CHAPTER 1

5G AND D2D COMMUNICATIONS AT THE SERVICE OF SMART CITIES

Abstract

Typical smart city applications generally require two different communications infrastructures, a wide area cellular network to provide connectivity and long-range communications and efficient communication strategies for transmitting short data packets, particularly in case of Internet of Things (IoT) devices. The cellular infrastructure is optimized for high data rates and large data sizes while IoT devices mostly exchange small data packets with high energy efficiency and low data rates. To fully exploit both communication infrastructures together, different strategies related to 5G and Device-to-Device (D2D) communication are proposed in literature. In this chapter, we survey these strategies and provide useful considerations for seamless integration of smart city applications in 5G networks. Moreover, we present smart city scenarios, their communication requirements and the potential impact on the life of citizens. Finally, we elaborate big data impact on smart cities with possible security and privacy concerns.

1.1 Introduction

More than half of the world population lives in cities and the trend of moving to bigger cities is increasing with the time [1]. This increase in population of the cities is resulting in technical, physical and material problems. Air pollution, traffic congestion, human health concerns, aging infrastructures and difficulty in waste management are a few to mention [2]. Smart city is a recent concept, which aims at solving the aforementioned problems and improving the quality of life of citizens [3]. A city is considered to be smart when Information and Communication Technologies (ICT) based solutions are employed in order to provide a high quality of life to its citizens, thus potentially achieving economic growth [4]. According to "European Smart Cities", an EU project, [3], six areas of smartness are identified, including smart economy, smart people, smart governance, smart mobility, smart environment, and smart living.

ICT has become the nerve of smart cities enabling new ways of transport management, traffic control, environmental pollution monitoring, health care, public safety and security, surveillance and maintenance of public areas and preservation of cultural heritage [3]. The communication infrastructure in ICT represents the backbone of the smart city, connecting Internet of Things (IoT) over cellular networks. IoT in smart cities exhibits diverse requirements to communication infrastructure with heterogeneous data sizes, traffic demands and services [4]. For example, applications like environmental monitoring and water management do not require very low latency communication. On the other hand, applications like collision avoidance in smart cars impose stringent requirements on the communication requiring extremely low latency and very high reliability [5]. The network must evolve to meet the diverse needs and preferences of aforementioned services. For this evolution, a unified communication infrastructure is needed, which should not only support voice and data but also diverse users, services and applications.

The conventional cellular networks such Long Term Evolution Advanced (LTE-A) are mainly designed for high data rates and large data sizes while IoT devices mostly exchange small data packets. It is important to note that LTE-A is not optimized for IoT devices with respect to achieving energy efficiency. However, a new variant of LTE for Machine to Machine (M2M) communication, referred to as LTE-M, is developed to meet the needs of low power and low data rate of IoT. In addition, multiple competing technologies are proposed to fulfil the communication requirements of smart cities. These technologies include [6], but are not limited to, 5G, Device-to-Device (D2D) communication, SigFox, IPv6 over Low power Wireless Personal Area Networks (6LoWPAN), Thread, Bluetooth Low Energy (Bluetooth LE), Low Power Wide Area Network (LPWAN or LoRaWAN), ZigBee and IEEE wireless technologies such as 802.11, 802.15.1, 802.15.3, 802.15.4, 802.15.6 and 802.16. A combination of these technologies can be employed, depending upon the smart city scenario. However, this chapter focuses on 5G and more specifically D2D communication to act as a bridge between IoT and cellular communication [7]. This is due to wide coverage of cellular networks, which are available in almost all urban environments. Moreover, 3rd Generation Partnership Project (3GPP) has already started standardizing different technologies for various smart cities scenarios from release 12 to 14 [8], which will provide a path to integrate smart city applications in 5G networks [9]. These standardization efforts are summarized in Table 1.1.

Table 1.1 An overview of new features of LTE-A networks in 3GPP releases 12 to 14 to enable different smart city applications.

