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5G Networks Scope of Mobile and Wireless Communications

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Abstract

IoT applications have literally driven the demand for increasing capacity of mobile networks. Hence, it becomes important to understand the challenges and full potential of 5G networks. 5G services can meet the needs for different vertical domains like industrial IoT (IIoT), AR/VR, sustainable energy, and smart mobility. Some 5G applications call for low latency, while others need high security and bandwidth. This paper is aimed to identify the scope and limitations of 5G applications in terms of mobile and wireless communications.

We review the areas of applications and some requirements and open challenges of 5G networks. We provide a complete overview of latest wireless communication technologies like 5G and a concise view of latest advancements investigated by previous studies in deployment of 5G networks in an effective way. This study provides state of the art and easy insight to challenges and applications of 5G networks. Existing approaches are grouped in this study for a critical insight to 5G technology.

A key challenge here is to come up with a network architecture to adapt to changing traffic patterns dynamically and accompany several technologies like blockchain, edge computing, virtualization, and software defined networking. This study has highlighted the need for working with 5G applications, open challenges, tangible steps to comprehend the configuration of 5G and use of applications in different vertical domains.

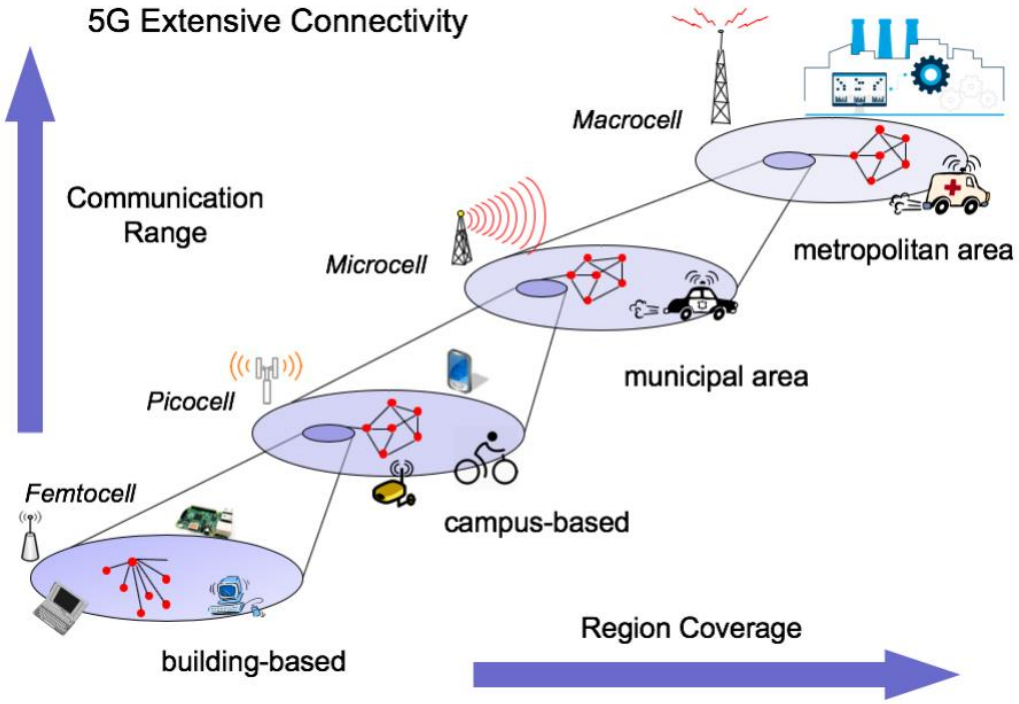
Keywords: *Industrial IoT, IoT, 5G applications, 5G networks, blockchain, edge computing, Internet of Things, wireless communications*

1. Introduction

Mobile communication has been successful from its considerable ecosystem and universal coverage which has led to the boost of innovation in terms of new ventures and applications. The most awaited 5G technology of mobile networks would withhold its prosperity in the long term and generate more opportunities in the world of Internet of Things (IoT), AR/VR, self-driving vehicles, and AI. The ongoing development of 5G technology would support its ongoing development and enhance its air interface (Wang et al., 2014; Shakhatreh et al., 2019) to ensure large-scale deployment of IoT sensors which are projected to cross the 75 billion mark by the end of 2025 (Statista, 2022).

