The outlook for intelligent air quality monitoring in megacities as a 5G service

Solution Brief

The superior performance and flexibility of 5G networks will enable intelligent air quality monitoring that can improve the lives of people in large, dense urban areas. Monitoring air quality and providing insight and services to help cities and businesses respond to air quality hazards will demand the use of accurate measurement stations and the calibration of massive clusters of low-cost sensors in near real time.

5G will provide the required connectivity and processing performance to achieve this goal. The network slicing, edge computing, high bandwidth, ultra-low latency and other capabilities of 5G can support massive-scale sensing and environmental monitoring. This will enable mobile network operators to offer 5G-enabled scalable, smart city sensing-as-a-service to meet a diverse range of air quality monitoring scenarios and generate new sources of revenue.
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Executive Summary

Outdoor and indoor air quality and pollution monitoring is an emerging service for megacities. Outdoor air pollution from particulates and ground-level ozone is projected to become the top cause of environmentally-related deaths worldwide by 2050. Citizens are becoming increasingly interested in air quality and there is demand for tools and services to protect their health. This creates a need for intelligent monitoring of urban air quality to improve sustainability, health and wellbeing.

The current approach of using a small number of measurement stations and low-density sampling methods to create city-wide air quality indices cannot achieve high quality pollution maps at the scale of city blocks and buildings.

In this paper, we present intelligent air quality monitoring in megacities as an emerging 5G service that builds on the elastic and adaptive 5G network using features such as network slicing and edge computing. 5G can unify sensing tasks, in which control, data aggregation, and artificial intelligence are supported and optimized by the network.

5G enabled intelligent air quality monitoring will support city planning and decision-making, and create significant new services that are built on the sensing data and insights. For example, accurately pinpointing and mitigating pollution sources can help to significantly improve air quality. Residents benefit from new smart city services and enjoy an improved experience, for example, in terms of reduced congestion, better air quality and timely, personalized information.

Introduction

Air pollution as a global challenge

Air pollution is a global challenge that needs to be urgently addressed. According to the World Health Organization, air pollution exposure caused nearly 7 million deaths in 2012. More recently, the Global Burden of Disease (GBD) project reported that air pollution exposure kills 5.5 million people prematurely each year.

To make matters worse, we are witnessing exponential growth of urban areas and the emergence of megacities. Today, more than half of the world's population live in cities and it is forecast this will increase to 66 percent by 2050, with the global population of megacities growing from 3.2 billion to 5 billion by 2030. This hyper-densification results in compact energy consumption, more waste and more traffic congestion that threatens to lower air quality and further increase city pollution.

State of the art in air quality sensing

Cities have sophisticated monitoring stations to measure urban air quality caused by urban sources (traffic, domestic heating, industry) and by sources outside the city such as agriculture, shipping, natural sources and emissions in distant areas. However, the high costs of installation and maintenance of reference monitoring stations results in relatively sparse monitoring. While this provides data on background sources, satisfying the legislative requirements, it does not provide information about localized gradients of critical importance to citizens.
Cities lack high-resolution massive sensing capabilities to identify pollution hotspots (traffic junctions, construction sites, compact living areas) and allow far more precise and more cost-effective measures best suited for that microenvironment. Sensor arrays attached to street lights are being piloted in a few cities, for example Chicago’s Array of Things\(^3\) and the Barcelona Lighting Masterplan project\(^4\). Sensor arrays attached to 5G base stations are being tested by the LuxTurrim5G project of Espoo, Finland\(^5\). Citizen access to air quality measurements from the reference monitoring stations has been opened by the Helsinki metropolitan Air Quality Testbed\(^6\) and extended with Narrowband Internet of Things (NB-IoT) and 5G support by the UrbanSense project. The OpenSense research project supports mobile measurement stations with GSM/GPRS and WiFi\(^7\). Several research projects, namely OpenSense, explore participatory sensing, in which new devices can be added to the system.

However, the scale of the pilots is limited, for example the Chicago deployment aims to have 500 sensor nodes in 2018 and the Barcelona deployment comprises 1,100 nodes. This is minor against the backdrop of more than 270,000 street lamps in Chicago and more than 146,000 points of light in Barcelona. As an emerging requirement, the smart city environment needs to connect and manage hundreds of thousands of sensors.

