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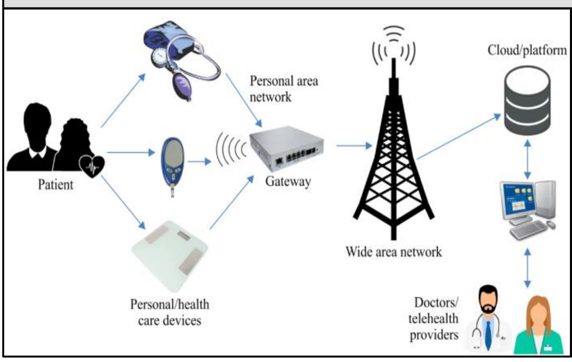
# TECHNICAL REPORT

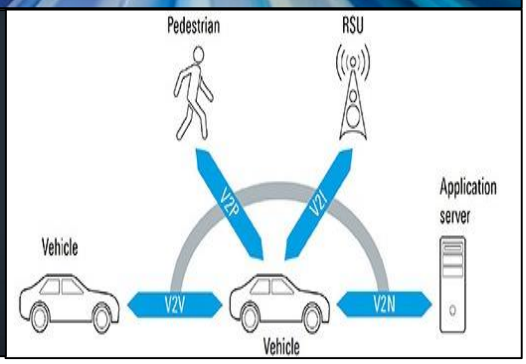
## EMERGING COMMUNICATION TECHNOLOGIES & USE CASES in IoT DOMAIN

**TEC 31168:2021**

**WORKING GROUP: EMERGING COMMUNICAION TECHNOLOGIES in IoT domain**



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TELECOMMUNICATION ENGINEERING CENTRE
DEPARTMENT OF TELECOMMUNICATIONS
MINISTRY OF COMMUNICATIONS
GOVERNMENT OF INDIA

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Azadi Ka Amrit Mahotsav

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**Government of India**
**Ministry of Communications**
**Department of Telecommunications**

# Message

I am happy to note that Telecommunication Engineering Centre (TEC) has prepared a Technical Report on ***Emerging Communication Technologies and Use Cases in IoT domain,*** which is being released as a guiding document for all related stakeholders.

IoT division, TEC has already released fourteen Technical Reports covering various verticals viz. Automotive, Power, Health, Safety & Surveillance, Smart Homes, Smart Cities, and in the horizontal layer - M2M Gateway & Architecture, Communication Technologies in M2M/ IoT domain, Code of practice for Securing consumer IoT etc. This document will add to the series of expert reports.

This document covers emerging communication technologies like 5G, Wi-Fi 6 / 6E and Bluetooth Mesh and the use cases such as Intelligent transport system (C-V2X, connected vehicles etc.), Industry 4.0, Smart Homes/ campus etc. Communication network (OFC) being provisioned in BharatNet may be used as a backbone for extending these technologies to provide smart services in rural community. These services will be quite helpful in a pandemic like Covid 19 scenario.

I hope that this Technical Report will help in developing the ecosystem for IoT domain. I also request TEC to enable speedy dissemination and adoption of these useful standards by the Indian manufacturers.

I appreciate the efforts put in by Telecommunication Engineering Centre in bringing out this report. I wish them success in all their endeavours.

(K.Rajaraman)

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# Message

I am delighted to note that Telecommunication Engineering Centre (TEC) is bringing out one more Technical Report on relevant subject namely ***Emerging Communication Technologies and Use Cases in IoT domain***.

I feel good that IoT division, TEC has continued the excellent work, by releasing fourteen Technical Reports in the last 4-5 years, covering various verticals as well as horizontal layers namely Automotive, Power, Health, Smart Homes, Smart cities, M2M Gateway & Architecture, communication technologies in M2M/ IoT domain besides Code of Practice for Securing Consumer IoT. A number of actionable points that emerged from these reports such as 13-digit numbering scheme for SIM based devices/ gateways, embedded SIM, spectrum for Low Power Wireless Communication technologies, spectrum for V2V applications & common service layer etc. are being used in standards / policies then enabling the development of M2M / IoT eco-system in India.

I am also happy to share that this technical report has elaborated emerging communication technologies like 5G (3GPP Release 15/16), IEEE 802.11 based technologies such as Wi-Fi 6/ Wi-Fi 6E, Wi-Fi HaLow; and Bluetooth Mesh and the related use cases. This technical report of TEC is going to be a good reference for the related stakeholders in developing the standard based ecosystem in our country.

Timing of this release and publication is relevant in view of unfolding scenario of upcoming 5G ecosystem in the country.

I appreciate endeavors by Telecommunication Engineering Centre in bringing out this report. I congratulate IoT division for all their excellent initiative and hard work. I further wish them enhanced success for the future.

10/11/2021

(Deepak Chaturvedi)

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# Message

I am pleased to note that Telecommunication Engineering Centre (TEC) is bringing out a Technical Report on ***Emerging Communication Technologies and Use Cases in IoT domain***. This report is in continuation to the various technical reports already released by TEC in M2M/ IoT domain.

This Technical Report covers emerging communication technologies like 5G, Wi-Fi 6/ Wi-Fi 6E etc. and provides the recommendations related to spectrum and regulatory aspects for the development of use cases.

TEC has also adopted oneM2M Release 2 specifications as National Standards; an important step towards developing standards based M2M/ IoT ecosystem, specially for smart cities.

I appreciate the efforts of Telecommunication Engineering Centre specially its IoT Division and the members of the Working Group for bringing out this technical report in a very timely manner. I wish them success in all their endeavours.

10/11/21
(A K Tiwari)

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# Foreword

TEC is the National Standardization Body (NSB) for telecommunication in India and the national enquiry point for WTO-TBT (Technical Barrier to Trade) for telecom sector. TEC has also been mandated to interact with various international standardization bodies like ITU, APT, ETSI, IEEE, oneM2M, 3GPP etc. for standardization works.

TEC takes up development of standards based on study, continuous participation / submitting contributions in the meetings of standardization bodies and interaction with stakeholders. Certification of telecom products as per Essential Requirements (ERs) is also one of the major activities under MTCTE, which is being implemented in a phased manner by TEC.

M2M/ IoT is one of the most emerging technologies and it is being used to create smart infrastructure. As per NDCP 2018, eco-system is to be developed for connecting five billion devices by 2022. TEC has already released fourteen Technical Reports covering various verticals viz. Automotive, Power, Health, Safety & Surveillance, Smart Homes, Smart Cities, Smart Village & Agriculture and also in horizontal layer, the documents namely V2V/V2I Radio communication & Embedded SIM, Communication Technologies in M2M/ IoT domain, M2M Gateway & Architecture, M2M/ IoT security etc. ***Code of Practice for Securing Consumer IoT*** is the recently released document in this series. Guidelines available in this document may provide a direction to the related stakeholders in provisioning of secured consumer IoT devices and also help in reducing the vulnerabilities. All the technical reports are available on TEC website (https://tec.gov.in/M2M-IoT-technical-reports).

A number of actionable points emerged from these reports, a few important ones are 13-digit numbering scheme for SIM based devices/ gateways, Embedded

Contd..

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SIM, IPv6 for devices / gateways to be connected to PSTN/ PLMN, Spectrum for low power wireless communication technologies, Common services layer- important for sharing of data.

TEC has adopted oneM2M Release 2 standards (transposed by TSDSI) as National standards (https://tec.gov.in/onem2m). These TEC standards have been referred by BIS in its standard on IoT Reference Architecture released in June 2021. Same has also been issued as an advisory by MoHUA for smart cities SPVs.

The TEC Working group on *Emerging Communication Technologies and Use Cases in IoT domain* is having members from Government, industry, academia, R&D organisations and start-ups. Around 15 virtual meetings and a number of informal discussions have already been held in drafting and finalizing the content of the Technical Report titled ***"Emerging Communication Technologies and Use Cases in IoT domain"***. This report covers emerging communication technologies from 3GPP (Release 15/ 16) like 5G, C-V2X etc., IEEE 802.11 based technologies like Wi-Fi 6/ Wi-Fi 6E, Wi-Fi HaLow; Bluetooth Mesh, and requirements related with Factory automation – Industrial IoT (Private Networks)/ Industry 4.0, Automotive IoT – Intelligent Transport system, Healthcare etc. This document may be downloaded from TEC website (https://tec.gov.in/M2M-IoT-technical-reports).

The recommendations mentioned in this document will provide technical guidance to concerned stakeholders related to spectrum and regulatory aspects. I hope the working group members will continue to provide their support to TEC in carrying out further study in M2M/ IoT domain for the holistic development of smart & sustainable infrastructure in the country.

D Tyagi

(Deepa Tyagi)

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# Executive Summary

IoT is one of the most emerging technologies as on date and being used to create smart infrastructure in various sectors namely Automotive, Power, Health care, Safety & Surveillance, Environment monitoring and pollution control, Water management, Waste management, Agriculture etc. These verticals will be the part of Smart cities, Smart villages and Smart homes etc.

IoT will revolutionize and change the way all businesses, governments, and consumers interact with the physical world. IoT is benefitted by a number of technologies namely sensors, Communication technologies, platforms, Artificial Intelligence, Machine Learning, Cloud computing, Edge computing etc.

Communication technologies have played an important role in digital transformation, which is a requirement and not a luxury. Communication technologies are contributing significantly in enabling remote health management, touch-free operations, contact tracing and performing geo-fencing during the Covid-19 pandemic and the subsequent planning and rollout of the vaccination. With 5G, the higher data rate and device density and lower latency will be useful in managing such type of pandemics in a much better way.

There will be billions of IoT devices in the eco system and the number will continue to rise rapidly. There may be around 26.4 billion IoT devices by 2026 across the globe, out of which, around 20% will be connected on Cellular communication technologies[1].

As per National Digital Communication Policy (NDCP) 2018 released by DoT, it has been envisaged to create an eco-system for connecting 5 billion devices in India by 2022.

TEC released a Technical Report on ***Communication Technologies in M2M/ IoT domain*** in 2017 covering cellular and non- cellular communication technologies and related use cases.

In view of development in communication technologies at a fast pace, it is required to study such emerging technologies. For this purpose, TEC formed a multi-stake holder working group to prepare a technical report with the outcome to be used in policy / standards.

Around 15 virtual meetings of the Working group have been held to carry forward the work. This document has covered 5G (3GPP Release 15 / 16), Wi-Fi 6 / Wi-Fi HaLow, and Bluetooth Mesh technologies. This report has also covered the use cases related to Automotive sector (Connected vehicles, Intelligent Transport System), Industry 4.0, Health care etc. and the recommendations related to spectrum and regulatory.

1 https://www.ericsson.com/4a03c2/assets/local/mobility-report/documents/2021/june-2021-ericsson-mobility-report.pdf

# 1 Introduction

The IoT has enormous beneficial opportunities for society, industry, and consumers—but its evolution has been affected by product development challenges, such as rapidly changing requirements, consumer expectations, specific industry requirements, pricing, heavy competition and it continues to be. As widespread consumer adoption of connected devices increases, so does the pressure on solution providers to create differentiated, high-end devices that are powerful yet power-efficient and interoperable yet highly secure.

Communication technology plays an important role in transmitting the data from the device to the headend system. In most of the IoT use cases, timely transmission of data is utmost important. For this, communication network is required to be reliable with low latency and should also have wider coverage. Even the data size may vary from use case to use case, as an example, data may be of few bytes (meter reading) to several megabytes (surveillance video) and may be in the form of bursts.

**ITU** has defined Internet of Things (IoT) "***As a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies***"[2].

DoT has released National Telecom M2M Roadmap[3] in 2015; and National Digital Communication Policy (NDCP)[4] in 2018 to provide a policy framework for emerging technologies.

A multi- stake holder working group was formed in TEC to study various communication technologies & related use cases in the IoT domain. Based on this study, TEC released the Technical Report ***Communication Technologies in IoT domain***[5] in July 2017. This Technical Report covered in detail the cellular technology (up to LTE 3GPP release 14), Low power wireless communication technologies, Low power wide area network technologies, IEEE 802.11 a, b, g, n, ac (variant of Wi-Fi), 802.11p (DSRC), wire line (PLC, DSL, FTTH) etc. and the related use cases. Recommendations from the above report are getting acceptance in recent policies and standards.

As the development of technology has accelerated, there is a need to study the emerging communication technologies for IoT domain and related use cases. Efforts have been made to cover the communication technologies namely 5G, Wi-Fi and Bluetooth Mesh in this report.

Details of the NDCP and the initiatives in TEC are covered in the rest of this chapter in Section 1.1 and 1.2 respectively. Rest of the chapters deals with emerging technologies, use-cases,

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[2] Source: ITU-T Y.2060 - Y.2060 : Overview of the Internet of things (06/2012) (https://www.itu.int/rec/T-REC-Y.2060-201206-I)

[3] https://dot.gov.in/sites/default/files/National%20Telecom%20M2M%20Roadmap.pdf

[4] https://dot.gov.in/sites/default/files/EnglishPolicy-NDCP.pdf

[5] https://tec.gov.in/pdf/M2M/Communication%20Technologies%20in%20IoT%20domain.pdf

requirements and recommendations.

## 1.1 National Digital Communication Policy (NDCP) 2018

NDCP 2018 was released by Department of Telecommunications in 2018. It covers many points related to IoT, Artificial Intelligence and 5G.

Extract related to IoT, 5G and other emerging technologies in NDCP is as given below:

1. **Propel India:** Enabling Next Generation Technologies and Services through Investments, Innovation, Indigenous Manufacturing and IPR Generation
   **2022 Goals:**
   a. Expand IoT ecosystem to 5 Billion connected devices by 2022
   b. Creation of innovation led Start-ups in Digital Communications sector
   c. Train/ Re-skill 1 Million manpower for building New Age Skills

2. **Accelerating Industry 4.0**
   a. Create a roadmap for transition to Industry 4.0 by 2020 by closely working with sector specific Industry Councils
   b. Establish a multi-stakeholder led collaborative mechanism for coordinating transition to Industry 4.0
   c. Developing market for IoT/ M2M connectivity services in sectors including Agriculture, Smart Cities, Intelligent Transport Networks, Multimodal Logistics, Smart Electricity Meter, Consumer Durables etc. incorporating international best practices

3. **Ensuring a holistic and harmonized approach for harnessing Emerging Technologies**
   a. Creating a roadmap for emerging technologies and its use in the communications sector, such as 5G, Artificial Intelligence, Robotics, Internet of Things, Cloud Computing and M2M
   b. Simplifying licensing and regulatory framework whilst ensuring appropriate security framework for IoT/ M2M/ future services and network elements incorporating international best practices
   c. Earmarking adequate licensed and unlicensed spectrum for IoT/ M2M services
   d. Encourage use of Open APIs for emerging technologies
   e. Ensuring the Transition to IPv6 for all existing communications systems, equipment, networks and devices

f. Enabling Hi-speed internet, Internet of Things and M2M for rollout of 5G technologies and services

- Implementing an action plan for rollout of 5G applications and services
- Enhancing the backhaul capacity to support the development of next-generation networks like 5G
- Ensuring availability of spectrum for 5G in < 1 GHz, 1-6 GHz and > 6 GHz bands
- Reviewing industry practices with respect to traffic prioritization to provide 5G enabled applications and services
- Developing framework for accelerated deployment of M2M services while safeguarding security and interception for M2M devices
- Defining policy for EMF radiation for M2M devices, with accompanying institutional framework to coordinate government-funded and India-specific research in this regard

g. Facilitating and supporting deployment of innovative solutions in identified Smart Cities

4. **Ensuring adequate numbering resources, by:**
   Allocating 13-digit numbers for all M2M mobile connections

5. **Recognizing Digital Communications as the core of Smart Cities by:**
   a. Developing, in collaboration with Ministry of Urban Development, a Common Service Framework and Standards for Smart Cities
   b. Facilitating and supporting deployment of innovative solutions in identified Smart Cities

6. **Promoting research & development in Digital Communication Technologies by:**
   a. Creating a framework for testing and certification of new products and services

## 1.2 Important initiatives taken by TEC in M2M/ IoT domain

### 1.2.1 Technical Reports

TEC formed 12 multi-stake holders Working Groups in the last 4 -5 years to study the M2M/ IoT domain and prepare Technical Reports with the outcomes to be used in policy / standards. As a result, 15 Technical Reports have been released so far, as mentioned below and available on TEC website[6]-

[6] https://www.tec.gov.in/M2M-IoT-technical-reports

1. M2M Enablement in Power Sector
2. M2M Enablement in Intelligent Transport System
3. M2M Enablement in Remote Health Management
4. M2M Enablement in Safety & Surveillance Systems
5. M2M Gateway & Architecture
6. M2M Number resource requirement and options
7. V2V / V2I Radio Communication and Embedded SIM
8. Spectrum requirements for PLC and Low Power RF Communications
9. ICT Deployments and strategies for India's smart cities: A curtain raiser
10. M2M/ IoT Enablement in Smart Homes
11. Communication Technologies in M2M / IoT domain
12. Design and Planning Smart Cities with IoT/ ICT
13. Recommendations for IoT / M2M Security
14. IoT/ ICT Enablement in Smart Village & Agriculture
15. Code of practice for Securing Consumer IoT

### 1.2.2 Actionable points emerged from Technical Reports

A number of actionable points emerged from these technical reports. Some of the important points which became the part of policy/ standard are given below:

1. **13-digit numbering scheme for SIM based devices/ Gateways:** As per the recommendation in Technical Report on "M2M Number resource requirement & options", 13-digit M2M Numbering scheme for SIM based devices/ Gateways, which will co-exist with the existing 10-digit numbering scheme in use, was prepared in TEC. **DoT has already approved this scheme and issued orders to all the Telecom Service Providers for implementation. Five codes of 3 digit each (559, 575, 576, 579 and 597) have been allotted as a M2M identifier[7].**

2. **M2M SIM / Embedded SIM and remote subscription management:** Based on the Technical Report on "V2V / V2I Radio communication and Embedded SIM", Interface Requirement (IR) was prepared in TEC. DoT has approved the use of Embedded SIM with OTA provisioning in May 2018[8].
   - Ministry of Road Transport and Highways, India has already included Embedded SIM with OTA provisioning in AIS140 standard which specifies the conditions and specifications for the use of connected devices in vehicles[9].

[7] https://dot.gov.in/sites/default/files/M2M%20numbering.pdf?download=1
[8] http://www.dot.gov.in/sites/default/files/M2M%20Guidelines.PDF?download=1
[9] https://hmr.araiindia.com/Control/AIS/14201910518PMAIS-140.pdf

- The Bureau of Indian Standards has released a new Standard for Automotive Tracking Device and Integrated Systems (IS: 16833/2018) which mandates the use of the embedded SIM as per the Standards/Specifications of the Telecommunication Engineering Centre (TEC), Department of Telecommunications, Government of India[10].

3. Any device / gateway having direct connectivity with PSTN / PLMN should have static IP (IPv6 or IPv4). As IPv4 addresses are going to exhaust, early adoption of IPv6 at device, network and application level will be necessary. Bureau of Indian Standards (BIS) has mandated IPv6 for Smart electricity meters to be connected on Cellular technologies, IS 16444.

4. **Testing and Certification of M2M devices: -** Now it is the part of Mandatory Testing and Certification of Telecom equipment (MTCTE) regime. Essential Requirements (ERs) for the IoT devices namely Smart security camera / CCTV camera, Smart electricity meter, Smart watch, Tracking device, Feedback device, Gateways and their variants have already been finalised and uploaded on the MTCTE portal.

5. **Multi-protocol gateway / IoT Gateway:** It is Important for Smart homes/ building solutions for interconnecting the devices with the communication networks and it performs the necessary translation between the protocols used in the communication networks and those used by devices.

6. **Common Service layer at the platform for sharing of data across verticals and across platforms:** TEC has adopted oneM2M Release 2 specifications (14 TS out of 17) as National Standards. These standards will be quite useful for the development of interoperable ecosystem for IoT domain, especially for Smart cities. These standards are voluntary in nature and may be made mandatory by user ministry by regulation[11].
   These standards have been incorporated as a normative / informative reference in the standard on IoT reference architecture ***IoT RA IS 18004 (Part 1): 2021*** released by BIS.

7. **Spectrum for low power wireless communication technologies:**
   - Based on Technical Report, additional Spectrum of 12MHz for Low power RF communication technologies in Sub GHz band, adjacent to existing delicensed spectrum (865-867 MHz) was recommended to reserve and release as per requirement. DoT referred the case to TRAI.
   - TRAI had recommended 7 MHz spectrum (1 MHz in 867- 868 MHz and 6 MHz in 915-935 MHz band) to be delicensed on priority, in its recommendation on "Spectrum,

[10] http://www.bis.org.in/sf/ted/TED28(10974)_24112016.pdf

[11] https://www.tec.gov.in/onem2m

Roaming and QoS related requirements in Machine-to-Machine (M2M) Communications” released in Sept. 2017.

- DoT approved the TRAI recommendations. This spectrum is expected to be released by WPC in the subsequent NFAP revisions.

8. **Spectrum requirement in 5.9 GHz for Intelligent Transport system: -** Intelligent Transport Systems can utilize 5.9 GHz frequency band. Multiple technology options exist for ITS, e.g., IEEE DSRC and 3GPP C-V2X. It is expected to be released by WPC in the next NFAP revision.

9. **Licensing/ Registration for non-cellular LPWAN technologies (such as LoRa, Sigfox etc.) service providers: -** It is important from the policy as well as security perspective to have the details of agencies providing public services. This may be the part of M2M Service provider registration policy, expected in near future.

### 1.2.3 Contributions at International level

1. **TEC achievements in ITU-T SG-20 on IoT and its applications in Smart Cities and Communities:** ITU-T Recommendation Y Suppl. 53 (12/2018) on IoT use cases (having five IoT use cases from India and one from Egypt) and Y Suppl. 56 (12/2019) on Smart city use cases (having smart city use cases from Japan, Korea, UK and India) are having significant contributions submitted by TEC.
   These use cases may be implemented to create smart infrastructure, which will resolve a number of issues of the respective vertical and in turn improve the quality of life.

2. **TEC participation and contributions in APT meetings:**

   a) Contributions were submitted and presented in APT WTSA-20 meetings, 2020 on **Resolution 98 “Enhancing the standardization of Internet of things and smart cities and communities for global development”.**

   b) Following contributions were prepared, submitted and presented on behalf of Indian Administration in **26th Meeting of APT Wireless Group (**AWG-26 Meeting), September 2020.

      i. Proposal for working document towards a draft new APT Report on “Technology and Spectrum Management Techniques for IoT Networks”

      ii. Proposal for LTE and 5G NR based V2X in Working Document Towards “Cellular Based V2X for ITS applications in APT Countries"

   These contributions have been incorporated suitably in the documents under development.

# 2 Global best practices

According to 5G PPP and 5G IA[12], the ongoing 5G evolution is built on strong beliefs in benefits from new applications, with many specific use cases coming from verticals. It further states, that the building of sustainable business cases is based on the identification of the problems verticals are facing, worthwhile to be solved through the validation of solutions based on distinctive 5G capabilities. In this report, five stakeholder type perspectives viz. Consumer, Business firm, Infrastructure provider, Public service, Third party; and four benefit categories viz. Quality increase, Cost decrease, Society critical, Business operational critical have been identified. This list is neither exhaustive nor mutually exclusive.

A study by IHS Markit[13] states that the 5G economy will introduce a new level of complexity to policymaking and regulation as new business models emerge and the old ways of delivering goods and services are either dramatically altered or abandoned completely. Areas where policy and regulatory modernization will be required for a 5G ready world include public safety, cybersecurity, privacy, public infrastructure, healthcare, spectrum licensing, education, training and development.

