Long-Term Evolution (LTE) of 3GPP

MODULE 6

LTE System Overview

- LTE stands for *Long Term Evolution* and it was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP).
- SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution. The term LTE is typically used to represent both LTE and SAE.
- LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM).
- A rapid increase of mobile data usage and emergence of new applications such as MMOG (Multimedia Online Gaming), mobile TV, Web 2.0, streaming contents have motivated the 3rd Generation Partnership Project (3GPP) to work on the Long-Term Evolution (LTE) on the way towards fourth-generation mobile.
- The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments.

2G/3G Versus LTE

Following table compares various important Network Elements & Signaling protocols used in 2G/3G abd LTE.

2G/3G	LTE
GERAN and UTRAN	E-UTRAN
SGSN/PDSN-FA	S-GW
GGSN/PDSN-HA	PDN-GW
HLR/AAA	HSS
VLR	MME
SS7-MAP/ANSI-41/RADIUS	Diameter
DiameterGTPc-v0 and v1	GTPc-v2
MIP	PMIP

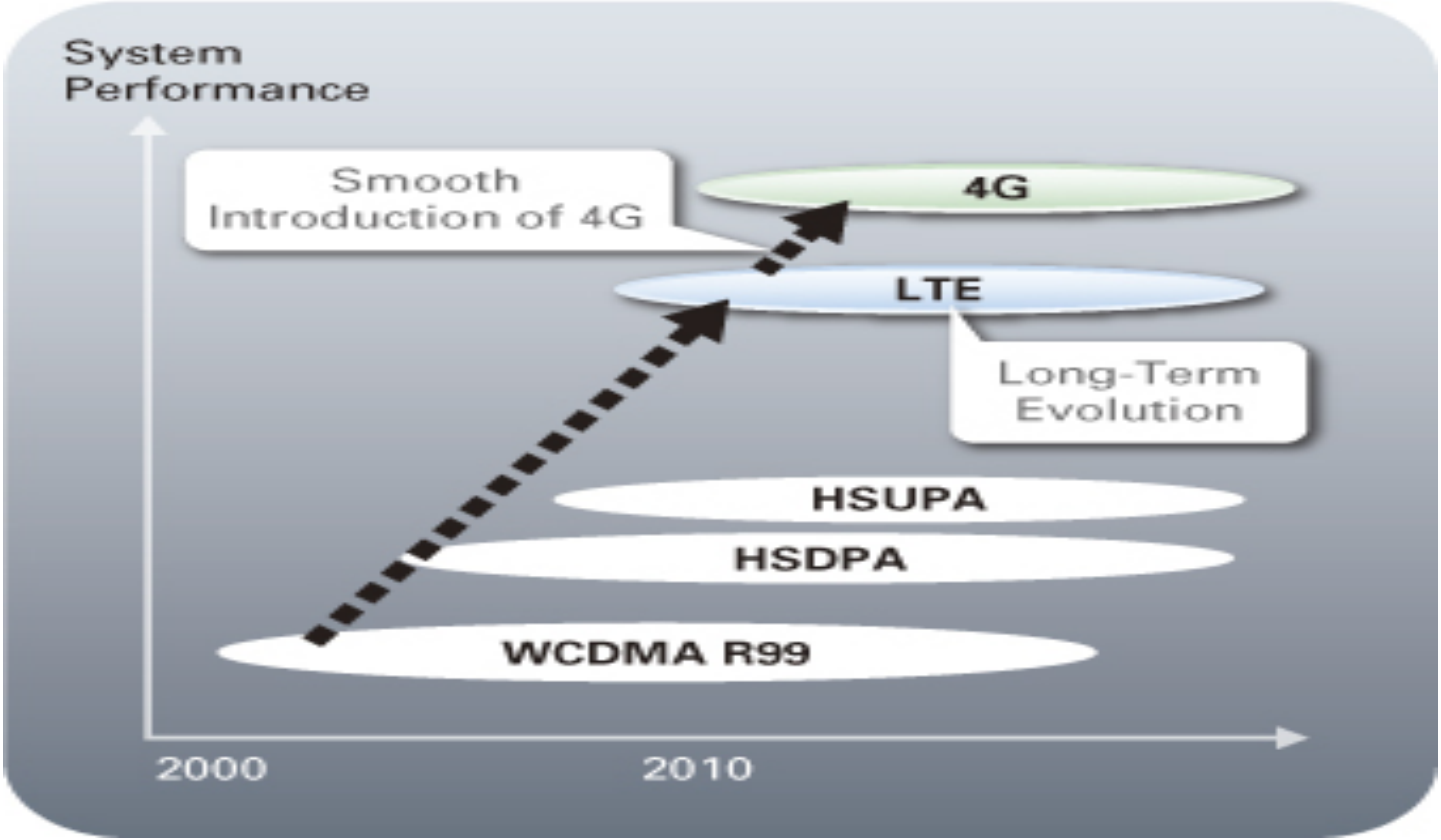
History of Mobile Telecommunication Systems

A)From 1G to 3G

- The first generation (1G) systems (1980)used analogue communication techniques, which were similar to those used by a traditional analogue radio.
- The individual cells were large and the systems did not use the available radio spectrum efficiently, so their capacity was very small by today’s standards.
- The mobile devices were large and expensive and were marketed almost exclusively at business users.
- The second generation (2G) systems (1990) were the first to use digital technology, which permitted a more efficient use of the radio spectrum and the introduction of smaller, cheaper devices.

- The most popular 2G system was the Global System for Mobile Communications (GSM). They were originally designed just for voice, but were later enhanced to support instant messaging through the Short Message Service (SMS).
- The success of 2G communication systems so-called 2.5G systems, General Packet Radio Service (GPRS)built on the original ideas from 2G, by introducing the core network's packet switched domain and by modifying the air interface so that it could handle data as well as voice.
- The data rates available over the internet were progressively increasing using techniques such as Enhanced Data Rates for GSM Evolution (EDGE) .
- The world's dominant 3G system is the Universal Mobile Telecommunication System (UMTS). UMTS was developed from GSM by completely changing the technology used on the air interface, while keeping the core network almost unchanged.

- The system was later enhanced for data applications, by introducing the 3.5G technologies of high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA), which are collectively known as high-speed packet access (HSPA).
- The final 3G technology is Worldwide Interoperability for Microwave Access (WiMAX). This was developed by IEEE standard (802.16,2001) that delivered data over point-to-point microwave links instead of fixed cables.
- A fixed WiMAX (IEEE 802.16–2004), supported point-to-multipoint communications between an omni-directional base station and a number of fixed devices.
- mobile WiMAX (IEEE 802.16e), allowed the devices to move and to hand over their communications from one base station to another.

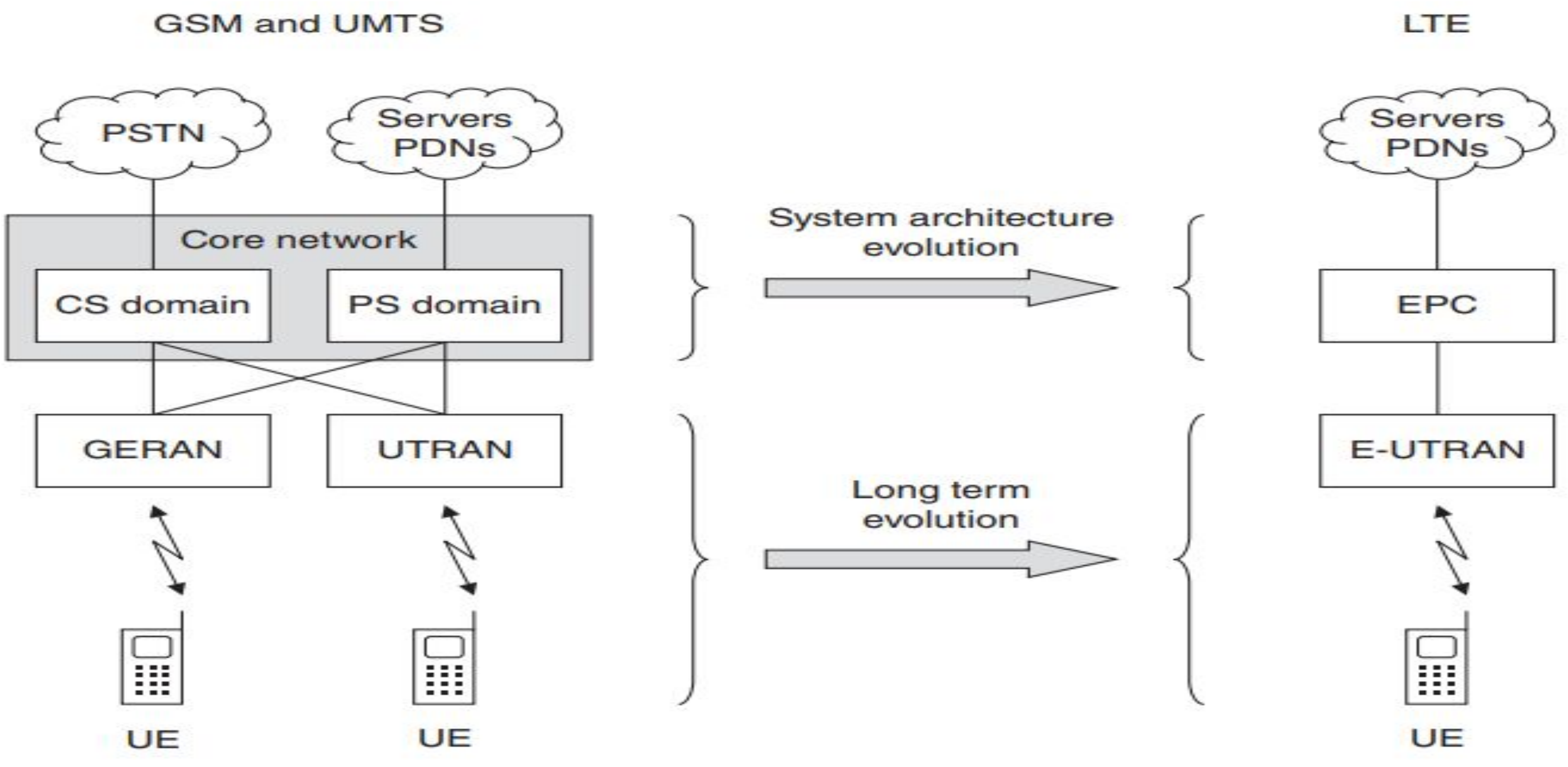


System
Performance
Smooth
Introduction of 4G
4G
LTE
Long-Term
Evolution
HSUPA
HSDPA
WCDMA R99
2000
2010

COMPARISON WITH OTHER MOBILE COMMUNICATIONS TECHNOLOGIES

	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE
Max downlink speed bps	384 k	14 M	28 M	100M
Max uplink speed bps	128 k	5.7 M	11 M	50 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

B) From UMTS to LTE



Evolution of the system architecture from GSM and UMTS to LTE

- In the new architecture, the evolved packet core (EPC) is a direct replacement for the packet switched domain of UMTS and GSM.
- There is no equivalent to the circuit switched domain, which allows LTE to be optimized for the delivery of data traffic, but implies that voice calls have to be handled using other techniques.
- The evolved UMTS terrestrial radio access network (E-UTRAN) handles the EPC’s radio communications with the mobile, so is a direct replacement for the UTRAN.

- The mobile is still known as the user equipment, though its internal operation is very different from before.
- The new architecture was designed as part of two 3GPP work items, namely system architecture evolution (SAE), which covered the core network, and long-term evolution (LTE), which covered the radio access network, air interface and mobile.
- Officially, the whole system is known as the evolved packet system (EPS), while the acronym LTE refers only to the evolution of the air interface. Despite this official usage, LTE has become a colloquial name for the whole system

Feature	WCDMA	LTE
Multiple access scheme	WCDMA	OFDMA and SC-FDMA
Frequency re-use	100%	Flexible
Use of MIMO antennas	From Release 7	Yes
Bandwidth	5 MHz	1.4, 3, 5, 10, 15 or 20 MHz
Frame duration	10 ms	10 ms
Transmission time interval	2 or 10 ms	1 ms
Modes of operation	FDD and TDD	FDD and TDD
Uplink timing advance	Not required	Required
Transport channels	Dedicated and shared	Shared
Uplink power control	Fast	Slow

Key features of the air interfaces of WCDMA and LTE

Key features of the radio access networks of UMTS and LTE

Feature	UMTS	LTE
Radio access network components	Node B, RNC	eNB
RRC protocol states	CELL_DCH, CELL_FACH, CELL_PCH, URA_PCH, RRC_IDLE	RRC_CONNECTED, RRC_IDLE
Handovers	Soft and hard	Hard
Neighbour lists	Always required	Not required

Key features of the core networks of UMTS and LTE

Feature	UMTS	LTE
IP version support	IPv4 and IPv6	IPv4 and IPv6
USIM version support	Release 99 USIM onwards	Release 99 USIM onwards
Transport mechanisms	Circuit & packet switching	Packet switching
CS domain components	MSC server, MGW	n/a
PS domain components	SGSN, GGSN	MME, S-GW, P-GW
IP connectivity	After registration	During registration
Voice and SMS applications	Included	External

The Need for LTE

1.The Growth of Mobile Data:

- For many years, voice calls dominated the traffic in mobile telecommunication networks. The growth of mobile data was initially slow, but its use started to increase dramatically.

2.Increasing the System Capacity:

- There are three ways of system capacity improvement namely cell splitting, increment in the bandwidth and improving the communication technology which is being used.
- The increasing use of mobile telecommunications has led to the increasing allocation of spectrum to 2G and 3G systems. However, there is only a finite amount of radio spectrum available.
- Thus progressive improvement is the main reason to develop LTE.

3.Using single core network

- 2G or 3G operator has to maintain two core networks. The circuit switched domain for voice, and the packet switched domain for data.
- Provided that the network is not too congested, however, it is also possible to transport voice calls over packet switched networks using techniques such as voice over IP (VoIP).
- By doing this, operators can move everything to the packet switched domain, and can reduce both their capital and operational expenditure.

