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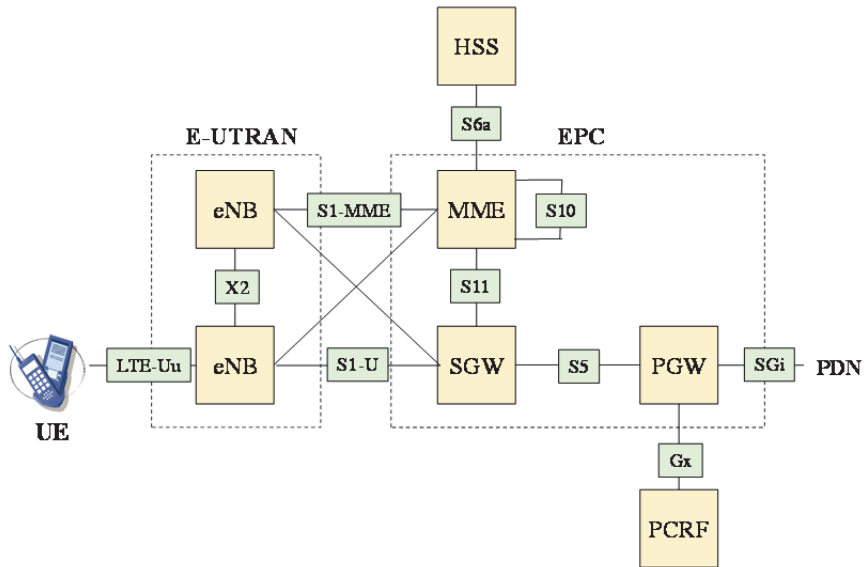
# **LTE Advanced Pro**

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*Towards the 5G Mobile Network*

Frédéric Launay  
André Perez

Color section



**Figure 1.1.** Functional architecture of the EPS network

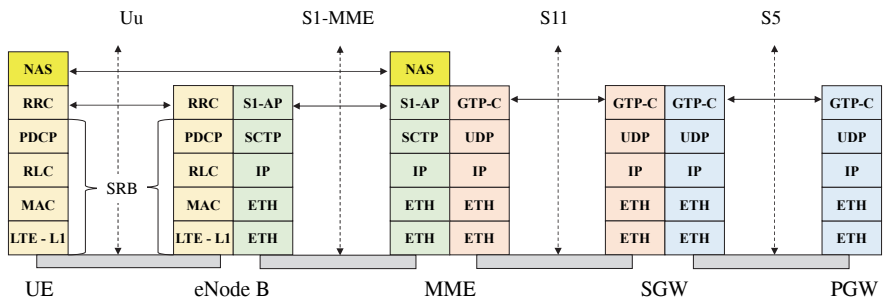


Figure 1.2. Protocol architecture: the control plane

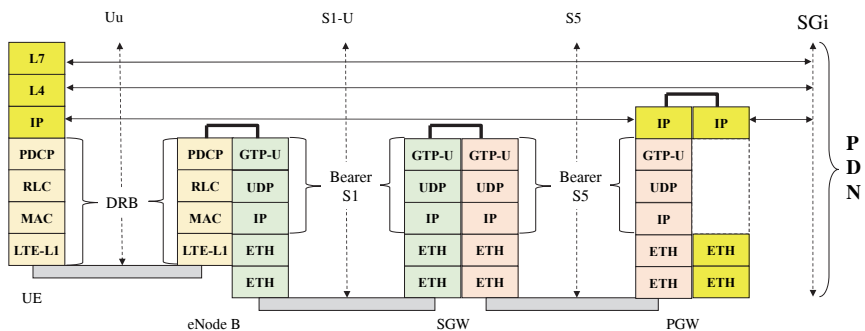
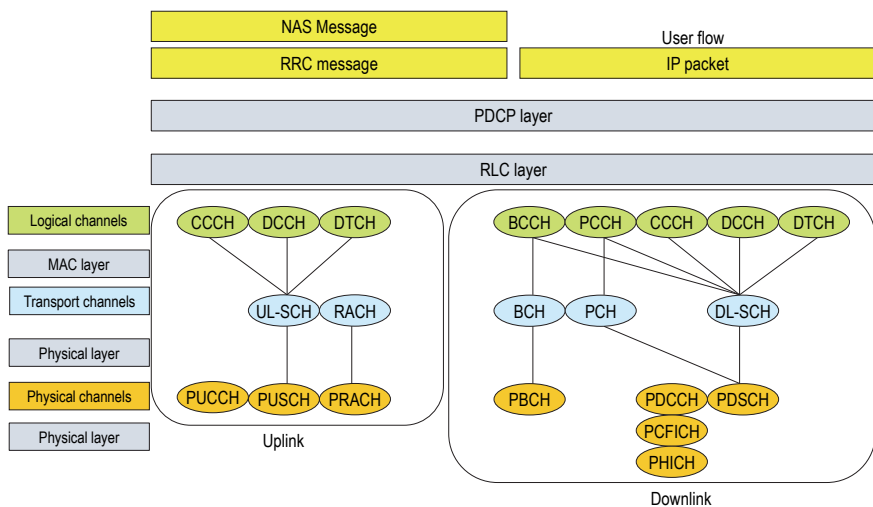
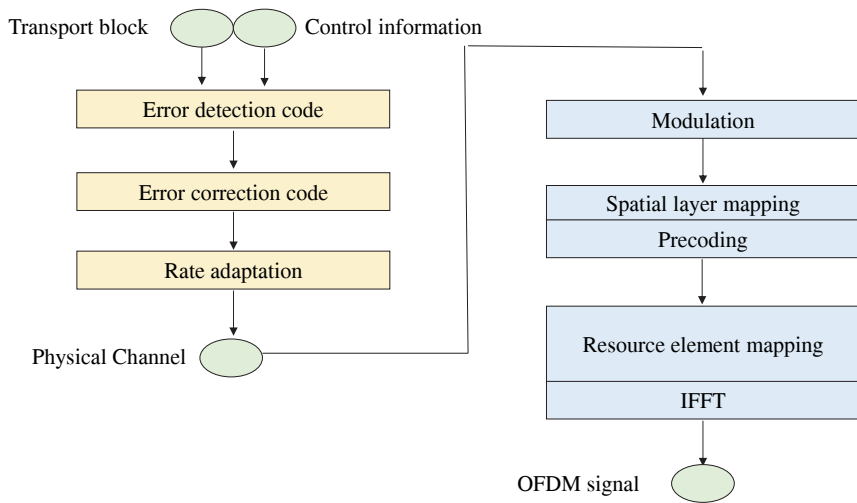


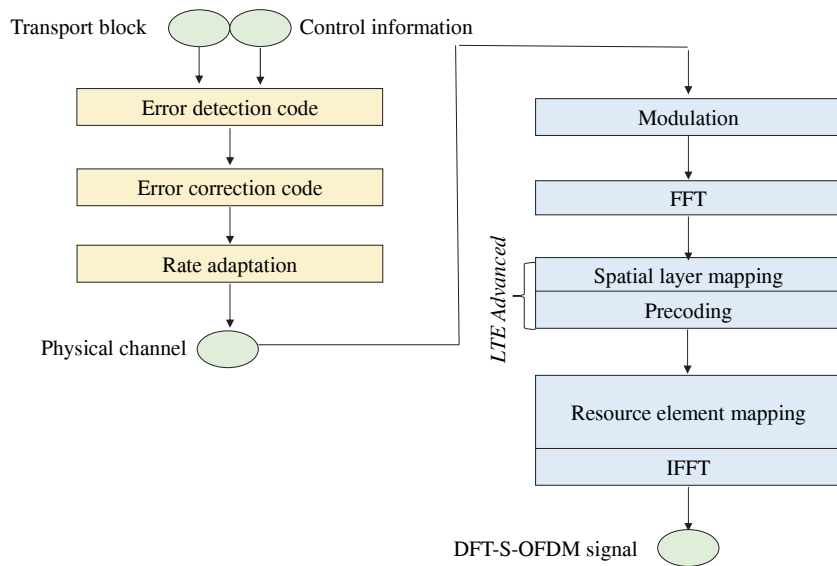
Figure 1.3. Protocol architecture: the user plane



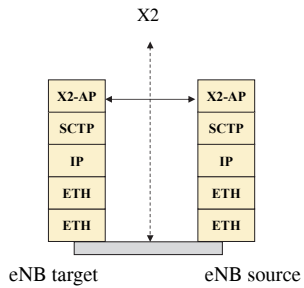
**Figure 1.4.** Protocol architecture of the LTE-Uu interface



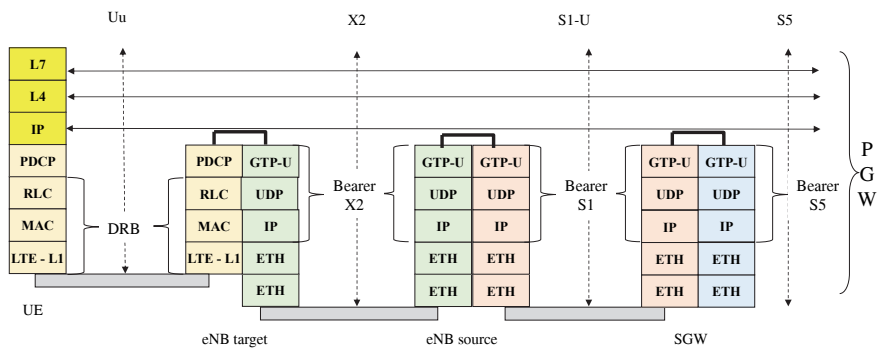
**Figure 1.5.** *The downlink chain of transmission*



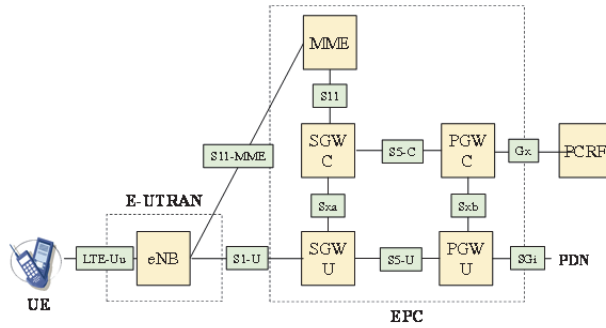
**Figure 1.6.** *The uplink chain of transmission*



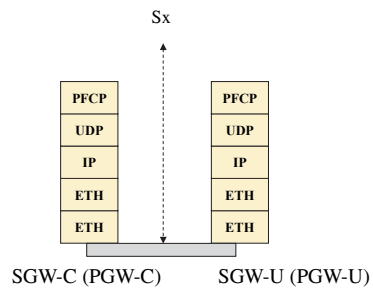
**Figure 1.7.** Protocol architecture of the X2 interface: the control plane



**Figure 1.8.** Protocol architecture of the user plane during the handover based on the X2 interface

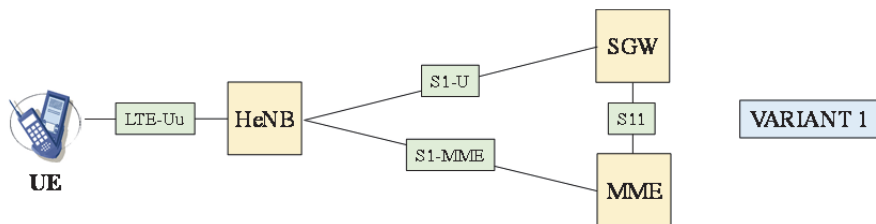


**Figure 1.9.** CUPS architecture

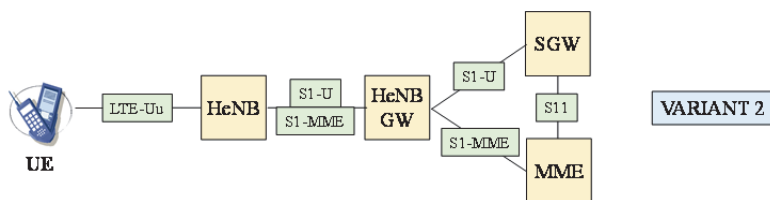


**Figure 1.10.** Protocol architecture of the Sx interface: the control plane

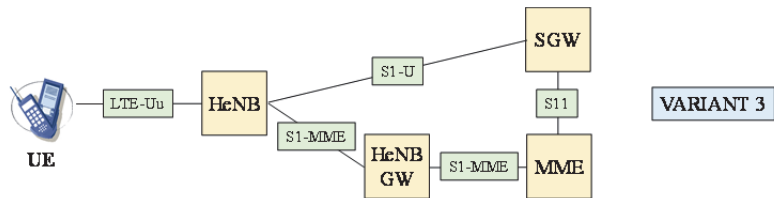




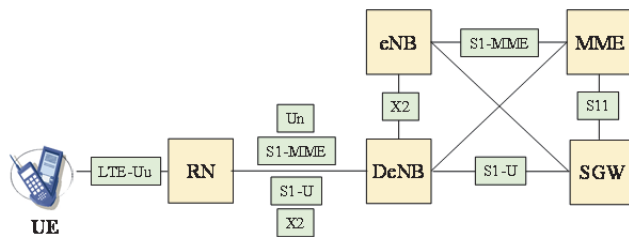
**Figure 1.11.** Functional architecture implementing the HeNB station: variant 1



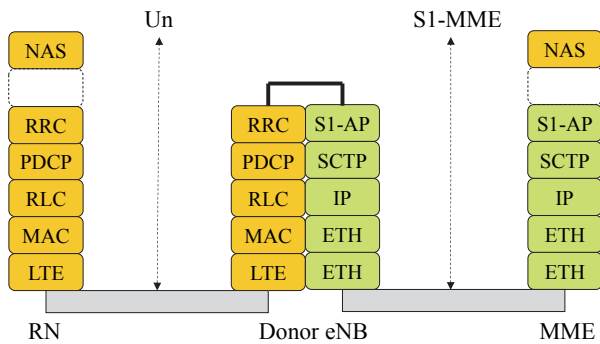
**Figure 1.12.** Functional architecture implementing the HeNB station: variant 2



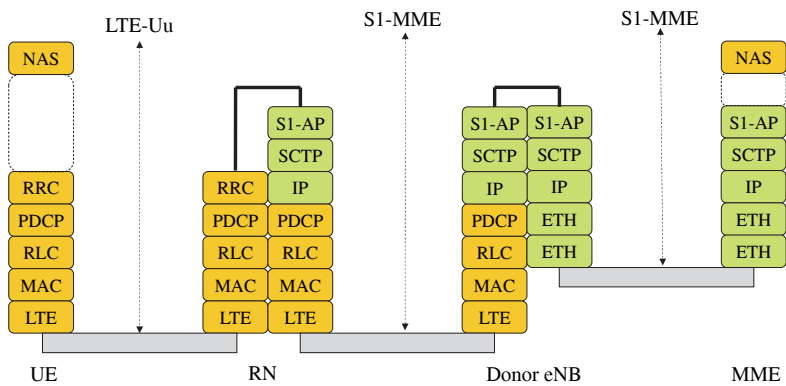
**Figure 1.13.** Functional architecture implementing the HeNB station: variant 3



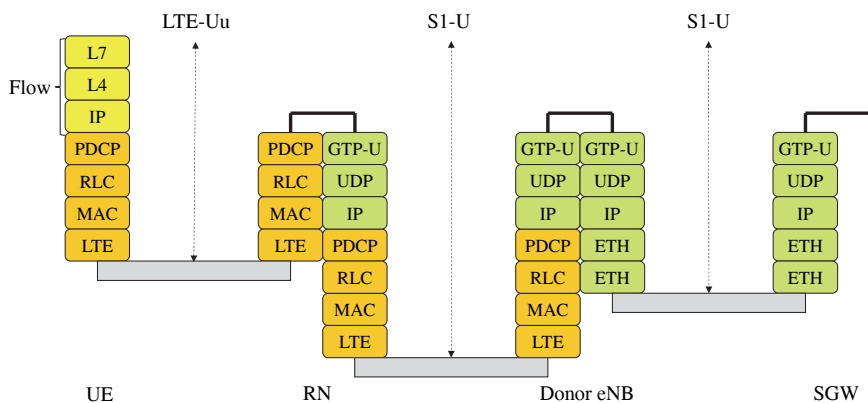
**Figure 1.14.** Functional architecture implementing the relay node



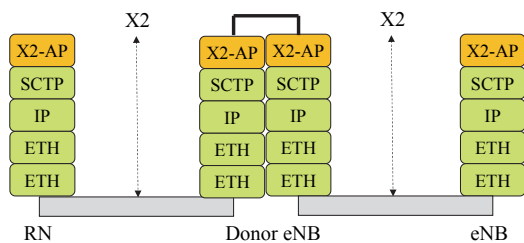
**Figure 1.15.** *Connecting the relay node: the control plane*



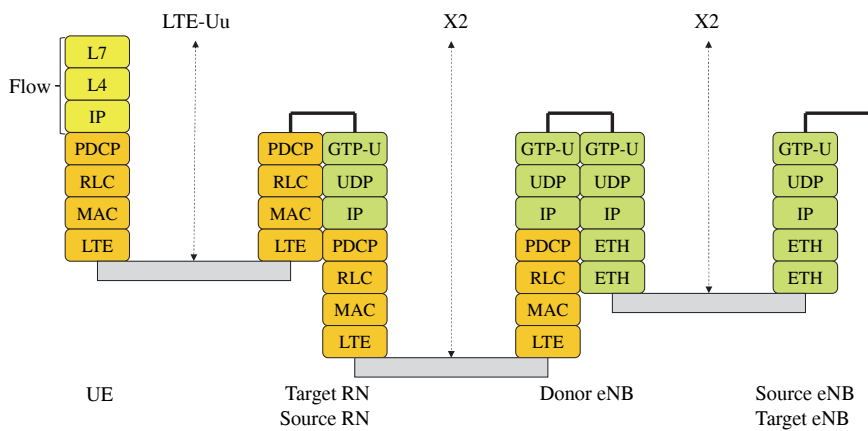
**Figure 1.16.** *Connecting the mobile: the control plane*



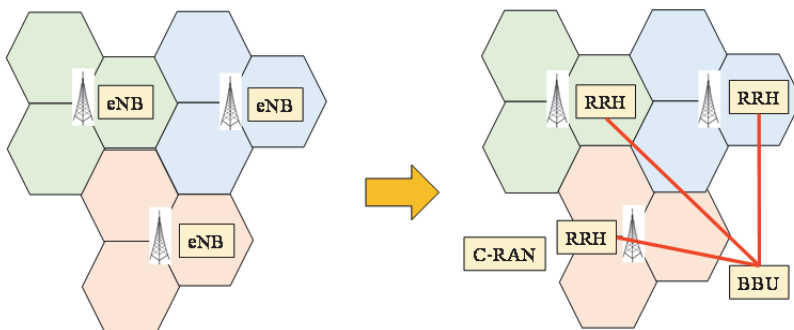
**Figure 1.17.** *Connecting the mobile: the user plane*



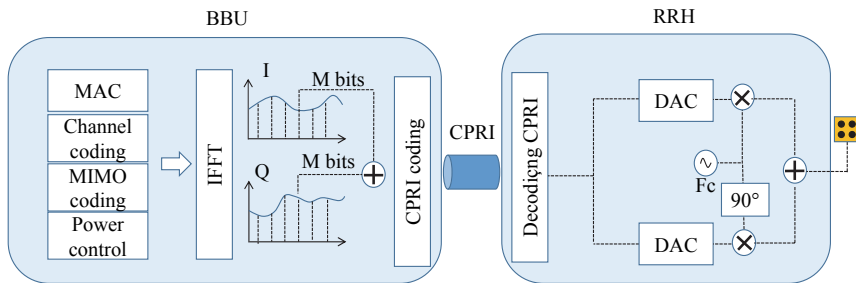
**Figure 1.18.** *Protocol architecture of the X2 interface: the control plane*



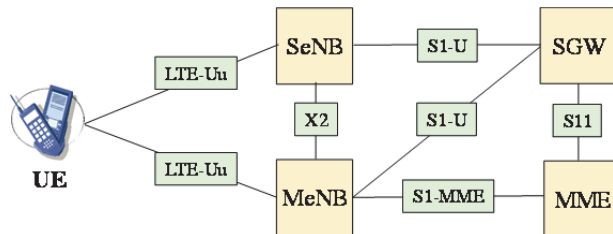
**Figure 1.19.** Protocol architecture of the X2 interface: the user plane



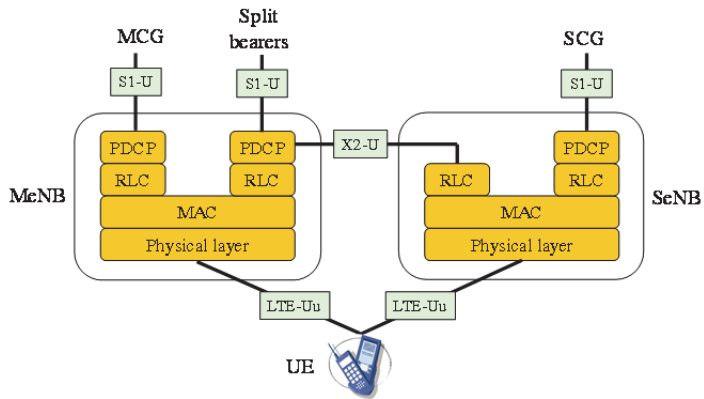
**Figure 1.20.** C-RAN architecture



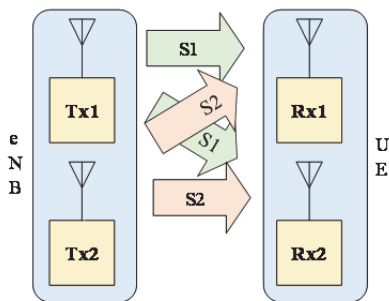
**Figure 1.21.** *Distribution of functions between the BBU and RRH modules*



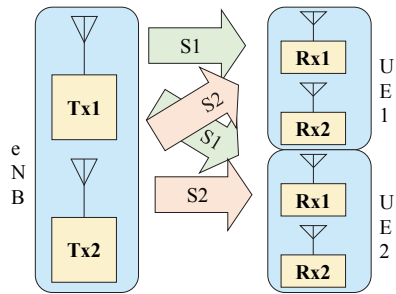
**Figure 1.22.** *Functional architecture implementing dual connectivity*