Smart City Applications	**LTE Variant**
Internet of things(IoT)	LTE-M (M2M)
Proximity services	LTE-D (D2D)
Terrestrial TV	LTE-B (Broadcast)
Vehicle communication	LTE for V2X (Vehicle to X)
Connectivity for public transport	LTE for backhauling WiFi access points

D2D communication is a new paradigm in cellular networks, which enables direct interaction between nearby User Equipments (UEs), minimizing data transmissions in radio access networks [10]. In conventional cellular networks, the UEs communicate with each other through a common base station; whereas, in D2D, the UEs in close proximity can directly communicate with each other by establishing a Peer-to-Peer (P2P) link between them as illustrated in Figure 1.1.

Exploiting D2D communication can potentially enhance the role of IoT in future smart cities. One such example is Internet of Vehicles (IoV), where vehicles communicate with each other in D2D mode, without traversing any data traffic to the base station. The nearby vehicles can be automatically alerted before any change of lane. This helps vehicles to better respond to emergency situations, thus avoiding potential accidents. Moreover, the traffic on the road can be prioritized. That is, school buses and ambulances can be assigned higher priorities over normal vehicles.

D2D communication has been addressed in release 12 [11] of 3GPP under the name of Proximity Services (ProSe). In particular, 3GPP Radio Access Network (RAN) working group proposed two basic functions, ProSe discovery and ProSe communications, in TR 36.843, Rel. 12 [12]. However, 3GPP has initially targeted public safety applications in D2D communication. In this regard, Table 1.2 presents the supported ProSe functions (ProSe discovery and ProSe communications) for public safety and non-public safety applications in three different network scenarios. In coverage scenario represents a situation when all user devices lie in the coverage area of the cellular network. Similarly, in out-of-coverage scenario, all user devices are located outside the coverage area of the cellular network. Partial coverage sce-

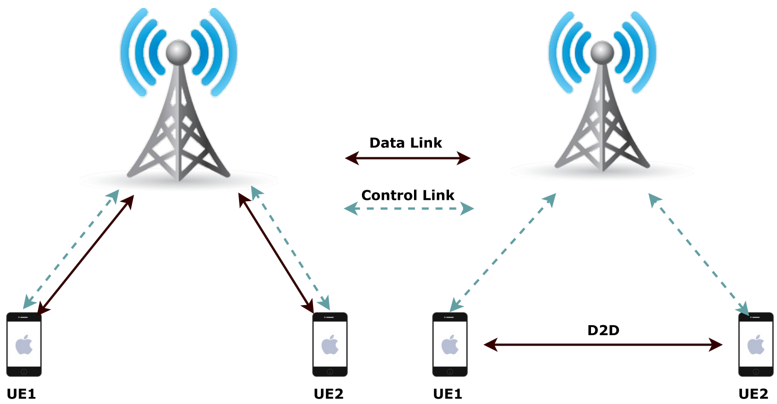

Figure 1.1 Conventional cellular communication (left side) versus direct D2D communication (right side): D2D communication minimizes data transmission in radio access networks, which improves spectrum efficiency.

nario represents a situation when some user devices are located outside the coverage area of the cellular network. The devices at the edge of the coverage area relay the information of out-of-coverage devices to the base station or core network.

Table 1.2 Supported ProSe functions in 3GPP release 12 to enable D2D communication in public safety and non-public safety applications.

Scenarios	**Within Network Coverage**	**Outside Network Coverage**	**Partial Network Coverage**
Supported Applications	*Supported ProSe Functions*		
Non-Public Safety	Discovery	-	-
Public Safety	Discovery, Communication	Communication	Communication

This chapter describes the smart city scenario, its requirements and the potential impact on the life of citizens. By analyzing the types of services offered in a smart city environment, the chapter introduces the communication requirements to support smart city applications. Based on such analysis, the relevance of 5G and D2D communications are outlined, together with the related security aspects.

The rest of the chapter is organized as follows. In Section 1.2, we review the current literature in the field of 5G architecture and D2D communications. Then, we briefly present various smart city scenarios to identify the types of data and services required by a smart city infrastructure in Section 1.3. Next, we provide a discussion regarding communication ways to integrate smart city applications and the role of big data in smart cities as several services in smart cities require analysis and processing of great amount of heterogeneous data (Section 1.4). The chapter then highlights potential security and privacy problems, raised by the excessive use of ICT in smart cities (Section 1.4). Finally, Section 1.5 concludes the chapter.