4.Reduce the end-to-end delay

- 3G networks introduce delays of the order of 100 ms for data applications, in transferring data packets between network elements and across the air interface.
- This is barely acceptable for voice and causes great difficulties for more demanding applications such as real-time interactive games. Thus need to reduce the end-to-end delay, or latency, in the network.

5.Reducing complexity

- The specifications for UMTS and GSM have become increasingly complex over the years, due to the need to add new features to the system while maintaining backwards compatibility with earlier devices

LTE/SAE Requirements

1. Requirement on peak data rate:

- LTE was required to deliver a peak data rate of 100 Mbps in the downlink and 50 Mbps in the uplink. For comparison, the peak data rate of WCDMA, in Release 6 of the 3GPP specifications, is 14 Mbps in the downlink and 5.7 Mbps in the uplink.
- This requirement was exceeded in the eventual system, which delivers peak data rates of 300 Mbps and 75 Mbps respectively. These peak data rates can only be reached in idealized conditions, and are wholly unachievable in any realistic scenario.

2. Requirement on spectral efficiency :

- LTE was required to support a spectral efficiency three to four times greater than that of Release 6 WCDMA in the downlink and two to three times greater in the uplink.
- These peak data rates can only be reached in idealized conditions, and are wholly unachievable in any realistic scenario.

3.Requirement on Latency:

- The requirements state that the time taken for data to travel between the mobile phone and the fixed network should be less than 5 ms, provided that the air interface is uncongested.

- The mobile phones can operate in two states: an active state in which they are communicating with the network and a low-power standby state. The requirements state that a phone should switch from standby to the active state, after an intervention from the user, in less than 100 ms.

4. Requirements on coverage and mobility:

- LTE is optimized for cell sizes up to 5 km, works with degraded performance up to 30 km and supports cell sizes of up to 100 km. It is also optimized for mobile speeds up to 15 km h^{-1}, works with high performance up to 120 km h^{-1} and supports speeds of up to 350 km h^{-1}.

5. Requirement on bandwidth:

- Finally, LTE is designed to work with a variety of different bandwidths, which range from 1.4 MHz up to a maximum of 20 MHz.

Advantages of LTE

a) High throughput:

- High data rates can be achieved in both downlink as well as uplink. This causes high throughput.

b) Low latency:

- Time required to connect to the network is in range of a few hundred milliseconds and power saving states can now be entered and exited very quickly.

c) FDD and TDD in the same platform:

- Frequency Division Duplex (FDD) and Time Division Duplex (TDD), both schemes can be used on same platform.

d) Superior end-user experience:

- Optimized signaling for connection establishment and other air interface and mobility management procedures have further improved the user experience. Reduced latency (to 10 ms) for better user experience

e) Seamless Connection:

- LTE will also support seamless connection to existing networks such as GSM, CDMA and WCDMA.

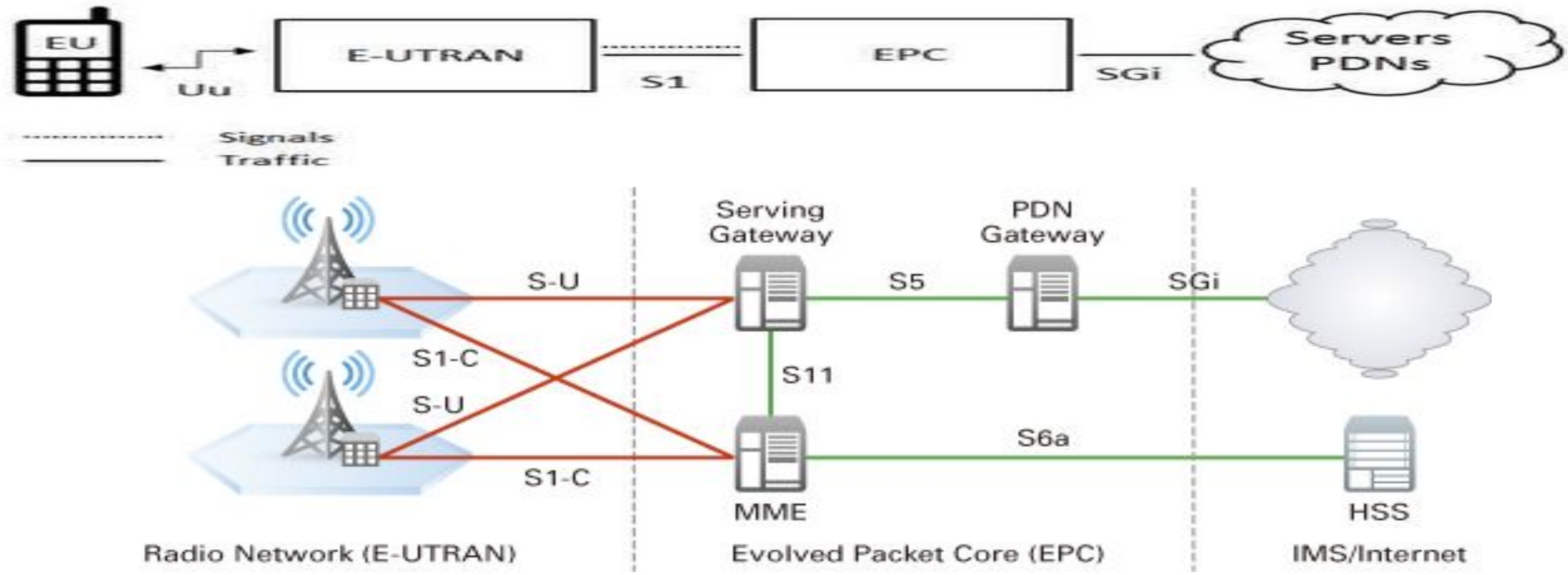
f)Plug and play:

- The user does not have to manually install drivers for the device. Instead system automatically recognizes the device, loads new drivers for the hardware if needed, and begins to work with the newly connected device.

g) Simple architecture:

- Because of Simple architecture low operating expenditure (OPEX).

System Architecture Evolution (SAE)



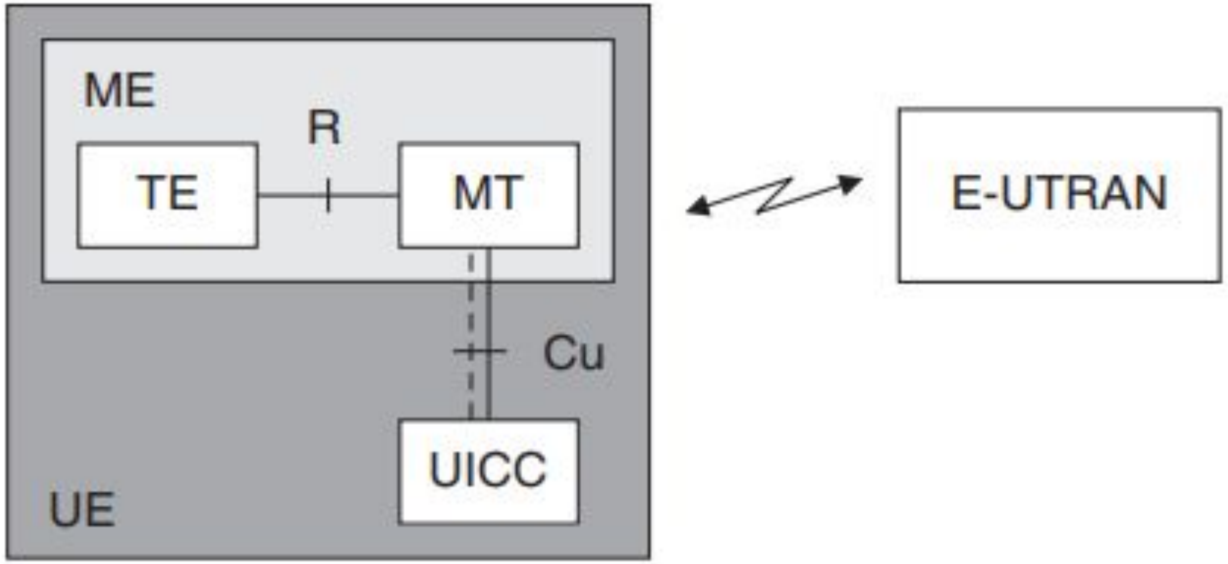
SAE (System Architecture Evolution)

- System Architecture Evolution (SAE) is a new network architecture designed to simplify LTE networks and establish a flat architecture similar to other IP based communications networks.
- SAE uses an eNB and Access Gateway (aGW) and removes the RNC and SGSN from the equivalent 3G network architecture to create a simpler mobile network.
- This allows the network to be built with an “All-IP” based network architecture.
- SAE also includes entities to allow full inter-working with other related wireless technology (WCDMA, WiMAX, WLAN, etc.).
- These entities can specifically manage and permit the non-3GPP technologies to interface directly with the network and be managed from within the same network.

- The high-level network architecture of LTE is comprised of following three main components:

1. The User Equipment (UE).
2. The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).
3. The Evolved Packet Core (EPC).

1.The User Equipment (UE)



Internal architecture of the UE.

The internal architecture of the user equipment for LTE is identical to the one used by UMTS and GSM which is actually a Mobile Equipment (ME). The mobile equipment comprised of the following important modules:

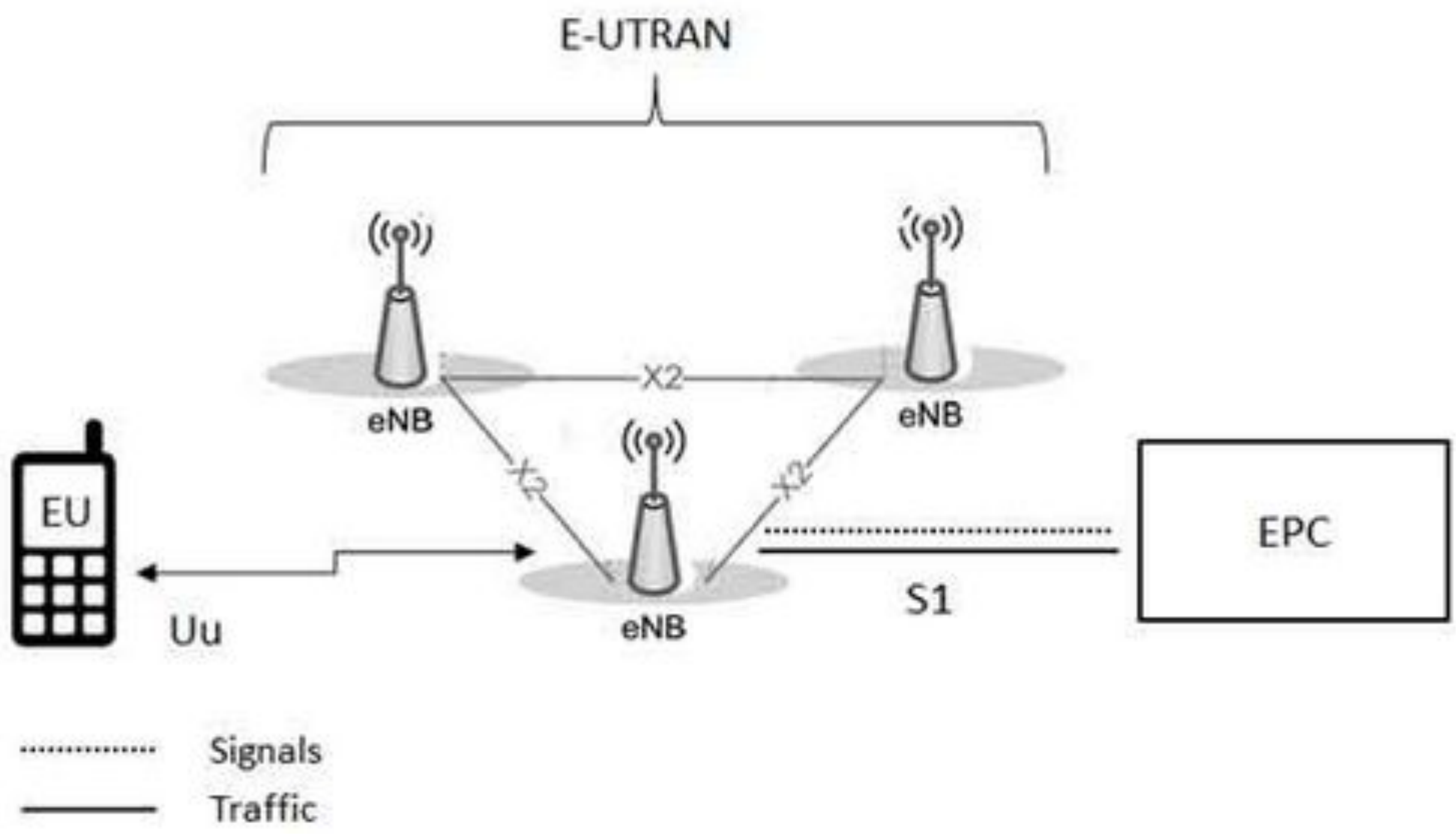
- **Mobile Termination (MT)** : This handles all the communication functions.
- **Terminal Equipment (TE)** : This terminates the data streams.
- **Universal Integrated Circuit Card (UICC)** : This is also known as the SIM card for LTE equipments. It runs an application known as the Universal Subscriber Identity Module (USIM).
- A **USIM** stores user-specific data very similar to 3G SIM card. This keeps information about the user's phone number, home network identity and security keys etc

2.The E-UTRAN (The access network)

- The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved base stations, called **eNodeB** or **eNB**. Each eNB is a base station that controls the mobiles in one or more cells. The base station that is communicating with a mobile is known as its serving eNB.
- There are following two main functions supported by eNB:

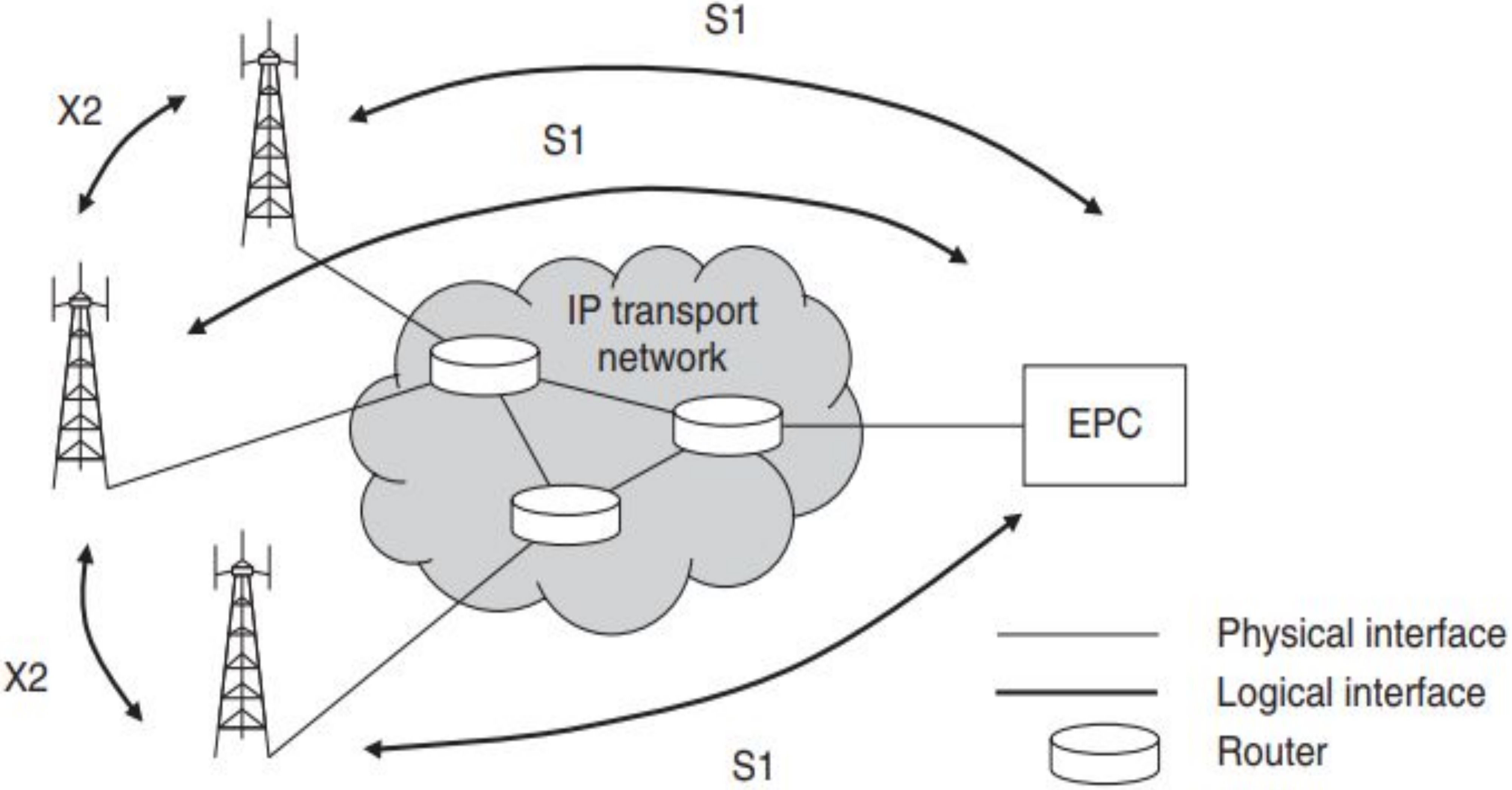
a) The eBN sends and receives radio transmissions to all the mobiles using the analogue and digital signal processing functions of the LTE air interface.

b) The eNB controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands.



Architecture of the evolved UMTS terrestrial radio access network

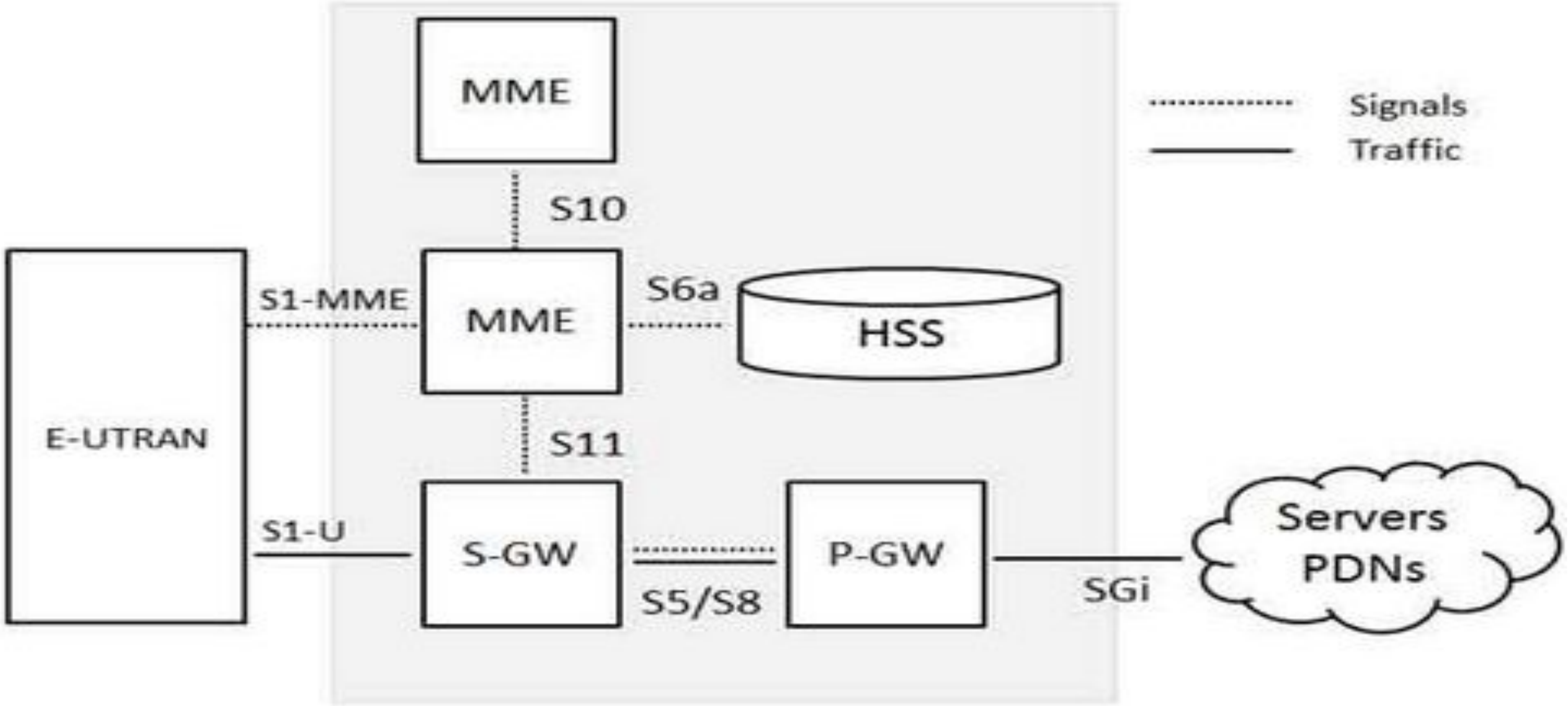
- Each eBN connects with the EPC by means of the S1 interface and it can also be connected to nearby base stations by the X2 interface, which is mainly used for signalling and packet forwarding during handover.
- A home eNB (HeNB) is a base station that has been purchased by a user to provide femtocell coverage within the home.
- A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber group.
- A mobile’s list of closed subscriber groups is stored by the USIM and can be downloaded from a device management server that is controlled by the network operator.
- Home eNBs have lower power limitations than normal base stations, can control only one cell.



Internal architecture of the E-UTRAN transport network

- Usually, the S1 and X2 interfaces are not direct physical connections,
- Each base station and each component of the core network has an IP address, and the underlying routers use those IP addresses to transport data and signaling messages from one device to another.
- On the S1 interface, a home eNB can communicate with the evolved packet core either directly or through a device known as a home eNB gateway that shields the EPC from the potentially huge numbers of home eNBs.
- The S1 data and signaling messages are transported by the consumer’s internet service provider rather than by the network operator,

3. The Evolved Packet Core (EPC) (The core network)



Main components of the evolved packet core

- **The Home Subscriber Server (HSS)**
  - This component has been carried forward from UMTS and GSM and is a central database that contains information about all the network operator's subscribers.
- **MME (Mobility Management Entity):**

a) The MME is an important controller node in the LTE network. It is responsible for:

b) Idle mode UE (User Equipment) tracking

c) Paging procedure such as re-transmissions

d) Bearer activation and deactivation process

e) S-GW selection for a UE at the initial attach

f) Intra-LTE handover with Core Network node relocation

g)User authentication with HSS.

h) When the signaling of Non-Access Stratum (NAS) terminates at the MME, it generates and allocates temporary identities to Ues.

i) It is also responsible for the enforcement of UE roaming restrictions.
J) The MME handles the ciphering/integrity protection for NAS signaling and the security key management.

k) It supports lawful interception of signaling, and the control plane function for mobility between LTE and legacy networks with the S3 interface.

l)The S6a interface connects the MME to the HSS for roaming UEs.

•SGW (Serving Gateway):

- The main function of the Serving Gateway is routing and forwarding of user data packets.
- It is also responsible for inter-eNB handovers in the U-plane and provides mobility between LTE and other types of networks, such as between 2G/3G and P-GW.
- The DL data from the UEs in idle state is terminated at the SGW, and arrival of DL data triggers paging for the UE.
- The SGW keeps context information such as parameters of the IP bearer and routing information, and stores the UE contexts when paging happens.
- It is also responsible for replicating user traffic for lawful interception.

•PGW (PDN Gateway):

- The PDN Gateway is the connecting node between UEs and external networks. It is the entry point of data traffic for UEs. In order to access multiple PDNs, UEs can connect to several PGWs at the same time.
- The functions of the PGW include:

a) Policy enforcement

b) Packet filtering

c) Charging support

d) Lawful interception

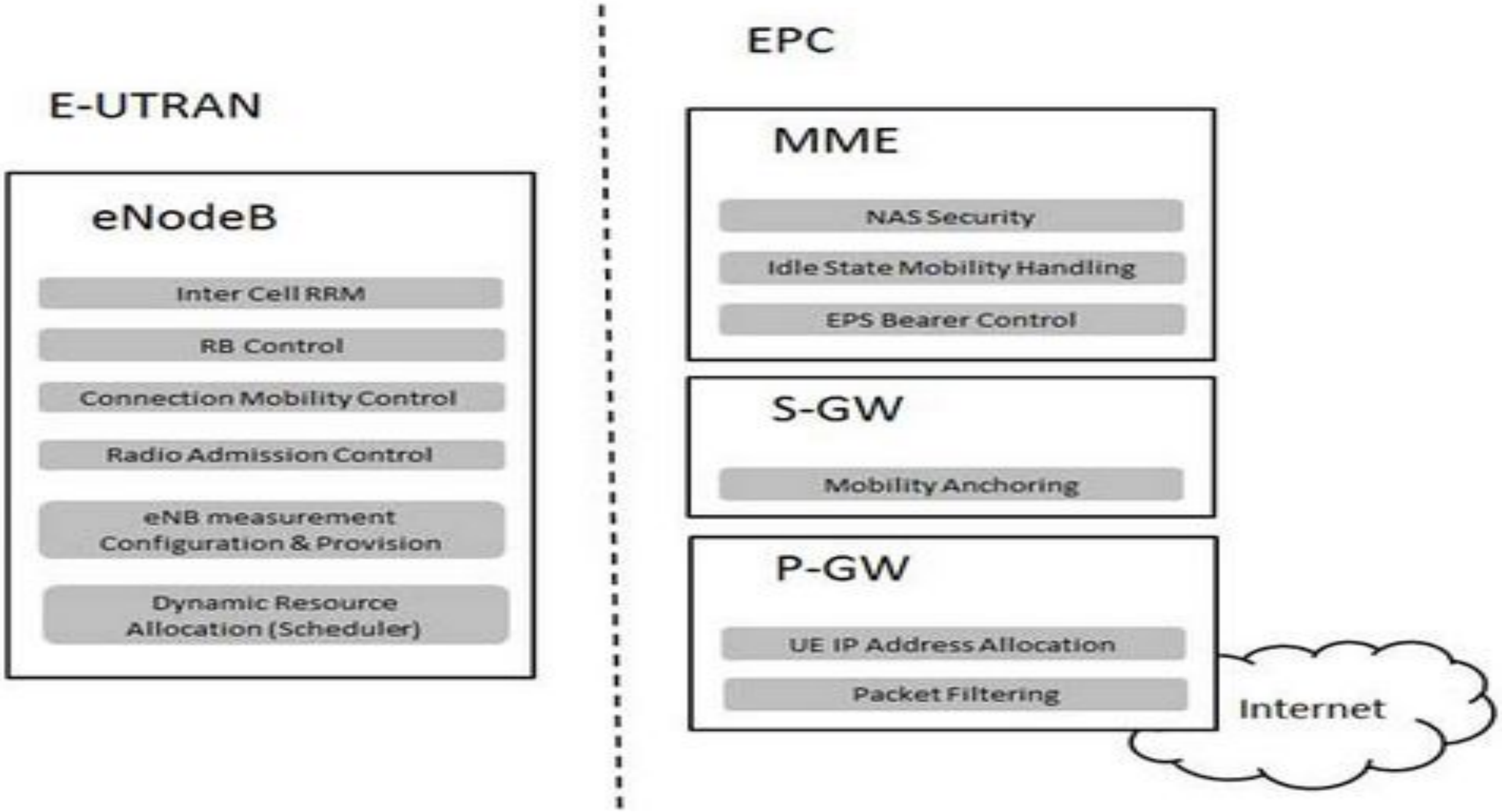
e) Packet screening

- Another important role of the PGW is to provide mobility between 3GPP and non-3GPP networks. For example, mobility between WiMAX and 3GPP2 or between CMDA 1X and EVDO are supported by the PGW.