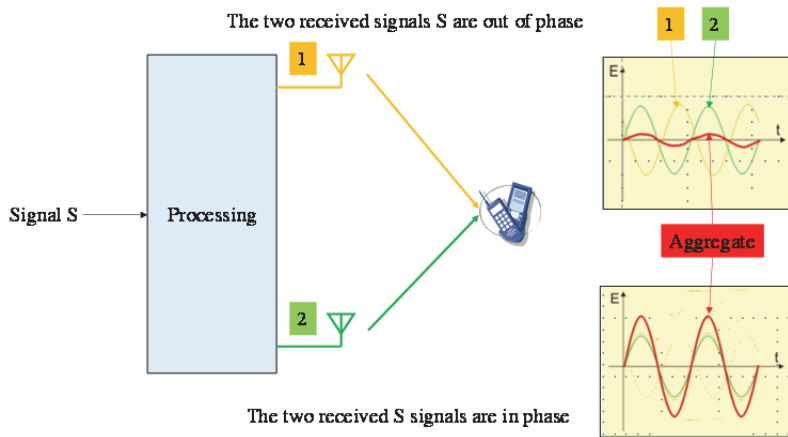
**Figure 1.23.** *Protocol architecture of the radio interface implementing dual connectivity*



**Figure 2.1.** *SU-MIMO mechanism*

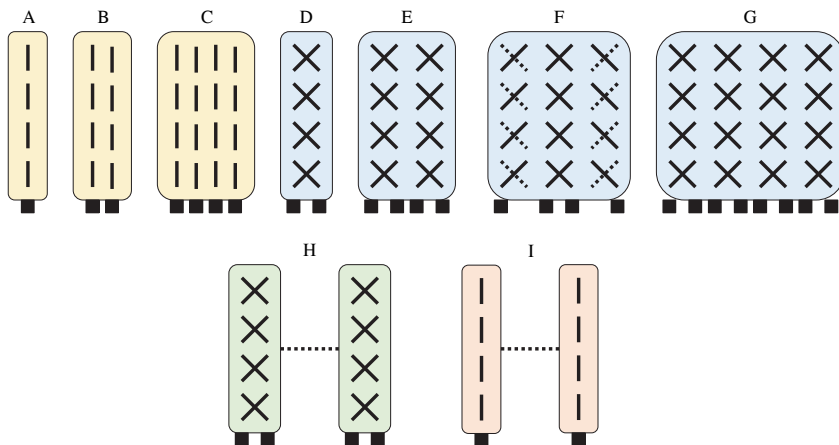


**Figure 2.2. MU-MIMO mechanism**

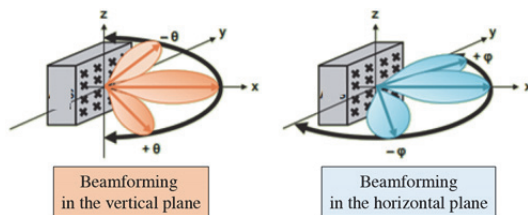


**Figure 2.3. Beamforming**

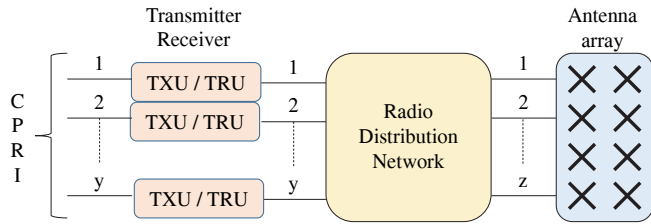




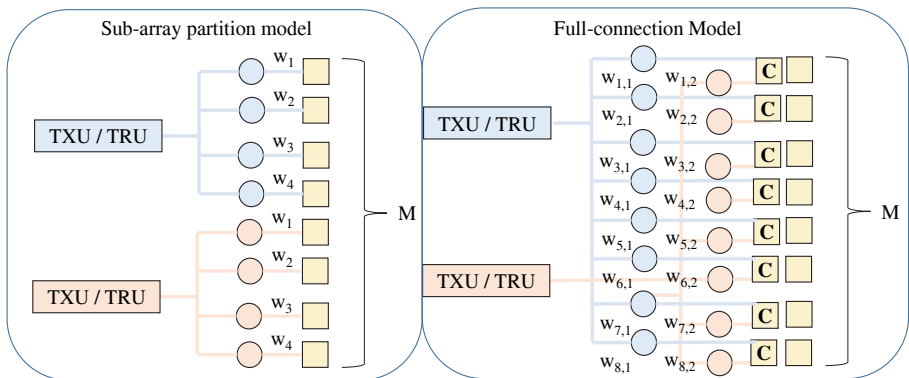
**Figure 2.4.** *Antenna configurations*



**Figure 2.5.** *Beamforming in different planes*  
 (source: NTT DOCOMO Technical Reports Journal, vol. 18 no. 2)

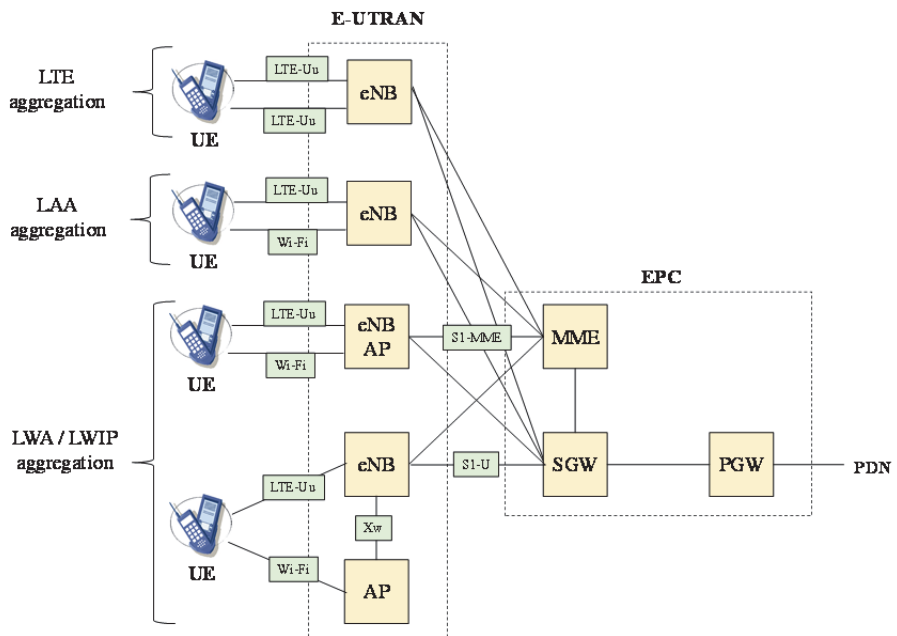


**Figure 2.6. AAS**

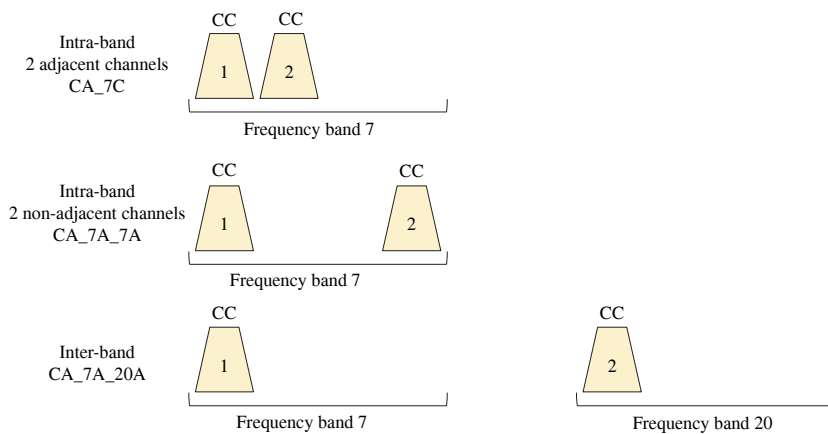


**Figure 2.7. Mapping between the TXU/TRU and the antenna elements**

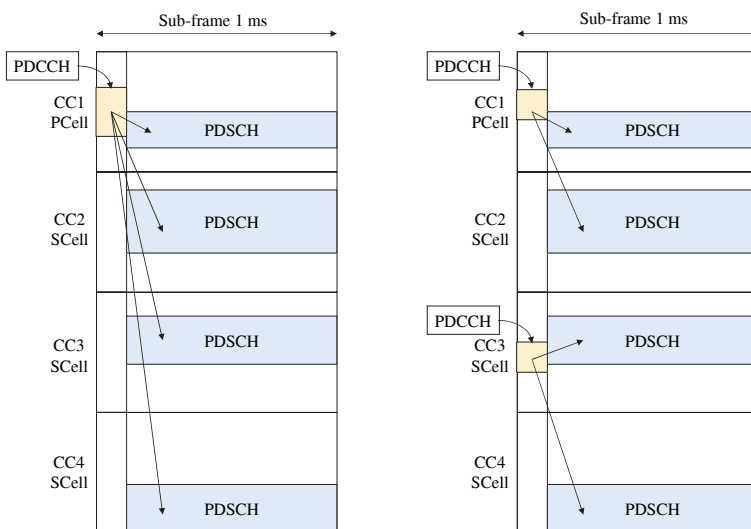




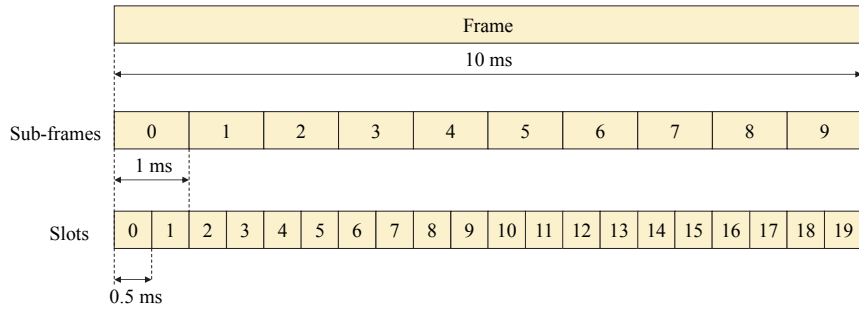
**Figure 3.1.** Functional architecture for LTE and Wi-Fi carrier aggregation



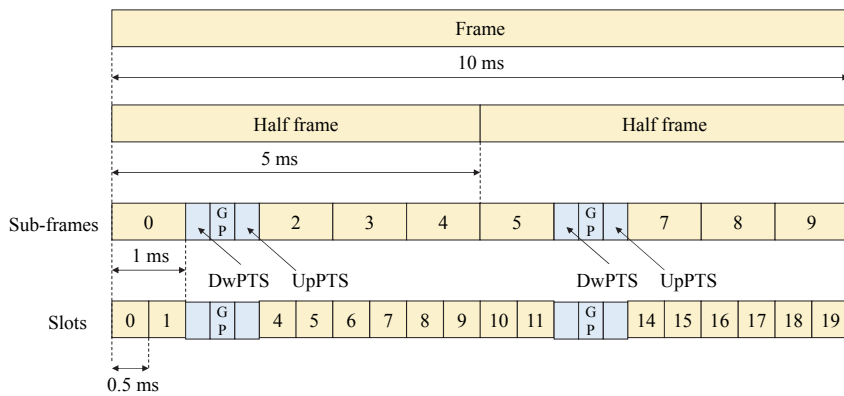
**Figure 3.2.** *Radio channel aggregation*



**Figure 3.3.** *Inter-carrier scheduling*



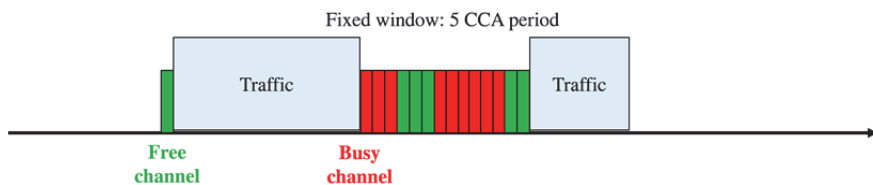
**Figure 3.4.** *Structure of type-1 frame*



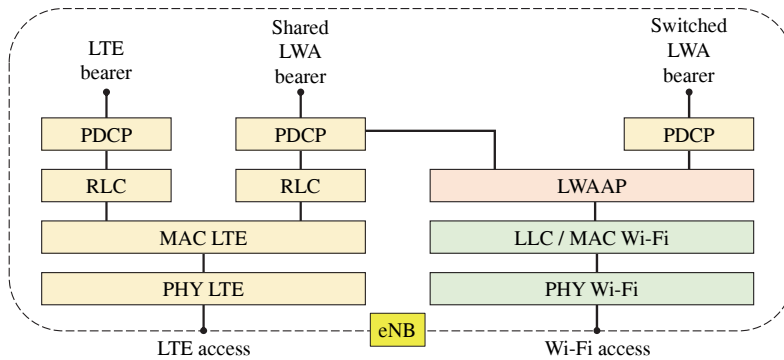
**Figure 3.5.** *Structure of type-2 frame*



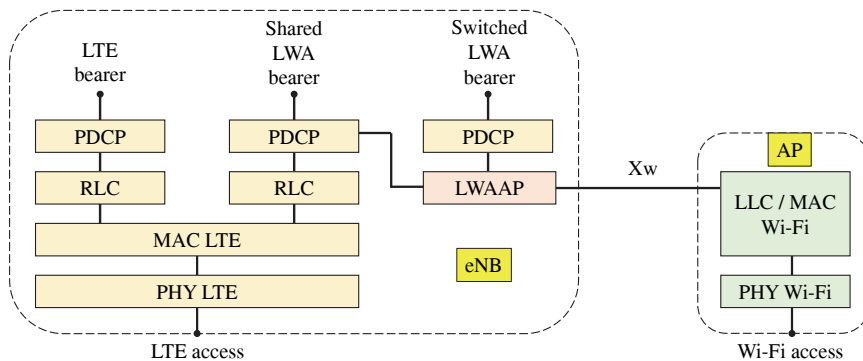
**Figure 3.6.** *LBT mechanism: FBE option*



**Figure 3.7.** *LBT mechanism: LBE option*

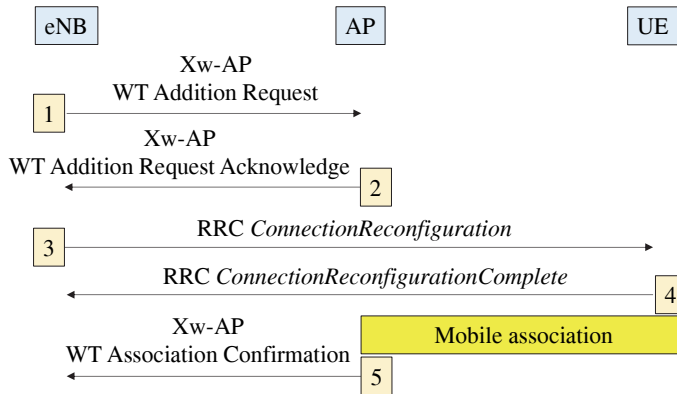


**Figure 3.8.** *Protocol architecture for LWA: collocated eNB and AP entities*

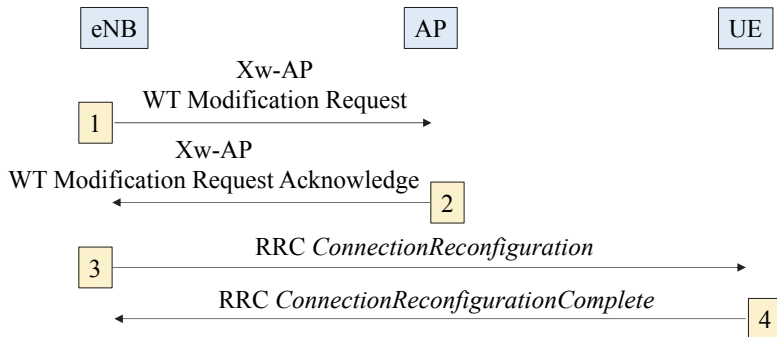


**Figure 3.9.** *Protocol architecture for LWA: distant eNB and AP entities*

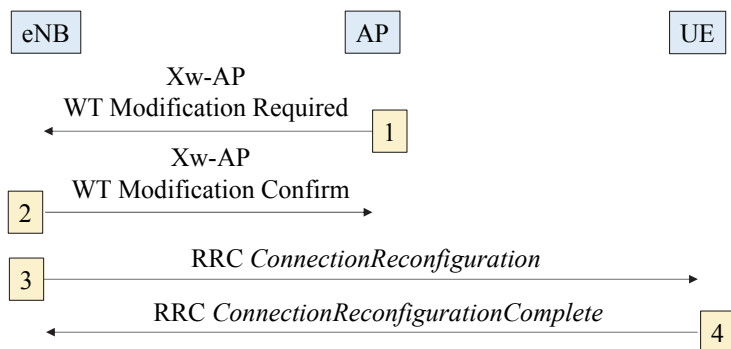




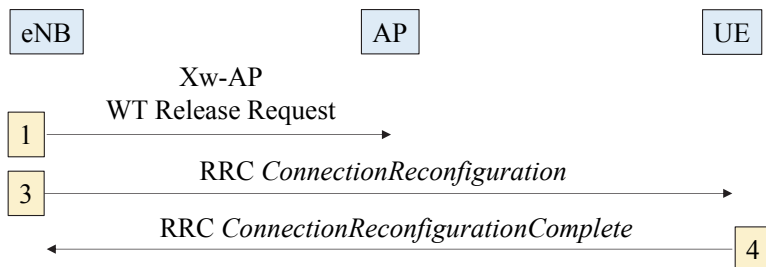
**Figure 3.10.** *WT Addition procedure*



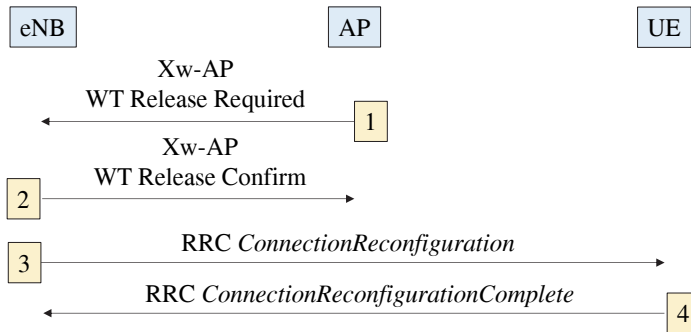
**Figure 3.11.** *WT Modification procedure initiated by the eNB entity*



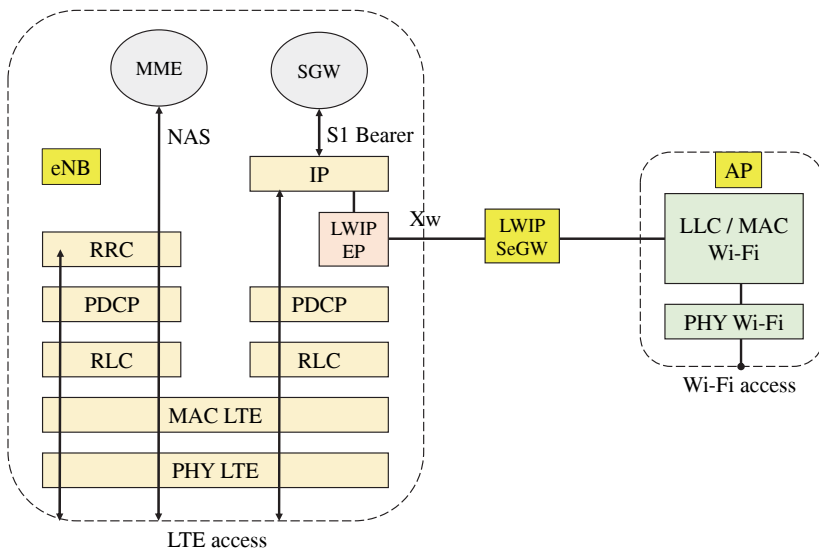
**Figure 3.12.** WT Modification procedure initiated by the access point



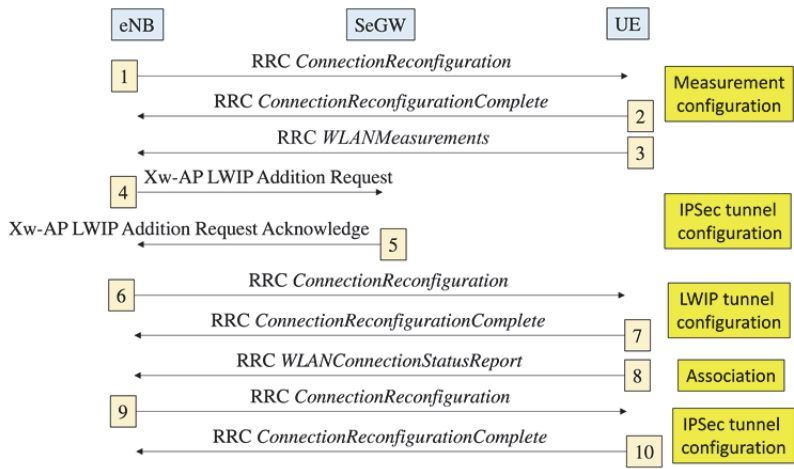
**Figure 3.13.** WT Release procedure initiated by the eNB entity



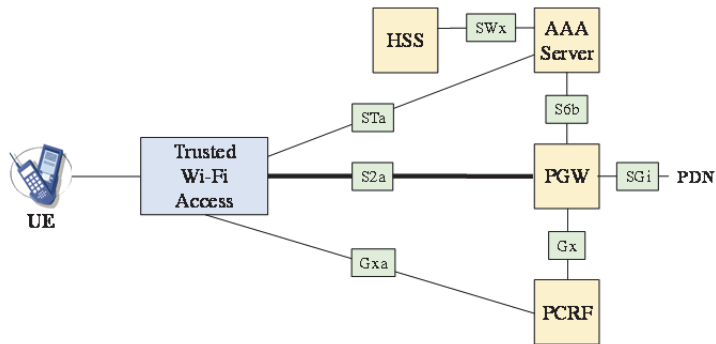
**Figure 3.14.** WT Release procedure initiated by the access point



