Saudi Arabia
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Fourth Industrial
Revolution

IOT & AIOT

Embedding Intelligence Everywhere

Briefing Paper

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Contents

Executive summary

The Internet of Things (IoT) has initiated a transformative revolution of technology that is continuing to drive us into an era where there is convergence between the physical and digital worlds.

IoT is about the power of interconnection, through a complicated web of sensors, data analytics, and smart technologies. IoT allows common objects to communicate, adapt, and provide invaluable insights. In addition, IoT can be deployed using different methods of connectivity.

IoT enables industries with digitalization in a plethora of sectors such as healthcare, agriculture, manufacturing and transportation to evolve and innovate in unprecedented ways. From predictive maintenance to supply chain optimization, from smart cities to precision agriculture, IoT is driving a model shift.

As we begin on this specific IoT journey, it becomes clear that we are living in a time where the digital landscape of today is fundamentally different from what it was a few years ago. IoT is proof of human skills and our unlimited journey for invention and innovation.

This briefing paper marks a significant milestone in our collective examination and understanding of IoT and explores the multilayered world of IoT, including the intricate details, as well as its remarkable potential, and anticipated impact on our lives and businesses.

Also, we will explore IoT with cellular connectivity that binds the power of cellular networks to enable seamless communication between devices, systems and applications. We will also explore the core principles in cellular IoT while examining real-world applications.

Furthermore, we will explore the futuristic opportunities IoT has to offer, while envisioning the future and extending the horizons of IoT to provide innovative insights into the convergence of Artificial Intelligence (AI) and IoT technologies.

Introduction

A digital heartbeat for the Network

Welcome to the world of the IoT, an innovative technology that bridges the physical and digital worlds. IoT is a network of interconnected physical objects or 'things' embedded with sensors, software, and other technologies to collect and exchange data over the internet connectivity. In this introduction, we will dive into IoT, focusing on its core elements: sensors, cellular connectivity, and the applications and visualization that transform raw data into actionable insights, enhancing efficiency, and improving various aspects of our lives.

The diagram above illustrates the three primary domains of a typical IoT system. Sensors serve as the primary interface for capturing real-world data. This data is then shipped to application servers via networks such as cellular, Wi-Fi, etc. The collected sensor data undergoes visualization and analysis within the application servers, facilitating informed decision-making. We will explore the three domains separately in the upcoming sections.

Sensors

Sensors are the foundation of the IoT ecosystem. These devices are responsible for collecting data from the physical world. They come in various types, like environmental , motion, proximity, etc. Sensors can be deployed in diverse contexts like industries, smart homes, and wearables. They capture real-time data and play a crucial role in providing the input necessary for monitoring and decision-making in IoT systems.

We will begin our introductory session by focusing on different sensor types, although it is important to note that there are other varieties of sensors.

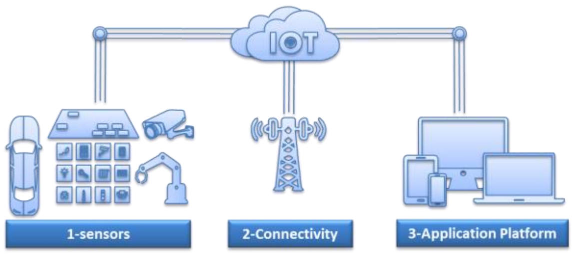


Fig. 1 IoT components

Sensors

Biometric Sensors

Biometric sensors represent a cutting-edge category of IoT devices that have gained significant importance for their remarkable applications in enhancing security and enabling seamless authentication processes. Biometric sensors have emerged as powerful tools for verification and identification, making them vital in both personal and professional environments.

Sensor on Mobile Devices

Sensors on mobile devices are essential components of the IoT ecosystem, enabling a wide range of applications. Positioning sensors in mobile devices provide precise and semi-precise locations, enabling tracking, turn-by-turn directions, and location-based services. Light sensors, commonly used in smartphones, adjust screen brightness based on the environment.[1]

Medical Sensors

Medical sensors in IoT cellular applications have revolutionized healthcare by allowing continuous monitoring and remote patient care.

Devices like Apple Watch (introduced in 2015) and Fitbit incorporate medical sensors to collect data, including heart rate, blood pressure and blood glucose levels. These sensors are essential for remote patient monitoring, which reduces hospital visits and ensures efficient patient monitoring. [1]

Environmental Sensors

Environmental sensors are vital for tracking and managing our surroundings for example, temperature and humidity sensors, such as those found in climate control systems and products. Air quality sensors monitor pollution levels and provide data for smart cities and environmental protection agencies. Soil sensors help optimize irrigation in precision agriculture.

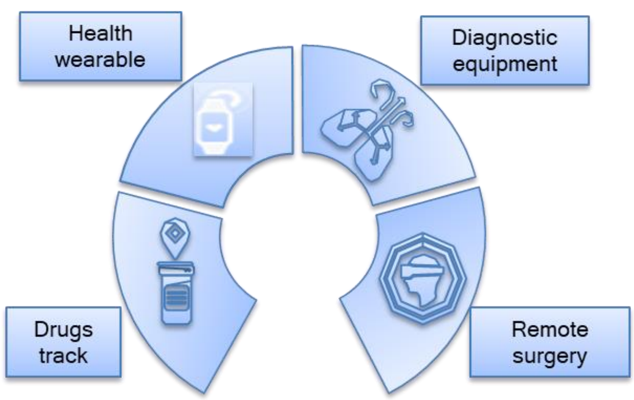


Fig. 2 Medical sensors

Fig. 3 Biometric impression

Connectivity

Connectivity in IoT exists in multiple networks with different technologies based on their coverage requirement; each IoT connectivity can be categorized into one of the main connectivity mechanisms below.

Wi-Fi
Wi-Fi offers high-speed connectivity within a limited range, typically up to 100 meters. It is suitable for smart homes, offices, and commercial settings.

Bluetooth
Bluetooth is a short-range wireless technology that connects IoT devices over distances of up to 100 meters. It is commonly used in applications like smart wearables and proximity-based systems.

Zigbee
Zigbee is a low-power and short-range wireless technology with a range of up to 100 meters. It is ideal for home automation, smart lighting, and sensor networks.

Z-Wave
Z-Wave is a low-power and short-range technology with a range of up to 100 meters. It operates in the sub-GHz frequency band, making it suitable for smart home applications.

LoRaWAN
LoRaWAN provides low-power and long-range connectivity with a range of several kilometers to tens of kilometers. It is suitable for applications like smart agriculture, environmental monitoring, and asset tracking.

Sigfox
Sigfox is a low-power and wide-area network technology that offers long-range connectivity of up to tens of kilometers. It is used in many applications, such as smart metering and logistics tracking.