**Vision and solution**

**Intelligent air quality monitoring**

The China Mobile, University of Helsinki and Nokia joint vision is to use the best available knowledge and technologies to monitor air quality and provide the relevant services cities and businesses require to respond to air quality hazards posed by rapid urbanization and climate change. We include a combination of dense observation networks, high-resolution forecasts and multi-hazard Artificial Intelligence (AI) enabled early warning systems for outdoor air quality services. This will help cities and businesses to set and implement mitigation and adaptation strategies for air pollution that will enable the building of a healthier, sustainable environment.

This vision is achieved through intelligent air quality monitoring that uses highly accurate measurement stations to calibrate massive clusters of low-cost sensors and improve their capabilities in near real time\(^8\). Sensor clusters are accessed using 5G networks and the data is processed locally using Virtual Network Functions (VNFs). With new calibration methods and edge computing, multivendor low-cost sensor clusters can be significantly extended in terms of accuracy, management capability and value-added features and services.

Low cost connected air quality sensing is a prerequisite for dense sensor networks to monitor highly dynamic air mass flows. It is important to capture time and space differences in air quality, such as the peaks caused by traffic rush hours and the emissions of Volatile Organic Compounds (VOC), such as pesticides, paints and other consumer and industrial products emitted from buildings. Sensor nodes can be deployed as stationary networks, mounted on vehicles or embedded in everyday devices, combining to collect a wealth of near real-time high-resolution data. Consumers participate through wearable sensors and provide constant data to the distributed sensing system. However, achieving high accuracy with low-cost sensors is an open challenge\(^9,10\). The solution requires intelligent dense measurement networks with advanced capabilities, such as data aggregation and fusion; sophisticated modeling and prediction techniques; and decision-making that optimizes the formation and execution of the low-cost sensing task, as well as the sensing accuracy.
System architecture for massive scale sensing

Massive sensing of the typically monitored pollutants carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide, ozone and particulate matter (fine particles PM$_{2.5}$ and PM$_{10}$ and ultra-fine aerodynamic particles with diameters smaller than 2.5 μm) is enabled by Stations for Measuring Earth Surface-Atmosphere Relations (SMEAR)\textsuperscript{11} devices. Master SMEAR is a highly accurate scientific measurement tower for measuring air quality parameters. The SMEAR towers form a global scientific air quality measurement network operating currently in three countries (China, Estonia and Finland). The SMEAR concept has been extended include categories of lower cost measurement devices with reduced functionality, namely mini-SMEAR and micro-SMEAR stations summarized in Table 1. Hot spot sensing and location of pollution sources are achieved through micro-SMEAR stations with access to 5G networks and converged edge cloud.

Table 1. SMEAR categories of measurement devices

<table>
<thead>
<tr>
<th>Measurement device</th>
<th>Parameters</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMEAR tower as base measure or real-time sensor network calibration</td>
<td>State-of-art system with 300-800 parameters per second Observing trace gas concentrations, aerosol particle number and mass concentrations, micrometeorological flux measurements of CO$_2$, water vapor and aerosol particles and weather at different heights on a 31m mast. Typically, one or two masts per city with fixed line connectivity.</td>
<td>1.5 MEUR</td>
</tr>
<tr>
<td>Mini-SMEAR for ambient air quality sensing</td>
<td>Vendor Sensor device tracking 10-50 parameters on a second to minute granularity at high accuracy. Typically, from a few dozen to a few hundred low mounted fixed sensors with fixed line or 5G connectivity.</td>
<td>5-10 KEUR</td>
</tr>
<tr>
<td>Micro-SMEAR for massive-scale sensing</td>
<td>Low-cost device tracking &lt;10 parameters per second/minute. Typically, hundreds of thousands to millions of low-powered sensors with massive scale access via 5G connectivity.</td>
<td>100-200 EUR</td>
</tr>
</tbody>
</table>

Figure 1 illustrates a hierarchical intelligent air quality monitoring system that supports different types of sensor as well as different connectivity models. The key innovation is to use highly accurate measurement stations (SMEAR station shown in Figure 2) to calibrate a hierarchy of 5G connected low-cost and less accurate stations. Unlike traditional air quality monitoring systems, this architecture includes mobile sensing platforms that are adaptively calibrated in real time by the system.

