Evolved Packet Core

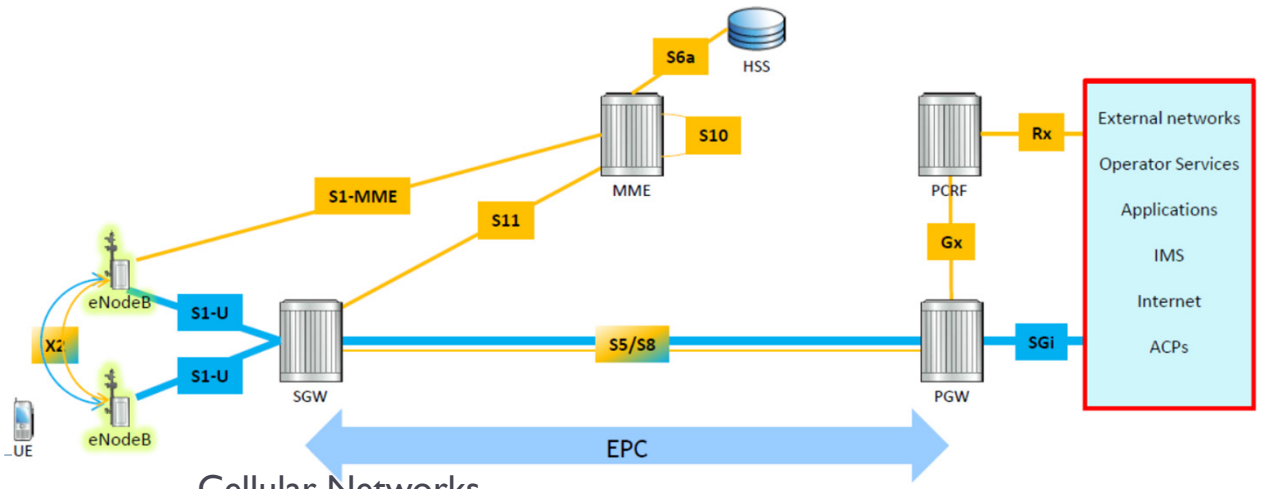
Vahid Shah-Mansouri, Fall 1397
Faculty of ECE, University of Tehran

References

- M. Sauter, "From GSM to LTE", John Wiled and Sons, 2011. Chapter 1.
- S. Sesia, I. Toufik, and M. Baker, "LTE: The UMTS Long Term Evolution," 2nd Edition, John Wiley & Sons Ltd, 2011.

EPC Structure

- EPC has several functions:
  - Core network functions
  - Network attachment, bearer set ups, paging, IP addressing, handover.
  - Three main elements with network functions: SGW, MME, PGW
  - Some servers: HSS, PCRF
  - Several interfaces: S1, S11, S5/S8, S10, S6a, Gx, SGi
  - IMS is something besides EPC but strongly related.



Serving Gateway (SGW)

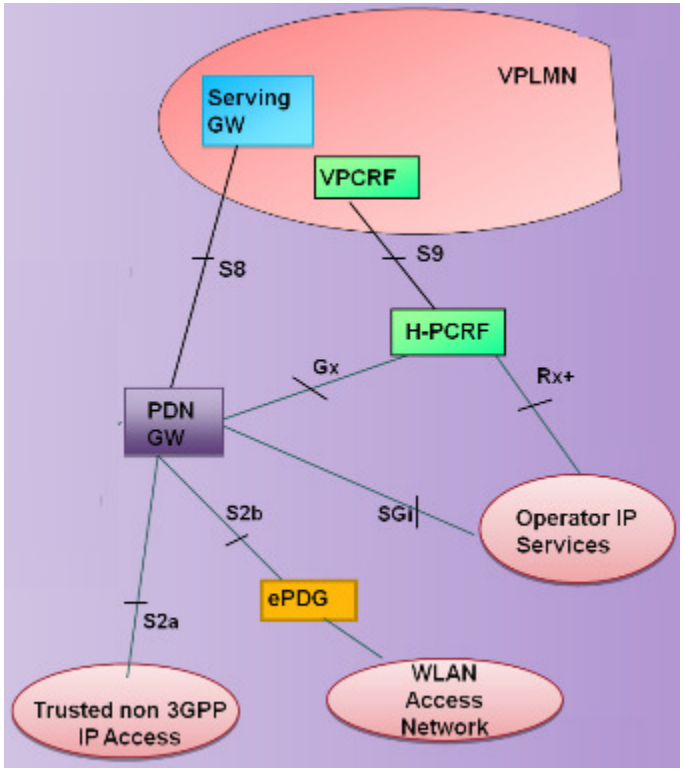
- It is the main border between the RAN and the core.
  - On the RAN side, it terminates the S1 GTP tunnels,
  - On the core network side, it terminates the S5 GTP tunnels to the gateway.
- The SGW is a data plane element within the LTE SAE.
  - Routing and forwarding data packets between eNBs and PDN gateway based on tunnels.
- Acts as mobility anchor for the user plane during inter-eNB handovers.

Mobility Management Entity (MME)

- MME is the main player of the control plane of the LTE SAE.
- As the MMEs are not involved in air interface matters, the signaling it exchanges with the radio network is referred to as Non-access Stratum (NAS) signaling.
- MME handles a number of functions:
  - Authentication:
    - with the help of HSS, MME performs UE authentication.
  - Bearer management:
    - This includes the establishment, maintenance and release of the bearers and it is handled by the NAS protocol.
    - S-GW tunnel creation, maintenance, and release are handled by MME.
  - Handover support:
    - In case no X2 interface is available, the MME helps to forward the handover messages between the two eNBs involved.
  - Functions related to inter-working with other networks:
    - This includes handing over of voice calls to legacy networks.

Packet Data Network (PDN) Gateway (PGW)

- The P-GW is responsible for
  - Connecting the UE to the external world.
  - The PDN-GW terminates the S5 user plane interface.
  - IP address allocation for the UE.
    - Requested by MME after authentication.
  - QoS enforcement.
  - Flow-based charging according to rules from the PCRF.
  - It also serves as the mobility anchor for
    - inter-working with non-3GPP technologies.
    - Roaming to other operators.



Home Subscriber Server (HSS)

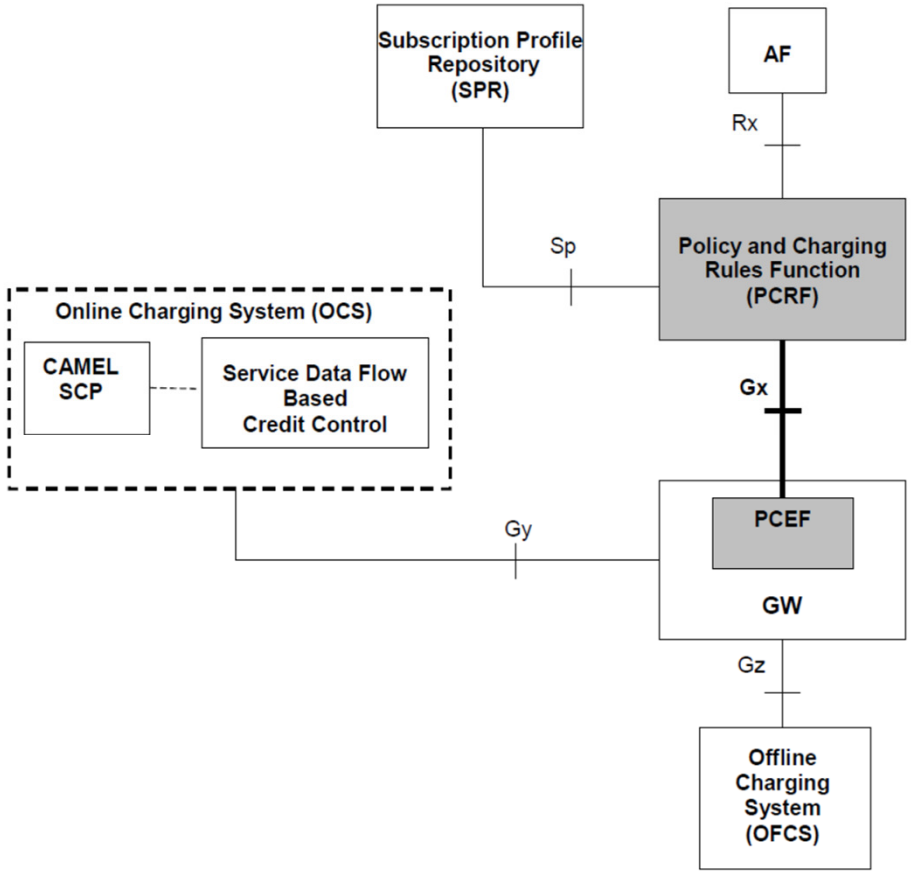
- The HSS contains users' SAE subscription data such as the EPS-subscribed QoS profile and any access restrictions for roaming.
- LTE shares its subscriber database with GSM and UMTS.
- HLR and HSS are usually combined physically.
- It also holds information about the PDNs to which the user can connect.
- In addition, the HSS holds dynamic information such as the identity of the MME to which the user is currently attached or registered.
- The HSS may also integrate the Authentication Centre (AuC) server which generates the vectors for authentication and security keys.