In comparison to the current LTE (4G) network, 5G has new wireless technologies that can support higher spectrum and frequencies. It has great improvements in management, signalling, and accounting processes at core networks to meet the needs from various new applications that are out of traditional broadband (NGMN Alliance). 5G technology would deliver great connectivity in terms of design with its heterogeneous wireless network, i.e. from short range “femtocell” to long range “microcell”. As given in Figure 1.1, the coverage of the 5G network would cover villages, metropolitan areas, and even buildings and campuses with pervasive connectivity, service availability, and smooth mobility which has been based on cellular systems since the beginning.

Figure 1.1. Extensive Coverage of 5G Network



Source – Ding & Janssen (2018)

Considering emerging demands from AR/VR, self-driving vehicles, IoT, and smart city applications, 5G technology is an important pursuit to meet the scalability needs of several 5G-based technologies in a sustainable and cost-effective way. It covers communication technologies, network infrastructure, deployment and design of ecosystems. Some of the recent efforts to improve the efficiency of 5G networks are "software-defined networking (SDN)", "distributed data analytics" like Apache Spark, "network function virtualization (NFV)", offloading and edge computing, etc. These technological innovations have achieved great results (Han et al., 2015; Ding et al., 2014; Costa-Requena et al., 2014; Ding et al., 2015). At the same time, with the onset of new domains, 5G networks would be part of the daily lives of people in different ways. This article fills the gap of complete understanding on needs for various vertical domains like both governance and technical perspectives, challenges, and opportunities of 5G technology in the existing phase of transition.

2. Literature Reviews

Tang et al. (2021) conducted a study on effects of 5G on agriculture industry and explored the need and role of accurate and smart farming, 5G applications in real-time monitoring, and benefits of farming, data analytics, predictive maintenance and virtual consultation, and future prospects of 5G technology in agriculture.

Chen et al. (2021) explored the need for 5G and blockchain for using drones in medical applications and presented some major challenges. They discussed some preliminaries of blockchain and 5G technology, explored inherent features of them to provide security and reliable communication, and presented illustrative examples of that in disaster management. They found 5G with great potential when combined with blockchain to promote usage of drones in medical applications with analytical findings.

Edge and fog computing are the latest cloud technologies and "software defined networking (SDN)" is the next generation for 5G applications that can support its implementation. **Ahvar et al. (2021)** discussed the potential challenges and opportunities with SDN in "cloud-fog hybrid systems" to meet the needs for 5G+ applications.

Another great application in 5G wireless communication is the "massive Multiple-Input Multiple-Output (mMIMO)" technology that can potentially improve reliability of link, spectral efficiency, and meet the needs for a lot of clients while focusing on accuracy, estimation, and efficacy of several "channel estimations (CE)". **Shaik & Malik (2021)** review 5G wireless communications specially to meet the needs of "channel estimation" with "efficient candidate waveform". They also review the design and architecture challenges which are needed in 5G wireless comms.

Siddikov et al (2021) analysed 5G-based IoT and "Cognitive Radio Network (CRN)" applications, opportunities and challenges in implementing them. They revealed the use of 5G and CRN in implementing IoT technologies. They explained the concepts of cognitive IoT and cognitive radio and their possibilities. The 5G and CRN-based IoT design is proposed and their operation is elaborated. They analysed the use of 5G-based IoT and CRN in smart cities, smart homes, smart medicine, smart grid, environment, and smart transportation. They also discussed key challenges in implementing these technologies like rapid data analysis, hardware design issues, standardisation link in radio location and construction, security and energy efficiency, and scope to solve them.

Varga et al. (2020) identified existing solutions and research challenges on 5G-based IIoT solutions as per the initial needs and promises in both domains. The researchers surveyed state of the art responses, compared findings to look for further issues, and drew conclusions as lessons to be learned for each area. Some of these research domains are "mobile edge cloud", Industrial IoT needs and challenges, tuning backend performance,

security and virtualization of networks, AI for 5G, blockchains for Industrial IoT, and networks in private campuses. Along with discussing existing solutions and challenges, they provided sensible comparisons for 5G-based IIoT and existing knowledge gaps.

Ivashina et al. (2021) discussed "Antenna Technologies for Beyond-5G Wireless Communication", a cooperative research plan between Taiwan and Sweden to come up with energy-efficient and strong "integrated antenna solutions" for 5G+ applications and their frequencies over 100 GHz in future. They also discussed tech issues in integration and manufacturing with opportunities and electronics.