A report by Capgemini Research Institute[14] also highlights a key requirement for close collaboration between various stakeholders for successful adoption. To exploit 5G's potential to digitally transform organizations, industrial companies and telecom companies need to collaborate more closely. They need to identify the areas where 5G can add value, both in the immediate and longer term, and design the right implementation road map. By working closely and with an ecosystem of partners, the two sides can avail the full potential of this transformative technology. A recently released report[15] also discusses the current state of the adoption of 5G & edge in industrial operations with recommendations for industries and telecommunication ecosystem to help accelerate the adoption.

A white paper by World Economic Forum[16] states that a use-case driven analysis reveals that the way 5G will primarily contribute to industrial advances by enabling faster and effective inspections through predictive intelligence, improving workplace and worker safety, and enhancing operational effectiveness. It also identifies strong use-case level linkages to social value creation in the context of UN Sustainable Development Goals (SDGs). It also states that 5G could transform certain industries, bearing in mind that, while some have more clearly

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12 5G PPP - Empowering Vertical Industries through 5G Networks – Current status & future trends - https://5g-ppp.eu/wp-content/uploads/2020/09/5GPPP-VerticalsWhitePaper-2020-Final.pdf

13 IHS Markit – The 5G economy - https://www.qualcomm.com/documents/ihs-5g-economic-impact-study-2019

14 Capgemini – 5G in Industrial operations - https://www.capgemini.com/in-en/research/5g-in-industrial-operations/

15 Capgemini – The 5G Industrial Revolution - https://www.capgemini.com/research/the-5g-industrial-revolution/

16 World Economic Forum whitepaper - The Impact of 5G: Creating New Value across Industries and Society - https://www.weforum.org/whitepapers/the-impact-of-5g-creating-new-value-across-industries-and-society

defined use cases that could generate greater impact, 5G deployment will take place in phases. 5G has the potential to provide quality internet access to geographical areas that are currently underserved by the telecommunications network. This could unlock significant social impact through use cases related to tele-education and tele-medicine.

# 3 Technology developments, opportunities, and challenges

5G systems serve the variety of use cases, often with diametrically opposing requirements. 5G systems manage this by dynamically allocating the network resources depending on the use case. The requirements for 5G set by ITU-R broadly cover three main usage scenarios as shown in Figure 3-1:

- Mobile IoT/ Massive IoT/ LPWAN: improved network coverage, long device operational lifetime and a high density of connections. This is also known as Massive MTC (mMTC).
- Critical communications: high performance, ultra-reliable, low latency for industrial IoT and mission critical applications. This is also known as Ultra Reliable Low Latency Communications (URLLC).
- Enhanced Mobile Broadband: improved performance and a more seamless user experience accessing multimedia content for human-centric communications. This is also known as Enhanced Mobile Broadband (eMBB).

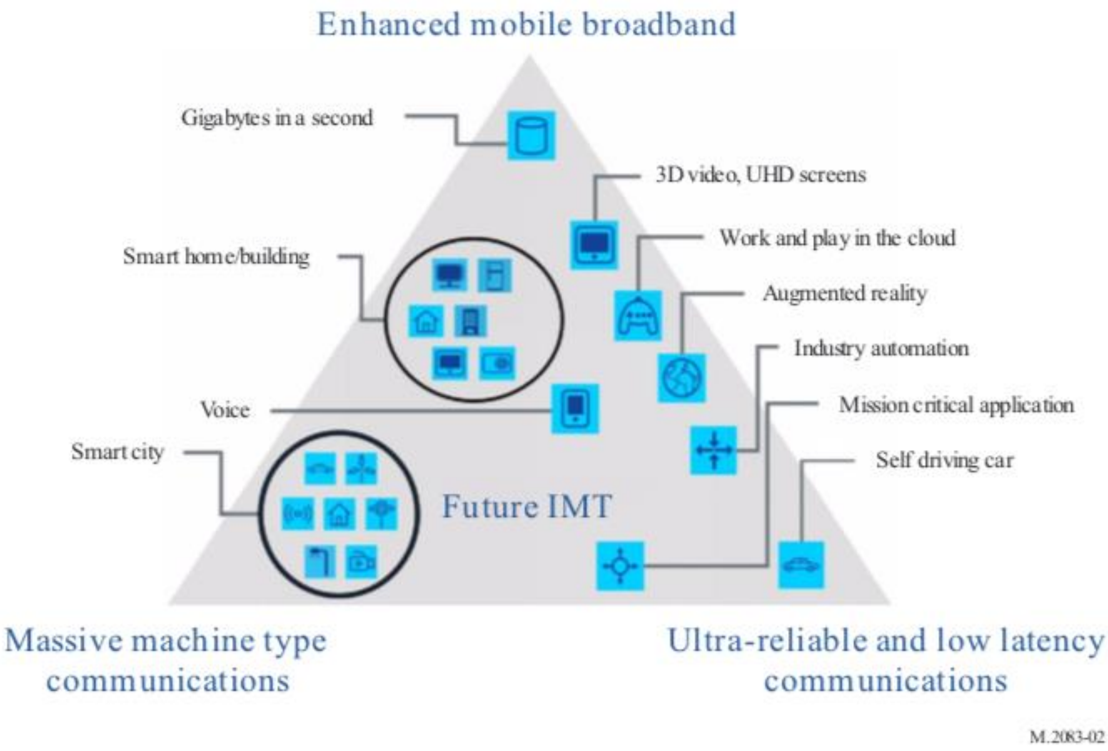



**Figure 3-1: 5G Usage Scenarios of IMT-2020 and beyond**

5G and beyond technologies are envisaged to expand on the IMT-Advanced performance requirements like Peak data rate, User experienced data rate, Spectrum efficiency, Mobility, Latency, Connection density, Network energy efficiency, and Area traffic capacity as depicted in Figure 3-2.

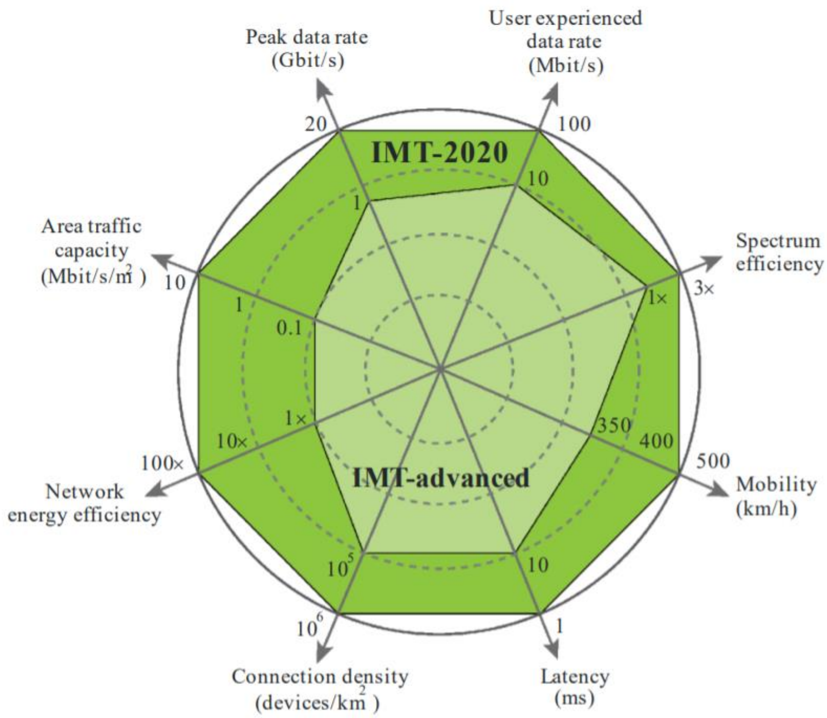



**Figure 3-2: Enhancement of key capabilities from IMT-Advanced to IMT-2020 (4G to 5G)**

Each of the different usage scenarios utilize the capabilities of IMT-2020 to realize the various use-cases. A summary of the IMT-2020 minimum technical performance requirements as described by ITU-R is provided in the table below:

**Table 3-1: Summary of Minimum Technical Performance Requirements**

| Minimum Technical Performance Requirement | Key Use-Case | Values |
|---|---|---|
| Peak Data Rate | eMBB | DL: 20 Gbps; UL: 10 Gbps |
| Peak Spectral Efficiency | eMBB | DL: 30 bps/Hz; UL: 15 bps/Hz |
| User Experienced Data Rate | eMBB | DL: 100 Mbps; UL: 50 Mbps (Dense Urban) |
| 5% User Spectral Efficiency | eMBB | DL: 0.3 bps/Hz: UL: 0.21 bps/Hz (Indoor Hotspot)<br>DL: 0.225 bps/Hz; UL: 0.15 bps/Hz (Dense Urban)<br>DL: 0.12 bps/Hz; UL: 0.045 bps/Hz (Rural) |
| Average Spectral Efficiency | eMBB | DL: 9 bps/Hz/TRxP; UL: 6.75 bps/Hz/TRxP (Indoor Hotspot)<br>DL: 7.8 bps/Hz/TRxP; UL: 5.4 bps/Hz/TRxP (Dense Urban)<br>DL: 3.3 bps/Hz/TRxP; UL: 1.6 bps/Hz/TRxP (Rural) |
| Area Traffic Capacity | eMBB | DL: 10 Mbps/$M^2$(Indoor Hotspot) |
| User Plane Latency | eMBB, URLLC | 4ms for eMBB and 1ms for URLLC |

| | | |
|---|---|---|
| Control Plane Latency | eMBB, URLLC | 20ms for emBB and URLLC |
| Connection Density | mMTC | $10^6$ devices/km$^2$ |
| Energy Efficiency | eMBB | Capability to support high sleep ratio and long sleep duration to enable low energy consumption when there is no data |
| Reliability | URLLC | 1-$10^{-5}$ success probability of transmitting a layer 2 protocol data unit of 32 bytes within 1ms in channel quality of coverage edge |
| Mobility | eMBB | Upto 500 km/h |
| Mobility Interruption Time | eMBB, URLLC | 0ms |
| Bandwidth | eMBB | At least 100 MHz; Up to 1GHz for operation in higher frequency bands (e.g., above 6GHz) |

The ITU-R SG-5 approved the Recommendation ITU-R M.2150[17] in Nov 2020 that includes three technologies to meet the IMT-2020 requirements-

- 3GPP 5G-SRIT[18]
- 3GPP 5G-RIT[19]
- 5Gi[20]

A brief overview of these technologies is given below:

**3GPP 5G-SRIT[21]:**

The IMT-2020 specifications, known as 5G-SRIT, is a set of radio interface technologies (RITs) consisting of E-UTRA/LTE as one component RIT, and NR as the other component RIT. 3GPP finalized these specs in July 2020. Both component RITs, NR and E UTRA/LTE, utilize the frequency bands below 6 GHz identified for International Mobile Telecommunication (IMT) in the ITU Radio Regulations. In addition, the NR component RIT can also utilize the frequency bands above 6 GHz, i.e., above 24.25 GHz, identified for IMT in the ITU Radio Regulations.

The LTE RIT satisfies the requirement for eMBB & mMTC, whereas NR satisfies the requirements of eMBB & URLLC. The 3GPP 5G System (5GS) also includes specifications for its non-radio aspects, such as the core network elements (the EPC Network and 5GC Network), security, codecs, network

[17] M.2150: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2020 (IMT-2020) (https://www.itu.int/rec/R-REC-M.2150/en)

[18] Developed by 3GPP Proponent as “5G, Release 15 and beyond – LTE+NR SRIT”.

[19] Developed by 3GPP Proponent as “5G, Release 15 and beyond – NR RIT”.

[20] Developed by TSDSI as “5Gi RIT”

[21] Annex 1 of ITU-R M.2150, Specification of the 3GPP 5G – SRIT radio interface technology

management, etc. These non-radio specifications are not included in the so-called "Global Core Specifications (GCS)" of IMT-2020.

**3GPP 5G RIT**[22]:

The IMT-2020 specifications known as 5G-RIT have been developed by 3GPP in July 2020 and encompass NR Releases 15 and beyond. The NR radio satisfies the requirements of eMBB, mMTC and URLLC. Also, NR fulfils the service and the spectrum requirements. NR utilizes the frequency bands below 6 GHz identified for International Mobile Telecommunication (IMT) in the ITU Radio Regulations. In addition, NR can also utilize the frequency bands above 6 GHz, i.e., above 24.25 GHz, identified for IMT in the ITU Radio Regulations.

The 3GPP 5G System (5GS) also includes specifications for its non-radio aspects, such as the core network elements (the Enhanced Packet Core (EPC) Network and 5G Core (5GC) Network), security, codecs, network management, etc. These non-radio specifications are not included in the so-called "Global Core Specifications (GCS)" of IMT-2020.

**5Gi[23]:**

The IMT-2020 specifications known as 5Gi has been developed by TSDSI as a versatile radio interface that fulfils all the technical performance requirements of IMT 2020 across all the different test environments. It is understood that 5Gi is built over the 3GPP Rel-15 specifications that were available in Mar 2019. The 5Gi RIT includes only the radio and relies on the EPC or 5GS for the non-radio aspects.

## 3.1 IoT Technologies from 3GPP

3GPP introduced technologies like NB-IoT and LTE-M to address requirements of IoT applications, specifically focusing on long-battery life, low complexity since Release 12 to 14 on LTE. NB-IoT and LTE-M have already been designed to address the requirements from these use cases, including requirements on support of large numbers of devices, low device cost, ultra-long battery life, and coverage in challenging locations, and these requirements still apply for Massive IoT in the 5G context.

In Release 15, 3GPP performed a 5G self-evaluation of NR, LTE-M and NB-IoT performance. Evaluation results show that LTE-M and NB-IoT both support the 5G connection density requirement of 1,000,000 connected devices per $km^2$ with a service delivery within 10 seconds.

Mobile network operators should be able to offer massive IoT applications in combination with enhanced mobile broadband (eMBB) and Critical-IoT services. To allow this, 3GPP Release 15 supports a close coexistence between NR, LTE-M and NB-IoT. The specifications allow the three

[22] Annex 2 of ITU-R M.2150: Specification of the 3GPP 5G – RIT radio interface technology
[23] Annex 3 of ITU-R M.2150: Specification of the 5Gi radio interface technology

technologies to:

- operate in the same frequency band,
- configure the same physical layer numerology, i.e. sub-carrier spacing,
- align the uplink and downlink transmissions in time and frequency, and,
- reserve NR time-frequency resources dedicated for LTE-M and NB-IoT transmissions.

Figure 3-3 illustrates the concept of LTE-M and NB-IoT operating within an NR carrier by means of reserving resources for their transmissions.


**Figure 3-3: NR, LTE-M and NB-IoT coexisting in the frequency band n8**

In summary, LTE-M and NB-IoT meet the IMT-2020 and 3GPP 5G requirements for Massive IoT and support seamless coexistence between NR, LTE-M and NB-IoT. This makes LTE-M and NB-IoT today's most prominent and futureproof 5G Massive IoT technologies.

### 3.1.1 E-UTRA/LTE RIT

The E-UTRA/LTE RIT is based on releases 15 and 16 of LTE, and it is the evolution of the previous releases, encompassing both FDD and TDD. Transmission bandwidths up to 640 MHz (Channel bandwidths up to 20 MHz for LTE and 500 MHz for NR) are supported, yielding peak data rates up to roughly 32 Gbps in the downlink (DL) and 13.6 Gbps in the uplink (UL). The Narrow Band Internet of Things (NB-IoT) UL allows the allocation of a single-tone in addition to multi-tone DFTS-OFDM with the possibility of a lower subcarrier spacing in addition to the normal subcarrier spacing.

E-UTRA/LTE RIT supports various types of machine-type communication. To better address the low-cost segment, a low-complexity terminal (Category 0) is supported, which has approximately 50% reduced modem complexity as compared to the least complex 'normal' UE (Category 1). Another 50% complexity reduction was made possible with eMTC (Category M1) and even more with NB-IoT (Category NB1). eMTC optionally supports half duplex (HD) operation and NB-IoT supports only HD. In addition, eMTC and NB-IoT extended the original LTE coverage area by ~15 dB and ~20 dB respectively. The narrow NB-IoT channel bandwidth of 200 kHz makes it possible to operate in re-farmed GSM channels or in LTE guard bands. To improve UE power consumption, a power saving state was introduced and extended Discontinuous Reception (eDRX) cycles range up to 10.24 seconds in connected mode and 43.69 minutes in idle mode. For eMTC and NB-IoT, it is possible to configure an additional uplink and an additional downlink carrier for traffic which is dedicated to a particular User Equipment, whilst common transmissions such as synchronization signals, and uplink transmissions during cell access, occur on the same carrier for all UEs.

### 3.1.2 NR RIT

The NR RIT represents the releases 15 and 16 of NR, which uses either 1) FDD operation and therefore is applicable for operation with paired spectrum or 2) TDD operation and therefore is applicable for operation with unpaired spectrum.

Channel bandwidths up to 400 MHz and Carrier Aggregation over 16 component carriers are supported, yielding peak data rates up to roughly 140 Gbit/s or Gbps in the downlink and 65 Gbit/s or Gbps in the uplink.

For optimal support of specific verticals, the NR RIT has been designed, or enhanced, with certain key features, to support Ultra-Reliable and Low Latency Communications (URLLC) and Industrial IoT (IIoT).

A short summary of these features is provided below:

- Logical Channel Priority (LCP) restrictions
- Packet duplication with DC or CA
- New QCI table for block error rate $10^{-5}$
- Physical layer short transmission time interval (TTI)
- NR PDCP duplication enhancements,
- Prioritization/multiplexing enhancements,
- NR Time Sensitive Communications (TSC) related enhancements, e.g. Ethernet header compression,
- Precise time information delivery and
- in-band coexistence with NB-IoT and eMTC

In 3GPP Rel-16, spectral efficiency is increased further for massive-MTC transmissions and reduced energy consumption for massive-MTC devices enabled e.g. uplink transmission using preconfigured resources in idle mode (allowing the device to skip random access procedures) and multi-transport-block scheduling in both the DL and UL transmission directions (reducing the control signaling overhead).

## 3.2 3GPP 5G key capabilities for vertical industries

### 3.2.1 Non-Public Networks

3GPP defined a term Non-Public Networks (NPN)[24] for a network that is intended for non-public use. It could be exclusively used by a private entity such as an industry enterprise and could utilize both virtual and physical elements and be deployed in different type of configurations. A Non-Public Network (NPN) enables deployment of 5G System for private use. An NPN may be deployed as:

[24] 3GPP 5G for Industry 4.0, https://www.3gpp.org/news-events/2122-tsn_v_lan

1. **Stand-alone Non-Public Network (SNPN):**
   SNPN is operated by an NPN operator and doesn't rely on the network functions provided by a Public Land Mobile Network (PLMN) owned by mobile network operator (MNO). An NPN operator could be the enterprise itself or a 3rd party. An NPN operator has full control and management capability on the network functions provided by SNPN.

2. **Public network integrated Non-Public Network (PNI-NPN):**
   PNI-NPN is an NPN deployed with the support from a public network. Based on the contract between the MNO and enterprise, the MNO could provide network resources extracted from the public network for the enterprise to use.

NPN architecture aspects have been standardized in 3GPP Release 16, and a number of enhanced features are further being discussed in Release 17, for example:

- enhancement to enable support for SNPN along with subscription / credentials owned by an entity separate from the SNPN
- support device onboarding and provisioning for NPNs
- enhancement to the 5GS (5G system) for NPN to support service requirements for production of audio-visual content and services e.g., for service continuity
- support voice/IMS (IP Multimedia Subsystem) emergency services for SNPN

5G-ACIA (5G Alliance for Connected Industries and Automation) further elaborated integration concepts and possible NPN deployment format in one of their white papers[25]

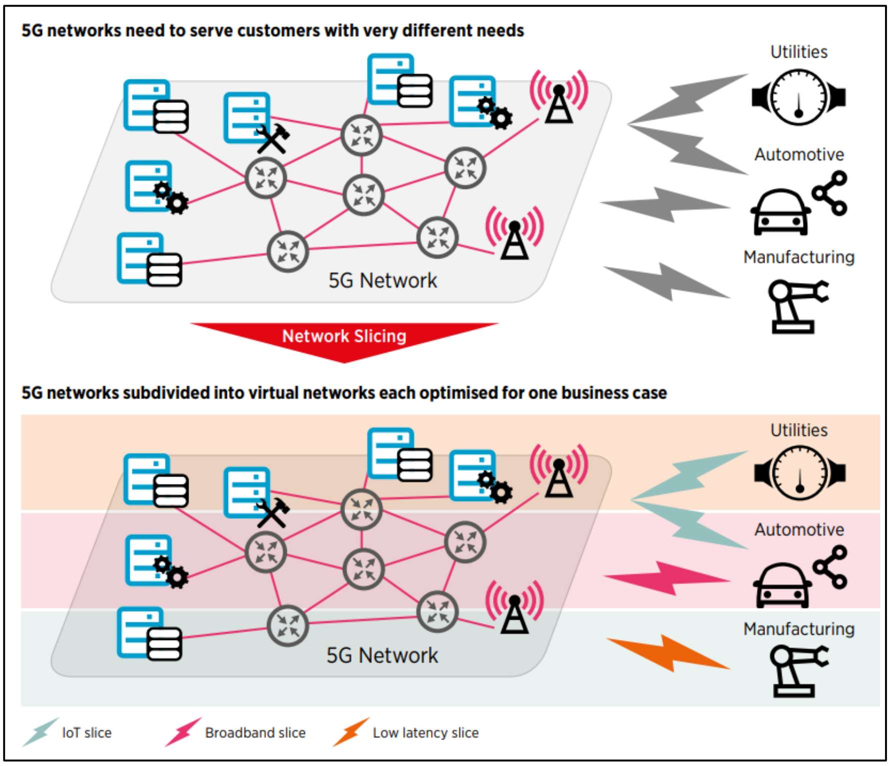
1. Standalone NPN (isolated deployment): the enterprise deploys its own mobile infrastructure and standalone network. It may optionally connect to the public network via a firewall. This is equivalent to SNPN defined by 3GPP.
2. Shared RAN: In this scenario the public network and the NPN network share one or multiple RAN. NPN may optionally connect to the public network via a firewall. This is equivalent to SNPN with RAN sharing defined by 3GPP
3. Shared RAN and control plane: In this scenario the NPN network share the RAN and the control plane with the public network. All control plane decisions are being done on the public network. Isolation and routing of the traffic to the NPN is achieved with network slicing or dedicated DNN (Data Network Name). NPN may optionally connect to the public network via a firewall.
4. NPN hosted by the public network: In this scenario the NPN is deployed upon the public network outside of the enterprise premises with isolation being performed by slicing or dedicated DNN mechanism. Optional connection to the public network (via the firewall) is not needed in this scenario.

[25] 5G-ACIA 5G Non-Public Networks for Industrial Scenarios, September 2019: https://5g-acia.org/wp-content/uploads/5G-ACIA_5G_Non-Public_Networks_for_Industrial_Scenarios_2021.pdf

### 3.2.2 Network Slicing

From a mobile operator's point of view, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated service quality. The technology enabling network slicing is transparent to business customers. A network slice could span across multiple parts of the network (e.g. terminal, access network, core network and transport network) and could also be deployed across multiple operators. Network slicing makes it possible to create a private 5G network with specific service characteristics as well as varying degrees of security/isolation, storage, bandwidth allocation, exposure, self-management, and so on. (refer 3GPP TS 23.501 for terminologies related to network slicing).

To provide the best level of isolation, resources assigned to a network slice are ideally dedicated.




NOTE- Source [GSMA]

**Figure 3-4: Network Slicing**

Assuming that it is acceptable, some slices may share resources to reduce cost. Distribution and coverage are considered per slice. Some slices are local, while others may be wider in reach. Some slices require local Network Functions (NFs) for latency reasons, while others do not.

