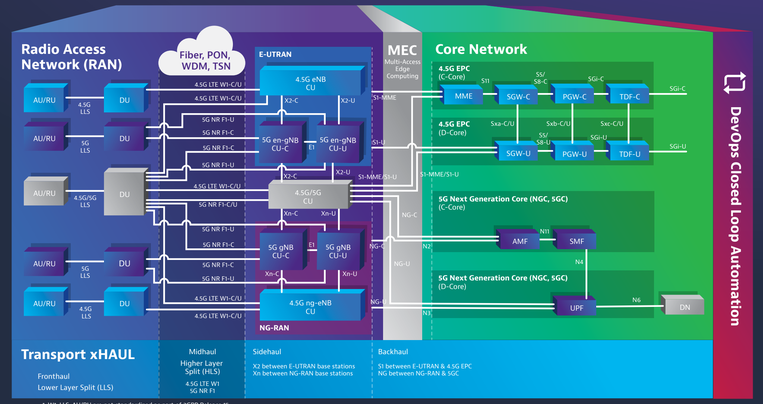
# 5G Architecture and Specifications

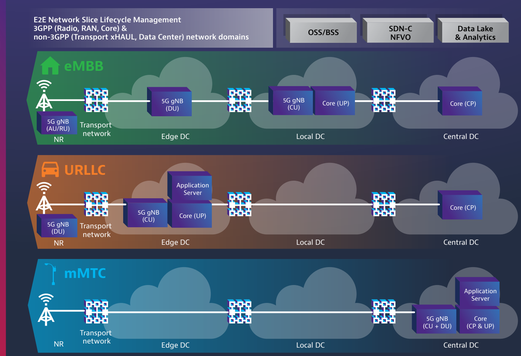
## 4G & 5G NEW RADIO (NR) END TO END (E2E) NETWORK ARCHITECTURE

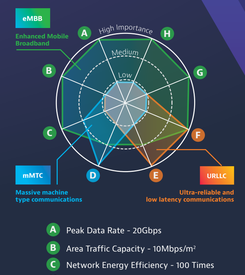



**NOTES** 1. W1, LLS, AU/RU are not standardized as part of 3GPP Release 15
2. 4.5G and 5G core network elements are not all shown in this network architecture diagram

## END TO END (E2E) NETWORK SLICING ARCHITECTURE

Examples of Service Adaptive Slices with Dynamic Deployments of Flexible Radio, RAN, Core functions and Transport, Data Centers resources




- A Peak Data Rate - 20Gbps
- B Area Traffic Capacity - 10Mbps/m²
- C Network Energy Efficiency - 100 Times
- D Connection Density - 10⁶/km² (1 per m²)
- E Latency - 1ms(Radio segment)
- F Mobility - 500 km/h
- G Spectrum Efficiency - 3 Times
- H User Experienced Data Rate - 100Mbps

Source: Rec. ITU-R M.2083-0 Figure 3 and 4

## 5G ARCHITECTURE OPTIONS

| Non Standalone (NSA) with Multi Connectivity | Standalone (SA) |
|---|---|
| Focus of 3GPP R15 5G NR Dec 2017 release | Planned for 3GPP R15 5G NR Jun 2018 release |
| **Option 3/3a/3x**: 4G EPC; 4G eNB (MN); 5G en-gNB (SN) | **Option 2**: 5G NGC; 5G gNB |
| Planned for 3GPP R15 5G NR Dec 2018 late-drop release | Planned for 3GPP R15 5G NR Jun 2018 release |
| **Option 4/4a**: 5G NGC; 4G ng-eNB (SN); 5G gNB (MN) | **Option 5**: 5G NGC; 4G ng-eNB |
| **Option 7/7a/7x**: 5G NGC; 4G ng-eNB (MN); 5G SgNB (SN) | |

