A Survey on 5G Enabled Multi-Access Edge Computing for Smart Cities: Issues and Future Prospects

Ali Tufail, Abdallah Namoun, Ahmed Alrehaili, Arshad Ali
ali.tufail@iu.edu.sa a.namoun@iu.edu.sa alrehailiium@iu.edu.sa a.ali@iu.edu.sa
Faculty of Computer and Information Systems, Islamic University of Madinah,
Madinah 42351, Saudi Arabia

Summary
The deployment of 5G is in full swing, with a significant yearly growth in the data traffic expected to reach 26% by the year and data consumption to reach 122 EB per month by 2022 [10]. In parallel, the idea of smart cities has been implemented by various governments and private organizations. One of the main objectives of 5G deployment is to help develop and realize smart cities. 5G can support the enhanced data delivery requirements and the mass connection requirements of a smart city environment. However, for specific high-demanding applications like tactile Internet, transportation, and augmented reality, the cloud-based 5G infrastructure cannot deliver the required quality of services. We suggest using multi-access edge computing (MEC) technology for smart cities' environments to provide the necessary support. In cloud computing, the dependency on a central server for computation and storage adds extra cost in terms of higher latency. We present a few scenarios to demonstrate how the MEC, with its distributed architecture and closer proximity to the end nodes can significantly improve the quality of services by reducing the latency. This paper has surveyed the existing work in MEC for 5G and highlights various challenges and opportunities. Moreover, we propose a unique framework based on the use of MEC for 5G in a smart city environment. This framework works at multiple levels, where each level has its own defined functionalities. The proposed framework uses the MEC and introduces edge-sub levels to keep the computing infrastructure much closer to the end nodes.
Keywords:
Fog Computing; MEC; Cloud Computing;5G Smart City, Issues, Opportunities.

1. Introduction

If we look at the history of the technology evolution for wireless communication networks, we can notice that it had a huge impact on various aspects of human life including the behavior, thinking, interaction, economics etc. The journey from 1G to 5G has witnessed an enormous shift in network capacity, services offered, the use of technology, etc. For example, 1G supported up to 2.4 kbps data rate; however, 5G is all set to support more than 1Gbps data rate. The main focus of 5G is to have a profound effect on enhanced mobile broadband (eMBB), ultra-reliable low latency communication (URLLC), and massive Internet of Things (IoT). These characteristics of 5G will enable a revolution in various new applications ranging from medical science, virtual reality, augmented reality, intelligent transportation, industrial automation, smart homes, smart cities, etc. [2].

5G is considered the enabling technology for smart cities and is expected to play a pivotal role in realizing this concept. The relevant features of 5G for smart cities include high-speed connectivity, ultra-low-latency, and massive connections. 5G will help provide various services in the context of smart city, such as education, security, privacy, healthcare, transportation, and energy. As per the International Data Corporation (IDC) report, the investments related to the technologies in smart cities are expected to surpass $135 billion by the end of 2021 [7].

All the expected growth and development of various applications will increase the demand of computational and communication demands. As per the white paper published by Cisco, the worldwide yearly growth in the data traffic from the year 2017-2022 is expected to be 26% and it will touch the mark of 122 EB per month by 2022 [10]. Although there has been a sharp increase in the devices' storage and computation capacities, the mobile devices still lack the capacity to process, store, and communicate an enormous amount of data required for various applications. In this project, we explored the feasibility of using MEC with the 5G infrastructure to reduce computation and storage burden at the central processing servers (like clouds). The load of computation and storage will be distributed between various distributed MEC servers residing close to the end device and within the Radio Access Network (RAN). One of the most important factors considered is latency and its impact on various application scenarios.

The concepts of '5G', 'Smart cities' and 'MEC' have been under focus for the last decade or so for various reasons. They have been in the limelight independent of each other; however, they have discussed how they can potentially strengthen and complement each other.

The main features being offered by 5G are high connectivity, lower latency, greater bandwidth, and better support to mobility. As per the reports, more than 66% of organizations are willing to deploy 5G by the end of 2020 [11]. As per the estimations of Cisco, by the end of the year 2020, 5G is expected to generate three times more traffic compared to 4G. 5G has been deployed in various

Manuscript received June 5, 2021
Manuscript revised June 20, 2021
https://doi.org/10.22937/IJCSNS.2021.21.6.15

countries at a fast rate. As per the statistics, almost 8% of LTE operators have already launched 5G services [12].

Similarly, the idea of smart cities is being realized at a fast pace too. With the increase of urbanization worldwide, the concept of smart cities promises effective and efficient ways to manage the ever-expanding cities. In North America alone, the investment in smart cities related projects is expected to reach $244.5 by 2021 [13]

While 5G and smart city-related concepts are being implemented, the fears of increased data traffic are worrying the researchers and investors alike. As per the white paper published by Cisco, the worldwide yearly growth in the data traffic from 2017-2022 is expected to be 26%, and it will touch the mark of 122 EB per month by 2022 [10]. Although there has been a sharp increase in the devices' storage and computation capacities, mobile devices cannot still process, store, and communicate an enormous amount of data required for various applications. Therefore, researchers are trying to find ways and means to reduce the computation, memory, and traffic loads on the central servers. In this paper, we want to explore the use of MEC for this purpose. The main idea behind MEC is to put most of the required resources at the edge of the network instead of a far-off central place (like a cloud). The benefit of storing and processing data locally can have a considerable impact; for example, it might reduce the latency many folds and congestion over the network. Researchers in both academia and industry are making some efforts to standardize the specifications of MEC. We have researched the latest work related to this domain to pinpoint the efforts to deploy MEC-enabled 5G networks in smart city scenarios. Furthermore, we have proposed a 5G Enabled Multi-Access Edge Computing Framework that can be utilized by the smart cities' environment in particular. This will impact various application scenarios in the context of a smart city, for example, medical science, virtual reality, augmented reality, intelligent transportation, industrial automation, smart homes.