The ability to engineer network slices depends on an evolving toolbox of versatile enablers in five areas: cloud infrastructure, RAN, core, transport, and operations support systems/business support systems (OSS/BSS). Depending on the scenario, different combinations of enablers will be required to engineer the appropriate network slice(s). The enablers specified by 3GPP are available in the

Technical Review paper on Network Slicing[26].

**3GPP Network: Enablers for network slicing**

The 3GPP has defined enablers that can be used within a RAN, Core to select appropriate functions and capabilities (such as policies) for network slices.

- A Network Slice is defined within a PLMN/TA (Tracking Area) and includes target functions for the control plane (CP) and user plane (UP).
- Identification of a Network Slice is done via the Single Network Slice Selection Assistance Information (S-NSSAI) where NSSAI is a collection of S-NSSAIs. Currently, 3GPP allows up to eight (8) S-NSSAIs in a NSSAI sent in the signaling messages between the UE and the Network. This means a single UE may be served by at most eight Network Slices at a time. S-NSSAI include the SST (Slice/Service Type) indicator. The well-known usage scenarios namely eMBB, URLLC and mMTC have the SST values 1, 2 and 3 respectively. Additional indicator like Slice Differentiator (SD) is used to differentiate slices within a SST.
- S-NSSAI signaled by the UE to the network, assists the network in selecting a particular Network Slice instance. Every protocol data unit (PDU) session is associated to this S-NSSAI as soon as a UE context is created in the network. Each PDU session is associated to Data Network Name (DNN).
- The RAN reduces a PDU session into dedicated radio bearers (DRBs), which allows the RAN to associate an S-NSSAI to each DRB and to select NFs and capabilities to serve the DRB traffic. As an example of capability, a specific next-generation node B central unit user plane (gNB-CU-UP) – hosting PDCP (Packet Data Convergence Protocol) – may be selected for a given S-NSSAI to fulfill delay and security requirements. RAN also configures Radio Resource Management (RRM) policies for Radio Resource Partitioning to provide QoS levels per slice. Hard partitioning of resources restricts resource usage to a specific slice; soft partitioning allows resources to be used by any slice when they are not utilized by the slice that is nominally assigned to them; shared resources can also be defined for resources accessible by all slices, on demand.
- Mobility across RAN nodes in a TA is also important to take handover decisions based on the ability to support the requirements of slice at the target RAN while maintaining service continuity and RAN efficiency.
- Specifications of the 5G Core enables steering of user-plane, control-plane network functions during orchestration of a slice during the instantiation. Design and deployment of UPF is the most valuable network function where application end-point terminates. The ability to steer traffic and deploy UPF is important for requirements like low-latency to keep it close to customer premises. A dedicated UPF also ensures survival of established sessions, even when

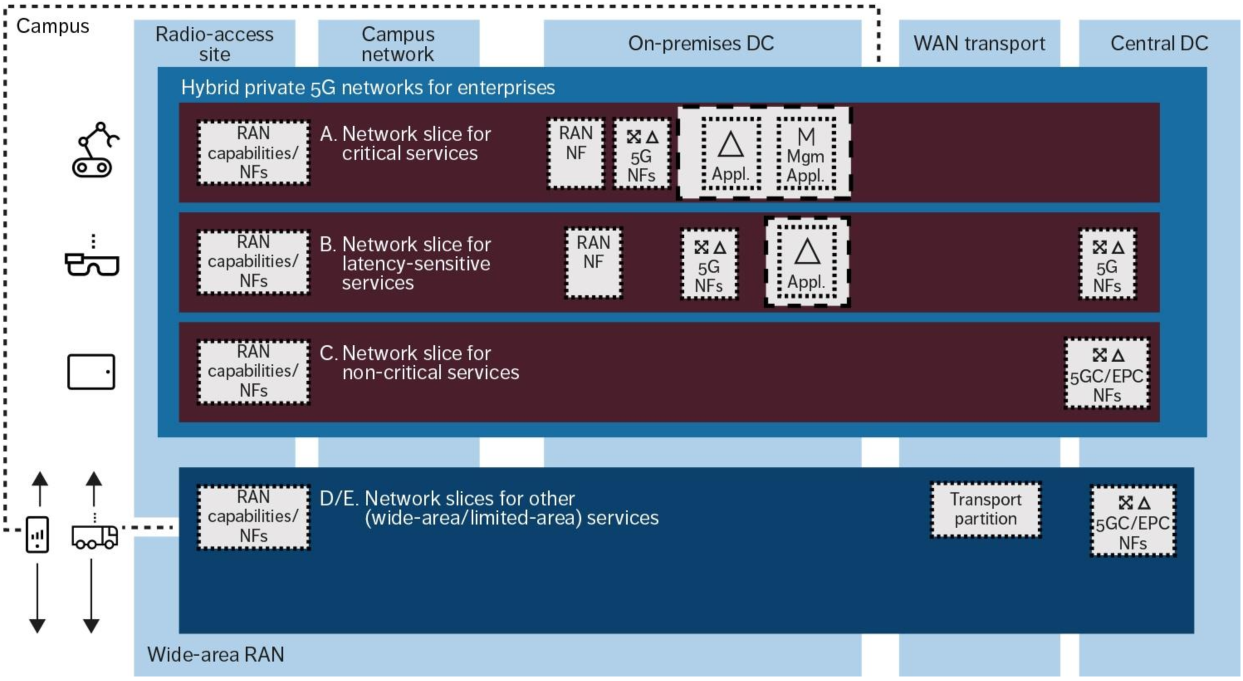
[26] Ericsson Technology Review, Applied network slicing scenarios in 5G, https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/applied-network-slicing-scenarios-in-5g

connectivity to control-plane NF is lost.

- When the RAN and core involved in a network slice involves transport network, it is essential to have configurable transport resources to match the Service Level Agreement (SLA) for all the network slices passing through the transport network links. This involves cross-domain orchestration - transport VPN and capabilities of OSS.

- Ability of OSS/BSS to manage service characteristics, analytics, monitoring of KPIs of slices are important aspects. Network orchestration provides faster service provisioning across all nodes through automation including instantiations and provisioning of network functions. According to Ericsson Technical Review paper[27] on Network Slicing, OSS/BSS layer should be possible to customize and repeat actions based on templates and policies. These templates reflect SLAs, deployment of NFs, system capabilities, etc. This helps for speedy and cost-efficient deployment slices for various business models and use-cases.

Various examples of slicing in a campus network are shown in the figure below-




NOTE- Source [Ericsson]

**Figure 3-5: Slicing in wide-area/limited-area deployment (supporting virtual private 5G networks)**

There are three main approaches to offering and delivering private 5G networks which are enabled by Network Slicing:

[27] Ericsson Technology Review, Applied network slicing scenarios in 5G, https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/applied-network-slicing-scenarios-in-5g

- **the standalone approach:**
  They may be facilitated through a mobile network operator, managed by a factory, or provided as a managed service. Network slicing is used to customize the behavior for different use cases/ traffic types and to provide isolation between them.

- **the virtual approach:**
  Network slicing is used to meet customization and isolation needs per use case/ traffic type as well as per enterprise customer. Public-safety and connected-car services that make use of the public 5G infrastructure are examples of virtual private 5G networks.

- **the hybrid approach:**
  Network slicing is used to customize and isolate slices per enterprise customer and use case/traffic type. The hybrid approach enables a more flexible distribution of functionality, more efficient use of infrastructure and improved mobility in and out of the customer premises.

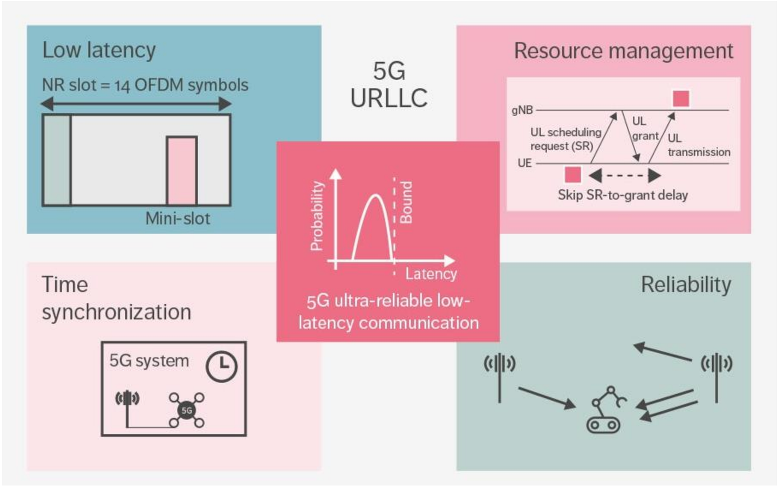
### 3.2.3 TSN (Time Sensitive Network)

Industrial automation (Industry 4.0)[28] is expected to be one of the important use-cases of 5G. This requires the reduction of cables in the factory. Factory automation is going through a transformation due to the fourth industrial revolution, and this requires convergence to support various types of traffic in a single network infrastructure. Most of the wired factory components highly depends on the IEEE 802.1 (https://1.ieee802.org/) ethernet-based standard for time-sensitive network of components in the factory. To introduce 5G for wirelessly connecting the various parts in a factory floor, integration of traffic from TSN traffic is important to co-exist with same guaranteed QoS requirements as the wired TSN applications.

In addition, to the low-latency requirements of control and user plane data for 5G, it was found essential to support integration of TSN into 5G NR.

3GPP 5G RAN introduced several features in NR over Release 15 and Release 16 to enable low-latency applications as depicted below:

[28] Ericsson Technology Review, Boosting smart manufacturing with 5G wireless connectivity, January 2019, Sachs, J.; Wallstedt, K.; Alriksson, F.; Eneroth, G.




NOTE- Source [Ericson Technology Review[29]]

**Figure 3-6: Components of enabling TSN in 5G**

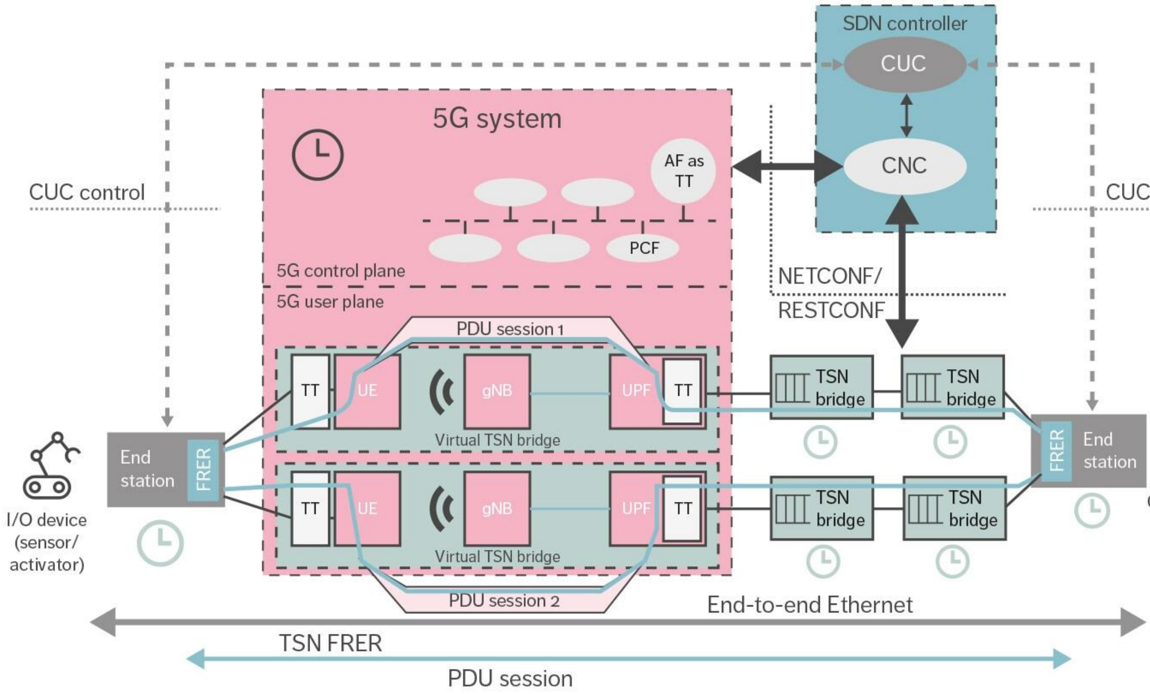
The requirements of URLLC expects a packet data to be delivered in a time bound manner (latency requirements: user plane 1ms, control plane 10ms) with high reliability of 10-5. 3GPP NR achieves such requirements using mini-slot transmissions, and UL transmissions without scheduling request (SR). The 5G RAN can reuse the existing time/phase synchronization used in telecom network30.

The 5G Core Network (CN) supports native Ethernet protocol data unit (PDU) sessions. 5G assists the establishment of redundant user plane paths through the 5GS, including RAN, the CN and the transport network. The 5GS also allows for a redundant user plane separately between the RAN and CN nodes, as well as between the UE and the RAN nodes.

Integration of TSN network components through 5G system is demonstrated in the figure below.

[29] 5G-TSN integration meets networking requirements for industrial automation https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/5g-tsn-integration-for-industrial-automation

[30] 1. ITU-T G.8275.1 Precision time protocol telecom profile for phase/time synchronization with full timing support from the network




NOTE- Source [Ericsson]

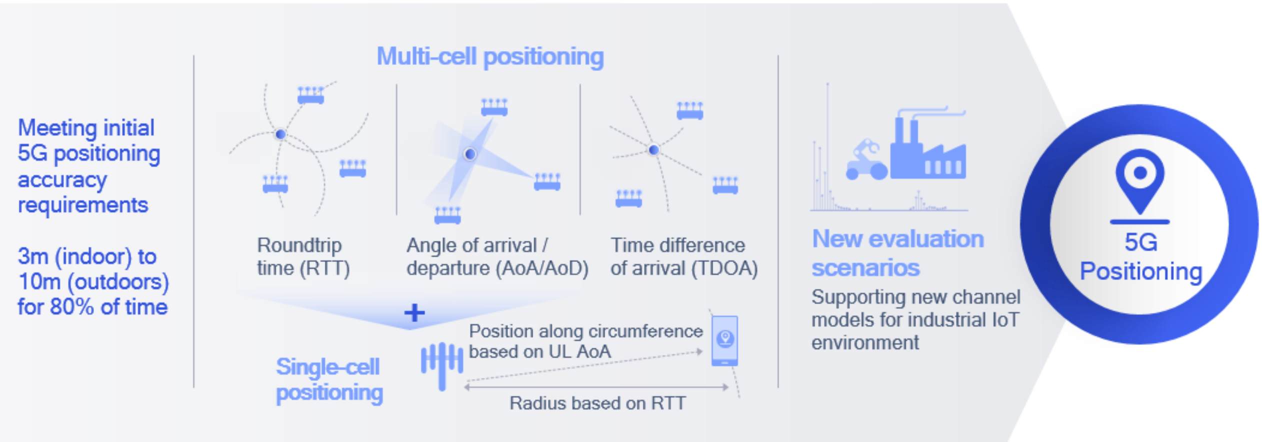
**Figure 3-7: 5GS integrated with TSN providing end-to-end deterministic connectivity**

TSN is a Layer 2 technology and includes IEEE 802.1Q based bridges and bridged network components. TSN uses Ethernet packets than Internet Protocol. And hence the data flow - forwarding decisions made by the TSN bridges uses the Ethernet header contents and not the IP address. This allows TSN to carry payload of any industrial application without requiring IP based network endpoints. TSN is focused on delivering the payload deterministically in time.

In the Figure 3-7 above, the entire 5G System appears as a TSN bridge component and ensures to deliver the PDU (FRER - 802.1CB) between the end-devices (End-station). The TSN Translator (TT) function in the 5G UE does the conversion from FRER data to 5G PDU and delivers it to the UPF which again translates back to TSN data formats before delivering it to the TSN bridge. The 5G system also hosts a function to support Link Layer Discovery Protocol (LLDP) (802.1AB) that helps end-stations connected via 5G system to discover the TSN network. Reliability of the delivery from End-Station through 5GS can be increased using multiple PDU sessions through multiple 5G modems integrated on the station for redundancy. The different TSN traffic classes are mapped to different 5G QoS Indicators (5QIs) in the AF and the Policy Control Function (PCF) as part of the QoS alignment between the two domains, and the different 5QIs are treated according to their QoS requirements.

### 3.2.4 High precision positioning

Accurate device positioning is a key enabler for many vertical applications, such as public safety and indoor navigation. The benefit of cellular-based positioning, which complements existing GNSS systems, is that it works well outdoors and indoors. Release 16 supports multi-/single-cell and device-based positioning, defining a new positioning reference signal (PRS) used by various 5G positioning techniques such as roundtrip time (RTT), angle of arrival/departure (AoA/AoD), and time difference of arrival (TDOA). Roundtrip time (RTT) based positioning removes the requirement of tight network timing synchronization across nodes (as needed in legacy techniques such as TDOA) and offers additional flexibility in network deployment and maintenance. These techniques are designed to meet initial 5G requirements of 3 and 10 meters for indoor and outdoor use cases, respectively. In Release 17, precise indoor positioning functionality is expected to bring sub-meter accuracy for industrial IoT use cases.




NOTE- Source [Qualcomm]

**Figure 3-8: 5G positioning technologies and new use-cases**

The positioning requirements for regulatory (e.g. E911) and commercial applications are described in 3GPP TR 38.855. For regulatory use cases, the following are the minimum performance requirements-

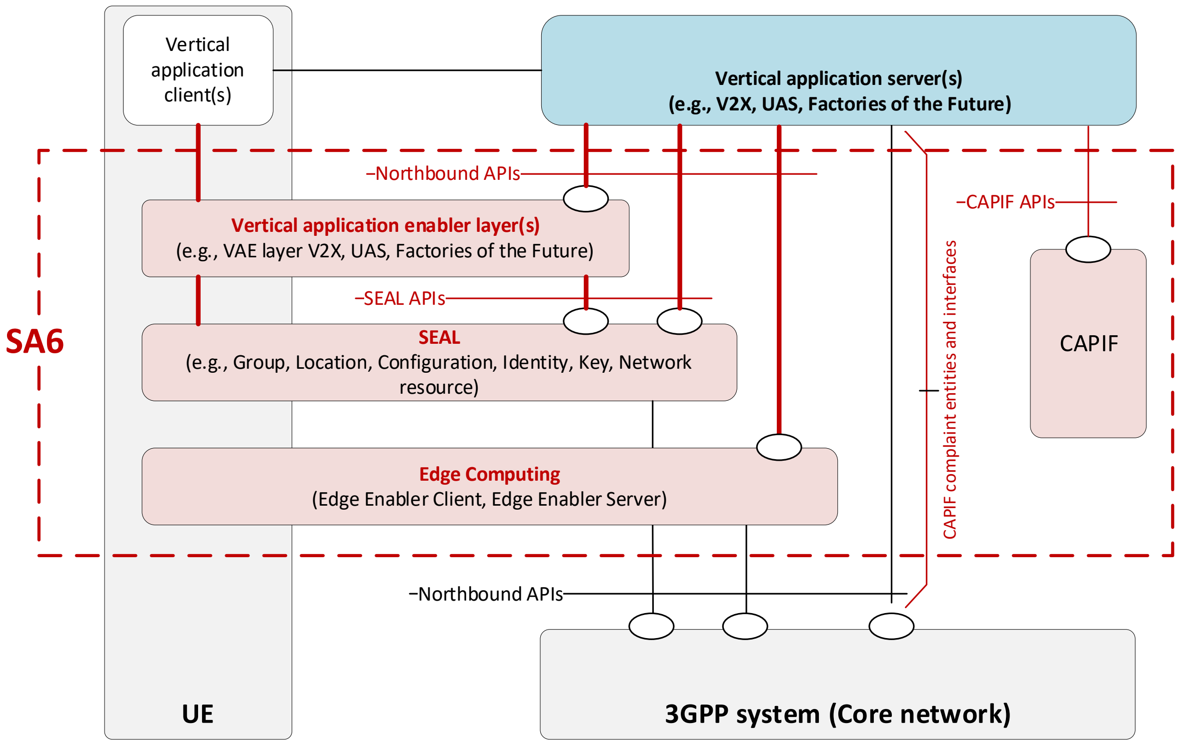
- Horizontal positioning accuracy better than 50 meters for 80% of the UEs.
- Vertical positioning accuracy better than 5 meters for 80% of the UEs.
- End-to-end latency less than 30 seconds.

For commercial use cases, for which the positioning requirements are more stringent, the following are the starting-point performance targets-

- Horizontal positioning accuracy better than 3 meters (indoors) and 10 meters (outdoors) for 80% of the UEs.
- Vertical positioning accuracy better than 3 meters (indoors and outdoors) for 80% of the UEs.
- End-to-end latency less than 1 second.

## 3.3 Vertical application enablement in 3GPP

3GPP has developed standards to enable integration of new vertical applications within the 3GPP system components. The key objective is to support accelerated time to market for vertical applications over 3GPP systems by providing right level of abstraction for network and common service northbound APIs. Figure 3-9 illustrates the overall view for 3GPP vertical application enablement:




**Source: 3GPP**

**Figure 3-9: 3GPP vertical application enablement**

These functionalities of 3GPP are enabled in:

- End Device (UE) using Vertical Application Client(s)
- Network side which integrates with Vertical Application Server(s) via northbound APIs

The following are the key components:

- The Common API Framework (CAPIF) is a RESTful architecture exposure framework which provides the API registry to enable vertical application server(s) to discover and invoker Northbound APIs. It is specified in 3GPP TS 23.222, TS 33.122, and TS 29.222.
- The Service Enabler Architecture Layer (SEAL) provides common services to support vertical applications like location management, group management, configuration management, identity management, key management and network resource management. It is specified in 3GPP TS 23.434.

- The Vertical Application Enablement Layer (VAEL) provides application specific support services like messaging, etc. towards the vertical applications. Currently support for V2X applications (specified in 3GPP TS 23.286), Smart Factory (specified in 3GPP TR 23.745) and Drones (specified in 3GPP TR 23.755) is in progress.
- The Edge Enabler Architecture Layer (EEAL) provides support for utilization and deployment of application servers utilizing Edge Computing technologies closer to the User's point of network attachment. It is specified in 3GPP TS 23.558.

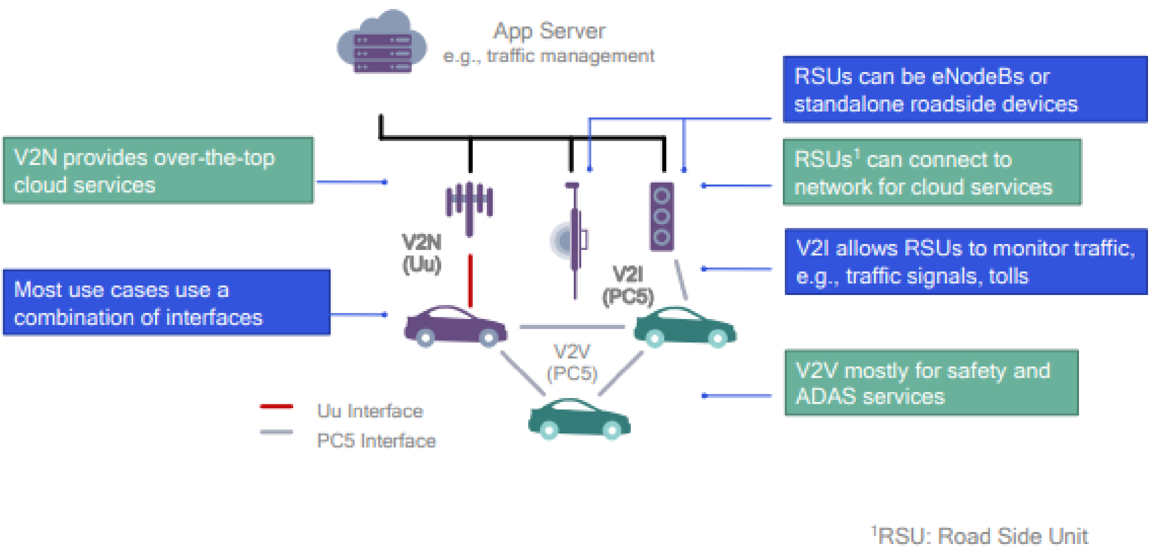
## 3.4 Overview of 3GPP C-V2X

C-V2X defines two complimentary Transmission Modes:

1. Direct safety communication independent of cellular network
   - Low latency Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Person (V2P) operating in ITS bands (e.g., 5.9 GHz, Band b47 and n47)
2. Network communications for other services
   - Vehicle-to-Network (V2N) operates in the mobile operator's licensed spectrum

Collectively, the transmission modes of shorter-range direct communications (V2V, V2I, V2P) and longer-range network-based communications (V2N) is called Cellular-V2X[31].