Home Subscriber Server (HSS)

- The most important parameters that the HSS holds are
  - The user's International Mobile Subscriber Identity (IMSI),
  - Authentication information
  - Circuit-switched service properties
  - Packet-switched service properties
  - The ID of the MME

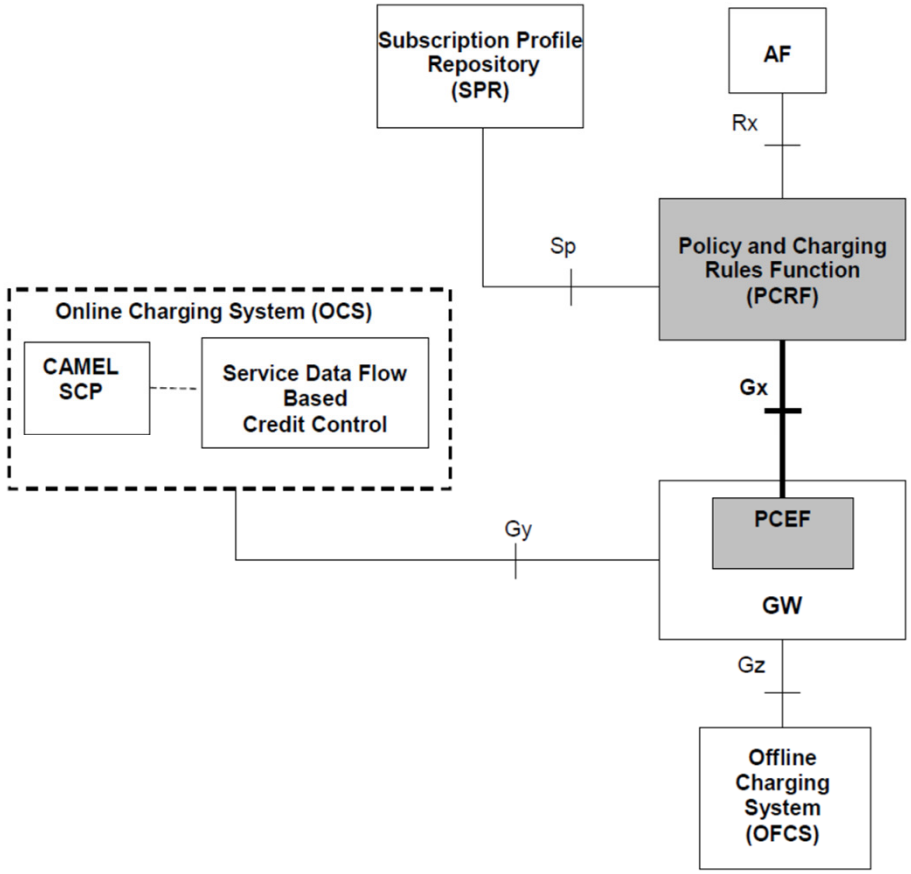
Policy Control and Charging Rules Function (PCRF)

- It is a server responsible for
  - controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF) which resides in the P-GW.
- PCRF feed PCEF with policy charging (PCC) rules.
- PCEF uses PCCs to make decision for charging, filtering, shaping, and QoS control.



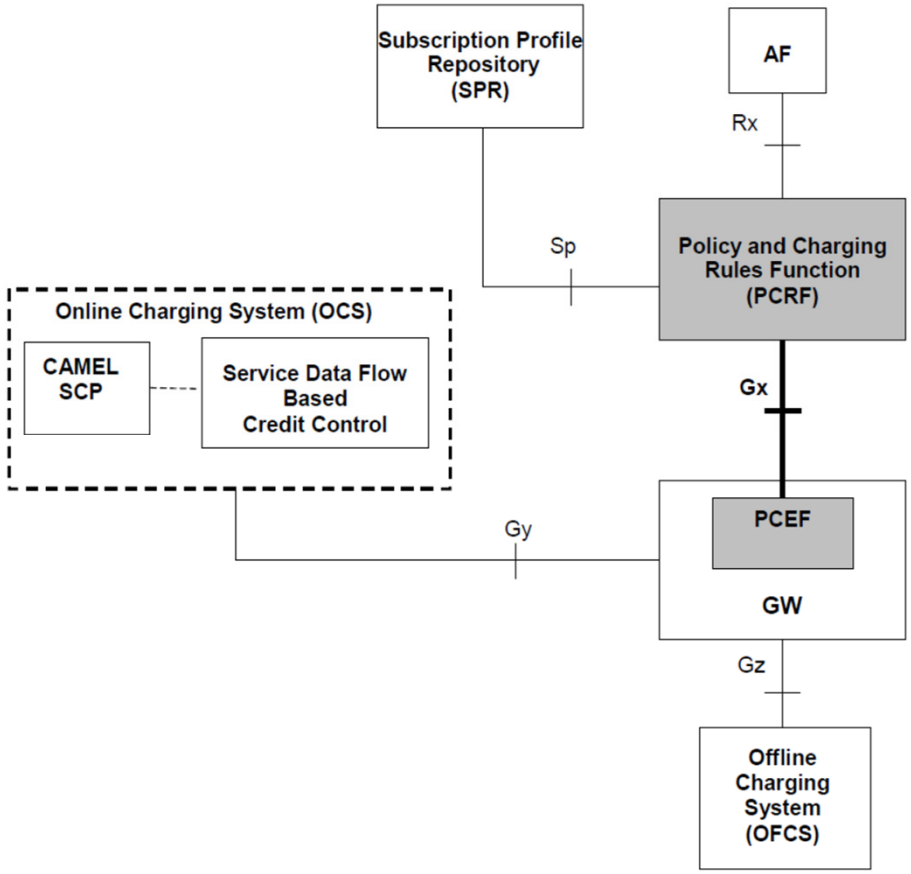
Policy Control and Charging Rules Function (PCRF)

- Policy Control Enforcement Function (PCEF) using PCC
  - Detects a packet belonging to a service data flow.
  - Identifies the service the service data flow contributes to.
  - Provides applicable charging parameters for a service data flow.
  - Provides policy control for a service data flow.



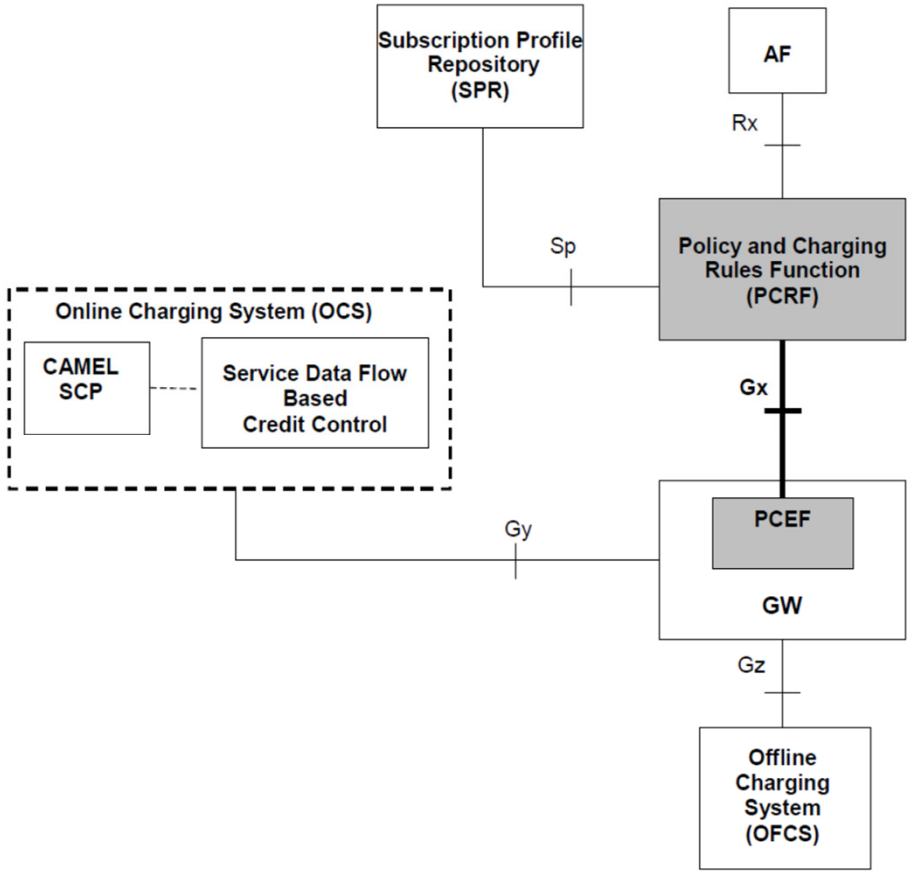
Policy Control and Charging Rules Function (PCRF)

- Policy charging control (PCC) rule
  - a rule name;
  - service identifier;
  - service data flow filter(s);
  - gate status;
  - QoS parameters;
  - charging key (i.e. rating group);
- The PCEF shall select a PCC rule for each received packet by evaluating received packets against service data flow



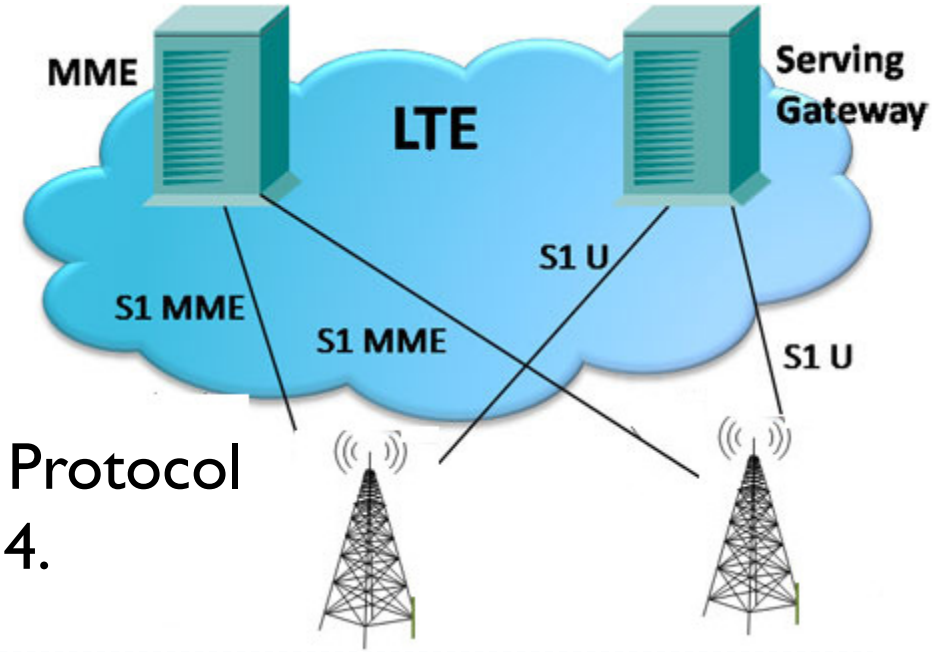
Policy Control and Charging Rules Function (PCRF)

- PCEP can have pre-configured rules and can operate independent of PCRF.
- PCRF make it dynamic.
- Connection of OCS, PCEF, and PCRF are based on Diameter protocol.



