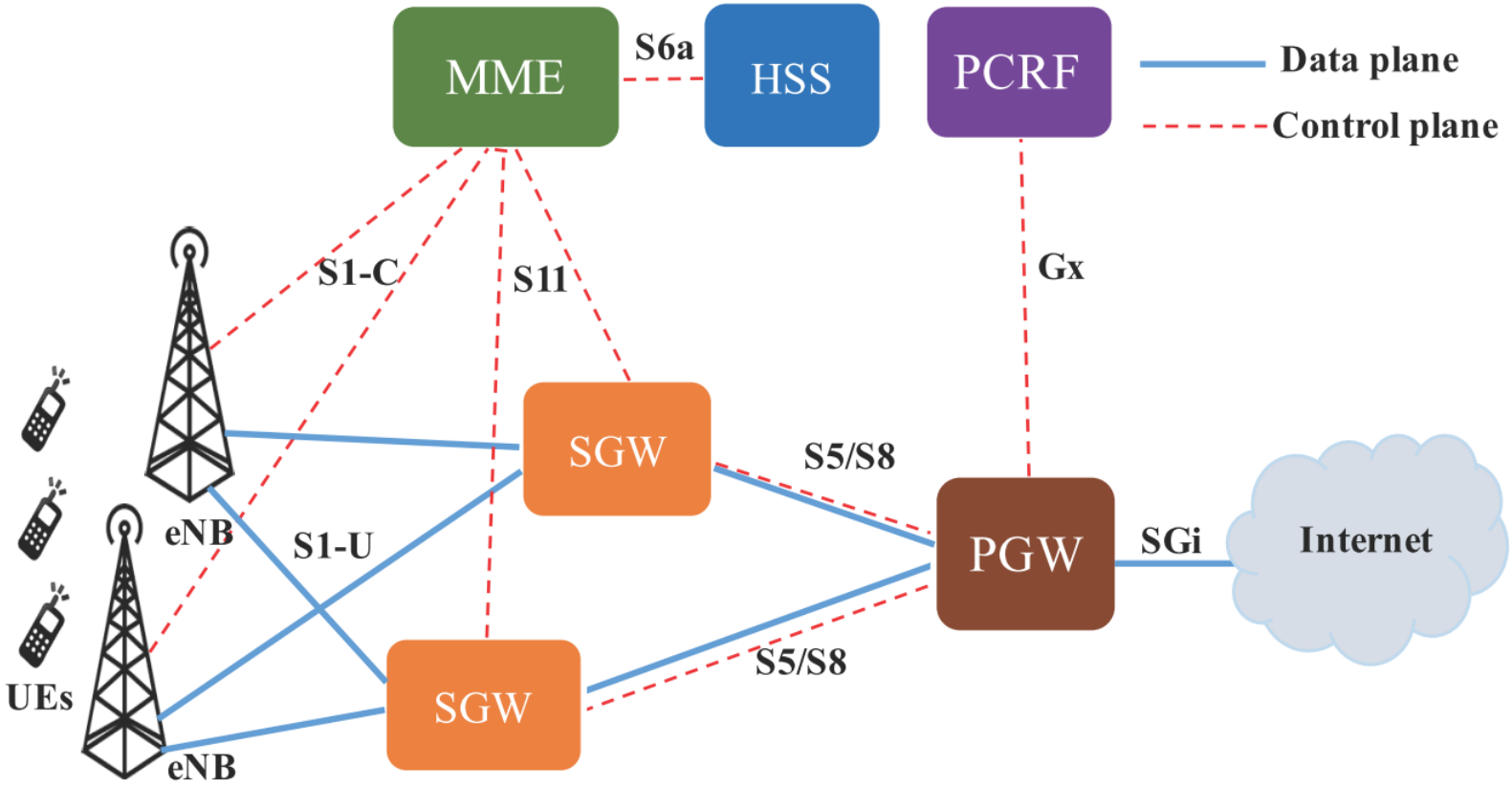
控制平面與使用者平面分離機制
CUPS: Control and User Plane Separation

陳懷恩 教授
國立宜蘭大學 資訊工程系
TEL: +886-3-9317309
FAX: +886-3-9353804
Email: wechen@niu.edu.tw

Introduction

- Many mobile operator's user data traffic has been **doubling on an annual** basis in recent years because of the rapidly increasing use of smart devices, the proliferation of video and other applications.
- To improve the core network, the **Software Defined Networking** (SDN) and **Network Function Virtualization** (NFV) technologies are proposed to change the network function development and the network architecture evolution.
- CUPS is **Control and User Plane Separation** of EPC nodes and provides the architecture enhancements for the separation of functionality in the Evolved Packet Core's Serving Gateway, PDN Gateway and Traffic Detection Function.
- CUPS enables flexible network deployment and operation, by **distributed** or **centralized** deployment and the independent **scaling** between control plane and user plane functions.

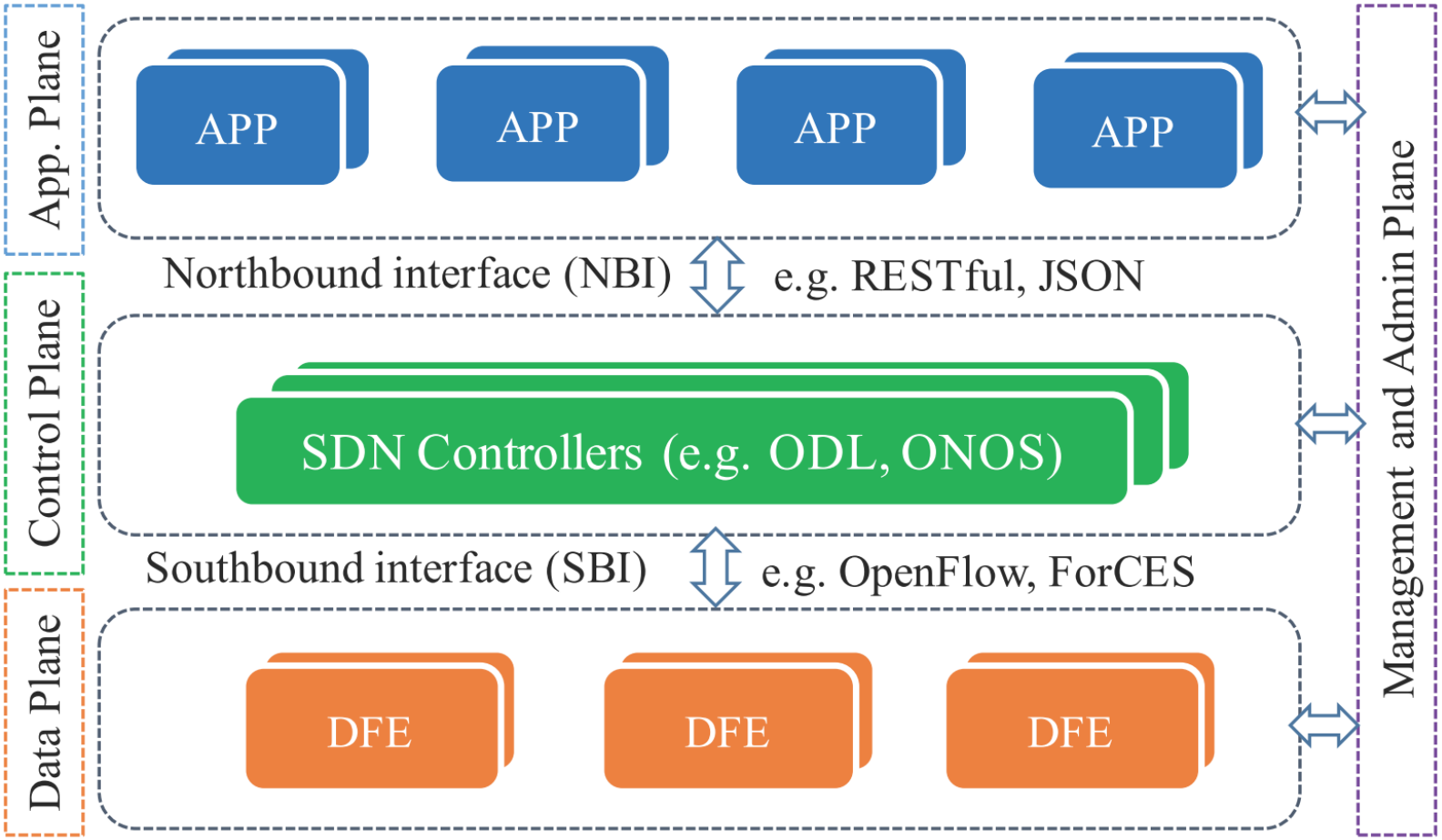
EPS in LTE-Advance



UE: User Equipment
eNB: evolved Node B
SGW: Sereving Gateway
PGW: Packet Data Network Gateway