Figure 1. Overview of hierarchical air quality monitoring for detecting pollution hot spots
The outlook for intelligent air quality monitoring in megacities as a 5G service

Massive sensing calibration of static and mobile measuring stations in real time will produce significant amounts of data transferred from measurement stations and end user devices to and from the computing cloud. This requires rapid data processing and computation within the network at central servers and at the edge near the sensor deployments. It also requires AI and cognitive computing to produce low latency near real-time high-resolution maps for air pollution data visualization. We envisage that in the near future, accurate and near real-time air quality sensing data will be available for applications and services through data sharing platforms and Application Programming Interfaces (APIs). The network infrastructure enables the sharing of data, sensors and computing resources to support a new range of services for smart cities and the industry.

Requirements for intelligent air quality monitoring

The deployment of long range massive-scale monitoring capabilities requires sensor network planning to forecast how the dense sensor networks will operate, the economic costs and the technical details of the sensor networks’ capabilities. Designing sensor arrays with similar sensing devices is challenging when considering interference and availability of power supply and network access points. However, with the SMEAR scalable management system, planning is simplified by a centralized tower and strategically located mini SMEAR measurement devices to correct measurement error and inaccuracies taken from clusters of low-cost sensors. Mobile air quality sensors can be employed for improved spatio-temporal pollution maps for low coverage areas of the city.

Figure 2. SMEAR tower at Helsinki, Finland monitoring close to 1,200 parameters per second
The first approach to sensor network planning is to estimate the different air quality sensing deployment parameters per square kilometer as outlined in Table 2. A coarse-grained deployment may have about 100 sensors per square kilometer and an update interval of one hour. In a typical case, a megacity would have only a few dozen expensive and accurate air quality measurement towers for the city area. This coarse-grained measurement does not capture fine spatio-temporal features of air quality and it does not support city block or building level analysis of air quality. The data communications requirements are modest for coarse-grained deployments with hundreds or thousands of sensors per square kilometer. In an ultra-dense network with one sensor every meter, the data communications requirement increases up to 0.4 MB/s per square kilometer.

As a more extreme case we can consider a city region with skyscrapers and indoor sensors in addition to outdoor sensors. This ultra-dense configuration could have sensors approximately every 10 meters resulting in up to 20 MB/s data usage per square kilometer for half a second latency. Mobile measurement units add a small traffic increase to the overall traffic with the requirement of handovers for sensor connectivity. Several traffic optimization techniques can be used to reduce the data transmission requirements, for example by data aggregation and localized processing through edge computing.

Future air quality and environmental monitoring may include hyperspectral cameras and LIDAR instruments for continuous environmental monitoring and mapping, and involve a high-density deployment of static and mobile sensor arrays that stream data to the back-end cloud for data processing. This demands hundreds of MB to terabyte per second capacity per square kilometer from the network.

Table 2. Basic air quality sensing deployment parameters per square kilometer

<table>
<thead>
<tr>
<th>Density per square km</th>
<th>Outdoor – today</th>
<th>Outdoor-loose</th>
<th>Outdoor-dense</th>
<th>Outdoor with mobility</th>
<th>Outdoor and indoor with mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 sensor measurement station</td>
<td>One sensor every 100 meters</td>
<td>Dense network One sensor every 50 meters</td>
<td>Dense network One sensor every 50 meters</td>
<td>Ultra dense network One sensor every 10 meters</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes, outdoor and indoor mobility.</td>
</tr>
<tr>
<td>Latency</td>
<td>60 minutes</td>
<td>1 second</td>
<td>1 second</td>
<td>1 second</td>
<td>0.5 second</td>
</tr>
<tr>
<td>Raw comms. per square km</td>
<td>1 KB/hour</td>
<td>0.1 MB/s</td>
<td>0.4 MB/s</td>
<td>0.4 MB/s</td>
<td>20 MB/s</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Fixed line</td>
<td>Fixed line or 5G</td>
<td>Fixed line or 5G</td>
<td>5G</td>
<td>5G</td>
</tr>
</tbody>
</table>

To support the granularity necessary for spatio-temporal air quality measurements, the amount of collected data will grow to a such a level that it would be difficult to support data collection and in-network data processing with legacy systems, such as 4G NB-IoT or LTE-M. This is due to the massive number of sensors, and in particular due to the high frequency and volume of air quality measurements.