Some of the emerging 5G technologies are "massive multiple-input multiple-output (mMIMO)", millimetre waves, and "small cell communications". These technologies would be enough to meet 5G needs. **Teli et al. (2018)** discussed "optical wireless communications (OWC)", a completely different wireless network. As far as OWC is concerned, "optical camera communications (OCC)" and "visible light communications (VLC)" are the most effective solutions for beyond 5G networks. With IoT integration and vast frequency, VLC can open a lot of doors of opportunities for outdoor and indoor usage of smart environments. The authors discussed "all-optical IoT (OIoT)" applications based on OCC and VLC and their potential challenges in the 5G network.

2.1 Research Gap

Given the trend of urbanisation and advancement in 5G technology (United Nations, 2014), this paper fills the knowledge gap of latest 5G applications, opportunities, and open challenges, with particular emphasis on vertical application domains built for target entities and enterprises with specific needs.

2.2 Research Question

As a vital step to demystify the needs of 5G technology in terms of smart city and IoT developments, this study is aimed to answer the following questions –

- What are the current applications of 5G technology?
- What needs to be done to facilitate future deployment and development of 5G systems?
- What is the scope and open challenges to explore the full potential of 5G?

2.3 Research Objectives

Along with identifying potential challenges of 5G, this study is also aimed to discuss the scope of 5G applications in several domains for further development for engineers, policymakers, and researchers. With that in mind, here are some of the research objectives –

- To explore the current applications of 5G technology
- To discuss the current requirements for future development of 5G
- To investigate open challenges and opportunities to make the most of 5G technology

3. Research Methodology

In order to provide extensive coverage of emerging and existing 5G applications and technologies, this study relies on secondary data collected from various sources like research papers, studies, news articles, publications, reports, etc. In this study, we first classify the existing applications of 5G technology, discuss their important requirements while covering important aspects like bandwidth, communication range, energy, reliability, latency, privacy, and security, and finally pinpoint opportunities and open challenges on the basis of various research and studies. We further recommend pilot 5G testing with strict cooperation across network operators, universities, government bodies, and equipment providers.

4. Analysis of Study

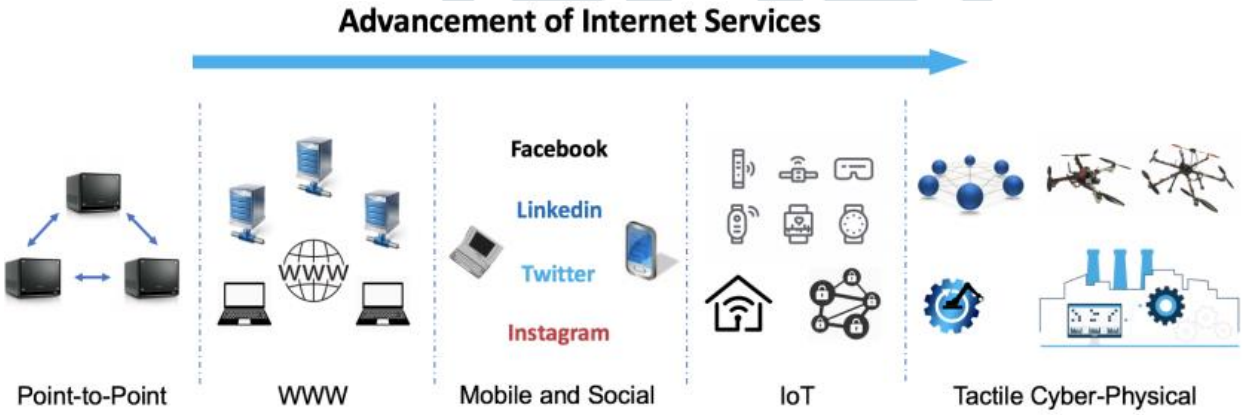
Advancements in mobile networking have come up with plenty of applications to improve the quality of life for end users like digital commerce, smart mobility, healthcare and social media. Mobile applications are related to online services in a broader perspective, which have seen a rapid growth over the decades.

4.1.What are the current applications of 5G technology?