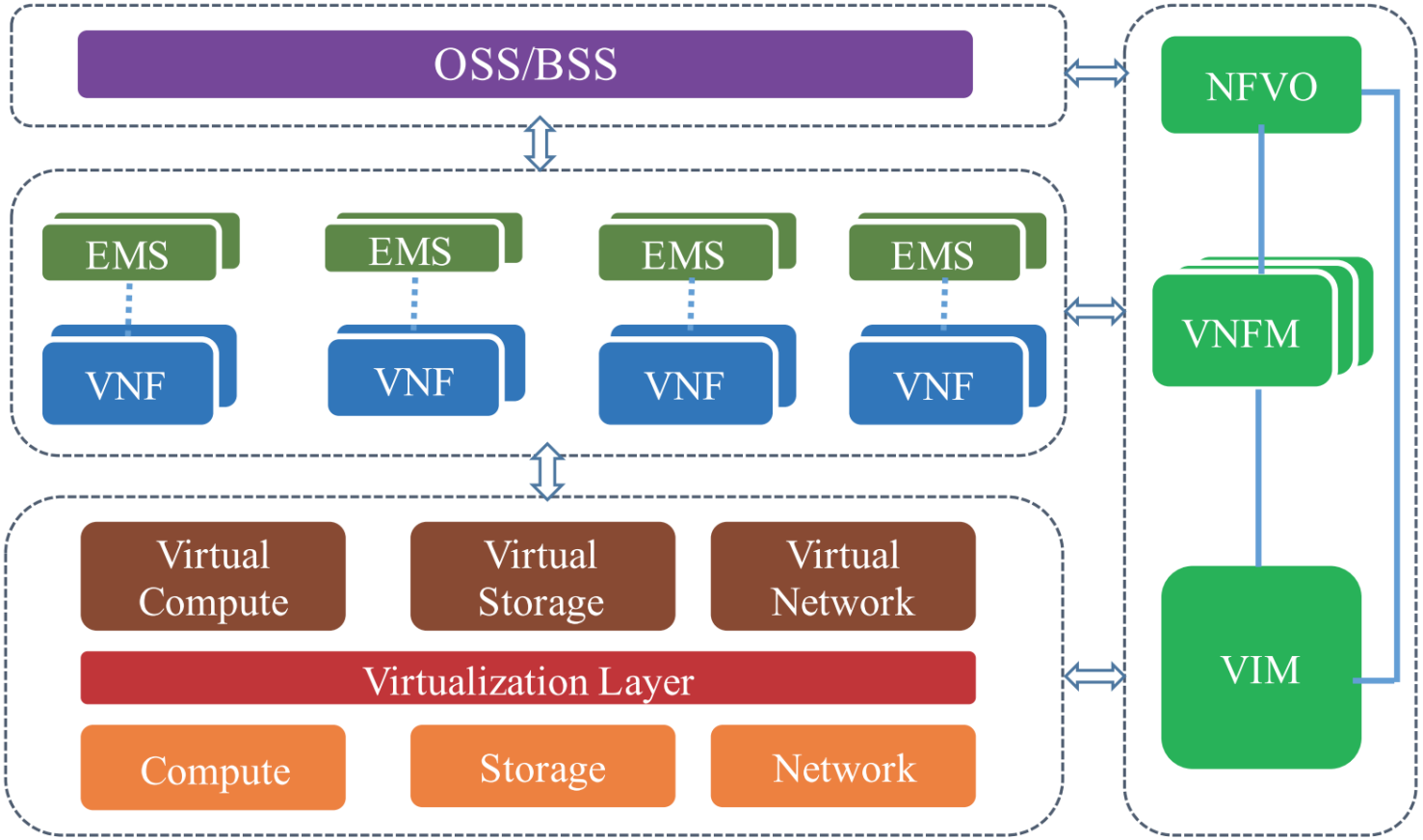
MME: Mobility Management Entity
HSS: Home Subscriber Server
PCRF: Policy Charging Rule Function

SDN Architecture



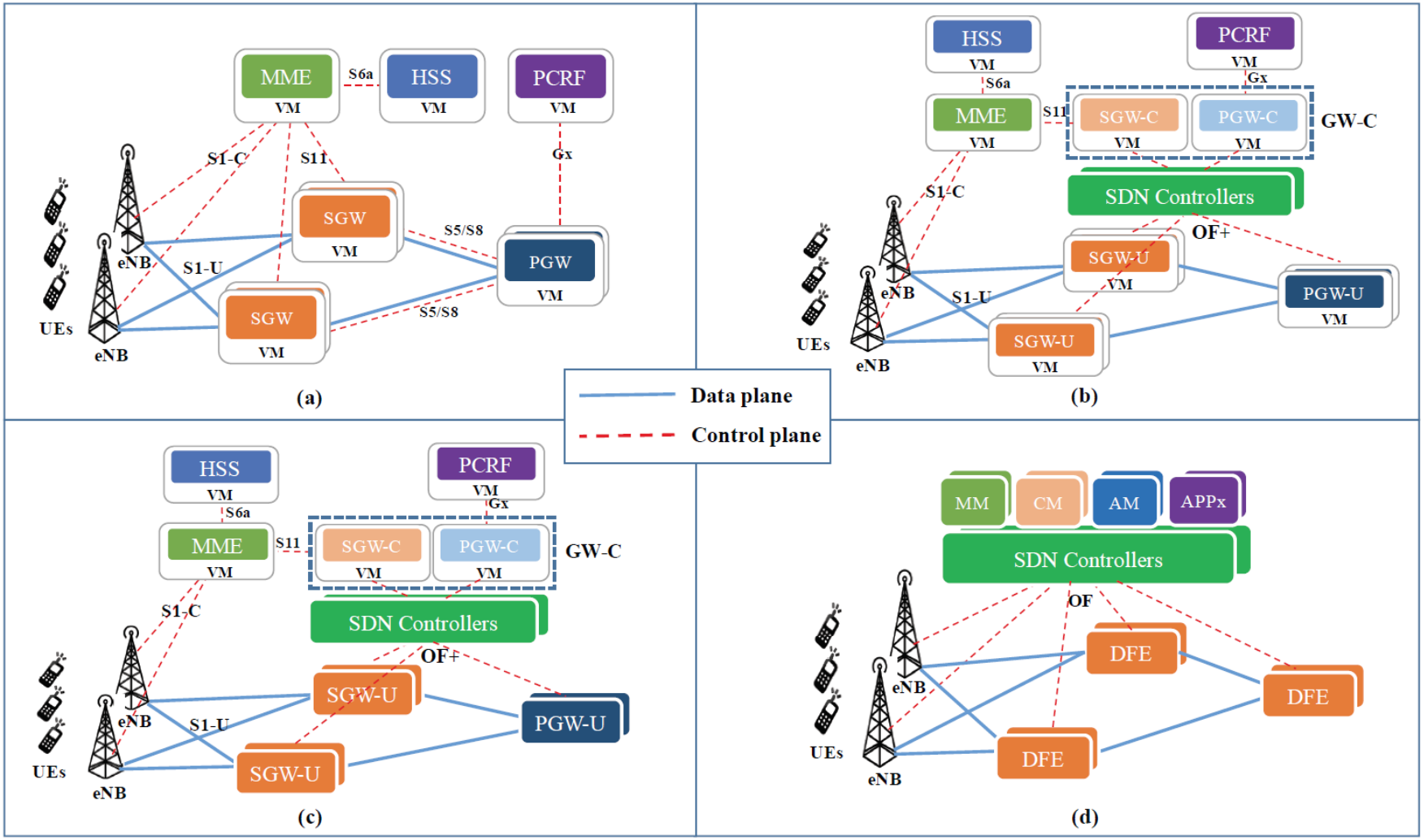
DFE: Data Forwarding Elements **SDN: Software Defined Network**