- There are few more components which have not been shown in the diagram to keep it simple. These components are like the Earthquake and Tsunami Warning System (ETWS), the Equipment Identity Register (EIR) and Policy Control and Charging Rules Function (PCRF).
- The Policy Control and Charging Rules Function (PCRF) is a component which is not shown in the above diagram but it is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.
- The interface between the serving and PDN gateways is known as S5/S8. This has two slightly different implementations, namely S5 if the two devices are in the same network, and S8 if they are in different networks.

Functional split between the E-UTRAN and the EPC

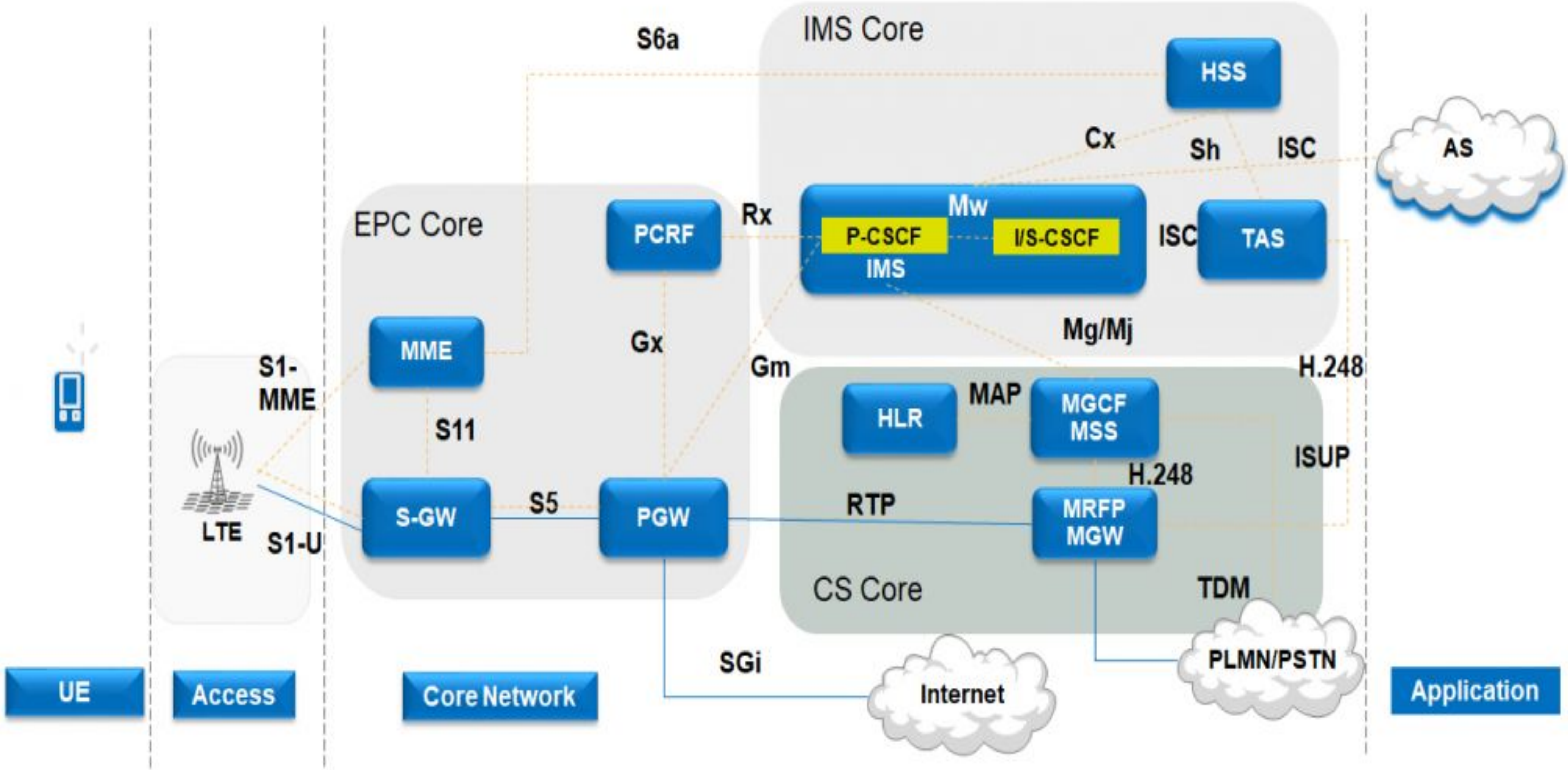
Following diagram shows the functional split between the E-UTRAN and the EPC for an LTE network:



Voice over LTE (VoLTE)

- The evolved packet core is designed as a data pipe that simply transports information to and from the user; it is not concerned with the information content or with the application.
- This is similar to the behavior of the internet, which transports packets that originate from any application software, but is different from that of a traditional circuit switched network in which the voice application is an integral part of the system.
- Because of this issue, voice applications do not form an integral part of LTE. However, an LTE mobile can still make a voice call using two main techniques.
- The first is circuit switched fallback, in which the network transfers the mobile to a legacy 2G or 3G cell so that the mobile can contact the 2G/3G circuit switched domain.
- The second is by using the IP multimedia subsystem (IMS), an external network that includes the signalling functions needed to set up, manage and tear down a voice over IP call

VoLTE Network Architecture



- The IP Multimedia Subsystem or IP Multimedia Core Network Subsystem, IMS is an architectural framework for delivering Internet Protocol, IP multimedia services.
- It enables a variety of services to be run seamlessly rather than having several disparate applications operating concurrently.

Entities within the reduced IMS network used for VoLTE:

- ***IP-CAN IP, Connectivity Access Network:*** This consists of the EUTRAN and the MME.
- ***P-CSCF, Proxy Call State Control Function:*** The P-CSCF is the user to network proxy. In this respect all SIP signalling to and from the user runs via the P-CSCF whether in the home or a visited network.
- ***I-CSCF, Interrogating Call State Control Function:*** The I-CSCF is used for forwarding an initial SIP request to the S-CSCF. When the initiator does not know which S-CSCF should receive the request

- ***S-CSCF, Serving Call State Control Function:*** The S-CSCF undertakes a variety of actions within the overall system, and it has a number of interfaces to enable it to communicate with other entities within the overall system.
- ***AS, Application Server:*** It is the application server that handles the voice as an application.
- **H*SS, Home Subscriber Server:*** The IMS HSS or home subscriber server is the main subscriber database used within IMS. The IMS HSS provides details of the subscribers to the other entities within the IMS network, enabling users to be granted access or not dependent upon their status.

- The IMS calls for VoLTE are processed by the subscriber’s S-CSCF in the home network. The connection to the S-CSCF is via the P-CSCF.
- Dependent upon the network in use and overall location within a network, the P-CSCF will vary, and a key element in the enablement of voice calling capability is the discovery of the P-CSCF.
- An additional requirement for VoLTE enabled networks is to have a means to handing back to circuit switched legacy networks in a seamless manner, while only having one transmitting radio in the handset to preserve battery life. A system known as SRVCC – Single Radio Voice Call Continuity is required for this.

Advantages of VoLTE

- **High-quality voice calls**
- Traditional 2G and 3G networks use circuit-switched technology, which is less efficient than the packet-switched technology used in 4G LTE networks. This means that voice calls made over a 4G LTE network are generally clearer and more reliable than those made over a 2G or 3G network. Additionally, VoLTE supports a wide range of codecs, which allows for even higher-quality calls.
- **Faster call setup times**
- Traditional 2G and 3G networks require separate signaling and voice channels, which can take several seconds to establish a call. With VoLTE, the signaling and voice channels are combined into a single channel, which allows for much faster call setup times. This means that users can place and answer calls more quickly, which can be particularly useful in emergency situation

- **Multi-tasking capabilities**
- VoLTE also allows users to multi-task while on a call. Traditional 2G and 3G networks use circuit-switched technology, which means that the user's data connection is temporarily suspended while they are on a call. With VoLTE, the data connection is not suspended, which means that users can continue to use data services such as browsing the internet or sending text messages while on a call.
- **Bettery coverage**
- VoLTE also offers better coverage than traditional 2G and 3G networks. The 4G LTE network is generally more extensive and has a higher capacity than the 2G and 3G networks. This means that users are more likely to have a reliable voice call connection in areas where traditional 2G and 3G networks might have poor coverage.

- **Enhanced features**
- VoLTE also offers several enhanced features that are not available on traditional 2G and 3G networks. For example, VoLTE supports high-definition (HD) voice calls, which provide a more natural and realistic voice quality. Additionally, VoLTE supports video calls, which allow users to see and hear each other in real-time. These enhanced features can be useful in both personal and business situations.

Disadvantages of VoLTE

- **Limited device compatibility**
- One of the biggest disadvantages of VoLTE is that it is not compatible with all devices. Currently, only a limited number of smartphones support VoLTE, and many older devices may not be compatible with the technology. This means that users who want to take advantage of the benefits of VoLTE will need to purchase a new device, which can be expensive

- **Limited network availability**
- Another disadvantage of VoLTE is that it is not yet widely available. Currently, only a few mobile operators have deployed VoLTE networks, and even in those areas, coverage may be limited. This means that users may not be able to take advantage of the benefits of VoLTE in their local area.
- **Battery drain**
- VoLTE can also have a negative impact on battery life. VoLTE uses more power than traditional 2G and 3G networks, which can cause a significant drain on the device's battery. This is because VoLTE uses a more complex signaling process, which requires more power to function. Additionally, the use of data services while on a call can also contribute to battery drain. Users who frequently make long VoLTE calls may need to carry an extra battery or a power bank to ensure that their device stays charged.

- **Higher data usage**
- VoLTE also requires a higher data usage than traditional 2G and 3G networks. This is because VoLTE uses packet-switched technology, which requires more data to transmit the same amount of information. This means that users who frequently make VoLTE calls may need to purchase a higher data plan to ensure that they do not exceed their data usage limit.
- **Interoperability issues**
- Finally, VoLTE also has some interoperability issues. VoLTE uses a different signaling protocol than traditional 2G and 3G networks, which means that calls made between different mobile operators or networks may not be fully compatible. Additionally, VoLTE calls may not be able to connect to traditional 2G and 3G networks, which can be problematic in areas where 4G LTE coverage is limited.

Introduction to LTE-Advanced

- Release 10 enhances the capabilities of LTE, to make the technology compliant with the International Telecommunication Union’s requirements for IMT-Advanced. The resulting system is known as LTE-Advanced.
- 3GPP continued development of the LTE standard, finalizing Release 10 in September 2011. LTE-Advanced, or LTE-A focused on improving network capacity.
- LTE-A is often informally referred to as a "4.5G" network.
- LTE Release 10 (LTE-Advanced) provided the following technological enhancements:

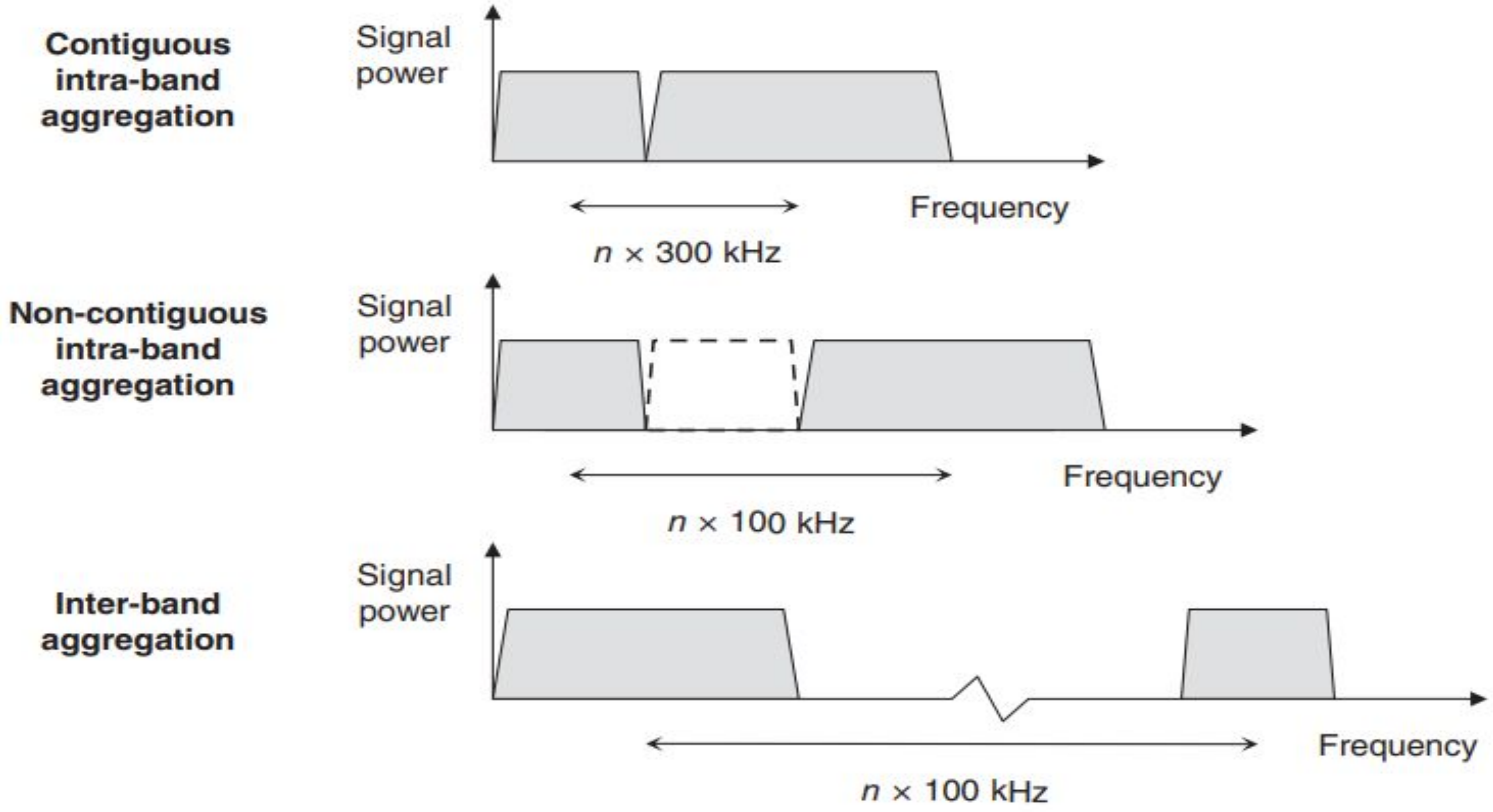
1. Increased peak data rate, DL 3 Gbps, UL 1.5 Gbps
2. Higher spectral efficiency, from 16 bps/Hz with 4X4 MIMO to 30 bps/Hz with 8X8 MIMO
3. Increased number of simultaneously active subscribers
4. Improved performance at cell edges, e.g. for DL 2X2 MIMO at least 2.40 bps/Hz/cell
5. Up to 5 Component carrier aggregation (100 MHz total bandwidth)
6. LTE Supplemental Downlink (SDL)

LTE-A Functionality

- The key new functionalities introduced were Carrier Aggregation (CA), enhanced use of multi-antenna techniques, and support for Relay Nodes (RN).