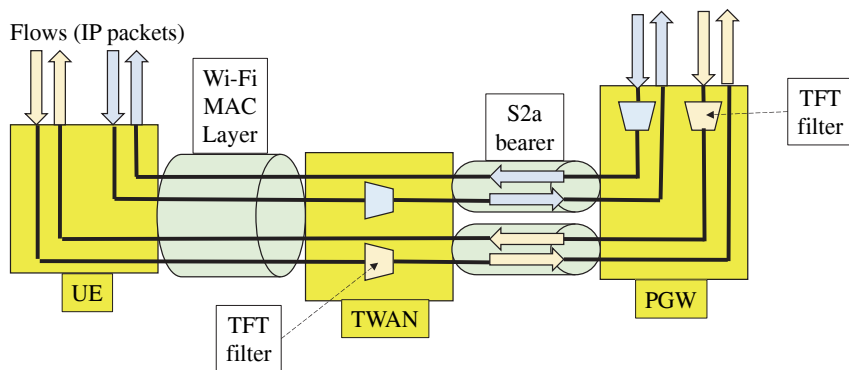
**Figure 3.15.** Protocol architecture for the LWIP aggregation



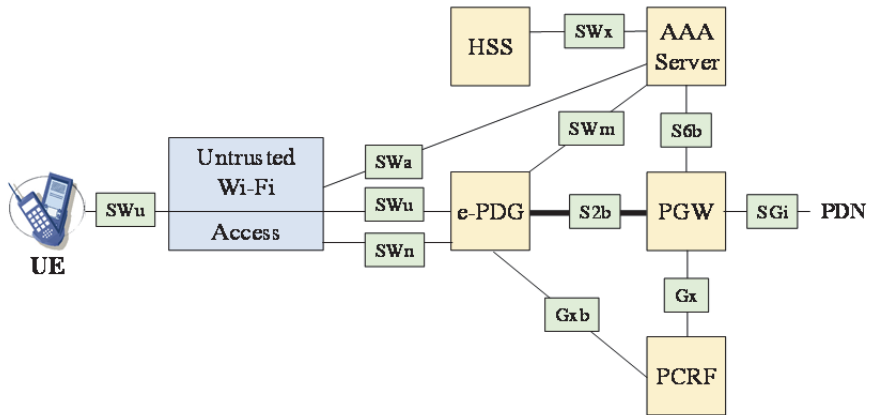
**Figure 3.16.** *LWIP and IPSec tunnel establishment*



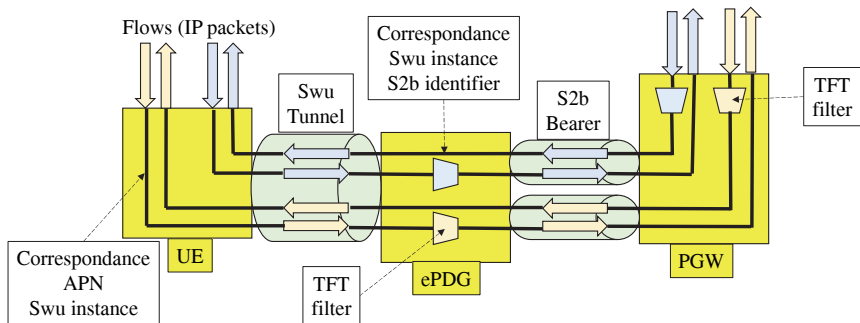
**Figure 4.1.** Functional architecture based on the S2a interface



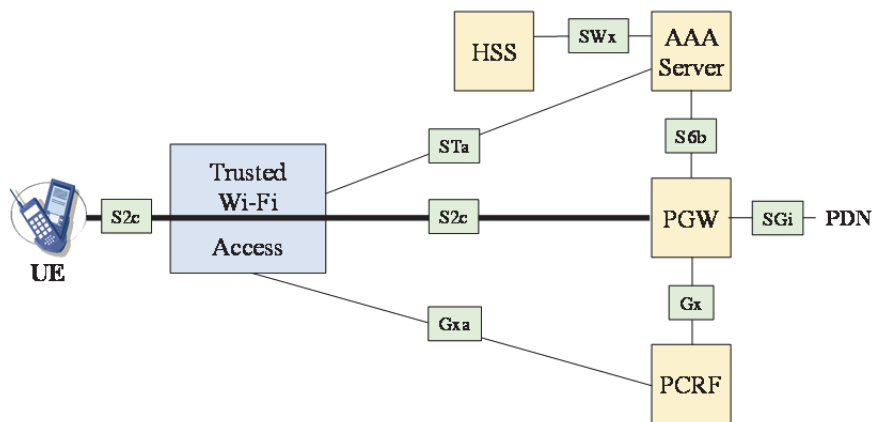
**Figure 4.2.** Connection to the PDN for the architecture based on the S2a interface



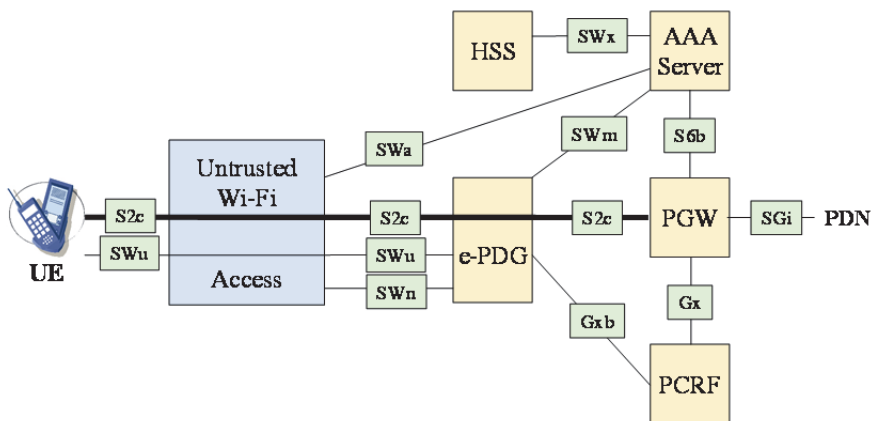
**Figure 4.3.** Functional architecture based on the S2b interface



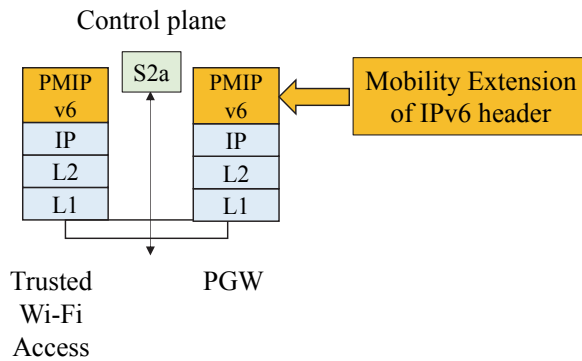
**Figure 4.4.** Connection to the PDN for the architecture based on the S2b interface



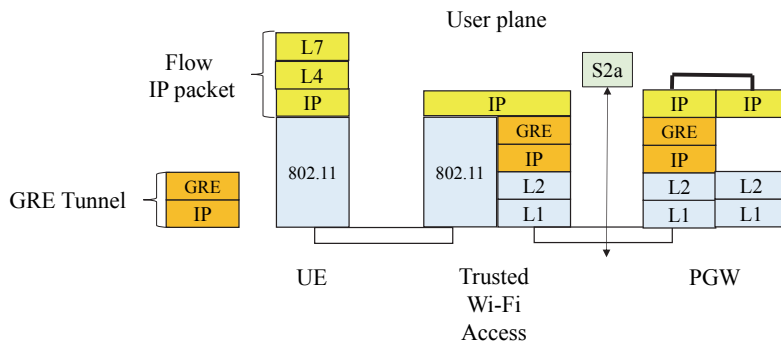
**Figure 4.5.** Functional architecture based on the S2c interface trusted Wi-Fi access



**Figure 4.6.** Functional architecture based on the S2c interface untrusted Wi-Fi access

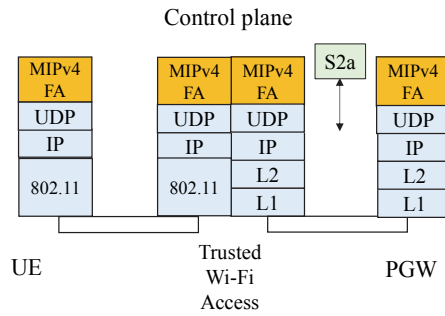


**Figure 4.7.** Protocol architecture based on the S2a interface control plane for the PMIPv6 mechanism

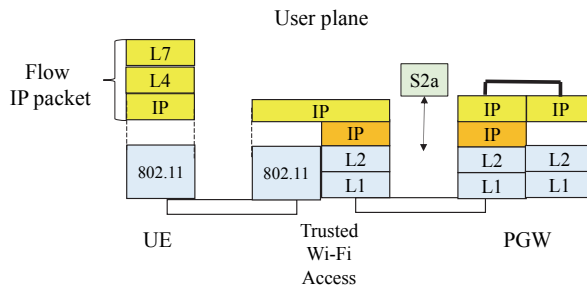


**Figure 4.8.** Protocol architecture based on the S2a interface user plane for the PMIPv6 mechanism

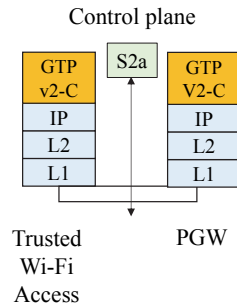




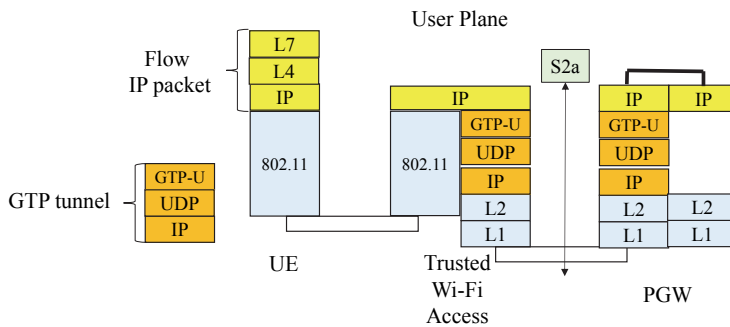
**Figure 4.9.** *Protocol architecture based on the S2a interface control plane for the MIPv4 FA mechanism*



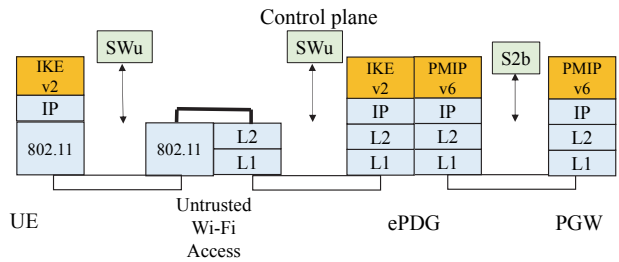
**Figure 4.10.** *Protocol architecture based on the S2a interface user plane for the MIPv4 FA mechanism*



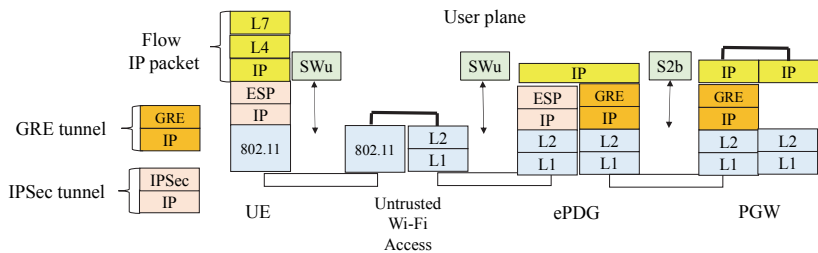
**Figure 4.11.** Protocol architecture based on the S2a interface control plane for the GTPv2 mechanism



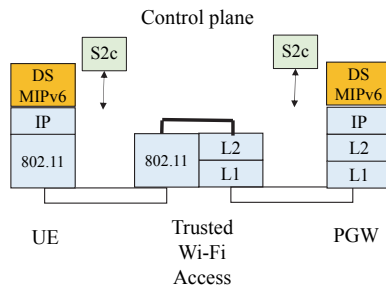
**Figure 4.12.** Protocol architecture based on the S2a interface user plane for the GTPv2 mechanism



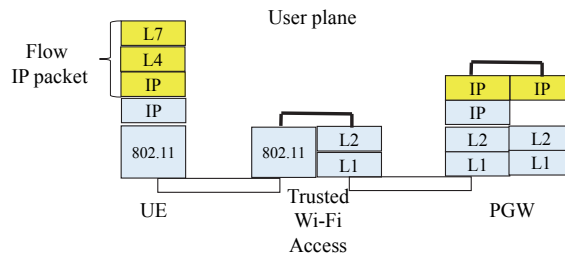
**Figure 4.13.** Protocol architecture based on the S2b interface control plane for the PMIPv6 mechanism



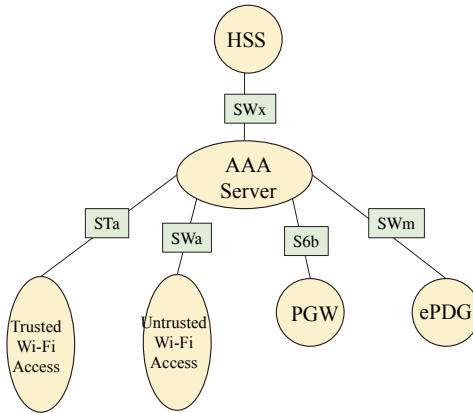
**Figure 4.14.** Protocol architecture based on the S2b interface user plane for the PMIPv6 mechanism



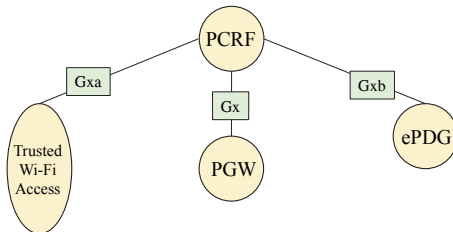
**Figure 4.15.** Protocol architecture based on the S2c interface control plane for the trusted Wi-Fi access



**Figure 4.16.** Protocol architecture based on the S2c interface user plane for the trusted Wi-Fi access



**Figure 4.17.** AAA server interfaces using the DIAMETER protocol



**Figure 4.18.** PCRF interfaces using the DIAMETER protocol

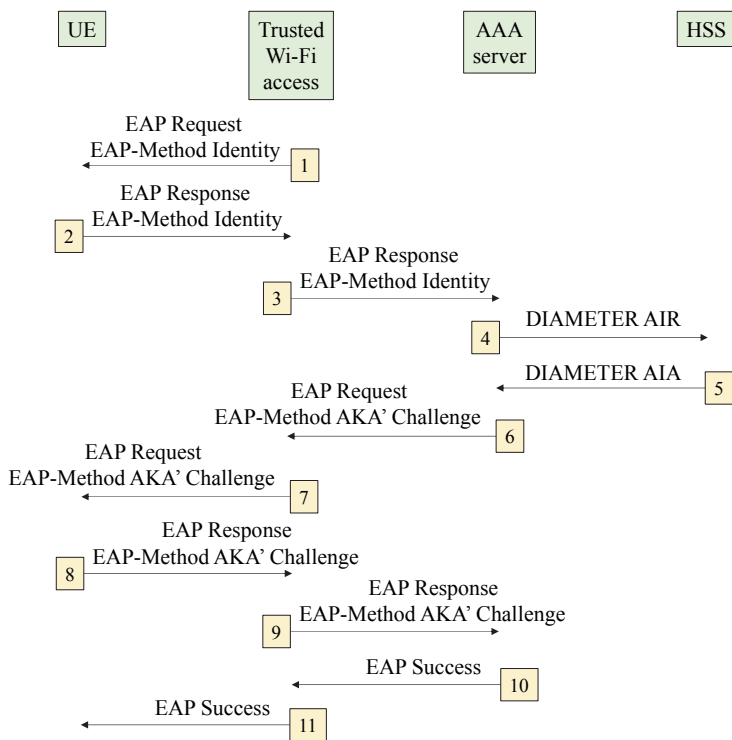
EAP-AKA'
EAP
DIAMETER
UDP
IP
Layer 2
Layer 1

Interface between  
trusted Wi-Fi access  
and the AAA server

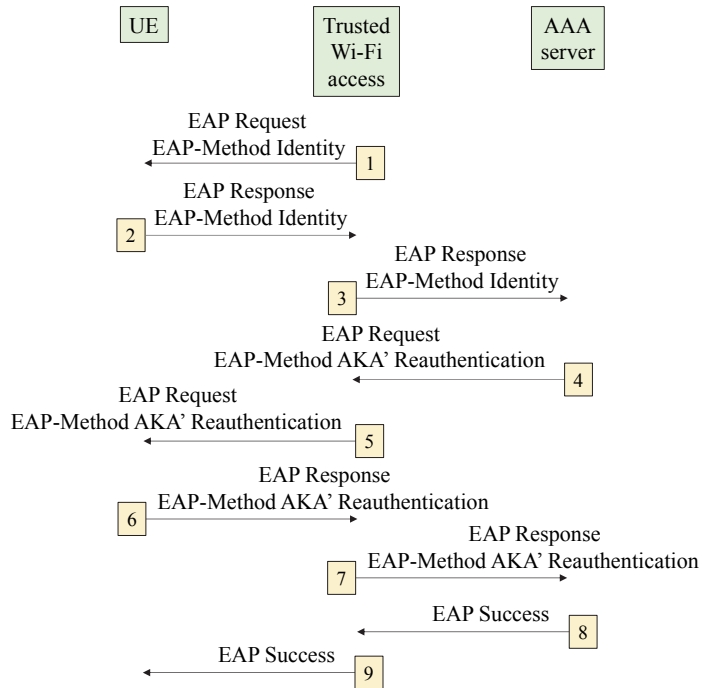
EAP-AKA'
EAP
EAPOL
LLC
WiFi (MAC)
WiFi (Layer 1)

Interface between  
trusted Wi-Fi access  
and the mobile

**Figure 5.1.** *Transport of the EAP-AKA' messages*

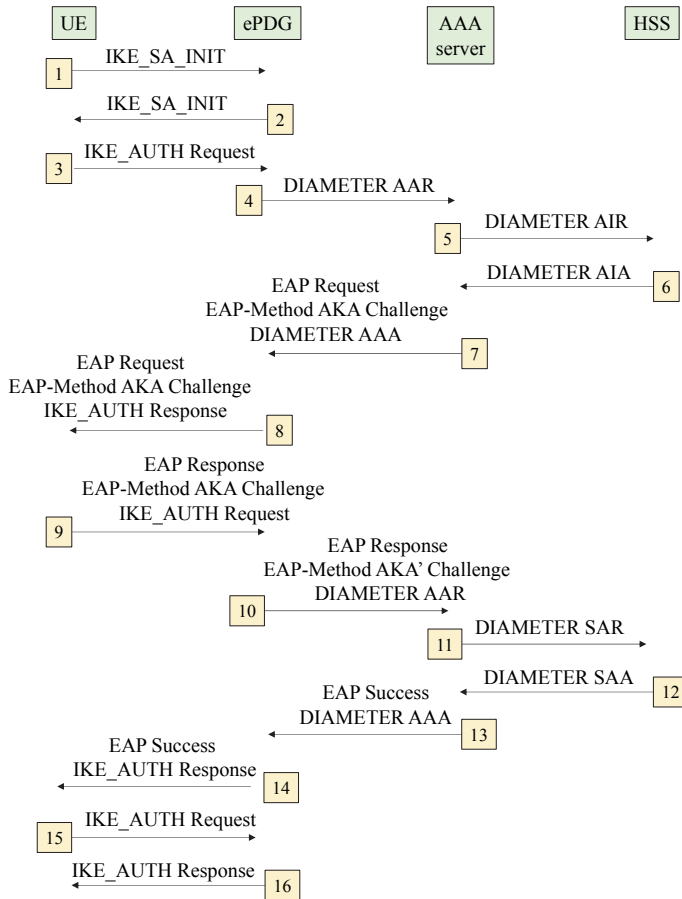


**Figure 5.2.** *Mutual authentication procedure*

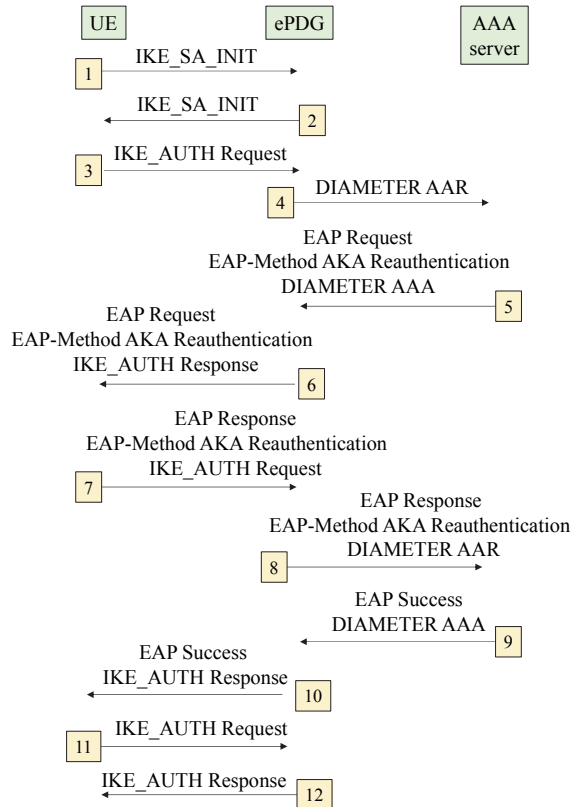


**Figure 5.3.** *Procedure for rapid renewal of authentication*





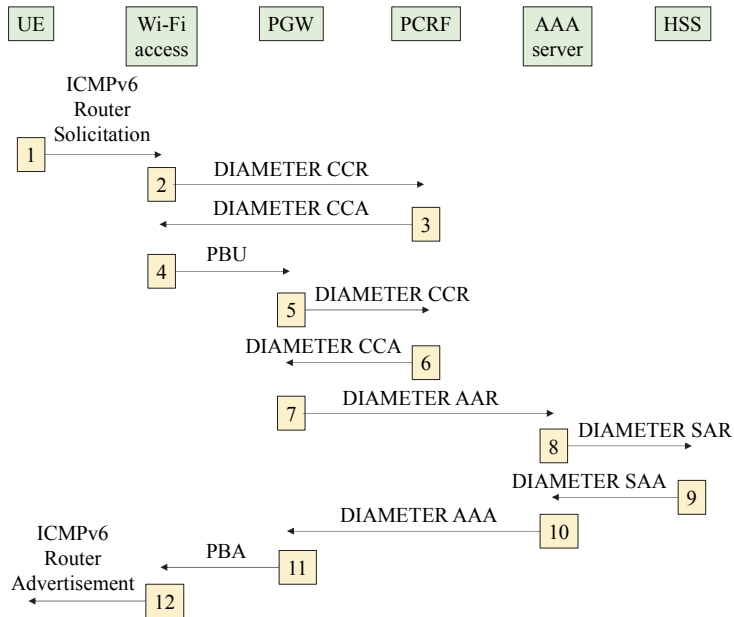
**Figure 5.4.** *SWu tunnel establishment procedure*