Cellular IoT
Cellular IoT comprises a range of cellular connectivity options for IoT devices. The network (4G/5G) provides high-speed and low-latency connectivity, making it ideal for a wide array of IoT applications, from smart cities to autonomous vehicles. 5G and 4G LTE offer fast cellular connectivity, serving applications like connected cars, industrial IoT, and mobile health monitoring. NB-IoT and LTE-M are both low-power, wide-area cellular technologies that provide extended coverage and moderate data rates for IoT applications, such as smart agriculture, asset tracking, and smart meters. These cellular options offer diverse solutions for the evolving IoT landscape.

Connectivity	Range	Application
Wi-Fi	100m	LAN, homes
Bluetooth	100m	Wearables
Zigbee	100m	Smart lighting
Z-Wave	100m	smart homes
LoRaWAN	1~10 km	Assets tracking
Cellular	35 km(band dependent)	Connected cars, industrial IoT

Table. 1 Connectivity

Application Platform

Application stands as the major domain in any IoT system, facilitating the monitoring and analysis of data gathered from sensors to inform comprehensive decision-making and actions. This domain covers six key subsections as defined below.

1.Data Collection

IoT devices use protocols like HTTP and sockets to communicate data to gateways or directly to central platforms, enabling seamless and efficient data transfer.

2.Data Processing

Data processing and filtering occur using tools like Apache Kafka and Apache Spark, facilitating real-time data processing. Companies like IBM are known for their data processing solutions.

3.Data Storage

IoT data is stored in various databases, such as relational-based, document-based, and/or key-value-based databases, often utilizing scalable storage options provided by cloud platforms such as Microsoft, Google, and Amazon.

4.Data Visualization

Data is visualized using tools like Tableau, Power BI and custom web applications. Typically, these visualization tools are connected to data sources through standard databases.

5.Analytics

Machine learning and predictive analytics are performed using tools, often with the support of powerful algorithms and data processing techniques to extract valuable insights and make data-driven decisions.

6.Security and Privacy

IoT data is secured using protocols such as HTTPS to encrypt data transmission. Encryption libraries are applied to IoT devices and cloud platforms to ensure the confidentiality and integrity of data throughout the IoT ecosystem.

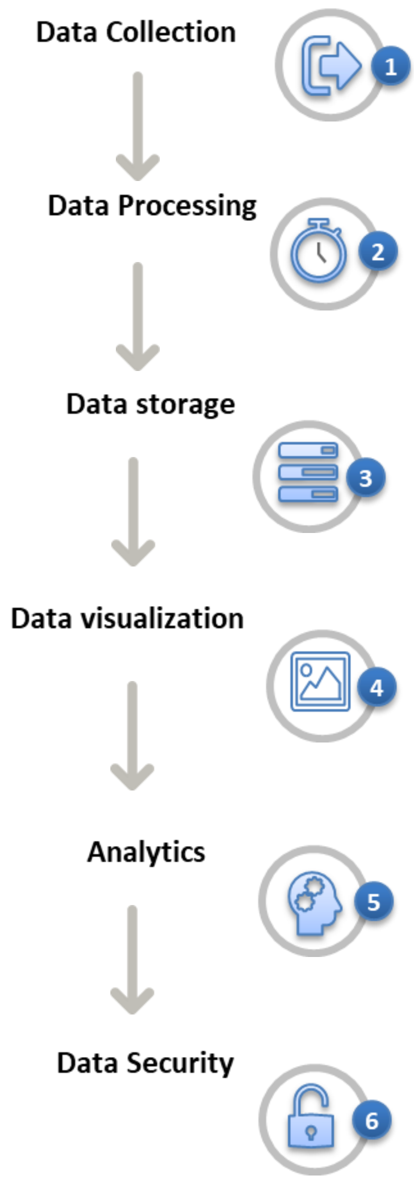


Fig. 4 Application platform data flow diagram

IoT Evolution

Building Tomorrow's World Starts Today

In the early 1990s, an attractive journey was initiated with the invention of GPRS (a revolutionary mobile data service). GPRS, though, initially offered limited internet speeds. Data SIM cards played a key role and became the main enabler of connectivity.

As technological demands evolved, a growing need for automated M2M communication emerged. M2M emerged as the key player, enabling direct and independent interactions between devices, free from human intervention. This invention facilitated remote monitoring and control in industries with efficient data exchange.

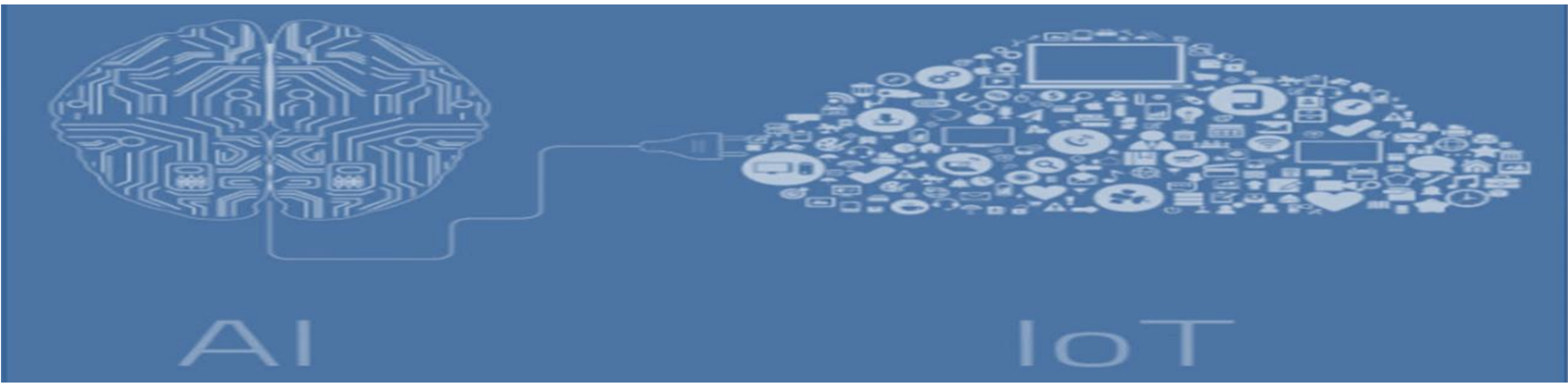
M2M revolutionized the way devices communicate by introducing standardized protocols and improved scalability. It enabled devices of various kinds to interact seamlessly, laying the groundwork for a highly interconnected world.

Today, IoT is a force reshaping our digital landscape, like smart homes. Beyond connectivity, it also provides intelligence derived from the data that IoT devices generate, promising an ever-evolving journey into a profoundly interconnected environment.

M2M Era (2G)

Start of the M2M era

IoT communication evolved into M2M connectivity. GSM introduced digital voice and text messaging, making it suitable for early IoT applications. IoT devices often depend on GPRS and EDGE for data transmission. These technologies allowed for circuit-switched and packet-switched data services. Data SIM cards became dominant for IoT connectivity. IoT devices primarily included basic sensor networks and remote monitoring systems. Examples included early asset tracking systems and security systems. Data rates typically ranged from 9.6 Kbps to 384 Kbps.