1. Carrier Aggregation (CA)

- The ultimate goal of LTE-Advanced is to support a maximum bandwidth of 100 MHz. This is an extremely large bandwidth, which is most unlikely to be available as a contiguous allocation in the foreseeable future.
- To deal with this problem, LTE-Advanced allows a mobile to transmit and receive on up to five component carriers (CCs), each of which has a maximum bandwidth of 20 MHz. This technique is known as carrier aggregation (CA)



Carrier aggregation scenarios

- There are three scenarios

1. in contiguous intra-band aggregation the carriers are in the same band and are adjacent to each other.
2. In non-contiguous intra-band aggregation, the carriers are in the same band,
3. In inter-band aggregation, the component carriers are located in different frequency bands and are separated by a multiple of 100 kHz, which is the usual LTE carrier spacing.

- In FDD mode, the allocations on the uplink and downlink can be different, but the number of downlink component carriers is always greater than or equal to the number used on the uplink.
- In TDD mode, each component carrier must have the same TDD configuration in Release 10.

- Carrier aggregation only affects the physical layer and the MAC protocol on the air interface, and the RRC, S1-AP and X2-AP signaling protocols. There is no impact on the RLC or PDCP and no impact on data transport in the fixed network.
- Carrier aggregation does not affect data transmission in the downlink, but it does lead to some changes in the uplink.
- In Release 8, a mobile uses SC-FDMA, which assumes that the mobile is transmitting on a single contiguous block of sub-carriers.
- In Release 10, this assumption is no longer valid: instead, the mobile uses a more general technique known as discrete Fourier transform spread orthogonal frequency division multiple access (DFT-S-OFDMA).
- This multiple access technique is the same as SC-FDMA, except that it supports transmission on a non-contiguous allocation of sub-carriers.

2.Enhanced Downlink MIMO

- Release 10 extends LTE’s support for downlink multiple antenna transmission using a new technique known as eight layer spatial multiplexing.
- The technique has three main objectives.

a) Firstly, it supports single user MIMO transmissions with a maximum of eight layers.

b) Secondly, it supports multiple user MIMO transmissions to a maximum of four mobiles and includes the accurate feedback that MU-MIMO requires.

c) Thirdly, it allows the base station to switch a mobile between the two techniques every subframe without the need for additional RRC signaling.

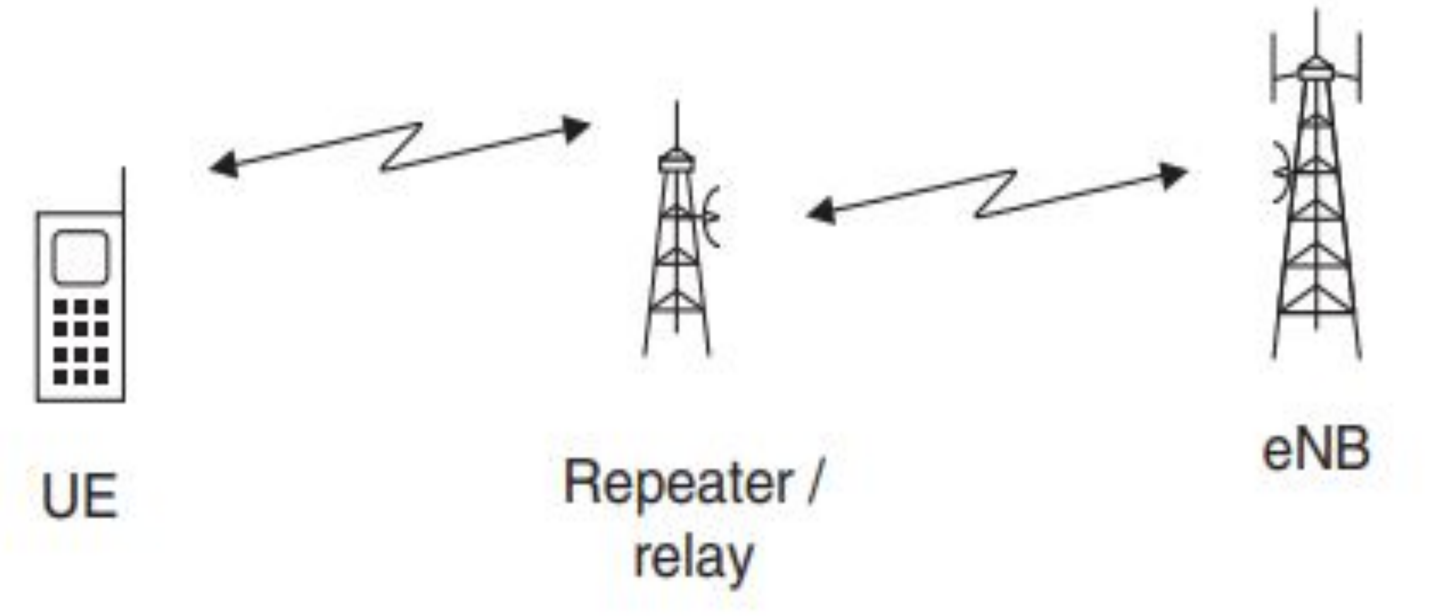
3. Enhanced Uplink MIMO

- In LTE-Advanced, the uplink is enhanced to support single user MIMO, using up to four transmit antennas and four transmission layers.
- The mobile declares how many layers it supports as part of its uplink capabilities.
- The peak uplink data rate in Release 10 is 600 Mbps. This is eight times greater than in Release 8, and results from the use of four transmission layers and two component carriers.
- Eventually, LTE should support a peak uplink data rate of 1500 Mbps, through the use of five component carriers

4.Relays

- Repeaters and relays are devices that extend the coverage area of a cell.
- They are useful in sparsely populated areas in which the performance of a network is limited by coverage rather than capacity.

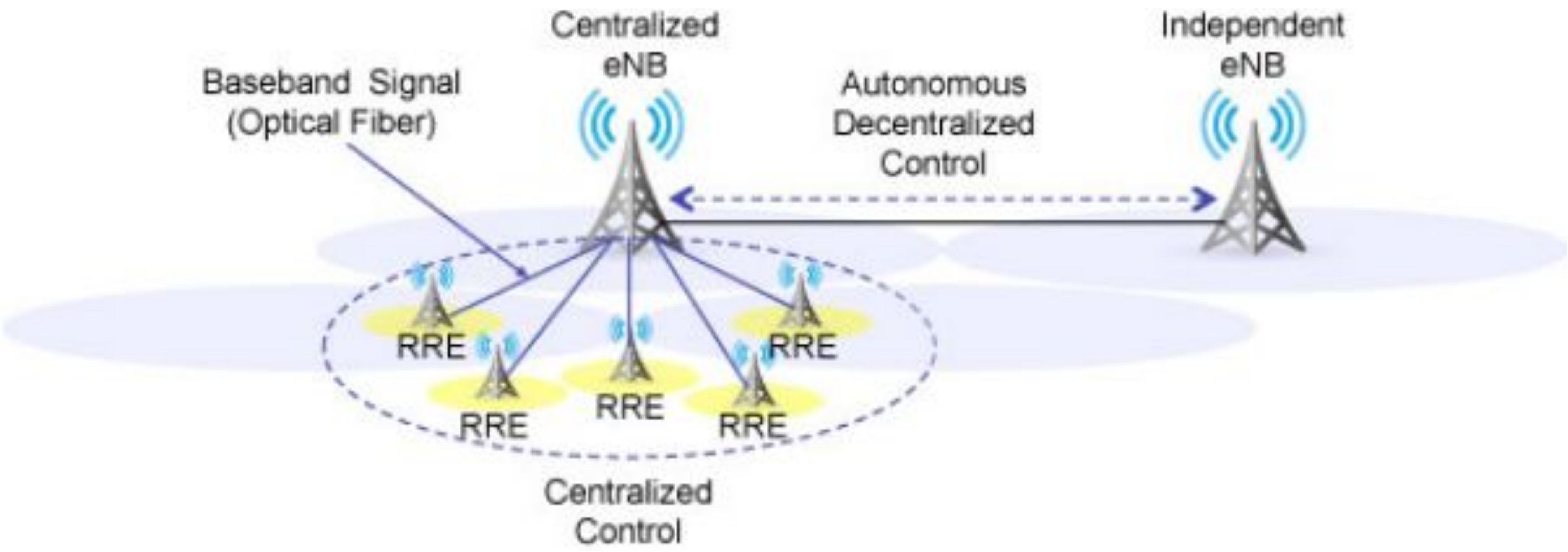
- They can also increase the data rate at the edge of a cell, by improving the signal-to-interference plus noise ratio there.
- A repeater receives a radio signal from the transmitter, and amplifies and rebroadcasts it, so appears to the receiver as an extra source of multipath.
- Unfortunately the repeater amplifies the incoming noise and interference as well as the received signal, which ultimately limits its performance.
- FDD repeaters were fully specified in Release 8, with the sole specification referring to the radio performance requirements.
- TDD repeaters are harder to implement, because of the increased risk of interference between uplink and downlink.



- A relay takes things a step further, by decoding the received radio signal, before re-encoding and rebroadcasting it.
- By doing this, it removes the noise and interference from the retransmitted signal, so can achieve a higher performance than a repeater.
- Relays are first specified in Release 10, for both FDD and TDD modes

5. CoMP Techniques

- Coordinated Multi-Point transmission/reception (CoMP) is a DL/UL technique for improving system capacity and cell edge user throughput.
- Currently, there are two different approaches for CoMP .

