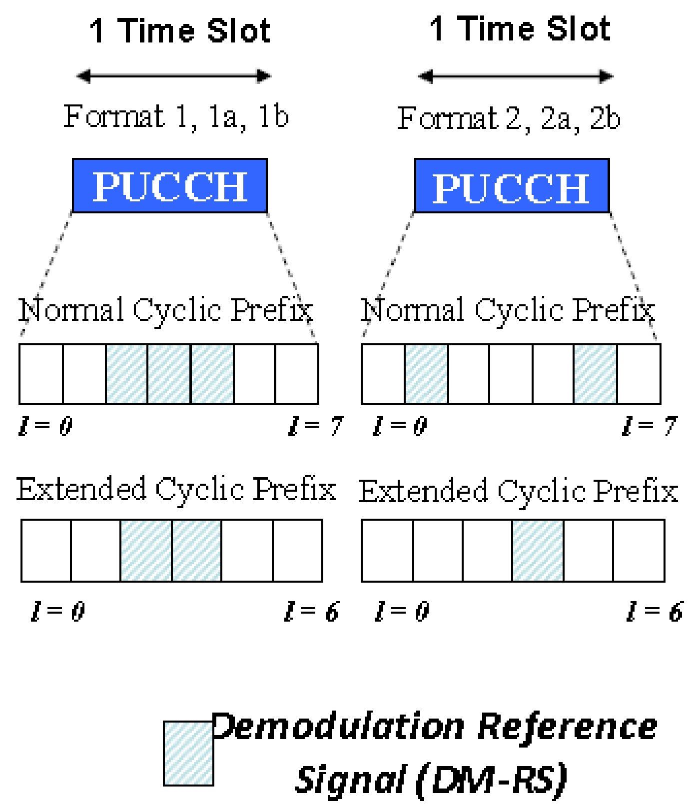
Physical Uplink Control Channel (PUCCH)



PUCCH may carry:

- **ACK/NAK for DL data**
- **Scheduling Request**
- **CQI/PMI/RI**



Sounding Reference Signals (SRS)

SRS shall be transmitted on the last symbol of the subframe.

PUSCH:

- The mapping to resource elements only considers those not used for transmission of reference signals.

PUCCH Format 1 (SR) / 1a / 1b (HARQ-ACK):

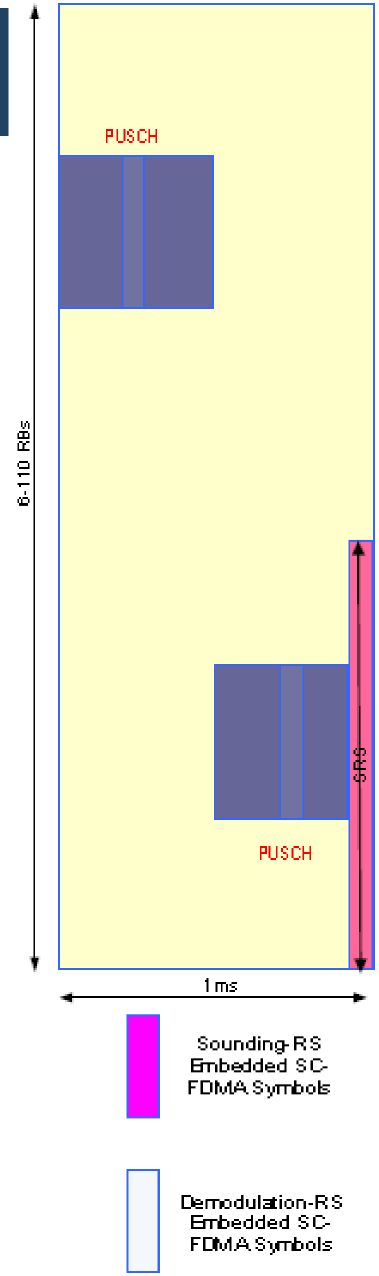
- When ACK/NAK and SRS are to be transmitted in SRS cell-specific subframes:
  - If higher-layer parameter *Simultaneous-AN-and-SRS is TRUE => Use shortened PUCCH format.*
  - Else UE shall not transmit SRS.