IoT Data Expansion (UMTS)

IoT Landscape Transformation

The 3G era brought a significant expansion in IoT data capabilities. UMTS (Universal Mobile Telecommunications System) and HSPA (High-Speed Packet Access) provided higher data rates and more extensive coverage for IoT applications. IoT data SIM cards with 3G connectivity allow for faster and more reliable data connections; its prominent applications include remote healthcare monitoring, video surveillance, etc. Data rates ranged from several hundreds of Kbps to a few Mbps.

Evolution of IoT Connectivity (LTE)

Time when smart agriculture, asset tracking and environmental monitoring took the Limelight

The 4G LTE era represented a significant technological advancement for IoT, introducing an all-IP architecture with higher data rates and low latency, ideal for real-time data. Data SIM cards for 4G IoT devices enable applications with refined sensors, real-time data exchange, AR experiences, remote robotics control and industrial automation. Data rates reached multiple Mbps, and IoT device deployment surpassed hundreds of millions.

Subsequently, the emergence of NB-IoT and LTE-M marked a transition to IoT-specific technologies designed for low power consumption and extended coverage. Data SIM cards for NB-IoT and LTE-M devices prioritized power efficiency. IoT applications during this period encompassed smart agriculture, asset tracking, environmental monitoring and utility metering. Devices were engineered for extended battery life with data rates ranging from a few Kbps to several tens of Kbps. The number of deployed IoT devices reached the billions.

Massive IoT (NR)

Entering an era defined by extensive IoT adoption

The latest generation, 5G NR (New Radio), promises to transform IoT by supporting massive device connectivity, ultra-low latency and network slicing for IoT applications. Technical vendors like Qualcomm, Nokia and Ericsson played key roles in 5G IoT development. Data SIM cards for 5G devices provided high-speed and low-latency connectivity. IoT applications in the 5G era include massive IoT deployments in smart cities, real-time industrial automation with precise robotics control and immersive AR experiences with minimal latency. Data rates can range from Mbps to Gbps. Billions of IoT devices that enable a wide range of innovative applications are expected to be deployed. [2] [3] [4]

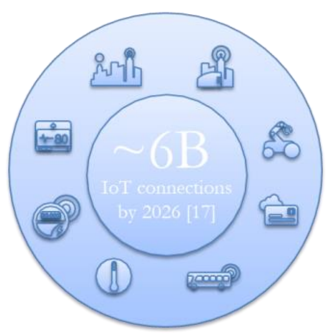


Fig. 5 6B IoT connections

3GPP Standardization & Spectrum

3GPP holds a central role in shaping the dynamic landscape of the IoT. This collaborative initiative, drawing together some of the world's foremost telecommunications standards organizations, serves as a foundation for defining the cellular technologies that support the material of IoT connectivity. With history across numerous releases, 3GPP standards have contributed to conducting a new era of IoT innovation, providing the essential framework and detailed specifications required to enable a vast range of IoT applications.

From the introduction of dedicated IoT standards such as NB-IoT and LTE-M to the ongoing development of Release 16 and the future prospects in Release 17 and beyond, 3GPP is steadfastly driving forward transformative innovations. These standards empower a diverse range of use cases across an array of industries, stretching from the world of smart agriculture to the demands of mission-critical industrial automation, highlighting 3GPP's commitment to shaping the IoT future.

3GPP Standardization

Here we explore with an overview of the key developments, features, and primary use cases associated with each 3GPP release and how it relates to IoT; by providing a snapshot of the recent past and future of IoT standards within the 3GPP framework.[5]

In 3GPP Release 13, NB-IoT and LTE-M were introduced as cutting-edge IoT standards. They extended the battery life, provided cost-effective connectivity, and brought features like extended coverage and energy-efficient communication. These technologies enabled various use cases, such as smart agriculture, asset tracking, and smart cities. In addition, eMTC (enhanced Machine Type Communication) and other advanced communications that improved data exchange were introduced in release 13. Releases 14 and 15 focused on IoT network support, enhancing scalability and location positioning.[1]

3GPP Release 16 - Focusing on Critical IoT (2021)

In the evolution to Release 16, an influential addition was the introduction of Time-Sensitive Networking, a key feature customized to support real-time industrial automation and vital IoT applications demanding both low-latency and high reliability. This release highlighted the significance of URLLC in fulfilling the requisites of mission-critical IoT scenarios. Notable key features included the support for latency-sensitive applications, the facilitation of mission-critical IoT deployments, and the evolution of industrial automation.

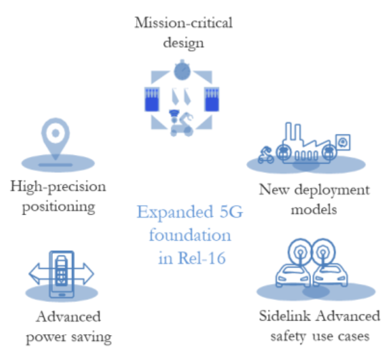


Fig. 6 IoT deployments

These advancements formed the basis for a spectrum of primary use cases, bridging from industrial automation and autonomous vehicles to telemedicine. [5]

3GPP Release 17 - Extending IoT Capabilities (2022/2023)

By Release 17, the IoT landscape encountered a transformative shift. Release 17 aims to be inclusive by catering to a wide range of IoT use cases. This release seeks to provide a solid foundation for diverse IoT scenarios, whether it is the intelligent infrastructure of smart cities, the ever-evolving healthcare applications, or the complex web of logistics management. [5]

Key features to be introduced within Release 17 comprise a host of IoT optimizations and broader support for various use cases, ensuring the standard's adaptability to meet each application's unique requirements. Smart cities and infrastructure projects are set to benefit from more efficient and interconnected systems, including healthcare, which will see advancements in remote patient monitoring, making healthcare services more accessible and effective. The logistics and supply chain sector will witness precision optimization and enhanced tracking capabilities, ensuring the efficient movement of goods. Additionally, the agricultural IoT sector is expected to experience growth and innovation, contributing to sustainable and technologically advanced farming practices. Release 17 embodies the ever-evolving nature of IoT standards and holds the promise of revolutionizing how we interact with technology in diverse sectors. [5]

Low Device Complexity
IoT standards evolve with low device complexity, with features like narrowband operation and half-duplex operation. This simplifies the design and operation of IoT devices, making them more cost-effective and accessible to a broader range of applications.

Optimized Power Consumption
The ongoing development of standards introduces optimized power consumption through enhanced low-power modes, such as eDRX, and lower output. This focus on energy efficiency is key for prolonging the life of IoT devices, particularly those operating on battery power for extended durations.

