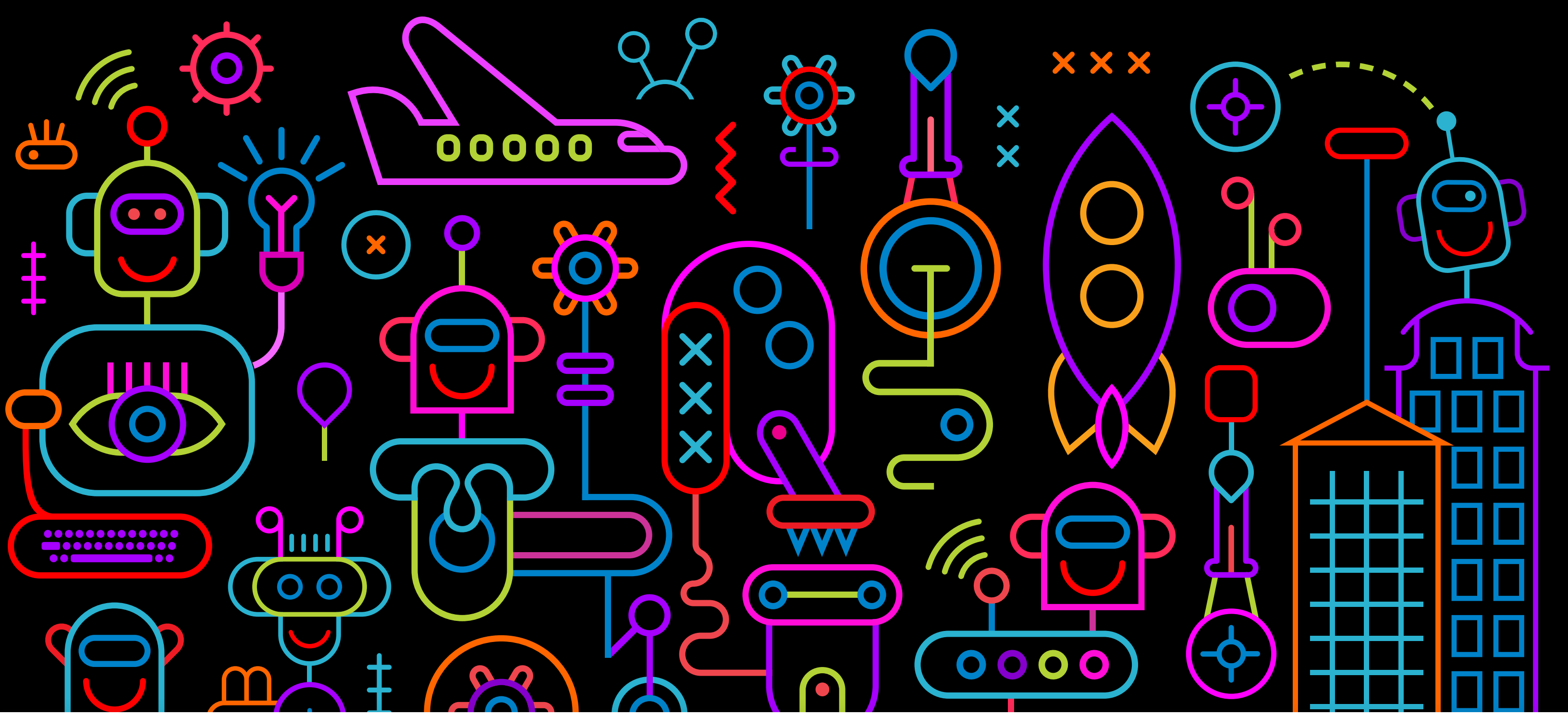

# IOT Categorization: Exploring the Need for Standardizing Additional Network Slices

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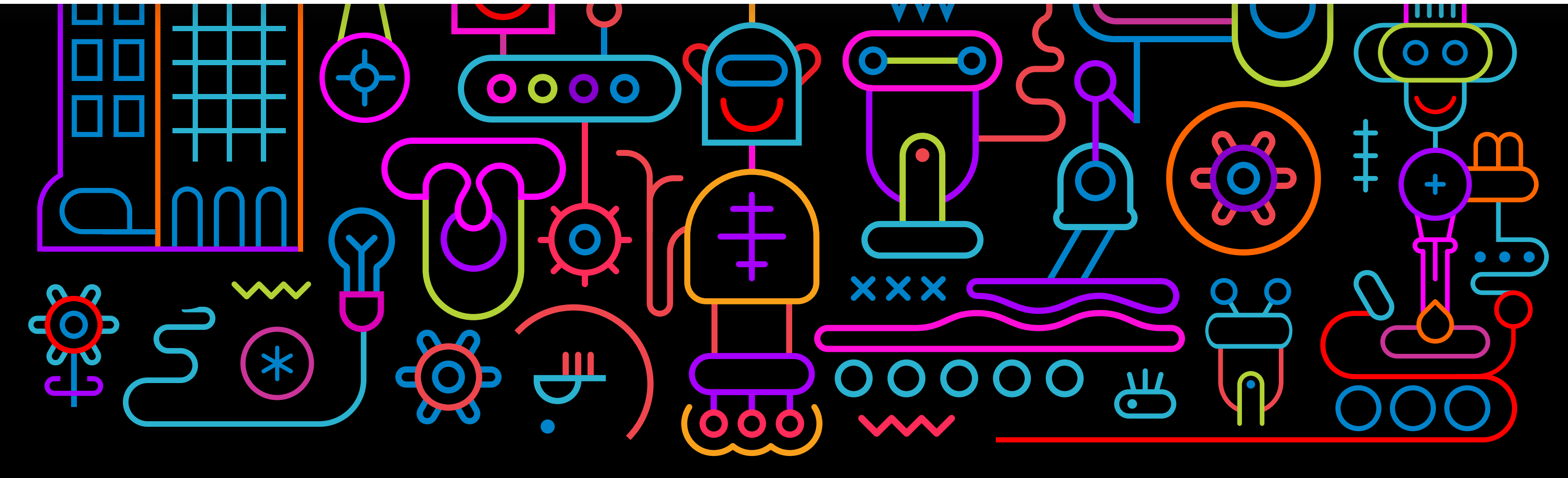
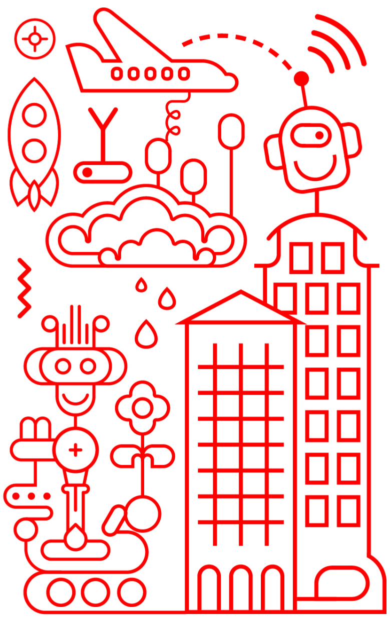


# Abstract

**THE BURGEONING GROWTH** in the IoT ecosystem — in terms of the number of connected devices globally and total spending on end-point devices and services — is driving a wide range of new uses and requirements on the network infrastructure. Network slicing has been devised as a way to structure a network to support diverse classes of services in a guaranteed way on the same network. This report considers the network requirements across the multidimensional landscape of IoT devices and applications to identify any additional network slice types that may be defined to ensure consistent service quality across operators.

01

# Foreword



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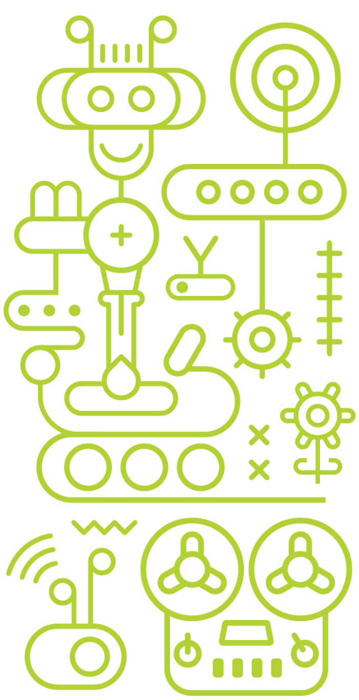
# Introduction and Background

With network slicing, network functions and resources that are specifically tailored to a vertical market's requirements are logically isolated creating multiple virtual networks on top of a common shared physical infrastructure.