1.2 Literature Review

Smart cities are often indicated as intelligent cities, virtual cities, digital cities or information cities due to the pervasive usage of ICT and its services at their very core. ICT penetration in smart cities does not only include Human Computer Interaction (HCI) but also Machine Type Communication (MTC), where devices communicate massively with each other and with the information infrastructure (typically cellular) through some gateways [13, 14]. In this regard, various techniques and solutions have been proposed in literature, which address the social and economic problems of cities using ICT.

In [15], FutureICT solves the major problems in integrating smart city applications in ICT sector. Piro *et al.* [16] propose ICT for smart cities as information-centric instead of user-centric to fully exploit the available wireless communication systems. The authors propose an Information Centric Network (ICN) able to (i) process real-time data packets according to information stored within them; (ii) provide content-aware caching and storage in network routers; (iii) efficiently transmit content oriented data; (iv) provide adaptive and flexible control mechanisms, which autonomously react to external events. In [17], Hernández-Muñoz *et al.* propose a user-driven approach, where IoT, Internet of Services (IoS) and Internet of People (IoP) act as major building blocks of the Future Internet (FI) infrastructure for smart cities. The authors propose important design considerations of FI, which includes capacity planning, scalability, inter-operability and faster development of new and innovative applications.

In ICT, the communication infrastructure plays an important role to efficiently connect smart city applications to the Internet. The cellular network, being most ubiquitous deployed wireless infrastructure, is a potential candidate for this connection [18]. The need is to have a communication infrastructure that can successfully integrate diverse services and traffic demands of smart city applications, including applications requiring ultra low latency, such as the tactile Internet and remote surgery. A 5G network is supposed to satisfy the diverse requirements of smart city application [18]. In this context, several architectures are proposed in literature to cover the various aspects of 5G networks. Most of the proposals are based on Software-Defined Networking (SDN), Network Functioning Virtualization (NFV) and cloud computing concepts, which help to improve the network capacity, flexibility, scalability, energy efficiency, spectral efficiency and management costs [19].

In [20], Zhang *et al.* propose SDN/NFV based architecture for 5G networks. The architecture is implemented in Long Term Evolution (LTE) ultra dense Heterogeneous Networks (HetNets). The virtualization and programmability make the network more flexible to adapt heterogeneous services and applications.

In [19], Droste *et al.* present a summary of the Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society (METIS) work on the 5G architecture. They consider three key aspects for the development of 5G architectures including flexibility, scalability and service-oriented management. To accomplish these aspects of 5G networks, METIS proposes an information-centric SDN/NFV based architecture for 5G, which can integrate IoT with a range of services and traffic demands.

In [5], Ziegler *et al.* propose an SDN/NFV based architecture for 5G networks. The proposed architecture [5], Cognitive and cloud Optimized Network Evolution (CONE), provides an ability to integrate Multiple Radio Access Technologies (Multi-RAT) in licensed and unlicensed bands. The authors introduce the service enablement layer and the application layer in the architecture to fully support the heterogeneous requirements of smart city applications.

Similar kind of SDN/NFV based architecture is proposed in [21] with a tendency to integrate smart city applications. Most of the proposed architectures aim at improving performance of cellular networks, without focusing on integrating smart city applications as a primary goal. The smart city applications impose diverse requirements on cellular networks in terms of data size, Quality of Service (QoS), latency and throughput. These requirements are different for what a cellular network is optimized for, thus a gap exists. D2D communication can be one of the options to bridge this gap by acting as a link between the cellular communication and smart city applications.

Steri *et al.* [7] propose a D2D communication protocol, which enables UEs as a hub of IoT traffic to upload data of smart city applications using mobile networks. The protocol enables multi-hop communication between D2D-enabled terminals with some security mechanism based on shared keys. The multi-hop communication extends the coverage of cellular networks to the devices/sensors that are not in the range of mobile networks.

Salpietro *et al.* [22] propose a smart parking system using D2D communication, embedded sensors of a UE and a remote server. The UE acts as both a sensor device and a gateway to disseminate parking information to nearby users using direct D2D links and to the remote server using cellular link. The remote server stores information about the empty places in the parking, which can be later retrieved by a UE using a cellular connection.