Following is the summary of our key contributions:

- We summarize the concepts and fundamentals related to distributed computing in general and MEC in particular.
- We talk about the evolution of wireless communication and compare various generations of wireless communication, including 6G.
- We provide an overview of efforts being made in the standardization process of MEC and the integration of MEC with 5G.
- We summarize the research efforts being made in distributed computing to integrate 5G, particularly in smart city scenarios.
- Apart from opportunities, we also discuss the challenges faced by the distributed computing as highlighted by various studies.
- We present a 5G enabled MEC framework tailored to be used in smart city scenarios by offering reduced latency and higher performance.

The remainder of the paper is divided into ten sections. Section two presents the evolution of wireless communication. Section three presents the MEC evolution and standardization. Section four details the MEC and 5G integration. Section five reminds of smart cities and their evolution. Section six highlights other distributed computing paradigms and presents their comparison. Section seven compares the MEC with the existing 5 G-based distributed computing paradigms. Section eight discusses the possible challenges for the MEC deployment in mobile networks in smart cities scenarios. Section nine suggests a 5G enabled MEC-based framework for smart cities. Section ten concludes by highlighting the contributions made by our research.

2. Evolution of Wireless Communication

Wireless communication has evolved tremendously, so much so that it has revolutionized all aspects of our daily lives. The first commercial mobile services were launched in the 1980s, where people could only use mobile devices to communicate using voice, and the peak data rate was merely 2.4 kbps. Since then, the wireless telecommunication industry has consistently launched different improved versions with marked differences in speed, latency, security, mobility, etc. With 5G in the deployment process and 6G in the design phase, we are talking about enhancing the data rate to more than a whopping 1 Tbps [33]. This unprecedented data rate and mobility support can help realize the applications such as tactile Internet, fully automated cars, and holographic communication. Figure 1 shows a summary of wireless evolution from 1G to 6G; it also highlights the standards, data rate, latency, mobility amongst all the wireless standards.

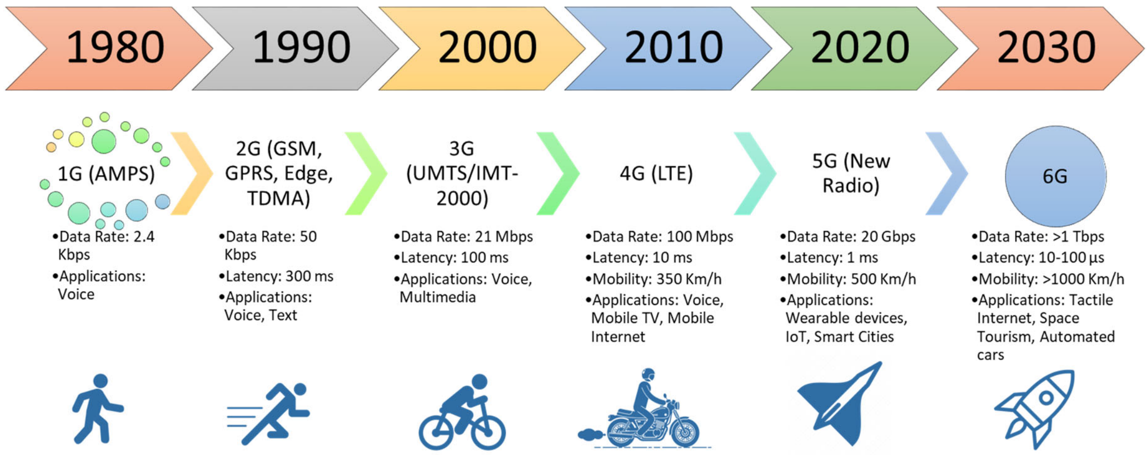

Fig. 1 Wireless Communication Evolution

3. MEC Evolution and Standardization

With the deployment of 5G, researchers focused on solving issues related to the applications requiring high computation and storage and real-time information. As a result of these efforts, concepts surrounding the MEC were developed and sharpened, where the computation was pushed towards the network's edge. With MEC, other technologies were also developed, such as fog computing, cloudlet computing, and mobile cloud computing. However, all of them had their inherent disadvantages, such as fog computing is dependent on cloud computing data center and cannot have its own managed data center; therefore, it is not integrated as a part of mobile network and usually work outside the mobile network independently [34]. On the other hand, the telecommunication industry took a particular interest in MEC. In 2014, the European Telecommunication Standards Institute (ETSI) initiated the MEC concept under MEC-ISG. They aimed to integrate MEC in the C-RAN architecture [35]. They also renamed mobile edge computing to multi-access edge computing and specific to C-RAN 5G architecture [36]. This MEC ISG worked towards the standardization of MEC for 5G. They focused on moving the computation closer to the user to enhance the network optimization and increase the service efficiency for the users. Following is the framework for MEC proposed by MEC ISG [37]:

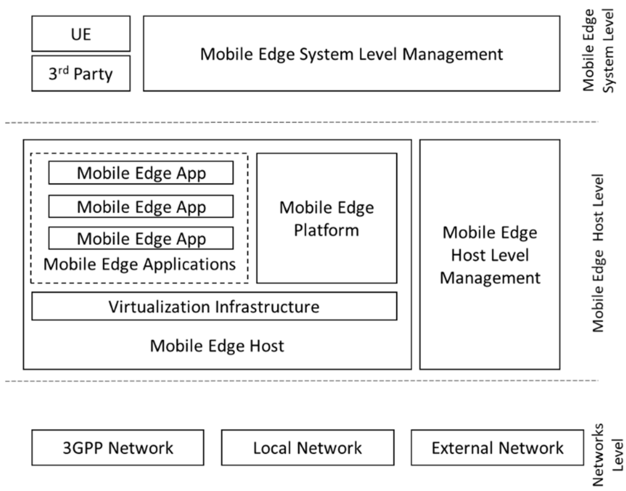

Fig. 2 ETSI MEC Framework

Other efforts were made in the industry towards the standardization of MEC and similar technologies for 5G; for example, the OpenFog Consortium was formed in 2015 to define a common open framework for distributed computing [38]. Similarly, 3GPP standards were developed to support MEC for 5G [39].