3GPP Cellular-V2X (C-V2X) defines a new air interface called PC5 for V2V, V2I communication. V2N is still over the legacy LTE Uu air interface and provides over the top cloud services.




NOTE- Source [Qualcomm]

**Figure 3-10: C-V2X Architecture**

[31]Refer 3GPP TR 22.885 Study on LTE Support for Vehicle to Everything (V2X) Services, https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2898

**Direct communications (V2V) via PC5 interface:**

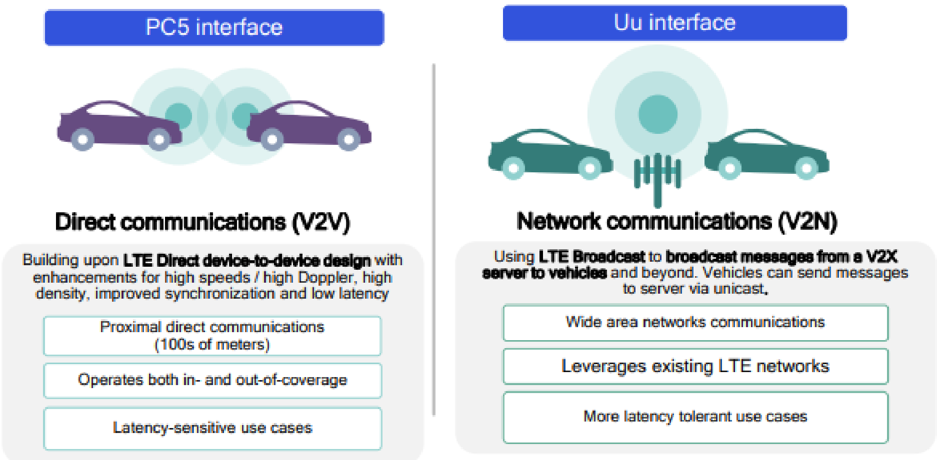
Building upon LTE direct device-to-device design with enhancements for high speeds / high Doppler, high density, improved synchronization, and low latency

- Proximal direct communications (few 100s of meters)
- Operates both in- and out-of-coverage
- Latency-sensitive use cases, e.g., V2V safety

**Network communications (V2N) via Uu interface:**

Using LTE to broadcast messages from a V2X application server to vehicles and beyond in the cellular bands. Vehicles can send messages to server via unicast.

- Wide area networks communications
- Leverages existing cellular networks
- More latency tolerant use cases, e.g., V2N situational awareness



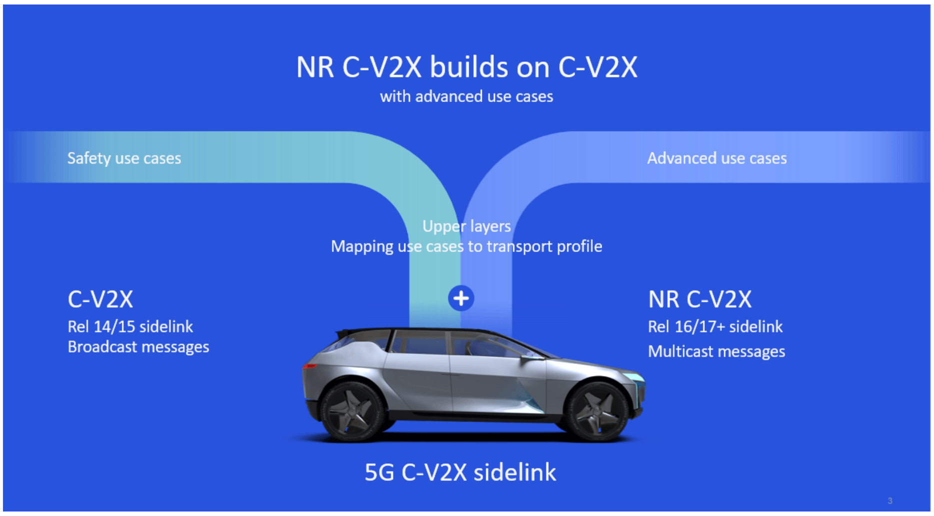

NOTE- Source [Qualcomm]

**Figure 3-11: C-V2X Communication Interfaces**

### 3.4.1 C-V2X development in 3GPP

3GPP Release 14 introduced direct communication modes that standardized how vehicles communicate virtually with everything around them — other vehicles (V2V), pedestrians (V2P), and infrastructure (V2I) — over a short range without relying on the cellular network. So, latency-sensitive basic safety messages aimed at improving road safety and traffic efficiency are conveyed using the direct communication mode operating on the globally harmonized 5.9 GHz ITS spectrum.

As C-V2X technology continues to evolve, the 3GPP Release 16 NR C-V2X direct communication mode (or sidelink) specifications will support advanced use cases that could enhance autonomous driving, once again, without using the cellular network.




NOTE- Source [Qualcomm]

**Figure 3-12: Overview of C-V2X development across releases**

3GPP Release 15 added transmit diversity (cyclic delay diversity) and improved performance, as advancements to the direct communication mode. The direct communication mode in Release 16 NR, C-V2X sidelink, offers major enhancements in terms of new short-range features enabling advanced applications to complement the basic safety use cases.

NR C-V2X sidelink includes enhancements in the form of higher throughput, lower latency, enhanced reliability, and improved positioning — all of which are expected to enhance autonomous driving. The sidelink time synchronization allows robust C-V2X operation even in the absence of GNSS coverage.

NR C-V2X sidelink also moves the default mode of operation from broadcast to reliable multicast communication. This is probably the first wireless system for ITS to introduce distance as a dimension at the physical layer. This helps in getting a uniform communication range across widely varying radio environments — for both line-of-sight and non-line-of-sight scenarios. Introducing distance as a dimension also enables formation of "on-the-fly" multicast groups based on distance and applications. Such multicast groups require little or no overhead for group formation and dismantling.

V2V or V2I technologies that use sidelink are complemented by vehicle-to-network (V2N), which requires participation from the mobile network operators to deliver information through the cellular network. V2N has been available for roughly 20 years, supporting telematics, automatic crash notification, infotainment, cloud services such as map and other software updates, route guidance with traffic information, and more recently, remote supervisory control (teleoperation) for driving and parking.

NR C-V2X is designed to facilitate negotiated intersection crossings (resolving the ambiguity that occurs at a four-way stop through intent sharing, thus improving traffic efficiency), coordinated lane changes leveraging lower latency communication, better positioning accuracy, and on-the-fly distance-based group formations. There is improved situational awareness and collective perception delivered through high-throughput sensor sharing from onboard cameras, radars, and LiDAR imagery; real-time updates of 3D High-Definition Maps; and the ability to see "through" vehicles and around blind corners, improving road awareness.

Services like e-Call in Europe, automakers' decision to deliver software and firmware updates have witnessed increased demand for cellular connectivity in new vehicles along with C-V2X functionality integrated in vehicles. According to Strategy Analytics, about 60% of new vehicles in the top three global automotive markets — North America, Europe, and China, have cellular connectivity and this number is projected to grow to 85% by 2025[32].

A technical report[33] on C-V2X Technical Performance provides an assessment of the technical features of C-V2X for various ITS applications, including the availability of C-V2X chipsets. An assessment of LTE V2X and 802.11p for improved road safety was published by 5GAA[34]; this report provides insights into the evaluation of technical performance of LTE V2X across use-cases. A contribution on proposal for LTE and 5G NR based V2X in Working Document Towards "Cellular Based V2X for ITS applications in APT Countries" was submitted by TEC in 26th Meeting of APT Wireless Group (AWG), as mentioned in point no. 2 of Section 1.2.3.

[32] How NR-based sidelink expands 5G C-V2X to support new advanced use cases, https://www.qualcomm.com/news/onq/2020/03/31/how-nr-based-sidelink-expands-5g-c-v2x-support-new-advanced-use-cases

[33] C-V2X Technical Performance, https://www.qualcomm.com/media/documents/files/c-v2x-technical-performance-faq.pdf

[34] An assessment of LTE-V2X (PC5) and 802.11p direct communications technologies for improved road safety in the EU, https://5gaa.org/wp-content/uploads/2017/12/5GAA-Road-safety-FINAL2017-12-05.pdf

## 3.5 Ongoing 3GPP Standardization on IoT

As part of the ongoing 3GPP work plan, it has started work on Release-17[35] on features like:

- Industrial IoT / URLLC enhancements
- NR Positioning enhancements
- Low complexity NR devices
- NB-IoT and LTE-MTC enhancements
- Non-Public Networks enhancements
- Network Automation for 5G – phase 2
- Edge Computing in 5GC
- RAN slicing
- Network Slicing – phase 2
- 5GC (5G Core) location services
- Satellite components in the 5G architecture
  - Study on IoT over Non-Terrestrial Networks (NTN)
  - NR over Non-Terrestrial Networks (NTN)
- And many others

The Release-17 is expected to be finalized by 3GPP in June 2022[36].

## 3.6 IEEE 802.11 based technologies for IoT

### 3.6.1 Wi-Fi 6 / Wi-Fi 6E

Wi-Fi 6 is the sixth generation Wi-Fi technology based on IEEE 802.11ax specifications and the upgradation of 802.11ac. The IEEE 802.11ac used only the 5 GHz band, while 802.11n used 2.4 GHz and 5 GHz band. 802.11ax has been designed to use both 2.4 and 5 GHz bands, thus staying backward compatible and providing a migration path for both 802.11n and 802.11ac devices. IEEE 802.11ax focuses on better efficiency, capacity and performance as compared to previous technologies of Wi-Fi family, thus providing 4x improvement in average throughput per user and better user experience even for dense indoor/outdoor deployments such as airports, railway stations, shopping malls, stadiums, homes, school campuses[37].

IEEE 802.11ax supports up to 8x8 MU-MIMO in both downlink and uplink, which allows it to serve up to 8 users simultaneously for a significant capacity boost. MU-MIMO also benefits the performance of legacy devices (such as 802.11ac Wave 2 and older devices) to improve every device's experience. 802.11ax uses 4G LTE's proven and foundational OFDMA technology for

[35] 3GPP Release-17 Work Program: https://www.3gpp.org/release-17

[36] 3GPP Release-17 timeline: https://www.3gpp.org/news-events/2145-rel-17_newtimeline

[37] https://devopedia.org/ieee-802-11ax

efficient access. OFDMA allows multiple users with varying bandwidth needs to be served simultaneously[38].

Wi-Fi devices were previously restricted to using only the 2.4 GHz and 5 GHz frequency bands, but that has recently changed. Several nations around the globe are making 6 GHz band available for unlicensed use. Wi-Fi 6E extends Wi-Fi 6 to the 6 GHz band. Wi-Fi 6 operation in the 6 GHz frequency band enables Wi-Fi to continue delivering positive experiences for the most bandwidth-intensive applications.

Wi-Fi CERTIFIED 6™, the industry certification program based on the IEEE 802.11ax standard, provides the capacity, efficiency, coverage, and performance[39].

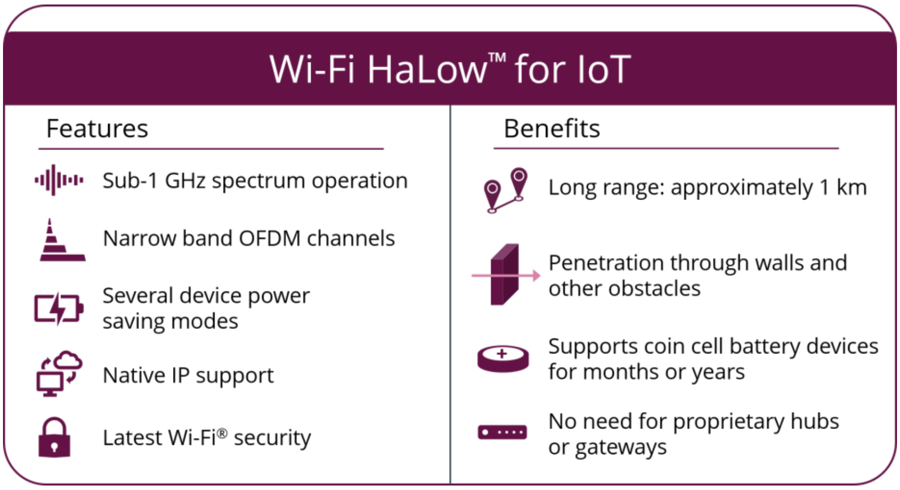
### 3.6.2 Wi-Fi HaLow

Wi-Fi HaLow[40] is based on IEEE 802.11ah specifications. Wi-Fi Halow operates in the delicensed frequency bands below one GHz, offering lower power, longer range connectivity to Wi-Fi certified products. Wi-Fi HaLow supports the Internet of Things (IoT) use cases in industrial, agricultural, smart building, smart homes, digital health care and smart city environments. Wi-Fi HaLow extends Wi-Fi into the 900 MHz band. Many devices that support Wi-Fi HaLow are expected to operate in 2.4 and 5 GHz in addition to 900 MHz band, allowing devices to connect with Wi-Fi's ecosystem. Wi-Fi HaLow devices will support IP-based connectivity to natively connect to the cloud, which will become increasingly important in reaching the full potential of the Internet of Things (IoT). Dense device deployments will also benefit from Wi-Fi HaLow's ability to connect thousands of devices to a single access point. Some of the features and benefits of this technology are as given in Figure below:

38 https://www.qualcomm.com/products/features/80211ax

39 https://www.wi-fi.org/discover-wi-fi/wi-fi-certified-6

40 https://www.wi-fi.org/discover-wi-fi/wi-fi-halow




NOTE- Source [Wi-Fi Alliance]

**Figure 3-13: Features and benefits of Wi-Fi HaLow for IoT**

## 3.7 Bluetooth Mesh

Bluetooth mesh enables the creation of large-scale device networks. It is ideally suited for control, monitoring, and automation systems where hundreds, or thousands of devices need to communicate with one another. Bluetooth mesh was designed from the beginning to meet the strict requirements of commercial and industrial environments where performance, reliability, and security are of the utmost importance. Bluetooth mesh is getting utilized in advanced commercial lighting control systems applications[41].

[41] https://www.bluetooth.com/learn-about-bluetooth/recent-enhancements/mesh/


NOTE- Source [https://www.bluetooth.com/]

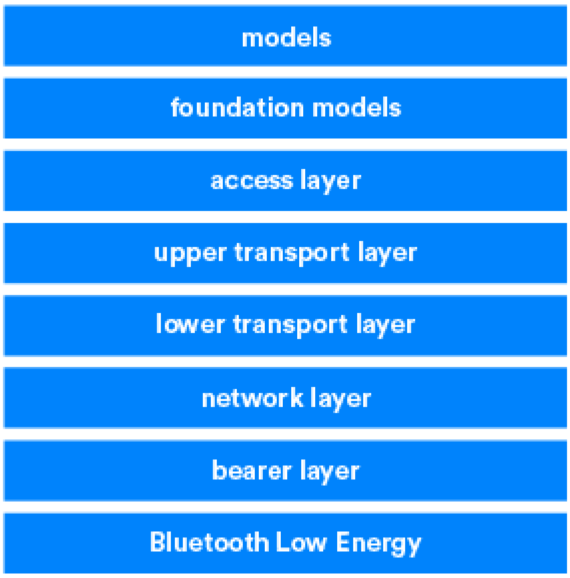
**Figure 3-14: Features of Bluetooth Mesh**


NOTE- Source [https://www.bluetooth.com/wp-content/uploads/2019/03/Bluetooth-Mesh-Overview.pdf]

**Figure 3-15: Applications of Bluetooth Mesh**

**Bluetooth Mesh Architecture:**

At the bottom of the mesh architecture stack, there is a layer entitled Bluetooth Low Energy. The top layer of the architecture is Models layer, which is defined in additional Mesh model specifications. More details of the architecture can be seen on the Bluetooth website[42].



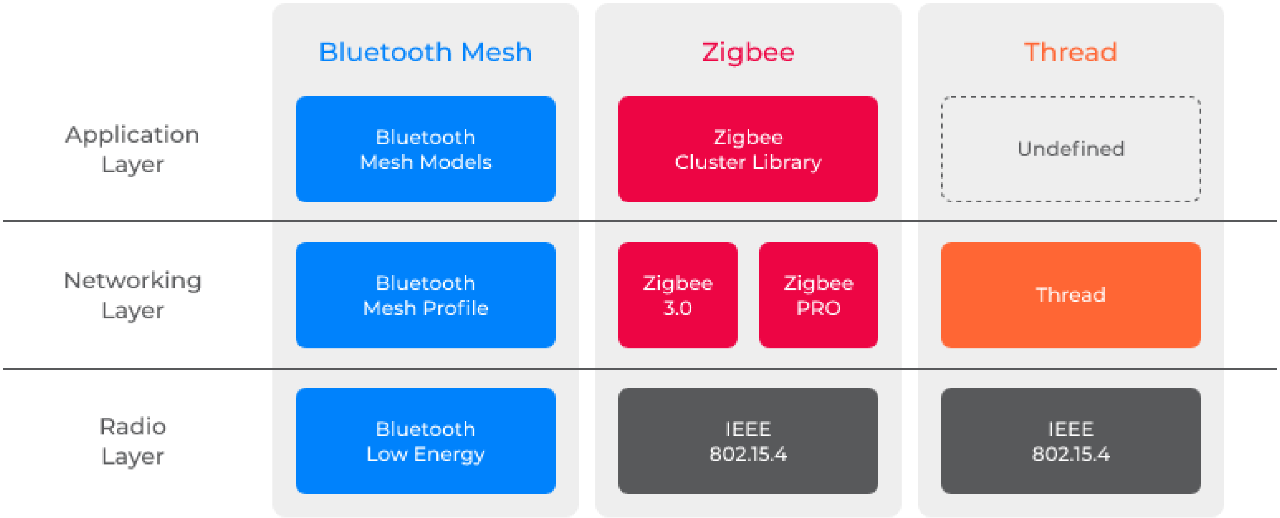

NOTE- Source [https://www.bluetooth.com/wp-content/uploads/2019/03/Mesh-Technology-Overview.pdf]

**Figure 3-16: Bluetooth Mesh Architecture**

**Full-Stack Solution:**

Bluetooth mesh is a complete, full-stack solution that defines everything from the low-level physical radio layer through high-level application layer. In addition to enabling easier product development and greater levels of product interoperability, this full-stack approach allows for a faster and smoother evolution of the technology.

[42] https://www.bluetooth.com/




NOTE- Source [https://www.bluetooth.com/learn-about-bluetooth/recent-enhancements/mesh/]

**Figure 3-17: Bluetooth Mesh Full-Stack Solution**

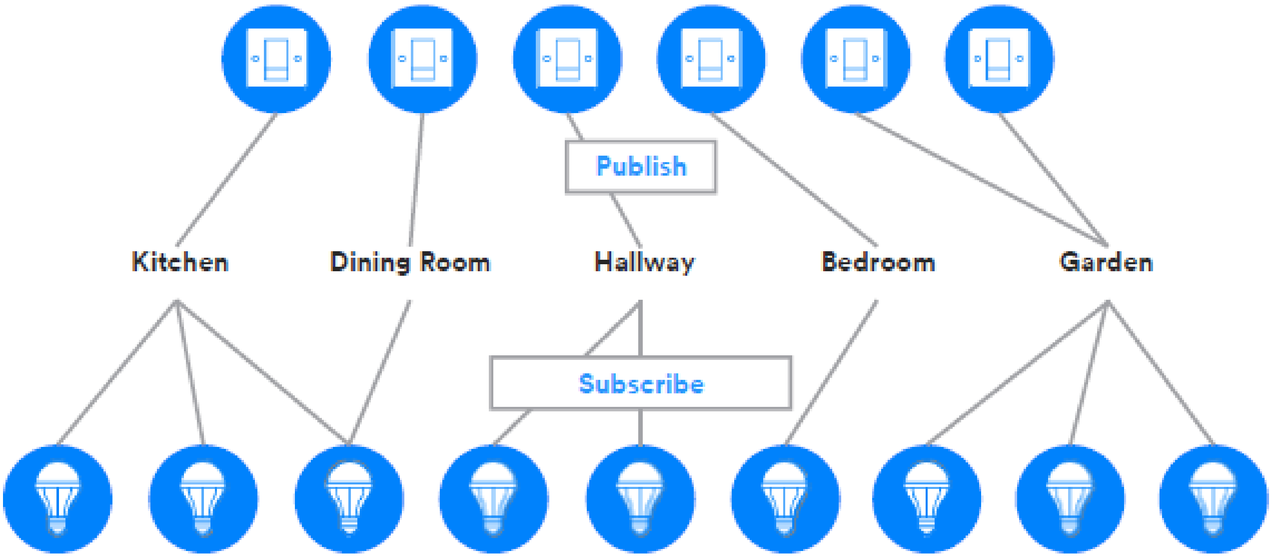
**Decentralized Control Feature:**

Bluetooth mesh utilized in control systems do not require centralized controllers, as intelligence is distributed to all end devices. For example, in a Bluetooth mesh lighting control system, switches and sensors do not communicate to a centralized controller which then controls the lights, but instead they communicate directly with the lights. This decentralized control architecture enables systems to achieve significantly greater scale, reliability, and performance, as well as lower costs.

**Addressing in Mesh Network:**

Messages must be sent from and to an address. Bluetooth mesh defines three types of addresses. A unicast address uniquely identifies a single element. Unicast addresses are assigned to devices during the provisioning process. A group address is a multicast address which represents one or more elements. Group addresses are either defined by the Bluetooth Special Interest Group (SIG) and are known as SIG Fixed Group Addresses or are assigned dynamically. Four SIG Fixed Group Addresses have been defined namely All-proxies, All-friends, All-relays and All-nodes.

Bluetooth mesh supports a unique publish/subscribe (pub/sub) addressing approach for multi-cast traffic. In pub/sub, devices, such as light switches, publish their messages to a group address, like a conference room. All devices that should receive that message, such as the lights in the conference room, subscribe to that group. The pub/sub approach results in significantly lower messaging traffic on the network, leading to greater network scale and performance.