NFV Architecture



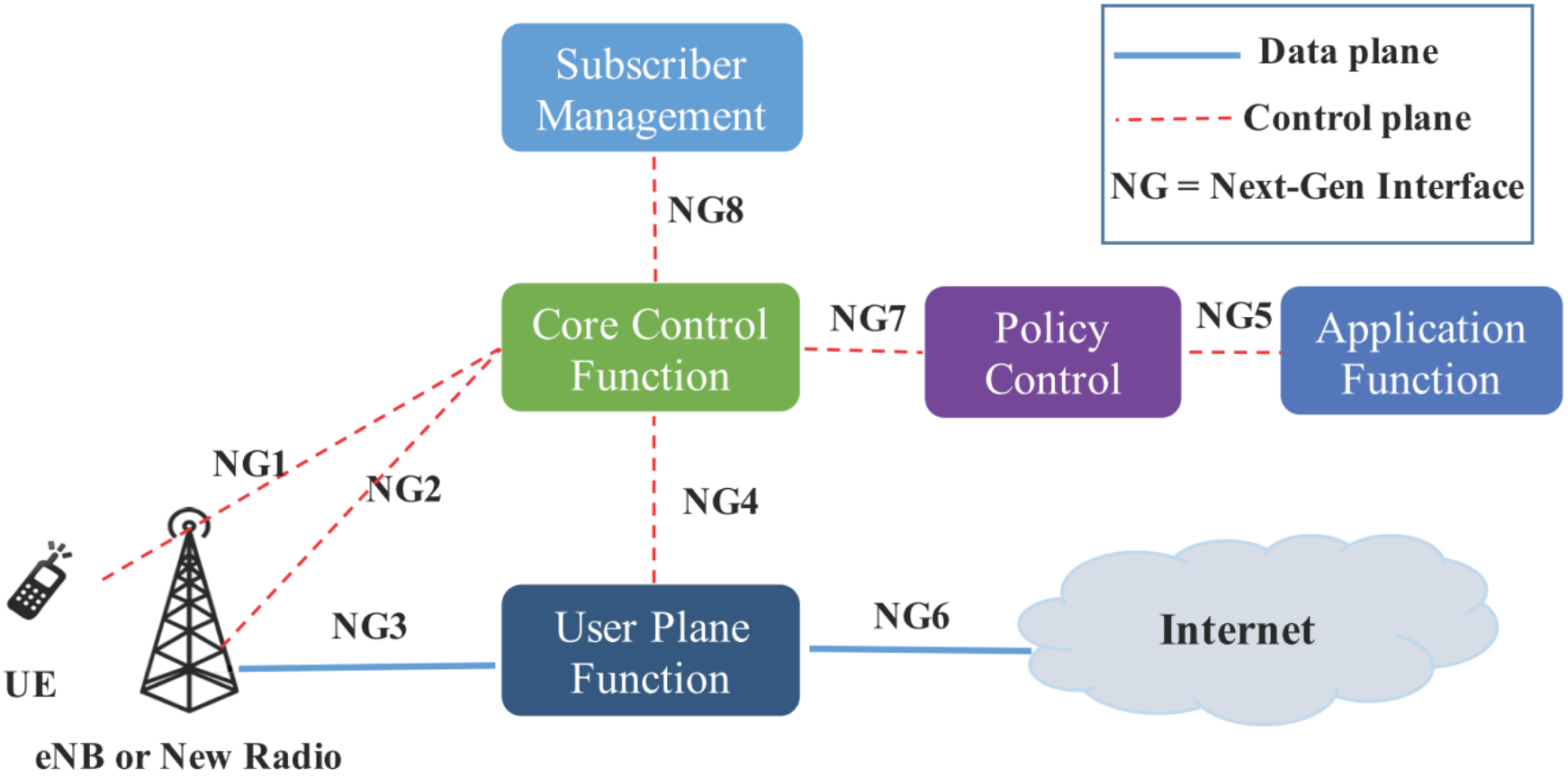
OSS/BSS: Operational and Business Support Systems
EMS: Element Management System
VNF: Virtual Network Functions
VNFM: VNF Manager VNFO: VNF Orchestrator
VIM: Virtualized Infrastructure Manager

SDN/NFV Architecture of Mobile Networks



（資料來源：[3]）

NextGen Core Network Architecture



Core Network Enhancement

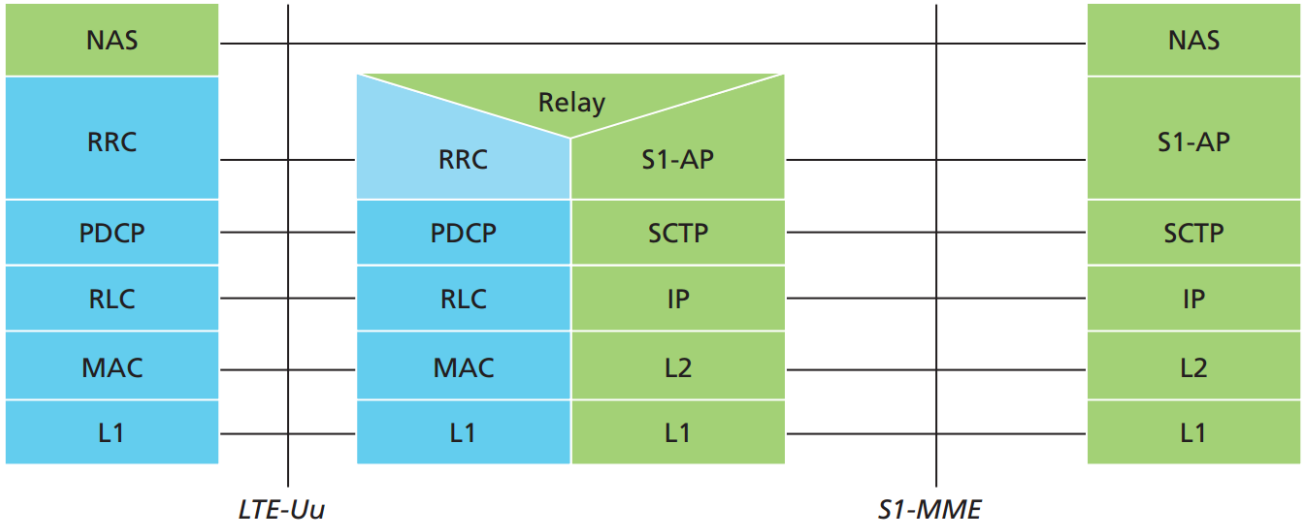
- **Architecture**
  - Revolution or Evolution
- **SDN/NFV Deployment**
  - SDN-only, NFV-only, SDN+NFV
- **Deployment Strategy**
  - Centralized or Distributed
- **Network Functions**
  - Virtualized
  - Splitting
  - Merging

CUPS Benefits

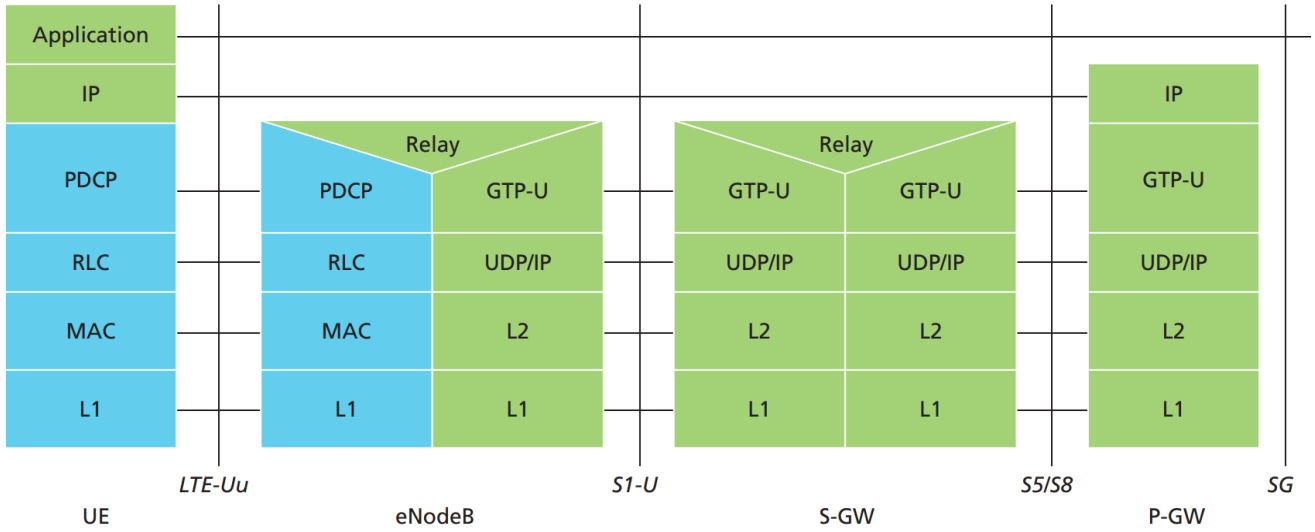
- Reducing Latency on application service, e.g. by selecting User plane nodes which are closer to the RAN or more appropriate for the intended UE usage type without increasing the number of control plane nodes.
- Supporting Increase of Data Traffic, by enabling to add user plane nodes without changing the number of SGW-C, PGW-C and TDF-C in the network.
- Locating and Scaling the CP and UP resources of the EPC nodes independently.
- Independent evolution of the CP and UP functions.
- Enabling Software Defined Networking to deliver user plane data more efficiently.