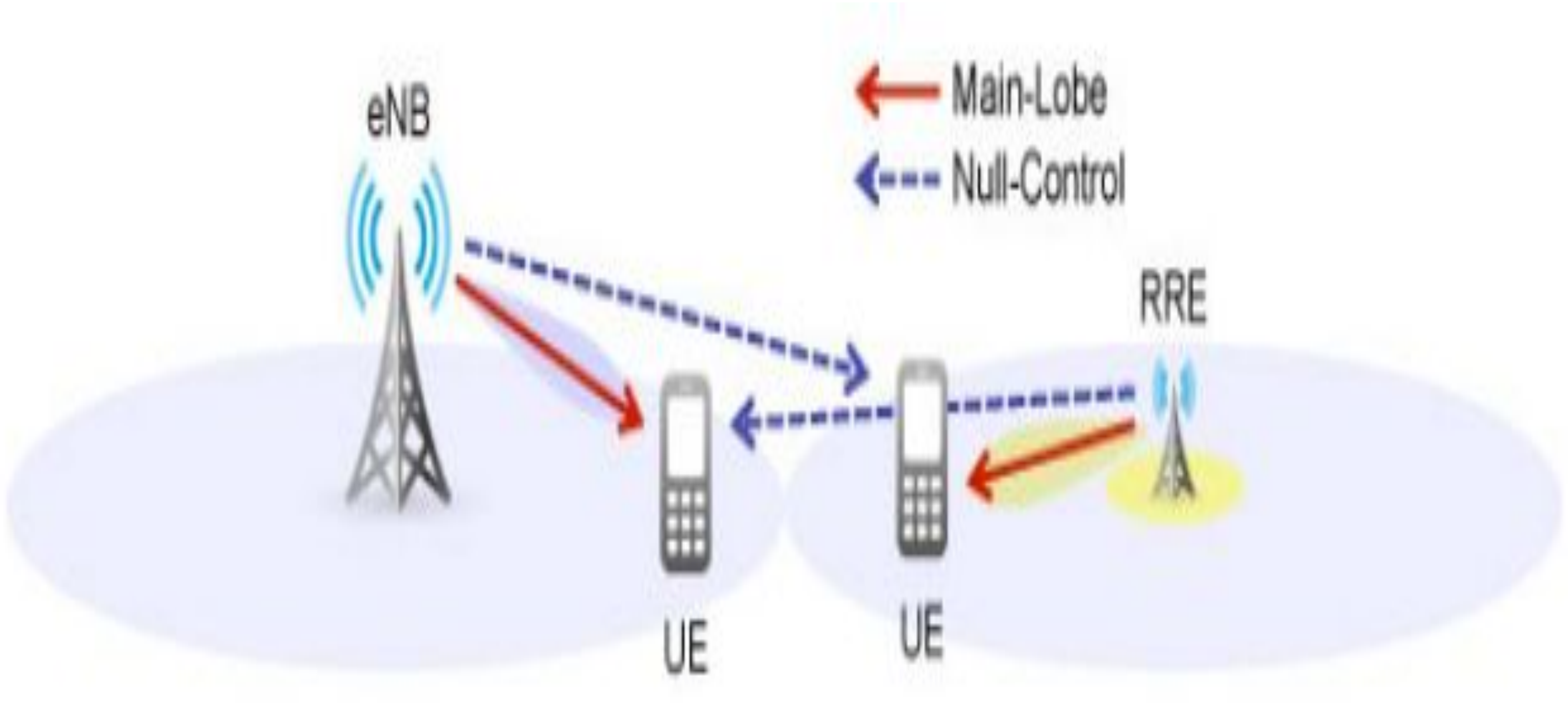


Centralized/Autonomous Decentralized Control

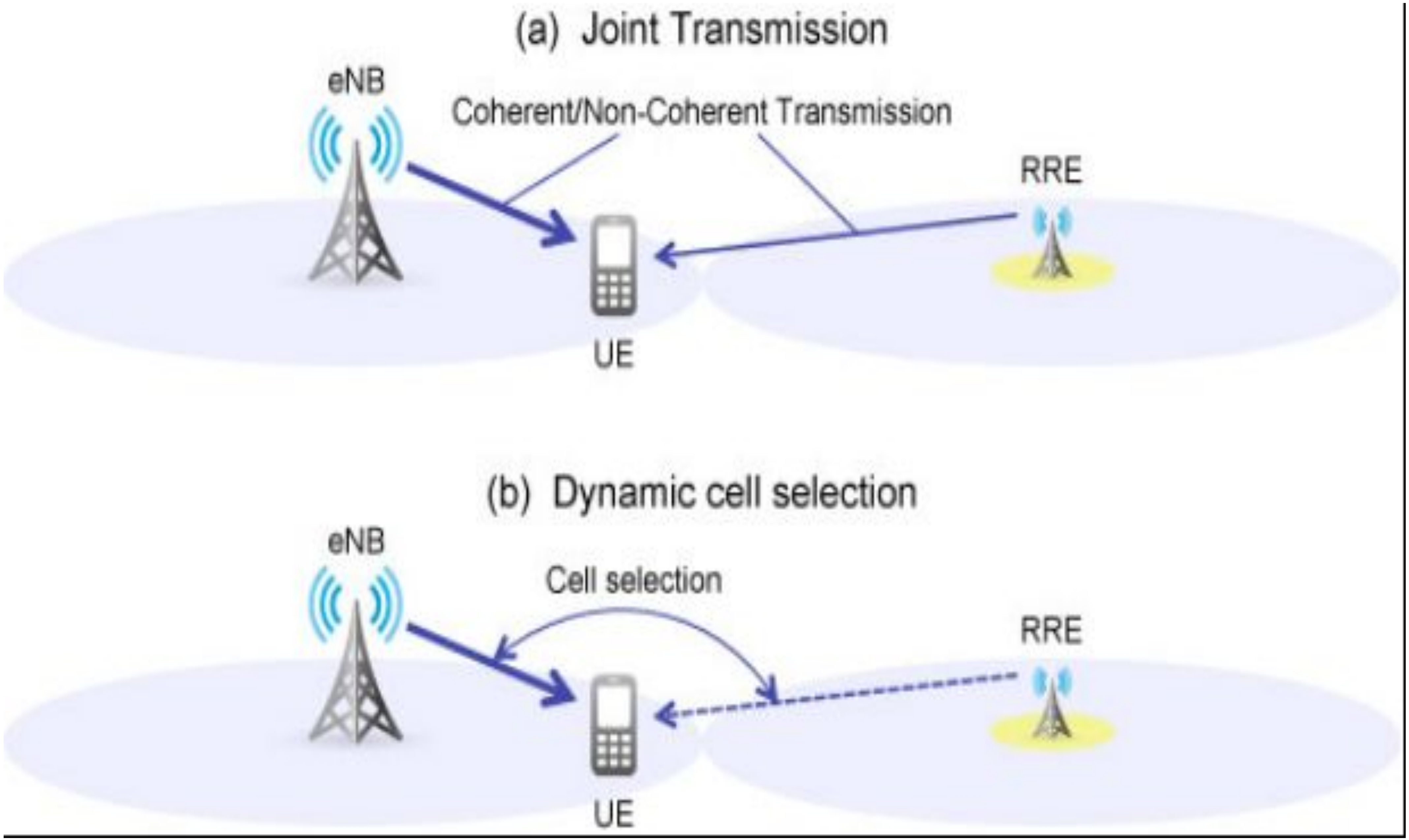
- One approach uses autonomous, decentralized control and an architecture with independent eNBs.
- In the approach with independent eNB architecture, CoMP is performed by signaling between eNBs. This technique can utilize legacy cells, but the disadvantages include signaling delay and other overheads.
- The second approach uses centralized control and an architecture based on Remote Radio Equipment (RRE).
- In the second approach that integrates RRE, the eNB can centralize and control all radio resources by transmitting baseband data directly between the eNB and RRE on optical fiber connections. There is little signaling delay or other overheads in this technique, and intra-cell radio resource control is relatively easy.

Downlink CoMP

Downlink CoMP also has two approaches under consideration for LTE-Advanced: Coordinated Scheduling/Beamforming (CS/CB) and Joint Processing.



- In CS/CB, transmission, the scheduling of transmissions is dynamically coordinated between the cells, including any beamforming functionality.
- In principle, schedule optimization will be based on the set of users being served, so that the transmitter beams are constructed to reduce interference with other neighboring users while increasing the served users' signal strength.

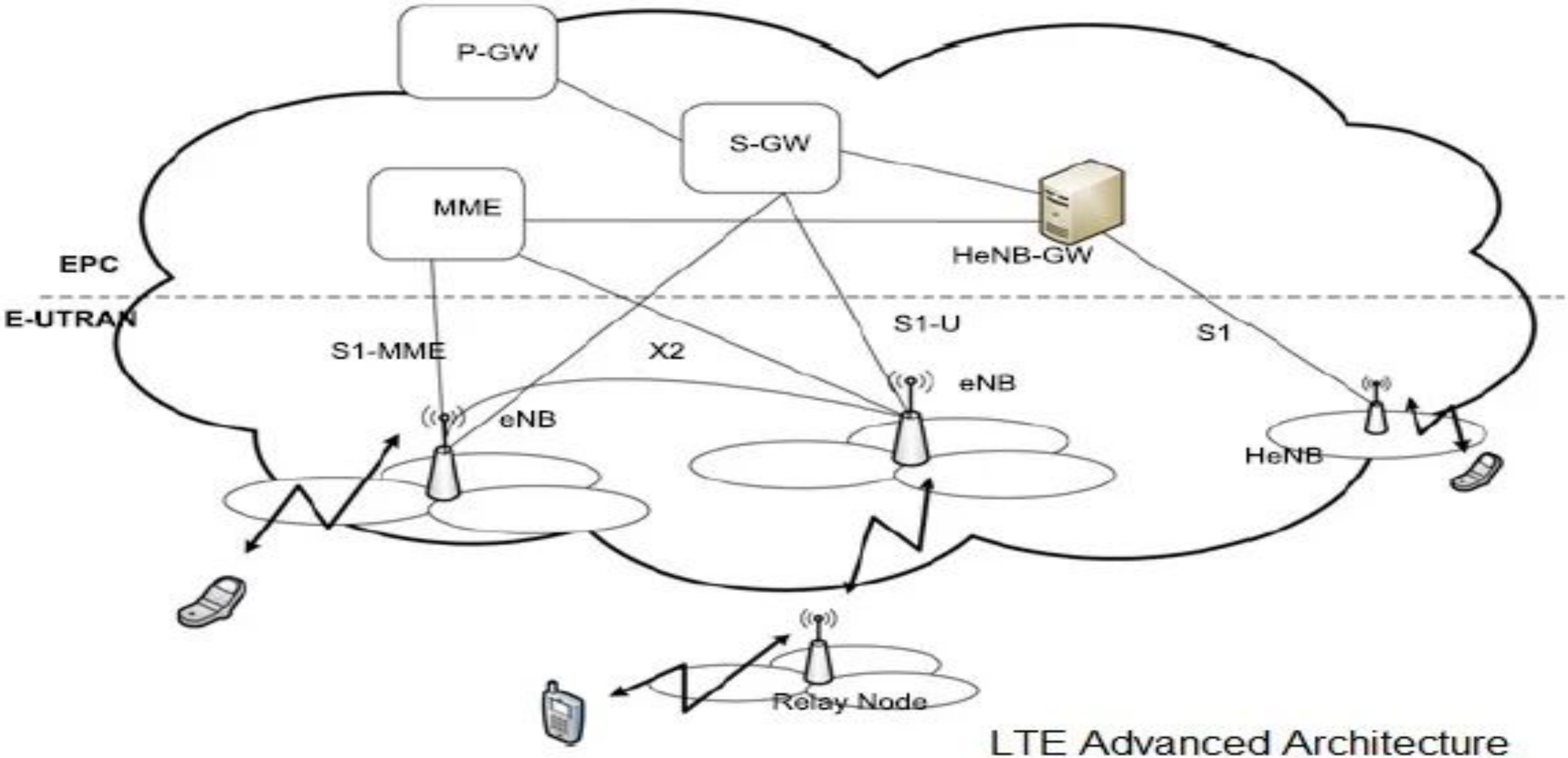

(a) Joint Transmission
eNB
Coherent/Non-Coherent Transmission
RRE
UE
(b) Dynamic cell selection
eNB
Cell selection
RRE
UE

- In Joint Processing, the Joint Transmission scheme transmits data to a single UE simultaneously from multiple transmission points.
- The multi-point transmissions will be coordinated as a single transmitter with multiple antennas that are geographically separated.
- This scheme offers potentially higher performance gains compared to CS/CB, but also places a high signaling overhead on the network.

Uplink CoMP

- Uplink CoMP uses geographically separated antennas for receiving signals from UEs, and scheduling decisions are coordinated by multiple cells to control interference.
- The UE is not aware that multiple cells are receiving its signal, so the impact on radio interface specifications is minimal.

LTE Advanced Architecture



LTE Advanced Architecture

- The figure depicts LTE Advanced (LTE-A) Architecture consisting of P-GW, S-GW, MME, S1-MME, eNB, HeNB, HeNB-GW and Relay Node etc.
- Following are the functions of these architecture entities.

1. **P-GW**:

- It stands for PDN Gateway. It interfaced with S-GW using S5 interface and with operator's IP services using SGi interface. It has connectivity with PCRP using Gx interface. It connects UE to packet data networks. P-GW assigns IP address to the UE. One UE can have connectivity with more than one PGWs in order to have access to multiple PDNs. It takes care of packet filtering, policy enforcement and charging related services. Moreover it fulfills connectivity between 3GPP (LTE, LTE-A) and non 3GPP (WiMAX, CDMA etc.) technologies.

2.S-GW:

- It stands for Serving Gateway. It interfaces with MME using S11 interface and with SGSN using S4 interface. It connects with PDN-GW using S5 interface.
- EPC gets terminated at this node/entity. It is connected with E-UTRAN via S1-U interface.
- Each UE in LTE-A is associated to unique S-GW which has several functions. It helps in inter-eNB handover as well as inter-3GPP mobility. It helps in inter-operator charging.
- It does packet routing and packet forwarding.

3.**MME**:

- It stands for Mobility Management Entity. It is major control plane element in LTE advanced architecture.
- It takes care of authentication, authorization and NAS signaling related security functions. It takes care of selecting either S-GW or PDN-GW or P-GW.

4. S1-MME:

- It provides connectivity between EPC and eNBs.

5. eNB:

- It is main building block or system in LTE-A. It provides interface with UEs or LTE-A phones. It has similar functionality as base station used in GSM or other cellular systems.
- Each of the eNBs serve one or several E-UTRAN cells. Interface between two eNBs is known as X2 interface.

6. HeNB:

- It stands for Home eNodeB or Home eNB. It is known as Femtocell. It is used to improve coverage in the indoor region of office or home premises. It can be interfaced directly to EPC or via Gateway.

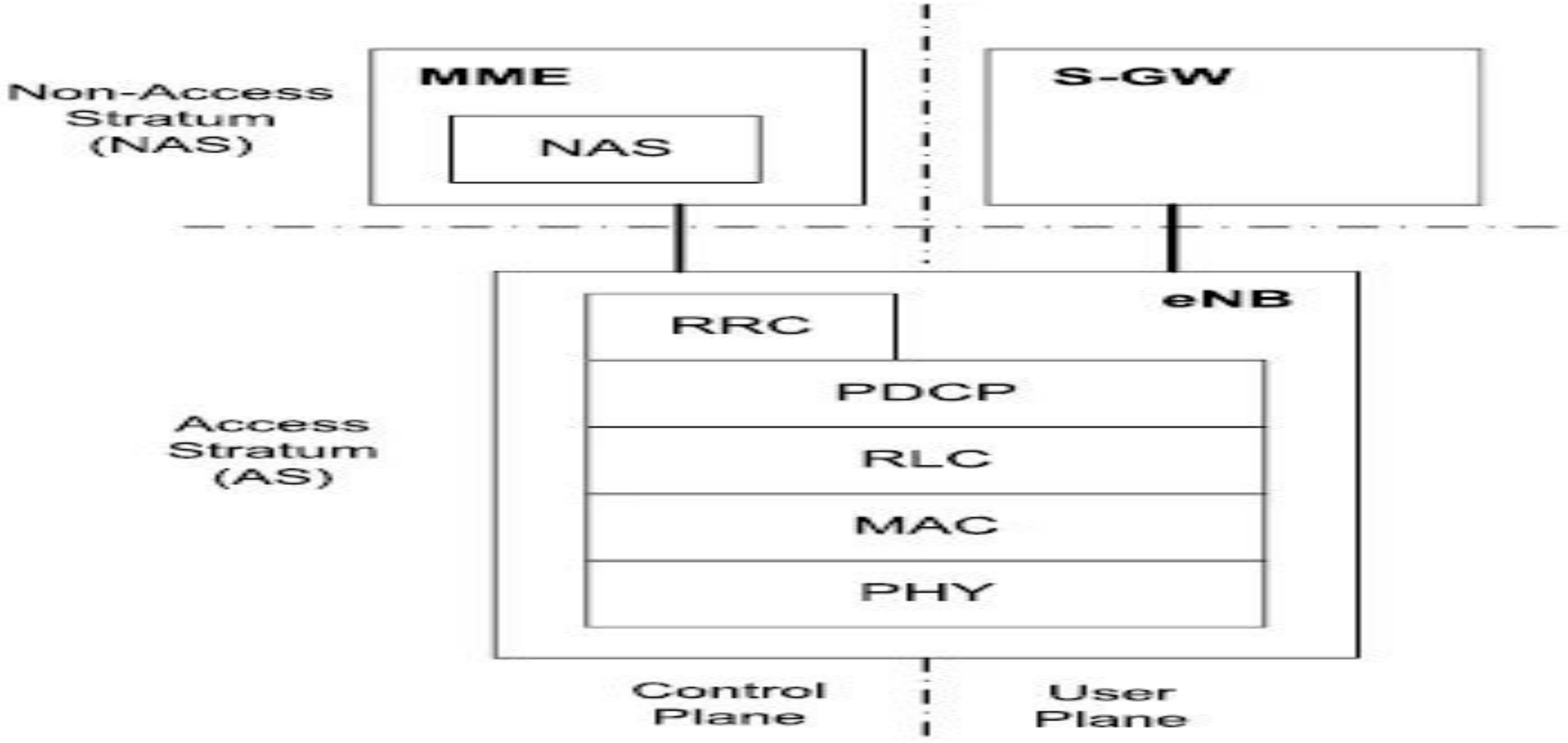
7.HeNB-GW:

It provides connectivity of HeNB with S-GW and MME. It aggregates all the traffic from number of Home eNBs to core network. It uses S1 interface to connect with HeNBs.