Network Enhancements
IoT standards evolve to support the coexistence of half- and full-duplex devices, reducing control signaling. These network enhancements enable more efficient and seamless communication between IoT devices, enhancing the overall performance and reducing interference.

Coverage Recovery
To ensure reliable connectivity in challenging environments, standards introduce features like the repetition and bundling of small payloads, frequency hopping and the utilization of relay and/or side links. These measures enhance the robustness of IoT networks and help overcome coverage challenges in various scenarios.

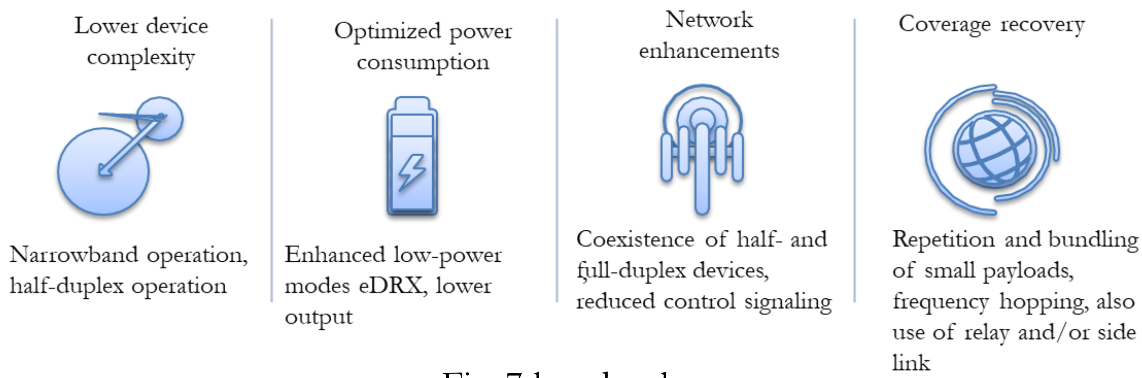


Fig. 7 key developments

Spectrum Consideration

Frequency band allocation is a fundamental aspect of cellular IoT deployments, impacting the entire E2E ecosystem. In cellular IoT, various frequency bands are allocated to provide different requirements and use cases. The choice of frequency bands has a profound impact on IoT device performance, network coverage, and overall requirements.

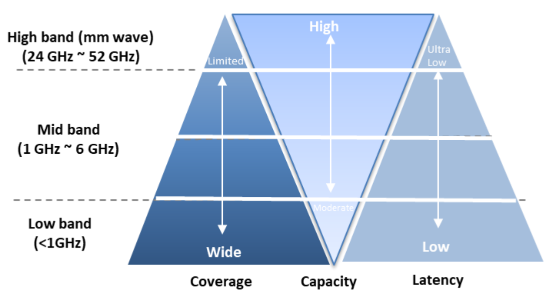


Fig. 8 Spectrum consideration

The primary consideration in selecting frequency bands for cellular IoT is balancing coverage and capacity. Low-frequency bands, such as those in the sub-1 GHz range, offer extensive coverage and excellent propagation characteristics, making them suitable for applications in agriculture and utilities. On the other hand, higher-frequency bands, like the 2.4 GHz band, can handle more devices simultaneously and are ideal for applications demanding higher data rates, like smart cities and industrial automation. The allocation of frequency bands should also consider interoperability and international standards. Cellular IoT technologies operate on harmonized frequency bands globally, ensuring seamless device communication across borders. Furthermore, the coexistence of IoT devices with other wireless technologies, like Wi-Fi and Bluetooth, must be carefully managed. Coexistence challenges may arise in densely populated areas, and solutions should be designed to mitigate interference.

These are general recommendations and the choice of frequency band may vary based on specific regional regulations and requirements

Below are some use cases with their expected spectrum based on the requirements of coverage, latency and capacity

Application	Spectrum	Reason
Smart Agriculture	Sub-1 GHz	Excellent coverage for vast agricultural areas
Smart Cities	Sub-1 GHz or 2.4 GHz	High-density areas may benefit from 2.4 GHz, while Sub-1 GHz is suitable for wide-area monitoring
Industrial Automation	Sub-1 GHz or 2.4 GHz	2.4 GHz for high data rates and sub-1 GHz for industrial coverage area
Healthcare Monitoring	2.4 GHz	short-range medical device communication
Home Automation	Sub-1 GHz or 2.4 GHz	2.4 GHz is ideal for high-data-rate, while Sub-1 GHz is suitable for low-power, long-range home sensors

Table. 2 Spectrum applications

Salient Features

Unveiling the key characteristics of IoT

The IoT is a vast landscape of interconnected devices, data streams, and applications that have the power to transform industries, enhance our daily lives, and create new opportunities. At the core of this dynamic ecosystem are several features. These features serve as the inherent properties of IoT.

In this chapter, we will delve into the features to gain a deeper understanding of their significance in the context of cellular IoT. From energy efficiency and interoperability to digital transformation enablement, shared value creation, and security and privacy, each feature plays a unique and crucial role in shaping the world of IoT and enabling its potential. Let us explore these to uncover the details and importance of each in the cellular IoT landscape.

Interoperability

Interoperability is a key to the seamless operation of IoT ecosystems. In both cellular IoT and Industry 4.0, following global standards and protocols ensures that devices and machines from various manufacturers can communicate effortlessly. This simplifies device deployment, promotes collaboration, and boosts the creation of comprehensive, globally accessible IoT ecosystems. For example, smart cities consist of a plethora of diverse devices, such as traffic sensors, waste management system devices, and public safety equipment. Those devices must communicate seamlessly. A practical example is the integration of traffic management systems in smart cities, where traffic lights from different manufacturers adhere to interoperable standards, enabling centralized traffic control and real-time traffic flow adjustments. In Industry 4.0, machines from different manufacturers in a smart factory communicate effortlessly with sensors and machines and coordinate in real-time to ensure synchronized manufacturing processes.