NOTE- Source [https://www.bluetooth.com/wp-content/uploads/2019/03/Mesh-Technology-Overview.pdf]

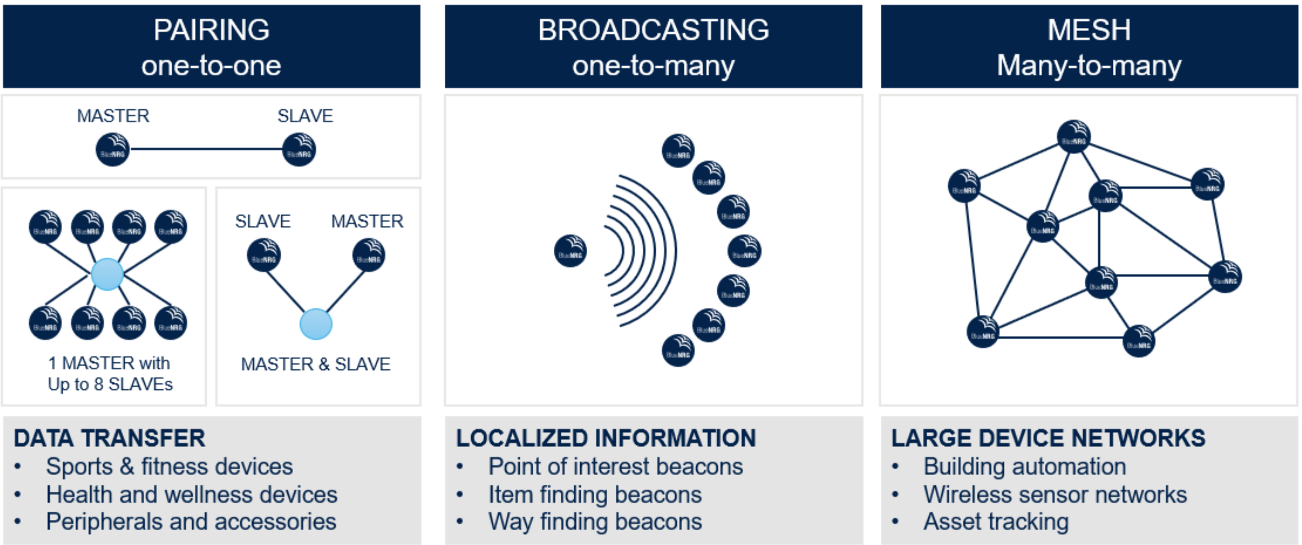
**Figure 3-18: Publish & Subscribe Mechanism**

**Extremely Efficient and Reliable Message Relay:**

When source and destination nodes are not in direct range of one another, messages must be relayed by other nodes in the network. Bluetooth mesh has adopted a managed flood message relay approach that is ideally suited for wireless networks, enabling them to scale to thousands of nodes while maintaining high performance and reliability.

**Bluetooth Low Energy (BLE) evolution and addressing:**

Bluetooth Low Energy (BLE) operates over the 2.4 GHz ISM bandwidth with forty 2 MHz channels (37 for connection data and rest 3 are for broadcasting and observing). It uses the frequency hopping spread spectrum to prevent overlapping interference of channels.



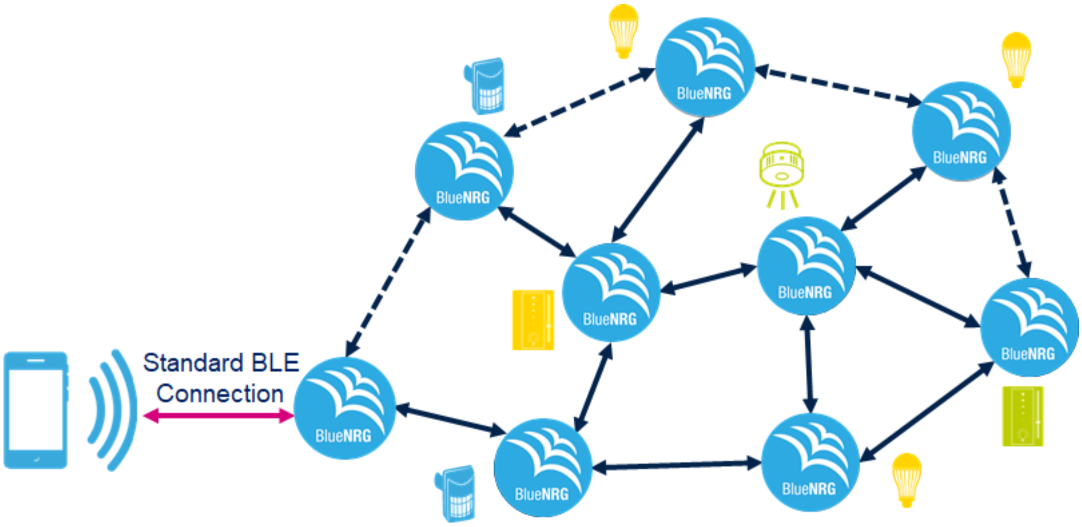

NOTE- Source [STMicroelectronics]

**Figure 3-19: Evolution of Bluetooth Low Energy usage**

**One to one:** The most common use case of BLE application is based on peer to peer communication. One example is fitness tracker or smart band application where the mobile phone is connected to the fitness tracker. The connection is peer to peer between mobile and fitness tracker. In peer to peer communication, a fixed connection is created between the two BLE entities.

**One to Many:** BLE Beacon based communication is an example of one to many communications. In one-to-many communication, no dedicated connection is made but beacon is transmitted in the air. This beacon is received by any BLE enabled mobile phone whose BLE radio is switched-on. BLE beacon sends small data packets over the air at an interval of approximately 10 seconds.

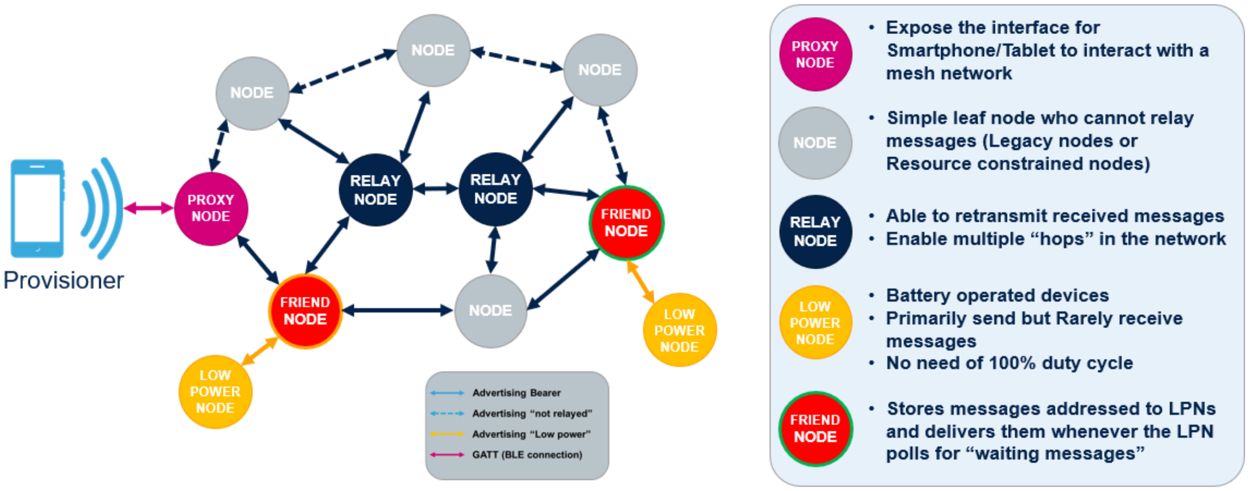
**Many to Many:** BLE-Mesh network is multi-hop, multi-path and multicast protocol. The message packets are relayed to extend the range of the communication. There is direct communication between the adjacent nodes. Each message contains a sequence number to optimize the network usage and protect against replay attacks. The below figure shows the BLE-Mesh network that depicts different types of nodes (light, sensors etc.) along with the provisioner which is the mobile in the below case.




NOTE- Source [STMicroelectronics]

**Figure 3-20: Bluetooth Mesh Network showing Proxy Node Connection to Smart phone**

The below figure gives an overview of the different kinds of BLE-Mesh nodes suggested by the BLE-Mesh specification body.




NOTE- Source [STMicroelectronics]

**Figure 3-21: Different Nodes types in Bluetooth Mesh**

# 4 Requirements from select vertical industries

## 4.1 Factory automation- Industrial IoT (Private Networks) and Industry 4.0

### 4.1.1 Description

Digital transformation of manufacturing, business and society includes advances in technology to combine the physical, digital and biological worlds, often referred to as the fourth industrial revolution or Industry 4.0.

Automated robotics, artificial intelligence (AI), cloud computing, sensors and data analytics, in these factories, connects all production and logistics processes together, making manufacturing more intelligent, efficient, and sustainable. Hence, reliable wireless connectivity plays an important role in making Industry 4.0 happen.

The industrial usages may be grouped into diverse applications of industry transformation as listed below:

a. **Digital shop floor** – using Industrial IoT and digital tools at the shop floor for operations management, analytics, real-time monitoring and control, dashboards and visualization
b. **Digital maintenance** – predictive maintenance, remote maintenance / expert assistance, preventive maintenance, analytics for maintenance
c. **Enhanced devices for workers** – mobile hand-held applications / HMIs, AR/VR trainings, remote operations, connected workstation
d. **Digital Twins and Flow simulations -** a virtual representation of the as-designed, as-built, and as-maintained physical product
e. **Advanced scheduling and intralogistics** – autonomous intralogistics mobile robots, intelligent vehicles, advanced planning and scheduling, track and trace
f. **Health, Safety and Environment management** – people and asset safety, autonomous / video security surveillance, proactive preventive measures, monitoring and quick response to hazardous conditions, digital PPE
g. **Digital Quality** – automated real-time quality control, anomaly detection, remote inspection, root cause analysis, quality analytics
h. **High precision processes** – wireless robotics, AI enabled motion control, robots
i. **Supply-chain process automation** and real-time monitoring of en-route assets and conditions

A further detailed representation and survey of the main use-cases with potential of significant business impact for early adopters is also presented in Annexure 1.

Unlike public cellular networks, the networks deployed in a factory may have stringent requirements on coverage, security, and performance. These may necessitate a dedicated network within the factory premises. The 3GPP 5G network provides such essential features to integrate various components in a factory environment. Some factories may also address these requirements through network slicing orchestrated over an existing public cellular network.

#### 4.1.1.1 Private Networks

LTE based Private Networks market is emerging globally with deployment activity across many sectors. According to GSA, companies looking to develop their own private mobile networks for the first time and those who currently operate LMR (Land Mobile Radio)/ PMR (Private Mobile Radio) private networks based on technologies such as TETRA (TErrestrial Trunked RAdio), P25 and DMR (Digital Mobile Radio) are considering private mobile networks based on LTE and 5G eventually[43]. Private LTE systems take advantage of the global LTE ecosystem, which benefits from high volume, standardized technology, and well-established suppliers' ability to design and deploy networks. For example, devices such as sensors, Automated Guided Vehicles (AGVs), security cameras, safety equipment, and so on are now already available with integrated LTE.

Though many industrial applications can be supported on LTE, certain applications within vertical industry have more demanding performance requirements – in terms of availability, reliability, latency, jitter, device density, throughput, etc. – where IMT-2020 technology is better suited.

Broadly, there are three drivers to deploy private mobile networks:

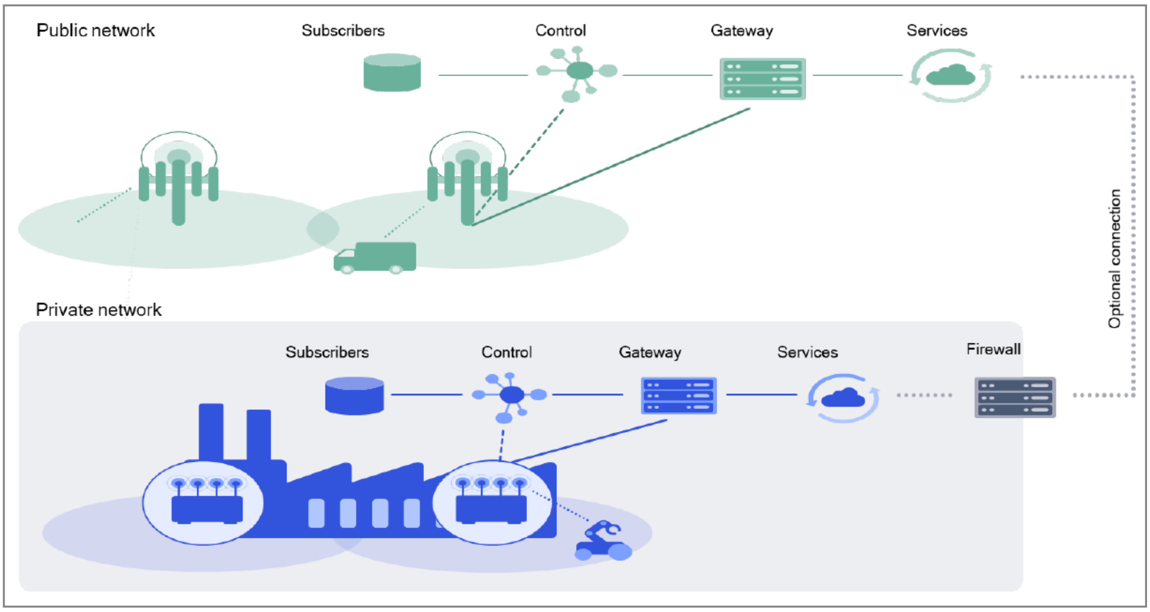
- **Coverage**: Often in locations with harsh radio frequency (RF) or operating conditions or where public network coverage is limited/nonexistent (e.g. remote areas).
- **Network control:** For example, to apply configurations that are not supported in a public network. Security and data privacy are also important. The ability to retain sensitive operational data on-premises is crucial to high tech industrial companies.
- **Performance profile:** Specifically, a profile that will support demanding applications. 5G NR has performance advantage over LTE and Wi-Fi in some cyber-physical industrial applications with stringent requirements on low latency and high throughput.

**Private Network Deployment Models**

There are two basic forms of private 5G networks (known as non-public networks in 3GPP terminology)-

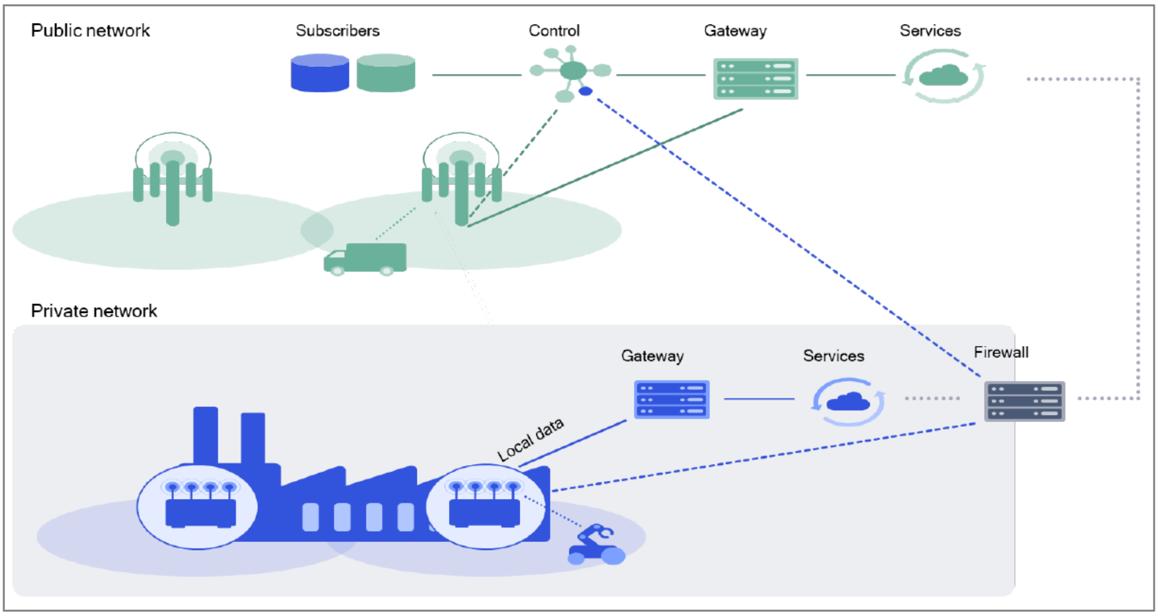
[43] https://gsacom.com/paper/private-mobile-networks-december-2020-global-update/

- Independent private networks without dependencies on a licensed public operator or a wide-area network. Optionally, integration with the public network is possible. (Shown in Figure 4-1)
- Private networks deployed in conjunction with a public network. Various levels of integration are possible. (Shown in Figure 4-2)




NOTE- Source [Qualcomm]

**Figure 4-1: Independent Private 5G Network**




NOTE- Source [Qualcomm]

**Figure 4-2: Private Network Integrated with Operator Network**

#### 4.1.1.2 Modeling Traffic for Factory Automation

As per 5G-ACIA, there may be different traffic model categories in a factory floor that address the use-cases.

According to 5G-ACIA, there are diverse use cases with varying demands on the communications networks. These have been prioritized and described in 3GPP TS 22.104 Annex 2. The traffic model addresses the use cases encountered in factory and process automation, human-machine interfaces and production IT, logistics and warehousing, and monitoring & maintenance, as shown in figure below-

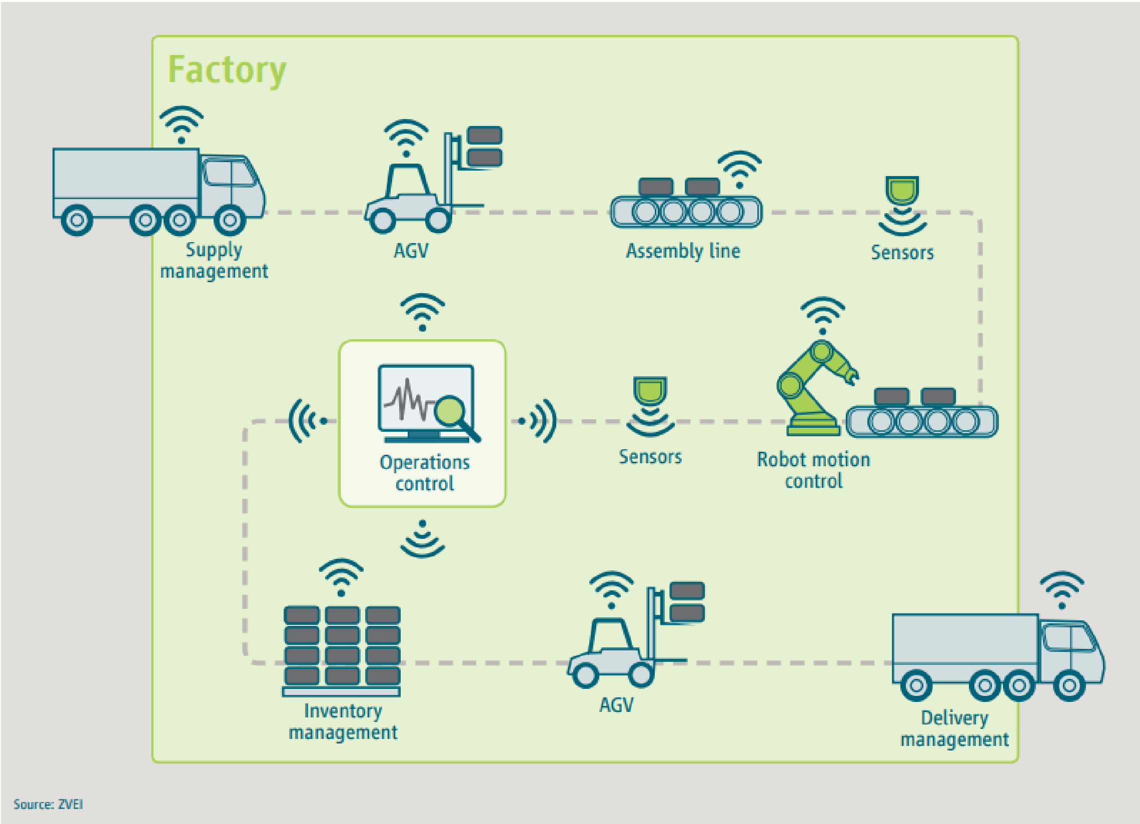



**Figure 4-3: Applications of 5G in Smart Factory**

Mapping of the IMT-2020 usage scenarios to potential use-case within a factory[44] is shown in the figure below-

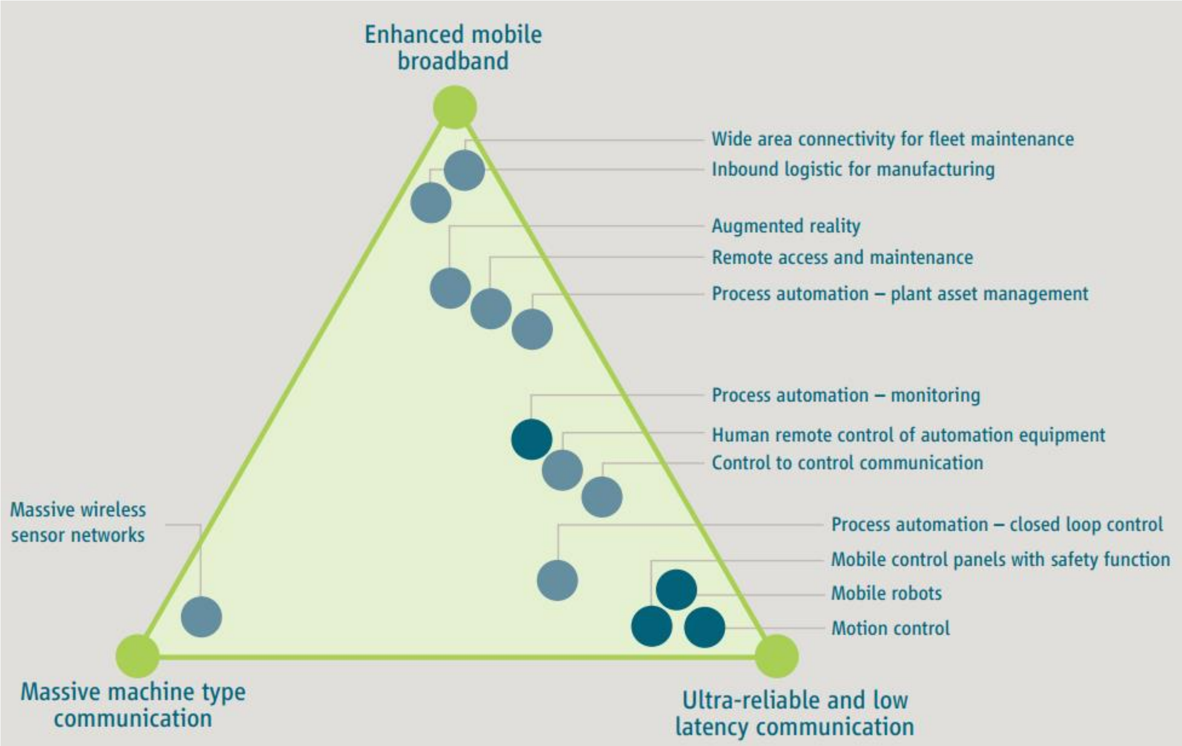



**Figure 4-4: Overview of selected industrial use cases and mapping with IMT 2020 scenario**

These use cases display diverse traffic behavior, ranging from periodically generated messages with small data volumes to aperiodic messages with, in some instances, very large data volumes. These traffic types are employed as the basis for defining parameters that describe a traffic model. The different types of traffic generated in factory may have different periodicity and predictability.

Overall, the following classifications are possible:
- Deterministic and Non-Deterministic (Burst traffic)
- Periodic and Aperiodic

The table below describes the generic traffic type, example applications and the parameters that describe the model based on 3GPP TS 22.104 and 5G-ACIA white-paper[45].