4. MEC and 5G Integration

Academicians and industry carried out much research to know various aspects of integrating 5G with MEC, the challenges, and opportunities. Here we will summarize the efforts being exerted by the academicians towards integrating 5G and MEC.

Authors in [2-5] survey MEC and its related technologies and suggest integrating 5G with MEC. In [2] authors discuss the increase in the data traffic after the deployment of 5G. They say that increase in the data traffic will add much more burden to the 5G infrastructure, so it will not be that easy to run the applications that need more computation and applications with fewer latency requirements. They survey the MEC technology and its use with 5G. However, they do not focus on applications with special requirements in the smart city environment.

In [3] authors talk about the importance of the location where the computation is performed. They talk about cloud architecture and the benefits and disadvantages attributed to this architecture. The authors then talk about MEC architecture and the benefits it can bring in the 5G environment. They further discuss Software Defined Networking (SDN) and Network Function Virtualization (NFV) and their relationship with MEC. They talk about the importance of the edge location and criteria that need to be considered for MEC deployment in the network.

Authors in [4] talk about the importance of MEC and its impact on the telecommunication industry. They also compare MEC with the cloud computing architecture and the benefits MEC can provide compared to the cloud architecture. The focus of their survey is MEC orchestration. They also discuss MEC platforms and application scenarios. Lastly, they talk about the efforts being put in by several standardization organizations towards producing a standard for MEC.

The main idea being discussed in [5] is the importance of MEC in the radio access network of 5G. The authors talk about the impact on latency with the use of MEC technology. They talk about three use cases in the 5G environment and how MEC will impact those use cases. They also talk about the challenges that might need to be addressed to integrate MEC and 5G.

In [42], the authors presented an analysis of multi-access edge computing (MEC) in the context of 5G and IoT. They presented several vital technologies which enable MEC to be applied in 5G and IoT. These technologies can be applied to cloud computing, software-defined networking/network function virtualization, virtual machines (VM), and smart devices. Further, the authors reviewed the role of MEC in 5G and IoT and the future directions of integrating MEC with 5G and IoT and elaborated on the challenges open issues of MEC for 5G and IoT.

5. Smart Cities and their Evolution

The notion of “Smart Cities” is being predominantly used these days all around the world. In this section, we explain this concept in detail and in the context of its usage for humanity.

We can refer to the smart city as a ‘framework. This ‘framework’ is majorly formed with the help of state-of-the-art technologies (information and communication). The motivation behind this idea to be developed and to be implemented to manage the increasing rate of urbanization. It is getting challenging for the governments to manage metropolitan cities and provide essential services to the citizens. Most of the technologies utilized in smart cities are wireless and seamless and mostly are communicating without human intervention. The data are typically transmitted from various sensors and objects and collected in the cloud for investigation and decision making.

There are various stakeholders in the ecosystem of smart cities, for example, citizens, government, enterprises, municipalities etc. With the help of various IoT devices, platforms, and frameworks in a smart city, energy consumption can be reduced, and traffic can be easily managed during the rush hours, emergency services can be provided in time. Even the cities can become cleaner and greener.

Generally speaking, we can divide smart cities into three layers or levels. At the first level, we can consider all the technological devices used to collect data and are available in a vast number. These devices include mobile phones and sensors. These devices are typically connected to a very high-speed communication network like 5G.

At the second level, we can place all the applications that are running on these devices. With the help of these applications, the data are converted into meaningful information for the end-users or other devices in the case of M2M communication. The stakeholders at this level include the application developer and the companies providing all the relevant technologies.

The third level includes the actual utilization of the applications (mentioned in level two) by the users. The services will not be useful and practical unless people and citizens are using them.

One of the most critical concerns in smart cities is the violation of privacy and security. In order to enhance the security of the city, a lot of smart devices might be deployed, for example, digital cameras, intelligent transportation system, monitoring the people for the concerns of protecting citizens. However, all these measures can violate the privacy of the citizens. Therefore, there should be a balance between these two factors.

Much research is being carried out to help achieve various smart city goals. The authors' focus in [6] is towards making the user experience better for video streaming applications in smart cities. The authors propose to use the MEC technology to increase the quality of service. Their focus is mainly on mobility, latency, and network congestion. They propose to create a MEC service to allow

easy access for the users. However, the authors do not talk about the use of 5G to achieve their goals.
Similarly, the authors of [40] provided and discussed the evolution of 5G technology and its working. The paper presents the security issues and impact of 5G on modern technologies such as the Internet of Things (IoT), self-driving cars, and artificial intelligence (AI). After solving problem-related to 5G network then it can be the keystone in the applications of a smart city such as transport, public services, health and other infrastructure.

In [41], the authors presented the impact and implications of 5G on Intelligent Transporting System (ITS) as ITS is one of the many smart city applications. The paper presents technological features in economic benefits and industries that will be affected in smart cities, such as public transport, manufacturing, health care, and the energy sector.

Various projects have been implemented and are still in progress in various cities around the world. For example, the following data shows a list of various smart cities around the world [30]:

1. According to Forbes, the following are considered the top 10 smart cities in the world in the given order (from 1-10): London, New York, Paris, Tokyo, Reykjavik, Copenhagen, Berlin, Amsterdam, Singapore, Hong Kong.
2. According to Cities in motion, the following are considered the top 10 smart cities in the USA in the given order (from 1-10): New York, Los Angeles, Chicago, San Francisco, Washington, Boston, Miami, Phoenix, Dallas, and San Diego.
3. According to computer world, the following are considered the top 10 smart cities in the UK in the given order (from 1-10): Milton Keynes, Glasgow, Nottingham, Cambridge, Bristol, London, Manchester, Birmingham, Leeds.