User Plane and Control Plane

Control Plane



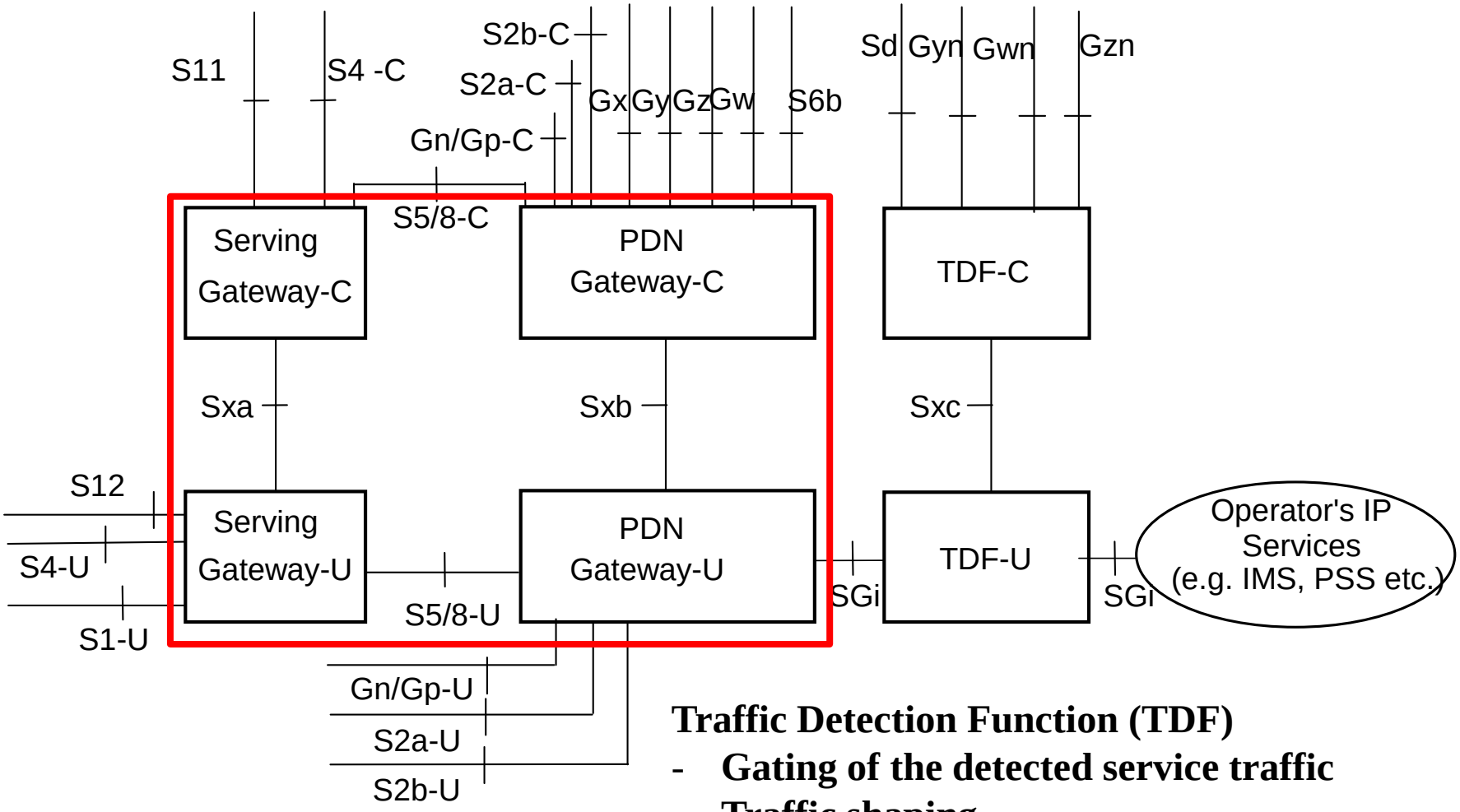
User Plane



High-level Principles of CUPS

- The CP function terminates the Control Plane protocols: GTP-C, Diameter.
- A CP function can interface multiple UP functions, and a UP function can be shared by multiple CP functions.
- An UE is served by a single SGW-C but multiple SGW-Us can be selected for different PDN connections.
- The CP function controls the processing of the packets in the UP function by provisioning a set of rules in Sx sessions, i.e. Packet Detection Rules, Forwarding Action Rules, QoS Enforcement Rules, Usage Reporting Rules.
- All the 3GPP features impacting the UP function (PCC, Charging, Lawful Interception, etc) are supported, while the UP function is designed as much as possible 3GPP agnostic. For example, the UPF is not aware of bearer concept.
- Charging and Usage Monitoring are supported by instructing the UP function to measure and report traffic usage, using Usage Reporting Rule(s).
- A legacy SGW, PGW and TDF can be replaced by a split node without effecting connected legacy nodes.
- The CP/UP function is responsible for GTP-u F-TEID allocation.

SGW/PGW CUPS介面

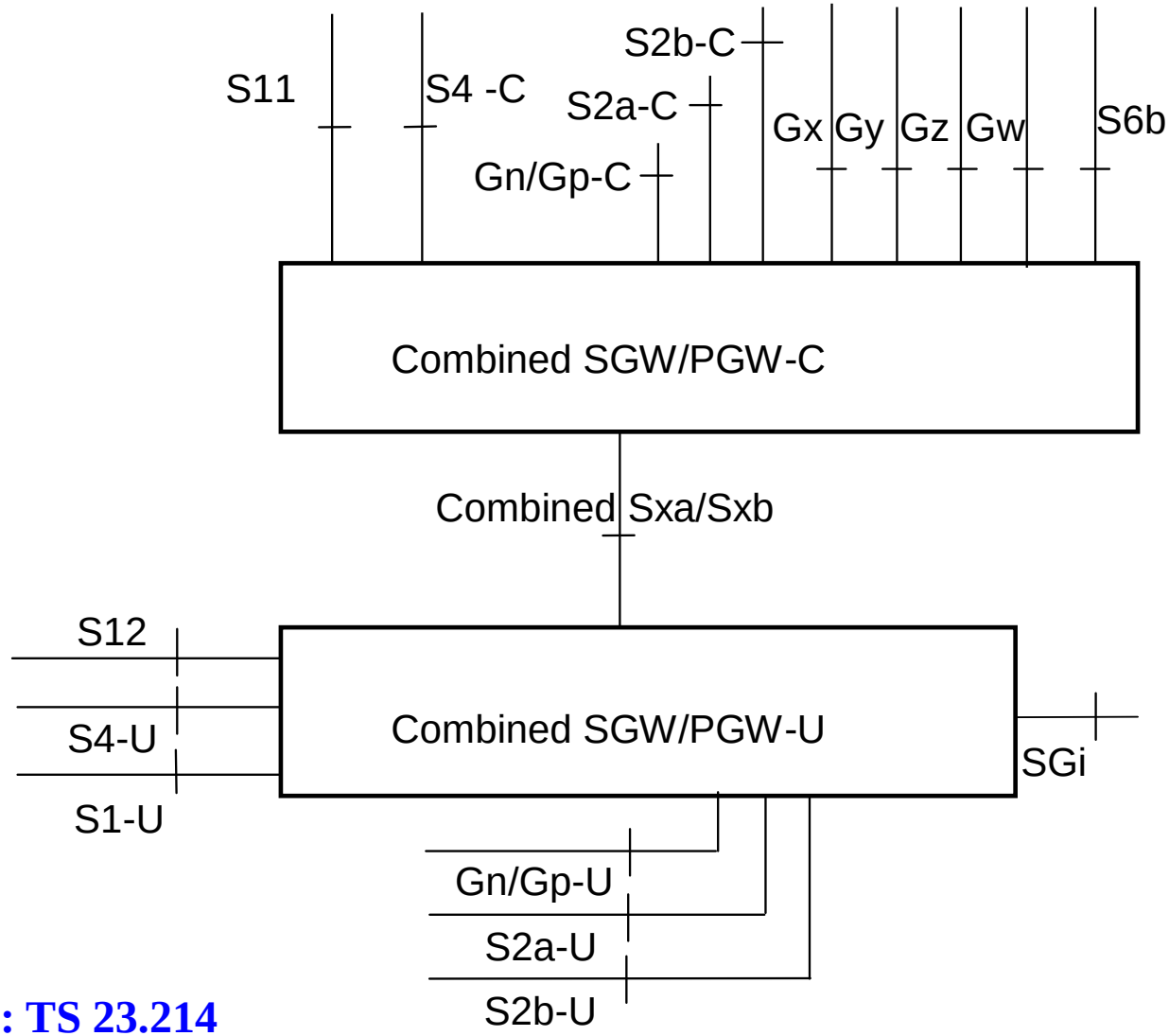


Traffic Detection Function (TDF)

- **Gating of the detected service traffic**
- **Traffic shaping**
- **Redirecting**

Source: TS 23.214

Combined SGW/PGW



Source: TS 23.214

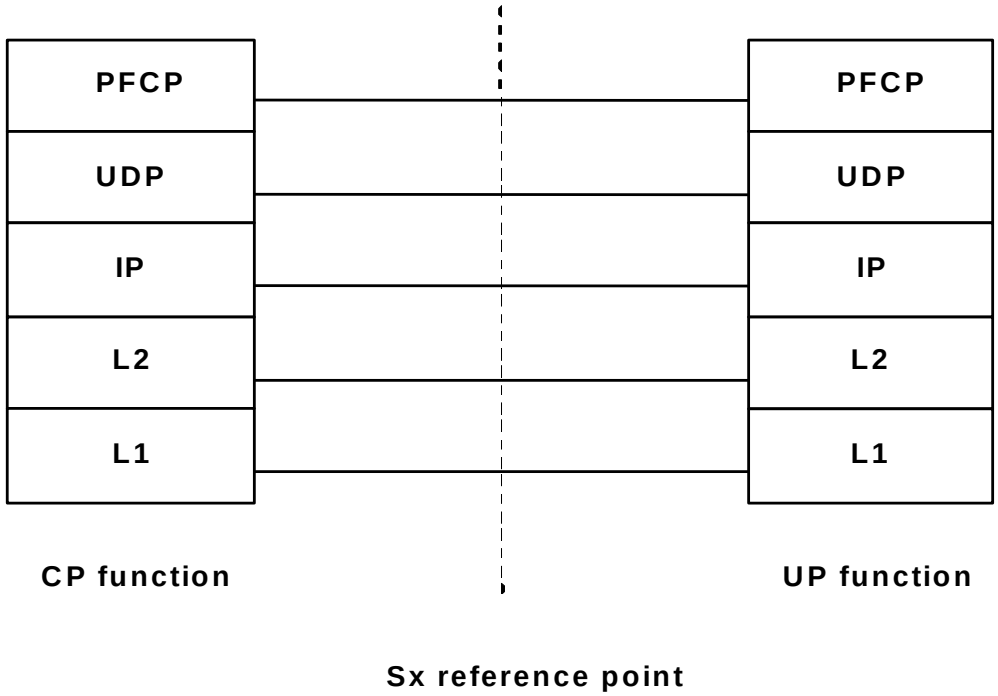
New Protocol (PFCP) on Sx (1/2)