**THE INTERNET OF** THINGS (IoT) ecosystem continues to expand, supporting a wide range of devices and services. A recent Strategy Analytics report predicts that 38.6 billion devices will be connected by 2025, and 50 billion by 2030. [1] To support this burgeoning growth, networks will need to handle a diverse set of use cases across different industry verticals, including smart cities, automotive, health care, transportation, and industrial automation, to name just a few. These vertical applications will require the underlying network infrastructure to meet a variety of different requirements for functionality (e.g., priority, security) and performance (e.g., latency, availability, mobility, data rates, connection density). For example, applications such as ultra-high-definition (UHD) video and augmented reality require high-speed, high-capacity communications, yet are generally capable of handling medium to high latencies. Other applications, such as autonomous vehicles, require ultra-low latency, ultra-reliable services to guarantee road safety.

To address the diversified service requirements of vertical industries, the concept of network slicing has been developed. A slice is composed of a collection of logical customized network functions that supports the communication service requirements of particular use cases or business models. [2] With network slicing, network functions and resources that are specifically tailored to a vertical market's requirements are logically isolated, creating multiple virtual networks on top of a common shared physical infrastructure. Each slice has a dedicated treatment in terms of performance (e.g., latency, throughput) or functionality (e.g., security, priority). Dynamic end-to-end network slicing enables a model where services expand and contract network resources as traffic demands. [3]

Network slices are categorized into different types according to the abstraction of characteristics of the services they facilitate. The Third Generation Partnership Project (3GPP) has defined four network slice types, as depicted in Table 1: Standardized Slice/Service Types. These slice types are based on the typical characteristics required for use cases and verticals to provide a way for establishing global interoperability for slicing. [4]

*Table 1: Standardized Slice/Service Types*

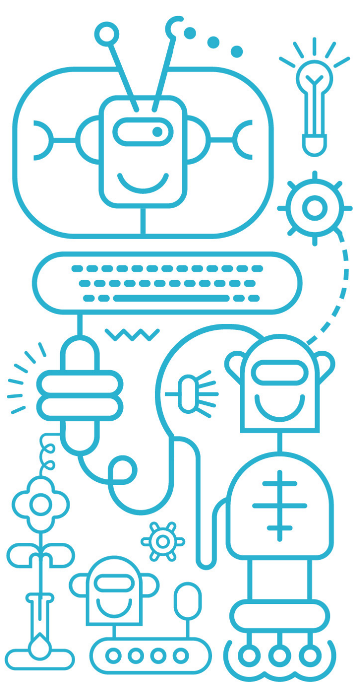
| Slice Type | Characteristics |
|---|---|
| Enhanced Mobile Broadband (eMBB) | This slice supports mobile broadband applications such as streaming high-quality video, fast large-file transfer, and real-time gaming. |
| Ultra-Reliable Low-Latency Communications (URLLC) | This slice type includes applications that require very high reliability and are extremely sensitive to latency, including autonomous driving, drones, augmented/virtual reality, and public safety. |
| massive Internet of Things (mIoT)<br>Note: Other industry groups use the term mMTC (massive Machine Type Communications) to classify this group of services. [5] | The main application scenarios for this slice type have a high density of heterogeneous devices with massive connectivity requirements. Examples include smart cities, smart grids, intelligent agriculture, and other services where networks need to support massive equipment access sending small data. These applications are not highly sensitive to latency. |
| V2X | This slice is customized for vehicle-to-everything (V2X) services. |

Network slicing enables specialization of the offered services on the same shared infrastructure. The slice/service types defined by various standards and industry organizations address a broad swath of services across different vertical industries. This paper investigates whether any additional network slice types are required. By identifying areas of commonality amongst slices that guarantee the same service characteristics, consistent service quality for a given IoT device used across different operators is enabled.

03

# Analysis of IoT Device and Application Characteristics

“The goal is to identify areas of commonality amongst slices that will guarantee the same service characteristics, keeping service quality consistent for a given IoT device used across different operators.”



## Performance Characteristics

To provide structure for the analysis, the major IoT application groups are identified and decomposed into further use cases along with the IoT devices used. Key performance characteristics that influence network slice requirements are identified in Table 2: IoT Device and Application Performance Characeristics.

*Table 2: IoT Device and Application Performance Characteristics*

| Characteristic | Definition | Range of Values |
|---|---|---|
| E2E latency | End-to-end latency, or one-trip-time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received at the receiving entity, (e.g., internet server, another device). [6] | Very low < 1 ms<br>Low <10 ms<br>Moderate<br>10 ms-100 ms<br>High<br>100 ms-500 ms<br>Best effort |
| Jitter | Measures variation in packet delay over time (ms) | Sensitive<br>Not Sensitive |
| Data rate | Required bit rate for the application to function correctly. “Data rate” refers to the data volume V that is transmitted within a given duration T. With V measured in bits and T in seconds the data rate D = V/T is a quantity measured in “bits per second.”<br>Per 3GPP:<br>• GBR: The minimum guaranteed bit rate per EPS bearer. Specified independently for uplink and downlink.<br>• MBR: The maximum guaranteed bit rate per EPS bearer. Specified independently for uplink and downlink. [7] | Very high data rate: ≥ 100 Mbps<br>High: 50-100 Mbps<br>Medium: 10-50 Mbps<br>Low: <10 Mbps<br>Very low: <100 Kbps |

| | | |
|---|---|---|
| Availability | Probability that a system will be operational when a demand is made for service.<br>Measured as:<br>Uptime / total time (uptime + downtime) | Best effort<br>Low: <90%<br>Medium: 90-95%<br>High: 95-99.999%<br>Very high: >99.999% |
| Criticality | IoT devices can provide services in situations when failure is not an option:<br>• Noncritical<br>• Mission critical: Failure by the device can jeopardize enterprise operation and cause significant loss in business and assets<br>• Safety critical: Execution failure or faulty execution by the device could result in injury or loss of human life | Noncritical<br>Mission critical<br>Safety critical |
| Communication direction | • One-way: Simple devices make one-way service requests while monitoring themselves. Device examples include home appliances, propane tanks, commercial vending machines, porta-potties, and garbage cans. Data flows only outward, with “Help me!” messages like “I need to be filled,” “I need to be emptied” or “I need to be serviced because of the following diagnostics code.”[8] No message is sent when no servicing is needed (unless a periodic ping of existence is required). Note that while communication is primarily one-way, the device may have ability to download configuration changes and updates to firmware, but this is done less frequently. [8]<br>• Two-way: Interactive devices with two-way communication of data. For example, a connected smoke detector must deliver a smoke alarm with absolute certainty. These devices need the network to provide acknowledgements of a received message to enable better fault management and the required level of reliability. [9] | One-way<br>Two-way |

| | | |
|---|---|---|
| Common communication mode | • Common communication mode: Excludes operational maintenance communication such as firmware updates and configuration changes.<br>• Unicast: "One-to-one" communication that passes from a single source to a single receiver or destination.<br>• Multicast: "One-to-many" technique that sends information from a single source to as many destinations that express a specific interest in receiving it.<br>• Broadcast: "One-to-all" communication technique that ensures that all the nodes on a network receive the same information. | Unicast<br>Multicast<br>Broadcast |
| Data reporting mode | • Time driven: Machines periodically turn on their sensors and transmitters to transmit the collected data.<br>• Query driven: Devices reply to certain instructions from application servers by transmitting data.<br>• Event driven: Devices react to a certain critical query or event.<br>• Continuous-based: Devices send their data continuously to the remote server at a pre-specified rate.<br>• Hybrid-driven: A combination of the aforementioned four types. [10] | Time driven<br>Query driven<br>Event driven<br>Continuous based<br>Hybrid driven |
| Mobility (type/ speed) | Maximum relative speed under which the specified reliability should be achieved.<br>• Fixed<br>• Pedestrian: >0-10 km/h<br>• Vehicular: 10-120 km/h<br>• High-speed vehicular: 120-350 km/h<br>• Very high speed: 350-500 km/h [11, 7] | Fixed<br>Pedestrian<br>Vehicular<br>High-speed vehicular<br>Very high speed |
| Service continuity | Seamless connectivity service: Service continuity is supported in scenarios where the IoT UEs are mobile and handover (intra/inter-technology) occurs achieving continuous service as the UE moves in-between cells. | Not required<br>Required |
| Device autonomy (power constrained)[7] | IoT devices that are power constrained use batteries or draw power from their environment using other devices. | Yes (power constrained)<br>No |