**Table 4-1: Traffic type, applications and the parameters**

| Traffic Type | Example | Parameters |
|---|---|---|
| Deterministic traffic | | |
| Periodic and time triggered | • Sensor-to-controller messages sent periodically between synchronized, time-sensitive | • Message size<br>• Transfer Interval |

[44] https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_for_Connected_Industries_and_Automation_Download_19.03.19.pdf

[45] https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_5G_Traffic_Model_for_Industrial_Use_Cases_22.10.19.pdf

| | | |
|---|---|---|
| periodic | applications.<br>• For example, a pressure sensor sending values to a machine PLC (Programmable Logic Controller), or emergency stop signals from hand-held controllers being sent to a machine PLC.<br>• Controller-to-actuator messages sent periodically, e.g. a PLC sends commands to a motor drive | |
| Aperiodic | • Sensor-to-controller messages sent e.g. on detected status changes or value changes between non-synchronized, time-sensitive, applications.<br>• For example, an optical sensor sending positional information to a conveyor belt PLC.<br>• Controller-to-actuator messages sent aperiodically, e.g. a light curtain PLC sending a stop command to a mobile robot | • Message size<br>• Transfer Interval (variable, typically characterized by statistical parameters) |
| Non-deterministic and burst traffic | | |
| Periodic | • Client/server traffic between non-synchronized, non-latency-critical applications, e.g. high-resolution cameras sending images to a pattern recognition server. | • Average data-rate<br>• Peak data rate |
| Aperiodic | • Client/server traffic with non-latency-critical characteristics, e.g. software updates, test report uploads, screwdriver torque documentation, etc. | • Average data-rate<br>• Peak data rate<br>• Delay Tolerance |

Other parameters like service reliability and availability, latency and jitter are also important for determining the network topology and radio network design in the factory. An estimated number of devices with such requirements is also an important factor for design of a private network.

### 4.1.2 Requirements

The Table below depicts a typical industrial automation requirement projected by 5G-ACIA[46].

**Table 4-2: Use-cases in industrial automation**

| Use case (high level) | Availability | Cycle Time (Interval time) | Typical payload size | No. of devices | Typical service area |
|---|---|---|---|---|---|

[46] 5G-ACIA white paper. https://www.5g-acia.org/fileadmin/5G-ACIA/Publikationen/Whitepaper_5G_for_Connected_Industries_and_Automation/WP_5G_for_Connected_Industries_and_Automation_Download_19.03.19.pdf

| | | | | | | |
|---|---|---|---|---|---|---|
| Motion Control | Printing machine | >99.9999% | < 2 ms | 20 bytes | >100 | 100 m x 100 m x 30 m |
| | Machine tool | >99.9999% | < 0.5 ms | 50 bytes | ~ 20 | 15 m x 15 m x 3 m |
| | Packing machine | >99.9999% | < 1 ms | 40 bytes | ~ 50 | 10 m x 5 m x 3 m |
| Mobile robots | Cooperative motion control | >99.9999% | 1 ms | 40 – 250 bytes | 100 | < 1 $km^2$ |
| | Video-operated remote control | >99.9999% | 10 – 100 ms | 15 – 150 kbytes | 100 | < 1 $km^2$ |
| Mobile control panels with safety functions | Assembly robots or milling machines | >99.9999% | 4 – 8 ms | 40 – 250 bytes | 4 | 10 m x 10 m |
| | Mobile cranes | >99.9999% | 12 ms | 40 – 250 bytes | 2 | 40 m x 60 m |
| Process automation (process monitoring) | | >99.99% | > 50 ms | Varies | 10000 devices per $km^2$ | |

A successful roll-out of a 4G/ 5G based factory automation will require advanced performance testing of the wireless connectivity and interfaces in actual deployment environments. For further reading, please refer to 5G-ACIA white paper on Performance Testing of 5G Systems for Industrial Automation[47].

These performance requirements may also result in corresponding requirements on spectrum needed in one or more frequency bands. See Chapter 6 for global trends on spectrum for private networks, in general.

## 4.2 Automotive IoT- Intelligent Transport System

### 4.2.1 Description

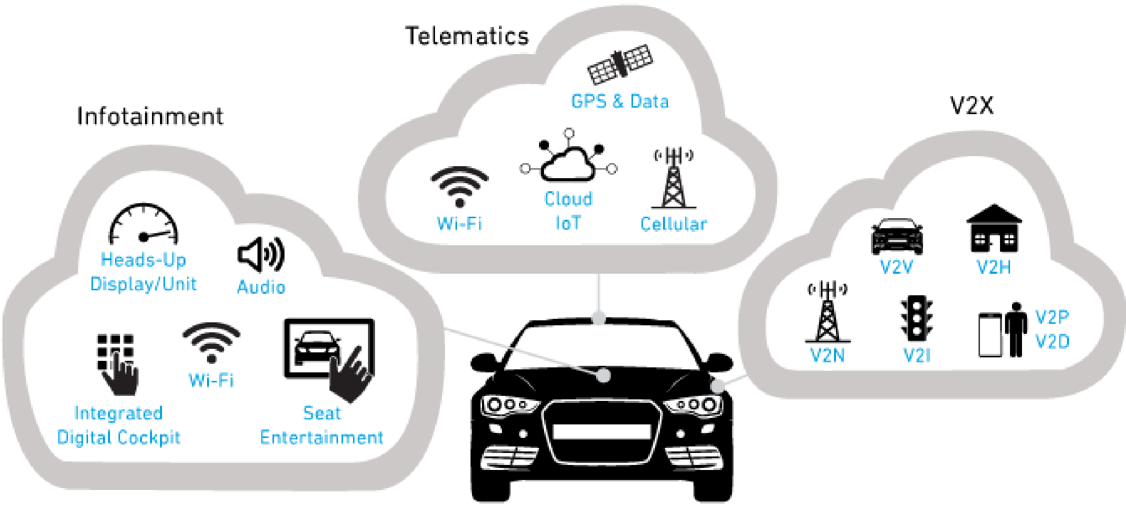
Currently, the intelligent transport system (ITS) deployment is in the third generation which revolves around enabling connectivity to cars/ vehicles and fully automated driving systems[48]. The applications ranging from infotainment, pedestrian safety and collision avoidance are part of a typical ITS. These are achieved through integration of various automotive IoT peripherals in the vehicles. The onboard line-of-sight (LOS) sensors such as cameras, radar, LiDAR (Light Detection

47 https://5g-acia.org/wp-content/uploads/2021/04/5G-ACIA_PerformanceTestingOf5GSystemsForIndustrialAutomation-1.pdf

48 Intelligent transport systems towards automated vehicles, https://news.itu.int/intelligent-transport-systems-towards-automated-vehicles/

and Ranging), and others enables vehicles to see, hear, and anticipate potential driving hazards, even at blind intersections or in poor weather conditions. A short-range direct-communication among nearby vehicles also provides 360° non line-of-sight (NLOS) awareness that complements the onboard sensors to improve safety and efficiency. These capabilities are also commonly termed as Advanced Driver Assistance Systems (ADAS).

Automotive connectivity — or "connected car" applications have found themselves into designs and can be represented as addressing one of the three applications: connect the car to the environment (V2X), the cloud (telematics), and infotainment for passengers and drivers. V2X applications can share and coordinate information to extend the effective range of ADAS up to several kilometers. This has been illustrated using the Figure 4-5, depicting a heterogeneous connectivity platform.

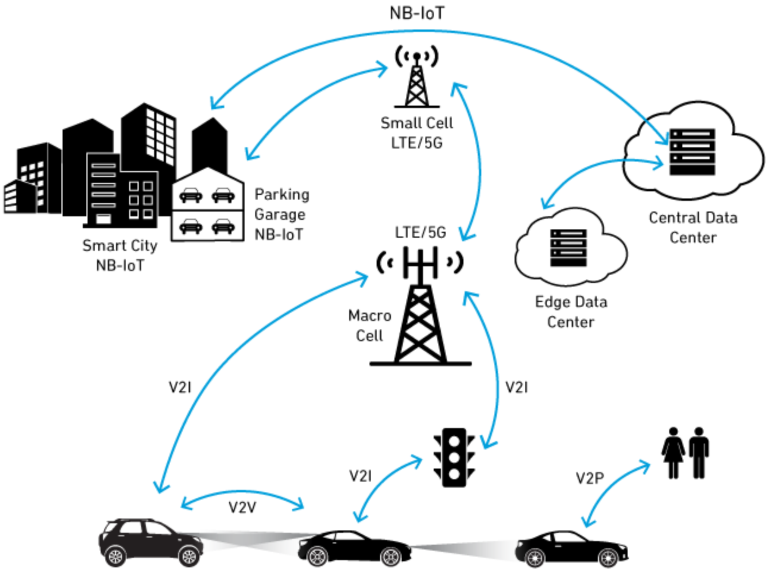



NOTE- Source [Qorvo[49]]

**Figure 4-5: Automotive connectivity**

Integrating short-range C-V2X direct communications with the expansive mobile cellular network for longer-range communications and access to the cloud can deliver measurable safety enhancements and traffic efficiency benefits, bringing the transportation and automotive industries to the cusp of a massive technology transformation.

[49] V2X in the Connected Car of the Future (link: https://www.qorvo.com/design-hub/blog/v2x-in-the-connected-car-of-the-future)




NOTE- Source [Qorvo]

**Figure 4-6: C-V2X communication**

Globally, different countries deploy one or more of the following applications as part of their ITS implementation. GSMA Report on C-V2X Enabling Intelligent Transport[50] contains more details of the following use-cases:

- Collision Avoidance
- Platooning
- Queue warning
- Dynamic Traffic Management
- Emergency Services
- Co-operative Driving
- Toll Connection Automation
- Autonomous driving

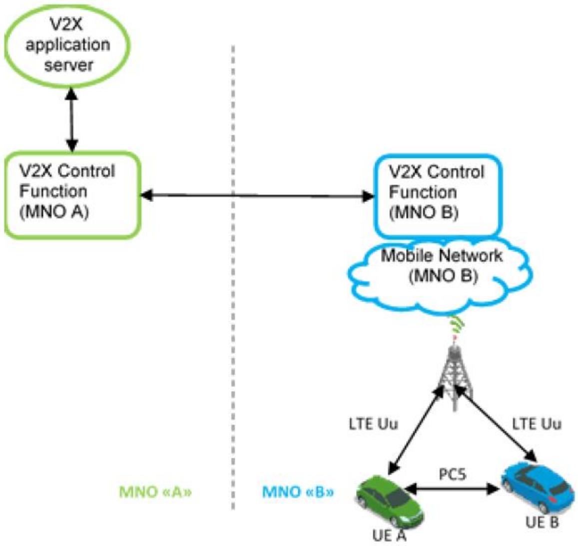
In the context of C-V2X adoption, the following aspects are taken into consideration for a successful implementation of ITS:

- **Coverage**:
  While V2V communication are possible in direct mode, even in the absence of cellular network coverage in the dedicated ITS spectrum bands, the availability of cellular network coverage in cities and highways greatly enhances the advanced applications of ITS.
- **Capacity & Availability:**
  When C-V2X devices use the public cellular network, it is essential to provide required QoS in terms of throughput and latency for some of the applications. This is more critical in case of roads with heavy congestion.

[50] GSMA Report on C-V2X Enabling Intelligent Transport https://www.gsma.com/iot/wp-content/uploads/2017/12/C-2VX-Enabling-Intelligent-Transport_2.pdf

- **Security:**
  Both network and device security should be integral part of the requirements to ensure safety of passengers, pedestrians, and ITS infrastructure.
- **Device Ecosystem:**
  Use of Harmonized technology in the implementation of ITS is essential to ensure interoperability, scalability and continued evolution of the future applications and use-cases. Although the C-V2X devices are integrated in a vehicle, the objective of ITS is for the wider public good. Hence, it is preferable to have the same technology like C-V2X in the ITS implementation.

An inter-PLMN working of a standardized C-V2X operation is also supported where multiple MNOs are involved in the provisioning of the service as described in a white paper by NGMN[51].




NOTE- Source [NGMN]

**Figure 4-7: Inter-PLMN for V2X communication over PC5 (direct V2V link)**

C-V2X, developed in 3GPP, has been recognized globally as a key essential component of ITS to improve automotive safety, transportation, and traffic efficiency. Collaborative efforts in global bodies like SAE, ETSI ITS, China-SAE/C-ITS, 5GAA, and few others are focused on ITS solutions based on C-V2X. ETSI ITS committee (TC ITS)[52] is working to achieve global standards for Co-operative ITS. The Technical Committee ITS develops standards related to the overall communication architecture, management (including e.g. Decentralized Congestion Control), security as well as the related access layer agnostic protocols: the physical layer, Network Layer, Transport Layer (e.g. with the Geo Networking protocol), Facility Layer, (e.g. with the definition of facility services such as Cooperative Awareness - CA, Decentralized Environmental Notification – DEN, Cooperative

[51] https://www.ngmn.org/publications/v2x-task-force-white-paper-v1-0.html

[52] https://www.etsi.org/technologies/automotive-intelligent-transport

Perception – CP and Maneuver Coordination – MC, used by the ITS applications). The Standards developed by ETSI TC ITS are summarized in Technical Report TR 101 607[53].

As a part of this report, it is required to study and understand which are the important use cases in Indian context and what kind of policy framework to be put in, in order to facilitate the development of eco-system for automotive sector.

While autonomous vehicles may take some time to become a reality in India, the pursuit towards this technology brings lot of advance safety functions to conventional vehicles. These use-cases will evolve as ADAS applications and its different level of safety gets implemented in a phase manner. In India, it is likely that the farming sector may adopt autonomous driving before the passenger cars.

All these applications will be developed in globally harmonized 5.9 GHz ITS spectrum using 3GPP C-V2X, DSRC/ IEEE 802.11p technology.

### 4.2.2 Requirements

The 5G Automotive Association (5GAA), is a global organization of members from the automotive, technology, and ICT industries, which are working together to develop end-to-end solutions for future mobility and transportation services. 5GAA is also a Market Representation Partner (MRP) of 3GPP to represent the requirements of automotive industry for C-V2X developed by 3GPP. The

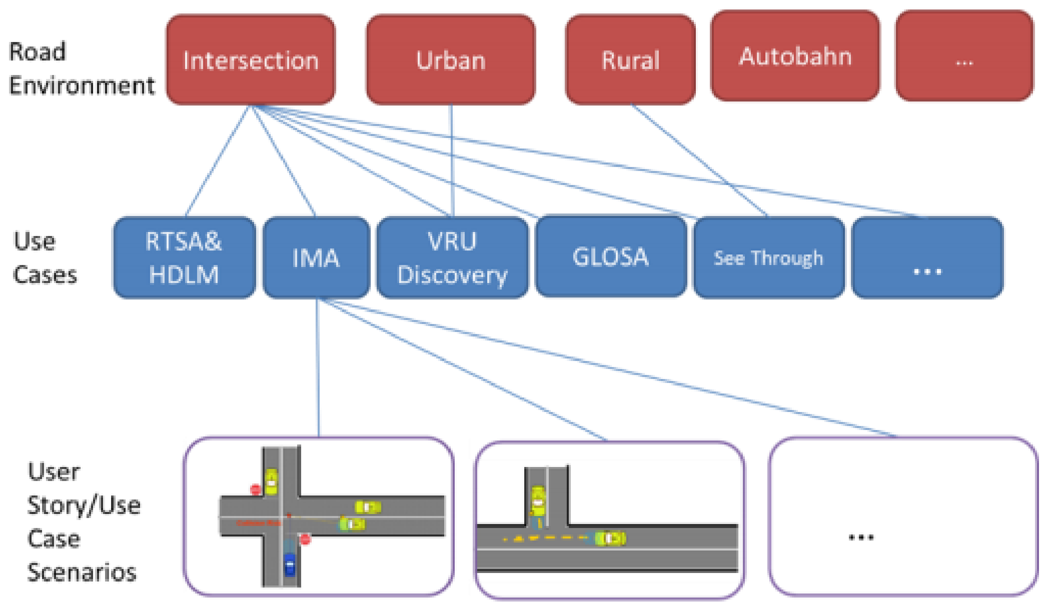



**Figure 4-8: Hierarchy of use-cases**

[53] https://www.etsi.org/deliver/etsi_tr/101600_101699/101607/01.02.01_60/tr_101607v010201p.pdf

two detailed technical reports on Use Cases and Service Level Requirements for C-V2X[54], describes the service level requirements based on the road environment, use-case and the user stories.

It can be observed that:

- Every Use Case is connected to at least one Road Environment and at least one Use Case scenario;
- Every Road Environment may serve a framework to many Use Cases;
- User Stories are specific variations of one Use Case

Based on the road environment, prioritized use cases in India, one has to evaluate the usage scenario, user stories and the corresponding service level requirements for the same. The key service level requirements according to 5GAA are listed in table below:

**Table 4-3: Key service level requirements**

| **Service Level Requirement** | **Unit of Measurement** | **Description** |
|---|---|---|
| Range | m (Meters) | Expected distance from Host Vehicle (HV) to Remote Vehicle (RV) / infrastructure based on scenario |
| Information Requested/Generated | Quality of information/ Information needs | Quality of information/information needs of the end-user. Typically, parameters related to the information (e.g., message type and periodicity). |
| Service Level Latency | ms | Measurements of time from the occurrence of the event in a scenario application zone to the beginning of the resulting actuation. Including latency of the connectivity technology. |
| Service Level Reliability | | Based on an agreed QoS framework, the guaranteed and expected performance to start/initialize, perform and finalize (end-to-end) applications within Use Cases. On the connectivity side, this may refer to the reliability of successful message transfer. |
| Velocity | m/s | Describes the maximum absolute speed of the vehicles involved for the specific use case, at which a defined QoS can be achieved (in km/h). The use-case may be based on average, peak velocity, and initial velocity. |
| Vehicle Density | vehicle/$km^2$ | Expected number of vehicles per given area (per $km^2$) during the execution of the Use Case. It indicates that |

[54] 5GAA Technical Report on Use Cases and Service Level Requirements.
Volume 1: https://5gaa.org/wp-content/uploads/2020/12/5GAA_T-200111_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_I-V3.pdf
Volume 2: https://5gaa.org/wp-content/uploads/2021/01/5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II_V2.1.pdf

| | | |
|---|---|---|
| | | multiple vehicles within the same area run the same (and potentially additional) Use Case(s) in parallel. |
| Position Accuracy | m | Positioning/ position/ location accuracy at the time when position information is delivered to the end-user (host vehicle) between the actual position and the position information. |
| Interoperability / Regulatory / Standardization Required | Yes/no | To indicate the need for inter-OEM interoperability, e.g. in cooperative safety Use Cases |
| Note:<br>• The values for the same use-case may vary depending on the road environment. | | |

The Service Level Requirement values for user applications like traffic jam warning, emergency brake warning, intersection movement, cooperative lane change, see through passing, automated valet parking, hazard and road event information collection by vehicles, etc. can be found in Technical Report Volume I and Volume II of 5GAA.

As the Automotive Industry fast accelerates into the era of Autonomous, Connected, Electric & Shared vehicles, one of the key underlying enablers for these trends is Connectivity - Wireless high-speed connectivity with low latency. Practical connectivity which can support a fast-moving vehicle at a speed of 100 Km/Hr to allow the vehicle to make split second data-based decisions is required. This is far away from today's practical conditions on the road. Further details about the Indian Automotive use-cases are provided in Annexure 2.

## 4.3 Other Verticals

Some additional verticals may also leverage the capabilities of 4G and 5G to deliver enhanced services. While, there may be many other IoT industry segments and usage scenarios which would need wireless connectivity that could be provided through public cellular network.

### 4.3.1 Process Automation- Smart Sustainable Cities

**A Smart Sustainable City as defined by ITU** is an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects[55].

Verticals like Automotive (Connected vehicles, C-V2X), Safety & Security (City Surveillance), Waste management, Water management, Smart metering, Remote health management (Remote

[55] [ITU-T Recommendation Y Suppl. 37] https://www.itu.int/ITU-T/recommendations/rec.aspx?id=12961&lang=en

surgery, telemedicine), Smart parking etc. may be the part of smart cities as per the need. 5G features (eMBB, URLLC and mMTC) as detailed in Section 3 will create faster and more intelligent Smart City services.

As detailed in Section 3.6.1, Wi-Fi 6 / Wi-Fi 6E technologies will provide high bandwidth and high user density, at a dramatically lower cost, which makes it ideal for indoor applications, such as stadiums, convention centers, shopping malls, school campuses and other places where people gather.

Continued enhancements to the 3GPP enables Wi-Fi to work in tandem with 3GPP 4G and 5G. 3GPP and Wi-Fi technologies can complement each other to enhance a variety of smart city use cases. These technologies will work together for capacity augmentation, range, traffic offload, positioning, and traffic steering.

In public offices, apartment buildings and private residences, upgrading to Wi-Fi 6 can add motion detection to wireless security systems or deliver higher-resolution video for 4k/8k video experiences. 5G network may be used for high-speed streaming of high-definition video to and from the cloud.

Gateway having Wi-Fi 6, Wi-Fi HaLoW and other short range communication technologies may be used to connect various IoT devices in the LAN/ HAN and 5G technology may be used in the wide area network. Smart phones / Tablet/ Laptop may also be used as a gateway.

### 4.3.2 E-Health

E-health involves a broad group of activities that use electronic means to deliver health-related information, resources and services- it is the use of Information and Communication Technologies (ICT) for health.

E-health encompasses a range of standards, tools and activities that use electronic means to deliver information, resources and services in relation to health and social care. At the heart of e-health is a vision of improving the quality of health information, strengthening national health systems and ensuring accessible, high-quality health care for all.

Recent advances in mobile technologies, improvements in broadband coverage and the growing acceptance of tele-health and mobile health (m-health) solutions are providing new and attractive options for health care delivery. As a result, many governments are investing in e-health as a means for reforming health systems and for ensuring equitable and affordable access to health care.

Healthcare use cases leveraging ICT can be classified into five main categories:

- Patient monitoring – remote monitoring applications, patient's medical data collection and

management, administration of precision medicine, improvement and facilitation of medical care
- Augmented doctor – strengthening medical technical expertise, aiding the doctor in medical procedures and creating new uses like remote diagnosis, surgeries etc.
- Smart ambulance – emergency and lifesaving care improvements
- Connected hospital – flow management, communication and disinfection activities, hospital applications like telemetry, quicker transmission of large imaging files, VR used in medical trainings
- Medical data management systems
- Remote Surgery

Once 5G network is deployed, uRLLC feature may be used for remote surgery of patients. Places which are not connected on OFC, 5G will be beneficial in providing high speed connectivity for provisioning of smart services including health care.

TEC has released a Technical Report on ***M2M Enablement in remote health management***, which is available on TEC website[56].

A detailed use case on "Remote monitoring the health of a patient" is available in ITU-T Recommendation Y Suppl.53. This document may be accessed using link[57]

### 4.3.3 Smart Body Area Network

Body Area Network (BAN) technology is the use of small, low power wireless devices which can be carried or embedded inside or on the body. Applications include:

- health and wellness monitoring
- sports training (e.g. to measure performance)
- personalized medicine (e.g. heart monitors)
- personal safety (e.g. fall detection)

A number of wireless BAN communication technologies have been implemented, based on existing radio technologies. However, if BAN technology is to achieve its full potential, there is need for a more specific and dedicated technology, optimized for BAN. For example, solutions for monitoring people during exercise one or two hours a day, a few days a week, may not be suitable for 24/7 monitoring as part of the Internet of Things (IoT).

Such a dedicated BAN technology would need features such as:

- ultra-low power radio, with a lower complexity Medium Access Control (MAC) protocol for extended autonomy

[56] https://tec.gov.in/pdf/M2M/M2M%20Enablement%20in%20Remote%20Health%20Management.pdf

[57] https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=13867&lang=en

- enhanced robustness in the presence of interference
- interoperability when communicating over heterogeneous networks in the future IoT

Majority of devices in BAN shall be communicating through smartphones as a gateway. 5G technology, once deployed, will provide high speed, reliable and low latency communication; and will be able to connect large number of devices per square km. (Refer Table 3-1)

### 4.3.4 Smart Appliances

Currently, household appliances are responsible for about two third of the energy consumed by buildings. Industrial appliances are also major energy users.