The advancement of the technologies in smart cities is supported by using wireless sensor networks and digital networks and applications [14]. Smart cities are often called viable, digital, or connected cities by using the Internet of Things (IoT), which further supports the Internet of Vehicles (IoV) [15]. The purpose of converting a city into a smart environment is to overcome urbanization and increased urban population. A smart city is an urban area that provides sustainable economic growth and quality of life. Smart solutions, like traffic congestion avoidance [16], green buildings [17], and modern industrial control systems (ICS) [18], are some of the technologies that can make today’s urbanization sustainable. A smart city involves the intelligent use of technology to improve how people live, work, commute, and share information [19]. A vital aspect of a smart city is next-generation vehicles that incorporate new sensing, communication, and social capabilities as part of the wider Internet of Things concept. By providing mobile wireless sensing and communications, vehicles can facilitate data access, which is fundamental to make smart cities a reality. Through their advanced communication capabilities, smart vehicles will be able to interact not only with navigation and broadcast satellites but also with passenger smart phones, roadside units, and other smart vehicles, making them an essential component of IoT and the development of smart cities [20].

6. Other Distributed Computing Paradigms

The inherent problem of cloud computing encouraged researchers to find alternatives where the computation load could be offloaded from the cloud to enhance efficiency and reduce latency. For the mobile telecommunication industry, this was crucial since the user demands were increasing with the development of ever new applications. MEC is an outcome of such a need. However, several other computing frameworks and architectures have been proposed on various forums. We have selected some of the proposed computing paradigms. These paradigms can equally be deployed in smart city environments just like MEC. These paradigms were intended to shift the computations and storage capabilities towards the user of the services.

6.1 Fog Computing

The term fog computing was first used by Cisco in 2012 when they started their efforts to move the cloud computing infrastructure away from the central cloud. They suggested to distribute edge nodes geographically to form a distributed cloud infrastructure [43]. The basic idea behind fog computing is to push the cloud nodes to the edge of the network to cater for the applications and high-speed Internet requirements. It also reduces the network load on the traffic that was previously going to the central cloud making unnecessary delays due to traffic congestion. It also makes network and device management easier since most of the management can be handled at the network's edge [44].

Many a times fog computing is mixed with MEC, where fog is considered as the concept to shift the computing resources away from the central cloud towards the edge of the network and MEC is considered one of the implementations of the fog where computation and storage resources are shifted to the extreme edge of the network usually with the base stations [45]. Fog computing can have varying devices and equipment.

6.2 Cloudlets

Cloudlets can be defined as a cloud near the edge of the network. They are usually a trusted set of computers accessible by the end devices just within a hop distance. They can also be called a data center in a box [45] since they can provide various resources to the end-users over wireless LANs. Typically, Cloudlets can be placed at community places such as train or bus stations, airports, malls, museums etc. Cloudlets must have access to high-speed Internet, and the end devices usually are very lightweight devices that depend on the Cloudlets for most of the processing.

6.3 Moisture Computing

Moisture computing (MC) concept has been introduced lately [46]. This distributed computing paradigm brings the necessary processing capabilities as close as possible to the users, typically below cloud infrastructure but above the edge of the network. This paradigm seeks to gather the advantages of both cloud and mobile edge computing paradigms since the computing and storage infrastructure has been placed a couple of hops away from the end-user, unlike MEC, which is one hop away, and in cloud computing it is tens of hops away [46].

Table 1: Summary of Distributed Computing Paradigms

	Fog Computing	Mobile Edge Computing	Moisture Computing	Cloudlets
Year Introduced	2012	2014	2021	2009
Supporting Organization	OpenFog Consortium	ETSI	None	Open Edge Computing Initiative
Driving Force	Internet of Things and Smart Cities Applications	5G requirements and Integration	5G, Internet of Things and Smart Cities Applications	Mobile Applications in Community Places
Support Features	OpenFog Reference Architecture	ETSI MEC Architecture	Moisture Computing Architecture	OpenStack++ Platform
Computing Infrastructure Location	Anywhere Between Cloud and End Device	Edge of the Network (Base Station)	Above the Edge of the Network (Typically two hops away from the End Device)	Edge of the Network (Typically One Hop away from the End Device)

7. Summary of Existing 5G Based Studies on Distributed Computing Paradigms

In this section, we compare the most recent frameworks and architectures presented by the research community in distributed computing for the smart city environment. We have most carefully selected eight parameters to summarize the work done on 5 G-based distributed computing paradigms. Following is the list of parameters along with the necessary explanation:

1. 5G
   This parameter indicates if the study talks about the use of distributed paradigm with 5G.
2. IoT
   This parameter tells if the study covers the IoT aspects or not.
3. Fog Computing
   This parameter talks about if the study presents concepts and frameworks related to the fog computing.
4. Multi-Access Edge Computing
   This parameter talks about if the study presents concepts and frameworks related to multi-access edge computing.
5. Architecture/Framework
   This parameter indicates if the study has presented any architecture or a framework.
6. Smart City Support
   This parameter tells if the study talks about the support it can provide for smart city environment.
7. Use Case
   This talks about various use cases that can be supported by the selected study.
8. Evaluation
   This parameter has been used to show if the selected study has been evaluated and which method has been used to evaluate such as simulation, mathematical analysis, real-time implementation.

Table 2: Summary of Studies on 5G Based Distributed Computing Paradigms

Study	Year	5G	IoT	Fog Computing	Multi Access Edge Computing	Architecture /Framework	Smart City Support	Use Case	Evaluation
[22]	2017	✓	✓	✓	×	TelcoFog Architecture	✓	Latency-sensitive and -Geo-distributed applications	Simulation
[23]	2018	✓	✓	×	✓	5G IoT Architecture	✓	None	None
[24]	2019	✓	✓	✓	✓	Blockchain-based sharing economy system	✓	Security- and privacy-oriented spatio-temporal smart contract services	Simulation
[25]	2019	✓	✓	×	✓	Architecture based on IIoT-MEC	✓	Intelligent entrance guard system and Industrial intelligent applications	Real Time Implementation
[26]	2020	✓	×	×	✓	Agile security risk-aware edge server mechanism	×	Security related applications	Mathematical Analysis
[28]	2018	✓	✓	✓	✓	A Fog-Based Management and Orchestration Framework for 5G Smart Cities	✓	Health monitoring and predictive maintenance applications	Real Time Implementation
[29]	2018	✓	✓	✓	✓	IEE5GG architecture	✓	Health care applications	Simulation

Most of the studies that have been proposed recently do not provide the complete validation of their proposed frameworks and protocol. This is very obvious in the above-given comparison table 2. The field is still evolving, and we are expecting much work in this particular domain in the near future. With the new protocols and standards, validation scenarios would also emerge that would strengthen this domain.