| | | |
|---|---|---|
| Connectivity type | A personal area network (PAN) is short range, where distances can be measured in meters, such as a wearable fitness tracker device that communicates with an app on a cell phone over BLE.<br><br>A local area network (LAN) is short to medium range, where distances can be up to hundreds of meters, such as home automation or sensors that are installed within a factory production line that communicate over Wi-Fi with a gateway device that is installed within the same building.<br><br>A wide area network (WAN) is long range, where distances can be measured in kilometers. | PAN: Bluetooth, Zigbee, Powerline Ethernet<br><br>LAN: Wi-Fi<br><br>WAN: cellular, LPWA, satellite |
| Priority services (NS/EP) | Critical Communications Priority Services: Various priority services exist today to support key personnel in their critical communications during a National Security and Emergency Preparedness (NS/EP) condition. In addition to priority voice, these services include priority video and data. Priority signaling/control and priority IP packet transport capabilities have been defined in standards to provide preferential treatment for communication by a service user (authorized by the Office of Emergency Communications (OEC)) for NS/EP. [12] | Yes (it would get priority treatment)<br><br>No (it would not) |
| Guaranteed service | In 3GPP, the two resource types—guaranteed bit rate (GBR) and delay-critical GBR—determine if dedicated network resources related to a service- or bearer-level GBR value are permanently allocated. The delay-critical GBR is used for low-latency and high-reliability requirements based on ultra-reliabile low-latency communications (URLLC).<br><br>Alarms and alerts from IoT devices that are sensing physical and kinetic events often have high priority. Endpoint devices and/or IoT gateways can decide on QoS requirements based on contextual information (e.g., time of day, volumes, environmental conditions such as rain, snow, earthquake). Allowing the endpoint to establish QoS requirements (e.g., priority) is supported in both IPv4 and IPv6 through a variety of packet options and packet flags, such as type of service (ToS) in IPv4 and flow control in IPv6. [13] | GBR<br><br>Non-GBR<br><br>Delayed-critical GBR |

| | | |
|---|---|---|
| Security | Security requirements need to factor in the cost of a security failure (e.g., economic, social, environmental), risk of attack, cost of implementation. Key requirements may include:<br>• Secure boot<br>• Encrypted communication<br>• For devices that are capable, implementation of security software such as anti-malware, intrusion prevention systems, and even local firewalls<br>• Device tampering detection [14, 15] | Medium<br>High |
| Lifespan | Some standalone consumer products may have a relatively short lifespan (2-4 years) whereas infrastructure, automotive, and domestic appliance applications need to have stable support for more than a decade (or even longer). This will drive support requirements on the network. | Short: 2-4 years<br>Medium: 4-8 years<br>Long: More than 8 years |
| Location-based services | Location information from IoT devices is used for a variety of use cases, including inventory management and record keeping, monitoring and protecting assets, maintenance and servicing equipment, as well as security and compliance, and emergency communications. | High accuracy: <10 M<br>Accurate: <150 M<br>Coarse location: >150 M<br>Proximity based<br>Fixed (no LBS needed) |
| Density (number of devices) | Number of devices per km2[7] | High: ≥10,000)<br>Medium: 1,000-10,000<br>Low: <1,000<br>Variable |

### Application/IoT device grouping mapping to a network slice

Each application/IoT device grouping is mapped to a network slice, highlighting any areas that may warrant a new slice type. The goal is to identify areas of commonality amongst slices that will guarantee the same service characteristics, keeping service quality consistent for a given IoT device used across different operators.

# Smart Cities Applications

Smart city applications use IoT sensors and technology to connect components across a city to derive data and improve the lives of citizens and visitors. These applications are focused on providing greener, safer, and more efficient infrastructure and services. [16]

Smart Parking


**Smart Parking**

Smart parking leverages IoT devices that provide drivers with information such as which parking slot is open and which is occupied. The IoT devices are installed on each parking slot and send a signal to a nearby receiver, which broadcasts a continuous live update about the availability of all the slots. The collected data will be used to broadcast parking information to a parking guidance system and smartphone app for drivers. [17]

Besides the parking space's location, drivers will get information such as the space's size and even nearby public transportation information if the suggestion is needed. Smart parking provides efficient management of parking facilities with real-time, individual vehicle, individual space data. The solution can keep track of the number of cars in a lot, notify drivers about open spaces, and notify them when their parking time has expired.

*Table 3: Smart Parking Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Parking sensors: infrared, passive infrared (PIR)<br>• Ultrasonic vehicle detection sensors: Individual parking space sensors that gather and transmits information for management, payment, and compliance monitoring | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |
| • Cameras for monitoring of parking lot occupancy in real time. Image data from the cameras connected to a gateway directly sent to the parking lot's management system. | Latency: moderate<br>Data rate: medium<br>Sensitive to jitter<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | eMBB |

Smart Waste Management

**Smart Waste Management**

It's expensive to send garbage trucks to every waste bin in the city when the containers are empty. Cities have developed rough algorithms for minimizing the cost of various municipal services such as collecting trash, but IoT sensors can improve the services by notifying relevant public works officials when particular trash bins are full. [18] The smart waste management application monitors containers' fill level and status in real time and enables dynamic scheduling and routing of garbage trucks in the city.

*Table 4: Smart Waste Management Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smart waste bin with wireless ultrasonic fill-level sensors and other indicators such as temperature and tilt within waste container. | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | MMTC |

Smart Waste Pickup

### Smart Waste Pickup

Smart waste pickup systems enable tracking of the real-time location of waste bins or portable toilets. Once data related to fill rates and temperatures of the smart bins/toilets are collected, sensors relay the exact location and other waste related information of the bins in question so waste management can send text messages to nearby garbage collectors for collection/emptying before harmful carbon emissions are released. [19]

*Table 5: Smart Waste Pickup Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Portable waste bin or portable toilets enabled with GNSS. | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Smart Street Lighting

### Smart Street Lighting

Cities are using IoT-enabled street lighting to improve their citizens' quality of life, increase revenues, cut costs, and support the deployment of a range of smart city applications. Smart street lighting enables city officials to increase and decrease street lighting illumination levels at different times of the day or night in response to weather events. Cities can use it to develop "follow-me" strategies that turn on street lighting only in response to specific pedestrian or vehicular activity, allowing them to reduce their energy costs. They can enable light flashing and sequencing to support traffic and crowd control during special events. Additionally, they can use connected street lighting to improve safety by increasing lighting in high-crime areas and by providing first responders with the ability to increase lighting when they respond to an incident. [20]

*Table 6: Smart Street Lighting Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| "Smart" streetlights equipped with light and object detection sensors | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: high | mMTC |

Smart Water

### Smart Water

Water supply and infrastructure are significant areas of concern as many cities are challenged by access to clean reliable sources of water. The use of IoT technologies may be used to improve urban water supply management. A smart water IoT solution can connect smart devices with faucets and pipelines that are embedded with sensors, actuators, and network connectivity to collect and report real-time information about water consumption, quality, and losses. [21] The solution can initiate alerts in emergency situations and gather data about the incident. Municipalities can sustainably use and reuse water resources through optimized contamination monitoring, leak detection, quality control, and maintenance enabled by smart water IoT solutions.

*Table 7: Smart Water Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Smart meters that collect granular real-time data across the water grid<br>• LED light sensors to monitor water levels in tanks<br>• pH sensors, temperature sensors, and turbidity sensors in pipelines and storage and distribution tanks<br>• Volume sensors | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Smart Buildings/ Homes

### Smart Buildings/Homes

Lighting and fire protection, security, intrusion and access control systems, elevators, heating, ventilation, and air conditioning (HVAC) are key components of a smart, connected building. The most common use cases driving initial deployment of smart building solutions focus on efficiency, whether of energy, space, or operations. Smart building applications support operational initiatives of the business, such as decreasing energy consumption and creating a healthier, safer environment.

Smart HVAC

### Smart HVAC

Smart HVAC solutions employ real-time weather data provided by intelligent sensors to regulate temperature automatically. Sensors also monitor building occupancy, and the data is used to make adjustments for building-wide device energy consumption and control comfort settings in offices, labs, conference rooms, and other workspaces. [22] Other sensors are used to continually monitor the environment and trigger alerts if an unsafe condition exists, thus ensuring comfortable and safe working environments.