Internet services have evolved from traditional P2P data exchange, social and mobile applications, WWW, to the upcoming tactile internet and recent IoT solutions as given in Figure 4.1 (Zanella et al., 2014; Fettweis, 2014; Simsek et al., 2016). The tactile internet services specifically facilitate connection between real world and digital sphere, covering the modern use cases of communication across the machines. Those emerging applications are known for the need for networks with high availability, very low latency, security and reliability. A lot of those applications are based on context where it is sensed to trigger the actions. These days, smartphones are smart enough to know whether to avoid disturbing the driver or the owner is driving (Shishkov et al., 2018).

The IoT-based smart city has become the primary concern for 5G networks along with other applications. Both modern and traditional ICT communications are integrated in smart cities with this regard for a simple and unified access to services for the residents and city administration. The key here is to improve the use of resources, improve service quality for citizens while saving on operational costs and minimising the administrative load for businesses and citizens (Anthopoulos, 2015). Pollution and congestion must be reduced by smart transportation and promote utilisation of public transport.

Figure 4.1. Evolution of Internet Services



Source - Ding & Janssen (2018)

There are five application areas of 5G networks –

4.1.1. **Smart Vehicles** – From conventional route planning to developing smart driving solutions and sharing economies, there are wide ranges of 5G mobility applications. Some of the benefits are efficient routing, balanced traffic, prevention of accidents, reduced carbon emission, and energy saving (Benevolo et al., 2016). 5G services are in strong demand with these applications for low latency, flawless connectivity, high speed, minimal power consumption, and security.

4.1.2. **Smart Health** – Smart health services are getting more and more popular due to increasing awareness of well-being and fitness among mobile users. This application category has covered several mobile-based diagnosis and condition monitoring, inspection of environmental quality, and advancement of smart gadgets. Smart health would have a positive influence on healthcare and medical services as sensors on wearable techs collect more data (Akpakwu et al., 2017). 5G will further boost AR/BR based surgery with high bandwidth and low latency.

4.1.3. **Smart Grid** – It consists of smart grid management, power failure response and detection, power plant monitoring, and new energy-saving services for offices and homes, EV charging stations, and energy marketplace. Smart energy can boost reliability and efficiency with smart distribution and renewable energy. (Fang et al., 2011; Wang & Lu, 2013).

4.1.4. **Industrial IoT** – It is the next-gen cyber-physical network for "Machine-to-Machine (M2M)" communication, manufacturing, AI-based construction, and additive manufacturing (3D printing) (Wang et al., 2016). Those industrial applications will further boost plants and factories and benefit the whole society. Ultra-low latency, high reliability, privacy, security, and support for vast deployment would be some of the characteristics of 5G.

4.1.5. **Consumer applications –** 5G mobile services will further boost the utilisation of apps or consumer applications. With increasing number of tablet and smartphone users, 5G would take entertainment and gaming to the next level, i.e. with the likes of AR/VR mixed reality, UAVs, HoloLens[1] and other holographic technologies, immersive gaming experiences like Pokémon Go[2], FinTech, and 4K/8K ultra-

[1] Microsoft HoloLens - https://www.microsoft.com/en-us/hololens
[2] Pokémon Go - https://pokemongolive.com/en/

HD streaming. 5G is much needed for all such modern services with high bandwidth, vast connectivity, low latency, security, and low power consumption.