Authors in [21] reviewed a fog computing-based 5G architecture. The author claimed that their reviewed architecture could benefit telecom operators who wanted to provide highly responsive and ultra-low latency services to their customers.

Authors in [22] presented an architecture which they called TelcoFog. The architecture is based on fog computing infrastructure. The author claimed that the telecommunication industry could use their proposed architecture.

Authors in [24] proposed a 5G-IoT based architecture that they claimed could be used for various services supporting next-generation technologies.

Another study (Rahman et al., 2019) presented a Blockchain and IoT-based framework for smart city scenarios. The authors claimed that their proposed framework could support various services in a smart city, such as smart contracts and sharing economies.

Authors in [25] talked about an Industrial Internet of Things-based framework. They claim that the framework overcame the existing weaknesses in the 5G enabled MEC networks.

A framework of MEC based on 5G networks has been proposed in yet another study [26]. Several security controls were suggested in the study that could be utilized to minimize the problems that occurred due to violation of service level agreements.

Authors in [27] presented an approach to be used in the smart city context. They utilized the mobile edge computing concepts to enhance the speed of notifications sent back and forth in the smart cities. They claim that their proposed approach could be handy for smart cities.

Authors in [28] proposed a framework for smart cities. The proposed framework is based on fog computing in 5G networks. The authors claimed that their proposed protocol worked for exchanging application services provisioning between the fog nodes.

Authors in [29] have proposed 5 G-based smartphone gateway exclusively for the healthcare industry. Their study claims that the proposed protocol increased energy efficiency and reduces service response time.

8. Major Challenges for MEC Deployment in Mobile Networks in Smart Cities

Following is a set of key issues and challenges that can arise with the deployment of mobile edge computing in smart cities scenarios:

1. Artificial Intelligence and Big data mining
   With high-speed networks and the massive generation of data a big challenge arises to come up with efficient tools and techniques to manage the data as per the needs. Artificial intelligence can be utilized to get the interesting pattern of data from this huge database. Although some work has been done in this domain, such as the development of distributed learning mechanisms [50] and edge machine learning [49], we still need to go a long way before having common standards to solve these issues.
2. Network Slicing
   Another crucial challenge in the deployment of MEC for 5G enabled networks is network slicing. It is anticipated that in smart city scenarios, there will be diverse and distinct requirements of applications and businesses in required QoS and data. Therefore, we need efficient network slicing techniques and mechanisms for edge networks. Some efforts have been made [51, 52] to introduce software-defined networks to allocate resources in edge computing networks efficiently.
3. Mobility
   Mobility should be supported for varied applications and business requirements. It is a challenge to make sure that the network supports mobility reliably. Approaches are required to make handovers seamless and less since with edge computing, there is a big chance that frequent handovers might occur that can affect the performance of different applications. These issues have been discussed in detail in different studies [53, 54].
4. Interaction of Distributed Infrastructure with the Cloud
   In most cases, the edge computing nodes will interact with the central cloud data center since, most likely, the edge node will be implemented hierarchically. Therefore, developing efficient and reliable techniques and mechanisms for this interaction is required to avoid any performance degradation. Some studies discuss these problems in detail [55, 56].
5. Privacy and Security
   This is a fundamental challenge for all data-driven networks and especially wireless communication networks. Not much work has been done in this domain for edge computing networks. Some authors [47, 48] have tried to develop authentication mechanisms and encryption mechanisms; however, many issues remain un-tackled.

9. Proposed 5G Enabled MEC Based Framework for Smart Cities

In this section, we propose a 5G Enabled MEC-based framework. This framework is expected to support the ongoing efforts of integrating MEC in the 5G environment to push the resources towards the edge of the network. The following figure explains the overall architecture of the proposed framework. A total of four different layers or levels of the architecture have been proposed. Each level is responsible for a set of functionality and operations. Following is the detail of the proposed levels:

9.1 Application Level

This is the topmost level, i.e., 4 of the proposed architecture. This level is responsible for having interaction with the users and providing services. The users at this level will be the cooperate users or the government officials who would be involved in various decision-making processes. The applications can range from a complex dashboard explicitly designed to serve the need of a particular government agency or as simple as giving some predictions based on the gathered data.

The application-level will be having a close interaction with the level below, i.e., the cloud level since it will be the cloud that will be gathering all the data from various sources. However, the applications running at the application level will support the authorities to take various decisions.

9.2 Cloud Level

This is level 3 of the architecture. This level is responsible for maintaining all the cloud-related infrastructure, including the specialized servers, storage etc. This level provides services to the applications in the level above it (Application Level), and at the same time, Cloud Level interacts with the level below it, i.e., Fog Level. The infrastructure at the fog level has to have close coordination with the Cloud Level infrastructure to localize the processing of various queries coming from Level 1. Analytic engines will also be running at this level. These analytic engines will provide an interface to the level above, i.e., The Application Level. The analytics engine will also provide visualization of various scenarios with the help of a specialized dashboard for authorities or other organizations.

9.3 Fog Level

This is level 2 of our proposed architecture. Fog Level brings the cloud-like infrastructure to a lower level closer to the users using the services. This level will be doing local processing of the various queries from the level below it, i.e., Edge sublevel and the Sensing Level. Fog level helps in reducing the latency and providing various services at a much faster rate.