*Table 8: Smart HVAC Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Temperature & humidity sensors<br>• Volumetric airflow & fluid sensors<br>• Mold sensors<br>• Occupancy-detecting sensors<br>• $CO^2$ demand-controlled ventilation (DCV) sensors work with sensors that detect a building's occupancy and adjust ventilation accordingly<br>• Light sensors tied to motorized window treatments can pick up on sunlight and adjust window shading during the course of a day | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Smart Lighting

### Smart Lighting

A smart lighting IoT solution uses LED technology that enables luminaires to become digital data nodes on a lighting system network. LEDs can send information and receive commands from software or other digital devices on the network. Sensors detect some type of event or change in the physical environment such as light, temperature, or motion and feed data to a central control system. Software enables control and automation based on different variables within the space. The lighting systems may be integrated with other smart building systems, such as HVAC, to contribute to energy savings. Historical and real-time data is stored and analyzed so that adjustments can be made, and greater efficiencies can be realized. [23]

*Table 9: Smart Lighting Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| LED sensors equipped to capture data around ambient light levels, temperature, occupancy, security, performance & energy consumption, and shading during the course of a day | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Smart Access & Security

### Smart Access and Security

Smart access and security solutions control access to remote installations from a centralized system and initiates alerts if unauthorized access occurs. Access control provides policy-based smart access to specific areas for designated individuals based on user identity captured from sources such as biometrics and cameras.

*Table 10: Smart Access and Security Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Access card reader<br>• Biometrics | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | mMTC |
| Cameras | Latency: best effort<br>Data rate: high<br>Availability: medium<br>Mobility: fixed position<br>Density: low | eMBB |

Smart Elevators

### Smart Elevators

Smart elevator IoT sensors enable remote monitoring and maintenance capabilities that can provide alerts in advance about when elevator servicing is required, and which issues need attention. An IoT gateway installed on each elevator, with sensors on the elevator car, landing door, and other elevator components, collects data that is then sent to a cloud-based controller to be analyzed. The system initiates alert if abnormal parameters detected.

*Table 11: Smart Elevators Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensors in elevator to measure the usage in real time | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Environmental Monitoring

**Environmental Monitoring**

Environmental monitoring, as part of a smart building, is a solution that describes any activities in a building to monitor the quality of an environment, including such things as air quality and carbon dioxide. It is used in the assessments of any risk that to humans and the environment and initiates alerts if dangerous environmental conditions occur.

*Table 12: Environmental Monitoring Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensors that monitor a building's air quality (i.e., carbon monoxide and other volatile carbon emission detection) | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low<br>Safety critical | mMTC |

Fire Detection

**Fire Detection**

When fire is detected, the fire protection system triggers actions, such as closing fire shutters, turning on fire sprinklers, and activating notification devices such as horns, strobe lights, and speakers to alertnoccupants. Building sensors send an alarm to the local controller that sends information to a building management system. The management platform will then automatically send the information to corresponding departments and alert personnel by voice messages or SMS.

*Table 13: Fire Dectection Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smoke detectors | Latency: high<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low<br>Safety critical | mMTC |

Sanitation

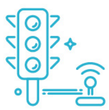
## Sanitation

Smart sanitation services are another way smart buildings can reduce cost. Connecting sanitation devices with sensors provides the ability to control water flow, paper consumption, air flow for hand drying, and aroma or cleaning chemical sprays on a timer that can be controlled by a single source. [24]

*Table 14: Sanitation Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sanitation devices connected with sensors | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |

Traffic Monitoring



## Traffic Monitoring

Smart traffic management is a system that gathers data to analyze traffic flows and congestion situations, initiates alerts when accidents occur, and gathers data about incidents. Centrally controlled traffic signals and sensors regulate the flow of traffic in response to specific demand levels. The system allows cities to reduce traffic congestion by smoothing traffic flows and prioritizing traffic in response to demand in real time.

*Table 15: Traffic Monitoring Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Roadway sensors<br>• Intersection monitoring sensors<br>• Speed sensors | Latency: best effort<br>Data rate: low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | mMTC |
| • Traffic cameras | Latency: best effort<br>Data rate: medium<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | eMBB |

Smart Public Transport

## Smart Public Transport

Smart public transport provides connected solutions for shared passenger transport services such as buses, trains, and ferries. The data from IoT sensors can help to reveal patterns on public transportation usage. Public transportation operators can use this data to enhance traveling experience, punctuality, and achieve higher levels of safety. Smart public transport solutions can combine multiple sources, such as ticket sales and traffic information. [25]

*Table 16: Smart Public Transport Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Ticket readers<br>• Pass cards readers | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position and vehicular<br>Density: low | mMTC |

**Urban Package Delivery**

Urban Package Delivery

Urban package delivery IoT solutions optimize and coordinate package delivery and logistics. Leveraging the GNSS and vehicle sensors, delivery systems analyze possible routes before picking the most optimal path for a driver to take to reduce the overall time spent driving around from delivery to delivery. By maximizing the benefits of IoT, parcel delivery services will become intelligent and dynamic, decrease unnecessary delivery times, and more efficiently serve customers. [26]

*Table 17: Urban Package Delivery Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Mobile-enabled IoT sensors<br>• Bluetooth beacons<br>• Infrared counters or sensors embedded in the pavement, turnstiles | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | mMTC |
| • Video cameras that aggregate changes to an image to estimate crowd density | Latency: best effort<br>Data rate: medium<br>Availability: medium<br>Mobility: fixed position<br>Density: low | eMBB |

**Crowd Management**

Crowd Management

Smart crowd management refers to the ability to monitor, direct, and manage large groups of people. By providing real-time insight, city administrators, event planners, and public safety authorities can maintain safety, avoid gridlock, and improve the customer experience. Key uses cases include transport hubs, sports and entertainment venues, and retail. [27] Connected motion sensors monitor traffic patterns such that cities and event venues can identify which areas are the busiest and distribute resources accordingly. Sensor data provides crucial insights to guide the location of barriers and street closures and the size and distribution of officers and security guards. Infrared cameras can help track crowd density, giving security teams the ability to react to dangerous situations proactively. [28]

*Table 18: Crowd Management Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Mobile-enabled IoT sensors<br>• Bluetooth beacons<br>• Infrared counters or sensors embedded in the pavement, turnstiles | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | mMTC |
| Video cameras that aggregate changes to an image to estimate crowd density | Latency: best effort<br>Data rate: medium<br>Availability: medium<br>Mobility: fixed position<br>Density: low | eMBB |

Smart Infrastructure

**Smart Infrastructure**

Essential city infrastructure includes tunnels, bridges, roads, railways, buildings, and utilities. Smart infrastructure monitors the condition of this infrastructure to quantify and define the extent of aging and the consequent remaining design life of infrastructure to ensure resilience and reduce the risk of failure. Proactive monitoring enables maintenance, inspection, and refurbishment of infrastructure assets. [29]

*Table 19: Smart Infrastructure Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Stress sensors<br>• Various mechanical sensors<br>• Roadway sensors | Latency: best effort<br>Data rate: very low<br>Availability: low<br>Mobility: fixed position<br>Density: low<br>Safety critical | mMTC |

# Smart Energy Applications

Smart energy application areas include power generation, transmission, distribution, and the monitoring at the consumer/user end. These applications enable real-time data analytics, dynamic control, and disruption mitigation, which can be empowered by a variety of IoT technologies.

Smart Grid

**Smart Grid**

The smart grid can be defined as a smart electrical network that combines electrical network and smart digital communication technology. With smart grid applications, smart meters communicate with utility infrastructure about important metrics such as energy usage and electrical quality. The meters are used to control and monitor home appliances and collect information for diagnosis about the utility grid. [30]

*Table 20: Smart Grid Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smart meters | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: high<br>Mission critical | mMTC |

A Smart transmission grid requires systems that can monitor the health and safety of transmission lines and circuit breakers. These include various combinations of sensors to measure voltage, current, capacitance, humidity, moisture, temperature, time, synchronization, and intelligent electronic devices. These sensors initiate alerts for critical events (e.g., voltage collapse). [30]

*Table 21: Smart Transmission Grid Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smart transmission grid sensors | Latency: very low<br>Data rate: very low<br>Availability: high<br>Mobility: fixed position<br>Density: low<br>Safety critical | URLLC |

Smart control and monitoring sensors are integrated with current fault monitoring circuits to provide more reliable and accurate monitoring of, and response to, outages along the grid. These sensors can provide real-time critical system information, often inductively powered using batteries or energy harvesting systems. [30]

*Table 22: Smart Control and Monitoring Sensors Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smart control and monitoring sensors | Latency: very low<br>Data rate: very low<br>Availability: high<br>Mobility: fixed position<br>Density: low<br>Safety critical | URLLC |

**Renewable Energy (Wind, Solar)**
The critical applications for renewable energy include monitoring and control. To maximize wind power, it's imperative that the data collected from sensors are analyzed quickly and turned into "actionable insights"—meaning each turbine can adjust its settings accordingly, based on data it receives from the system.

Renewable Energy

A reliable connection to a control center lets a turbine continually assess and account for changes in wind speed, temperature variations, and vibration to best optimize power generation. [31] With IoT-enabled monitoring of solar panels, issues with a particular panel can be easily identified and maintenance teams can be sent immediately, knowing exactly which panel is broken. Wind turbine and solar panel sensors transmit data back to a control center enabling discovery of opportunities to lower maintenance and operating costs.