New, more accurate Air Quality Index (AQI) concepts demand massively more information delivered over the network. The capacity of an NB-IoT or LTE-M cell is typically in the order of millions of sensors. In this case, the reporting frequency and data amount per message is rather low with several bytes per message reported a few times per day. This leads to an average data rate in the range of kiloBytes per second per cell. As shown in Table 2, the required data rates for novel air quality measurement system can be up to 20 MB/s/km². This demand for high data rate is due to the frequent reporting (e.g. once per minute) leading to a capacity demand that is several hundred times more than can be supported by LTE-M and NB-IoT.
The cellular network infrastructure can support such distributed sensing deployments by connecting the sensors and offering a management plane for the deployment. Base stations can be extended with sensing functions to make them modular sensing systems connected either to the fixed network or to act as wireless relays.

In a similar manner to outdoor base stations, indoor base stations can connect indoor air quality sensors and other smart building sensors. Alternatively, longer range technologies such as LTE-M and NB-IoT, pave the way for 5G mMTC to be used for pervasive connectivity. The mobility features of cellular networks make them ideal for supporting mobile sensor units placed in vehicles.

**Value-added applications**

The key added value applications for intelligent air quality sensing include:

- High resolution spatial-temporal outdoor air quality map for city and traffic planning and decision making for targeted pollution mitigation and generating accurate and timely air pollution alerts. For example, air quality can be significantly improved by accurately pinpointing and mitigating pollution sources.

- Live and accurate outdoor air pollution data visualization for end users and enterprises providing information on the current and predicted air quality. Air quality aware navigation and IoT systems, such as applications indicating areas and routes with least pollution for outdoor activities.

- Live and accurate indoor air quality data visualization and analysis. A significant part of outdoor air pollution is due to harmful VOCs from indoors. The indoor measurement network would enable the automatic assessment of the VOC emissions of buildings.

- Wearable health and fitness devices that make recommendations regarding indoor and outdoor air quality for sports and activities.
5G for intelligent air quality monitoring

New capabilities with 5G

The 5G network with its new radio and core network is significantly more versatile than previous generation networks for supporting new services and vertical applications in megacities\textsuperscript{12}. For the radio part, the versatility stems from the different communications techniques supported. For the core network part, network slicing and function decomposition result in an adaptable and reconfigurable system that has built-in support for Quality of Service (QoS) functions and edge computing. The 5G architecture enables vertical and horizontal slicing of the network, meaning that a slice could be configured for a specific application or use case, such as intelligent air quality monitoring or for a specific customer of a network operator. Furthermore, these slices, for example a customer-specific vertical slice, could be provided to the customer as Network as a Service.

The International Telecommunication Union (ITU) has classified 5G mobile network services into three categories: enhanced Mobile Broadband (eMBB), ultra-reliable and Low-latency Communications (uRLLC), and massive Machine Type Communications (mMTC). The mMTC classification envisions ultra-dense machine communications to fulfil the expectations of digitization. This is even more critical in mega-cities where the deployment of machines and sensors is expected to be ultra-dense. The mMTC aims to support 10-100 times more devices than today with very long battery life and low signaling overhead\textsuperscript{13}. The 3GPP and the ITU 5G mMTC requirements specify that the connection density should support one million devices per square kilometer meeting certain quality of service requirements. NB-IoT and LTE-M (Rel 14) approach the 5G requirements and pave the way for meeting the 5G mMTC requirement.

5G is expected to bring a paradigm shift over 3G and 4G networks as it will natively support massive scale, low latency, very high reliability and high throughput for new use cases and applications such as massive intelligent sensing or augmented reality. This will be realized through increased spectral efficiency, support for contiguous and non-contiguous spectrum, and much broader channel bandwidths. 5G spectral efficiency is increased mainly by inter-cell interference cancellation and avoidance, and massive MIMO with much higher number of beams leading to a superior antenna gain, less interference between users and more MIMO layers for high capacity and throughput. 5G Multi Radio Access Network (Multi-RAT) will take benefit from all available spectrum options from 400 MHz to 90 GHz, including licensed, shared access and license exempt bands, FDD and TDD modes, including Supplementary Uplink (SUL), as well as narrowband and wideband Carrier Components (CC).