E-UTRAN Network Interfaces: S1 Interface

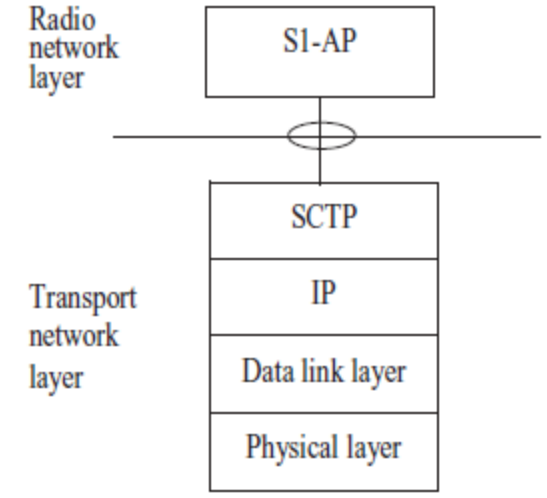
- The S1 interface connects the eNodeB to the EPC.
- It is split into two interfaces control plane and user plane.
- The protocol structure over S1 is based on a full IP transport stack with no dependency on legacy SS7.

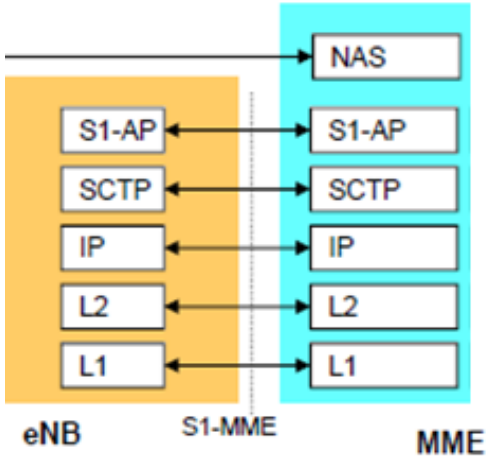


3GPP TS 36.413 , "S1 Application Protocol (S1AP)", version 14.4.0 Release 14.

S1-MME Interface (Control Plane)

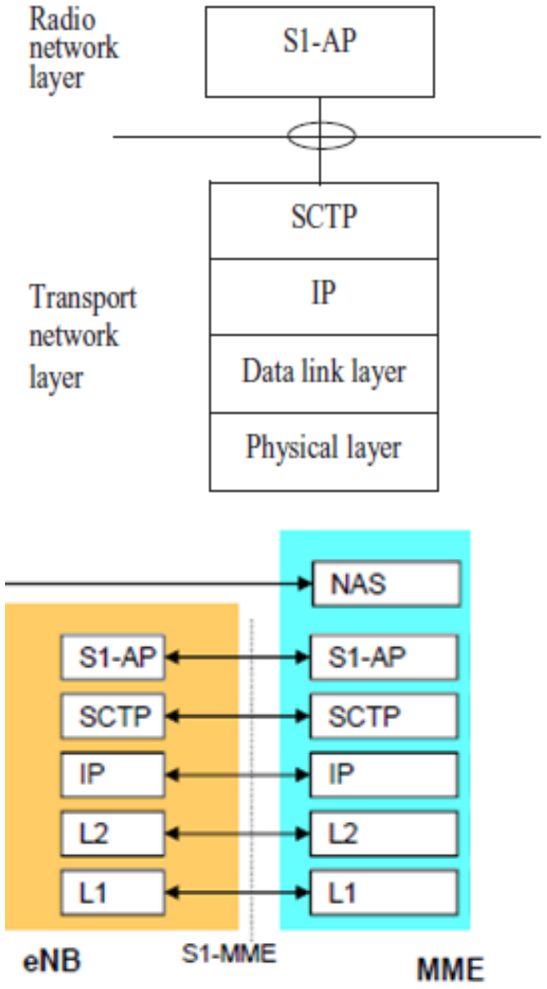
- Connects UE to MME.
- Control Plane
  - IP plus SCTP construct the transport protocol.
  - S1-Application Protocol (S1-AP) is the main application protocol of the user plane.
  - NAS protocol is passed through this interface.





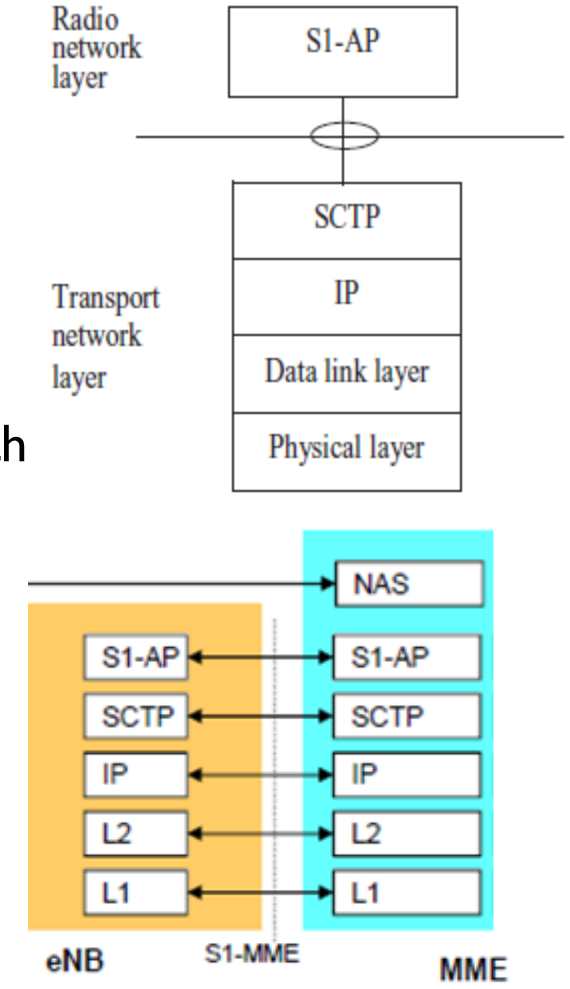
S1-MME Interface (Control Plane)

- S1-AP functions:
  - Bearer-level procedures
    - On the scope of the S1 interface, a bearer corresponds to the S1 segment of a session plus the radio interface path.
    - S1-AP is responsible for all procedures related to bearer setup, modification and release resources on Uu and S1 for one or several E-RABs.
    - Procedures: E-RAB Setup, E-RAB Modify, E-RAB release



S1-MME Interface (Control Plane)

- S1-AP Tasks (continued)
  - Handover procedures
    - Encompasses all the S1 functions related to user mobility between eNodeB or with 2G or 3G 3GPP technologies.
    - Procedures: Handover Preparation, Handover Resource Allocation, Handover Notification, Path Switch Request, Handover Cancellation, eNB/MME status transfer.
  - NAS signalling transport
    - this corresponds to the transport of UE–MME signalling over the S1 interface.

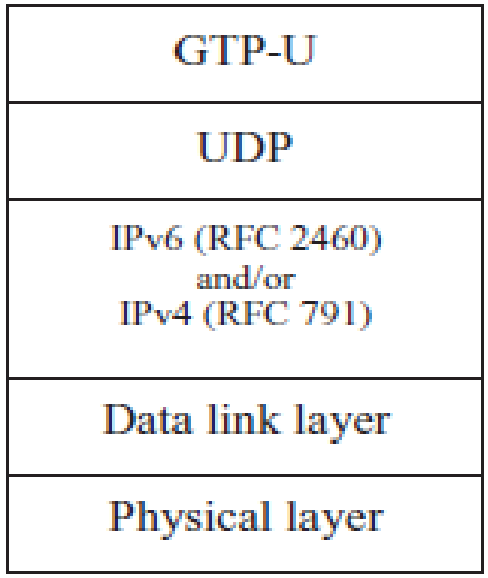


S1-MME Interface (Control Plane)

- S1-AP Tasks (continued)
  - Paging procedure
    - Through the paging procedure, the MME requests the eNodeB to page UE in a given set of cells.
  - Managements procedure
    - Functions: reset, error indications, S1 set up, eNB configuration data, and update, overload start, overload stop,
  - Trace Function:
    - In order to trace the activity of a UE in connected mode, MME can command eNB to log all the events or part of them.
    - Trace can be activated for the interface rather than UE as well.