*Table 23: Renewable Energy (Wind, Solar) Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Wind turbine sensors to continually assess acceleration, temperature and vibration<br>• Irradiance, temperature, humidity sensors, and voltage sensors used to measure photovoltaic (PV) output current and voltage on solar panels | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low<br>Mission critical | mMTC |

Smart Oil & Gas

**Smart Oil & Gas**

For remote surveillance and data acquisition, each wellhead supports a full array of automated data logging, monitoring, and control devices connected via cellular to a distant central control room. Streams of sensor data from drilling and other equipment transmit to metering, processing, and control stations:

- Field and seismic data continuously transmit to an onshore network operations center (NOC).
- The onshore NOC remotely monitors and controls platform equipment.
- Initiates alerts when systems are about to experience a high-pressure situation or any other unsafe issues.[32]

*Table 24: Smart Oil & Gas Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Types of sensors: remote metering, cathodic protection, gas density, pipeline pressure, custody transfer flow meters, fire/gas/H2S alarms, tank levels, tank batteries, temperature sensors, control valves, flow monitoring, electricity consumption, structural health & deformation, air pollution [33], [34] | Latency: best effort<br>Data rate: very low<br>Availability: low<br>Mobility: fixed position<br>Density: low<br>Mission critical | mMTC |

# Intelligent Transportation System Applications

Intelligent transportation systems (ITS) use of ITe, sensors, and communications in road transport applications. Using sensing, positioning, mapping, communication, and networks, vehicles can interact directly with each other and with the road infrastructure. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS), which allows road users and traffic managers to share information and use it to coordinate their actions. Through this cooperative element, it is expected to improve road safety, traffic efficiency, and comfort of driving, by helping the driver to make the right decisions and adapt to the traffic situation. [35]

Vehicle Safety

**Vehicle Safety**

Vehicle safety-related services are concerned with real-time safety messages, such as warning messages (e.g., abrupt brake warning message) to reduce the risk of car accidents.

Cooperative awareness is comprised of warnings and increased of environmental awareness, ability to detect location, speed, and heading of surrounding vehicles. Cooperative ITS safety applications rely on a combination of data from in-vehicle sensors and data shared by surrounding vehicles over a wireless link. Examples of safety-related services as defined by 3GPP [36] include:

- Forward collision warning (FCW)
- Control loss warning (CLW)
- Emergency stop
- Emergency vehicle warning
- Queue warning

*Table 25: Vehicle Safety Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Car-embedded sensors (LIDAR and RADAR), video, GNSS, and potentially data from brakes, accelerator, steering wheel, etc. | Latency: moderate [37]<br>Data rate: low<br>Availability: medium for semi-autonomous vehicles, but very high for fully autonomous<br>Mobility: high speed vehicular<br>Density: high<br>Safety critical | V2X |

Autonomous Vehicles

**Autonomous Vehicles**

With the emergence of autonomous vehicles and automated driving functions, the need for synchronization of the various traffic participants becomes increasingly necessary. Connected vehicles have the potential to cooperate to improve traffic flow on highways, in intersections, in and parking lots, resulting in increased safety. The convergence of V2X communication technologies with advanced sensors inside the vehicle, combined with ubiquitous network connectivity and available traffic information data enables cooperative automated driving. Some of the main categories of V2X communication use cases include:

- Cooperative sensing: Exchange of sensor data (e.g., raw sensor data) and object information that increase vehicles environmental perception. [38]
- Cooperative maneuvers: Includes a wide range of use cases (e.g., cooperative collision avoidance, cooperative lane change).
- High-density platooning: Platooning is operating a group of vehicles in a closely linked manner where to maintain distance between vehicles, the vehicles need to share status information such as speed, heading, and intentions such as braking, acceleration, etc. By use of platooning, the distances between vehicles can be reduced, overall fuel consumption is lowered, and the number of needed drivers can be reduced. [39]
- See-through: Real-time exchange of live video images and high throughput sensor data from surrounding cameras. In a typical "see-through" use case scenario, a vehicle following a large truck with limited forward visibility can receive high-quality, real-time video feeds from cameras installed on the trunk or other nearby vehicles to gain visibility. [40]
- Vulnerable road user: Warnings are provided for vulnerable road users (e.g., pedestrians, bicyclists, wheelchair users) to avoid collision with moving vehicles. The use of local communication systems can assist in the detection of a crossing vulnerable road user (VRU) by the use of an intelligent roadside unit that captures the VRU's messages and transmits them to the approaching vehicles. [41]

*Table 26: Autonomous Vehicles Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| To sense the environment, AVs use a combination of sensors:<br>• External sensors (e.g., GNSS, cameras, lidar)<br>• Internal automotive sensors and actuators (e.g., brakes, steering wheel, accelerator) [42, 43] | Latency: low<br>Data rate: low<br>Availability: very high<br>Mobility: high speed vehicular<br>Density: high<br>Safety critical [44, 45] | V2X |
| Vision-based sensor (e.g., stereo camera) | Latency: moderate<br>Data rate: medium<br>Availability: very high<br>Mobility: high speed vehicular<br>Density: high<br>Safety critical [44, 45] | V2X |
| Sensors based on radar, visual or infrared technology integrated into the road infrastructure. The sensors detect approaching road users and signal this to the road users by visual and audio warnings. | Latency: moderate<br>Data rate: low<br>Availability: high<br>Mobility: fixed position<br>Density: high<br>Safety critical [44] | V2X |

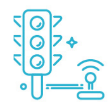
Teleoperated driving enables operation of a vehicle by a remote driver.

*Table 27: Teleoperated Driving Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensor information (e.g., lidar, radar), vehicle status (e.g., speed), and video streaming images (e.g., two cameras at front and end). | Latency: low<br>Data rate: medium<br>Availability: very high<br>Mobility: high speed vehicular<br>Density: high<br>Safety critical [44, 45] | V2X |

**Cooperative Traffic Management**

It is necessary to establish communication between vehicles, infrastructure, and drivers to improve the quality of traffic management in urban areas. A cooperative approach where these traffic entities exchange information is required to measure and manage traffic flows and congestion, traffic light timing, etc.



Cooperative Traffic Management

*Table 28: Cooperative Traffic Management Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Smart traffic signal<br>• Roadside sensors<br>• Smart signs | Latency: best effort<br>Data rate: very low (low for smart signs)<br>Availability: low<br>Mobility: fixed position<br>Density: low<br>Mission critical | V2X |

**Electronic Toll Collection System**

Electronic toll collection (ETC) automates the manual in-lane toll collection process so drivers do not have to stop and pay cash at a toll booth. ETC systems improve efficiency of traffic flow and reduce pollution levels and fuel consumption. [46] ETC system architecture may include wireless sensor nodes for identification of vehicles and vehicle owners, and establishes a communication link to the back end of the system. A central database and the web server are hosted in the cloud, while a mobile application is used for electronic transactions, subscription renewal, notification of toll payments, and for tracking toll payment history. [47]

Electronic Toll Collection System

Another technology used for electronic toll collection on pay-per-use roads is automatic number-plate recognition (ANPR), which uses optical character recognition on images to read vehicle registration plates. Electronic license plates with connectivity to the mobile network may also be used to automatically pay tolls. [48]

*Table 29: Electronic Toll Collection System Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Wireless sensor nodes<br>• Video cameras with ANPR | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | eMBB |
| Electronic license plates | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: high speed vehicular<br>Density: high | mMTC |

# Industrial Automation Applications

Industrial IoT (IIoT) applications use smart sensors and actuators to enhance manufacturing and industrial processes. These applications monitor, collect, exchange, and analyze data to enhance manufacturing and industrial processes. Some of the key IIoT applications include predictive maintenance, manufacturing efficiency, and asset tracking. [49]

Smart Logistics

**Smart Logistics**

With connected devices in the supply chain and intelligent asset tracking tools, smart logistics brings end-to-end visibility and improves the way companies transport goods, control inventory and mobile assets, replenish stock, and manage the retail experience. [50] GNSS asset tracking devices operate over cellular networks to ensure that users are always able to see the location of the asset to which the device is attached.