8.Relay Node:

It is used for improving network performance

LTE Advanced Protocol Stack



LTE Advanced Protocol Stack

- LTE Advanced protocol stack is divided into two main parts viz. NAS (Non-Access Stratum) and AS (Access Stratum).
- Further it is categorized into control plane and user plane. User plane of eNB consists of PHY, MAC, RLC and PDCP layers. Control plane of eNB consists of these 4 layers and in addition houses RRC layer also.
- Following are functions of these LTE Advanced protocol stack layers.
- **PHY** :
- This layer takes care of frame formation as per TDD or FDD topology and as per OFDMA structure based on BW/FFT. Moreover it takes care of modulation and coding of different control and traffic channels.
- It covers scrambling and codeword to layer mapping functionalities. It incorporates reference signals which are used for channel estimation and channel equalization.

MAC-Medium Access Control :

- It takes care of following functions:
  -Multiplexing/demultiplexing of RLC Packet Data Units (PDUs).
  -Scheduling information reporting.
  -Error correction through Hybrid ARQ (HARQ).
  -Local Channel Prioritization.
  -Padding.

RLC-Radio Link Control :

-Error correction through Automatic Repeat reQuest (ARQ).
-Segmentation according to the size of the transport block and re-segmentation in case a retransmission is needed.
-Concatenation of SDUs for the same radio bearer.
-Protocol error detection and recovery.
-In-sequence delivery.

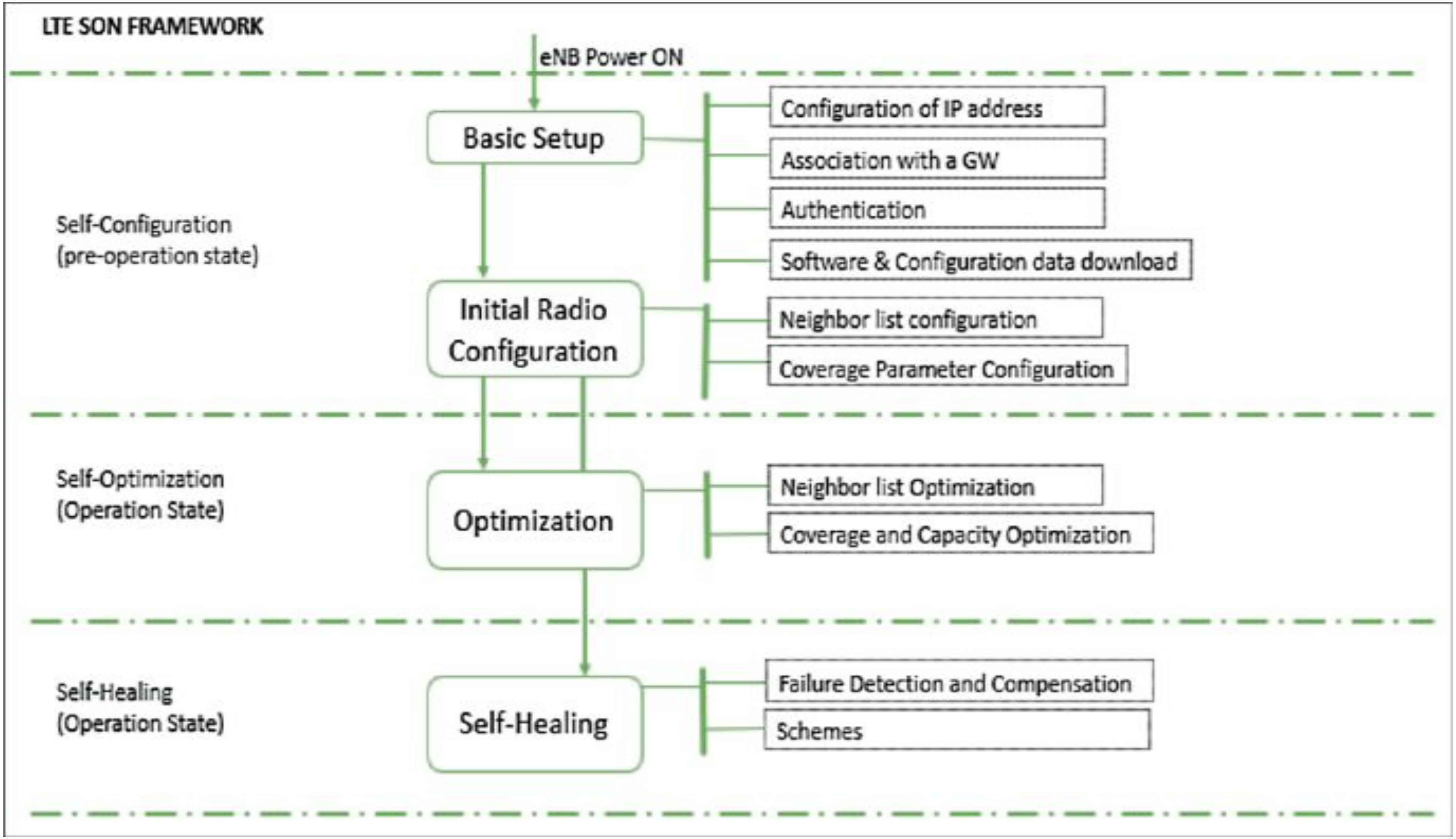
PDCP-Packet Data Convergence Protocol :
-Header compression.
-In-sequence delivery and retransmission of PDCP Session Data Units (SDUs) for acknowledge mode radio bearers at handover.
-Duplicate detection.
-Ciphering and integrity protection.

RRC-Radio Resource Control:
-Broadcast system information related to Non-Access Stratum (NAS) and Access Stratum (AS).
-Establishment, maintenance, and release of RRC connection.
-Security functions including key management.
-Mobility functions.
-QoS management functions.
-UE measurement reporting and control of the reporting.
-NAS direct message transfer between UE and NAS.

- **NAS-Non Access Stratum** :
  -Connection/session management between UE and the core network.
  -Authentication.
  -Registration.
  -Bearer context activation/deactivation.
  -Location registration management.

Self-Organizing Network (SON-LTE)

- Self-organizing networks are radio access networks (RANs) that automatically plan, configure, manage, optimize, and heal themselves. SONs can offer automated functions such as self-configuration, self-optimization, self-healing, and self-protection.
- These functions are made possible through artificial intelligence, predictive analytics, and pre-optimized software algorithms.
- SONs strive to make complicated network administration a thing of the past by enabling the creation of a plug-and-play environment for both simple and complex network tasks.
- The main benefit of SONs is that their inherent automation reduces the need for costly manual, human attention for installation and network management.
- Instead, the network is quicker to install and easier to maintain while providing higher performance.

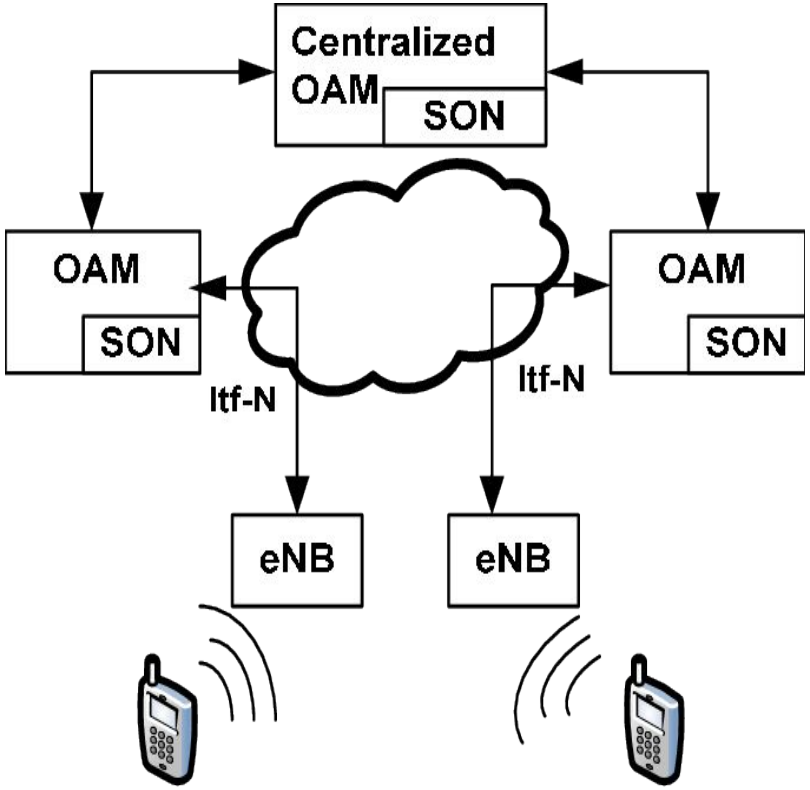

LTE SON FRAMEWORK
eNB Power ON
Self-Configuration
(pre-operation state)
Basic Setup
Configuration of IP address
Association with a GW
Authentication
Software & Configuration data download
Initial Radio
Configuration
Neighbor list configuration
Coverage Parameter Configuration
Self-Optimization
(Operation State)
Optimization
Neighbor list Optimization
Coverage and Capacity Optimization
Self-Healing
(Operation State)
Self-Healing
Failure Detection and Compensation
Schemes

- **Self-configuration** means the SON automatically recognizes and registers new access points / base stations made part of the radio access network (RAN).
- Neighboring radios automatically adjust their emission power and other technical parameters to avoid interference and maximize both coverage and capacity.
- **Self-optimization** automatically optimizes base stations' technical parameters for a specific purpose.
- For example, a self-optimizing network could optimize wireless airtime resources to ensure specific service level agreements (SLA) per device and application groups are maintained at times of congestion, high device density and changing spectrum availability.
- **Self-healing** allows the SON to automatically heal itself when base stations fail and connectivity is lost.
- Self-healing networks adjust adjacent cells' parameters to provide continued service—or at least minimize degradation of service—to affected users.

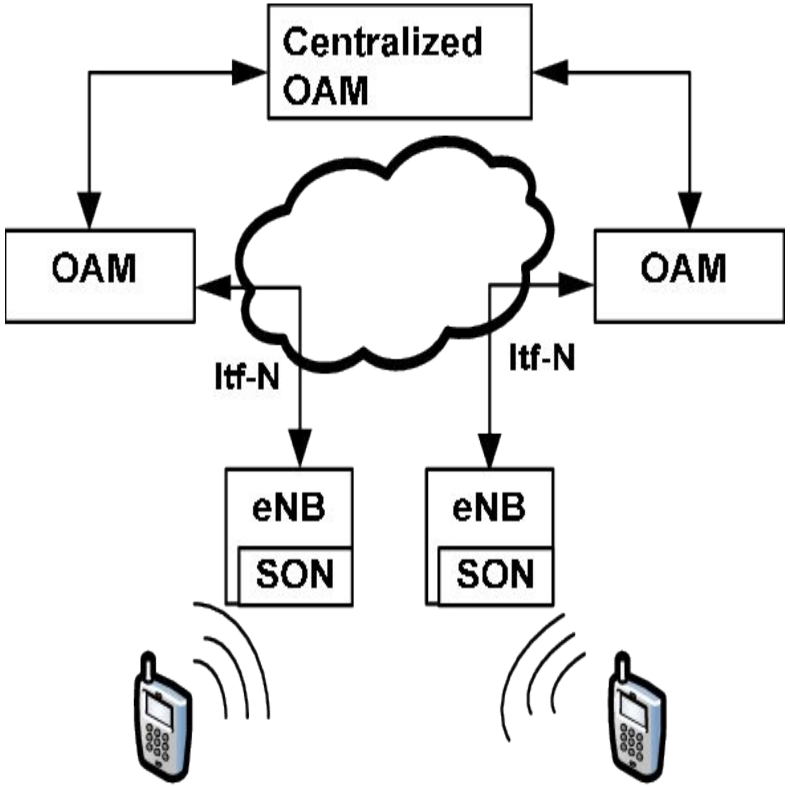
- **Self-protection** means the self-organizing network automatically defends itself from penetration by unauthorized users.
- The primary goal of self-protection is to maintain network security and data confidentiality.

- **Automatic Neighbor Relations (ANR)** helps facilitate smooth signal transitions from cell to cell as a device moves through a cellular network.
- Traditionally this has been a very complicated and laborious task for human operators, but can now be handled through SONs.
- ANR works constantly to analyze and communicate with neighboring cells to ensure handovers are timely, reliable, and efficient.