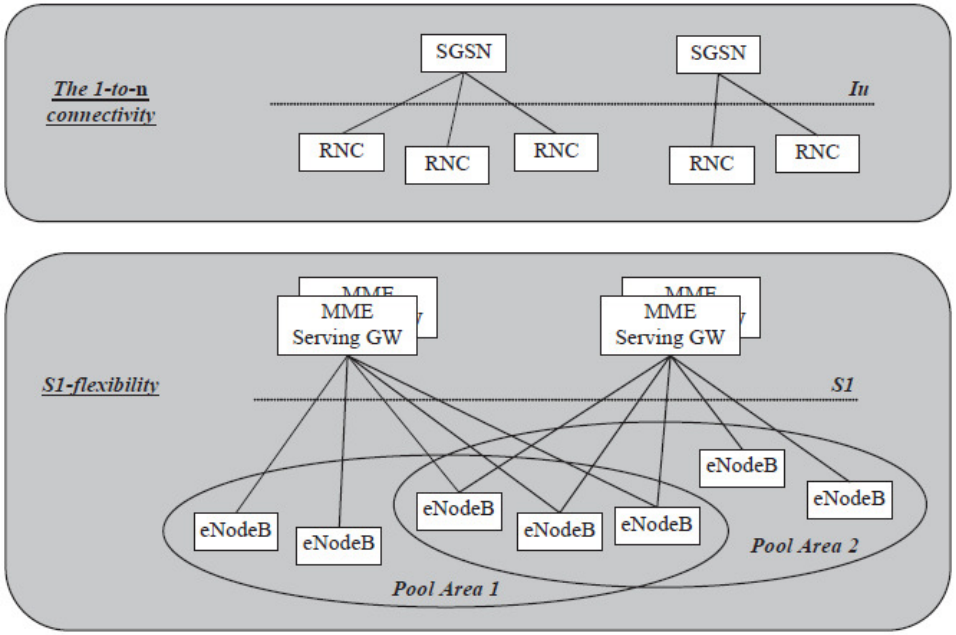
S1-U Interface (User Plane)

- A simple protocol.
- The S1-U (or S1 User plane interface) role is to transport user data packet between the eNodeB and the Serving GW.
- Compared to S-MME which uses a variant of TCP, S-1 uses UDP.
- It is based on GPRS Tunneling Protocol and UDP or IP.



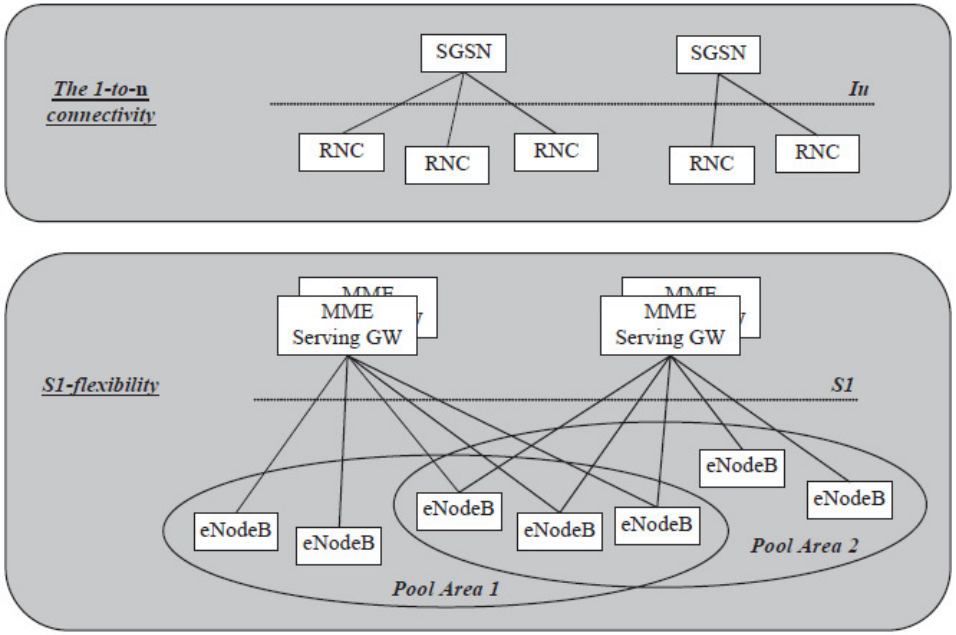
S1-Flexibility

- In UMTS network, each RNC is connected to only one SGSN.
- EPC allows eNBs to be connected to multiple MME/SGWs at the same time.
- A pool area is an area which a UE may move into without a need to change its serving Core Network node.



S1-Flexibility

- The S1 flexibility
  - allows the network to become more robust to core node failure
  - allows reduction of the number of inter-core network node handover procedures (in Connected mode) or Tracking Area updates (in Idle mode).
  - allows core network load balancing



Stream Control Transport Protocol (SCTP)

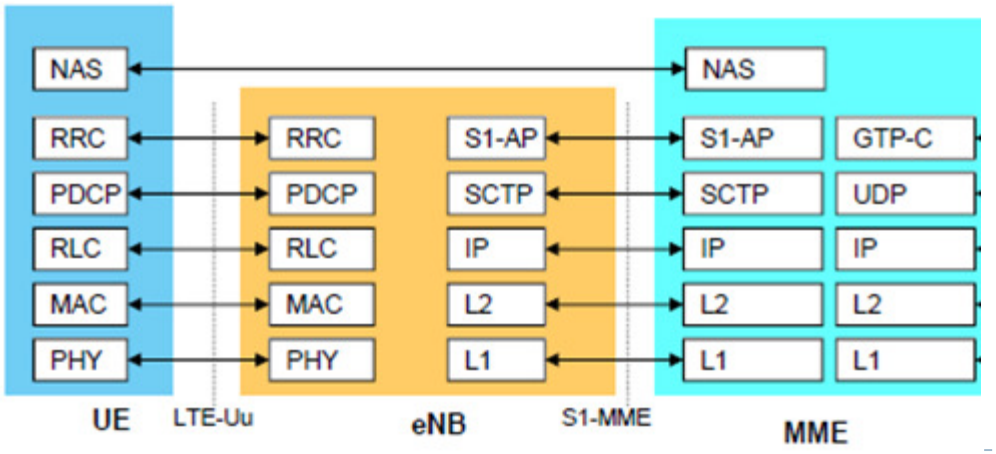
- STCP is a reliable connection-oriented transport protocol which is very similar to the well known and widely used TCP.
- STCP implements congestion and flow control, detection of data corruption, loss or duplication of data and supports a selective retransmission mechanism.
- When comparing TCP and SCTP from a functional perspective, SCTP provides three key features which TCP does not support:
  - The multi-streaming,
  - The multi-homing,
  - SCTP framing.

Stream Control Transport Protocol (SCTP)

- Multi-Streaming:
  - Allows setting up several independent streams between two peers connected by one SCTP connection.
  - In such a case, when a transmission error occurs on one of the stream, it does not affect data transmission on the other streams.
- Multi-homing:
  - This allows a SCTP endpoint to be reached through multiple IP addresses.
- SCTP framing:
  - SCTP works at the message level whereas TCP is an octet stream protocol.
  - TCP transport bytes and may assemble or fragment packets but SCTP transport whatever it has received from upper layer.

Non Access Stratum Protocol

- The non-access stratum (NAS) described in the present document forms the highest stratum of the control plane between UE and MME.
- The NAS is used to convey non-radio signalling between the User Equipment (UE) and the Mobility Management Entity (MME) for an LTE/E-UTRAN access.
- NAS has two main functionalities
  - The support of mobility of the user equipment (UE);
  - The support of session management procedures to establish and maintain IP connectivity between the UE and a packet data network gateway (PDN GW).

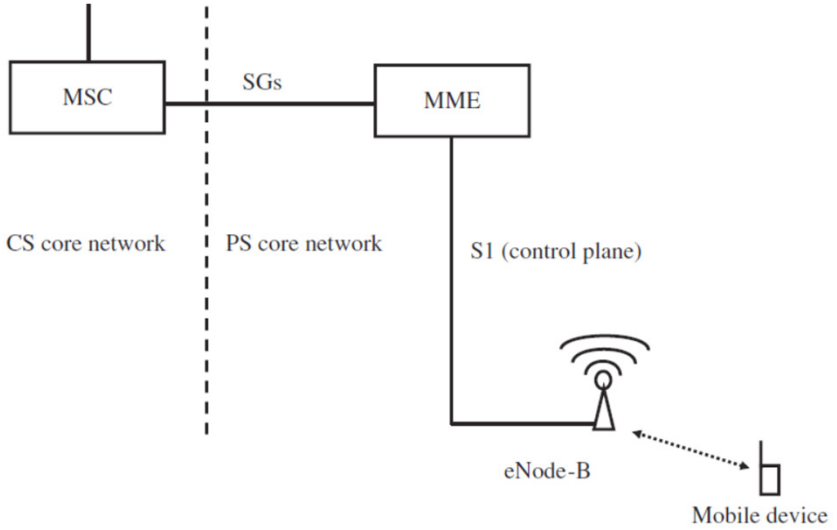


Non Access Stratum Protocol

- The MME creates a *UE context* when a UE is turned on and attaches to the network.
- UE context holds user subscription information downloaded from the HSS plus dynamic information.
- The NAS uses UE context and convey non-radio signalling between the UE and the MME.
- NAS procedures:
  - attach, detach, PLMN selection, paging, authentication, tracking area updating, bearer establishment, modification, release, security management

Circuit Switch Fall Back (CSFB)

- Circuit Switched FallBack (CSFB) is a technology whereby voice and SMS services are delivered to LTE devices through the use of GSM or another circuit-switched network.
- The SGs interface is used to deliver non EPC paging messages that inform the mobile device of an incoming call.
- It is delivered via S1AP paging.
- The call itself, however, is not delivered over the LTE interface and the mobile device has to fall back to a GSM or UMTS network where a circuit-switched connection is then established for the call.
- Solution is Voice over LTE (VoLTE).