In the future, domestic and industrial appliances will be intelligent, networked smart devices, forming complete energy consuming, producing and managing systems, based on the integration of products from different vendors and vertical industrial sectors. The need for all these connected appliances to be able to communicate among themselves and with the service platforms needs to be addressed. This requires open interfaces. Interoperability is thus a key factor in creating an IoT ecosystem, and the availability of a standardized solution, along with related test suites, will be the essential enabler of the IoT.

Smart appliances include white goods, heating, ventilation and air conditioning systems and storage systems.

To ensure such systems are technically and commercially successful – and widely adopted – it must be possible to combine appliances from different vendors. These systems will also need to be able to communicate with service platforms from different energy service providers in order to manage and control energy use.

Bluetooth/ Bluetooth Mesh and Wi-Fi technologies may be used to connect the smart appliances within residential buildings, hotels, etc. Gateways having these technologies in the LAN/ HAN may be used to connect devices and the collect the data, which may be further transmitted using cellular technologies.

# 5 Summary and Recommendations

This report captures the recent developments in communication technologies to address the advanced IoT connectivity requirements in various sectors such as factory automation, automotive (Intelligent transport system), etc. Based on various performance requirements documented in the earlier chapters of this report, in this chapter a summary of recommendations on spectrum, regulatory and security aspects are provided.

## 5.1 Spectrum aspects for vertical industries

Earlier chapters covered advanced IoT applications that span various usages in - Factory Automation, Intelligent Transportation, etc. These advanced IoT applications depend on evolving technologies such as 5G, Wi-Fi 6/ 6E/ HaLow and Bluetooth Mesh, as described in Section 3 and the related use cases such as C-V2X and Private industrial network etc. in Section 4. The 5G technology operates in globally harmonized spectrum bands identified by the ITU-R, and the Wi-Fi and BLE Mesh technologies operate in delicensed frequency bands. The amount of spectrum needed by advanced IoT technologies will depend on their requirements of QoS and scalability.

**Table 5-1: Global snapshot of spectrum for different services / technologies**

| Category | Remarks |
|---|---|
| IMT spectrum | - The existing frequency arrangements for IMT, detailed in Recommendation ITU-R M.1036, help enable a wide range of applications and devices.<br>- The ITU-R Report M.2440 addresses the technical and operational aspects of terrestrial IMT-based networks and systems for supporting MTC applications, as well as their spectrum needs. |
| C-V2X | - ITS highly relies on globally harmonized spectrum band between 5850 – 5925 MHz dedicated for ITS applications as per ITU-R Recommendation M.2121.<br>- ITU-R M.2444 captures the frequency arrangements for ITS in various regions and countries. |
| Sensors (e.g., Radars) | - IoT sensors using radar equipment for ITS may use various mm Wave bands (e.g., see ITU-R Recommendation M.1452) |
| Ultra-Wide Band / SRD | - Used in IoT sensors for many applications like short-range indoor and outdoor communications, radar imaging, medical imaging, asset tracking, surveillance, vehicular radar, and intelligent transportation.<br>- This may extend over a very large frequency range operating at very low power and on non-protected, non-interference basis. See ITU-R Recommendation SM.1755 and SM.1756. |
| Wi-Fi 6/ Wi-Fi 6E | - Wi-Fi 6 operates in delicensed 2.4 GHz and 5 GHz bands. Wi-Fi 6E extends Wi-Fi 6 to 6 GHz band also. Many countries have already delicensed 6 GHz band (5925-7125 MHz, |

| | |
|---|---|
| | or parts thereof)[58]. |
| BLE Mesh | - BLE operates over the 2.4 GHz ISM band with forty 2 MHz channels. |

Note:
1. For frequencies allocated to specific services in India, refer to latest version of the National Frequency Allocation Plan[59].
2. Also refer TRAI Recommendation https://www.trai.gov.in/sites/default/files/Recommendations_M2M_05092017.pdf

### 5.1.1 Spectrum for IMT in India

(A). Licensed wireless frequency bands in India for cellular networks are as given below:

| Frequency | Range of frequency (MHz) | Paired / Unpaired |
|---|---|---|
| 800 MHz | Uplink: 824-844; Downlink: 869-889 | Paired |
| 900 MHz | Uplink: 890-915; Downlink: 935-960 | Paired |
| 1800 MHz | Uplink: 1710-1785; Downlink: 1805-1880 | Paired |
| 2100 MHz | Uplink: 1920-1980; Downlink: 2110-2170 | Paired |
| 2300 MHz | 2300-2400 | Unpaired |
| 2500 MHz | 2535-2555, 2635-2655 | Unpaired |

(B). Additionally, some bands and parts thereof available, but not yet assigned to a cellular network are:

| Frequency | Range of frequency (MHz) | Paired / Unpaired |
|---|---|---|
| 600 MHz | Downlink: 614-654; Uplink: 663-703 | Paired |
| 700 MHz | Uplink: 703-748; Downlink: 753-803 | Paired |
| 3500 MHz | 3300-3700 | Unpaired |

(C). Further, newly identified spectrum for IMT in WRC-19 includes:

| Frequency | Range of frequency (MHz) | Paired / Unpaired |
|---|---|---|
| 26 GHz | 24.25 – 27.5 | Unpaired |
| 40 GHz | 37 – 43.5 | Unpaired |
| 48 GHz | 47.2 – 48.2 | Unpaired |
| 66 GHz | 66 - 71 | Unpaired |

(D). Spectrum identified by DoT for 5G includes:

| Frequency | Range of frequency (MHz) | Paired / Unpaired |
|---|---|---|
| 28 GHz | 27.5 – 28.5 | Unpaired |

[58] https://www.wi-fi.org/countries-enabling-wi-fi-6e

[59] https://dot.gov.in/spectrummanagement/nfap

(E). Other Relevant Allocations in India relevant to UWB/SRD:

An extract from the National Frequency Allocation Plan Annex 1 relevant to UWB and SRD is reproduced below.

**Table 5-2: Frequency ranges and corresponding GSRs**

| Frequency Range | Remarks | GSR No. |
|---|---|---|
| 76 – 77 GHz | Use of very low power radio frequency devices or equipment for Short-range Radar Systems (Exemption from Licensing Requirement) Rules, 2015 | GSR No. 699(E) dated 16-Sep-2015 and subsequent amendments, if any. |
| Frequency details as per GSR 1047(E) dated 18.10.2018 (for SRDs Devices) | Use of Low Power and Very Low Power Short Range Radio Frequency Devices (Exemption from Licensing Requirements) Amendment Rules, 2018 | GSR No.1047(E) dated 18-Oct.2018 and subsequent amendments, if any |
| Frequency details as per GSR 1046(E) dated 18.10.2018 (for UWB Devices) | Use of Very Low Power Ultra-Wide Band Devices (Exemption from Licensing Requirements) Rules, 2018 | GSR No.1046(E) dated 18-Oct.2018 and subsequent amendments, if any |

### 5.1.2 Spectrum for Private Networks

The GSMA Report[60] on 5G IoT Private & Dedicated Networks for Industry 4.0 discusses private and dedicated 5G networks for manufacturing, production, and supply chains. Many enterprises in manufacturing, production and supply chains have traditionally used unlicensed Wi-Fi technologies to deliver limited scale wireless networks. Other enterprises have made use of 4G-based private networks which may operate in unlicensed spectrum. The 4G networks also have capability to operate entirely in unlicensed spectrum or entirely in licensed spectrum, or a mixture of the two (e.g., through the 4G LTE technology of 'Licensed Assisted Access'). 5G, however, supports a much-expanded range of spectrum options especially across licensed frequency bands which support more diverse requirements.

Many countries have taken proactive steps to promote the growth and adoption of industrial transformation, use of cellular networks in new verticals (e.g., mining, ports, factories, etc.). In the GSA Report on Private Mobile Networks[61] (as of Jan 2021), there are more than 35 countries/territories who have identified or evaluating spectrum for private networks. Typically, the spectrum for private network is in 1800 MHz, 2.6 GHz, 3.5 GHz, 4.8 GHz, 24 GHz, 26 GHz, 28 GHz, etc. According to the report, the bandwidth of up-to 400 MHz is being considered for

[60] GSMA Report on 5G IoT Private & Dedicate Networks https://www.gsma.com/iot/wp-content/uploads/2020/10/2020-10-GSMA-5G-IoT-Private-and-Dedicated-Networks-for-Industry-4.0.pdf

[61] GSA Report on Private Networks. https://gsacom.com/paper/private5g-summary-january-2021-global-update/

private networks even in the Mid-Band, and upwards of 6 GHz in mmWave bands. A snapshot of the global status of 4G and 5G spectrum for local and private networks is shown in table below-

**Table 5-3: Global snapshot of spectrum optimized for industrial IoT / vertical / private network use – local licensing or sharing**

Source: Qualcomm[62]

| Country | Frequency and Remarks |
|---|---|
| USA | • 3.5 GHz CBRS (Citizen broadband radio service), exclusive & shared licenses, deployments in 2H19 (2nd half of 2019)<br>• 37 - 37.6 GHz shared spectrum/local licenses, under evaluation |
| Germany | • 3.7 – 3.8 GHz<br>• 24.25 - 27.5 GHz, local licenses, expected Q4 2020<br>• Local licenses. Assignment complete; available 2H 2019 |
| UK | • 3.8 - 4.2 GHz<br>• 24.25 - 26.5 GHz, local licenses, applications open since end of 2019<br>• Local licenses (50 meters square); regulator database; decision formalized; applications invited from end 2019 |
| Sweden | • 3.72 - 3.8 GHz, in consultations |
| Finland | • Sub-licensing of 3.4 - 3.8 GHz<br>• Local permission via operator lease; assignment complete |
| Netherlands | • 3.5 GHz for local industrial use; 3.7 - 3.8 GHz (in consultations); 2.3 - 2.4 GHz (licensed shared access online booking system)<br>• 3.5 GHz for local industrial use; however, users may need to move to 3.7 - 3.8 GHz, if allocated; 2.3 GHz approved for PMSE (Programme making special event) |
| France | • 2.6 GHz, regulator database & approval. Up to 40 MHz approved for Professional Mobile Radio |
| Czech Republic | • 3.4 - 3.44 GHz for private networks |
| Brazil | • 3.7 – 3.8 GHz, under consideration<br>• 27.5 – 27.9 GHz, allocation completed |
| Chile | • 3.75 – 3.8 GHz, allocation completed at end of 2019 |
| Australia | • 24.25 - 27.5 GHz and 27.5 – 29.5 GHz for local licensing in 1Q21 first quarter 2021.<br>• 3.7 – 4.2 GHz under consultation for local licensing |
| New Zealand | • Licenses in 2575 – 2620 MHz may be assigned for localized use |
| Malaysia | • 26.5 – 28.1 GHz will be assigned for the deployment of local/private networks |
| Singapore | • Each operator has acquired 800 MHz of 26/28 GHz spectrum to deploy local networks |

62 https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf

| | |
|---|---|
| Hong Kong | • 24.25 - 28.35 (400 MHz) available for local licenses |
| Japan | • Phase 1: 2,575 - 2,595 MHz (NSA anchor) and 28.2 - 28.3 GHz; local licenses, legislated in December 2019<br>• Phase 2: 1888.5 - 1916.6 MHz (NSA anchor), 4.6 - 4.9 GHz (4.6 - 4.8 GHz indoor only, 4.8 - 4.9 GHz outdoor possible) & 28.3 - 29.1 GHz (150 MHz outdoor use; total 250 MHz range 28.2 – 28.45 MHz); local license. Legislation in 4Q 2020. Uplink heavy TDD configuration using semi-sync is allowed in sub-6 & 28 GHz |

As of now no framework exists in India for using spectrum for dedicated private industrial networks. Identification and provisioning of the spectrum for private industrial networks have been summarized in 5.1.3.2. Identifying spectrum for private networks in India will help to promote the growth and adoption of industrial transformation, use of cellular networks in new verticals (e.g., mining, ports, factories, etc.).

## 5.1.3 Recommendations related with the spectrum

### 5.1.3.1. Spectrum requirement for V2X applications in Intelligent transport system for India

As per ITU-R Recommendation M.2121, 5850 – 5925 MHz spectrum has been reserved for ITS applications (table 5-1 - V2X applications). Same has also been recommended by TEC as mentioned in point no. 8 of Section 1.2.2. The current National Frequency Allocation Plan allows for use of frequency band 5875 – 5925 MHz for Intelligent Transport Networks (IND 30). For realizing the full potential of V2X, a unified technology and enabling regulatory provision for a deployment authority is required.

### 5.1.3.2. Spectrum requirements for Private networks in India

1. Spectrum bands widely adopted for the industry applications are required to be considered. 3GPP TS 36.101-1 and 38.101-1 provides supported channel bandwidths in Sub-6GHz (e.g., 5, 10, 20, 40, 100 MHz) and mmWave (e.g., 200-400 MHz).
2. Frequency bands identified for IMT globally / regionally, but not identified in India should also be considered for private networks.
3. Frequency bands identified for IMT by India, but not assigned due to other users in limited regions (e.g., certain limited locations in the country) should be considered. A technical feasibility study/mechanism to protect incumbent users may be considered on a case-by-case basis.
4. Contiguous spectrum is essential for providing efficient network deployment which ensures interference management. This also helps in efficient coordination for:
    - Re-use of the spectrum across multiple private industries.
    - Interference management and coordination between Public network and Private networks.
5. Sharing / leasing spectrum from public networks may be studied/ considered.

#### 5.1.3.3. Spectrum requirement for low power wireless communication technologies in India

7 MHz spectrum (1 MHz in 867- 868 MHz and 6 MHz in 915-935 MHz band) is required to be delicensed on priority in the subsequent NFAP (point no. 6 of Section 1.2 may be referred for more details).

#### 5.1.3.4. Spectrum requirement for Wi-Fi 6E technology in India

Study of 6 GHz band for delicensing is required as it will be used in Wi-Fi 6E technology. (refer table 5-1 for Wi-Fi 6 / Wi-Fi 6E and Section 3.6 for more details).

## 5.2 Regulatory aspects for vertical industries

The possibility of deployment of innovative services that gets enabled through emerging communication technologies like 5G and others, encourages the prospect for the development of various applications (services) covering almost every area of human activity. Apart from sustaining the uptake and preserving the future of existing mobile application services like videos on demand, video conferencing, tele presence, etc., these future communication services are essential for transforming our cities into smart cities, increasing the business efficiency of our industries, revolutionizing health care. The significant paradigm shift in 5G network services is its ability to deliver customized QoE to the users through the flexibility and agility of the network itself. Features like Network Slicing, in combination with technologies like Network Function Virtualization (NFV) and Software Defined Networks (SDN) contribute towards adapting the network for better user's experience of services.

Recognizing this, the NDCP 2018 [Para 2.1(b)(v)] has aptly recommended "Enabling unbundling of different layers (e.g., infrastructure, network, services and applications layer) through differential licensing" as a means of "Reforming the licensing and regulatory regime to catalyze Investments and Innovation and promote Ease of Doing Business". However, realization of the full potential of these emerging communication technologies would require pursuance of a comprehensive multi-pronged regulatory strategy to accelerate the proliferation and adoption of digital services in India.

**Recommendation on aspects related to regulation should include:**

- Consistent with NDCP 2018, 2.2 (d), update of regulations based on industry best practices with respect to traffic prioritization to 5G enabled application and services in vertical industries. Regulations should include alignment with global standards (3GPP specifications) and global regulations (WRC resolutions).
- Regulations related to spectrum usage should be aligned with the frequency band plans and channel bandwidth as defined by global standards (3GPP specifications).
- To meet the current and future requirements of network deployment for various use cases, the existing regulations be reviewed and updated regularly.
- Addressing the needs for fast paced infrastructure development.

**A. Aligning the existing telecom regulations to the requirements of various innovative services 'Use Cases' that get evolved through these emerging communication technologies.**

A1. Factory automation - Industrial IoT/ Industry 4.0

- Factory automation and industrial networks may need new regulations for deployment of private 5G networks which would entail provisioning of spectrum to the enterprises.
- Update of existing regulations on captive networks to meet the requirements of factory automation/ Industry 4.0.

A2. Automotive IoT - C-V2X (Intelligent Transport System)

- As detailed in the Section 4.2 of this report, there is an increasing requirement of bringing more intelligence into the transport system, deployment of AR services for enhanced safety, VR based remote repair services, in-vehicle infotainment, ADAS for autonomous vehicles and vehicle telematics. As part of the regulatory evolution for future communication systems, it is important to ensure regulations supporting availability of high throughput, ubiquitous network along the highways and in cities / urban areas by different stakeholders / service providers. This would enable realizing full potential of C-V2X for safety and advanced use-cases.
- Collaborative and coordinated initiatives of DoT/TEC and MoRTH, during the implementation of AIS 140 for safe public transportation, need to be replicated between multiple ministries for faster and smoother deployment of newer innovative IoT services, that get facilitated through these future communication systems.
- While many automotive manufacturers may consider inclusion of V2X communication module as part of the standard offering, the safety benefits of V2X communication can only be achieved if a significant part of the vehicles fleet is equipped. Adequate regulatory provisions may be introduced to encourage adoption of V2X.
- Dedicated and globally harmonized spectrum for ITS applications (including V2X) is essential for reliable services.

A3. Need for Co-ordinated Efforts of Various Government Agencies / Sectoral Regulators / Ministries for Ensuring Timely Availability and implementation of Regulations.

- Close coordination among various regulatory bodies which are related with deployment of 5G private networks / ITS applications, is essential to ensure timely and effective deployment of services for consumers.
- Coordination among various related agencies at center/state government level is required for ensuring nationwide uniform adoption of technologies and standards.
  This will enhance the contribution of Digital Communications sector to India's GDP and also enhancing India's contribution to Global Value Chains.

**B. Addressing the needs for fast paced infrastructure development.**

B1. Making available time-bound and low-cost RoW permissions-

This issue needs firm resolution at national level for ensuring timely and cost-effective permissions for RoW for laying OFC for 5G deployments. Agencies involved in development of national highways may be advised to lay multiple OFC pipes in the road-dividers and lease out to telecom service providers.

B2. Infrastructure development and RoW for deployment of these essential services be rationalized with time bound priorities across the country.

B3. Concerned ministries/ departments / agencies may adopt the global best practices for automotive connectivity to accelerate the deployment of C-V2X.

## 5.3 Security aspects in the IoT domain

The Internet of Things (IoT) is connecting people, places, and devices at a rapid pace. With the surge in the number of connected devices comes the demand to support enhanced security features for IoT devices. Readers are encouraged to look into the upcoming TEC IoT division document on Security by Design principles for IoT devices. As a part of this, a report on ***Code of practice for Securing Consumer IoT***[63] has been released by TEC in August 2021. Guidelines available in this report may provide a direction to the related stakeholders in provisioning of secured consumer IoT devices and also help in reducing the vulnerabilities. It is worth noting that the Govt. of India has agreed on this principle with the QUAD in making a common statement on *the Principles on Technology Design, Development, Governance, and Use*[64] as follows "Technology developers should also build in safety and security-by-design approaches so that robust safety and security practices are a part of the technology development process."

63 https://tec.gov.in/pdf/M2M/Securing%20Consumer%20IoT%20_Code%20of%20pratice.pdf

64 Quad Principles on Technology Design, Development, Governance, and Use SEPTEMBER 24, 2021 STATEMENTS AND RELEASES available at https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/24/quad-principles-on-technology-design-development-governance-and-use/

# Abbreviations

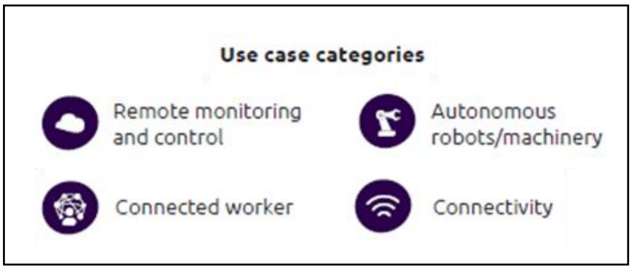
| | |
|---|---|
| **3GPP** | 3rd Generation Partnership Project |
| **5G-AA** | 5G Automotive Association |
| **5G-ACIA** | 5G Alliance for Connected Industries and Automation |
| **5GPPP** | 5G Infrastructure Public Private Partnership |
| **ADAS** | Advanced Driver Assistance Systems |
| **AGVs** | Automated Guided Vehicles |
| **AI** | Artificial Intelligence |
| **AoA/AoD** | Angle of Arrival/Departure |
| **API** | Application Programming Interface |
| **ASR** | Automatic Speech Recognition |
| **BAN** | Body Area Network |
| **BIS** | Bureau of Indian Standards |
| **BLE** | Bluetooth Low Energy |
| **BTS** | Base Transceiver Station |
| **CAPIF** | Common API Framework |
| **CN** | Core Network |
| **CoEs** | Center of Excellence |
| **DFTS** | Direct Fourier Transform Spread |
| **DNN** | Data Network Name |
| **DoT** | Department of Telecommunications |
| **DRBs** | Dedicated Radio Bearers |
| **DSRC** | Dedicated Short Range Communications |
| **EEAL** | Edge Enabler Architecture Layer |
| **eMBB** | enhanced Mobile Broadband |
| **eDRX** | extended Discontinuous Reception |
| **eMTC** | enhanced Machine Type Communication |
| **ETSI** | European Telecommunications Standards Institute |
| **FATC** | Full Automatic Temperature Controller |
| **FDD** | Frequency Division Duplex |
| **FTTH** | Fiber To The Home |
| **GPS** | Global Positioning System |
| **GSMA** | Global System for Mobile Communications Association |
| **ICT** | Information and Communications Technology |
| **IEEE** | Institute of Electrical and Electrical Engineering |
| **IMT** | International Mobile Telecommunications |
| **IoT** | Internet of Things |
| **IIoT** | Industrial Internet of Things |
| **IR** | Interface Requirement |
| **ITS** | Intelligent Transport System |

| | |
|---|---|
| **ITU** | International Telecommunication Union |
| **LBS** | Location Based Service |
| **LiDAR** | Light Detection and Ranging |
| **LLDP** | Link Layer Discovery Protocol |
| **LMR** | Land Mobile Radio |
| **LOS** | Line of Sight |
| **LPWAN** | Low-Power Wide-Area Network |
| **LTE** | Long Term Evolution |
| **MAC** | Medium Access Control |
| **M2M** | Machine to Machine |
| **MNO** | Mobile Network Operator |
| **MoRTH** | Ministry of Road Transport Highways |
| **MTCTE** | Mandatory Testing and Certification of Telecom Equipment |
| **NB-IoT** | Narrowband-Internet of Things |
| **NDCP** | National Digital Communication Policy |
| **NFAP** | National Frequency Allocation Plan |
| **NFs** | Network Functions |
| **NFV** | Network Function Virtualization |
| **NGMN** | Next Generation Mobile Networks Alliance |
| **NLOS** | Non-Line-of-Sight |
| **NR** | New Radio |
| **NSSAI** | Network Slice Selection Assistance Information |
| **OBUs** | On-Board Units |
| **OEM** | Original Equipment Manufacturer |
| **OFDM** | Orthogonal Frequency Division Multiplexing |
| **OSS/BSS** | Operations Support Systems/Business Support Systems |
| **OTA** | Over the Air |
| **PCF** | Policy Control Function |
| **PDCP** | Packet Data Convergence Protocol |
| **PDU** | Protocol Data Unit |
| **PLC** | Programmable Logic Controller |
| **PLMN** | Public Land Mobile Network |
| **PSTN** | Public Switched Telephone Network |
| **QoE** | Quality of Experience |
| **QoS** | Quality of Service |
| **RAN** | Radio Access Network |
| **RF** | Radio Frequency |
| **RRM** | Radio Resource Management |
| **RSUs** | Road-Side Units |
| **RTT** | Round Trip Time |
| **SAE** | Society of Automotive Engineering |
| **SDGs** | Sustainable Development Goals |

| | |
|---|---|
| **SDN** | Software Defined Networks |
| **SEAL** | Service Enabler Architecture Layer |
| **SLA** | Service Level Agreement |
| **TDD** | Time Division Duplex |
| **TDOA** | Time Difference of Arrival |
| **TEC** | Telecommunication Engineering Center |
| **TETRA** | TErrestrial Trunked RAdio |
| **TRAI** | Telecom Regulatory Authority of India |
| **TSC** | Time Sensitive Communications |
| **TSN** | Time Sensitive Network |
| **TSDSI** | Telecommunications Standards Development Society, India |
| **TTI** | Transmission Time Interval |
| **URLLC** | Ultra-Reliable Low Latency Communications |
| **U4SSC** | United for Smart Sustainable Cities |
| **UWB** | Ultra-Wide Band |
| **VAEL** | Vertical Application Enablement Layer |
| **V2I** | Vehicle-to-Infrastructure |
| **V2N** | Vehicle- to- Network |
| **V2P** | Vehicle-to-Person |
| **V2V** | Vehicle-to-Vehicle |
| **V2X** | Vehicle-to-Everything (X refers to V, I, P and N) |
| **VR** | Virtual Reality |
| **WPC** | Wireless Planning & Coordination Wing |

# Annexure 1: Important Use Cases in Industrial Operations / Manufacturing

A recent survey by Capgemini Research Institute[65] captures the use-cases identified by more than 300 industrial users globally with maximum business impact for early adopters. The use-cases have also been identified in three different sectors, viz: Energy & utilities, Manufacturing, and Transport & logistics.