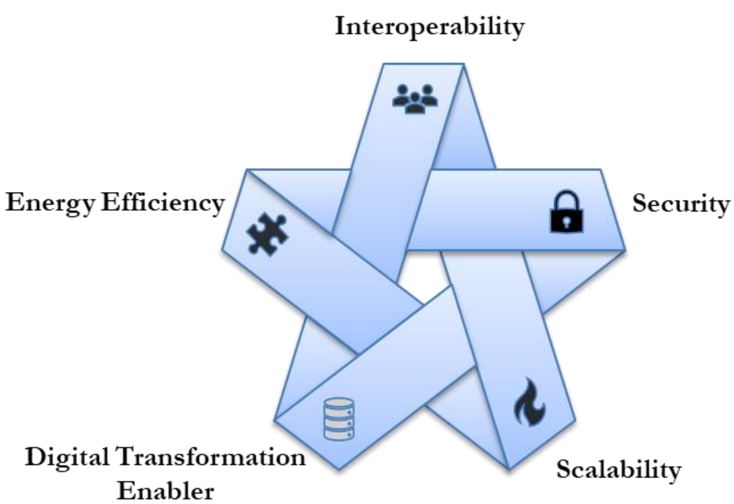


Fig. 9 IoT key features

Digital Transformation Enabler

Cellular IoT serves as a key enabler of digital transformation in diverse domains, including smart cities, agriculture, and industrial automation. Cellular IoT facilitates real-time data collection from remote devices and sensors by connecting physical assets and environments. This data collection facilitates analytics, machine learning, and automation, which leads to operational efficiency, informed decision-making, and innovation. In the context of agriculture, cellular IoT enables digital transformation by connecting soil moisture sensors, weather sensors, and automated irrigation systems, allowing farmers to monitor and optimize their operations remotely for increased crop production while maintaining low resource demand. In Industry 4.0, it is evident in smart factories where real-time data from machines and sensors perform predictive maintenance. For example, a machine learning predictive module can predict when a critical component is about to fail, allowing maintenance to be scheduled beforehand. This minimizes the downtime and optimizes production. These applications demonstrate the key role that cellular IoT plays in digital transformation.

Scalability

Scalability is a fundamental characteristic that empowers IoT solutions adapting to the evolving needs and accommodates the exponential growth in numbers of devices and sensors. In cellular IoT, scalable solutions are inherently capable of handling millions of connected devices and applications in diverse sectors like healthcare, smart cities, and agriculture [6].

For instance, large-scale agricultural monitoring using cellular IoT allows farmers to add more IoT sensors as their operations expand; and to continuously collect data on soil conditions, weather, and crop health. Wearable IoT devices for health tracking, such as fitness trackers and smartwatches, can scale to accommodate more users. As the demand for personal health monitoring increases, these devices can handle growing users' demand for health insights.

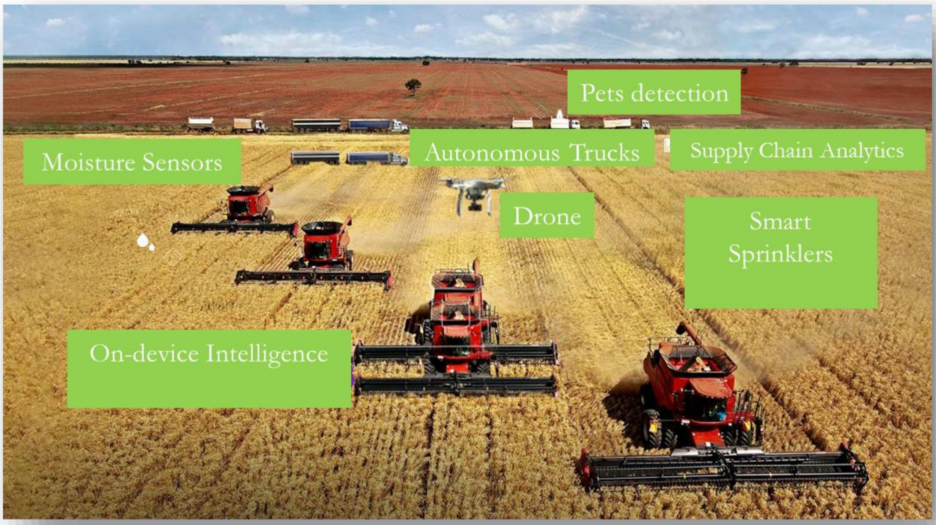


Fig. 10 Agriculture digital transformation

Energy Efficiency

Energy efficiency is a core consideration in the design and deployment of IoT solutions, especially in cellular IoT and Industry 4.0 contexts. Cellular IoT technologies, including low-power options like NB-IoT and LTE-M, extend the battery life of connected devices, making them well-suited for remote and long-term deployments, ultimately reducing operational costs and promoting sustainability. Innovative features like RedCap, introduced by 3GPP, further enhance energy efficiency by allowing IoT devices to adjust their power consumption dynamically based on network conditions, enabling extended operational lifetimes and low-frequency maintenance. In practice, applications in smart buildings comprise these principles, where IoT sensors are connected via cellular networks to monitor lighting, heating, and cooling systems.[15] Furthermore, such devices dynamically adjust settings based on occupancy and environmental conditions, leading to significant energy savings. In smart factory setups, cellular IoT optimizes machine operations, ensuring equipment operates efficiently and minimizing energy consumption. [7][8]

Security

Security is a top consideration in cellular IoT to safeguard sensitive data, critical processes, and user trust. Cellular IoT networks offer robust security features, including end-to-end encryption, authentication, and secure device management, ensuring the confidentiality and integrity of transmitted data. Compliance with standards like GSMA IoT SAFE in cellular IoT is complemented by industry-specific security measures such as network segmentation and adherence to standards, like in Industry 4.0 [9]. These comprehensive security measures protect against unauthorized access, data breaches, and cyber threats for real-world applications, such as healthcare, where remote patient monitoring devices are connected via cellular networks and transmit sensitive health data securely to healthcare providers, ensuring patient privacy. In smart cities, secure communication of data from surveillance cameras to law enforcement agencies is essential for maintaining public safety. In the Industry 4.0 context, secure communication between industrial machines safeguards manufacturing processes and intellectual property from potential cyber threats.

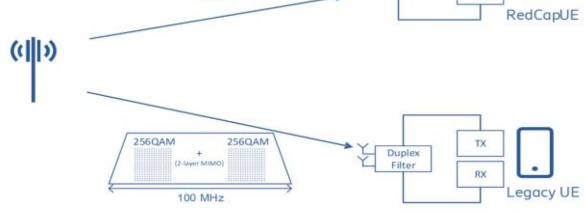


Fig. 11 RedCap devices Vs Legacy UE

Addressing The Challenges

The IoT has rapidly emerged as a transformative force across industries and daily life, leading to a new era of connectivity and data-driven decision-making. Given its remarkable potential, IoT faces a multitude of challenges. One of the prime challenges is data privacy protection, as the growing number of interconnected devices contains enormous user data. As a result, data protection is compulsory. Furthermore, achieving cellular signal penetration remains a hurdle to providing connectivity in population dense indoor areas. In parallel, pricing is a key challenge to address, as sensors are deployed in large, tremendous amounts of devices. Therefore, highly-priced devices and/or sensors will not be suitable for viable business cases. These key challenges and their possible solutions will be explored in this section.

Penetration

In IoT, coverage has to play the key role in connectivity given the complex IoT ecosystem challenges, where there is a variety of manufacturers, communication protocols, and network technologies. The availability of reliable network coverage in deep indoor areas, remote areas, or under-served regions remains a limiting factor for IoT solutions. Additionally, ensuring a minimum level of Rx (receiver, typically -120dBm to -130dBm based on the device's design) signal strength is often vital for properly functioning IoT devices, especially in challenging environments. Below, we explain the major methods used to increase the penetration in high-speed networks.