9.4 Sensing Level

This is level one of the proposed architecture. This level has all the sensing devices that will be deployed at various locations of a smart city. These devices (also called smart devices in IoT) are involved in gathering various data and sending it to the servers. Users also interact in this layer. For example, if a user wants to download the best restaurants of a particular area, he or she will interact with the local server to get the required information. Since the focus of the proposed framework is 5G, the layer is mainly concerned with providing all 5 G-related services to the users. Moreover, all the smart devices are also collecting and sending data using 5G services.

In order to provide on-the-fly services and reduce the latency to get emergency services, the proposed framework introduces a sub-layer towards the edge of the network. This sublayer is called the Edge sublayer. The Edge sublayer possesses the basic infrastructure like the server to process the data before sending it to the Fog level. This will reduce the response time significantly and for providing 5G services much faster.

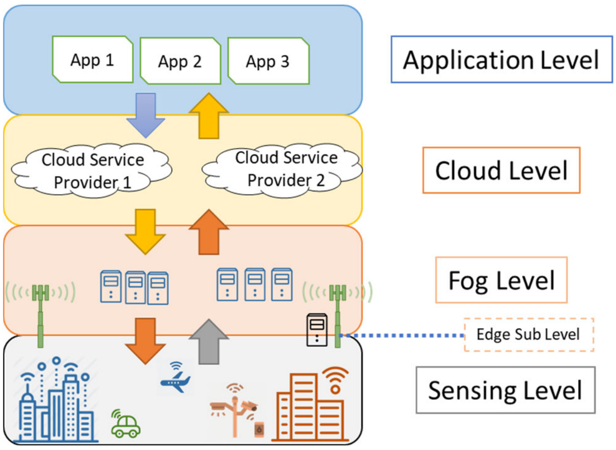

Fig. 3 Proposed 5G Enabled MEC Based Architecture

The following figure shows an example scenario where a user is requesting some services using his mobile phone. The mobile phone uses 5G as the underlying network to communicate. The user who is in the Level 1 of the proposed framework first interacts with the device (i.e., a smart device) and requests a list of restaurants in that particular area. The mobile phone will first interact with the Edge sublayer. Most likely, the local server will reply to the query after local processing. It means a fast response time and excellent interactivity for the user. Now, let us suppose that the user wants to get the best restaurant for the adjacent areas. Maybe the local server does not have that information to send the query to Level 2, i.e., the Fog Level. Since there is more infrastructure at this level and less local than the Edge sublayer, this layer will respond with the required list. The user still enjoys less response time and good interactivity.

Now let us further assume that the user requests for the best restaurant in the entire city, the Second Level, i.e., the Fog Level, might not have that information to go to the level above, i.e., the Cloud Level. The user now gets the response not as quick as the last time, but still, he gets in a reasonable time and has still good interactivity level.

At level 4, i.e., the Application Level, the city authorities might be getting the information of these queries with the help of data visualization tool and the dashboard, and they might like to do something about it to enhance the response time by pushing the required information to the Fog Level.

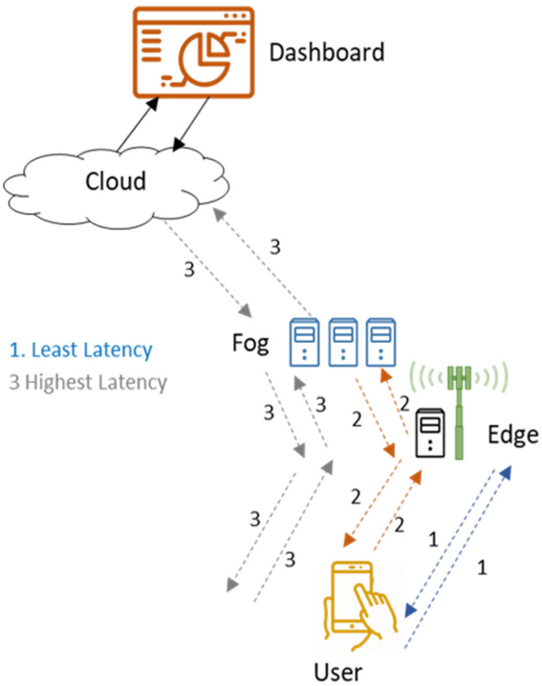

Fig. 4 Scenario Showing User Requesting Information

10. Conclusion

The integration of 5G and MEC is now a reality, and the standards provided by ETSI emphasises its importance. With the deployment of 5G and the prevalence of smart cities, this integration will play a pivotal role in fulfilling the ever-increasing demands of users and businesses. 5G is designed to support the enhanced data delivery requirements and the mass connection requirements of a smart city environment. However, for high-demanding applications like tactile Internet, transportation, and augmented reality, the cloud-based 5G infrastructure cannot deliver the required quality of services. Therefore, MEC is added as a distributed paradigm with 5G networks. This paper summarizes various fundamental concepts and technologies related to MEC. In particular, we presented the evolution of wireless communication, MEC evolution and standardization, MEC and 5G integration, smart cities and their evolution, other distributed computing paradigms, compared MEC with the existing 5G based distributed computing paradigms. Moreover, we have proposed an innovative framework that can augment smart cities. The proposed framework uses a hierarchical architecture where 5G serves as the leading technology to provide several services for the comfort and convenience of citizens of a smart city. Unique concepts of using MECs close to the end-users have been proposed. That will increase the ease of managing the data generated in a smart city, and at the same time, it will reduce the latency and will help to provide critical information in no time. In the future, we would like to validate our proposed framework using a implementation-based simulation of real-life scenarios in smart cities.

Acknowledgments

This research work was funded by the Deanship of Research, Islamic University of Madinah, Saudi Arabia.