## 4.5G & 5G 3GPP RELEASES HIGHLIGHTS

| | Key Features | Release 13 | Release 14 | Release 15 (Stage 3 Freeze Jun 2018) |
|---|---|---|---|---|
| 4G LTE-Advanced Pro | Cellular V2X (C-V2X) | | Cellular V2X (C-V2X) introduction | V2X enhancements (eC-V2X) |
| | Cellular (Narrowband) Internet of Things (C-IoT ) | LTE-M (Cat M1) NB-IoT (Cat NB1) | LTE-M enhancements (Cat M2) NB-IoT enhancements (Cat NB2) | LTE-M further enhancements NB-IoT further enhancements |
| | Mission Critical | Mission Critical Push To Talk over LTE (MCPTT) | Enhancements for Mission Critical Push To Talk Mission Critical Video over LTE Mission Critical Data over LTE | Mission Critical Push To Talk over LTE (MCPTT), Data, Video enhancements |
| | Radio Access Network (RAN) evolution | Higher Order Modulation: Uplink 64 QAM Licensed-Assisted Access (LAA Downlink) Elevation Beamforming/Full-Dimension (FD-MIMO) 16TX | Uplink 256 QAM Enhanced LAA for LTE (LAA Uplink) Enhanced FD-MIMO 32TX CBRS 3.5GHz band for LTE in the United States | Downlink 1024QAM E-UTRAN Ultra Reliable Low Latency Communication (URLLC) RAN LAA/LAA for the CBRS 3.5GHz Enhanced LTE Support for Aerial Vehicles eNB(s) Architecture Evolution for E-UTRAN and NG-RAN |
| | Core Network evolution | Dedicated Core Networks (DECOR) | Dedicated Core Networks (DECOR) enhancements Control and User Plane Separation of EPC nodes (CUPS) | E-UTRAN Ultra Reliable Low Latency Communication (URLLC) Core (EPC) |
| 5G New Radio (NR) | **Release 15 (Stage 3 Freeze Jun 2018), Release 15 Late Drop (Stage 3 Freeze Dec 2018)** | | | |

**Dec 17 (Non-Standalone - NSA)**
- 5G New Radio (NR)
- Massive MIMO – Beam centric Radio
- FDD and Dynamic TDD
- Flexible Numerologies (subcarrier spacing, cyclic prefix)
- FR1: 450MHz – 6GHz FR2: 24.25 – 52.6GHz
- Channel Bandwidths up to 100MHz (FR1) & 400MHz (FR2)
- Bandwidth Adaptation utilizing Bandwidth Parts (BWP)
- Flexible frame structure with scalable TTI (mini-slot, slot or multiple slots) and Self-Contained slot structure
- Channel Coding – LDPC (data), Polar Codes (control), Block (control uplink lower rates) Codes
- Supplementary Uplink (SUL)
- RAN Dis-aggregation CU-DU Higher Layer Split (HLS)
- Non-Standalone (NSA) Architecture Option 3/3a/3x
- EPC enhancements to support 5G NR via E-UTRA-NR Dual Connectivity (EN-DC)

**Jun 18 – Full Release (Standalone – SA)**
- 5G Next Generation Core Network (5GC)
- Architecture Options 2 & 5 (Standalone)
- Remaining features (Network Slicing, others)
- Separation of NR Control Plane (CP) and User Plane (UP) for Split option 2 (Higher Layer Split – PDCP)

**Dec 18 – Late Drop (Non-Standalone – NSA)**
- Architecture Options 4 & 7

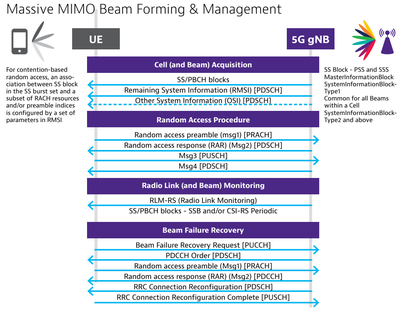
Release 16 scheduled for Stage 1, 2, 3 freeze: Dec 2018, Jun 2019 and Dec 2019 respectively