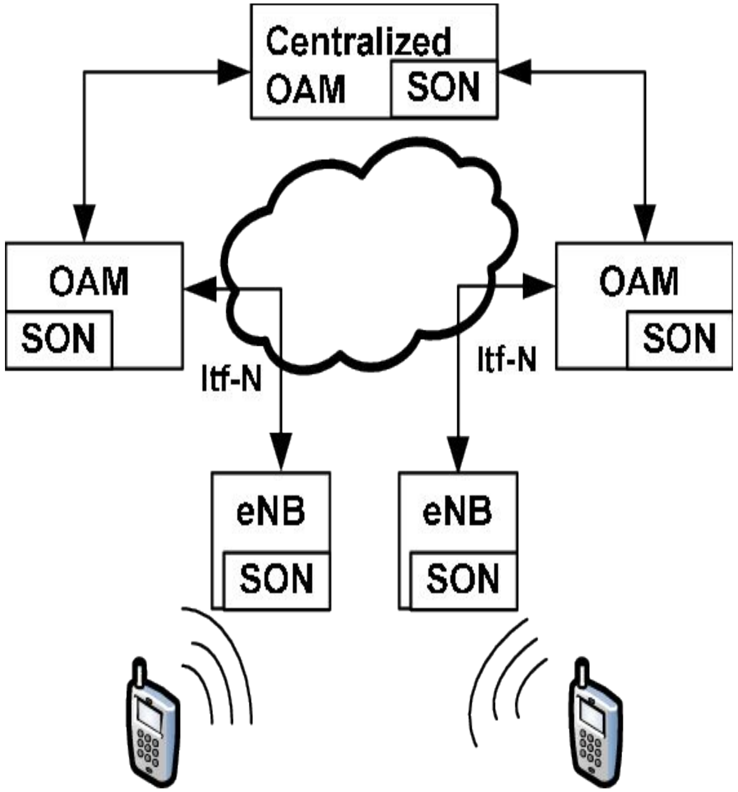
- There are three main types of self-organizing networks: distributed, centralized, and hybrid.



Centralized SON Architecture



Distributed SON Architecture



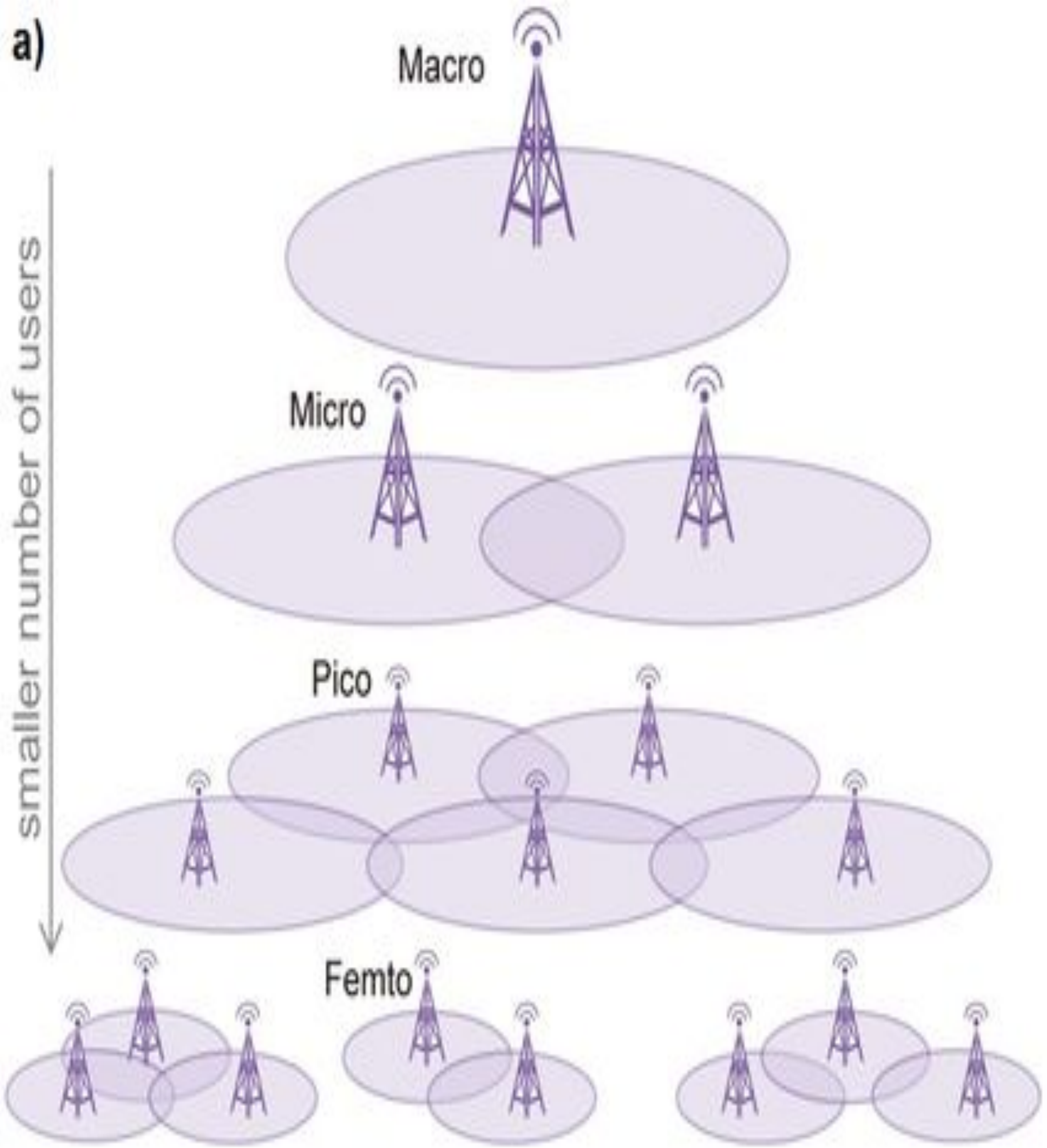
Hybrid SON Architecture

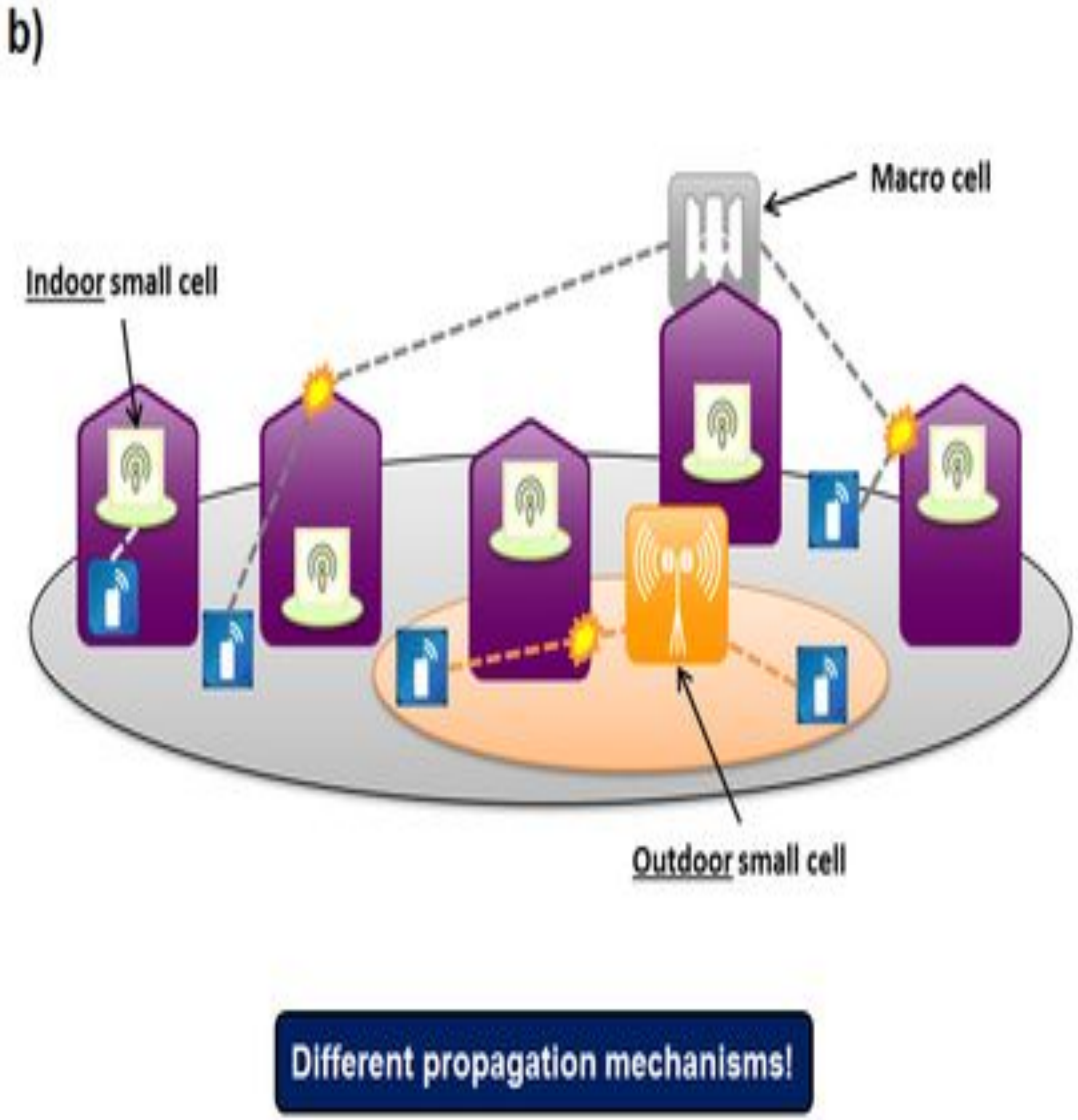
- **Centralized self-organizing networks’** functions are centralized at higher-order network nodes. Commands, changes, settings, and requests are distributed directly from the network management console, and then propagated out to each node.
- This type of SON can easily scan and take in all aspects of the network, allowing the algorithm to make better decisions regarding optimizations and future configurations.
- A drawback of this configuration is slightly longer response times when compared to a distributed SON, where you tend to trade a bit of speed for additional control and precision of the network assets.
- **Distributed self-organizing networks** relay commands that are distributed across the edge of the network where each node exchanges information with each other.
- This type of architecture allows more flexibility than a centralized SON, and enables the network to respond and see changes on the network more quickly.

- A challenge with this type of network architecture is that each node's optimization doesn't always ensure that the network will improve as a whole since each node acts as its own relay.
- **Hybrid self-organizing networks** are a mix of distributed and centralized SONs. Hybrid environments attempt to strike a balance between advantages between the approaches, where the network can both quickly respond to changes while maintaining a centralized method of management.

SON For Heterogeneous Networks (HetNet)

- HetNet basically refers to Heterogeneous Networks, which is nothing but a combination of networks of different access technologies and cell types interworking with each other to give user a better, seamless and reliable, communication experience.
- The user gets the feel of being connected to a single never failing network. The prime motivation for deploying “HetNet” is to boost the network capacity/capability.


a)
Macro
Micro
Pico
Femto
smaller number of users


b)
Macro cell
Indoor small cell
Outdoor small cell
Different propagation mechanisms!

In heterogeneous networks the cells of different sizes are referred to as **macro, micro, pico and femto-cells**; listed in order of decreasing base station power.

a. Macro cells are the common cells sites supporting technologies like HSPA+ and LTE.

- The normal range may vary from a few hundred meters to a few kilometres. Output power is of the order of tens of watts.

b. Microcells typically cover smaller areas maybe up to a kilometre. They usually transmit within a range of milliwatts to a few watts.

- Microcells are deployed for providing temporary cellular coverage and capacity to places like sports stadiums, convention centres etc.
- Sometimes, microcells may use distributed antenna systems(DAS) to improve bandwidth and reliability.

c. Pico cells offer capacities and coverage areas, supporting up to 100 users over a range of less than 250 yards.

- Pico cells are frequently deployed indoors to improve poor wireless and cellular coverage within a building, such as an office floor or retail space.

d. Femtocells are typically user-installed to improve coverage area within a small vicinity, such as home office or a dead zone within a building.

- Femtocells can be obtained through the service provider or purchased from a reseller.
- Unlike pico cells and microcells, femtocells are designed to support only a handful of users and is only capable of handling a few simultaneous calls.
- They are sold by the operator but self-installed by the customer.

- In LTE networks, the actual cell size depends not only on the eNodeB power but also on antenna position, as well as the location environment; e.g. rural or city, indoor or outdoor etc. Different nodes, for small cells, used in LTE/LTE-A HetNets are listed below:

Home eNodeB (HeNB)

- It is a 3GPP term for femto-cell in LTE, was introduced in LTE Release 9 (R9).
- It is a low power eNodeB which is mainly used to provide indoor coverage, for Closed Subscriber Groups (CSG), for example, in office premises.
- HeNBs are privately owned and deployed without coordination with the macro-network.
- If the frequency used in HeNB is the same as the frequency used in the macro-cells, and the HeNB is only used for CSG, then there is a risk of interference between the HeNB and the surrounding network.

Relay Node (RN)

- It is another type of low-power base station added to the LTE R10 specifications.
- In LTE-Advanced, the possibility for efficient heterogeneous network planning is increased by the introduction of Relay Nodes (RNs).
- The Relay Nodes are low power base stations that will provide enhanced coverage and capacity at cell edges, and hot-spot areas and it can also be used to connect to remote areas without fibre connection.
- The Relay Node is connected to the Donor eNodeB (DeNB)1 via a radio interface, Un, which is a modification of the E-UTRAN air interface Uu.

RRHs (Remote Radio Head)

- It is connected to an eNB via fibre can also be used to provide small cell coverage. It is an alternative solution to a BTS housed in a shelter at the bottom of the tower.
- It is a distributed base station, in which the majority of the base station equipment is no longer located in the shelter, but in an enclosure at the top of the tower near the antennae.
- This separate but integrated radio frequency (RF) unit is called a remote radio unit or remote radio head.
- It is compact in size. RRH is generally used to extend the coverage of a base station sub-system in the remote rural areas.