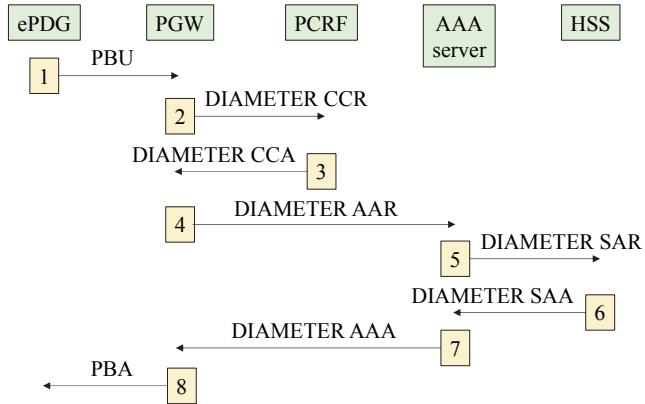
**Figure 5.5.** *Procedure for rapid renewal of authentication*



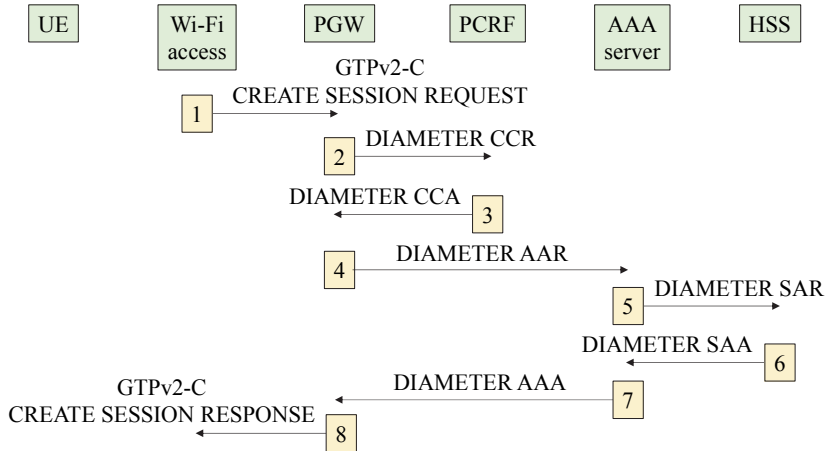
**Figure 5.6.** *PMIPv6 architecture*



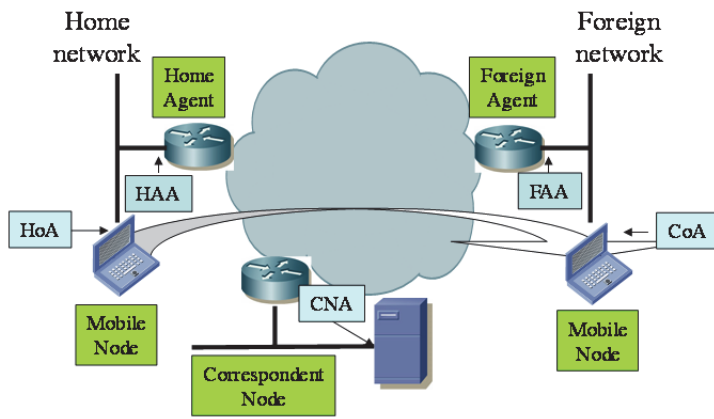
**Figure 5.7.** S2a tunnel establishment using the PMIPv6 mechanism



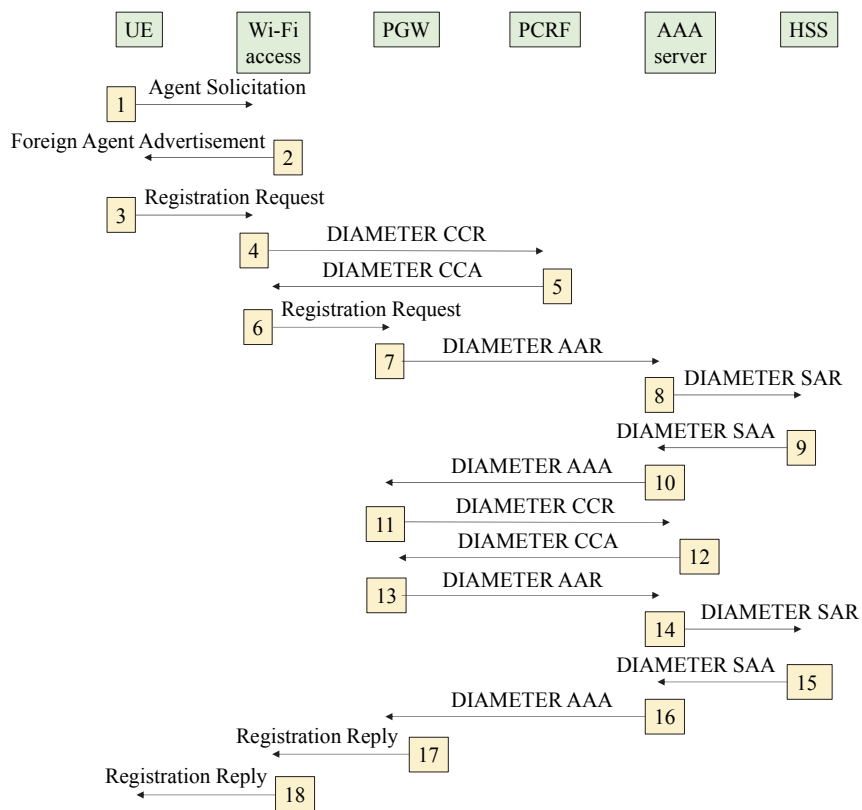
**Figure 5.8.** S2b tunnel establishment using PMIPv6 mechanism



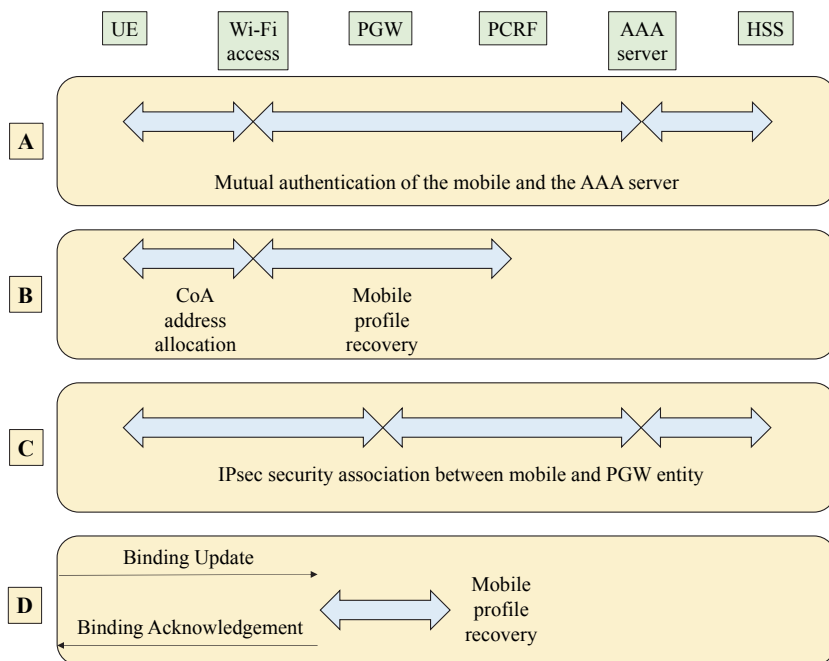
**Figure 5.9.** S2a tunnel establishment using the GTPv2 mechanism



**Figure 5.10.** *Components of mobility*

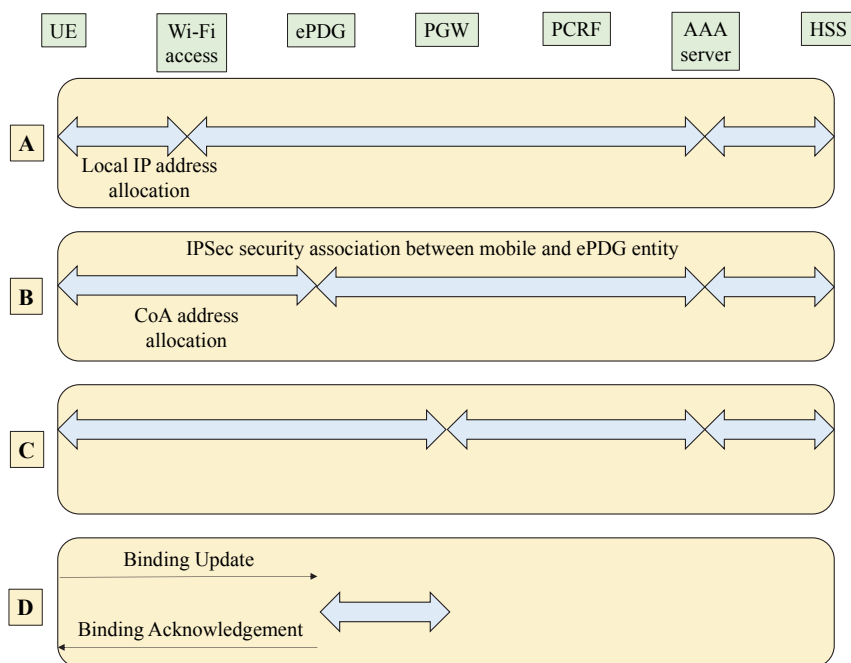


**Figure 5.11.** S2a tunnel establishment using the MIPv4 FA mechanism



**Figure 5.12.** *S2c tunnel establishment: trusted Wi-Fi access*





**Figure 5.13.** *S2c tunnel establishment: untrusted Wi-Fi access*

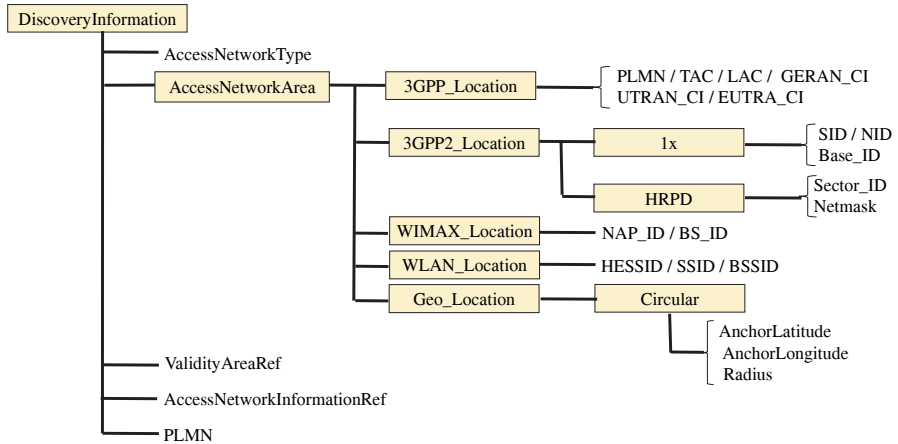


Figure 6.1. ANDI

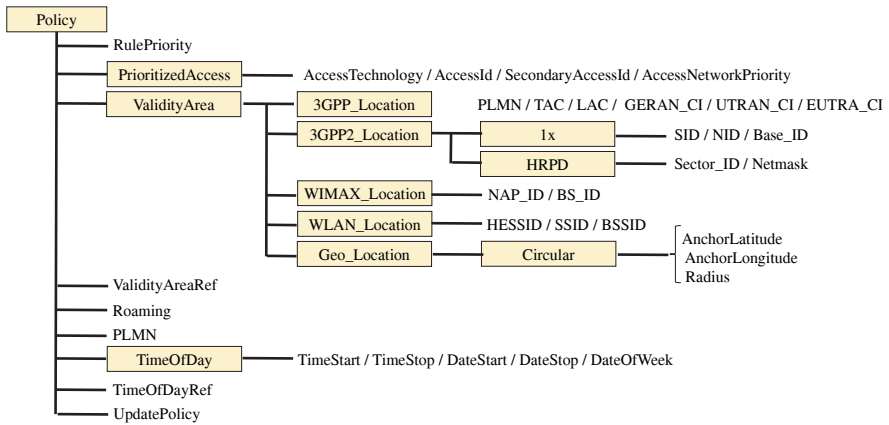
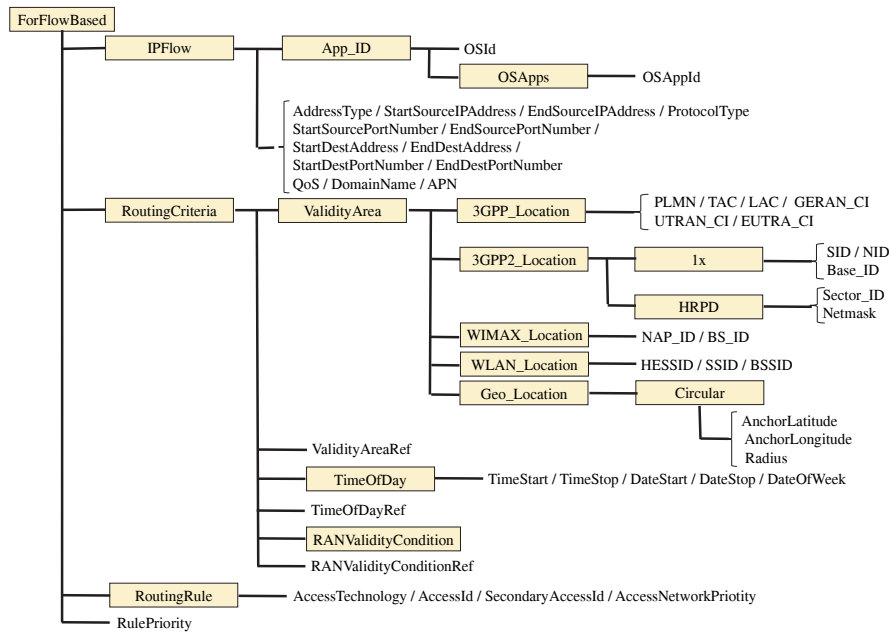
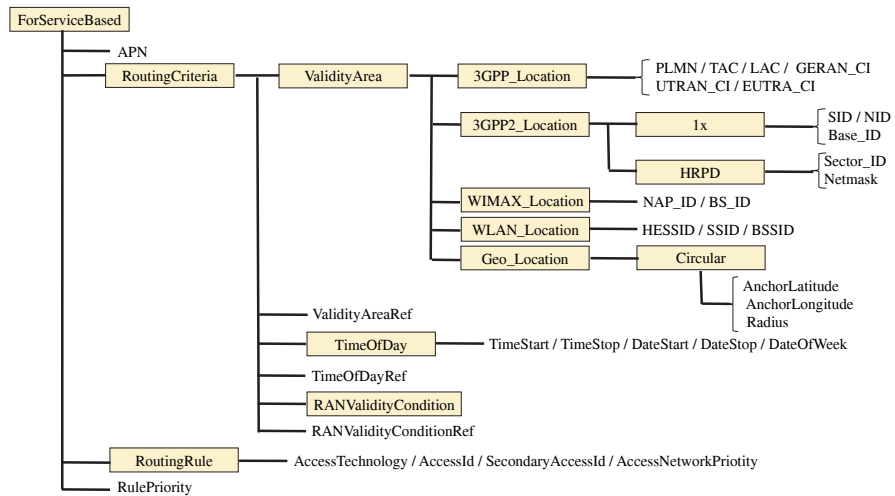


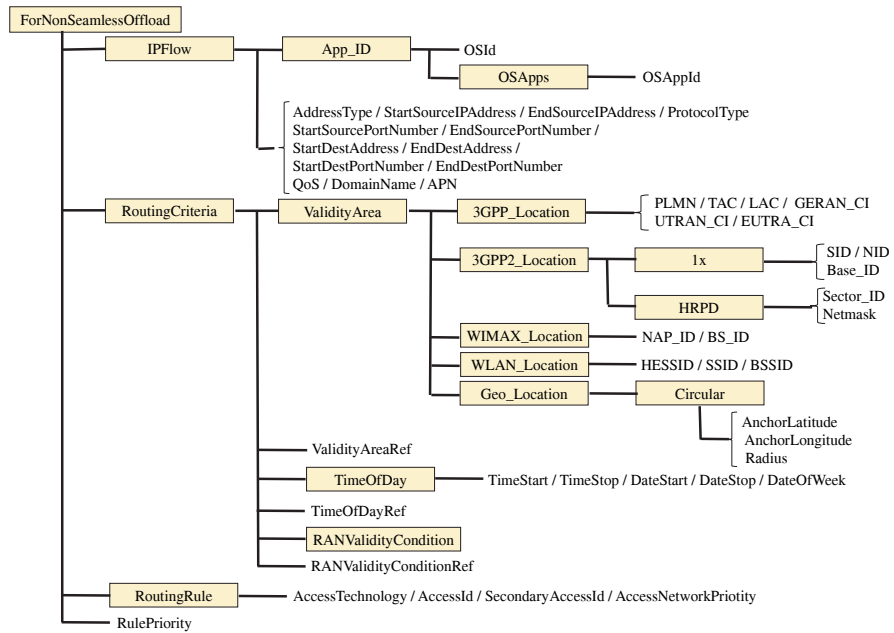
Figure 6.2. ISMP



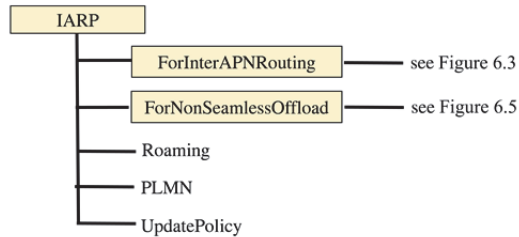
**Figure 6.3. IFOM rules**



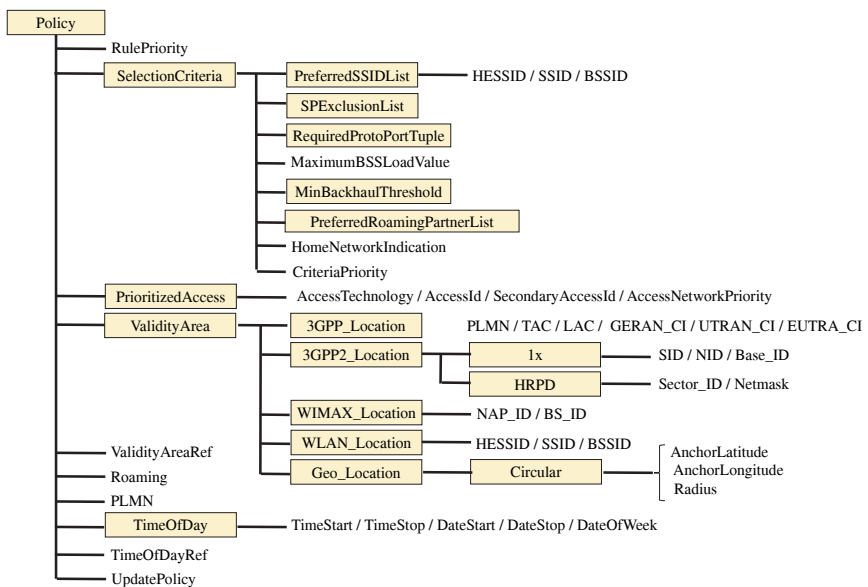
**Figure 6.4. MAPCON rules**



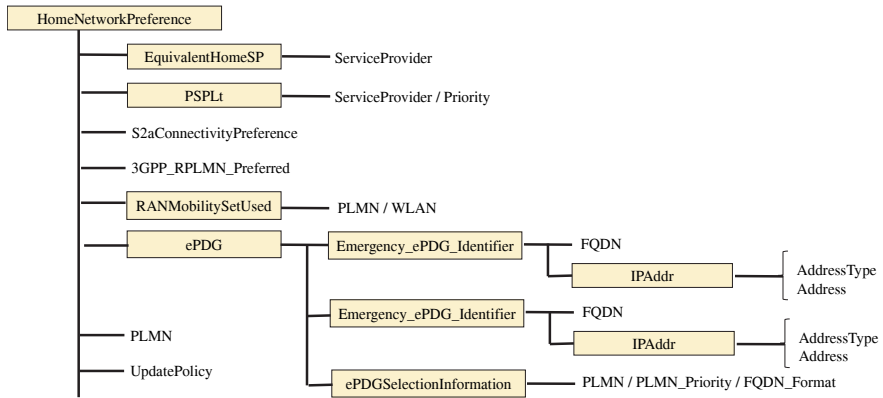
**Figure 6.5. NSWO rules**



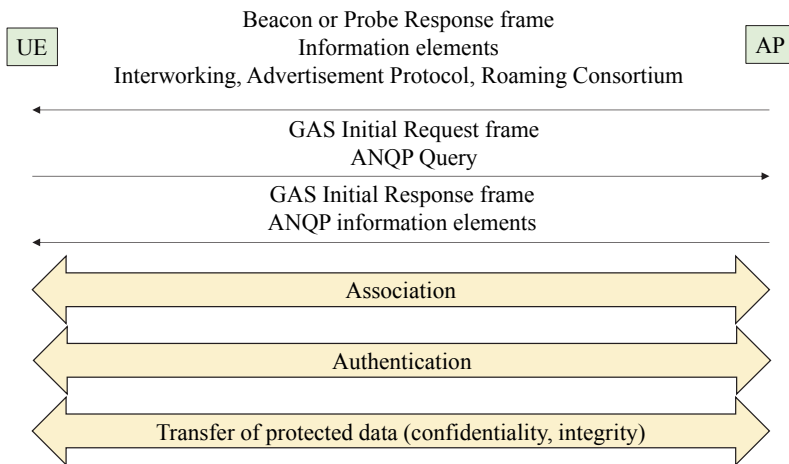
**Figure 6.6. IARP rules**



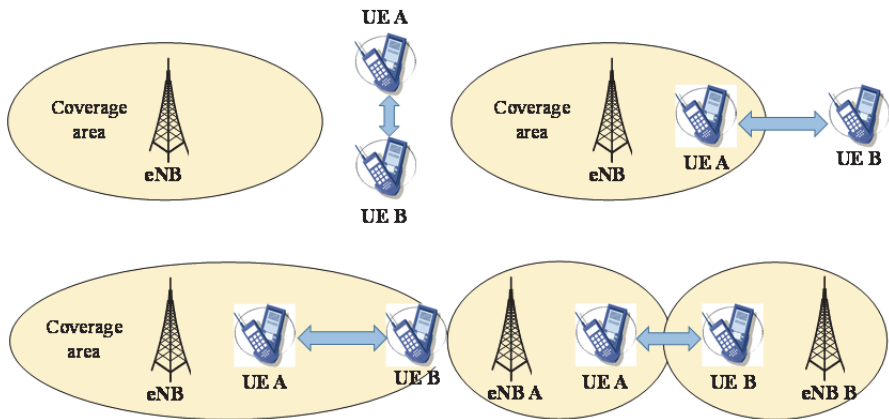
**Figure 6.7. WLANSP**



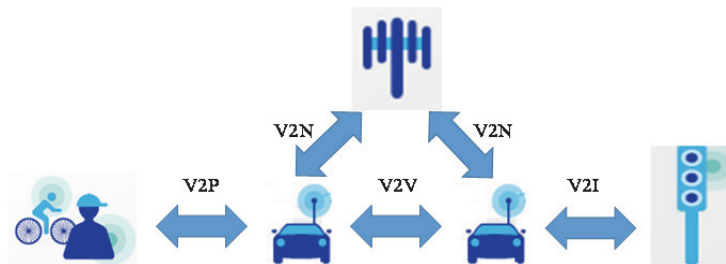
**Figure 6.8.** *Wi-Fi access network preferences*