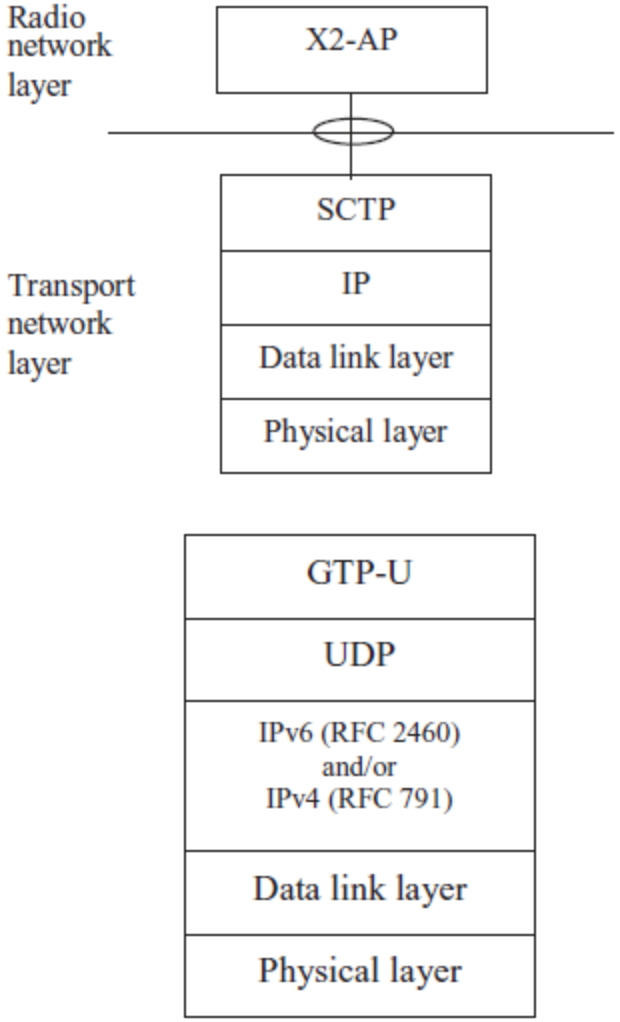


The E-UTRAN Network Interface: X2 Interface

- The X2 interface is established between one eNB and some of its neighbours.
- A full mesh is not mandated in an E-UTRAN network.
- Two types of information typically need to be exchanged over X2 :
  - Interference/overload related information
  - handover related information.

The E-UTRAN Network Interface: X2 Interface

- The control plane and user plane protocol stacks over the X2 interface are the same as over the S1 interface.
- Big part of SON capability.



X2-AP Procedures

- The X2 interface X2-AP procedures are divided into two modules :
  1. X2AP Basic Mobility Procedures :The X2AP Basic Mobility Procedures module contains procedures used to handle the UE mobility within E-UTRAN.
  2. X2AP Global Procedures: The Global Procedures module contains procedures that are not related to a specific UE. The procedures in this module are in contrast to the above module involving two peer eNBs.
- Basic mobility procedures
  - Handover Preparation, SN Status Transfer, UE Context Release, Handover Cancel
- Global Procedures
  - Load Indication, Error Indication, X2 Setup, Reset, eNB Configuration Update, Resource Status Reporting Initiation, Resource Status Reporting, Mobility Settings Change, Radio Link Failure Indication, Handover Report, Cell Activation.

X2-AP Functions

- The X2AP protocol provides the following functions:
- Mobility Management
  - allows the eNB to move the responsibility of a certain UE to another eNB. Forwarding of user plane data, Status Transfer and UE Context Release function are parts of the mobility management.
- Load Management.
  - This function is used by eNBs to indicate resource status, overload and traffic load to each other.
- Reporting of General Error Situations
  - This function allows reporting of general error situations, for which function specific error messages have not been defined.
- Resetting the X2:
  - This function is used to reset the X2 interface.
- Setting up the X2
  - This function is used to exchange necessary data for the eNB for setup the X2 interface and implicitly perform an X2 Reset.

X2-AP Functions

- eNB Configuration Update.
  - This function allows updating of application level data needed for two eNBs to interoperate correctly over the X2 interface.
- Mobility Parameters Management.
  - This function allows the eNB to coordinate adaptation of mobility parameter settings with a peer eNB.
- Mobility Robustness Optimisation
  - This function allows reporting of information related to mobility failure events.
- Energy Saving.
  - This function allows decreasing energy consumption by enabling indication of cell activation/deactivation over the X2 interface.

Mapping of Functions to Procedures

Function	Elementary Procedure(s)
Mobility Management	a) Handover Preparation b) SN Status Transfer c) UE Context Release d) Handover Cancel
Load Management	a) Load Indication b) Resource Status Reporting Initiation c) Resource Status Reporting
Reporting of General Error Situations	Error Indication
Resetting the X2	Reset
Setting up the X2	X2 Setup
eNB Configuration Update	a) eNB Configuration Update b) Cell Activation
Mobility Parameters Management	Mobility Settings Change
Mobility Robustness Optimisation	a) Radio Link Failure Indication b) Handover Report
Energy Saving	a) eNB Configuration Update b) Cell Activation

Self Organizing Network (SON) Operation

- A Self-Organizing Network is an automation technology designed to make the planning, configuration, management, optimization and healing of mobile radio access networks simpler and faster.
- There are three main areas over which the self-organising networks operate.
  - Self configuration: The aim is for base stations to become essentially "Plug and Play" items. They should need as little manual intervention in the configuration process as possible.
  - Self optimisation: Once the system has been set up, it will be necessary to optimise the operational characteristics to best meet the needs of the overall network.
    - Mobility robustness optimisation
    - Mobility load balancing and traffic steering
    - Energy saving
    - Coverage and capacity optimisation
    - RACH optimisation

Self Organizing Network (SON) Operation

- Self-healing: Any system will develop faults from time to time. This can cause major inconvenience to users, however it is often possible for the overall network to change its characteristics to temporarily mask the effects of the fault.
  - Self recovery of software
  - Self-healing of board faults
  - Cell outage detection
  - Cell outage recovery
  - Cell outage compensation
  - Return from cell outage compensation

X2 Set up Procedure

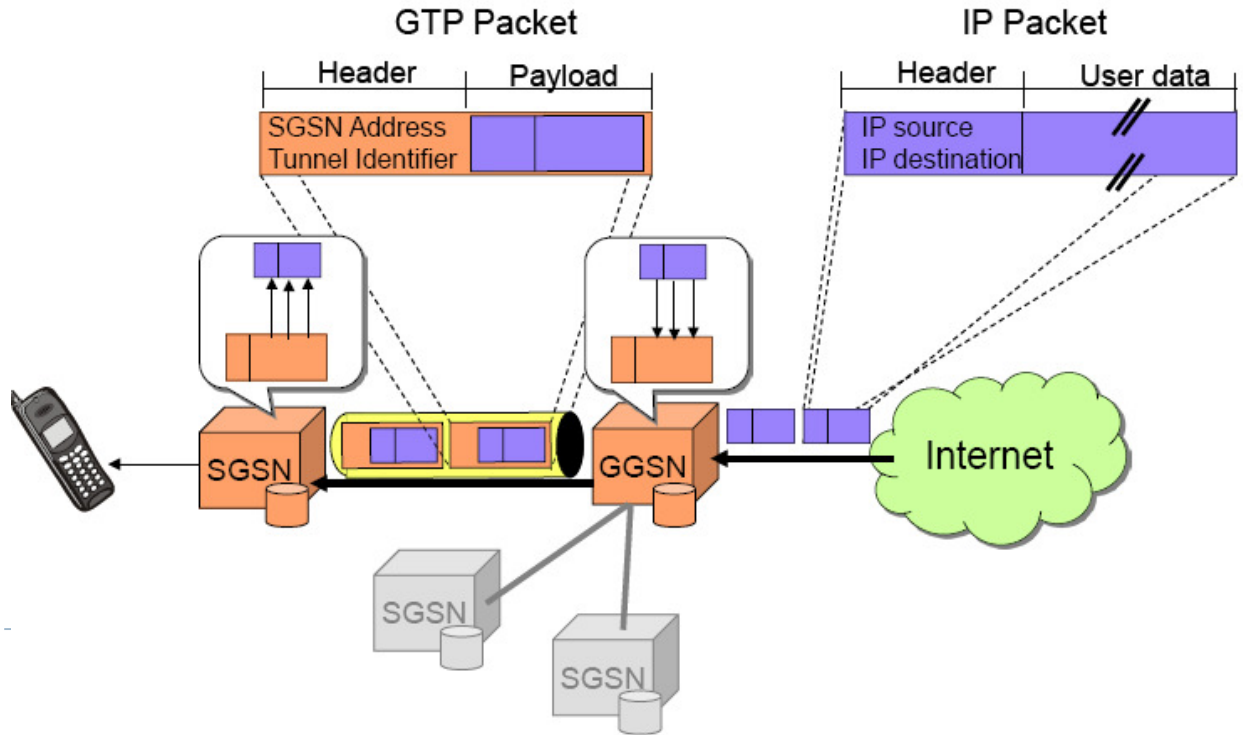
- The initialization of the X2 interface starts with the identification of a suitable neighbour followed by the setting up of the neighbor relation table (NRT).
- The identification of a suitable neighbour may be done by configuration, or alternatively by a self-optimizing process known as the Automatic Neighbour Relation Function (ANRF).
- Once the transport network layer (TNL) has been set up, the initiating eNodeB must trigger the X2 setup procedure.
- This procedure enables an automatic exchange of application level configuration data relevant to the X2 interface (X2 SETUP REQUESTS) which includes cell's physical identity, the frequency band, the tracking area identity and/or the associated PLMNs.