Optimizing the use of low-frequency bands can significantly improve penetration and coverage in challenging environments. Furthermore, considering higher-end technologies (e.g., 5G) and other techniques, such as Carrier Aggregation (CA), can enhance connectivity options for providers. Expanding the network infrastructure of 4G/5G will bridge the connectivity gaps by extending reliable coverage to remote and under-served areas.

User Data Privacy

Each sensor is associated with user information, for example, in case of single user information like user location, face image and other sensitive information. Such data need to be protected and not allowed to spread. Compliance with data protection regulations such as GDPR is key, and ongoing efforts to harmonize privacy standards globally should be followed to strengthen security in cellular IoT.

In addition, it is required to make the system robust from the connectivity network side, with the adoption of encryption methods and regular firmware updates essential for safeguarding cellular IoT devices. Ongoing collaboration between industry stakeholders is important for addressing such cases.

Pricing

In the early stages of IoT adoption, one of the most prominent challenges is the prohibitively high cost of IoT devices and platforms. These elevated expenses discouraged many potential adopters from accepting this transformative technology.

However, over time, market forces and innovative companies have addressed these pricing challenges, resulting in more affordable and reliable sensors with enhanced functionalities. One of the key factors was the realization of economies of scale. As the demand for IoT devices increased, manufacturers could produce sensors and platforms in larger quantities, significantly reducing per-unit costs.

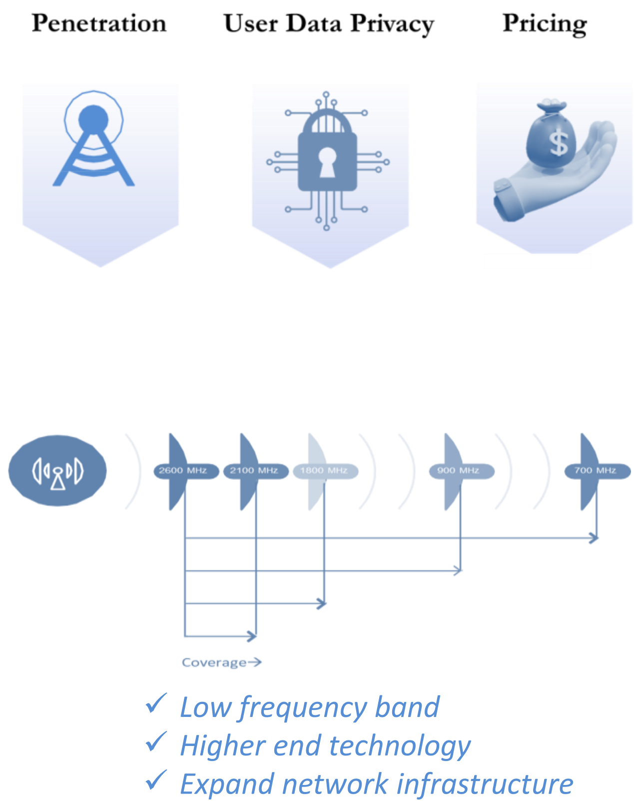


Fig. 12 Main challenges in IoT

Real Network Challenges Case Study

Let us dive deeper into the real-world challenges encountered in IoT projects using IoT-enabled electricity meters as a use case. Such projects are essential for modernizing the utility field. However, they come with complexities and challenges.

The deployment of IoT-enabled electricity meters marks a crucial step toward modernizing the utilities infrastructure. This project requires careful planning and assessment, including determining the number of meters required, sourcing and provisioning numerous SIM cards for connectivity, and proactive monitoring. Consequently, maintenance is vital in such projects, and it can be achieved by establishing the necessary power infrastructure with proper funds and and resource allocation. The project challenges are listed below,

Deployment Phase

The actual deployment phase involves the installation of IoT-enabled electricity meters across the designated areas.

It is essential to manage logistics effectively, ensuring that the right meters are installed in the right locations. The deployment team must consider factors such as power access for each meter, secure connectivity, and the timely activation of SIM cards to facilitate real-time data transmission. Installation teams must adhere to safety standards and may require specialized training to handle electrical components and IoT equipment.

SIM Provisioning

Managing millions of SIM cards activations is a common challenge in large-scale deployments and can be specifically demanding. Ensuring each meter has a unique functional SIM card is crucial for uninterrupted data transmission. Additionally, allocating and managing these SIM cards effectively while ensuring the unique assignment of identification numbers to each meter adds complexity to the IoT enabler company.

Power Consideration

Reliable power supply is vital for IoT-enabled electricity meters. These devices require a constant source of electricity to function accurately. In certain cases where grid power is unreliable, it may be necessary to install backup power solutions like batteries or solar panels. Power considerations are critical to ensure uninterrupted data collection and communication and can impact the maintenance cycle. Solar devices are one of the effective ways to address power considerations.

Proactive Maintenance

Once the IoT meters are operational, continuous maintenance is essential to ensure their reliability and accuracy. Routine inspections, firmware updates, and system monitoring help prevent technical issues and data discrepancies. Maintenance tasks should be scheduled to minimize disruptions to utility services and to address any connectivity issues promptly.

Funding and Resource Allocation

Funding plays a pivotal role in the deployment of IoT-enabled electricity meters. Budget allocation is required for purchasing meters, SIM cards, power infrastructure, and maintenance resources. It is important to manage funds efficiently, stay within budget, and address any unexpected expenses. Satisfactory funding ensures the successful execution of the project and helps meet the long-term goals of improved utility management and energy efficiency.

In conclusion, deploying IoT-enabled electricity meters is a complicated process that involves careful planning, extensive deployment efforts, power management, ongoing maintenance, and careful budget allocation. Addressing these aspects comprehensively ensures the success of the project, which, in turn, leads to efficient utility management and better services for consumers.

Artificial Intelligence of Things

In this section, we talk about Artificial Intelligence (AI), the transformative technology that combines intelligence with existing technologies. Indeed, AIoT is the combination of IoT and AI technologies. The use of AI in the context of IoT refers to the fusion of AI technologies, such as machine learning and data analytics, into the IoT to enhance its capabilities. AI in IoT allows for intelligent data analysis, real-time decision-making, automation, and the extraction of valuable insights from the data generated by IoT devices. It is a key enabler of more efficient and optimized IoT applications and systems. [10][11]

The primary aim of this fusion is to enhance the capabilities of both IoT and AI. IoT devices serve as sources of data, and to leverage their full potential, the incorporation of machine learning is crucial. This empowers systems to self-adjust, adapt to evolving contexts, and continuously enhance their performance.

Combining these two technologies, makes it possible to create intelligent solutions for a wide array of applications like smart cities, industrialization, healthcare, transportation, and more. Furthermore, the objective is to update automation processes while strengthening security and privacy measures.