## 4.5G & 5G ARCHITECTURE SPECIFICATIONS

| | 4G LTE-Advanced Pro | 5G New Radio (NR) |
|---|---|---|
| System Architecture | 3GPP TS 23.401: GPRS enhancements for E-UTRAN access 3GPP TS 23.402: Architecture enhancements for non-3GPP accesses | 3GPP TS 23.501: System Architecture for the 5G System 3GPP TS 23.502: Procedures for the 5G System |
| Policy and Charging Control | 3GPP TS 23.203: Policy and charging control architecture | 3GPP TS 23.503: Policy and Charging Control Framework for the 5G System; Stage 2 |
| Security Architecture | 3GPP TS 33.401: 3GPP SAE; Security architecture | 3GPP TS 33.501: Security architecture and procedures for 5G System |
| RAN Overall Description | 3GPP TS 36.300: E-UTRA and E-UTRAN; Overall description; Stage 2 | 3GPP TS 38.300: NR; Overall description; Stage-2 |
| RAN Architecture | 3GPP TS 36.401: E-UTRAN; Architecture description | 3GPP TS 38.401: NG-RAN; Architecture description |
| Multi-connectivity | 3GPP TS 37.340: Evolved Universal Terrestrial Radio Access (E-UTRA) and NR; Multi-connectivity; Stage 2 | |
| CU Control User Plane Separation | 3GPP TS 23.214: Architecture enhancements for control and user plane separation of EPC nodes | 3GPP TR 38.806: Study of separation of NR Control Plane (CP) and User Plane (UP) for split option 2 |
| CU DU RAN functions dis-aggregation | 3GPP TR 37.876: Study on eNB(s) Architecture Evolution for E-UTRAN and NG-RAN | 3GPP TR 38.816: Study on CU-DU lower layer split for NR |

## 5G RADIO

### Massive MIMO Beam Forming & Management




For contention-based random access, an association between SS block in the SS burst set and a subset of RACH resources and/or preamble indices is configured by a set of parameters in RMSI

SS Block - PSS and SSS MasterInformationBlock-Type1 Common for all Beams within a Cell SystemInformationBlock-Type2 and above

### Radio Protocols, Management & Procedures Specifications

| | 4G LTE-Advanced Pro | 5G New Radio (NR) |
|---|---|---|
| Service Data Adaptation Protocol | | SDAP: 3GPP TS 37.324 |
| Radio Resource Control | RRC: 3GPP TS 36.331 | NR-RRC: 3GPP TS 38.331 |
| Packet Data Convergence Protocol | PDCP: 3GPP TS 36.323 | NR-PDCP: 3GPP TS 38.323 |
| Radio Link Control | RLC: 3GPP TS 36.322 | NR-RLC: 3GPP TS 38.322 |
| Medium Access Control | MAC: 3GPP TS 36.321 | NR-MAC: 3GPP TS 38.321 |
| **Physical Layer** | **PHY** | **NR-PHY** |
| Physical channels and modulation | 3GPP TS 36.211 | 3GPP TS 38.211 |
| Multiplexing and channel coding | 3GPP TS 36.212 | 3GPP TS 38.212 |
| Physical layer procedures | 3GPP TS 36.213 | 3GPP TS 38.213 (control) 3GPP TS 38.214 (data) |
| Physical layer Measurements | 3GPP TS 36.214 | 3GPP TS 38.215 |
| User Equipment (UE) radio transmission and reception | 3GPP TS 36.101 | 3GPP TS 38.101-1: Part 1: Range 1 Standalone 3GPP TS 38.101-2: Part 2: Range 2 Standalone 3GPP TS 38.101-3: Part 3: Range 1 and Range 2 Interworking operation with other radios 3GPP TS 38.101-4: Part 4: Performance requirements |
| Base Station (BS) radio transmission and reception | 3GPP TS 36.104 | 3GPP TS 38.104 |
| Requirements for support of radio resource management | 3GPP TS 36.133 | 3GPP TS 38.133 |
| Physical layer; General description | 3GPP TS 36.201 | 3GPP TS 38.201 |
| Services provided by the physical layer | 3GPP TS 36.302 | 3GPP TS 38.202 |
| User Equipment (UE) procedures in idle mode | 3GPP TS 36.304 | 3GPP TS 38.304 |
| Multi-RAT Co-Existence | 3GPP TR 37.872: Supplementary uplink (SUL) and LTE-NR co-existence | |