References

[1] https://www.smartcitiesworld.net/opinions/opinions/what-5g-means-for-smart-cities
[2] Pham, Quoc-Viet & Fang, Fang & Ha, Vu & Le, Mai & Ding, Zhiguo & Le, Long & Hwang, won-Joo. (2020). A Survey of Multi-Access Edge Computing in 5G and Beyond: Fundamentals, Technology Integration, and State-of-the-Art.
[3] Belghol, Hibat Allah & Idrissi, Abdellah. (2017). MEC towards 5G: A Survey of Concepts, Use Cases, Location Tradeoffs. Transactions on Machine Learning and Artificial Intelligence. 5. 10.14738/tmlai.54.3215.
[4] Taleb, Tarik & Samdanis, K. & Mada, Badr Eddine & Flinck, Hannu & Sabella, Dario. (2017). On Multi-Access Edge Computing: A Survey of the Emerging 5G Network Edge Architecture & Orchestration. IEEE Communications Surveys & Tutorials. PP. 1-1. 10.1109/COMST.2017.2705720.
[5] Tran, Tuyen & Hajisami, Abolfazl & Pandey, Parul & Pompili, Dario. (2017). Collaborative Mobile Edge Computing in 5G Networks: New Paradigms, Scenarios, and Challenges. IEEE Communications Magazine. 55. 10.1109/MCOM.2017.1600863.
[6] Taleb, Tarik & Ksentini, Adlen & Iqbal, Muddesar & Flinck, Hannu. (2017). Mobile Edge Computing Potential in Making Cities Smarter. IEEE Communications Magazine. 55. 38-43. 10.1109/MCOM.2017.1600249CM.
[7] https://www.kaspersky.com/blog/secure-futures-magazine/5g-securing-smart-cities/32175/
[8] https://www.govtech.com/fs/infrastructure/5G-Can-Enable-Smart-Cities-If-Policymakers-Allow-It.html
[9] https://www.nec.com/en/global/insights/article/2020022501/index.html
[10] Cisco. (2019, Feb.) Cisco visual networking index: Global mobile data traffic forecast update, 2017-2022, white paper.

Available At: .https://www. Cisco.com/c/dam/m/en_us/network-intelligence/service-provider/digital-transformation/knowledge-network-webinars/pdfs/1213-business-services-ckn.pdf
[11] "What Is 5G Technology And How Must Businesses Prepare For It?" https://www.forbes.com/sites/bernardmarr/2019/10/25/what-is-5g-technology-and-how-must-businesses-prepare-for-it/#c987e0d1758b
[12] https://gsacom.com/paper/5g-market-status-snapshot-january-2020/
[13] "Thinking about becoming a smart city? 10 benefits of smart cities" Available at:https://www.plantemoran.com/explore-our-thinking/insight/2018/04/thinking-about-becoming-a-smart-city-10-benefits-of-smart-cities
[14] Caragliu, A.; Del Bo, C.; Nijkamp, P. Smart cities in Europe. J. Urban Technol. 2011, 18, 65–82.
[15] Ishida, T.; Isbister, K. Digital Cities: Technologies, Experiences, and Future Perspectives; Number 1765; Springer Science & Business Media: Berlin, Germany, 2000.
[16] Xiong, Z.; Sheng, H.; Rong, W.; Cooper, D.E. Intelligent transportation systems for smart cities: A progress review. Sci. China Inf. Sci. 2012, 55, 2908–2914.
[17] Bowerman, B.; Braverman, J.; Taylor, J.; Todosow, H.; von Wimmersperg, U. The vision of a smart city. In Proceedings of the 2nd International Life Extension Technology Workshop, Paris, France, 28 September 2000; Volume 28.
[18] Su, K.; Li, J.; Fu, H. Smart city and the applications. In Proceedings of the 2011 International Conference on Electronics, Communications and Control (ICECC), Zhejiang, China, 9–11 September 2011; pp. 1028–1031.
[19] Hollands, R.G. Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? City 2008, 12, 303–320.
[20] Gubbi, J.; Buyya, R.; Marusic, S.; Palaniswami, M. Internet of Things (IoT):Avision, architectural elements, and future directions. Future Gener. Comput. Syst. 2013, 29, 1645–1660.
[21] Velasco, L. and Ruiz, M., 2018, July. Flexible fog computing and telecom architecture for 5G networks. In 2018 20th International Conference on Transparent Optical Networks (ICTON) (pp. 1-4). IEEE.
[22] Vilalta, R., López, V., Giorgetti, A., Peng, S., Orsini, V., Velasco, L., Serral-Gracia, R., Morris, D., De Fina, S., Cugini, F. and Castoldi, P., 2017. TelcoFog: A unified flexible fog and cloud computing architecture for 5G networks. IEEE Communications Magazine, 55(8), pp.36-43.
[23] Rahimi, H., Zibaeenejad, A. and Safavi, A.A., 2018, November. A novel IoT architecture based on 5G-IoT and next generation technologies. In 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON) (pp. 81-88). IEEE.
[24] Rahman, M.A., Rashid, M.M., Hossain, M.S., Hassanain, E., Alhamid, M.F. and Guizani, M., 2019. Blockchain and IoT-based cognitive edge framework for sharing economy services in a smart city. IEEE Access, 7, pp.18611-18621.
[25] Hou, X., Ren, Z., Yang, K., Chen, C., Zhang, H. and Xiao, Y., 2019, April. IIoT-MEC: A novel mobile edge computing framework for 5G-enabled IIoT. In 2019 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 1-7). IEEE.
[26] Carvalho, G.H., Woungang, we., Anpalagan, A. and Traore, we., 2020. When Agile Security Meets 5G. IEEE Access, 8, pp.166212-166225.
[27] Sapienza, M., Guardo, E., Cavallo, M., La Torre, G., Leombruno, G. and Tomarchio, O., 2016, May. Solving critical events through mobile edge computing: An approach for smart cities. In 2016 IEEE International Conference on Smart Computing (SMARTCOMP) (pp. 1-5). IEEE.
[28] Santos, J., Wauters, T., Volckaert, B. and De Turck, F., 2018. Fog computing: Enabling the management and orchestration of smart city applications in 5G networks. Entropy, 20(1), p.4.
[29] Sigwele, T., Hu, Y.F., Ali, M., Hou, J., Susanto, M. and Fitriawan, H., 2018, December. Intelligent and energy efficient mobile smartphone gateway for healthcare smart devices based on 5G. In 2018 IEEE Global Communications Conference (GLOBECOM) (pp. 1-7). IEEE.
[30] https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/inspired/smart-cities
[31] https://www.mckinsey.com/business-functions/operations/our-insights/smart-cities-digital-solutions-for-a-more-livable-future#
[32] https://www.i-scoop.eu/internet-of-things-guide/smart-cities-smart-city/
[33] https://www.libelium.com/libeliumworld/top-50-iot-sensor-applications-ranking/
[34] Akhtar, M.W., Hassan, S.A., Ghaffar, R., Jung, H., Garg, S. and Hossain, M.S., 2020. The shift to 6G communications: vision and requirements. Human-centric Computing and Information Sciences, 10(1), pp.1-27.
[35] Mukherjee, M., Shu, L. and Wang, D., 2018. Survey of fog computing: Fundamental, network applications, and research challenges. IEEE Communications Surveys & Tutorials, 20(3), pp.1826-1857.
[36] Hu, Y.C., Patel, M., Sabella, D., Sprecher, N. and Young, V., 2015. Mobile edge computing—A key technology towards 5G. ETSI white paper, 11(11), pp.1-16.
[37] Kekki, S., Featherstone, W., Fang, Y., Kuure, P., Li, A., Ranjan, A., Purkayastha, D., Jiangping, F., Frydman, D., Verin, G. and Wen, K.W., 2018. MEC in 5G networks. ETSI white paper, 28, pp.1-28.