*Table 30: Smart Logistics Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Temperature, pressure, vibration and ultrasound sensors | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: high | mMTC |

Manufacturing Efficiency

**Manufacturing Efficiency**

IIoT can enhance operational efficiencies through real-time monitoring of the entire production line for any potential weak spots and remote monitoring of equipment function and manufacturing operations. By leveraging streaming data from sensors, plant operators can assess current conditions and recognize warning signs, reducing the risk of disruption from equipment failures, allowing for an uninterrupted workflow. [51]

*Table 32: Manufacturing Efficiency Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensors embedded in manufacturing equipment | Latency: low<br>Data rate: medium<br>Availability: high<br>Mobility: fixed position<br>Density: high | uRLLC, but has some characteristics of eMBB |

Sensors feed data from the production equipment on the factory floor into factories' analytics systems, tracking everything from access logs to vibrations. This data is aggregated in the cloud and can be used to bring visibility to production facilities, help identify bottlenecks in the manufacturing process, and support better decisions for improvements. For example, production equipment on the factory floor can communicate when quantities are low and order more raw materials to safeguard against the line shutting down, utilizing just-in-time, cost-effective replenishment. [52]

*Table 33: Manufacturing Sensors Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensors embedded in manufacturing equipment | Latency: best effort<br>Data rate: medium<br>Availability: best effort<br>Mobility: fixed position<br>Density: high | eMBB |

**Packaging Efficiency**

Packaging Efficiency

By using IoT sensors in products and packaging, manufacturers can gain valuable insights into the usage patterns and handling of product from multiple customers. Smart tracking mechanisms can track product deterioration during transit and impact of weather, road, and other environment variables on the product. This tracking also offers packaging efficiency related insights that can be used to re-engineer products and packaging for better performance in both customer experience and packaging costs. [53]

*Table 34: Packaging Efficiency Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Sensors in products and/or packaging | Latency: best effort<br>Data rate: low<br>Availability: best effort<br>Mobility: pedestrian<br>Density: high | mMTC |

# Smart Health & Wellness Applications

When connected to the internet, ordinary medical devices can collect invaluable additional data, give extra insight into symptoms and trends, enable remote care, and generally give patients more control over their lives and treatment.

Real Time Patient Monitoring

**Secure Real-Time Remote Patient Care and Monitoring**

Real-time patient monitoring leverages connected medical devices equipped with sensors that are capable of measuring different parameters such as heart rate, pulse, blood pressure, blood glucose, respiration rate, and body temperature. Sensor data is communicated wirelessly so it can be processed by medical professionals and/or stored for tracking the history of the device user. Gateway devices may be used to aggregate edge medical device sensor data and transmit it to the cloud for further processing/analysis. [54] In the event of a medical emergency, the system can initiate a call to 911 or a specialized medical response service, or contact the doctor if an episode is not life threatening but still requires intervention. The medical professional may require remote control capabilities as well (e.g., infusion pumps). [54]

*Table 35: Secure Real-Time Remote Patient Care and Monitoring Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Medical-grade wearables:<br>• Wearable device worn or placed on a body part to record a particular physiological change (e.g., respiratory rate sensors or blood pressure monitors).<br>• Any biosensor device for recording data from biological or chemical reactions (e.g., pulse oximeters or spirometers). [55] | Latency: high<br>Data rate: low<br>Availability: high<br>Mobility: pedestrian<br>Density: variable<br>Safety critical | URLLC |

Patient Care & Monitoring

**Secure Remote Patient Care and Monitoring - Non-Real-Time**

Common clinical data captured by biosensors includes vital signs, weight, blood pressure, oxygen levels, and heart rate. Data is sent to a physician's office via an application installed on the patient's mobile device. Data is stored in a database so the healthcare professional can view the data as a specific instance or as a trend and intervene if necessary.

*Table 36: Secure Remote Patient Care and Monitoring – Non-Real-Time Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Wearable devices with biosensors automated to capture and transmit health data to healthcare providers in a different location for assessment and recommendations.[54] | Latency: best effort<br>Data rate: medium<br>Availability: best effort<br>Mobility: fixed position<br>Density: high | eMBB |

### Fall Detection

Fall Detection

According to the World Health Organization, fall-related injuries are more common among the elderly and are a significant cause of pain, disability, loss of independence and premature death. Approximately 28-35% of people aged 65 and over fall each year, increasing to 32-42% for those over 70 years of age. [56] Wearable IoT sensor-based methods that alerts when a fall event has occurred can help in securing timely medical attention to avoid serious consequences from a fall.

*Table 37: Fall Dectection Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Wearable equipped with motion sensors, including accelerometers, gyroscopes, magnetometers | Latency: best effort<br>Data rate: low<br>Availability: high<br>Mobility: pedestrian<br>Density: variable<br>Safety critical | eMBB |

### Personal Fitness

Personal Fitness

Health and fitness are areas in which wearables play an essential role in facilitating self-management and self-monitoring. Wearable devices record an individual's exercise and health statistics and progress. These devices may cache the gathered data and transfer it when the network is available or according to a predefined schedule.

*Table 38: Personal Fitness Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Wearables equipped with a variety of sensors including 3-axis accelerometer, gyroscope, altimeter, temperature sensor, bioimpedance sensor, optical sensor, GNSS | Latency: best effort<br>Data rate: low<br>Availability: medium<br>Mobility: pedestrian<br>Density: high | eMBB |

Robotic Surgery

**Remote Robotic Surgery**

Integration of IoT and robotics enable complex operations such as remote surgery. Remote surgery requires real-time high-definition video transmission, low latency, and high-throughput communication capabilities to enable doctors to use surgical robots to perform surgeries on patients even though they are not in the same location. The surgical robots incorporate sensors to relay information or provide image-guided, haptic controls for remote tactile interaction.

*Table 39: Remote Robotic Surgery Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| On the patient side, this application may require several cameras (some of which could be wearable by the local staff). | Latency: low<br>Data rate: very high<br>Availability: high<br>Mobility: fixed position<br>Density: low<br>Safety critical [57, 58] | uRLLC, but may require high bandwidth |
| Robotic assisted surgical device.<br>On the remote expert/surgeon side, these applications may require a VR interface in order to provide an immersive sense of experience. [59] | | |

# Unmanned Aerial Vehicle (UAV) Applications

UAVs may be used to offer new IoT value-added services when equipped with suitable and remotely controllable machine type communications devices (i.e., sensors, cameras, and actuators). [60] UAV application areas include intelligence, surveillance, and reconnaissance operations, cargo and parcel delivery, internet provision in remote areas, emergency aid, industrial asset monitoring (pipelines), and more. [61]

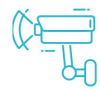
Command and Control

**Command and Control**

Command and control (C&C) commands are sent on regular intervals from the ground station to the UAVs. These commands include telemetry, waypoint update for autonomous UAV operation, real time piloting, identity, flight authorization, and navigation database update. [62]

*Table 40: Command and Control Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
| --- | --- | --- |
| Drones equipped with mobile communication link for C&C between the vehicle and a ground control station | Latency: moderate<br>Data rate: very low<br>Availability: high<br>Mobility: high-speed vehicular<br>Density: low [63] | V2X |



Surrveillance and Monitoring

**Surveillance and Monitoring**

Surveillance UAVs are used by many government organizations, such as police forces, environment agencies (for detection and management of natural events and threats), and border agencies (to detect smuggling and illegal immigrants). [64] Some of the key benefits of using a UAV for surveillance include the ability to rapidly deploy and provide a bird's eye view of an area otherwise difficult to reach, along with the UAV's ability to follow a moving object on the ground. [64]

*Table 41: Surveillance and Monitoring Control Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
| --- | --- | --- |
| Depending on the application, different types of cameras are used for surveillance. Visual cameras are used for capturing images during daylight, while a thermal camera is used for night vision, seeing through smoke or fog, vegetation monitoring, fire and heat detection using infrared patterns, etc. Data may be streamed directly from the UAV via a secure communications channel to a remote central location. | Latency: moderate<br>Data rate: medium [65]<br>Availability: low<br>Mobility: high-speed vehicular<br>Density: low | V2X |

Inspections and Surveys

**Inspections and Surveys**

Inspections and surveys are one of the first UAV applications that have been embraced by industries that need to inspect assets that are remote or difficult to reach using a vehicle or are inaccessible because of safety hazards. Some of the potential uses for UAV inspection and survey services include oil and gas pipelines, cooling towers, critical infrastructure, transmitter sites (for TV broad-cast and mobile networks), transport infrastructure (e.g., bridges and viaducts), and land mapping (e.g., agricultural fields, quarries). [64]

*Table 42: Inspections and Surveys Control Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| UAV generally carries a video camera and other sensors such as laser scanner, GNSS, gyroscope, accelerometer, and barometer. Streaming the video and other sensor data to a remote location for instant storage, verification, and analysis allows the survey team to gauge whether additional data needs to be collected. | Latency: best effort<br>Data rate: medium<br>Availability: low<br>Mobility: pedestrian to low<br>Density: low | V2X |