¹Applicable only when the 5G gNB is connected to the 5G NGC

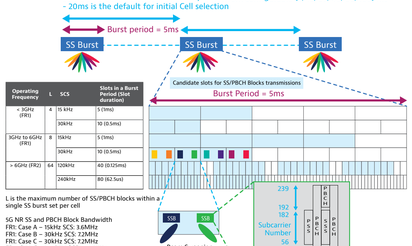
### Physical Channels & Signals

| | | | |
|---|---|---|---|
| 5G New Radio (NR) | Downlink | | |
| | Channels | NR-PDSCH: Physical Downlink Shared Channel<br>NR-PBCH: Physical Broadcast Channel<br>NR-PDCCH: Physical Downlink Control Channel | |
| | Signals | NR-PSS: Primary Synchronization Signal<br>NR-SSS: Secondary Synchronization Signal<br>NR-DM-RS: Demodulation Reference Signal | |
| | | NR-CSI-RS: Channel-State Information Reference Signal | Can be used for estimation of channel-state information (CSI) to further prepare feedback reporting to gNB to assist in MCS selection, beamforming, MIMO rank selection and resource allocation. CSI-RS also can be used for interference measurement and fine frequency/time tracking purposes |
| | | NR-PT-RS: Phase-Tracking Reference Signal | Can be used in addition to the DM-RS for PDSCH for correcting common phase error between PDSCH symbols not containing DM-RS. It may also be used for Doppler and time varying channel tracking |
| | Uplink | | |
| | Channels | NR-PUSCH: Physical Uplink Shared Channel<br>NR-PUCCH: Physical Uplink Control Channel<br>NR-PRACH: Physical Random Access Channel | |
| | Signals | NR-DM-RS: Demodulation Reference Signal | |
| | | NR-PT-RS: Phase-Tracking Reference Signal | Can be used in addition to the DM-RS for PUSCH for correcting common phase error between PUSCH symbols not containing DM-RS. It may also be used for Doppler and time varying channel tracking |
| | | NR-SRS: Sounding Reference Signal | |

Reference source: 3GPP Submission of initial 5G description for IMT-2020

### SS and PBCH Block

SS/PBCH Blocks Burst Set Periodicity is network configurable {5, 10, 20, 40, 80, 160} ms - 20ms is the default for initial Cell selection




| Operating Frequency | L | SCS | Slots in a Burst Period (Slot duration) |
|---|---|---|---|
| < 3GHz (FR1) | 4 | 15 kHz | 5 (1ms) |
| | | 30kHz | 10 (1.5ms) |
| 3GHz to 6GHz (FR1) | 8 | 15kHz | 5 (1ms) |
| | | 30kHz | 10 (1.5ms) |
| > 6GHz (FR2) | 64 | 120kHz | 40 (0.125ms) |
| | | 240kHz | 80 (62.5us) |

L is the maximum number of SS/PBCH blocks within a single 5G burst set per cell

5G NR SS and PBCH Block Bandwidth
FR1: Case A – 15kHz SCS: 3.6MHz
FR1: Case B – 30kHz SCS: 7.2MHz
FR1: Case C – 30kHz SCS: 7.2MHz
FR2: Case D – 120kHz SCS: 28.8MHz
FR2: Case E – 240kHz SCS: 57.6MHz

Each SS/PBCH blocks is
- 4 OFDM Symbols in the time domain
- 240 contiguous Subcarriers in the frequency domain

Refer to 3GPP TS 38.213 Section 41 for more details

Time-frequency structure of the synchronization signal and PBCH block
Source: 3GPP TS 38.300 V15.0.0 (2017-12) Figure 5.2.4-1