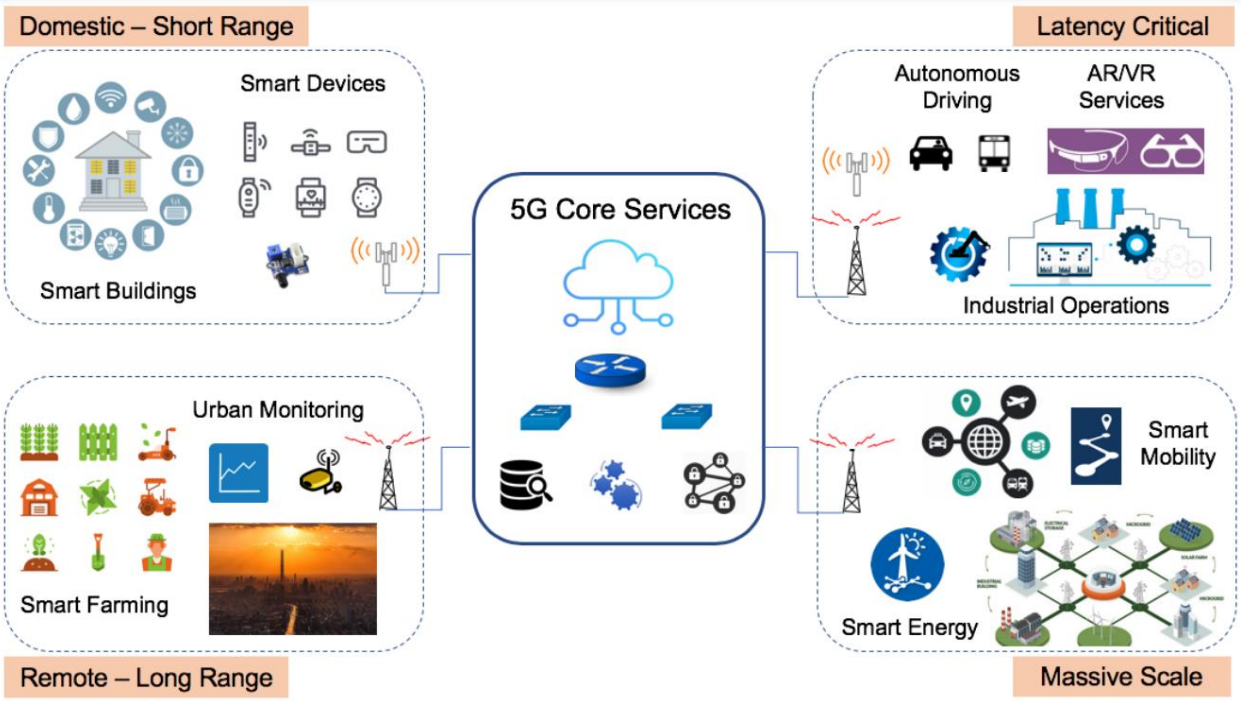
4.2.What needs to be done to facilitate future deployment and development of 5G systems?

There are four categories of applications of 5G services – "(1) Short Range or Domestic, (2) Long Range or Remote, (3) Massive Scale, and (4) Latency Critical" (Figure 4.2). This section manifests their key requirements for deploying and developing 5G services.

4.2.1. Basic Requirements for 5G Network

- **Domestic** – It consists of consumer applications in terms of office complex and smart homes (Figure 4.2) (Anthopoulos, 2015). 5G must support low-energy networks for gadgets as per their communication requirements. Regulating unwanted traffic on wireless networks is paramount in smart homes due to security concerns (Hafeez et al, 2016).
- **Latency Critical** – Industrial applications usually require safety and security of high level in manufacturing. For AR/VR, self-driving, and other consumer domains, high bandwidth and low latency would be needed. High link reliability is also a concern for autonomous driving.
- **Long-Range** – 5G services are required in urban monitoring and smart farming for network coverage. Devices used in urban monitoring and farming should work in the long run and they also need energy-saving.
- **Massive Deployment** – This scenario needs 5G services in smart transportation and smart grid to scale, meet rising traffic demand, end devices, acceptable cost, and applications.

Figure 4.2. Applications of 5G core services



4.2.2. Emerging Applications and Services

In both vertical domains and smart cities, 5G architecture should meet the needs from various angles for emerging services and applications. Change in traffic pattern is the first need from downlink-based to uplink-based. It is especially true with the use of high data volume from drones, smart vehicles, and deployment of IIoT. Traffic patterns are subject to shift and demand from various vertical domains may change over time. It is important for 5G services to adapt with those changes over time.

Data privacy has become a serious concern with the introduction of "General Data Protection Regulation (GDPR)". This regulation covers data of an identified or identifiable entity. 5G must guarantee the security of autonomous robots/flying drones and more embedded sensors to gather surveillance data and ensure privacy in communication.

4.3.What is the scope and open challenges to explore the full potential of 5G?

4.3.1. Scope

There are four technology advancements identified to benefit 5G, such as blockchain, "software defined networking (SDN)", "lightweight visualisation", and edge computing.