Goods Delivery

**Goods Delivery**

UAVs can deliver parcels and all types of goods to rural areas, as well as within urban areas. Last-mile deliveries using UAVs reduce delivery times and relieve traffic congestion in densely populated cities. Rural areas benefit as they become instantly accessible and connected. UAVs can also be used in agriculture for crop planting and spraying or to deliver medical supplies where the delivery is over a large area that is otherwise difficult to reach. [64]

*Table 43: Goods Delivery Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| UAV | Latency: high<br>Data rate: medium<br>Availability: medium<br>Mobility: pedestrian to low<br>Density: low | V2X |

Disaster Response

**Emergency/Disaster Response/Search and Rescue**

UAVs can improve the effectiveness of disaster relief and emergency response efforts by enhancing first responder capabilities and providing advanced predictive capabilities and early warnings. [66] UAV systems can aid in many disaster and emergencies, including natural disasters such as storms, heavy snow, floods, earthquakes, tsunamis, and volcanic eruptions, civil disturbances, oil or chemical spills, and urban disasters. These events can make land routes and waterways temporarily inaccessible by terrestrial or marine means and may also interrupt the communication infrastructure, leaving the affected area isolated. UAVs collect real-time data about the scale of the damage caused by the disastrous event and relay information about the disaster zone in real time to the disaster coordination base. By having timely and correct information, first responder agencies can distribute aid supplies effectively and to the places most in need. [64], [66]

*Table 44: Emergency/Disaster Response/Search and Rescue Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| If a speaker has been installed in the UAV, voice messages from the disaster coordination base can be delivered to disaster victims via the cellular network, while the voice of victims can be picked up using the microphone mounted on the UAV, and relayed back to the disaster coordination base. | Latency: moderate<br>Data rate: medium<br>Availability: medium<br>Mobility: pedestrian to low<br>Density: low<br>Safety critical | V2X |

Communication and Media

**Communications and Media**

UAVs in the media industry are being used mainly to cover news footage in journalism, film movies, and television serials, record events and functions, and for aerial photography. Photographers can use UAVs to document subjects and events in inaccessible or dangerous areas such as war zones and disaster areas where the data and video are live streamed to cover the action live on the ground and in real-time. [64]

*Table 45: Communications and Media Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| UAV equipped with a video camera | Latency: moderate<br>Data rate: medium<br>Availability: best effort<br>Mobility: pedestrian to low<br>Density: low | V2X |

Public Safety Applications

# Public Safety Applications

IoT public safety applications offer numerous benefits including greater situational awareness and improved decision making of first responders, reduction in the response time, and improved response capabilities to emergencies, improved safety of first responders and citizens and security of infrastructure, enhanced prevention and escalation of critical incidents, and extension of notifications to citizens (mass notifications and personalized). [67]

Mission Critical Communications

**Mission Critical Communications**

Mission critical communication services (voice, data, and video) provide public safety responders with highly available, always-on, reliable, and continuous connectivity between dispatch agencies and public safety users, as well as among multiple agencies' users. [68]

*Table 46: Mission Critical Communications Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Smartphones | Latency: low<br>Data rate: medium<br>Availability: high<br>Mobility: high-speed vehicular<br>Density: low | eMBB |

**Emergency Response (Police, fire, and emergency medical services)**
First responder applications use critical communication networks with broadband capabilities and make use of public safety specific devices such as first responder wearables, hazmat suits, and gunshot detectors. IoT sensor data can enhance the safety of first responders. Biometric sensors provide health tracking (heart rate, respirations, EKG, body temperature). [67], [69] Additional sensors enable remote sensing of all types, such as hazmat gases, radiological materials, biohazards, and the amount of air in a firefighter's self-contained breathing apparatus tank. Gunshot wearables can notify first responders when a "man down" vest is pierced. [69]

Emergency Response

*Table 47: Emergency Response (Police, fire, and emergency medical services) Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| • Body-worn sensors to track the health (heart rate, respirations, EKG, body temperature) and location of responders<br>• Additional body-worn sensors to detect a bullet impacting an officer's vest or detect the absence of movement that might indicate a crisis condition<br>• Sensors that will track the amount of air in a firefighters SCBA tank [69]<br><br>Meters/detectors:<br>• Air quality sensors<br>• Gunshot sensors<br>• Radiation detectors, [69] | Latency: low<br>Data rate: very low<br>Availability: high<br>Mobility: pedestrian<br>Density: low | URLLC |

Vehicle-to-infrastructure (V2I) systems help guide first responders to the scene of an emergency by way of the fastest and most direct route. V2I communications allow emergency vehicles to communicate with traffic lights, rail crossings, traffic cameras, and roads to ensure prioritized access. [70]

*Table 48: Vehicle-to-Infrastructure Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Emergency response vehicles equipped with GNSS, V2I | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: high-speed vehicular<br>Density: low | eMBB |

Images captured by first responders can provide real-time situational awareness back to commanders and headquarters, which assist incident commanders in managing resources. [70]

*Table 49: First Responders Imaged Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| High-res video cameras | Latency: low<br>Data rate: medium<br>Availability: high<br>Mobility: pedestrian<br>Density: low | uRLLC, but may require high bandwidth |

Law enforcement can use bomb disposal robots for surveillance, to investigate suspicious packages, and to safely detonate explosive devices.

*Table 50: Law Enforcement Robots Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Bomb disposal robot equipped with video cameras and chemical, biological, and nuclear sensors for detection of explosive materials. | Latency: low<br>Data rate: medium<br>Availability: high<br>Mobility: pedestrian<br>Density: low | uRLLC, but may require high bandwidth |

**Emergency Notification**

Early-warning systems leveraging IoT sensors and networks aid in mitigating and preventing loss of life and property caused by severe weather and geologic occurrences. IoT sensors can deliver accurate advance notice of what is likely to be a forest fire, earthquake, volcano, flash flood, avalanche, or tsunami. An IoT-aware crisis communication software solution can automatically issue the appropriate alerts.

Emergency Notification

*Table 51: Emergency Notification Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Environment sensors for fire, smoke, water levels, snowfall levels. | Latency: high<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | mMTC |

Earthquake early-warning systems work by deploying highly sensitive sensors near fault lines. Each sensor has an accelerometer that measures tremors and algorithms that detect earthquakes. When an earthquake is detected, a signal is sent to a server in hundredths of a second. Sensor data is aggregated across the individual devices and processed by computational engines to determine where the earthquake epicenter is located and where damaging seismic waves are headed. [71]

Alerts are issued to the local or regional community when an earthquake event occurs, usually with an indication of the expected severity of the earthquake and an approximate arrival time. Generally, the alert will be issued in the manner of a few, to tens, of seconds before the earthquake reaches the users. This warning time allows for automated systems to shut down services such as elevators, gas supplies, and even transport networks, and allows time for people to take steps to protect themselves.

*Table 52: Seismic Monitoring Sensors Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Seismic monitoring sensors | Latency: low<br>Data rate: very low<br>Availability: high<br>Mobility: fixed position<br>Density: low | URLLC |

Surveillance for Critical Infrastructure

**Surveillance for Critical Infrastructure**

Critical infrastructure assets require high-quality video monitoring to help address remote and perimeter locations, extreme environments, homeland security, and issues with vandalism. Smart surveillance cameras are critical IoT sensors that capture high-level descriptions of the scene and analyze what they see. The cameras require high bandwidth speeds to support a wide variety of applications, including object detection, surveillance, sophisticated movement detection, and facial identification. [72] The system provides live streaming and initiates alerts to operators of detected threats carried out by persons/vehicles.

*Table 53: Surveillance for Critical Infrastructure Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| High-resolution smart camera | Latency: high<br>Data rate: low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | eMBB |

Perimeter intrusion-detection systems protect the external perimeter of a facility, control access to restricted areas, and detect and monitor anomalies. Access control includes the control of persons, vehicles, and materials through entrances and exists in a controlled area or premises. [73] By utilizing thermal cameras, facilities can detect intruders from greater distances regardless of light and environmental factors, giving security personnel more time to react and respond. [74] Intrusion alarm systems signal entry or attempted entry of a person or an object into the area or volume protected by the system.

*Table 54: Perimeter Intrusion-Detection Systems Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Contact switch (gate, door, window, fence) Thermal cameras enable detection of intruders from much greater distances [74 | Latency: best effort<br>Data rate: very low<br>Availability: medium<br>Mobility: fixed position<br>Density: low | eMBB |

# Entertainment Applications

By using sensors and actuators, IoT can provide users with highly adaptive and multisensory experiences across entertainment applications.