Automatic Neighbour Relation Function (ANRF)

- ANRF is an example of a SON function.
- Each eNodeB can automatically populate a Neighbour Relation Table (NRT) for each cell it controls using ANRF.
- When an eNodeB receives from a UE a Physical Cell Identity (PCI) of a neighbour cell as part of a normal measurement report, and the eNodeB does not recognize the PCI, the eNodeB can instruct the UE to execute a new dedicated reporting procedure which uses the newly discovered PCI as a parameter.
- Through this procedure, the UE reads and reports to the requesting eNodeB some system information of the detected neighbouring cell, including the ECGI, the Tracking Area Code (TAC) and all available PLMN IDs.

GPRS Tunneling Protocol (GTP)

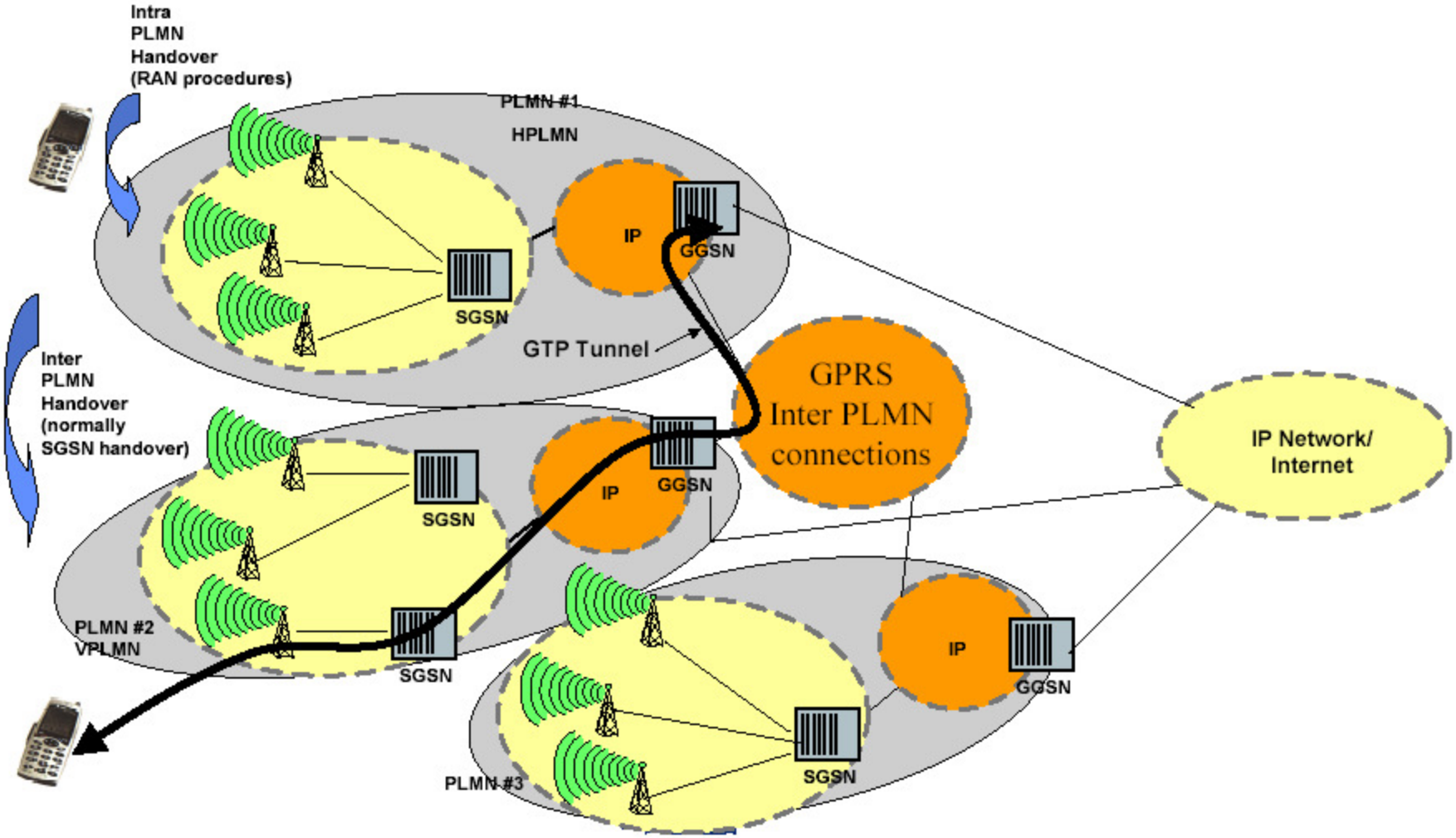
- What is Tunneling?
  - a two-way communication path between two end-points.
  - Encapsulation of a traffic packet in a new packet with new src/dest addresses.
  - Tunneling transparently transfers packets between the mobile station and external data networks.



GPRS Tunneling Protocol

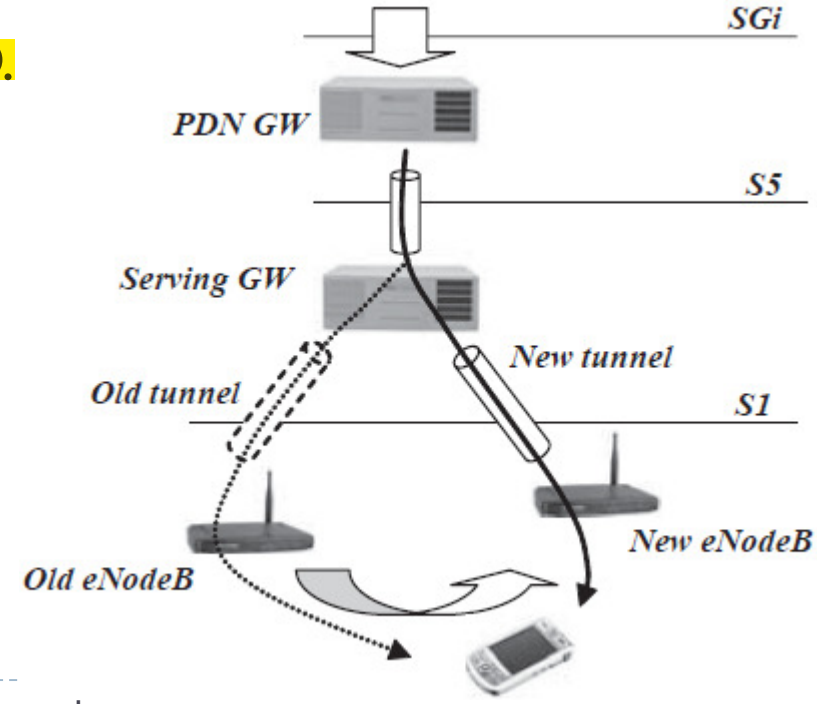
- Why a new addressing protocol over IP?
  - IP does not support mobility (i.e., keeping the host address while moving to other points of attachment.)
  - If we use UE IP address for packet forwarding, the packet may never arrive the UE after UE changes its location.
- Tunnels are solution to cope with mobility of the UEs in the network.

Example of GPRS Tunneling in 2G/3G



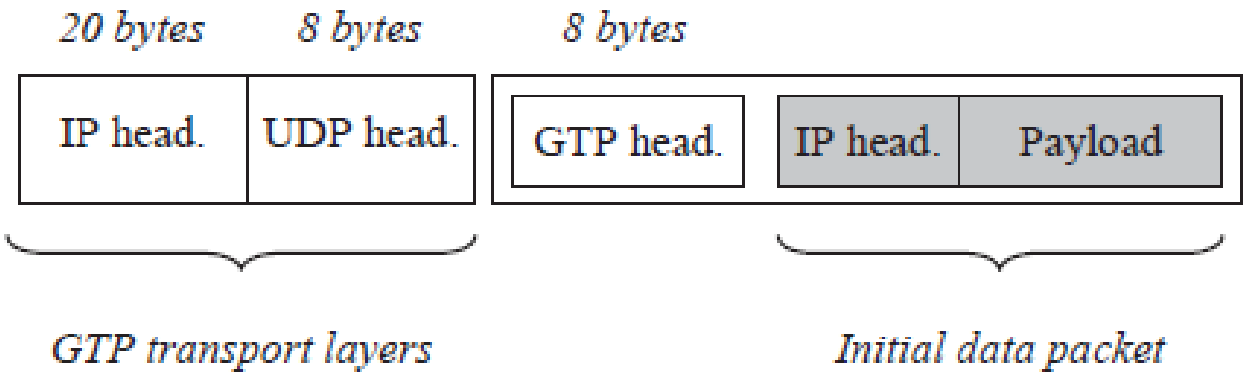
GPRS Tunneling Protocol (GTP)

- EPS tunnels are
  - One between eNB and SGW
  - the other between SGW and PGW.
  - In case of handover, there is a temporary tunnel on the X2 interface.
  - MME to MME for Inter-MME HO.



GPRS Tunneling Protocol (GTP)

- Using the GTP protocol, the user plane packet is inserted in a new packet and serves as its payload.
- A new header is created for the new packet.
- The new header information is used for routing purposes.
  - User is sending a packet to the google. Source ip address is the UE address and destination is google's.
  - Packet reaches eNB. It encapsulate the packet in a new packet. The source address is the eNB. Destination address is SGW.
  - GTP Header is added as well.



GPRS Tunneling Protocol (GTP)

- GTP Header Format:
  - Payload/protocol Type – which indicates if the packet is pure user data or a GTP control message
  - Tunnel Endpoint Identifier: uniquely identifies the receiving protocol entity at the destination.
  - Extension header flag (E): states whether there is an extension header.
  - Sequence number flag (S): states whether there is a Sequence Number.
  - N-PDU number flag (PN): states whether there is a N-PDU number.
  - N-PDU: different meaning in different connections.