Benefits of AIoT

AIoT is not yet another technological advancement. It is a dynamic that thrives in society, affects personal and professional lives, and furthers the world around us. In the following section, we will explore the benefits of AIoT. **Enhanced Efficiency:** AIoT optimizes operations, automates tasks, and improves resource allocation, leading to greater efficiency and cost savings.

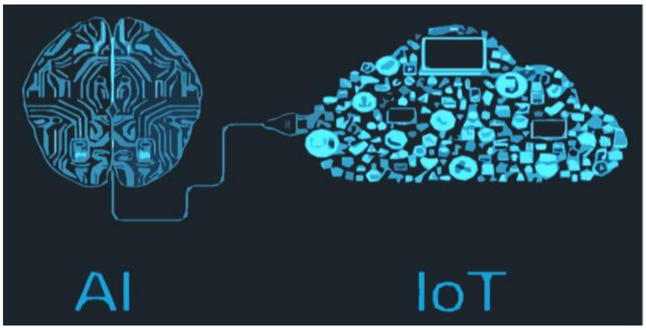
Real-time Insights: AIoT provides real-time data analysis, allowing businesses to make informed decisions and respond swiftly to changing conditions.

Predictive Maintenance: AIoT can predict equipment failures, reducing downtime and maintenance costs by enabling proactive maintenance.

Improved Customer Experiences: AIoT enables personalization and better customer service through data-driven insights and automation.

Cost Reduction: AIoT reduces operational costs, energy consumption, and resource waste through optimized processes.

Increased Productivity: AIoT automates routine tasks, freeing up human resources for more valuable activities.



AI + IoT = AIoT

Scalability: AIoT solutions can scale with business needs, matching the high demand for various industries and applications.

Competitive Advantage: Early adopters of AIoT gain a competitive advantage through improved products, services, and operational efficiency.

Environmental Impact: AIoT promotes sustainability by reducing energy consumption, green solutions, and resource waste.

Proactive Problem-solving: AIoT identifies issues before they escalate, enabling proactive intervention through data-backed predictive models.

Enhanced Decision-making: AIoT delivers data-driven insights, improving the quality and speed of decision-making.

Data Security: Advanced security measures in AIoT protect sensitive data and prevent systems breaches.

Fig. 13 Sectors benefits from AIoT

AIoT Industry Transformation

AI has a transformative impact on IoT, making IoT systems more intelligent, efficient, and responsive to user needs. AIoT can be leveraged in many areas, such as industrial environments, agriculture, and livestock farming (e.g., transport and logistics), as they use intelligent applications that can adapt and respond automatically. Below are some aspects of how AI has influenced the IoT industry.

AI enriches IoT systems in numerous ways. It excels in Data Analysis and Insights, allowing IoT devices to process and interpret large volumes of data uncovering real-time patterns and insights. employs sensor data to forecast maintenance requirements and minimize downtime.

Optimization is another gem; AI-driven agricultural IoT optimizes irrigation schedules based on weather and soil data generated from IoT sensors. IoT significantly impacts automation; AI empowers robots in industrial IoT for autonomous task execution. Since advanced telecom solutions and standards have enabled AI processing at the edge and near IoT devices, reducing latency and bandwidth consumption can be achieved.

Furthermore, AI significantly contributes to enhancing energy efficiency in the context of IoT. In scenarios like smart buildings, AI plays a crucial role in optimizing energy consumption. Through a combination of sensor data and real-time analytics, AI-driven systems can make informed decisions regarding lighting and HVAC usage based on factors such as occupancy levels and environmental conditions. [12] [13]

The table below shows the AI algorithms implementation on existing IoT Industry use cases.

IoT Industry	Use Case	AI Algorithm	Description
Manufacturing	Predictive Maintenance	Time Series Analysis	Predicts when equipment maintenance is needed to reduce downtime
Marketing	Personalized Marketing	Collaborative Filtering	Recommends products to customers based on their preferences.
Automotive	Autonomous Vehicles	Deep Learning	Enables self-driving cars to navigate safely and efficiently
Manufacturing	Quality Control in Manufacturing	Convolutional Neural Networks	Ensures product quality in real-time by analyzing images and data.
Smart Cities	Traffic Management and Optimization	Deep Learning	Analyzes traffic patterns and optimizes signal control for improved traffic flow.
Agriculture	Crop Health Monitoring	Convolutional Neural Networks	Analyzes images of crops to detect diseases, pests and nutrient deficiencies for precision agriculture.
Personalized Learning Paths	Education	Recommender Systems	Recommends customized learning materials and pathways to students based on their individual progress and preferences

Table. 3 AI algorithms implementation on existing IoT Industry use cases

Furthermore, AIoT-based systems introduce the need to monitor devices continually. This does not only conserve valuable resources but also contributes to sustainability. Moreover, the advancement of 5G networks facilitates the interconnection of a greater number of devices, streamlining processes, and enhancing scalability.

Saudi Arabia's IoT Adoption

In Saudi Arabia, the landscape of the IoT is defined by three primary domains, each playing a significant role in the proliferation and integration of IoT technologies.

To begin with, the telecommunications sector is represented by major enablers such as stc and other SPs. These companies have been instrumental in driving IoT innovation by offering robust and high-speed connectivity solutions that serve as the fundamental infrastructure for IoT deployments throughout the Kingdom. Their expertise and network capabilities empower businesses and individuals to join the full potential of IoT, enabling a wide spectrum of applications, from smart cities to industrial automation.
The second domain includes a dynamic companies ecosystem, often referred to as IoT service providers. These entities provide a diverse array of IoT services, products, and platforms that caters to the specific needs of various stakeholders. They act as intermediaries between connectivity providers and end-users, offering specialized knowledge in IoT application development, data analytics [12], and system integration. Their role is crucial in facilitating the accessibility and implementation of IoT solutions, making it more convenient for organizations to adopt and benefit from IoT technologies.
Lastly, Saudi Arabia has observed significant IoT deployments in crucial sectors, with major organizations like Aramco and water metering companies taking the lead. Aramco deployed IoT solutions for their oil and gas domain, while water metering companies use IoT for efficient consumption tracking. These large-scale implementations not only reflect the nation's commitment to technological progress, but also serve as transformative potential of IoT in enhancing productivity.

Together, these three domains – IoT enabler, service provider, and industry-specific deployment cases, constitute a comprehensive ecosystem that drives IoT innovation and applications across Saudi Arabia.

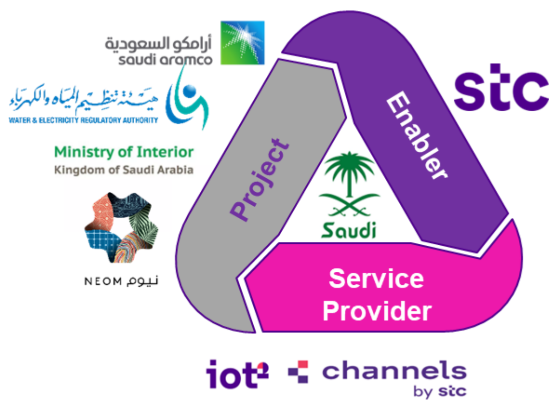


Fig. 14 Saudi's IoT adoption

Key IoT Projects in Saudia Arabia

Analyzing the Saudi Vision 2030 and its primardirection to improve its citizens' quality of life, meet their needs, and simultaneously protect y objectives underscores the environment and natural resources.