**Gaming**

IoT will make games more interactive by using more sensors and smarter gaming equipment. By combining bio-sensing and virtual or augmented reality, video games can enhance the gamer experience by allowing the player to detect people in the game, in real or imaginary worlds. Augmented reality lets the gamer experience the real world in tandem with the game played by using motion capture to interact with surrounding objects and realistic force feedback or haptic input.

Gaming

*Table 55: Gaming Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Gaming console control | Latency: low<br>Data rate: very low<br>Availability: best effort<br>Mobility: fixed position<br>Density: low | URLLC |
| Virtual reality headsets/glasses | Latency" low, latency of rendered image of more than 15 ms can cause motion sickness [75]<br>Data rate: very high [76]<br>Availability: best effort<br>Mobility: high-speed vehicular<br>Density: low | eMBB but has low-latency requirements |
| Wearable motion controllers (gloves, vests), sensor gaming suits | Latency: low<br>Data rate: very low<br>Availability: best effort<br>Mobility: high-speed vehicular<br>Density: low | URLLC |

Ultra-High-Fidelity Media

**Ultra-High-Fidelity Media**
Multimedia platforms that support UHD video and high-fidelity audio technologies provide a highly immersive viewing experience with ultra-crisp, wide-view pictures with deep contrast and multi-channel sound. [77]

*Table 56: Ultra-High-Fidelity Media Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Portable devices (smartphones, tablets, laptops) | Latency: high<br>Data rate: medium<br>Availability: best effort<br>Mobility: high-speed vehicular<br>Density: low | eMBB |
| Passive virtual reality headsets/ glasses | Latency: low<br>Data rate: medium<br>Availability: best effort<br>Mobility: high-speed vehicular<br>Density: low | eMBB but has low-latency requirements |

**Asset Management Applications**

IoT-enabled, smart asset management solutions, locate and manage any connected asset remotely using sensors in real-time from a centralized, consolidated tracking and monitoring and analytics system.

Asset Management Applications

**Automated Asset Traceability and Monitoring**

Automated asset traceability and monitoring provides visibility into the locations of company assets, instant notifications to communicate asset arrival time and delivery destinations, and ensures valuable equipment and machineries stay on the required site. Example use cases:

- Hospitals: key and/or critical assets including machineries, equipment, ambulances, patients, instruments, etc.
- Shipping and logistics: shipping, containers, and goods.
- Industrial automation: water meters, offshore drills, and oil & gas tanks.
- Industrial assets: trailers, generators, construction equipment, cars, fleets of trucks, and service vehicles.
- Consumer products: in-transit pharmaceuticals and electronics.[78]

Asset Traceability and Monitoring

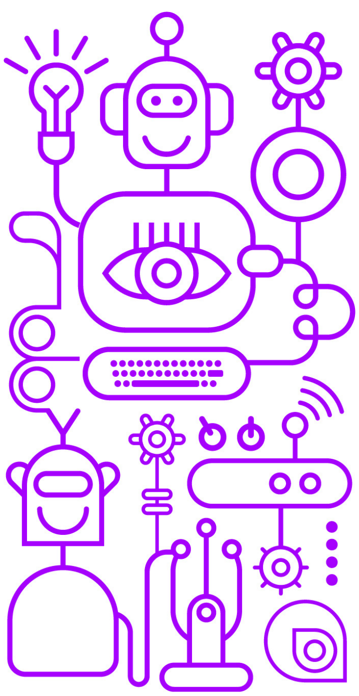
*Table 57: Automated Asset Traceability and Monitoring Characteristics and Network Slice Type*

| Devices Used | Key Characteristics | Network Slice Type |
|---|---|---|
| Mobile monitoring and tracking devices equipped with GNSS and other sensors (temperature, humidity, motion, shock, vibration, pressure, light/darkness) to monitor condition of the asset | Latency: best effort<br>Data rate: very low<br>Availability: best effort<br>Mobility: high-speed vehicular<br>Density: low | mMTC |
| Bluetooth low-energy (BLE) beacons<br>Typical uses:<br>• Warehouses: automatic inventory of assets<br>• Indoor positioning: tracking assets' location automatically [79] | Latency – best effort<br>Data rate – very low<br>Availability – best effort<br>Mobility – fixed position<br>Density – low | mMTC |
| RFID readers (e.g., handheld)<br>Typical uses:<br>• Warehouses: tracking assets that are packaged or inside a container<br>• Hospitals: tracking asset locations automatically within a limited distance range [79] | Latency: best effort<br>Data rate: very low<br>Availability: low<br>Mobility: pedestrian<br>Density: low | mMTC |

04

# Findings and Recommendations

"Defining a sufficient number of standardized network slice types is essential as customers will expect the same level of service no matter where they are. With the addition of the recommended HMTC slice definition, the resulting standardized slice types should address the most commonly used services and associated performance characteristics."



The objective of our analysis was to determine if additional network slice types are needed to support the varied IoT applications and devices that will connect to the network. Standardized definitions for the most commonly used slice types provide a mechanism for enabling roaming, as well as global interoperability for network slicing across network operators.

For our initial analysis, we assessed the performance requirements for IoT devices and applications against the three standardized slice types eMBB, URLLC, and mMTC. We determined that these three standardized network slices were insufficient. During the period of our study, 3GPP defined an additional slice type, V2X, that was incorporated into our analysis. This slice addresses the requirements of V2X applications, including ultra-low latency, high-bandwidth, highly reliable communication, high mobility, and high density. The V2X slice type also meets the performance requirements of the rapidly growing number of UAV applications requiring high mobile broadband data rates, low latency, large system capacity, and robust reliability. With the addition of the V2X slice, our analysis shows that the majority of the IoT applications and devices we examined generally map to the four currently defined slice types.

Ultimately, a smaller subset of the applications and devices were found to exhibit characteristics across multiple slices that were not a perfect match to the currently defined four standardized slice types. As a result, we are recommending consideration of an additional standardized slice type to address the performance requirements for this subset, which encompasses use cases across industrial automation, robotic surgery, and public safety. Industrial automation use cases are emerging requiring time-critical communication along with collaborative functions of robots, wearables on the manufacturing floor, and augmented reality. These functions require the transfer of large data (3D models, sizeable historical data sets, etc.) for fast intervention, maintenance, or assembly tasks. [80] Remote robotic surgery applications make use of multimodal communications, such as video, audio, and haptics, and demand a high data rate to facilitate good-quality and fast visual feedback. [81] Critical public safety applications using real-time video surveillance require high throughput and low latency to ensure high quality of service for the video stream.

The proposed new network slice type, High-Performance Machine-Type Communications (HMTC), would be defined by the key performance characteristics common to the applications in the above subset, including low latency, high availability, and high data rates. Although similar to the characteristics of the newly defined V2X slice, no mobility or sidelink is required. Below are the key performance characteristics that would typify the HMTC slice:

*Table 58: High-Performance Machine-Type Communications (HMTC) Slice Characteristics and Values*

| Performance Characteristic | Range of Values |
|---|---|
| Latency | Low (<10 ms) |
| Data rate | High-very high (>50 Mbps) |
| Availability | High (95-99.999%) |
| Mobility | Fixed position |
| Density per km | Low (<1000) |
| Criticality | Mission/safety critical |

5G is envisioned to support a wide range of IoT verticals with a diverse set of performance and service requirements. Network slicing is a key component of the 5G architecture, enabling network operators to expand their customer base and offer new, differentiated services. Through network slicing, operators can allocate their network resources based on a precise set of performance requirements. Defining a sufficient number of standardized network slice types is essential as customers will expect the same level of service no matter where they are. With the addition of the recommended HMTC slice definition, the resulting standardized slice types should address the most commonly used services and associated performance characteristics. Providing this broader set of standard slice types ensures roaming support, as well as global interoperability for network slicing across network operators.

05

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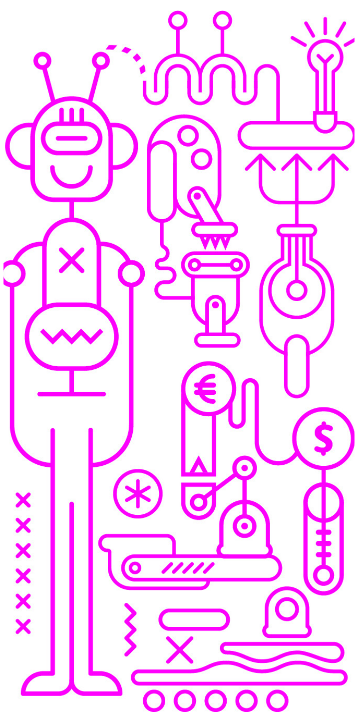

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# Appendix

*IoT Categorization Matrix*
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