**Figure 6.9.** *GAS/ANQP exchanges*

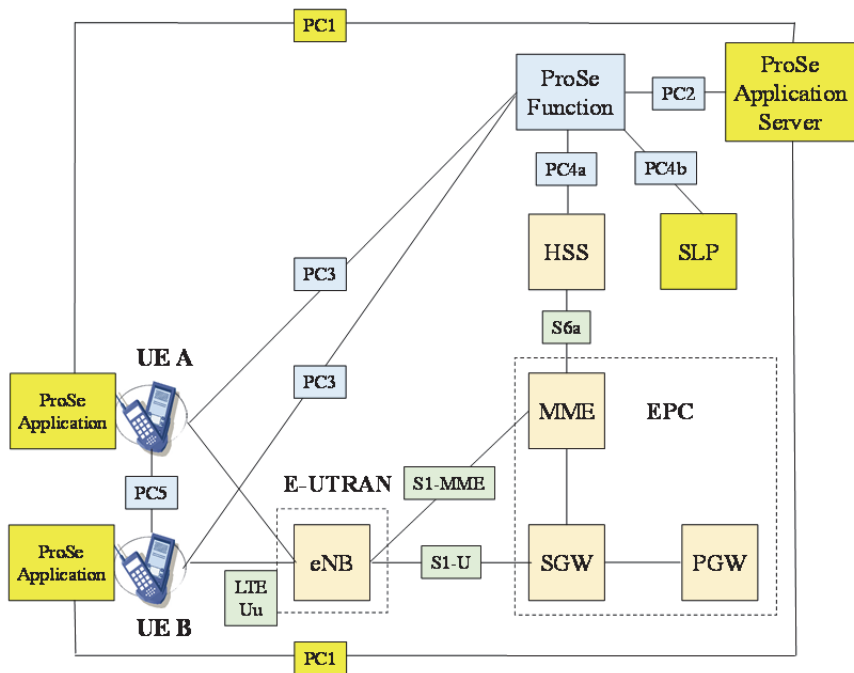


**Figure 7.1.** *Deployment scenarios for D2D communications*



**Figure 7.2.** *Different types of V2X communication*





**Figure 7.3.** Functional architecture: D2D communications

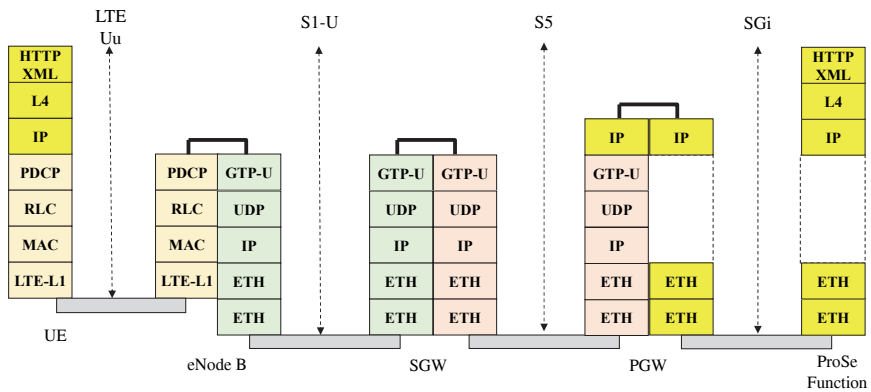


Figure 7.4. Transport of the HTTP/XML message

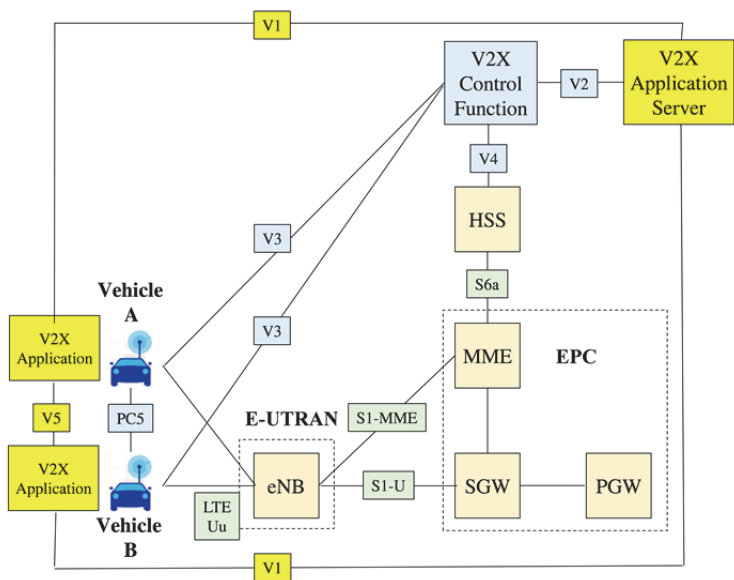
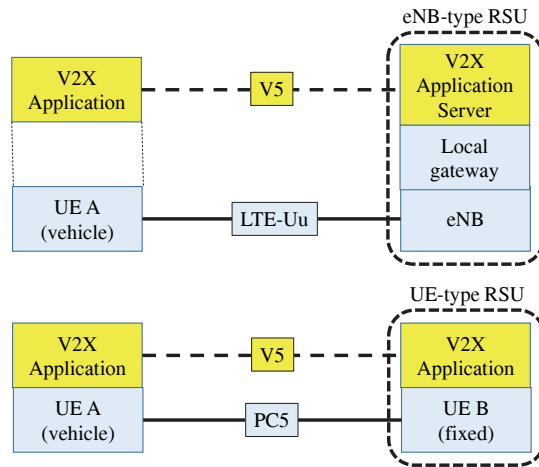
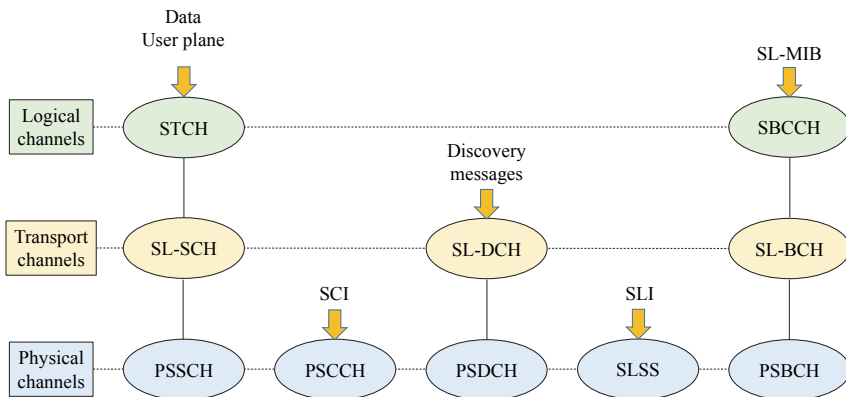


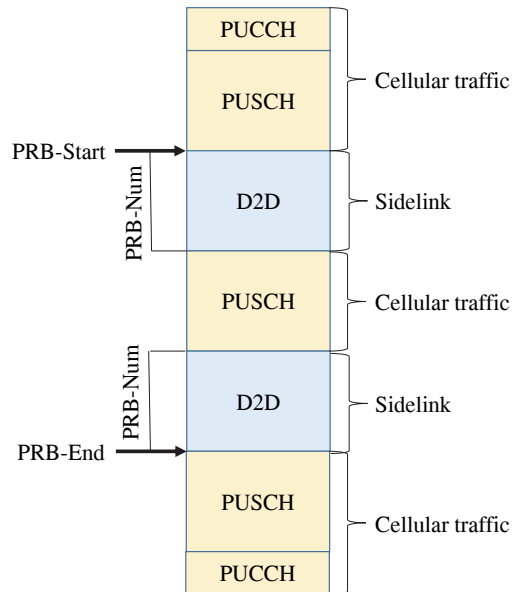
Figure 7.5. Functional architecture: V2X communications



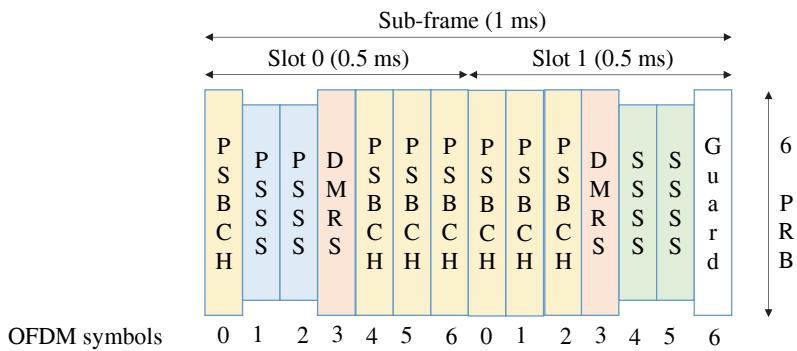
**Figure 7.6. eNB-type and UE-type RSU**



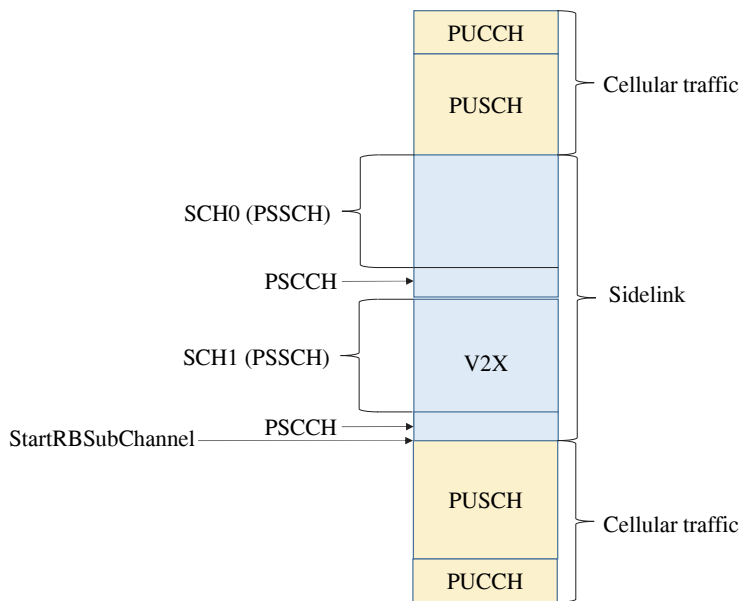
**Figure 7.7. Radio interface structure**



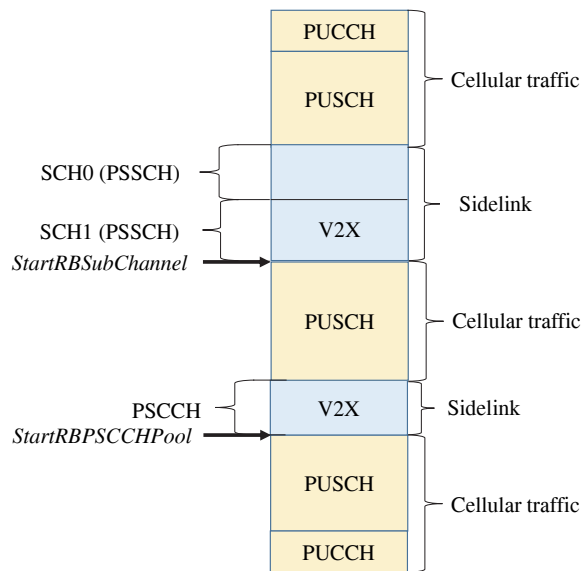
**Figure 7.8.** Resources allocated to the sidelink



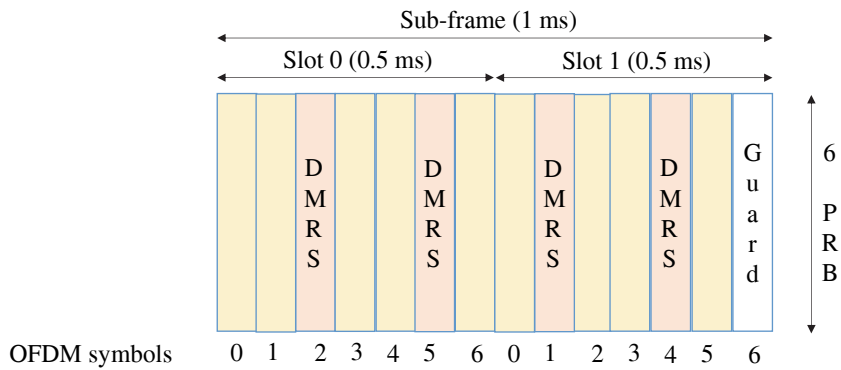
**Figure 7.9.** Resources allocated to SLSS and PSBCH



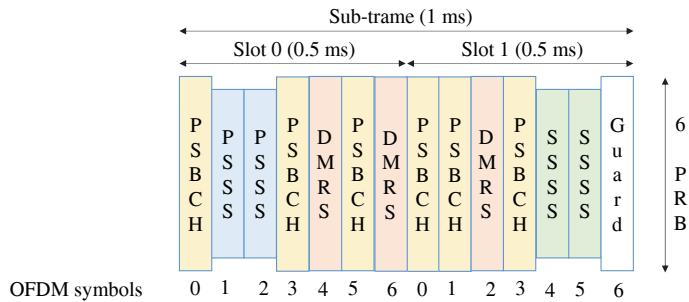
**Figure 7.10.** Resources allocated to the sidelink: adjacent resource blocks



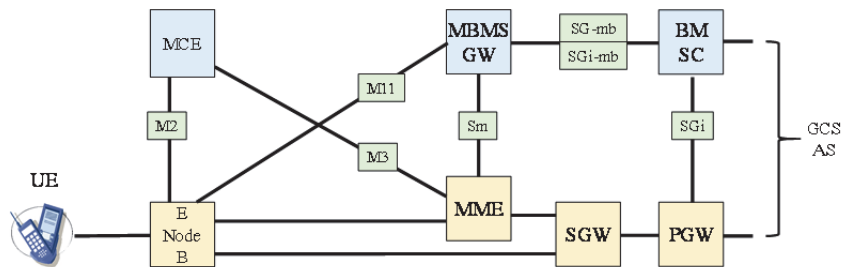
**Figure 7.11.** Resources allocated to the sidelink: non-adjacent resource blocks



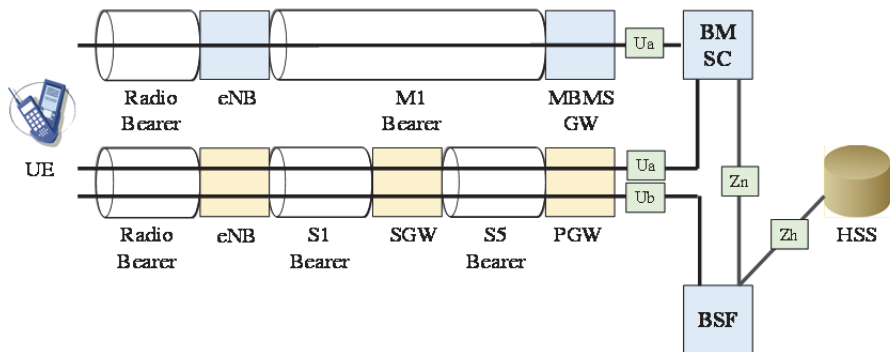
**Figure 7.12.** *DMRS associated with PSCCH and PSSCH*



**Figure 7.13.** *DMRS associated with SLSS and PSBCH*

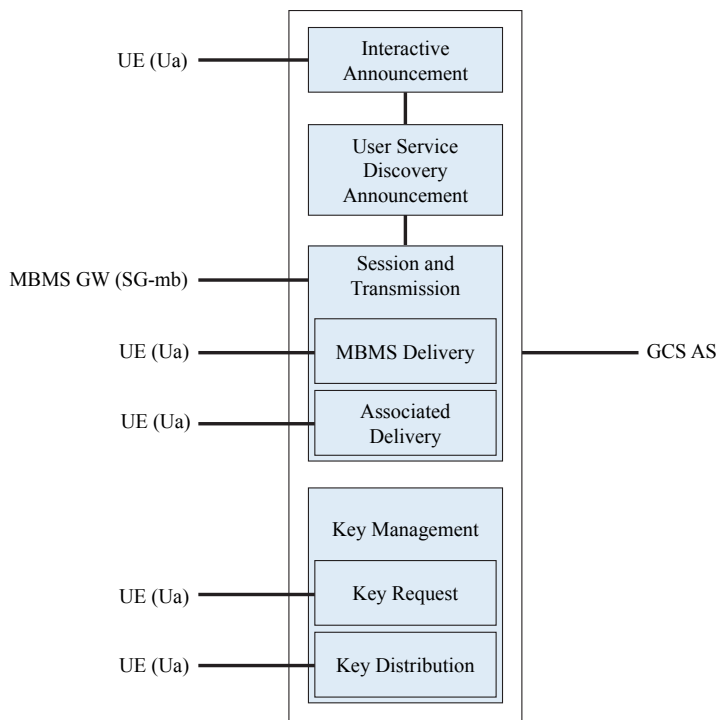


**Figure 8.1.** *eMBMS network: transport architecture*

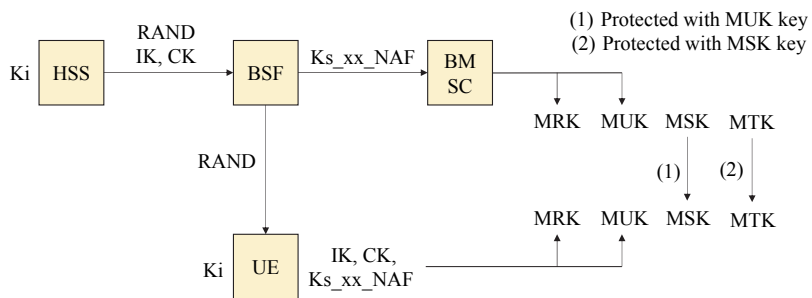


**Figure 8.2.** *eMBMS network: service architecture*

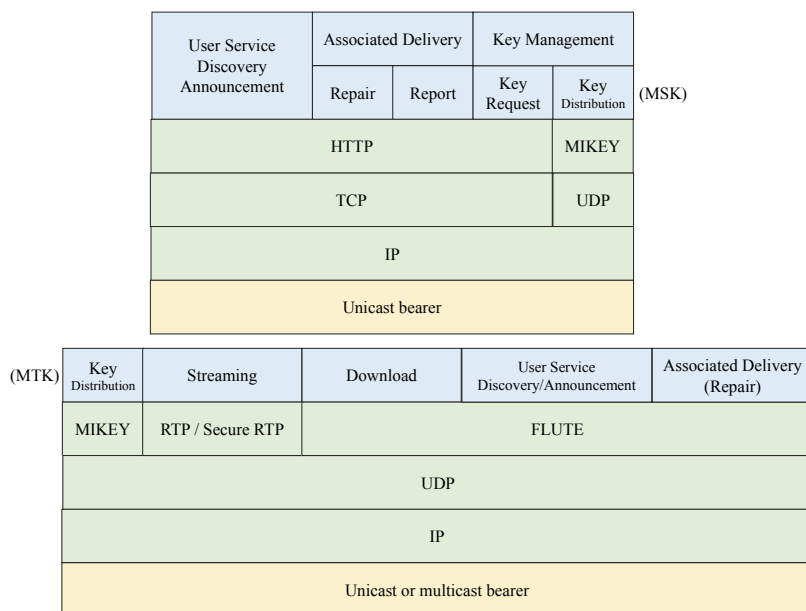




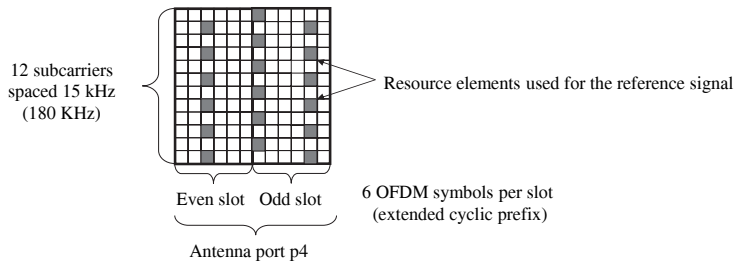
**Figure 8.3.** *Structure of the BM-SC entity*