Another important part of 5G is its new core network (5GC) that evolves towards a service-based architecture suitable for megacities. 5GC will support many new enabling network technologies. 5GC will enable Network as a Service (NaaS) and therefore support improvements in performance, flexibility and agility. The key elements of the 5G core network are function decomposition, VNFs and distributed cloud for layered and modular architecture, and network slicing for automation and business agility and mitigating environmental problems.

As an enabler for NaaS, network slicing is expected to bring the required flexibility into the 5G network to address services with diverse requirements. A network slice is composed of a collection of logical network functions that support the communication service requirements of particular use cases.
As a related concept to network slicing, mobile edge computing has been introduced to address network resource congestion and latency challenges by supporting connectivity management and computing at the edge of the network, with ultra-low latency for delay sensitive applications and very high bandwidth, near the communicating endpoints. The network slice provisions the network infrastructure and QoS requirements, whereas VNF placement and edge computing enable the distribution of IoT and other application logic across the network substrate. The network edge provides location awareness and real-time insight into network and context information for applications. Therefore, it can benefit innovative services and network-based service innovations towards subscribers, enterprises and verticals.

5G as an enabler for scalable sensing

The forthcoming 5G architecture depicted in Figure 3 will provide a foundation for massive scale sensing by supporting energy efficient wireless communications, high-resolution sensor positioning and high bandwidth communications, as well as localized data processing and analytics through mobile edge computing. The 5G driven architecture can adapt its needs and scale according to demand. The 5G network will support air quality sensing through its architecture, which is characterized by massive scale, converged edge cloud, universal adaptive core, programmable network OS and augmented cognition systems, and therefore can adapt its needs and scale according to demand.

Figure 3. 5G driven architecture to provide necessary flexibility, scale and intelligence for an air quality monitoring system.
In massive sensing scenarios, such as accurately monitoring air quality, the high volume of data sent to the cloud for processing can impair drastically the performance of the network infrastructure. To support efficient local communication at the pollution hot spot level, 5G will feature edge computing that enables ultra-fast and ultra-reliable communications between sensing devices within a local context that can be leveraged to reduce the load on the infrastructure network. Figure 4 illustrates massive-scale air quality monitoring supported by edge computing and the Machine Type Communications (MTC) infrastructure of the 5G architecture.

Figure 4. 5G and massive-scale air quality monitoring

[Diagram of 5G and MTC infrastructure with labels for MTC Application Domain, Service and cloud-based core network with VNFs, mMTC sensing Slice and VNFs, Mobile Edge Computing, Aggregated air quality sensing data, Sensor management and calibration, 5G Radio, Air quality sensor, Air quality sensor, Air quality sensor, MTC device, MTC device, MTC device.]
Table 3 presents a comparison of pertinent network features for large-scale sensing. 4G LTE provides the baseline mobile broadband connectivity that is enhanced for IoT devices in LTE-M. LTE-M leverages LTE and provides data and voice communications and mobility support with low power utilization. LTE-M is suitable for sensing tasks that require up to 1 Mbps bandwidth and mobility support. NB-IoT, on the other hand, targets smaller typically stationary devices with reduced power consumption and more limited available bandwidth.

Table 3. Summary network features for large-scale sensing

<table>
<thead>
<tr>
<th></th>
<th>LTE Cellular</th>
<th>NB-IoT</th>
<th>LTE-M</th>
<th>5G mMTC Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network performance</td>
<td>Medium</td>
<td>&lt;250kbps</td>
<td>&lt;1Mbps, voice</td>
<td>Versatile</td>
</tr>
<tr>
<td>Mobility</td>
<td>Yes</td>
<td>No handovers</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Real-time</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Edge computing</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Network positioning</td>
<td>Yes</td>
<td>Yes (since Rel14)</td>
<td>Yes</td>
<td>Accurate 3D positioning</td>
</tr>
<tr>
<td>Power requirements</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Cellular network architecture is an attractive enabler for intelligent sensing applications, because it can offer reliability, management operations, as well as take security and privacy into account. Sensing as a service has great potential as offered by the network through largely software-defined architecture with the network slicing mechanism and the placement of VNFs across the slices. As a network service, distributed sensing can be optimized and deployed for various intelligent air quality scenarios creating significant value for the network as a versatile platform.