+	0-2	3	4	5	6	7	8-15	16-23	24-31
0	Version	Protocol type	Reserved	Extension Header Flag	Sequence Number Flag	N-PDU Number Flag	Message Type	Total length	
32	TEID								
64	Sequence number							N-PDU number	Next extension header type

GTP Message Type

Message Type	
0	Reserved
1	Echo request
2	Echo response
3	Version not supported
4-31	Reserved
32	Create Session Request
33	Create Session Response
34	Modify Bearer Request
35	Modify Bearer Response
36	Delete Session Request
37	Delete Session Response

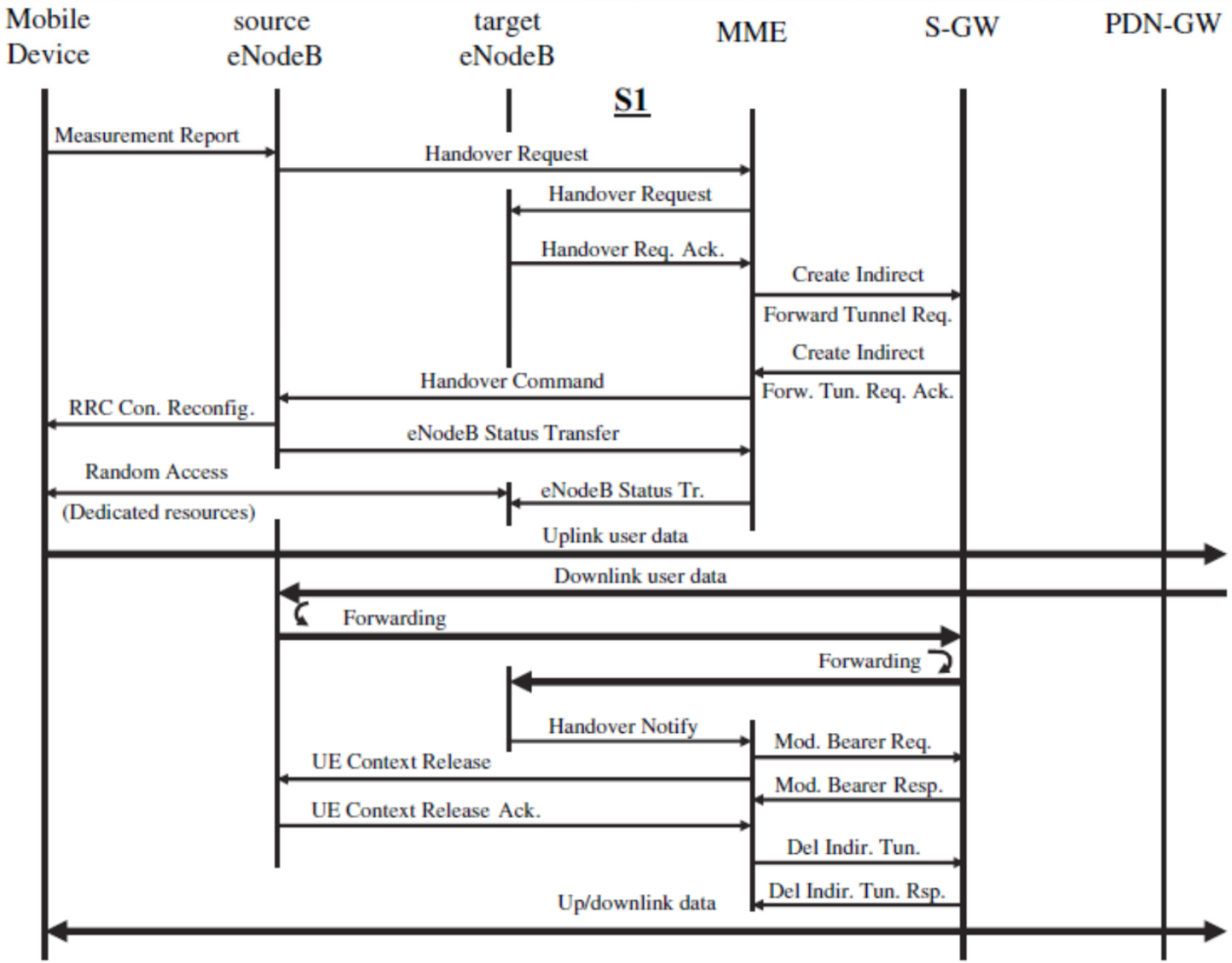
LTE Handover Function

- On the basis of the measurement and reporting configuration that the mobile device has received
- from the eNode-B, it starts measuring the signal strength of neighboring cells.
- Once a configured reporting criterion has been met, it reports the current values for the signal strength of the active cells and neighboring cells to the eNode-B.
- On the basis of this input, the eNode-B can take a decision if a handover of the connection to a neighboring cell with a better signal is necessary.
- In LTE, there are two types of handovers.
  - X2 Hanover: Performed by X2-AP and is the most efficient one where the source eNode-B and the target eNode-B directly communicate over X2 interface.
  - S1 handover: the MME assists in the process in this case via S1-AP procedures.

Handover Using S1-AP

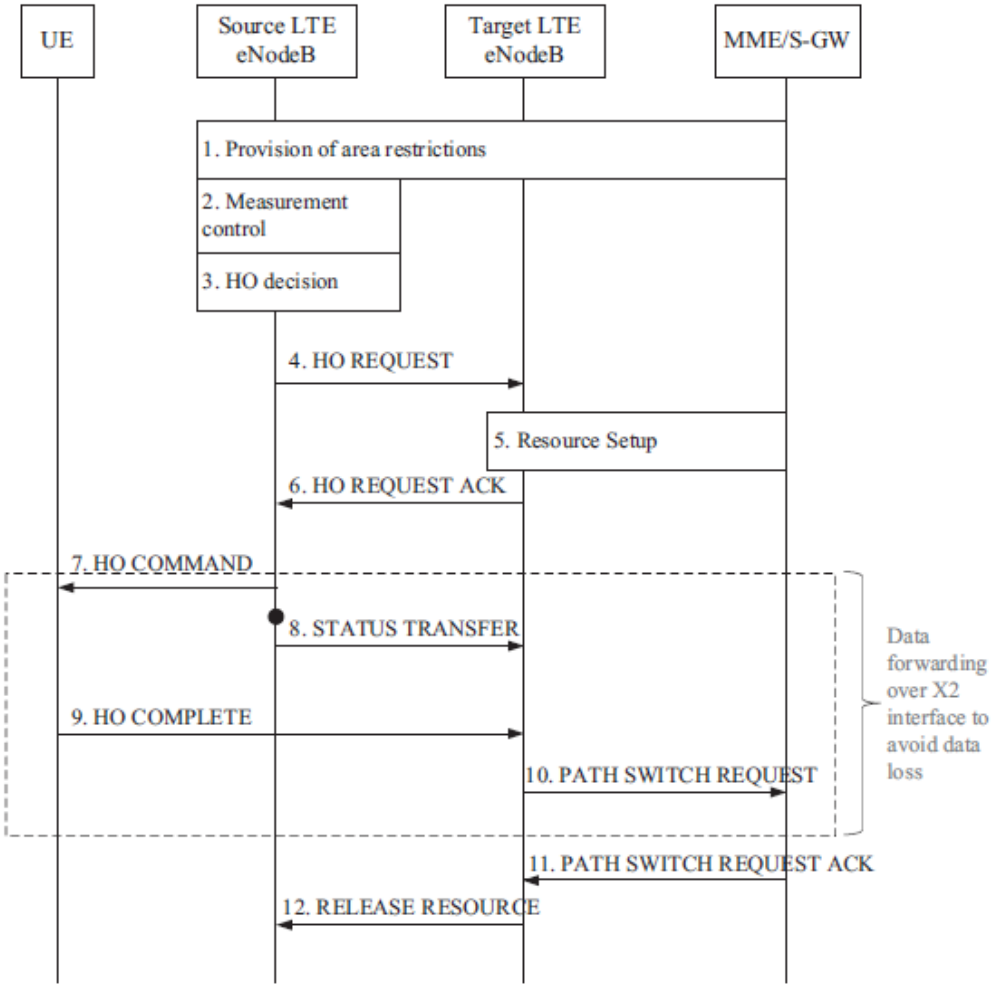
- When there is no X2 interface between the two eNodeBs, or if the source eNodeB has been configured to initiate handover towards a particular target eNodeB via the S1 interface, then an S1-handover will be triggered.
- Compared to UMTS, the main difference is the introduction of the 'STATUS TRANSFER'.
- Status transfer contains PDCP Sequence Numbers (SN) and Hyper Frame Numbers (HFN).

Handover Using S1-AP



Handover Using X2-AP

- The handover is directly performed between two eNodeBs. This makes the preparation phase quick.
- The MME is only informed at the end of the handover.
- The release of resources at the source side is directly triggered from the target eNodeB.