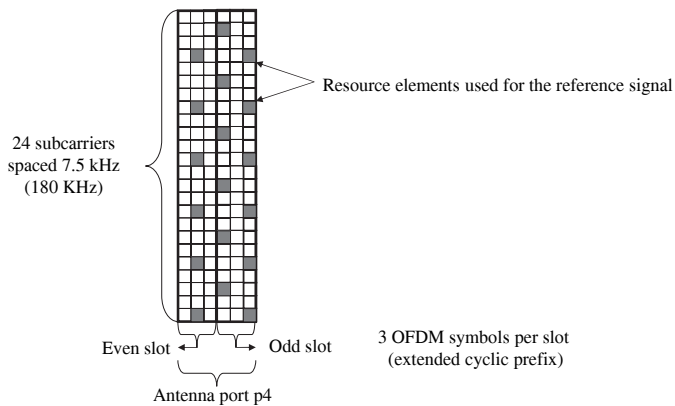
**Figure 8.4. Setting up the keys**



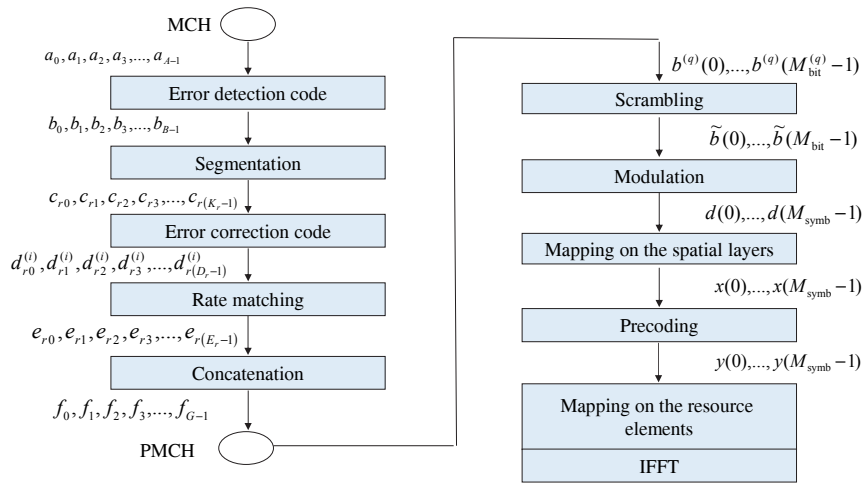
**Figure 8.5. Protocol architecture of the Ua interface**



**Figure 8.6.** Mapping of the MBSFN-RS: a step of 15 kHz between the sub-carriers



**Figure 8.7.** Mapping of the MBSFN-RS: a step of 7.5 kHz between the sub-carriers



**Figure 8.8.** Processing associated with the PMCH

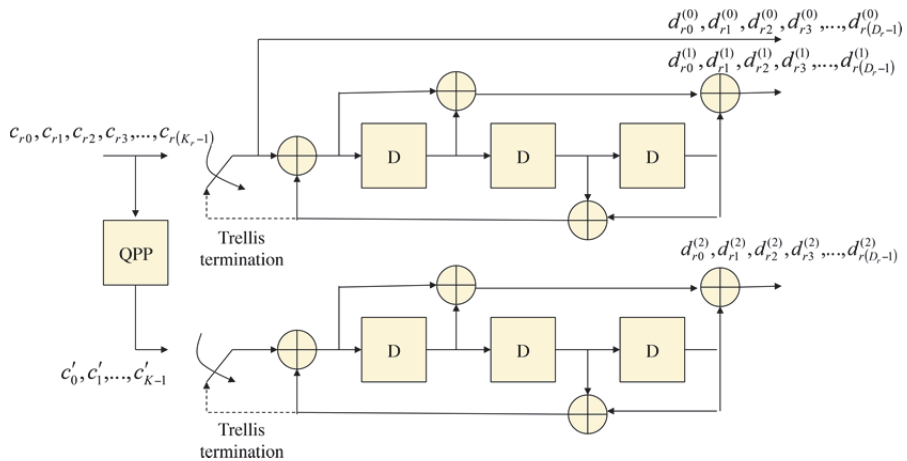


Figure 8.9. Turbo code

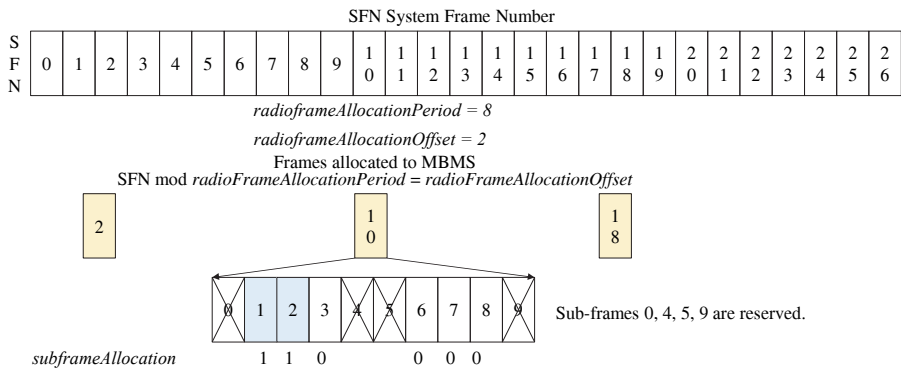
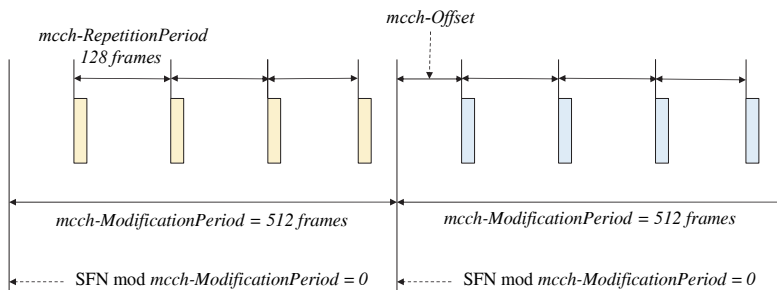
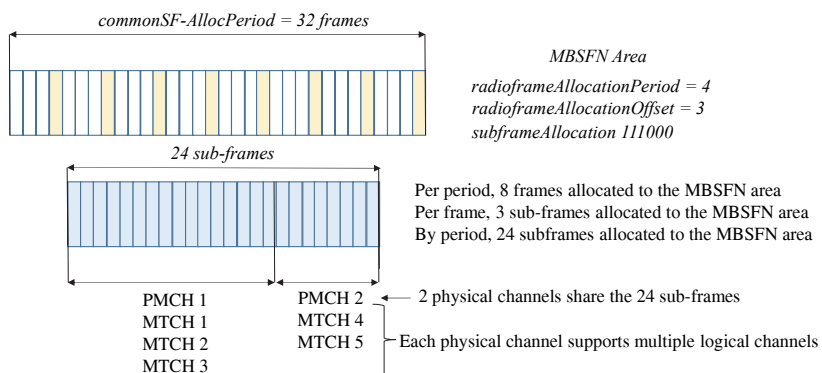


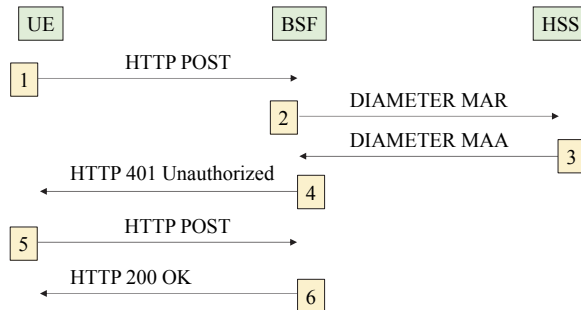
Figure 8.10. Allocation of frames and sub-frames to the MBMS



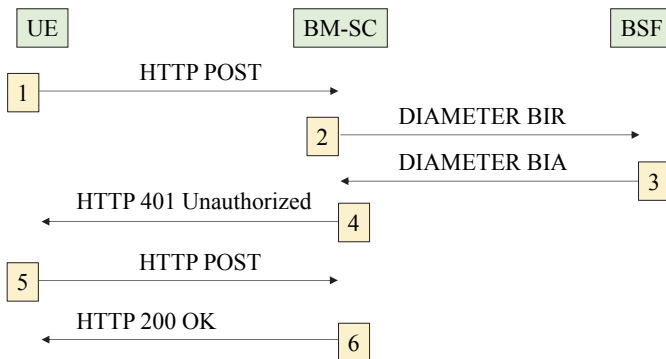
**Figure 8.11. MCCH scheduling**



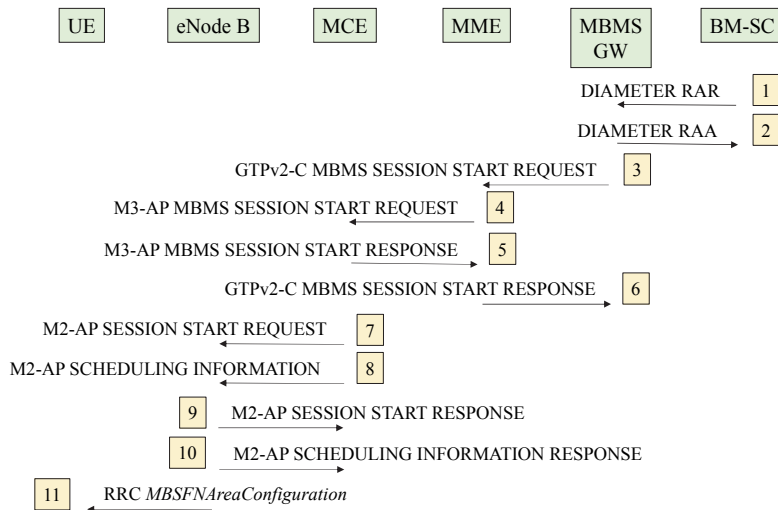
**Figure 8.12. MTCH scheduling**



**Figure 8.13.** *Mutual authentication*



**Figure 8.14.** *Mobile registration*



**Figure 8.15. Multicast bearer establishment**



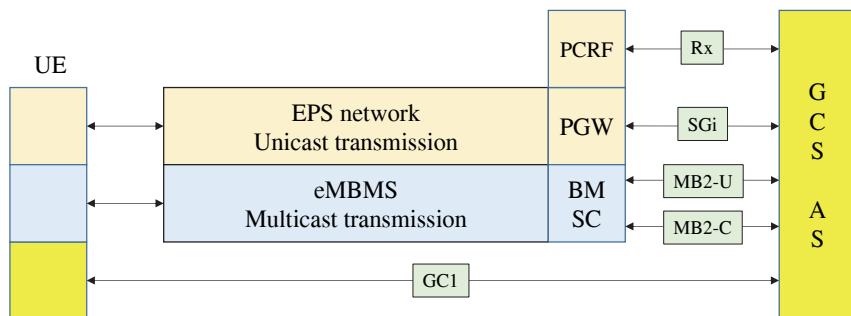


Figure 9.1. GCSE function

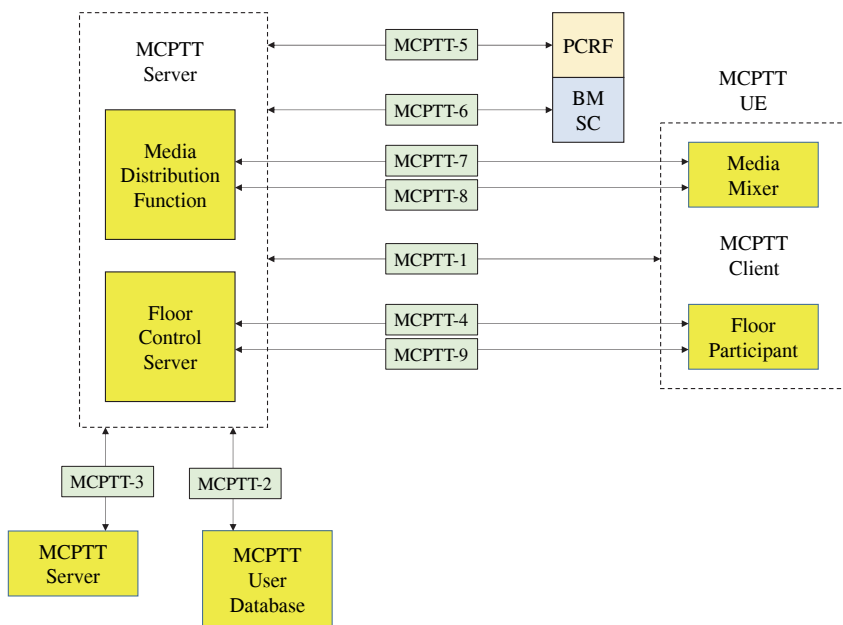
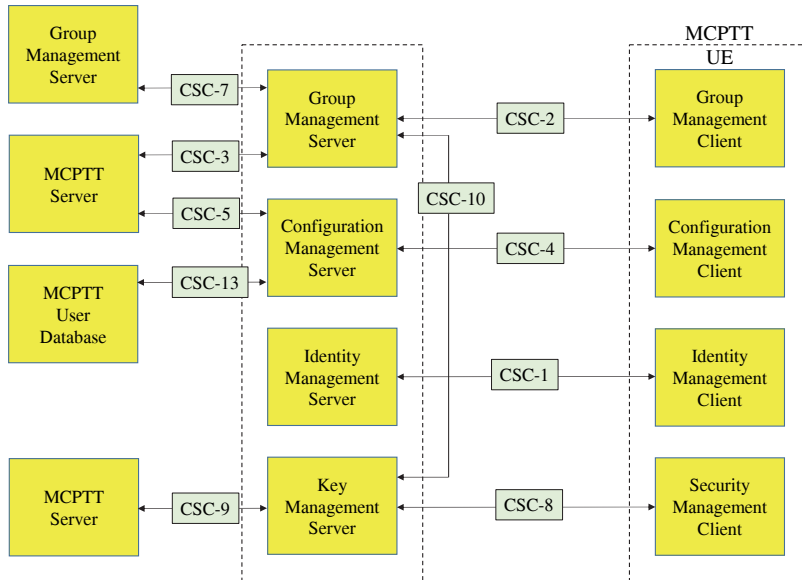
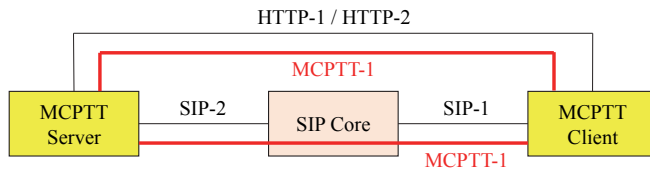


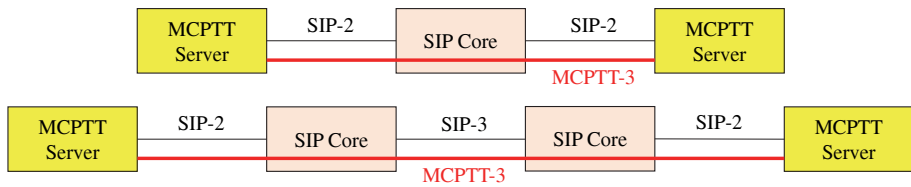
Figure 9.2. Application services



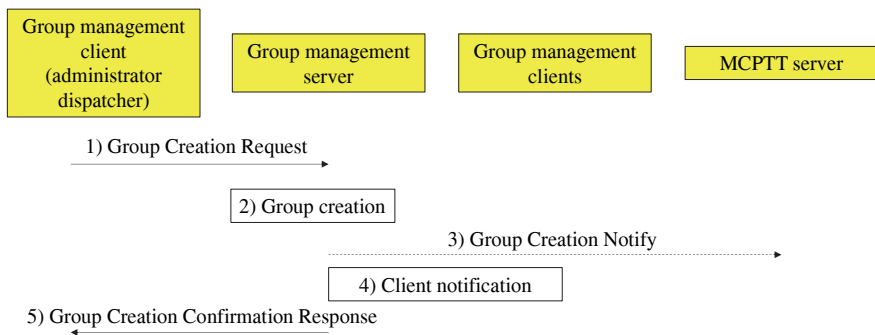
**Figure 9.3. Management services**



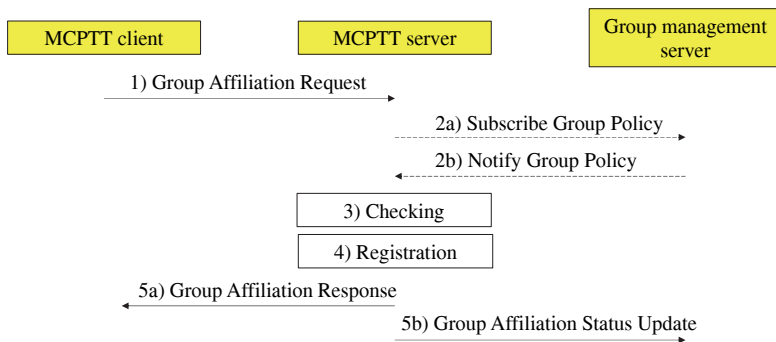
**Figure 9.4.** *MCPTT-1 interfaces*



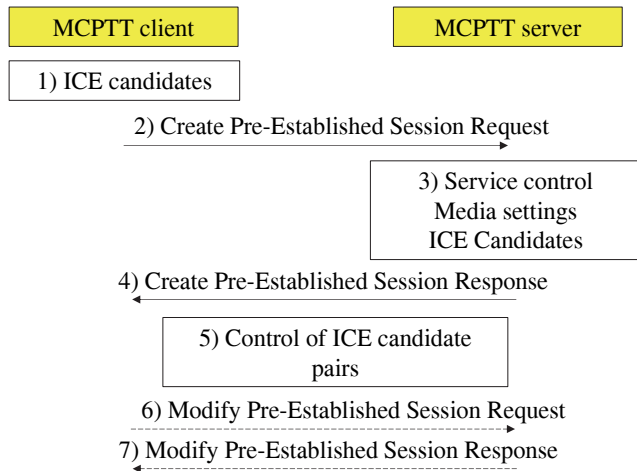
**Figure 9.5.** *MCPTT-3 interfaces*



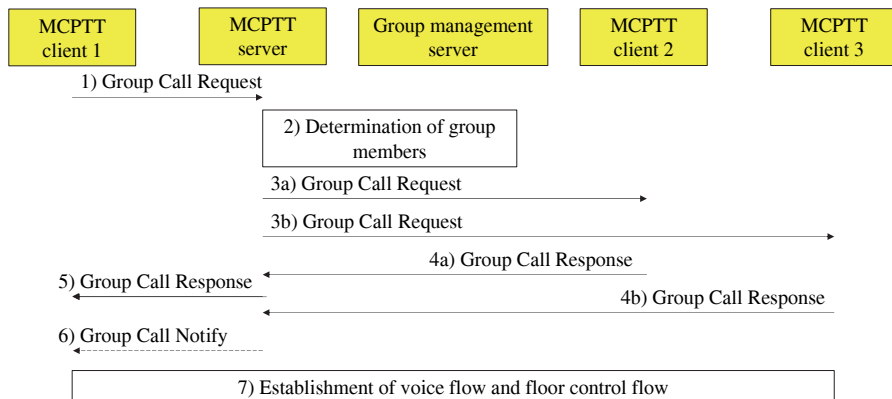
**Figure 9.6. Group creation**



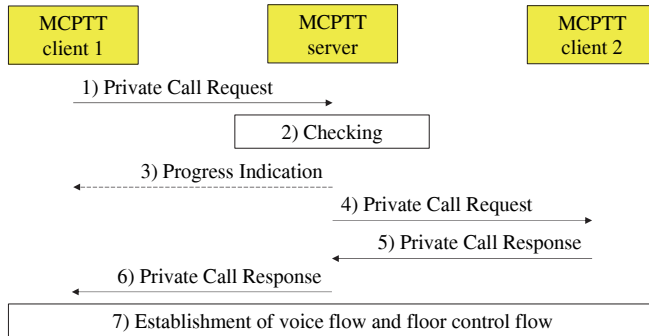
**Figure 9.7. Group affiliation**



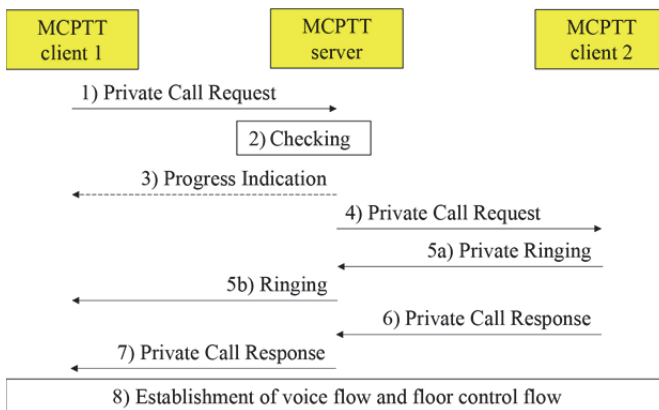
**Figure 9.8. Session pre-establishment: group call**