- An Sx Association shall be setup between a CP function and a UP function before establishing the Sx sessions. The Sx association may be established by the CP function (**mandatory**) or by the UP function (**optional**).
- An Sx session is established on the UP function to provision rules instructing the UP function how to process a certain traffic.
- The Sx Session may correspond to an individual PDN connection, TDF session or a standalone session, e.g. forwarding DHCP/DIAMETER signalling between the PGW-C and PDN (SGi).
- Sx Node related procedures:
  - Sx Association Setup / Update / Release procedures;
  - Heartbeat procedure to check that a PFCP peer is alive;
  - Load Control and Overload Control procedures to balance the load across UP functions and reduce signalling towards UP function in overload;
  - Sx PFD Management procedure to provision PFDs (Packet Flow Descriptions) for one or more Application Identifiers in the UP function.

New Protocol (PFCP) on Sx (2/2)

- Sx Session related procedures:
  - Sx Session Establishment / Modification / Deletion procedures;
  - Sx Session Report procedure to report traffic usage or specific events (e.g. arrival of a DL data packet, start of an application).
- Data Forwarding between the CP and UP functions is supported by GTP-U encapsulation, e.g. for forwarding RS/RA/DHCP signalling between UE and PGW-C, or forwarding user plane data to the SGW-C when buffering of DL packets is done in the CP function.
- PFCP supports reliable delivery of messages.
- New DNS procedures are defined for UP function selection. The CP function selects a UP function based on DNS or local configuration, the capabilities of the UP function and the overload control information provided by the UP function.

Control Plane stack over Sx

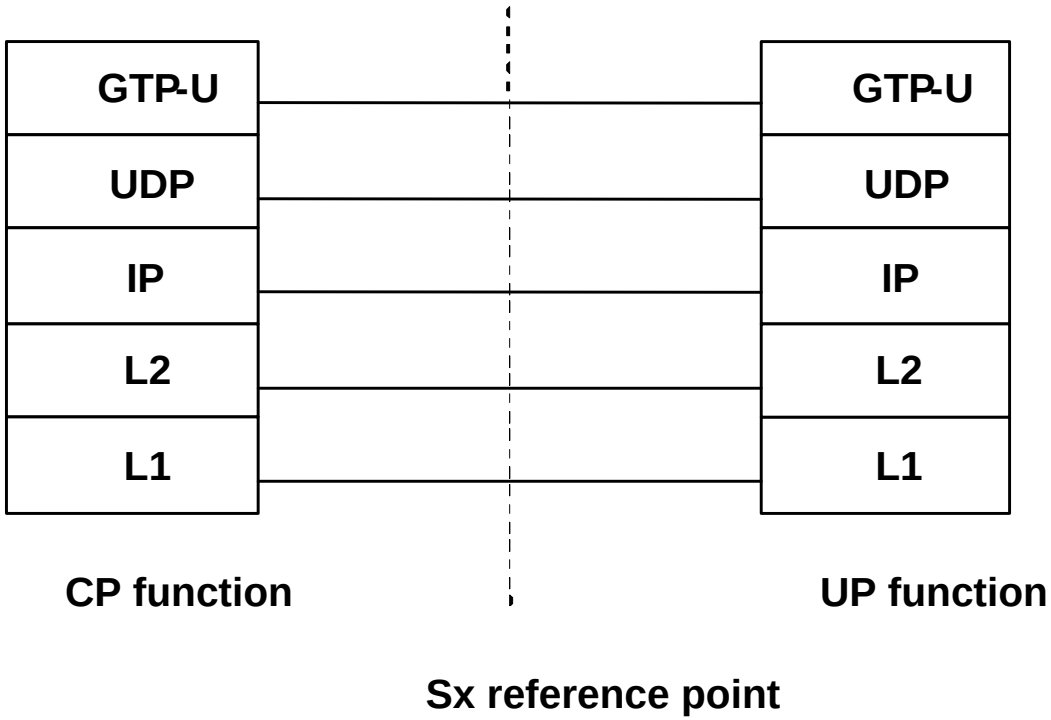


Packet Forwarding Control Protocol (PFCP)

Source: TS 29.244

Note: Message Format of PFCP is defined in TS29.244.

User Plane stack over Sx



Source: TS 29.244

User Plane stack over Sx

- The PGW-U shall support forwarding of the UE IP address management related messages (e.g. Router Solicitation) to the PGW-C, when they are received via the user plane signalling from the UE or from the external PDN.
- For IPv6 default prefix management via IPv6 stateless address auto-configuration (3GPP TS 23.401): PGW-C shall configure PGW-U to forward Router Solicitation and Neighbor Solicitation messages from the UE to the PGW-C.
- The PGW-C shall forward Router Advertisement and Neighbor Advertisement messages to the PGW-U for relaying them to the UE.

UDP Port Numbers for PFCP

- A User Datagram Protocol (**UDP**) compliant with IETF RFC 768 [4] shall be used.
- The UDP **Destination** Port number for a **PFCP** Request message shall be **8805**.
- The UDP **Source** Port for a Request message is a locally allocated port number at the sending entity.
- The UDP **Destination** Port value of a Response message shall be the value of the UDP **Source** Port of the corresponding Request message.
- The UDP **Source** Port of a Response message shall be the value from the UDP **Destination** Port of the corresponding message.

Functional Split of SGW

Main functionality	Sub-functionality	SGW-C	SGW-U
Session management	1. Resource management for bearer resources	X	X
	2. IP address and TEID assignment for GTP-U	X	X
	3. Packet forwarding		X
	4. Transport level packet marking		X
Support for UE mobility	1. Forwarding of "end marker" (as long as user plane to source eNB exists)		X
	2. Sending of "end marker" after switching the path to target node	X	X
	3. Forwarding of buffered packet	X	X
	4. Change of target GTP-U endpoint within 3GPP accesses	X	
	5. Change of target GTP-U endpoint between 3GPP and non-3GPP access		
S1-Release / Buffering / Downlink Data Notification	1. ECM-IDLE mode DL packet buffering; Triggering of Downlink Data Notification message generation per bearer; Inclusion of DSCP of packet in DDN message for Paging Policy Differentiation	X	X
	2. Delay Downlink Data Notification Request	X	
	3. Extended buffering of downlink data when the UE is in a power saving state and not reachable (high latency communication); dropping of downlink data (if MME has requested SGW to throttle downlink low priority traffic and if the downlink data packet is received on such a bearer.	X	X
	4. PGW pause of charging procedure based on operator policy/configuration the SGW	X	
NBIFOM	Non-PCC aspects of NBIFOM	X	
Inter-operator accounting	1. Accounting per UE and bearer		X
	2. Interfacing OFCS through reference points specified in TS 32.240 [9]	X	
Lawful interception	Interfacing LI functions through reference points specified in TS 33.107 [10] and performing LI functionality	X	X

Functional Split of PGW (1/2)

Main functionality	Sub-functionality	PGW-C	PGW-U
Session management	1. Resource management for bearer resources	X	X
	2. IP address and TEID assignment for GTP-U	X	X
	3. Packet forwarding		X
	4. Transport level packet marking		X
UE IP address management	1. IP address allocation from local pool	X	
	2. DHCPv4 / DHCPv6 client	X	
	3. DHCPv4 / DHCPv6 server	X	
	4. Router advertisement, router solicitation, neighbour advertisement, neighbour solicitation (as in RFC 4861)	X	
Support for UE mobility	2. Sending of "end marker" after switching the path to target node	X	X
	4. Change of target GTP-U endpoint within 3GPP accesses	X	
	5. Change of target GTP-U endpoint between 3GPP and non-3GPP access	X	
S1-Release / Buffering / Downlink Data Notification	4. PGW pause of charging procedure based on operator policy/configuration the SGW (failed paging, abnormal radio link release, number/fraction of packets/bytes dropped at SGW)	X	
Bearer/APN policing	1. UL/DL APN-AMBR enforcement		X
	2. UL/DL bearer MBR enforcement (for GBR bearer)		X
	3. UL/DL bearer MBR enforcement (for nonGBR bearer on Gn/Gp interface)		X
PCC related functions	1. Service detection (DPI, IP-5-tuple)		X
	2. Bearer binding (bearer QoS & TFT)	X	
	3. UL bearer binding verification and mapping of DL traffic to bearers		X