The Smart City concept has a well-defined direction and the needed resources to invest in technology and scientific fields. The figure below shows the major elements necessary for any smart city.
The Kingdom of Saudi Arabia is experiencing a transformative shift, aiming to convert several cities into smart cities.

During the Hajj pilgrimage, IoT-enabled devices like wristbands and smartphone applications enhance communication and crowd management. By analyzing the vast data generated, authorities can quickly respond to triggered events to avoid undesirable situations. With immense data flow across the entire season, authorities are equipped with IoT to trigger events, draw valuable insights, and take corrective and preventive measures in real-time to ensure crowd safety. [14]

Integrating technology into The Red Sea Project is a thrilling project. Beyond offering personalized and seamless resort experiences, the objective is to unify various technologies across the extensive development area. The project aims to turn The Red Sea into a smart destination with interconnected smart services facilitated by a smart destination platform and robust infrastructure. Additionally, a smart irrigation system and sensor networks aim to save freshwater resources at one of the region's largest on-site plant nurseries. [15]

NEOM City is at the forefront of IoT to create a visionary and driverless environment. As a key component of Saudi Vision 2030, NEOM is redefining urban living through IoT technology, with a specific focus on autonomous systems. This advanced approach is evident in smart infrastructure, energy management, and environmental monitoring, where IoT sensors and devices are instrumental in shaping a connected ecosystem. In the context of transportation, NEOM City is pioneering self-driving vehicle networks.[16]

Smart Infrastructure	Energy Management	Environmental Monitoring
IoT to be used to create a smart and efficient infrastructure. This includes smart lighting, waste management and traffic control systems that can optimize resource usage and improve the overall quality of life for residents.	IoT sensors can be deployed to monitor and manage energy consumption in buildings and across the city. This can help in reducing energy wastage and making cities more sustainable.	IoT devices can be used to monitor air quality, water quality, and other environmental factors. This data can be used to take timely actions to ensure a clean and healthy environment in the city.
Transportation	**Security & Surveillance**	**Tourism**
IoT can play a crucial role in developing autonomous and connected transportation systems. Self-driving vehicles and smart traffic management can improve mobility and reduce congestion.	IoT can be used for advanced security and surveillance systems, helping in the prevention and management of security threats and ensuring the safety of residents and visitors.	IoT can enhance the experience of tourists in smart cities by offering personalized services and providing real-time information about attractions and events.

Futuristic Automotive Connectivity

In this section, we are exploring the futuristic vision of automotive vehicles. Connected cars, an integral IoT ecosystem component, are is revolutionizing the automotive industry by transforming vehicles into smart and data-driven components. We explore the concept of connected cars, their technological infrastructure, and real-world connected car use cases.[17]

Achieving the vision of connected cars requires a robust technological infrastructure, with these vehicles relying on a sophisticated network of technologies to function effectively. This includes 1) High-speed cellular networks (i.e., 4G and 5G) for seamless data transfer between vehicles; 2) Local Wi-Fi networks enable communication with nearby devices and infrastructure; 3) Satellite communication networks providing global coverage and ensuring connectivity even in remote or off-road areas; 4) The integration of radar sensors, which are instrumental in helping the car detect and respond to its surroundings, ensure safety and enable autonomous driving capabilities.

Satellite IoT plays an essential role in the connected car industry. It enables vehicles to stay connected in remote or off-grid locations, offering real-time updates on location, diagnostics, and safety features. This connectivity is vital for applications like GPS navigation and over-the-air updates, ensuring that connected cars operate efficiently and safely even in areas with limited cellular coverage.

Tesla's Autopilot System utilizes advanced sensors and machine learning models to achieve semi-autonomous driving features. Furthermore, other companies offer a wide range of safety, security, and navigation features, including automatic crash response and turn-by-turn directions.

Fig. 15 Driverless environment

Beneficial Use Cases

Water Management

Efficient water management is vital for any country. IoT solutions enable real-time monitoring of water distribution networks in order to reduce wastage and ensure a sustainable water supply. The key message is that IoT-driven water management is essential for conserving this precious resource and preserving the environment.[7]

Oil & Gas

IoT sensors and devices are deployed in critical equipment and facilities to enable predictive maintenance, minimize downtime, and prevent accidents. This use of IoT technology in one of the world's largest oil producers not only ensures consistent production but also upholds the highest standards of safety and environmental responsibility.

Security

Ensuring public safety and security is a top priority. IoT technologies support modern surveillance systems. Smart cameras, sensors, and analytics help monitor public spaces, detect threats, and respond swiftly to incidents. The use of IoT in security not only enhances the safety of citizens and visitors but also supports law enforcement and emergency services.

Tourism

Location-based services, smart cabins, and automated check-ins to enhance the visitor experience. IoT contributes to the development of tourist-friendly destinations, promotes cultural heritage preservation and boosts tourism revenues in the country.

Supply Chain Management

IoT is revolutionizing supply chain management. Real-time tracking and monitoring of goods in transit is made possible through IoT devices. This does not only streamlines logistics, but also improves transparency and security in the supply chain. The effective use of IoT technology in supply chain management will make this industry more reliable and efficient.

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Abbreviations

Key Acronyms

3GPP: 3rd Generation Partnership Projects

5G: Fifth Generation (of mobile networks)

AI: Artificial Intelligence

AIoT: Artificial Intelligence of Things

AR: Augmented Reality

DL: Deep Learning

E2E : End to End

EDGE: Enhanced Data rates for GSM Evolution

MTC: Machine Type Communication

eMTC: Enhanced Machine Type Communication

eURLLC: Enhanced Ultra-Reliable Low Latency Communication

Firmware: Software or program embedded in a hardware device

FWA: Fixed Wireless Access

GDPR: General Data Protection Regulation

GPRS: General Packet Radio Service

GSM: Global System for Mobile Communications

HTTPS: Hypertext Transfer Protocol Secure

HVAC : heating, ventilation and Air Conditioning

IoT: Internet of Things

IoT SAFE: Internet of Things Security and Privacy Features

LPWA: Low Power Wide Area Network

LoRaWAN: Long Range Wide Area Network

LTE-M: Long-Term Evolution for Machines

M2M: Machine-to-Machine

NB-IoT: Narrowband Internet of Things

RedCap: Reduced Capacity

ROI: Return on Investment

SIM: Subscriber Identity Module

UC: Use Case

Endnotes

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