PUCCH Format 2 / 2a / 2b (CQI):

- UE shall not transmit SRS whenever SRS and PUCCH 2 / 2a / 2b coincide.

SRS multiplexing:

- Done with CDM when there is one SRS bandwidth, and FDM/CDM when there are multiple SRS bandwidths.



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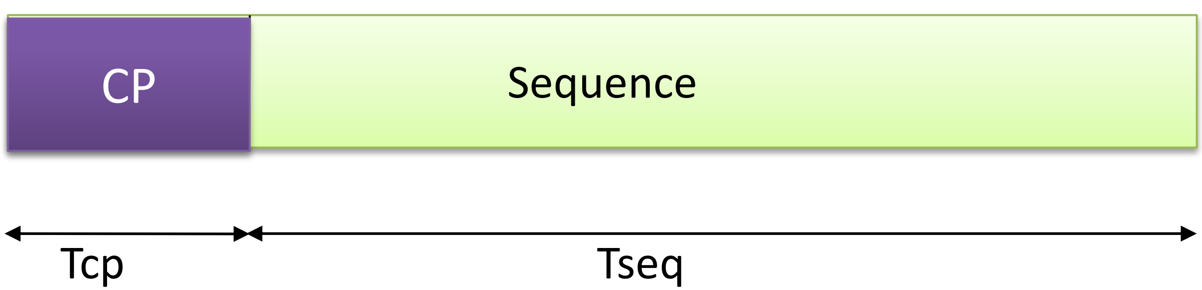
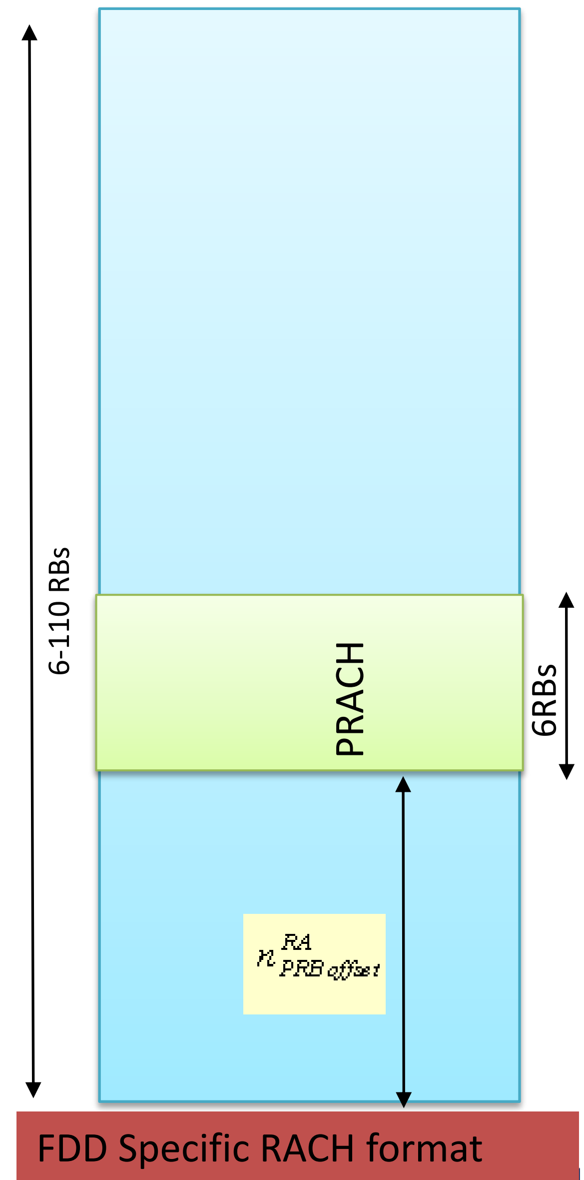
PRACH

- The preamble format determines the length of the Cyclic Prefix and Sequence.
- FDD has 4 preamble formats (for different cell sizes).
- 16 PRACH configurations are possible.
- Each configuration defines slot positions within a frame (for different bandwidths).
- Each random access preamble occupies a bandwidth corresponding to 6 consecutive RBs.
- $n^{RA}_{PRBOffset}$ is the starting RB for the PRACH.