**Figure 9.9. Group call**



**Figure 9.10. Private call: automatic start-up mode**



**Figure 9.11. Private call: manual start-up mode**

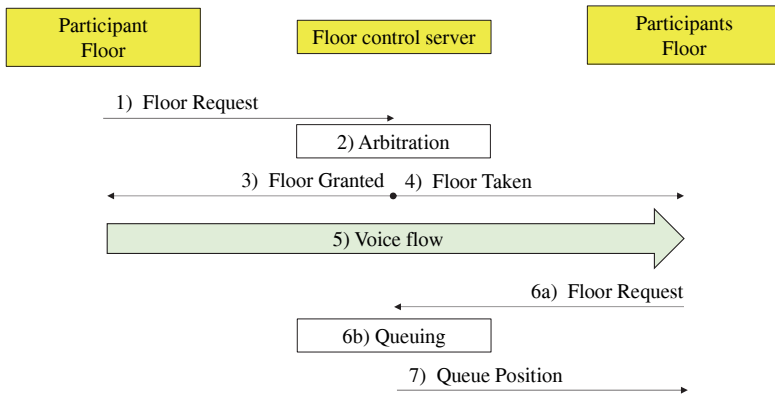


Figure 9.12. Floor

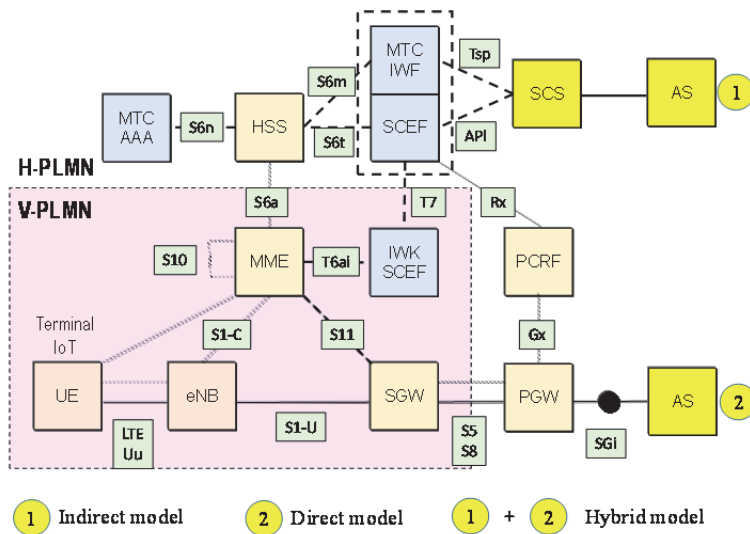
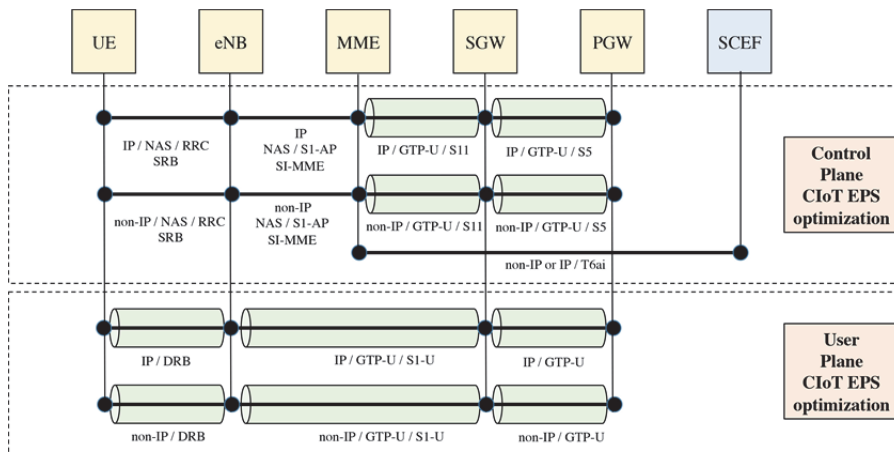
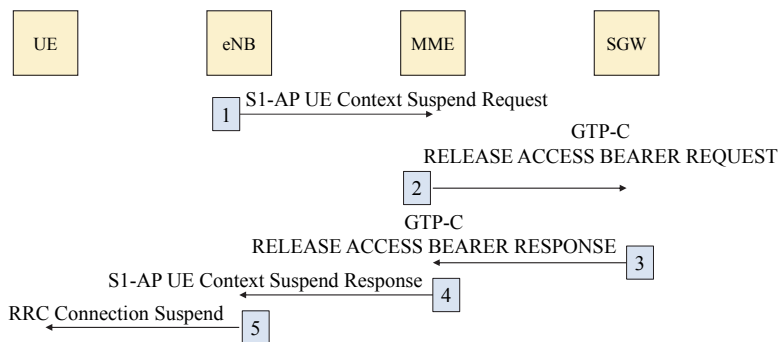


Figure 10.1. Network architecture

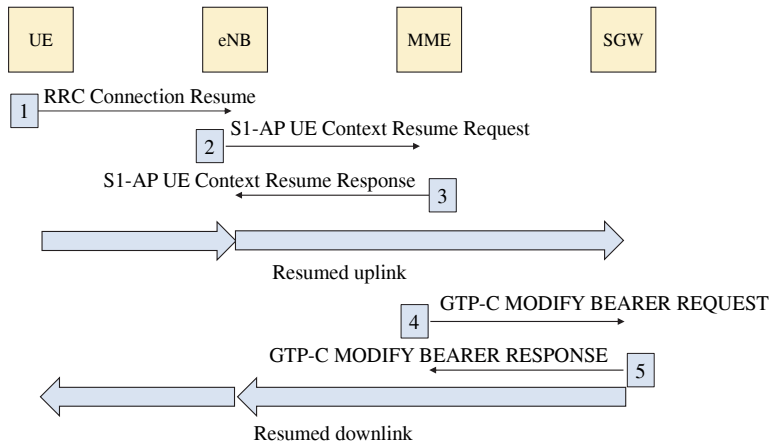


**Figure 10.2. Different variants of data transmission**

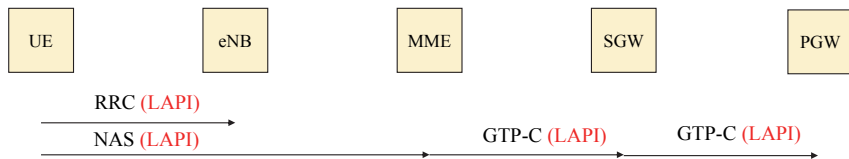


**Figure 10.3. RRC Suspend procedure**

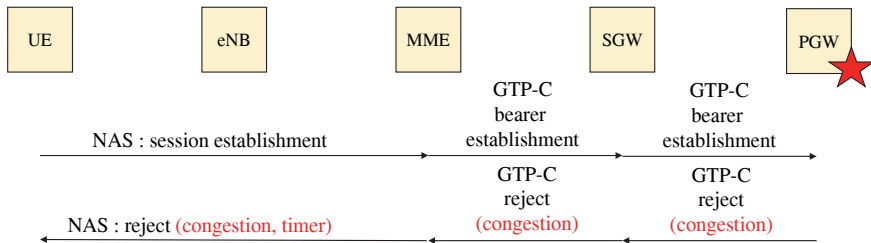




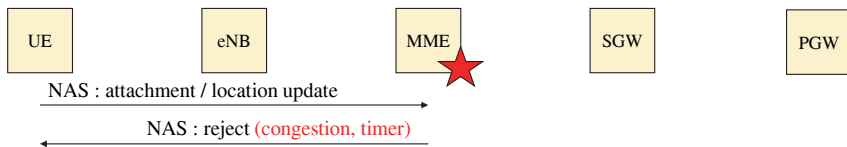
**Figure 10.4. RRC Resume procedure**



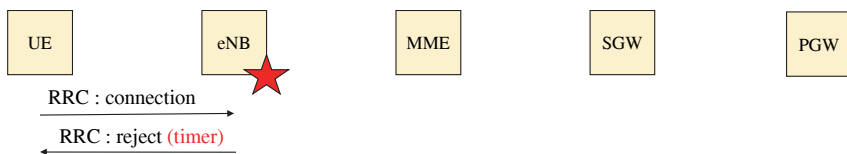
**Figure 10.5. LAPI notification**



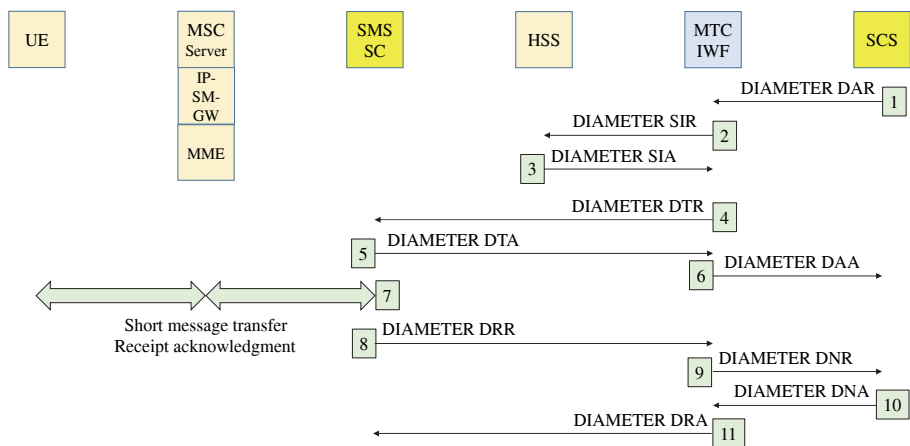
**Figure 10.6. Congestion control: session establishment reject**



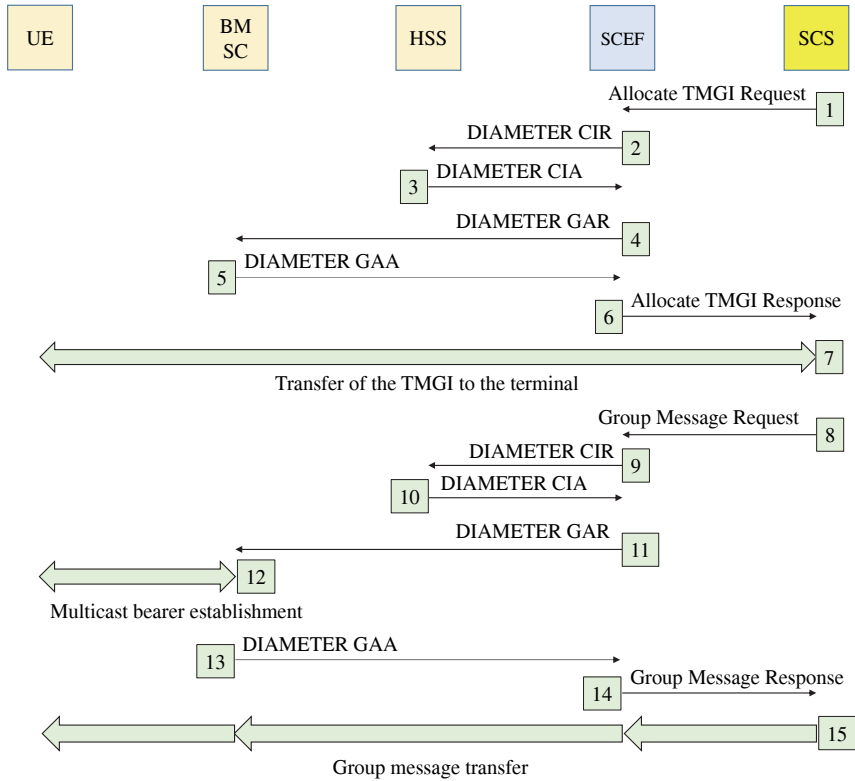
**Figure 10.7. Congestion control: attachment reject**



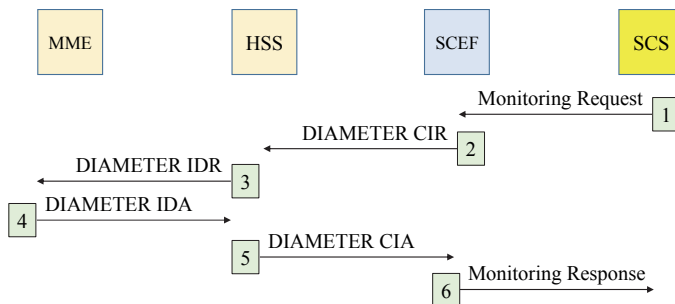
**Figure 10.8. Congestion control: connection reject**



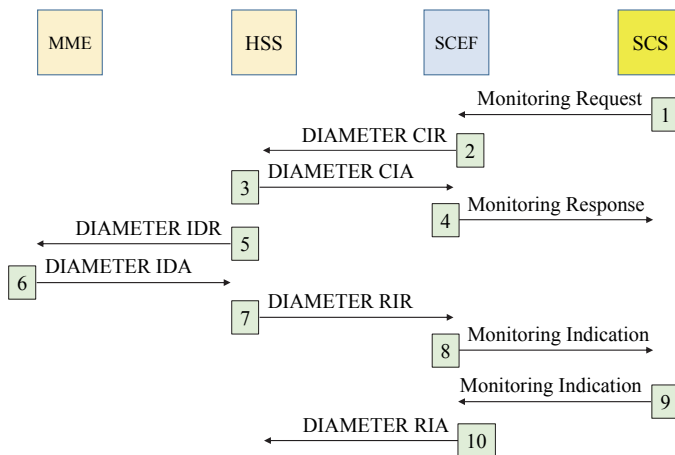
**Figure 10.9.** *Triggering procedure by short message*



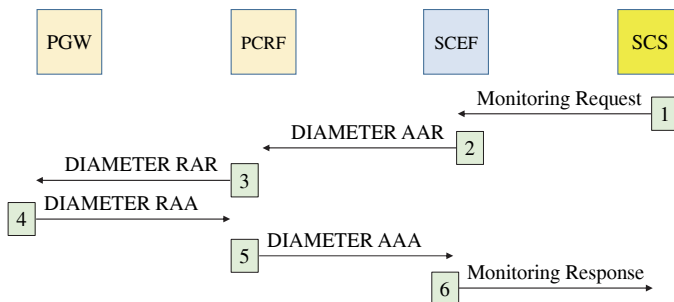
**Figure 10.10.** *Group message delivery*



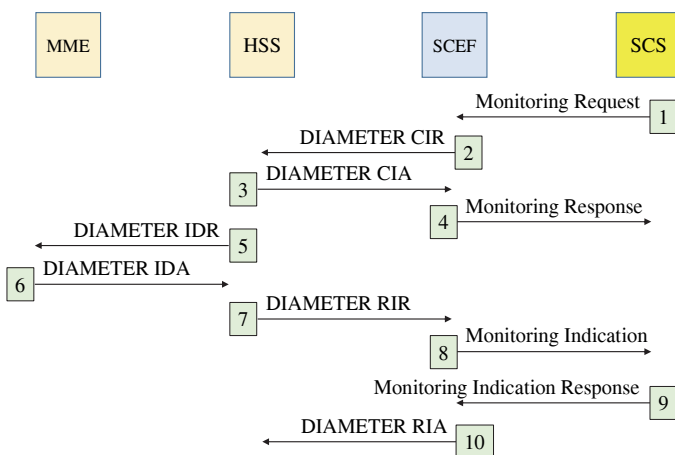
**Figure 10.11.** *HSS and MME configuration: single process*



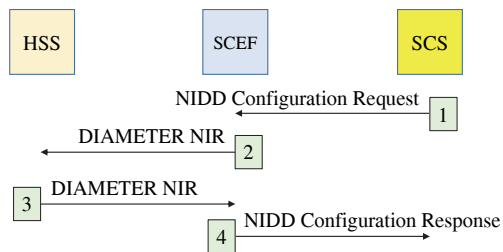
**Figure 10.12.** *HSS and MME configuration: group process*



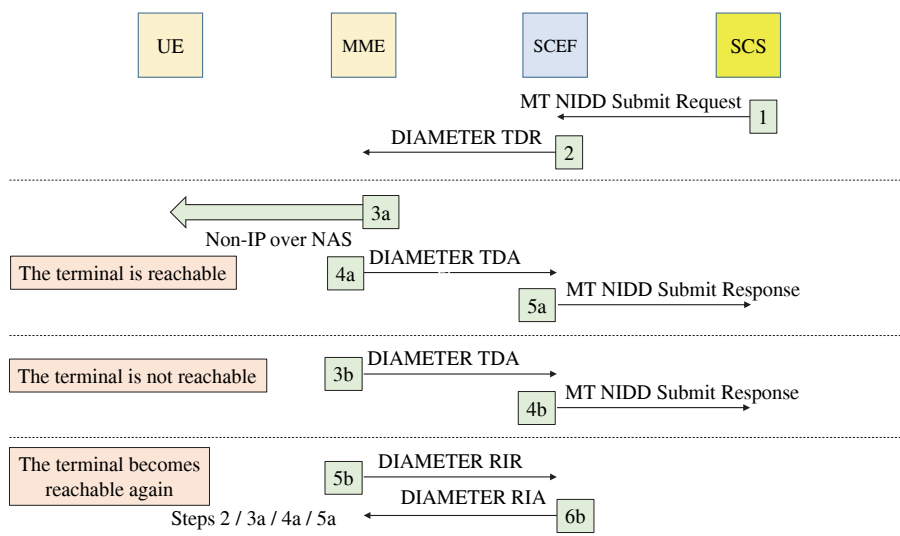
**Figure 10.13.** *PGW configuration: single process*



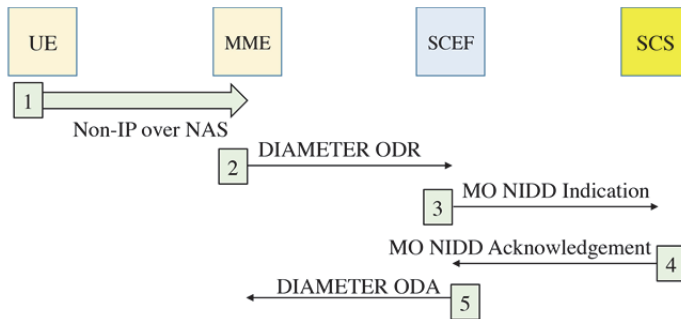
**Figure 10.14.** *PGW configuration: group process*