### Comparison of Key Radio Characteristics and Parameters

| | 4G LTE-Advanced Pro | 5G New Radio (NR) |
|---|---|---|
| Deployment mode | 4G works independent of 3G | Non-standalone (NSA): 4G Master – 5G Secondary in EN-DC mode 5G is dependent on 4G coordination- supports both fixed and mobility scenarios |
| Frame Size, Subframe Size | 10ms, 1ms | 10ms, 1ms |
| Waveform | OFDM | UL/DL: CP-OFDM UL: DFT-Spread OFDM |
| Multiplexing | FDD/TDD | FDD & Dynamic TDD |
| Channel Modulation | Downlink: 1024QAM Uplink: 256QAM | QPSK, 16QAM, 64QAM, 256QAM , π/2-BPSK (Transform precoding enabled in the UL) QPSK for control channels and signals |
| Channel Coding | Data: Turbo Control: Convolutional | Data: LDPC Control: Downlink – Polar Code Uplink – Block and Polar (higher rates) Codes |
| Frequency Bands | Up to 6GHz | FR1: 450 MHz to 6GHz FR2: 24.25 to 52.6 GHz |
| Carrier Aggregation | Up to 32 CCs | Different bandwidth parts can be associated with different numerologies (subcarrier spacing, cyclic prefix) Refer to 3GPP TS 38.300 Section 6.10 for more details Up to 16 CCs - can be aggregated to 6.4GHz of transmission bandwidth |
| Numerology | Static | Based on exponentially scalable sub-carrier spacing $\Delta f = 2^{\mu} \times 15$ kHz |
| Sub carriers Spacing (SCS) | 15KHz | $\Delta f = 2^{\mu} \times 15$ kHz μ={0,1,3,4} for PSS, SSS and PBCH μ={0,1,2,3} for other channels |
| Transmission Slot Duration | 14 (7 per slot) | FR1: 15, 30, 60kHz FR2: 60, 120kHz (240kHz applicable to only SSB) Higher SCS for larger bandwidth, shorter slots, lower latency Lower SCS improves delay spread robustness |
| Slot Duration | 0.5ms each slot | Normal Cyclic Prefix: 14 Symbols – supported for All SCS Extended Cyclic Prefix: 12 Symbols – supported for SCS 60kHz |
| Slots per Subframe | 2 | Number of Slots per Subframe depends on the Sub-carrier spacing (SCS) μ=0: 15 kHz SCS: 1 ms slot, 1 slot per sub-frame μ=1: 30 kHz SCS: 0.5 ms slot, 2 slots per sub-frame μ=2: 60 kHz SCS: 0.25 ms slot, 4 slots per sub-frame μ=3: 120 kHz SCS: 0.125 ms slot, 8 slots per sub-frame μ=4: 240 kHz SCS: 0.0625 ms slot (only used for synchronization, not for data) |
| Channel Bandwidth | Max. 20MHz | FR1: 5, 10, 15, 20, 25, 40, 50, 60, 80, 100MHz FR2: 50, 100, 200, 400MHz<br>Maximum Channel Bandwidth 15 kHz SCS (FR1): 50MHz 30 kHz SCS (FR1): 100MHz 60 kHz SCS (FR1): 100MHz 60 kHz SCS (FR2): 200MHz 120 kHz SCS (FR2): 400MHz |
| Bandwidth Part (BWP) | Not applicable | BWP consists of a group of contiguous physical resource blocks (PRBs)<br>UE can be configured with up to four carrier bandwidth parts in the downlink/uplink/supplemental uplink (if configured) with a single downlink/uplink/supplemental uplink (if configured) carrier bandwidth part being active at a given time<br>From network perspective, different bandwidth parts can be associated with different numerologies (subcarrier spacing, cyclic prefix) |
| TTI | 1ms | Scalable Transmission Time Interval (TTI) Schedulers assign radio resources in a unit of TTI (e.g. one mini-slot, one slot, or multiple slots). Data transmissions can be scheduled on a slot basis, as well as on a partial slot basis, where the partial slot transmissions that may occur several times within one slot. The supported partial slot allocations and scheduling intervals are - 2, 4 and 7 symbols for normal cyclic prefix - 2, 4 and 6 symbols for extended cyclic prefix |

## 5G RAN

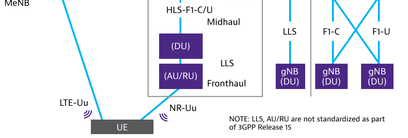
### Non-Standalone (NSA) (EN-DC) Architecture with Disaggregated RAN Functional Split