- **Blockchain** – GDPR is also boosting the growth of distributed ledger along with maintaining user privacy on the web. There is an upsurge in demand to unify the management of data across companies, end users, and government. It consists of right ways to track, receive, and fulfil user needs and update data as needed.
- **SDN and Virtualization** – Network computation can be organised with a robust technology called "Network Function Virtualization (NFV)". It uses virtualization to detach network devices from their functions (Han et al., 2015). It is possible to implement several virtual network features on various servers. SDN is the next robust tool to manage 5G networks in commercial networks and data centres. It detaches the control panel and data to implement all control functions in a centralised controller.
- **Mobile Edge computing** – In 5G, the convergence of wireless systems and mobile data can boost significant growth in computation- and resource-intensive applications which cover IoT applications like smart health, real-time audio/video surveillance, smart vehicles, etc.
- **Edge-enabled framework for 5G services** – In order to deploy 5G with latest technologies, an edge-based platform has been proposed by Ding & Janssen (2018) to combine data management in vast cyber-physical applications. The 5G layer might bring a lot of benefits with this platform like (1) very low latency between edge computing and smart devices for innovative, real-time applications, (2) rapid data processing for IoT devices, and (3) security and privacy for local communications.

4.3.2. Open Challenges

Edge computing and NFV are some of the promising technologies required to meet new application demands. There are still some challenges to overcome and make 5G a success –

- **Technical Challenges** – Security is a serious concern for operating 5G networks. There are a lot of concerns on encryption from operator side (Moriarty & Morton, 2018) across various service providers like Amazon

and Google, 5G equipment vendors like Ericsson, Nokia, etc. and ISPs like Airtel, Jio, Vodafone Idea, etc. in India. The security operations, traditional network management, and enhancement of performance in cellular networks have been done over several data flows with lack of encryption. Though unencrypted traffic could promote management and troubleshoot operations at various layers of the network, universal monitoring can be done by anyone. With rising awareness in privacy and service providers like Google on the web, a lot of traffic resources are end-to-end encrypted (Haus et al., 2017). 5G is still a challenge due to this trend as existing security, management, and operational practices rely on availability of clear text to work on. It is vital to find out if it is possible to meet major operational practices with less invasive mediums for 5G operations. Along with traditional balancing of traffic between usual online and real-time traffic, 5G should also prioritise the types of traffic with superior granularity (Järvinen et al., 2013). There are some vertical domains which call for instant response to avoid failure while there are some applications where rapid response is not required all the time. Net neutrality debate can correlate this differentiation in traffic as whether the fairness and freedom of the internet would be affected.

- **Governance and Regulatory Challenges** – Governance is needed as connectivity turns out to be a "common-pool resource (CPR)" to provide ample scalability and bandwidth, fair usage, prioritise specific vertical domains, and boost interoperability. Regulations are known to affect the role of 5G service providers. Smart vehicles also need ultra-low latency and priority to avoid accidents over other services. In addition, redundant coverage might be needed by the distributed nature in areas to avoid malfunction issues. Regulations might need recovery and backup plans.