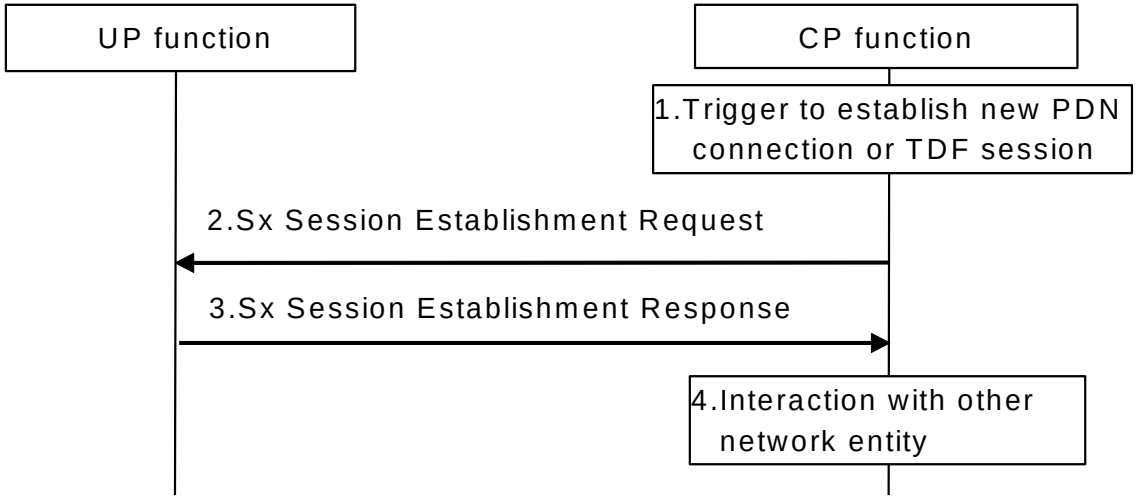
Functional Split of PGW (2/2)

Main functionality	Sub-functionality	PGW-C	PGW-U
PCC related functions	1. Service detection (DPI, IP-5-tuple)		X
	2. Bearer binding (bearer QoS & TFT)	X	
	3. UL bearer binding verification and mapping of DL traffic to bearers		X
	4. UL and DL service level gating		X
	5. UL and DL service level MBR enforcement		X
	6. UL and DL service level charging (online & offline, per charging key)	X	X
	7. Usage monitoring	X	X
	8. Event reporting (including application detection)	X	X
	10. Redirection	X	X
	11. FMSS handling		X
	12. PCC support for NBIFOM	X	
	14. Predefined PCC/ADC rules activation and deactivation	X	X
	15. PCC support for SDCI	X	X
NBIFOM	Non-PCC aspects of NBIFOM	X	
Inter-operator accounting (counting of volume and time)	1. Accounting per UE and bearer		X
	2. Interfacing OFCS through reference points specified in TS 32.240 [9]	X	
Lawful interception	Interfacing LI functions through reference points specified in TS 33.107 [10] and performing LI functionality	X	X
Packet screening function			X
RADIUS / Diameter on SGi		X	X

Forwarding for Different Scenarios

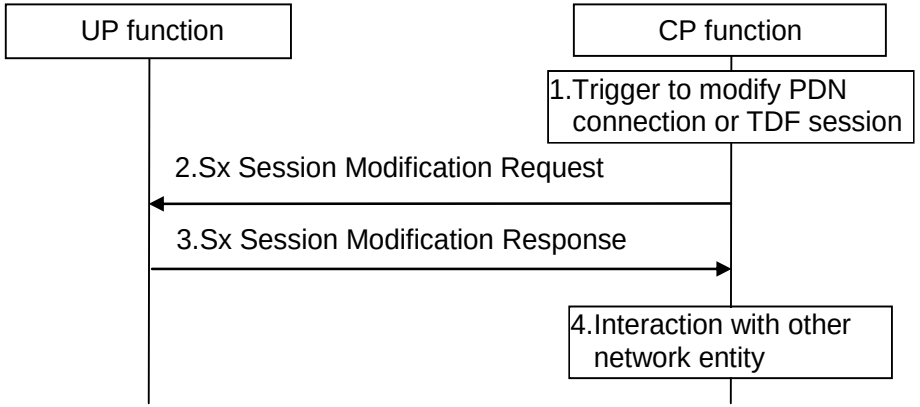
	Scenario description	Forwarding target and operation	Applicable to
1	Forwarding of user-plane between UE and PDN, including mapping onto GTP-U tunnels and mapping between GTP-U tunnels	GTP-U encapsulation information (F-TEID)	SGW, PGW
2	Forwarding of user-plane packets from UE and CP function (e.g. RS/RA, DHCPv4/v6, traffic subject to HTTP redirect etc)	Information that the CP function is source/target (CP function IP address)	PGW
3	Forwarding of packets from the external PDN / SGi and the CP function (e.g. for RADIUS, Diameter and DHCP signalling, traffic subject to HTTP redirect etc)	Information that the CP function is source/target (CP function IP address)	PGW
4	Forwarding of packets subject to buffering in CP function	Information that the CP function is source/target (CP function IP address)	SGW
5	Forwarding of packets between the UP function and the SGi-LAN for Flexible Mobile Service Chaining	Reference to a predefined traffic steering configuration (e.g. Traffic-Steering Policy identifier)	PGW, TDF

Sx Session Establishment



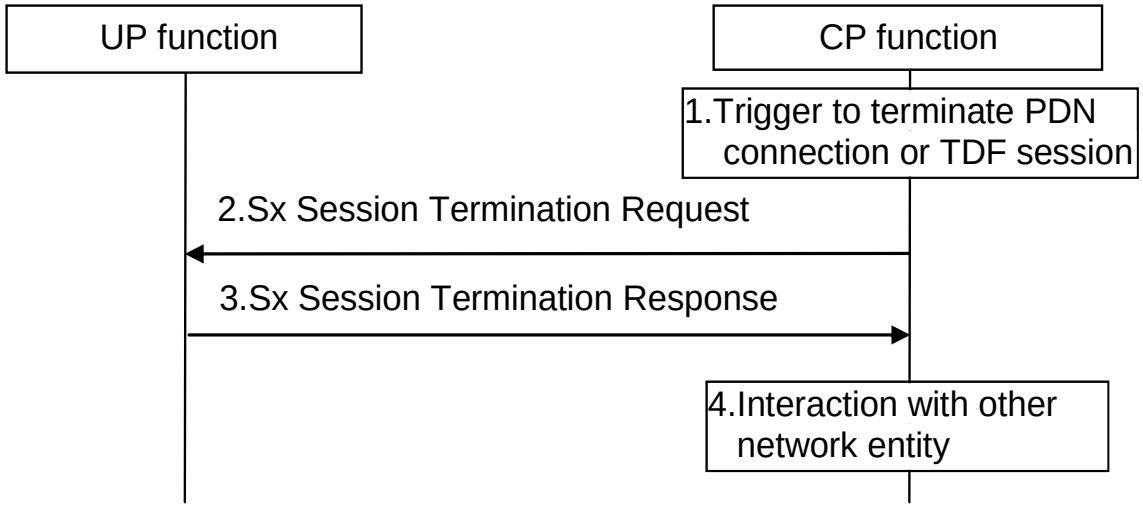
1. CP function receives the trigger to establish a new PDN connection or TDF session from a peer CP function, an MME or a PCRF.
2. The CP function sends an Sx session establishment request message to the UP function that contains the structured control information which defines how the UP function needs to behave.
3. The UP function responds with an Sx session establishment response message containing any information that the UP function has to provide to the CP function in response to the control information received.
4. The CP function interacts with the network entity which triggered this procedure (e.g. a peer CP function, an MME or a PCRF).

Sx Session Modification



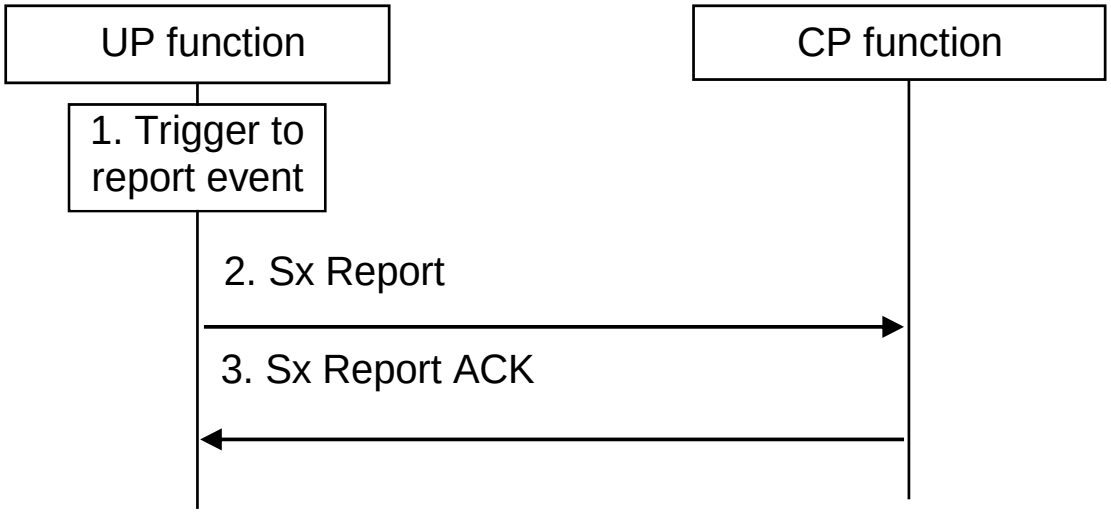
1. CP function receives the trigger to modify the existing PDN connection or TDF session from a peer CP function, an MME or a PCRF.
2. The CP function sends an Sx session modification request message to the UP function that contains the update for the structured control information which defines how the UP function needs to behave.
3. The UP function identifies the Sx session context to be modified by the Session ID. Then, the UP function updates the parameters of this Sx session context according to the list of parameters sent by the CP function. The UP function responds with an Sx session modification response message containing any information that the UP function has to provide to the CP function in response to the control information received.
4. The CP function interacts with the network entity which triggered this procedure (e.g. a peer CP function, an MME or a PCRF).