[38] ETSI, M., 2019. Multi-access edge computing (MEC) framework and reference architecture. ETSI GS MEC, 3, p.V2.
[39] OpenFog Consortium Architecture Working Group, 2016. OpenFog architecture overview. White Paper OPFWP001, 216, p.35.
[40] 3GPP Technical Specification Group Services and System Aspects; System Architecture for the 5G System, June 2019. Standard 3GPP TS 23.501 v16.1.0.
[41] Pisarov, J. and Mester, G., 2020. The Impact of 5G Technology on Life in 21st Century. IPSI BgD Transactions on Advanced Research (TAR), 16(2), pp.11-14.
[42] Gohar, A. and Nencioni, G., 2021. The Role of 5G Technologies in a Smart City: The Case for Intelligent Transportation System. Sustainability, 13(9), p.5188.
[43] Liu, Y., Peng, M., Shou, G., Chen, Y. and Chen, S., 2020. Toward edge intelligence: multi-access edge computing for 5G and Internet of things. IEEE Internet of Things Journal, 7(8), pp.6722-6747.
[44] https://www.cisco.com/c/en/us/solutions/computing/what-is-edge-computing.html#~revenue-opportunities
[45] Aazam, M., Zeadally, S. and Harras, K.A., 2018. Fog computing architecture, evaluation, and future research directions. IEEE Communications Magazine, 56(5), pp.46-52.
[46] Dolui, K. and Datta, S.K., 2017, June. Comparison of edge computing implementations: Fog computing, cloudlet and mobile edge computing. In 2017 Global Internet of Things Summit (GIoTS) (pp. 1-6). IEEE.
[47] Tufail, A., Namoun, A., Sen, A.A.A., Kim, K.H., Alrehaili, A. and Ali, A., 2021. Moisture Computing-Based Internet of Vehicles (IoV) Architecture for Smart Cities. Sensors, 21(11), p.3785.
[48] He, X., Jin, R. and Dai, H., 2019. Peace: Privacy-preserving and cost-efficient task offloading for mobile-edge computing. IEEE Transactions on Wireless Communications, 19(3), pp.1814-1824.
[49] He, T., Ciftcioglu, E.N., Wang, S. and Chan, K.S., 2017, June. Location privacy in mobile edge clouds. In 2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS) (pp. 2264-2269). IEEE.
[50] Park, J., Samarakoon, S., Bennis, M. and Debbah, M., 2019. Wireless network intelligence at the edge. Proceedings of the IEEE, 107(11), pp.2204-2239.
[51] Zhang, C., Patras, P. and Haddadi, H., 2019. Deep learning in mobile and wireless networking: A survey. IEEE Communications surveys & tutorials, 21(3), pp.2224-2287.
[52] Cao, B., Sun, Z., Zhang, J. and Gu, Y., 2021. Resource Allocation in 5G IoV Architecture Based on SDN and Fog-Cloud Computing. IEEE Transactions on Intelligent Transportation Systems, 22(6), pp.3832-3840.
[53] Zhuang, W., Ye, Q., Lyu, F., Cheng, N. and Ren, J., 2019. SDN/NFV-empowered future IoV with enhanced communication, computing, and caching. Proceedings of the IEEE, 108(2), pp.274-291.
[54] Sung, N.W., Pham, N.T., Huynh, T. and Hwang, W.J., 2013. Predictive association control for frequent handover avoidance in femtocell networks. IEEE communications letters, 17(5), pp.924-927.
[55] Dong, Y., Chen, Z., Fan, P. and Letaief, K.B., 2015. Mobility-aware uplink interference model for 5G heterogeneous networks. IEEE Transactions on Wireless Communications, 15(3), pp.2231-2244.
[56] Zhang, L., Wang, K., Xuan, D. and Yang, K., 2018. Optimal task allocation in near-far computing enhanced C-RAN for wireless big data processing. IEEE Wireless Communications, 25(1), pp.50-55.
[57] Dao, N.N., Lee, Y., Cho, S., Kim, E., Chung, K.S. and Keum, C., 2017, October. Multi-tier multi-access edge computing: The role for the fourth industrial revolution. In 2017 International Conference on Information and Communication Technology Convergence (ICTC) (pp. 1280-1282). IEEE.