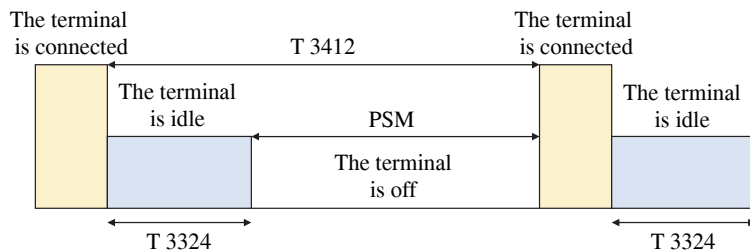
**Figure 10.15.** *NIDD configuration*



**Figure 10.16.** *Downlink NIDD transfer*

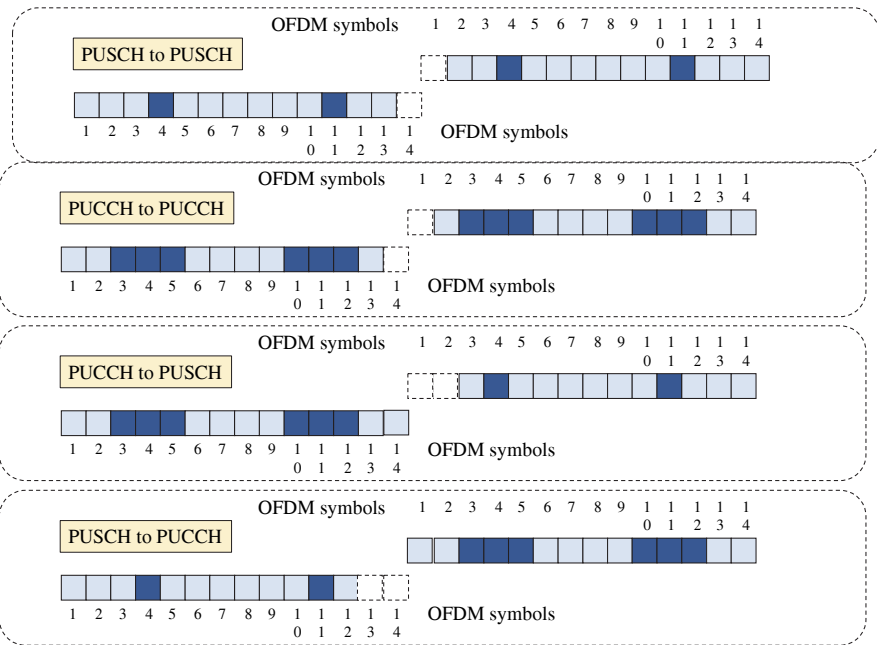


**Figure 10.17. Uplink NIDD transfer**



**Figure 11.1. PSM**





**Figure 11.2. Guard time**

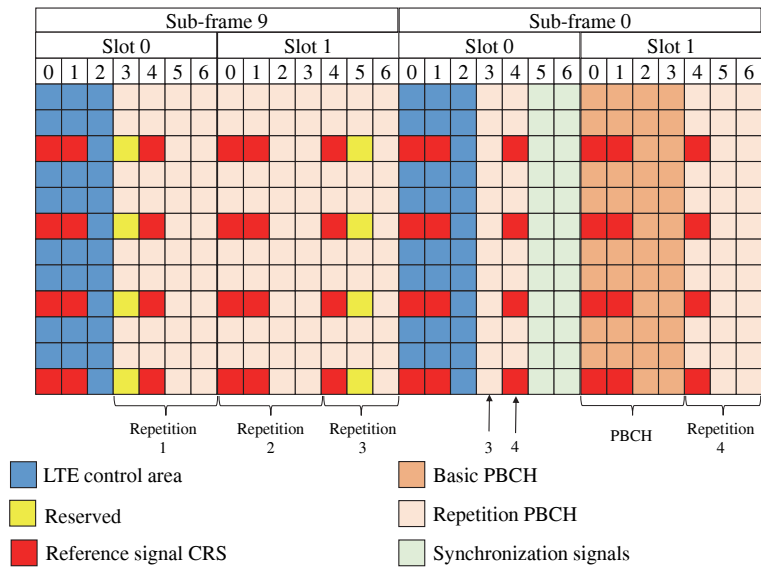


Figure 11.3. PBCH structure

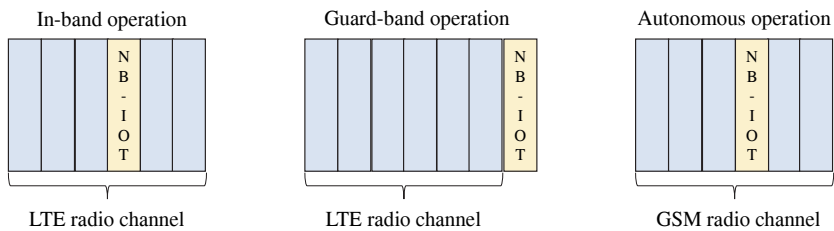


Figure 11.4. NB-IoT radio channel

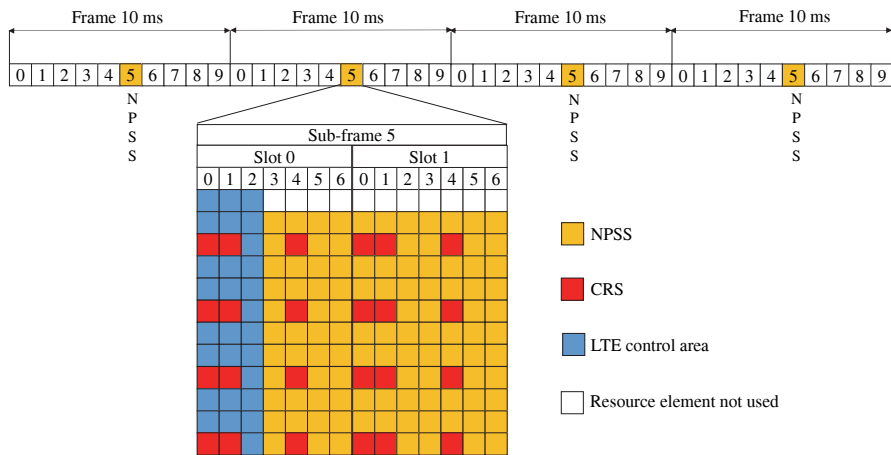


Figure 11.6. NPSS

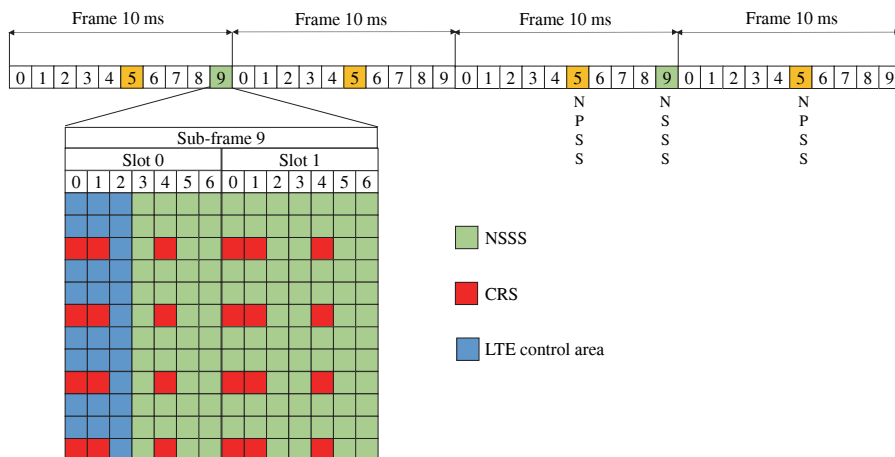


Figure 11.7. NSSS



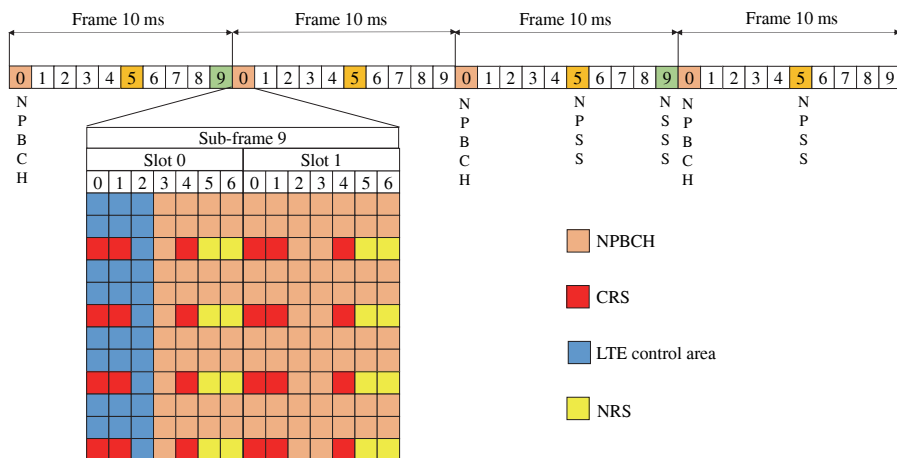


Figure 11.10. NPBCH: sub-frame structure

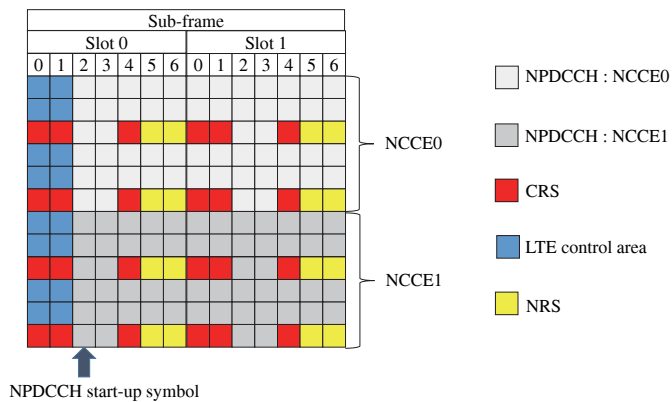
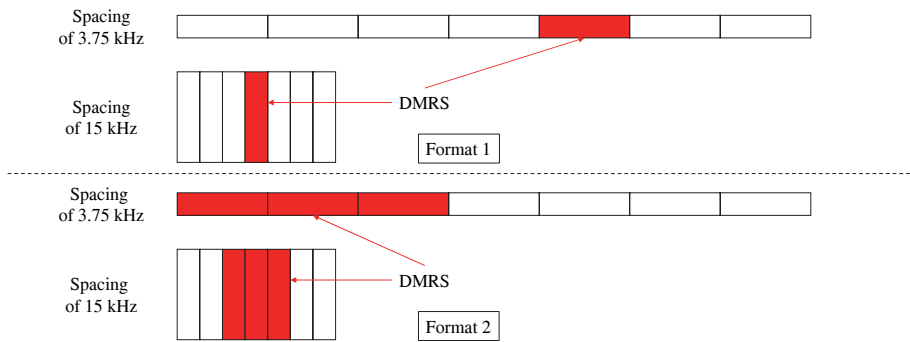
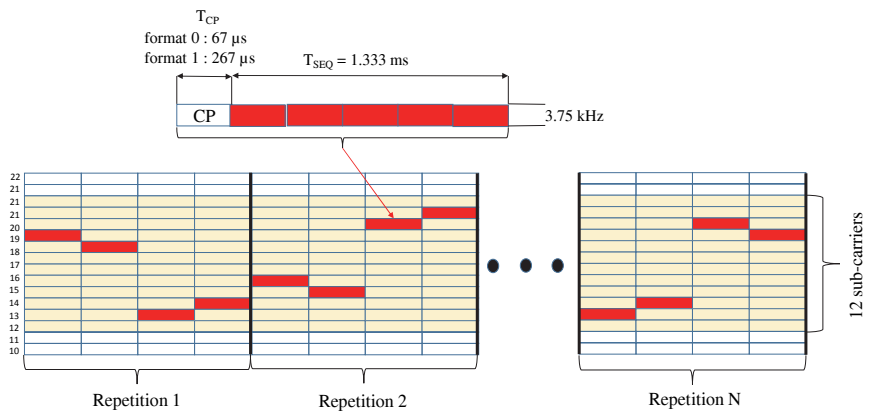


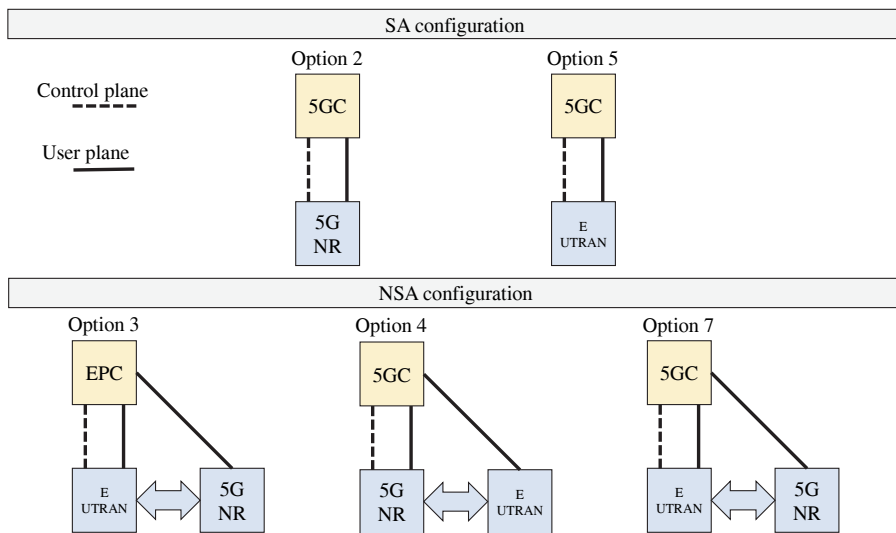
Figure 11.11. NPDCCH



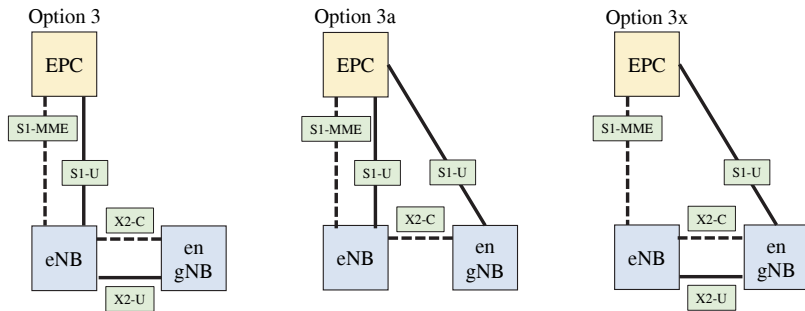
**Figure 11.12. DMRS**



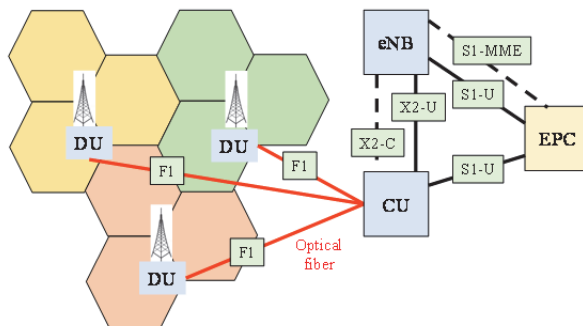
**Figure 11.13. NPRACH**



**Figure 12.1. SA and NSA configurations**

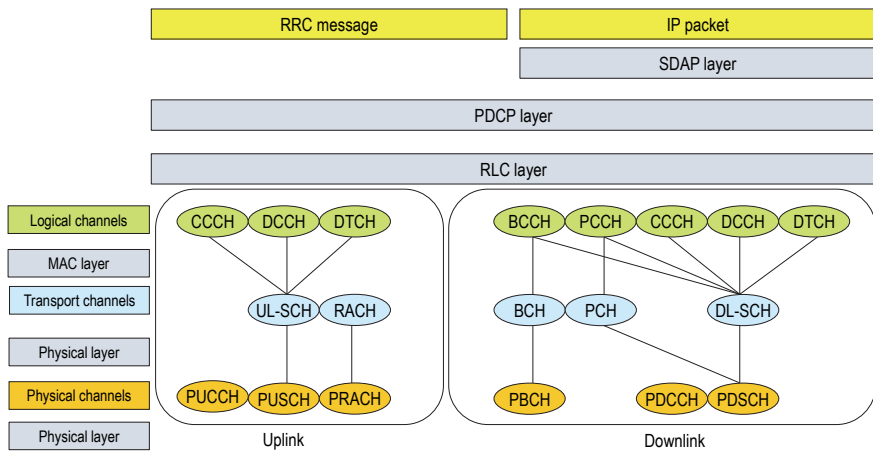


**Figure 12.2.** *Functional architecture*

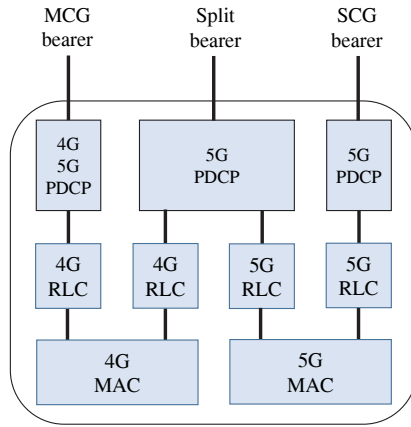


**Figure 12.3.** *en-gNB architecture*

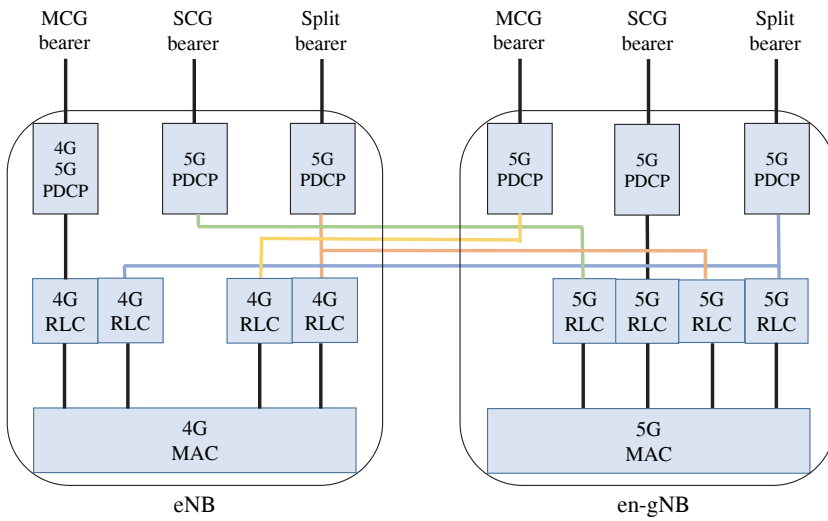




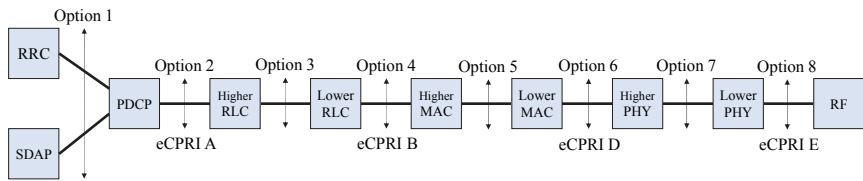
**Figure 12.4.** Protocol architecture of the NR interface



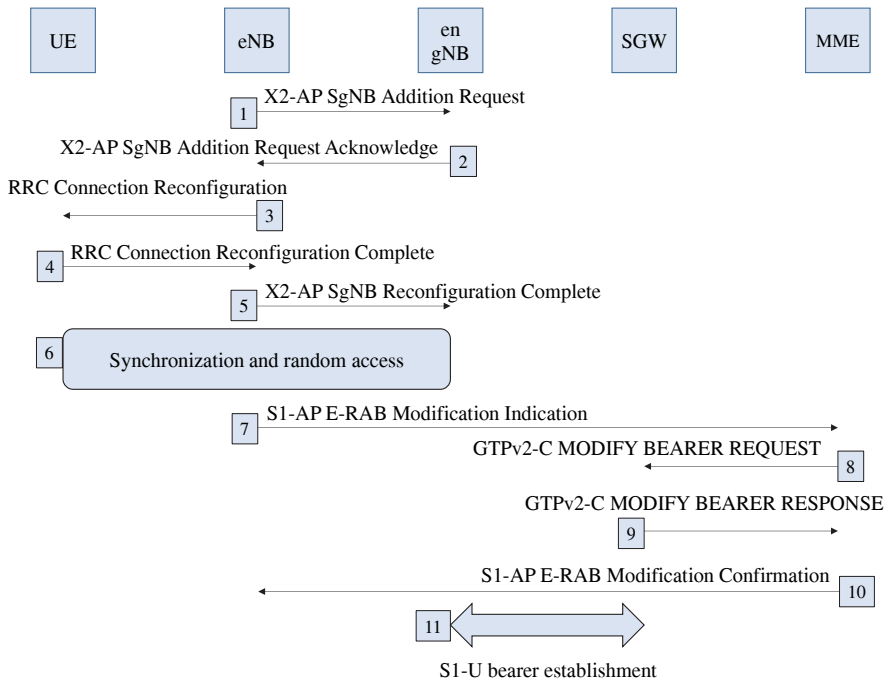
**Figure 12.5.** *Protocol architecture: mobile side*



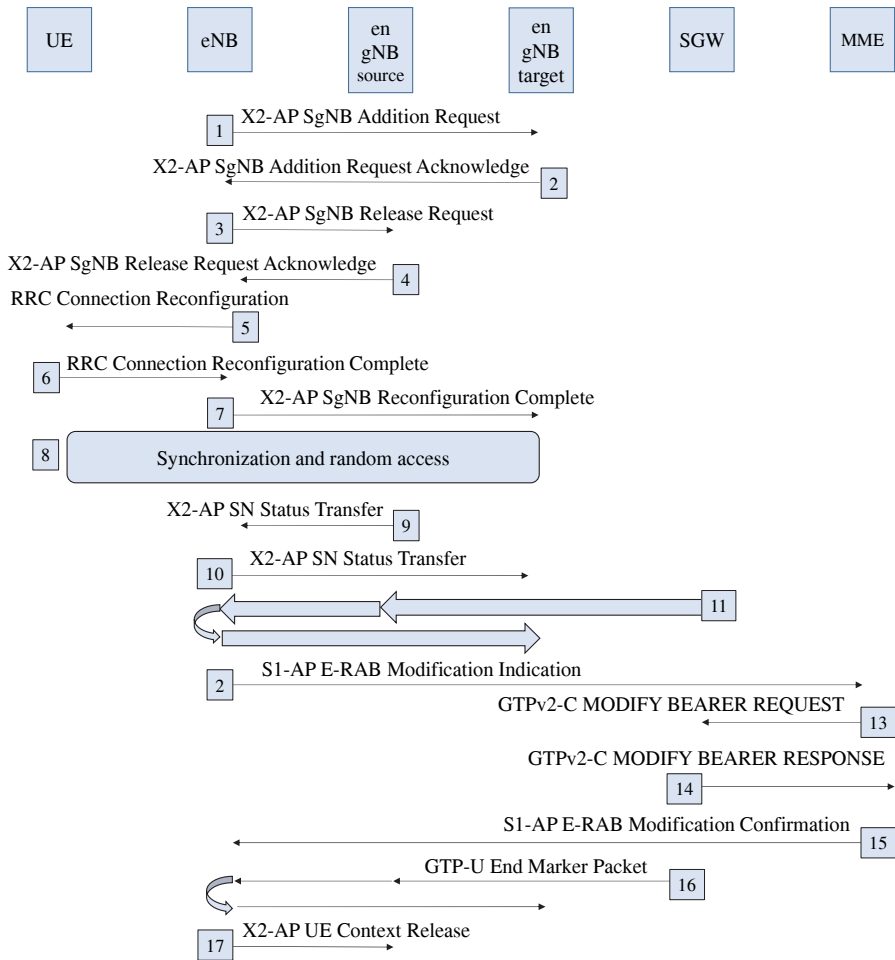
**Figure 12.6.** *Protocol architecture: eNB and en-gNB side*



**Figure 12.7.** Split configuration of the functions between CU and DU

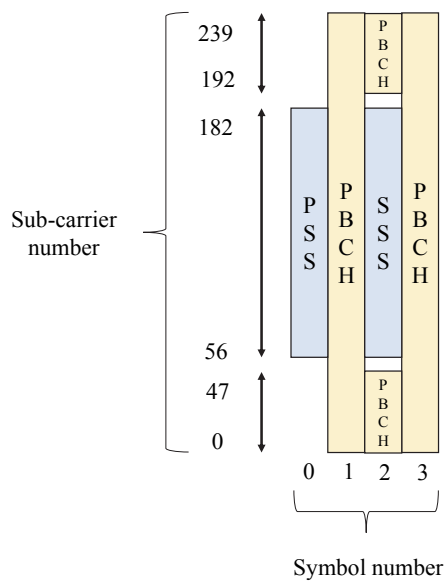


**Figure 12.8.** Adding a secondary node

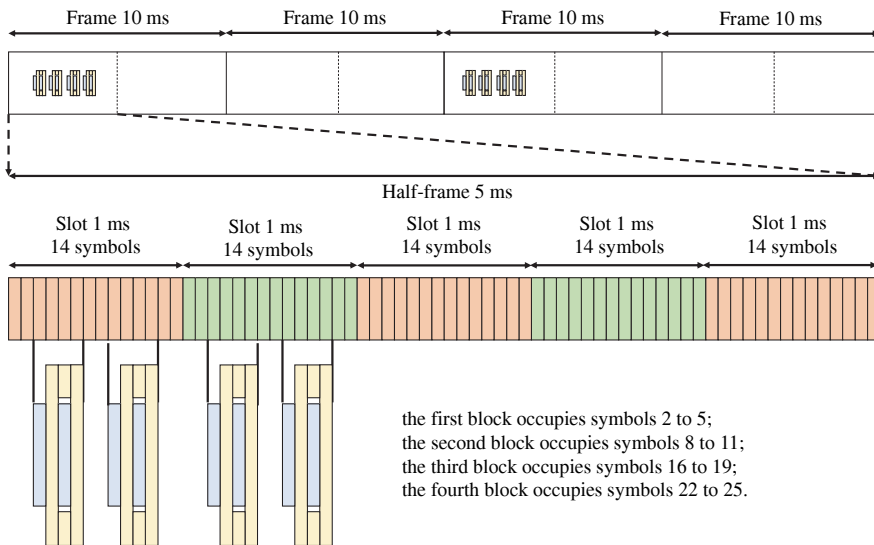


**Figure 12.9.** *Changing a secondary node initiated by the eNB entity*





**Figure 12.12.** *Block of PSS, SSS and PBCH*



**Figure 12.13.** PSS, SSS and PBCH location: NR interface