Sx Session Termination Procedure



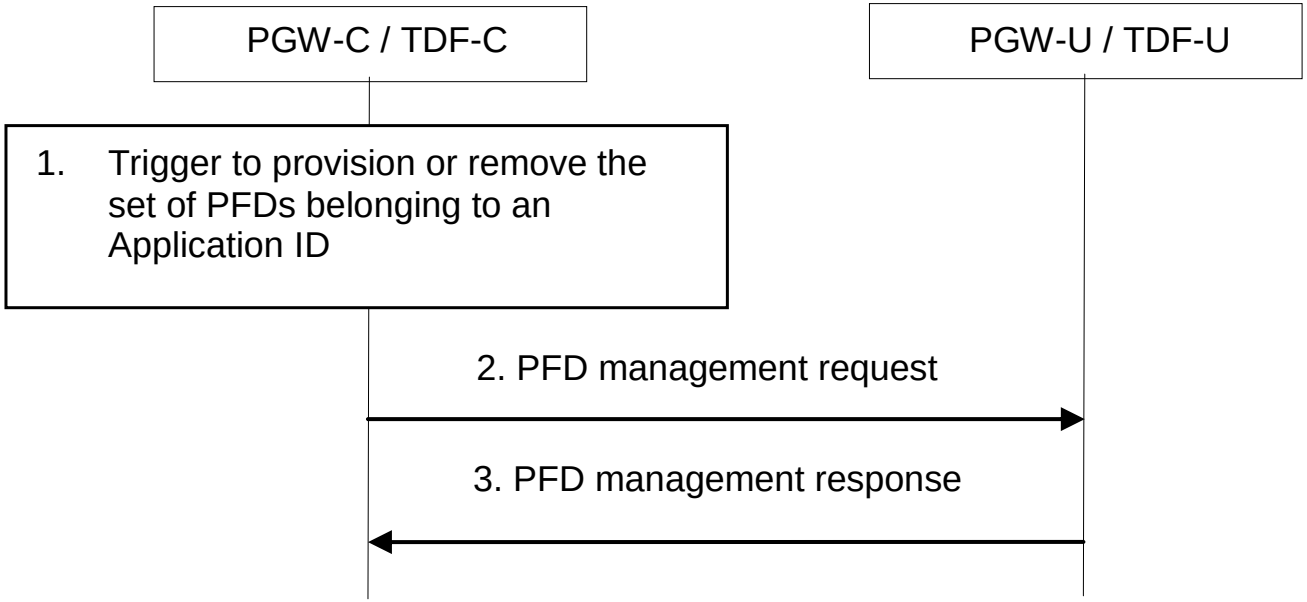
1. CP function receives the trigger to terminate the existing PDN connection or TDF session from a peer CP function, an MME or a PCRF.
2. The CP function sends an Sx session termination request message to the UP function.
3. The UP function identifies the Sx session context to be terminated by the Session ID and removes the whole session context. The UP function responds with an Sx session termination response message containing any information that the UP function has to provide to the CP function.
4. The CP function interacts with the network entity which triggered this procedure (e.g. a peer CP function, an MME or a PCRF).

Sx Session Level Reporting Procedure



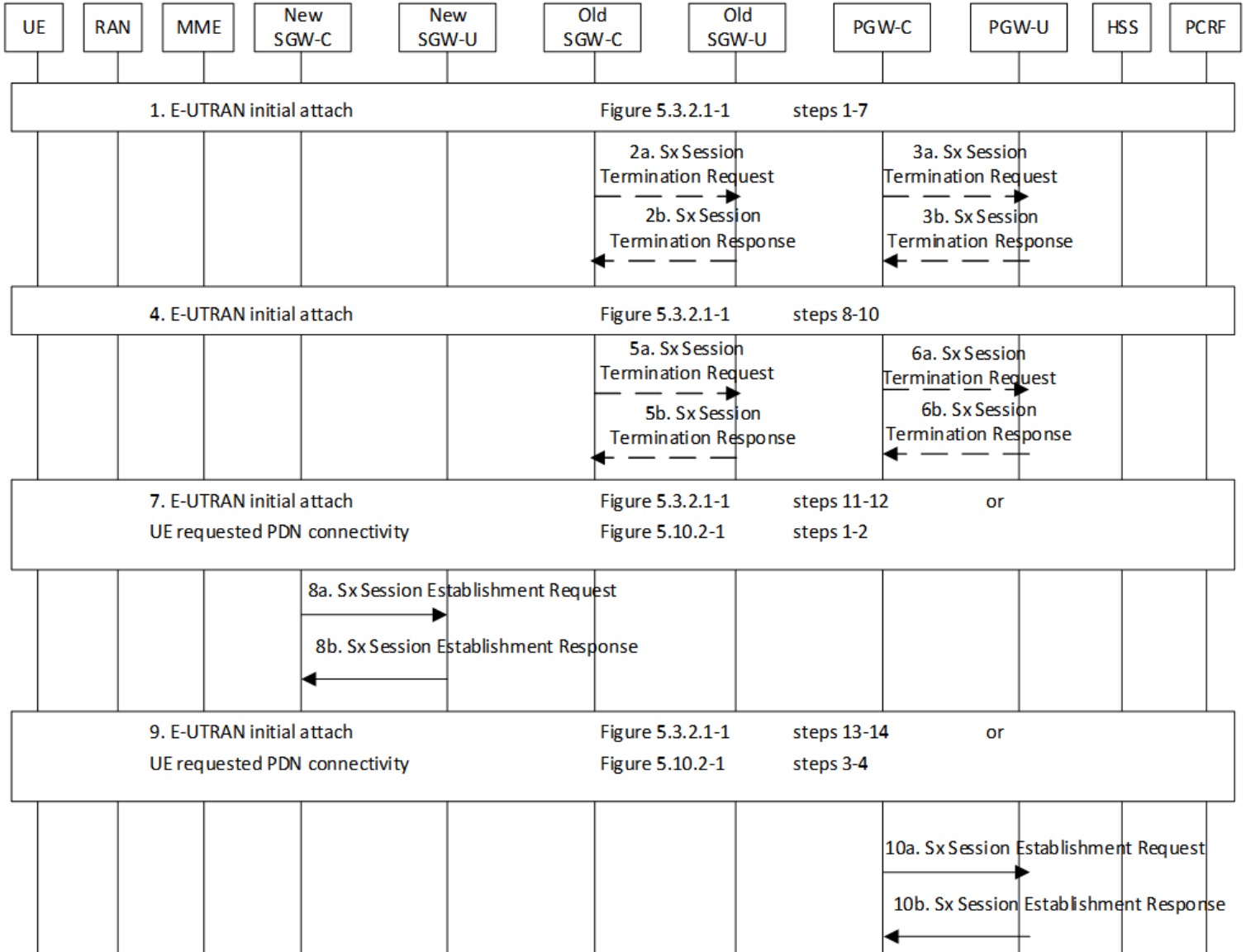
1. The UP function detects that an event has to be reported.The CP function sends an Sx session termination request message to the UP function. (Usage report, Start/Stop of traffic detection, Detection of 1st Downlink Data for Idle-Mode UE)
2. The UP function sends an Sx report message (Session ID, list of [Reporting trigger, Measurement information]) to the CP function.
3. The CP function identifies the Sx session context based on the received Session ID and applies the reported information for the corresponding PDN connection IP-CAN session, TDF session or TDF in unsolicited reporting mode. The CP function responds with an Sx report ACK message.