Option 3: User Plane anchored in the 4G MeNB - Dynamic Offload to 5G NR

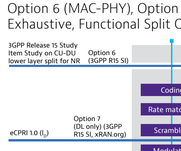
Option 3a: User Plane anchored in the 5G SgNB – No Offload

Option 3x: User Plane anchored in the 5G SgNB – Dynamic Offload to 4G LTE

| Interface | Estimated Transport Latency |
|---|---|
| X2 | 5-10 milliseconds between the 4G MeNB and 5G SgB in EN-DC mode |
| LLS | 250 microseconds (more likely to be <100 us) |
| HLS | 1.5–10 milliseconds (more likely to be <0.5-1ms) |
| S1 | Varies depending on services requirements (<1ms .. 10ms) |




Example variants of possible CU-DU splits

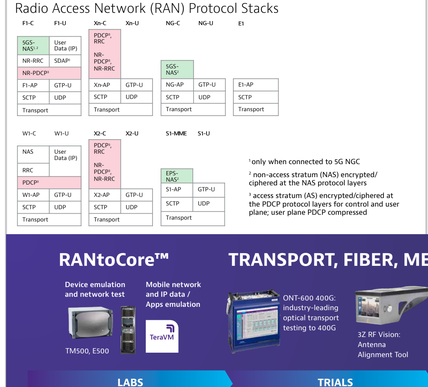



NOTE: LLS, AU/RU are not standardized as part of 3GPP Release 15

### Radio Access Network (RAN) Specifications

| | | Interface | Protocols and Specifications | NE1 | NE2 |
|---|---|---|---|---|---|
| 4G LTE-Advanced Pro | RAN – Core | S1 | S1-MME (S1-AP): 3GPP TS 36.413<br>S1-MME (EPS NAS): 3GPP TS 24.301<br>S1-U: 3GPP TS 29.281 | MME | eNB |
| | Inter base stations | X2 | X2-AP: 3GPP TS 36.423<br>X2-U: 3GPP TS 38.425 (TS 29.281) | eNB MeNB | eNB en-gNB/ SgNB |
| | CU DU Higher Layer Split (HLS) | W1 | W1-AP: 3GPP TS 37.473<br>W1-U: in progress | eNB-CU ng-eNB-CU | eNB-DU ng-eNB-DU |
| 5G New Radio (NR) | RAN – Core | NG | NG-C (NG-AP): 3GPP TS 38.413<br>NG-C (5GS NAS): 3GPP TS 24.501<br>NG-U: 3GPP TS 29.281 | NGC | NG-RAN |
| | Inter base stations | Xn | Xn-AP: 3GPP TS 38.423<br>Xn-U: 3GPP TS 38.425 (TS 29.281) | gNB gNB | gNB ng-eNB |
| | CU DU Higher Layer Split (HLS) | F1 | F1-AP: 3GPP TS 38.473<br>F1-U: 3GPP TS 38.425 (TS 29.281) | | gNB-CU gNB-DU |
| | CU Control User Plane Separation | E1 | E1-AP: 3GPP TS 38.463 | gNB-CU-CP | gNB-CU-UP |

### Radio Access Network (RAN) Protocol Stacks




¹ only when connected to 5G NGC

² non-access stratum (NAS) encrypted/ ciphered at the NAS protocol layers

³ access stratum (AS) encrypted/ciphered at the PDCP protocol layers for control and user plane; user plane PDCP compressed

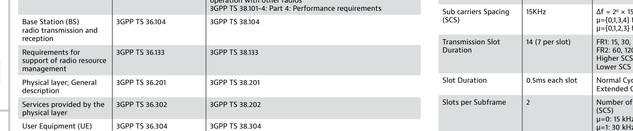
### Option 6 (MAC-PHY), Option 7 (Intra-PHY) Possible, Non-Exhaustive, Functional Split Options for DL (left) and UL (right)




Source: 3GPP TR 38.816 V15.0.0 (2017-12), Figure 4.2-1
Additional references
xRAN Forum: Fronthaul working group whitepaper, October 2017
Common Public Radio Interface: eCPRI Interface Specification, V1.0 (2017-08-22)