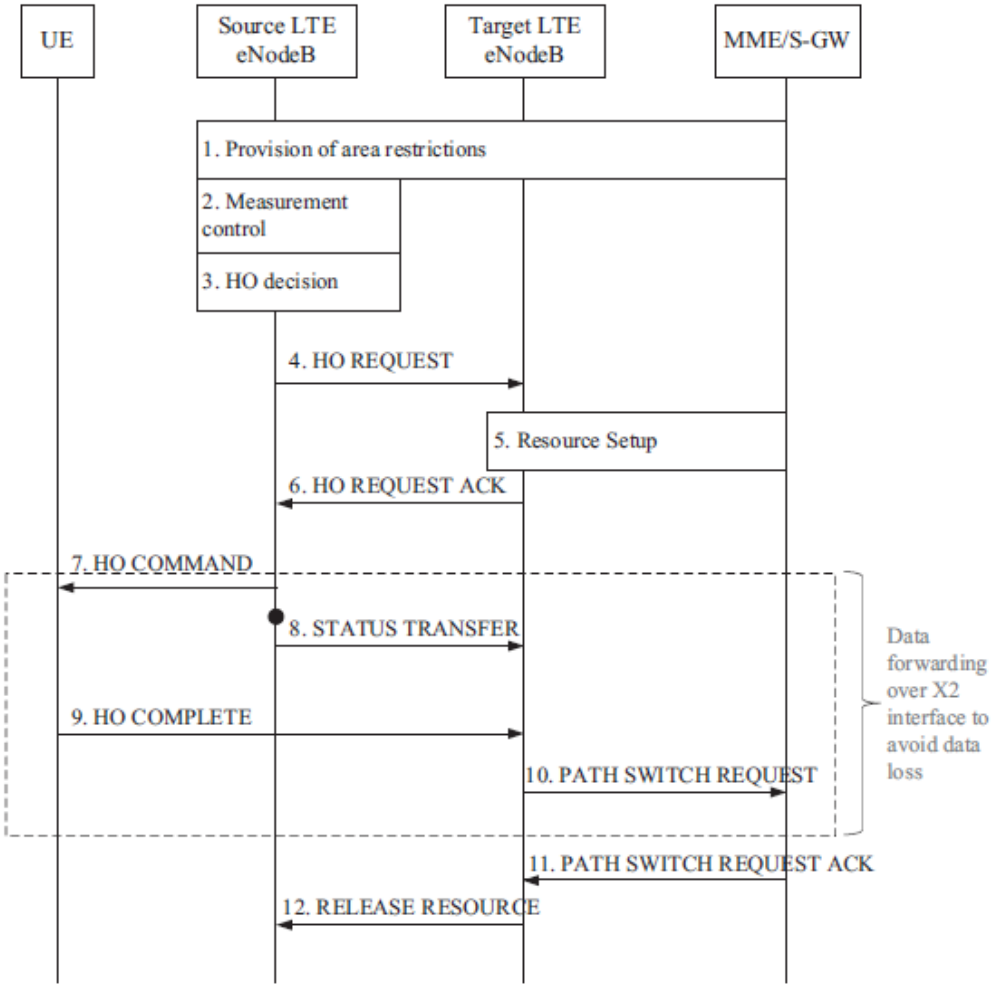


X2-AP HO Request Message

IE/Group Name	Presence	Range	IE type and reference	Semantics description	Criticality	Assigned Criticality
Message Type	M		9.2.13		YES	reject
Old eNB UE X2AP ID	M		eNB UE X2AP ID 9.2.24	Allocated at the source eNB	YES	reject
Cause	M		9.2.6		YES	ignore
Target Cell ID	M		ECGI 9.2.14		YES	reject
GUMMEI	M		9.2.16		YES	reject
UE Context Information		*1*			YES	reject
>MME UE S1AP ID	M		INTEGER ($0..2^{32}-1$)	MME UE S1AP ID allocated at the MME	–	–
>UE Security Capabilities	M		9.2.29		–	–
>AS Security Information	M		9.2.30		–	–
>UE Aggregate Maximum Bit Rate	M		9.2.12		–	–
>Subscriber Profile ID for RAT/Frequency priority	O		9.2.25		–	–
>E-RABs To Be Setup List		*1*			–	–
>>E-RABs To Be Setup Item		*1 .. <maxnoof Bearers>*			EACH	ignore
>>>E-RAB ID	M		9.2.23		–	–
>>>E-RAB Level QoS Parameters	M		9.2.9	Includes necessary QoS parameters	–	–
>>>DL Forwarding	O		9.2.5		–	–
>>>UL GTP Tunnel Endpoint	M		GTP Tunnel Endpoint 9.2.1	SGW endpoint of the S1 transport bearer. For delivery of UL PDUs.	–	–
>RRC Context	M		OCTET STRING	Includes the RRC Handover Preparation Information message as defined in subclause 10.2.2 of TS 36.331 [9].	–	–
>Handover Restriction List	O		9.2.3		–	–
>Location Reporting Information	O		9.2.21	Includes the necessary parameters for location reporting	–	–
>Management Based MDT Allowed	O		9.2.59		YES	ignore
UE History Information	M		9.2.38	Same definition as	YES	ignore

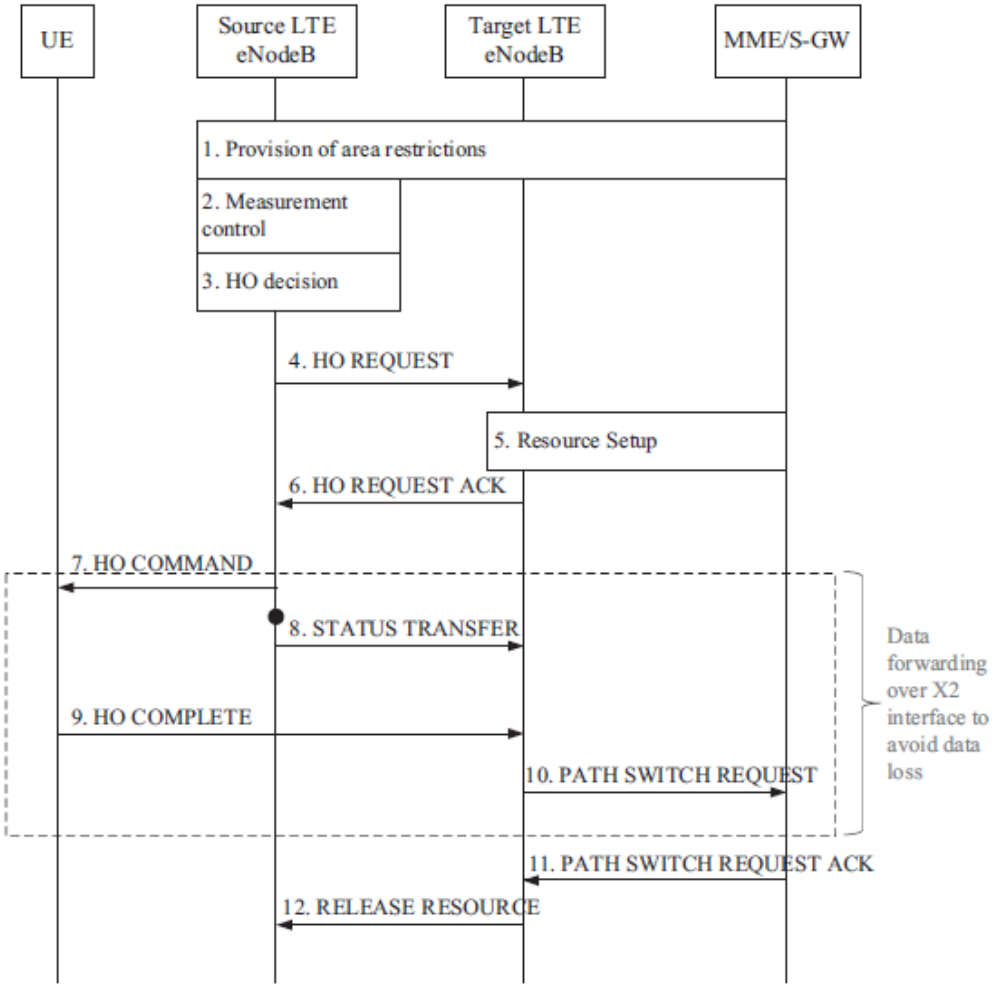
Handover Over X2

- HO over X2 can be categorized according to its resilience to packet loss:
  - Seamless
  - Lossless
- In the HO Request message, the source eNB requests for a GTP tunnel.
- In the response message, the tunnel end-point is declared.
- Seamless:
  - Packets arriving after HO REQUEST ACK are forwarded over X2 to the target eNB.
- Lossless:
  - Unacknowledged/buffered packets + packets arriving after HO REQUEST ACK are forwarded over X2 to the target eNB.



Handover Over X2

- Selective retransmission:
  - If target eNB is informed by the UE, it may not transmit some downlink packets received from source eNB.
  - Source eNB is also able to inform target eNB about unacked packets which have been acked after HO REQUEST ACK.
- Multiple preparation
  - This feature enables the source eNB to trigger the handover preparation procedure towards multiple candidate target eNBs.
  - It is transparent from UE.



Status Transfer

- Status Transfer Message includes (the following fields are present for each RAB)
  - The uplink PDCP sequence number
  - Uplink Hyper Frame Number
  - The downlink PDCP sequence number
  - Downlink Hyper Frame Number

X2-AP Status Transfer Message

IE/Group Name	Presence	Range	IE type and reference	Semantics description	Criticality	Assigned Criticality
Message Type	M		9.2.13		YES	ignore
Old eNB UE X2AP ID	M		eNB UE X2AP ID 9.2.24	Allocated at the source eNB	YES	reject
New eNB UE X2AP ID	M		eNB UE X2AP ID 9.2.24	Allocated at the target eNB	YES	reject
E-RABs Subject To Status Transfer List		*1*			YES	ignore
>E-RABs Subject To Status Transfer Item		*1 .. <maxnoof Bearers>*			EACH	ignore
>> E-RAB ID	M		9.2.23		–	–
>>Receive Status Of UL PDCP SDUs	O		BIT STRING (4096)	PDCP Sequence Number = (First Missing SDU Number + bit position) modulo 4096 0: PDCP SDU has not been received. 1: PDCP SDU has been received correctly.	–	–
>> UL COUNT Value	M		COUNT Value 9.2.15	PDCP-SN and Hyper Frame Number of the first missing UL SDU	–	–
>> DL COUNT Value	M		COUNT Value 9.2.15	PDCP-SN and Hyper frame number that the target eNB should assign for the next DL SDU not having an SN yet	–	–