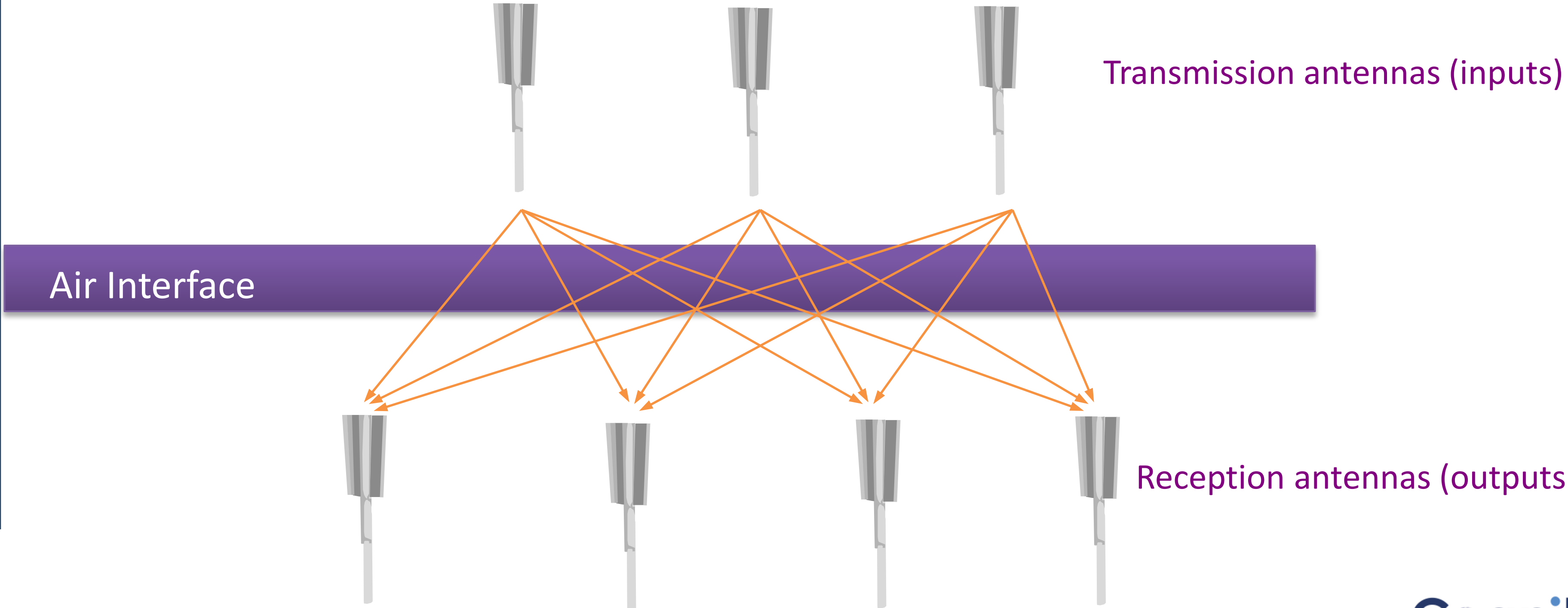




MIMO

MIMO

- MIMO stands for Multiple Input Multiple Output.
  - It is a key technology to increase a channel's capacity by using multiple transmitter and receiver antennas.
  - The propagation channel is the air interface, so that transmission antennas are handled as input to the channel, whereas receiver antennas are the output of it.
  - The very basic ideas behind MIMO have been established already 1970 , but have not been used in radio communication until 1990.
  - MIMO is currently used in 802.11n, 802.16d/e to increase the channel capacity.



THANK YOU