## 4.5G CORE

### Control and User Plane Separation of EPC Nodes (CUPS) Architecture



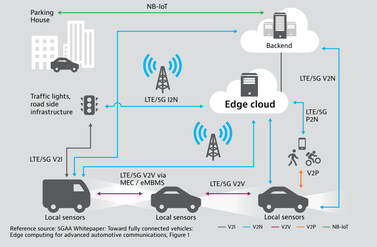

NOTE: this core network architecture diagram focuses on CUPS only and does not show all core network elements

### CUPS Protocol Stack and Specifications

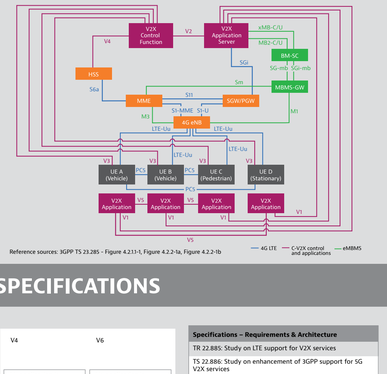
| 4G LTE-Advanced Pro | | | | |
|---|---|---|---|---|
| Interface | Protocols and Specifications | NE1 | NE2 | |
| EPC Control – EPC User Plane | Sxa, Sxb, Sxc and combined Sxa/Sxb | 3GPP TS 29.244 | SGW-C PGW-C TDF-C | SGW-U PGW-U TDF-U |

| Sx | |
|---|---|
| Control Plane | User Plane |
| PFCP | GTP-U |
| UDP | UDP |
| Transport | |

## VERTICALS, AUTONOMOUS DRIVING CELLULAR VEHICLE TO EVERYTHING C-V2X (V2I, V2N, V2V, V2P)




Reference source: 5GAA Whitepaper: Toward fully connected vehicles: Edge computing for advanced automotive communications, Figure 1




Reference sources: 3GPP TS 23.285 – Figure 4.2.1-1, Figure 4.2.2-1a, Figure 4.2.2-1b

## SPECIFICATIONS

| V4 | V6 |
|---|---|
| V4 application is 16777355 | V6 application is 16777356 |
| Diameter | Diameter |
| SCTP | SCTP |
| Transport | Transport |

| Specifications – Requirements & Architecture |
|---|
| TR 22.885: Study on LTE support for V2X services |
| TS 22.886: Study on enhancement of 3GPP support for 5G V2X services |
| TS 22.185: Service requirements for V2X services |
| TS 22.186: Service requirements for enhanced V2X scenarios |
| TS 23.285: Architecture enhancements for V2X services |
| TS 33.185: Security aspect for LTE support of V2X services |
| TR 37.885: Study on evaluation methodology of new V2X use cases for LTE & NR |

| Specifications - Protocols | Reference Points |
|---|---|
| TS 24.385: V2X services Management Object (MO) | |
| TS 24.386: User Equipment (UE) to V2X Control Function Protocol aspects; Stage 3 SDP | V3 |
| TS 29.388: V2X Control Function to HSS aspects (V4); Stage 3 | V4 |
| TS 29.389: Inter-V2X Control Function Signaling aspects (V6); Stage 3 | V6 |

| 3GPP TS 22.185 | V2V | V2I | V2N |
|---|---|---|---|
| Latency | <= 100ms With or without RSU <= 20ms (without RSU) | <= 100ms With or without RSU <= 20ms (without RSU) | <= 100ms (RSU) | <= 1000ms (E2E) |
| Potential V2X service | Road safety use cases | Road safety use cases | Mutual Vehicle Awareness use case |
| Reliability | High reliability without requiring application-layer message retransmissions | | |
| Message Size, Frequency | Periodic broadcast - 50-300 bytes, Event-triggered - up to 1200 bytes Up to 10 messages per second per transmitting UE | | |
| Range | Driver(s) ample response time (e.g. 4 seconds) | | |
| Speed | V2V maximum relative velocity of the UEs is 500 km/h V2V and V2P maximum absolute velocity is 250 km/h | | |