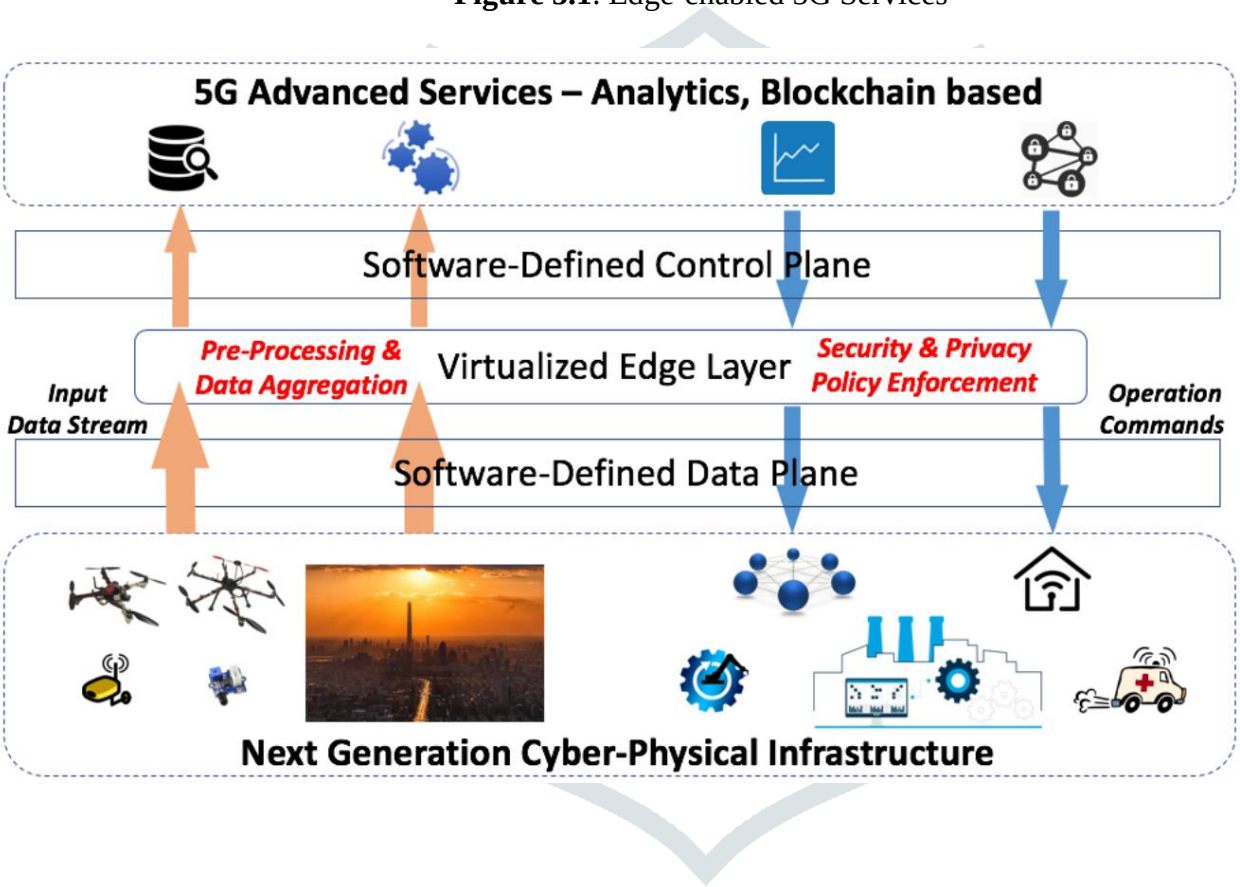
5. Results

It is not easy to ensure proper functioning of 5G services without regulation in case some components are failed or restricted because of market failure. For example, the auction for spectrum is open for discussion as some are occupied already by defence programs in some countries. Failures may lead to disasters for major areas of vertical applications. The architectures for edge computing might be required to operate individually from the network to avoid failure in larger systems. Additionally, it is vital to enforce security in a way that hackers cannot breach the whole system. Interoperability between various platforms and providers is yet another

aspect. Roaming must be possible between providers for proper functioning of vertical domains which might be handled by several 5G network providers.

The data protection laws in the European Union have been changed drastically by the GDPR laws. Private data is another major criteria for 5G applications from both real-world infrastructure and end users. It is also important to guarantee "privacy-by-design" with 5G applications. For better 5G integration, it is also vital to learn from studies on open-data application in smart cities, standardisation, and ambidexterity (Ding et al., 2014; Matheus & Janssen, 2017; Janssen et al., 2015).

Figure 5.1. Edge-enabled 5G Services



Creating a 5G network architecture which combines innovative technologies like SDN, edge computing, virtualization, etc., is capable of developing an adaptable network architecture to deal with changing traffic patterns, and combines wireless and wired devices to meet the demands of various industry domains is the main challenge here. There are many requirements yielded with vertical domains on 5G and actual usage is subject to change. It needs dynamic architecture which can manage traffic and ensure the availability of edge computing for efficient and rapid processing (Figure 5.1).

6. Conclusion

This study has highlighted the opportunities, challenges and applications of 5G services from both governance and technical points of view. It can be a stepping stone for further development for policymakers, engineers, and researchers. 5G should consider the economical and government needs along with technical aspects. 5G connectivity will be one of the most important “common pool resources" (CPR” like energy and water in future. In the context of interoperability among operators, “public-private ownership”, maintenance cost, wireless allocation and spectrum bidding, 5G networks have significant implications on management and regulation. Safety of operations is another concern as a public resource. There might be a merger of IoT and blockchain solutions for 5G-backed mobile and IoT financial services to achieve better privacy and accountability.

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