China Mobile, University of Helsinki and Nokia have identified the following 5G features for massive-scale sensing and environmental monitoring:

- Network slicing: a 5G physical network can be converted to multiple logical networks enabling the generation and instantiation of a sensing slice in support of sensing requirements and their specific SLAs, which will also bring new business models and value chains.

- Edge computing: participatory sensing can be supported by edge computing that enables localized communications, in which devices communicate with each other in the local context. This is expected to bring significant latency and scalability benefits and support the development of opportunistic sensing applications that connect nearby devices, such as smartphones and mobile sensors, to create an ensemble of sensors.

- High accuracy positioning: high accuracy positioning is instrumental for sensor calibration as well as for applications on the end devices. It is highly desirable for mobile sensors to have high spatio-temporal data.

- High throughput and capacity: the high spectral efficiency of 5G will support the collection of new types of environmental information, leading to massive data consumption, particularly for future advanced sensing solution with hyperspectral cameras and LIDAR instruments for continuous environmental monitoring and mapping.
Benefits and business models

Intelligent air quality monitoring provides the relevant services cities and businesses require to enable them to respond to air quality hazards created by rapid urbanization and climate change. 5G offers significant cost reductions through smart, city-wide optimization. It also creates significant new services, improved city planning and decision-making. Stakeholders across the value chain are given the opportunity to envision inspiring services and collaborate for a more livable environment.

Sensing data and insights are expected to provide a rich basis for ecosystems for new smart city solutions. Public and private sectors may take advantage of the data for accurate, comprehensive and timely environmental supervision, improvement and even prediction to help improve public service and business operation. Application developers and system integrators gain more inspiration and capability with sensing data for solutions to enterprise and consumer markets (e.g. smart masks that adapt automatically in real time to pollutants). Most importantly, residents benefit from new smart city services and improved experience, for example, enjoying less congestion, better air quality and timely, personalized information.

Figure 5 shows the potential value chain for a 5G-enabled air quality sensing system. Mobile operators can offer a unified solution for 5G-enabled scalable smart city sensing (Sensing as a Service) supported by micropayment platforms that can bring third parties into the data market and generate new revenue from data.

Figure 5. Potential air quality monitoring value chain enabled by 5G connectivity
In addition, distributed AI technologies with a wide range of analytics services can add more intelligence and value to the data collected and sold. This ranges from a variety of real-time data, unusual behavior and future values prediction, to site monitoring. Intelligence for the analysis of air quality measurements, offered by third party expert vendors, could be located in a central server or at the edge. In both cases, the operator could offer 5G resources through open APIs that will be integral features for 5G systems.

Diverse scenarios, business-to-business (e.g. accurate decision making in production to avoid pollution), business-to-consumer (e.g. more accurate air quality sensors, “green path” applications informing users of where the best air quality is from point A to B) and government use (e.g. warning systems or accurate location of pollution sources), are foreseen for air quality sensing. Common for all scenarios is that they will be part of modern smart cities, where a critical problem due to pollution is addressed with 5G-enabled sensors.

**Abbreviations**

- **API** Application Programming Interface
- **AQI** Air Quality Index
- **CC** Carrier Components
- **eMBB** enhanced Mobile Broadband
- **ITU** International Telecommunication Union
- **LIDAR** Light Detection and Ranging
- **mMIMO** massive Multiple Input Multiple Output
- **mMTC** massive Machine Type Communications
- **MTC** Machine Type Communications
- **NaaS** Network as a Service
- **NB-IoT** Narrowband Internet of Things
- **QoS** Quality of Service
- **SLA** Service Level Agreement
- **SUL** Supplementary Uplink
- **uRLLC** Ultra-reliable and Low-latency Communications
- **VNF** Virtual Network Function
- **VOC** Volatile Organic Compound
References


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