| 3GPP TS 22.186 | Vehicles Platooning[1] | Advanced Driving[2] | Extended Sensors[3] | Remote Driving[4] |
|---|---|---|---|---|
| Max end-to-end latency (ms) | 10–25 | 3 | 3-100 | 5 |
| Reliability (%) | 90–99.99 | 99.999 | 95–99.999 | 99.999 |
| Data Rate | 12kbps-65Mbps | 30Mbps | 10-1000Mbps (1Gbps) | UL: 25Mbps DL: 1Mbps |
| Min required communication range[5] | 80–350 meters 2.2–9.7 seconds | 500 meters 13.8 seconds | 50–1000 meters (1km) 1.4–27.7 seconds | N/A |

1: Cooperative driving for vehicle platooning Information exchange between a group of UEs
2: Emergency trajectory alignment between UEs
3: Sensor Information sharing between UEs
4: Information exchange between a UE supporting V2X application and a V2X Application Server) absolute speed of up to 250 km/h
5: meters, seconds, (1100km/h)

## ACRONYMS/ABBREVIATIONS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5GC | 5G Core Network | eMBB | Enhanced Mobile Broadband | NFVO | NFV Orchestrator | SDAP | Service Data Adaptation Protocol |
| SGS | 5G System | EPC | Evolved Packet Core | NG-RAN | NG Radio Access Network | SDN-C | SDN Controller |
| AMF | Access and Mobility Management Function | EPS | Evolved Packet System | NR | New Radio | SGW | Serving GW |
| AS | Access Stratum | FDD | Frequency Division Duplex | NSA | Non-Standalone | SMF | Session Management Function |
| BHR | Backhaul Rate | FFT | Fast Fourier Transform | OSI | Other System Information | SN | Secondary Node |
| BM-SC | Broadcast Multicast Service Center | FR | Frequency Range | OSS | Operations Support System | SUL | Supplementary Uplink |
| BSS | Business Support System | HLS | Higher Layer Split | PDCP | Packet Data Convergence Protocol | TDD | Time Division Duplex |
| BWP | Bandwidth Part | LDPC | Low-Density Parity-Check | PFCP | Packet Forwarding Control Plane | TDF | Traffic Detection Function |
| CBRS | Citizens Broadband Radio Service | LLS | Lower Layer Split | PGW | PDN Gateway | TSN | Time-Sensitive Networking |
| CoMP | Coordinated Multipoint | MAC | Medium Access Control | PHY | Physical Layer | TTI | Transmission Time Interval |
| CP | Control Plane | MBMS | Multimedia Broadcast Multicast Service | PON | Passive Optical Network | UP | User Plane |
| CP | Cyclic Prefix | MBMS-GW | MBMS Gateway | RAN | Radio Access Network | UPF | User Plane Function |
| CPRI | Common Public Radio Interface | MIMO | Multiple-Input Multiple-Output | RAT | Radio Access Technologies | URLLC | Ultra-reliable Low Latency Communications |
| CU | Central Unit | MME | Mobility Management Entity | RLC | Radio Link Control | V2I | Vehicle-to-Infrastructure |
| CUPS | Control and User Plane Separation | mMTC | Massive Machine Type Communications | RMSI | Remaining System Information | V2N | Vehicle-to-Network |
| DC | Data Center | MN | Master Node | RRC | Radio Resource Control | V2P | Vehicle-to-Pedestrian |
| DN | Data Network | NAS | Non-Access Stratum | RSU | Roadside Unit | V2V | Vehicle-to-Vehicle |
| DU | Distributed Unit | NB-IoT | Narrow Band Internet of Things | SA | Standalone | V2X | Vehicle-to-Everything |
| eCPRI | Enhanced Common Public Radio Interface | | | SCS | Sub carriers Spacing | WDM | Wavelength-division multiplexing |

## RANtoCore™

Device emulation and network test



TM500, E500

Mobile network and IP data / Apps emulation




## TRANSPORT, FIBER, METRO, AND RF TEST PRODUCTS



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Fiber optic test solutions: T-BERD/ MTS-2000 and FiberChek Sidewinder

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Network Integrated Test, Real-time analytics and Optimization

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