Sx PFD Management Procedure

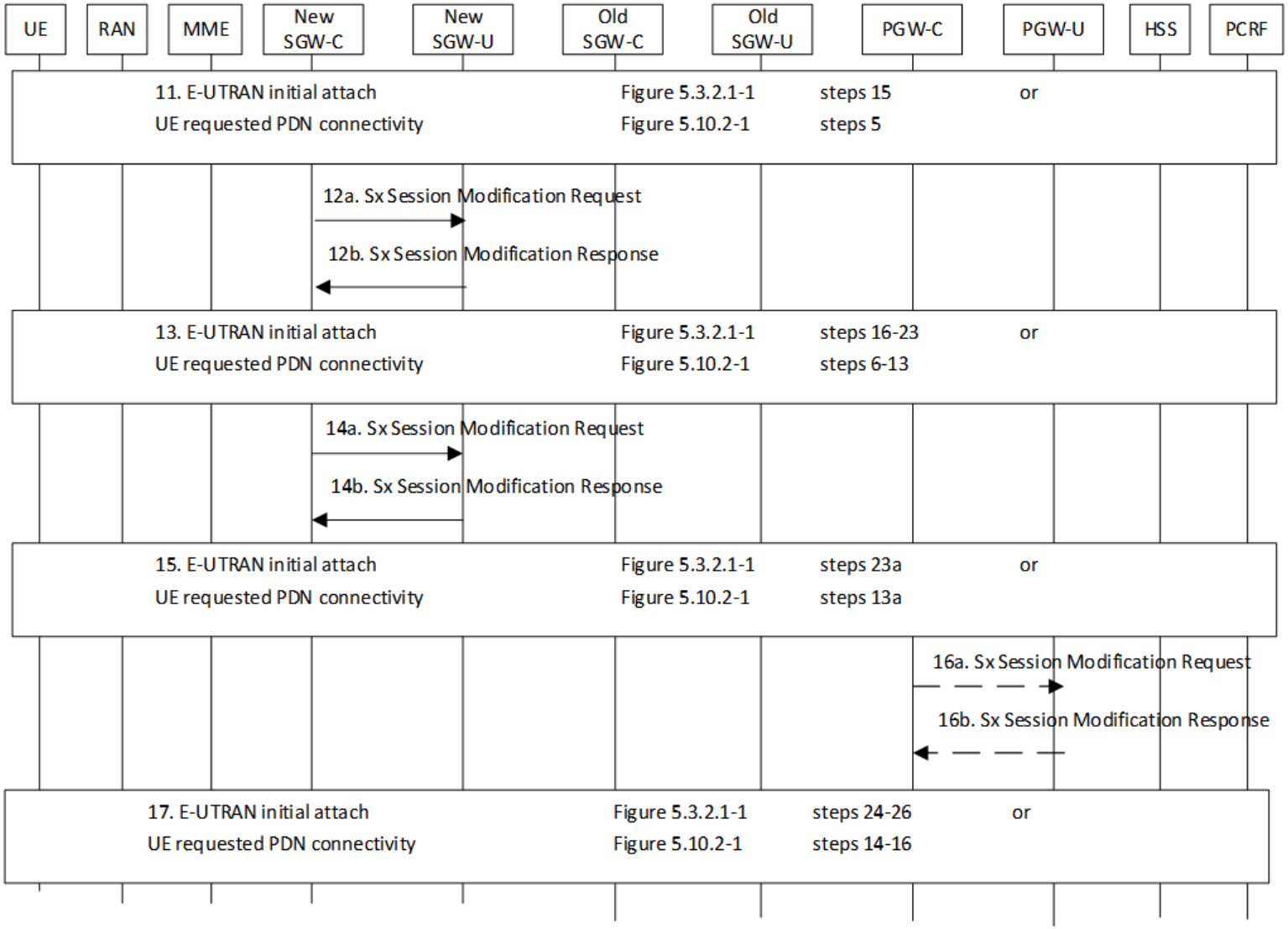


1. The CP function is triggered to provision or remove the PFD set belonging to an Application ID as described in clause 5.11.4.
2. The CP function sends a PFD management request message to the UP function to provision/remove the PFD set corresponding to the Application ID.
3. The UP function acknowledges by responding with a PFD management response message.

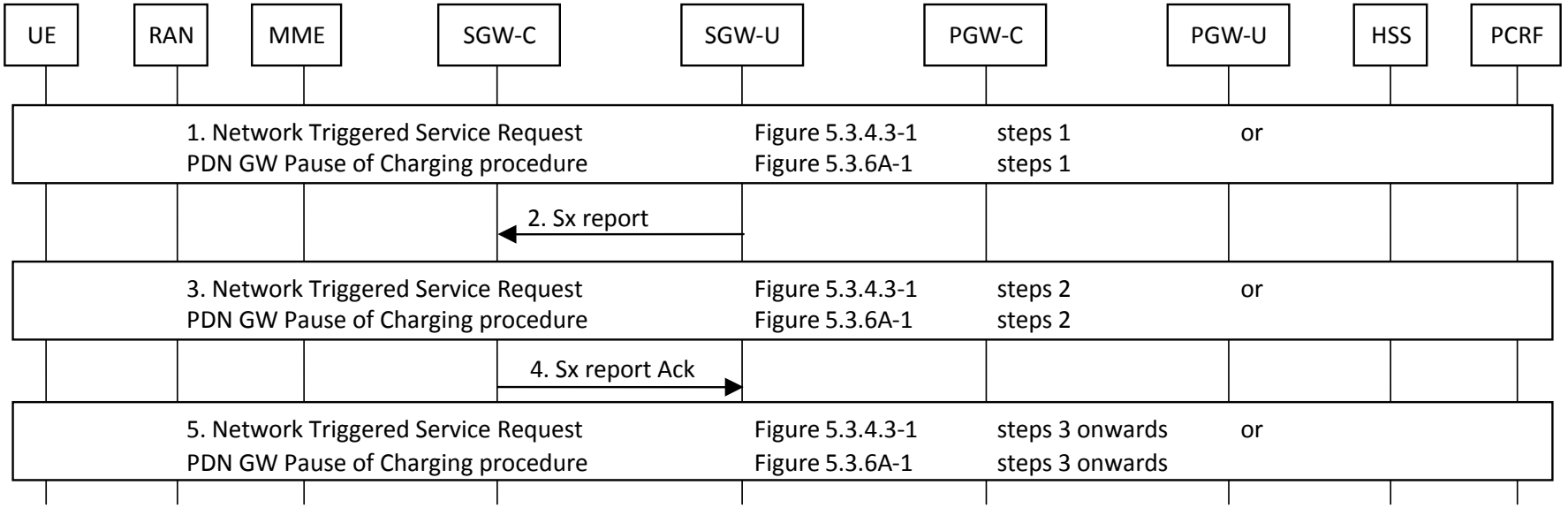
CP and UP Interactions during PDN Connection Establishment



CP and UP Interactions during PDN Connection Establishment



CP and UP Interaction when DL data is buffered in UP



1. Procedure as listed in this step is initiated as specified in the relevant clauses of this specification. The relevant steps of the procedure as specified in the figure above are executed.
2. When the downlink data is received, the SGW-U starts buffering it.
3. The relevant steps of the procedure as specified in the figure above are executed.
4. The SGW-C sends an Sx report Ack message to the SGW-U.

Further Reading

- **Functional Architecture and Procedures**
  - **TS 23.214** Architecture enhancements for control and user plane separation of EPC nodes
- **Protocols**
  - **TS 29.244** Interface between the Control Plane and the User Plane of EPC Nodes
  - **TS 23.007** Restoration procedures
  - **TS 29.303** DNS procedures for UP function selection

Conclusions

- To improve the **performance** and **flexibility** of the core network, the **SDN**, **NFV** and **CUPS** are proposed to change the network function development and the network architecture evolution.
- This talk briefly overviews the SDN/NFV enabled core network architecture and introduces the overall **stage 2 level** functionality for control and user plane separation of EPC's SGW and PGW.
- The CUPS enables a flexible placement of the separated control plane and user plane functions for supporting diverse deployment scenarios (e.g. **central** or **distributed**) without affecting the overall functionality provided by these EPC entities.
- By enabling SDN in CUPS, the user data can be delivered more efficiently.

Thank you for your attention.

Q&A

Reference

[1] Franco Callegati; Walter Cerroni; Chiara Contoli; Rossella Cardone; Matteo Nocentini; Antonio Manzalini. SDN for Dynamic NFV Deployment. IEEE Communications Magazine. Year: 2016, Volume: 54, Issue: 10. Pages: 89 – 95.

[2] Jon Matias; Jokin Garay; Nerea Toledo; Juanjo Unzilla; Eduardo Jacob. Toward an SDN-enabled NFV architecture. IEEE Communications Magazine. Year: 2015, Volume: 53, Issue: 4. Pages: 187 – 193.

[3] Van Giang Nguyen; Anna Brunstrom; Karl-Johan Grinnemo; Javid Taheri . SDN/NFV-based Mobile Packet Core Network Architecture- A Survey. IEEE Communications Surveys & Tutorials. Year: 2017, Volume: PP, Issue: 99. Pages: 1 – 1.

[4] Paul Veitch; Michael J. McGrath; Victor Bayon. An instrumentation and analytics framework for optimal and robust NFV deployment. IEEE Communications Magazine. Year: 2015, Volume: 53, Issue: 2. Pages: 126 – 133.

[5] TS 23.214 Architecture enhancements for control and user plane separation of EPC nodes