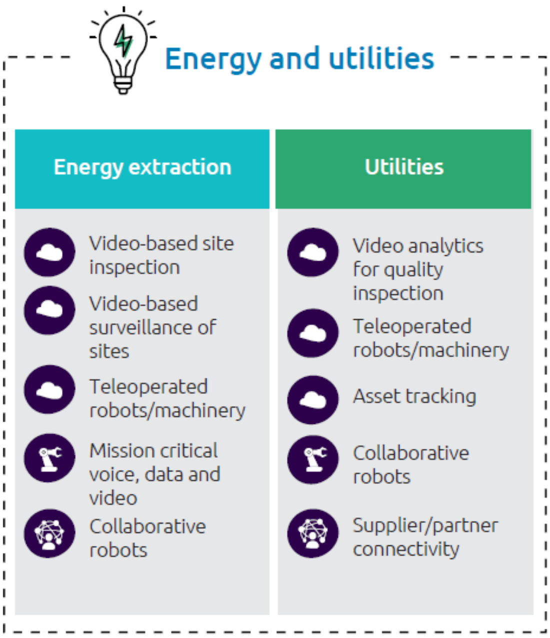
| | |
|---|---|
| The use-cases have been identified in four categories: |  |



The top five use-cases in each sector are shown in the figures below-

### 1) Energy and utilities

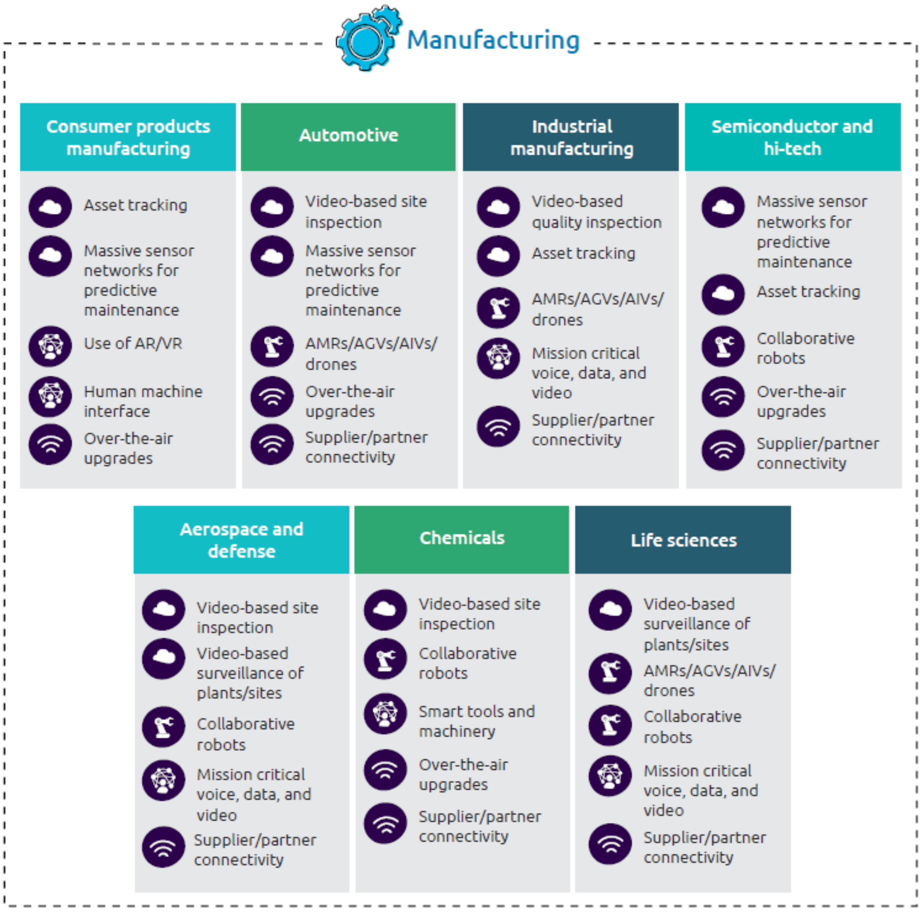
The main industries in this sector include Energy extraction and Utilities.




[65] Capgemini Research Institute, 5G and edge in industrial operations survey, February–March 2021, N=302 industrial organizations that have run pilots/trials or full-scale implementations of 5G - https://www.capgemini.com/in-en/research/accelerating-the-5g-industrial-revolution/

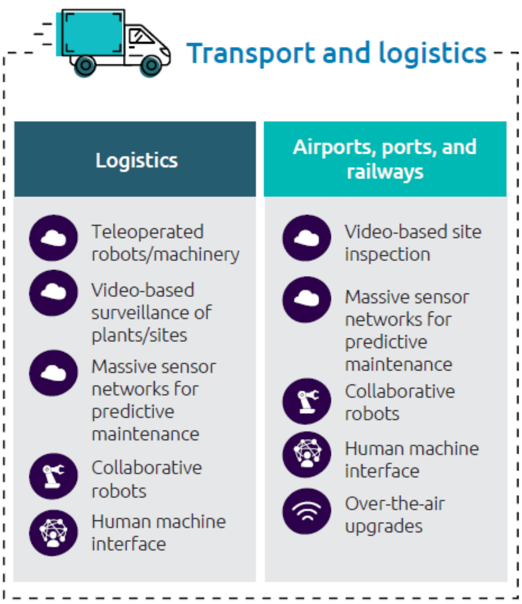
**2) Manufacturing**

The main industries in this segment include Consumer products manufacturing, Automotive,




Industrial Manufacturing, Semiconductor, Aerospace & defense, Chemicals, and Life-sciences.

3) **Transport and logistics** The main industries in this sector include Logistics and Airports, ports &



railways.

# Annexure 2: Important 5G Use Cases / applications in the Automotive Sector

The roll out of 5G technology brings in good hope for the Automotive Sector in India, just like across the globe. With 5G coming in, the Automotive Industry looks forward to rolling out a slew of new features in the new vehicle launches, which significantly enhance the on-road safety and vehicle experience of the vehicle users.

This section highlights some of the forward-looking use cases that may be of relevance for the Indian context with availability of 5G in India.

**1) Video Analytics**

Video Telematics is an integrated video camera technology that combines video surveillance with vehicle analytics. It incorporates multiple high resolution connected cameras equipped with specialized sensors.

Video Telematics includes front (road), back facing as well as bus facing cameras with sound for maximum audio-visual clarity on safety incidents. It can capture driver behavior as well as road information, analyze them using artificial intelligence (AI) tools and trigger alerts to prompt real time corrective actions.

Video Telematics also capture and transmit a live feed from inside the vehicle. Below are the use cases widely used in Video Telematics for decision making-

1. Promoting Driver Accountability
2. Correcting Driving in Real Time
3. Preventing Collisions
4. Improving Driver Training Programs
5. Driver Scorecards
6. Live Surveillance
7. Reducing Costs and Liabilities

**2) Location Based Services (LBS)**

Telematics LBS enables OEMs, their partners, independent content creators and aggregators to deliver content such as maps, weather forecasts, traffic conditions, news, stock quotes, social updates, messages, and entertainment to the vehicle. The vehicle location may be determined by using GPS coordinates or through triangulation of nearest cell towers coordinates. Now a day's vehicles are having a large number of sensors-based devices installed for various purposes and also the ECUs. Data coming from these sensory devices may be transmitted to the head end system or may be analyzed within the vehicle itself to create intelligence.

This data may be used in a number of applications. Few of them are mentioned below-

1. Vehicle Health– these solutions pull data directly from the in-vehicle diagnostics system and are primarily used to gather real time data on fuel efficiency and vehicle odometer readings that helps in powering digital fleet maintenance solutions.
2. Real-time Tracking – Instantly track all vehicles in real-time.
3. Route Management – Optimize daily routes based on traffic, construction, and real-time customer needs.
4. Turn by Turn Navigation – This feature will provide detailed information during navigation such as navigation maps, visual information from the front / back cameras, alert etc. The Telematics servers will provide the updated map and additional updates of weather, road conditions, traffic congestion/ accidents via connected cloud applications in real time.

**3) Prognostics**

Unscheduled maintenance of commercial vehicle brings users increasing maintenance cost, decreasing reliability of their fleet and quality of customer service. The prognostics systems are required for avoiding unexpected breakdowns in the vehicles.

Commercial vehicles, e.g. truck and bus, are obliged to undergo a legal inspection every year, due to being used in severe conditions and sometimes being used to carry passengers on them. In every year's inspection, a TCU (Telematics Control Unit) system evaluates health of each component in vehicles, e.g. steering, transmission, braking and exhaust processing etc., and specifies critical components, which should be replaced at the periodical maintenance.

In the commercial vehicle segment, Prognostics systems are useful for

1. Predictive maintenance
2. Product improvement
3. Warranty claim optimization
4. Over-the-air (OTA) updates
5. Dealer optimization

### 4) Real Time Alerts to the driver

There are chances of distractions in driving due to many reasons, resulting in accidents causing injuries, damages and sometimes loss of lives.

As drivers have to communicate back to the office and receive instructions to perform their duties, so providing them with a tool that does not compromise road safety is crucial. A telematics device will help drivers to track their hours of service, communicate with dispatchers, conduct pre/post trip inspections, and check performance reports. The device should be locked while driving, solidly affixed to the dashboard, and installed in a safe location.

1. Drivers to track their hours of service, communicate with dispatchers, conduct pre/post trip inspections, and check performance reports.
2. If a defect on the vehicle or trailer goes unrepaired, the telematics system can alert the driver before using it.
3. Warn drivers of hard braking, unsafe turns, over speeding and sudden maneuvers they make.
4. Data received from the smart cameras integrated with the telematics unit installed in the vehicle shall provide the alerts and can even stop the vehicle in case of emergency.

### 5) Guided Diagnostics

One of the emerging applications is remote diagnostics, which allows maintenance personnel to analyze vehicle data remotely.

A guided diagnostics system, using telematics technology, makes it easier to understand different vehicle fault codes and prioritize repairs by providing alerts. These can be sent to technicians with different levels of severity, the fault description, and recommendations for action. The technician can then be prepared for what’s wrong with the vehicle and ensure that the right parts are in stock, decreasing vehicle downtime.

The ultimate benefit of guided diagnostics is that it allows a fleet to take an unplanned vehicle failure and turn it into a planned maintenance event.

### 6) Fast & Reliable OTA (over the air)

The advantages of being able to perform in-the-field software updates to cars are well established: it will save manufacturers money, enable critical bugs to be patched immediately and allow compelling new features to be added to the vehicle at any time during its lifecycle.

Authenticity and integrity of the firmware may be protected using encrypted data. This ensures that the firmware originates from a trusted source and that it has not been modified. There are several methods of implementing such protection (e.g. a digital signature). With authenticity checking of the firmware, an OEM can guarantee that only trusted firmware is used in an update process.

With the rise of Electronic Control units and domain controllers the Software complexity is on exponential rise. The automotive is closely following the consumer electronic trend where any software is not finished and needs continues upgrade to be relevant and secure.

**7) Multi Edge Computation**

In an edge computing model, data is gathered, processed, and analyzed at the point nearest to its origin, in order to reduce the processing time as well as requirement of bandwidth. The results are transmitted to the cloud for purposes of viewing, reporting, and sharing.

Edge computing will be beneficial for the following applications-

1. Predicting breakdowns
2. Driving conditions and driver behavior
3. Detect driver fatigue or distracted driving
4. Collisions prevention in real time by alerting the drivers in case they are following too close to a vehicle

**8) BMS (Battery Management System) Remote Monitoring**

In the context of electric vehicle, BMS plays an important role. BMS needs to be able to communicate with other sensors and ECUs (Electronic control unit) in the vehicle. As CAN (Controller area network) bus is the standard in automotive, it is also the de facto standard for EV batteries. As such, it's possible to record data from the BMS of most EV batteries using a CAN bus data logger.

The BMS is an electronic system that integrates with rechargeable batteries to monitor critical data parameters. These include e.g., state, voltage, current and temperature.

Based on the data, the BMS performs vital tasks

1. Monitoring & reporting the battery state (State of Charge (SoC), State of Health (SoH))
2. Balancing cells to ensure a similar state of charge
3. Prolonging the life of the battery
4. Communicating with e.g., chargers or external devices
5. EV battery breakdowns

**9) High Bandwidth 3D HD maps with layers**

High-Resolution Real-time map with overlay meta data is very critical for future vehicles. Maps are used not just for navigating but for in vehicle Electronic Control Units (ECU’s) like ADAS (Advanced

Driver Assisted System), FATC (Fully Automated Temperature Control) etc. depend on the map data for processing.

The high-definition 3D maps come with 6-8 layers of overlay data. 5G high bandwidth will enable to provide the best-in-class online Maps with Real time traffic updates.

**10) Online Speech Recognition**

Speech Recognition has progressed from fixed token inputs to natural language speech recognition. With the rise of neural network, speech recognition is now feasible up to 18 Indian languages and 40 dialects. The Natural language speech recognition need constant upgrade of acoustic models to enhance the success rate of the ASR (Automatic Speech Recognition).

Speech has emerged as a distraction free simple interface for the driver to use in car and outside the car features. Online speech recognition is the key feature for the cars and 5G will enable copilot kind of feature, which is always available to assist the driver with real time data. This feature may work with a dedicated bandwidth of 6-8 Mbps speed, which can be enabled by 5G.

**11) Multimedia content**

With the rise of cloud servers and storage, the future of multimedia storage is all online. OTT has emerged as a dominant platform post COVID in India, which clearly shows the adaptation of online services for multimedia is real.

Automotive will also embrace online rich multimedia content streaming to the user on the move on his front infotainment system or Rear Seat Entertainment system. This will be possible only via 5G kind of bandwidth.

**12) Real time Analytics**

Huge amount of data is generated from the IoT devices available in the vehicles, which can be further analyzed in real time in the ECUs available in the vehicle and the intelligence may be further transmitted to the cloud / head end system. This data may be used for various planning and operational purposes as an example planning of other modes of transportation, new routes, visualizing the health of the vehicle by the manufacturers, location by the user / owner, insurance of the vehicle etc. Sharing of data may be controlled by a predefined policy.

**13) Augmented Reality (AR) / Virtual Reality (VR)**

AR is an emerging field in consumer electronics and gaming. Vehicles will have many AR based use cases like Map data meshed with real time video feeds or windscreen heads up display augmented with real time data.

VR is another enabling technology which has shown great prominence to enable Virtual show room for dealers. Virtual reality based in car features will enable users to take more informed decision and also have close to real experience. This feature will bring new virtual show rooms. 5G is the key enabler for this technology.

**14) Collision avoidance**

Once the intelligent transport system (ITS) with C-V2X technology is deployed, vehicles on the road can use C-V2X to broadcast its identity, position, speed, and direction. It will be easier for the vehicles to build its own real time map of the immediate surroundings and determine whether any other vehicles (including those out of the driver's sight) are on a potential collision trajectory. The vehicles involved can then take evasive action, such as braking or accelerating, that will enable a collision to be avoided. In cases where a human driver is about to cause an accident, the information collected by C-V2X can be used to over-ride the manual controls. For example, if a driver is about to pull out at a junction into the path of another vehicle, the on-board computer can automatically apply the brakes and prevent the car moving forward.

**15) Emergency Vehicle Alerts**

C-V2X features will help alert the drivers on the road well ahead of time (around 3 kms radius) to provide enough time for the drivers on the road to make way for the emergency vehicles (Police, Fire, Ambulance etc.), which needs priority. Emergency vehicles alert, ahead of time on Indian road, will be a key game changer to save many lives.

**16) Hazards ahead Warning**

C-V2X can be used to extend a vehicle's electronic horizon, to detect hazards around a blind corner, obscured by fog or other obstructions. C-V2X features may be used to broadcast hazard warnings to each vehicle on a particular stretch of road.

**17) Protecting vulnerable road users**

Vehicles equipped with C-V2X will be able to detect the pedestrians and cyclists in future, enabling them to avoid collisions with the vulnerable road users.

**18) Queue warning**

Roadside infrastructure can also use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking. More broadly, the roadside infrastructure can use C-V2X to help vehicles retain a consistent speed and reduce the number of traffic jams caused by the ripple effect of sudden braking and lane changes on Highways. Traffic lights can advise oncoming vehicles about when they will turn green or red, so the car can adjust its speed accordingly.

**19) Platooning**

It is the formation of a convoy in which the vehicles are much close together. Using C-V2X features, such automated convoys are safer, make better use of road space, save fuel, and make the transport of goods more efficient. C-V2X may also be used to signal the presence of the platoon to other vehicles and roadside infrastructure. Platoons will be flexible in that they will typically be established on a highway, then broken up when a vehicle leaves the highways.

**20) Toll payment /Parking / Smart chargers**

5G will play a key role to enhance the smart infrastructure related to multi layered parking, charging infrastructure for EV's and Electronic Toll Payment.

**21) DVR & Video Analytics**

As per the report on Road Accidents in India -2019 published by MoRTH[66], 151 K deaths were due to road accidents in 2019. Technology should help mitigate this by avoiding drowsy drivers off roads and make driving safe for all. Camera recordings and driver analytics with connectivity will enable safe driving. This data may be linked with the insurance to provide driver rating to keep bad drivers off the roads. This technology will leverage enhance safety features for vehicles. OEM-Insurance and Road Safety agencies may work together to exploit the 5G technology to help save lives.

**22) Advanced Driver Assistance Service (ADAS)**

Indian automotive industry has started introducing ADAS capability in some vehicles. The sensor pack including Radar, Camera and LiDAR need huge processing capability on the vehicle. ADAS features are already enabled in 4G however 5G will take it a step ahead.

**23) Digital Twin for Electric Vehicle battery**

The concept of Digital twin for Battery cell will help us use in vehicle sensor, connectivity, cloud computing and machine learning to digitally clone the battery and develop predict the battery cell degradation, Range polygon and accurate state of charge for battery. High bandwidth is key enabler for this technology to take off.

[66] https://morth.nic.in/sites/default/files/RA_Uploading.pdf

# Annexure 3: Ecosystem Readiness

The true success of a technology is evaluated based on the strong ecosystem it creates, that includes all the players: devices, networks, and system integrators. Finally, applications that realize the use-cases into real business impact are built on top of these.

The 5G Automotive Association[67] provides an overview of the C-V2X devices that are already available in the market. Their listing includes information about various form factors to these devices:

i. C-V2X-Chipset which includes an integrated modem,
ii. C-V2X-Module that may have additional components like an application processor and other capabilities,
iii. C-V2X-RSU which is a complete C-V2X ITS station unit with a C-V2X module and the necessary components to be mounted on a roadside unit,
iv. C-V2X-OBU which is a complete C-V2X ITS station incorporating a C-V2X module and all necessary components to be mounted on a vehicle, and
v. C-V2X-Software which includes program components supporting the C-V2X communication.

According to the report by GSA[68], the 3GPP standards based Low Power Wide Area Network (LPWAN) technologies have seen strong continued commitment by the mobile industry. The global NB-IoT and LTE-M networks supporting NB-IoT and LTE-MTC (LTE-M) has seen a substantial rise and there has been a sustained growth in the number of Cat-NB1, Cat-NB2 and Cat-M1 compliant devices. At the time of this writing, there are 136 operators that have already deployed / launched NB-IoT or LTE-M networks in 64 countries. In terms of equipment availability, there exists more than 500 devices supporting either Cat-M1, Cat-NB1 (NB-IoT) or Cat-NB2 as per the GSA GAMBoD. From the industry ecosystem, there has been continued progress in establishing partnerships and roadmap towards faster adoption of Industry 4.0[69].

OEMs are quickly adopting Wi-Fi 6 and the chipsets are available in multiple form factor consumer devices. ABI Research predicts that, by 2024, 70 percent of smartphones will support Wi-Fi 6, along with 93 million desktops and portable PCs[70].

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[67] 5GAA Website Listing of C-V2X Devices: https://5gaa.org/news/list-of-c-v2x-devices/

[68] GSA Report on NB-IoT and LTE-M ecosystem: https://gsacom.com/paper/nb-iot-and-lte-m-april-2021-executive-summary/

[69] Report from Enterprise IoT Insights https://enterpriseiotinsights.com/20200131/channels/news/ericsson-and-capgemini-combine-to-drive-private-lte-and-5g-deals, and https://enterpriseiotinsights.com/20210702/channels/news/qualcomm-capgemini-push-release-16-private-5g-to-industry

[70] https://www.nxp.com/company/blog/better-together-5g-and-wi-fi-6-enable-smart-cities:BL-5G-AND-WIFI-6-ENABLE-SMART-CITIES

# Annexure 4: List of WG meetings

| S. No. | Date |
|---|---|
| 1. | Meeting through GoToMeeting bridge, $14^{th}$ Feb 2020 |
| 2. | Meeting through GoToMeeting bridge, $30^{th}$ Mar 2020 |
| 3. | Meeting through GoToMeeting bridge, $21^{st}$ April 2020 |
| 4. | Meeting through GoToMeeting bridge, $20^{th}$ May 2020 |
| 5. | Meeting through GoToMeeting bridge, $22^{nd}$ June 2020 |
| 6. | Meeting through GoToMeeting bridge, $29^{th}$ July 2020 |
| 7. | Meeting through GoToMeeting bridge, $2^{nd}$ Sep 2020 |
| 8. | Meeting through GoToMeeting bridge, $28^{th}$ October 2020 |
| 9. | Meeting through GoToMeeting bridge, $16^{th}$ December 2020 |
| 10. | Meeting through GoToMeeting bridge, $11^{th}$ February 2021 |
| 11. | Meeting through GoToMeeting bridge, $22^{nd}$ March 2021 |
| 12. | Meeting through Microsoft Teams platform, $30^{th}$ April 2021 |
| 13. | Meeting through Microsoft Teams platform, $1^{st}$ June 2021 |
| 14. | Meeting through Microsoft Teams platform, $29^{th}$ June 2021 |
| 15. | Meeting through C-DOT VC platform, $14^{th}$ July 2021 |

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