In [23], Rigazzi *et al.* exploit D2D communication as an aggregation and trunking technique for the traffic generated by Machine-Type Devices (MTDs). A UE aggregates the MTD, supplements it with its own data and transmits it to the base station.

In aforementioned works [7, 22, 23], D2D communication provides a communication path for MTDs to connect with the Internet. However, this creates a problem of resource allocation to D2D users (*i.e.,* UEs) on their links to the cellular infrastructure and to MTDs or IoT. In literature, different solutions have been proposed to solve the resource allocation problem in D2D communication focusing on IoT applications [24–27].

Some works in the literature propose D2D as an effective solution for Disaster Response Networks (DRNs) and public safety applications. In this context, the most recent solutions include [28–34].

Despite all potential benefits of D2D communication, trust is a significant problem when communicating with unknown users. In this regard, social ties among users can potentially promote D2D communication. Considering this, social-aware D2D solutions are proposed in literature, exploiting social ties and social trust among users. One such solution is presented in [35]. The authors in [35] propose an energy efficient and social-aware cooperative D2D Medium Access Control (MAC) protocol, which exploits users social connections in D2D cooperation. Moreover, the authors suggest that green aspect of D2D networking should not be neglected and it should be incorporated in social-aware D2D cooperation in a way that the D2D Quality of Service (QoS) is improved.

Another work that stresses the need of social trust in D2D interactions is presented in [36]. The authors propose a combination of the Pretty Good Privacy (PGP) and reputation-based model to bootstrap trust in D2D environments. In particular, the authors introduce a profiling server that keeps track of the reputation information of D2D users. Some other works that focus on social ties and social trust among D2D users are recently presented in [37–45].

More recently, the authors in [42] consider the problem of reliability and secrecy enhancement for wireless content being shared between two communicating nodes. By exploiting social characteristics of multiple nodes in the presence of multiple independent eavesdroppers, the authors in [42] first investigate the impact of mobility for source node selection for transmission reliability, within a cooperative wireless network. Furthermore, the authors address social tie based jammer node selections for cooperative jamming to provide secrecy, while allocating power appropriately to the source node and the cooperative jammer node to maximize the worst-case ergodic secrecy rate.

In [39], Ometov *et al.* propose a social awareness layer in D2D communication to build trust among D2D UEs. Before establishing D2D clusters, the UEs examine the social behavior patterns and interpersonal relationship of humans, thus forming trusted user groups. However, the authors claim that this trust and social-aware cooperation between UEs and with the network operators remains conditional to the incentives provided to participating UEs by the network operators. The authors identify three kinds of possible user incentives that apply to different D2D scenarios; Pragmatic incentives (throughput gain, energy efficiency, latency gain), Indirect incentives (economic incentives) and Social incentives (lend resources to friends and family).

Table 1.3 briefly summarizes the literature based on two main categories of networking strategies; ICN and user-centric networks.

Table 1.3 The proposed 5G architectures in literature can be divided into broad categories: architectures based on Information-Centric Networks (ICN) and architectures based on user-centric networks.

Current Trends in 5G	Reference	IoT Integration	Enabling Technologies
Information-centric architectures	Hakiri *et al.* [46], 2015	Yes	SDN/NFV
	Iwamura *et al.* [47], 2015	Yes	SDN/NFV
	Wang *et al.* [48], 2014	-	NFV/D2D/eMBMS (Evolved Multimedia Broadcast Multicast Services)
	Su *et al.* [49], 2015	Yes	HetNets (Heterogeneous Networks)
	Liang *et al.* [50], 2015	Yes	SDN/NFV
	Droste *et al.* [19], 2015	Yes	SDN/NFV/D2D /Cloud Computing
User-centric architectures	Bangerter *et al.* [51], 2014	-	HetNets/D2D
	Peng *et al.* [52], 2015	Yes	SDN/NFV/HetNets
	Pirinen *et al.* [53], 2014	Yes	SDN/NFV/Cloud Computing
	Liu *et al.* [54], 2015	Yes	CoMP (Coordinated Multi-Point)
	Jaber *et al.* [55], 2016	-	CoMP\SON (Self-Organizing Network)
	Datta *et al.* [56], 2015	Yes	oneM2M (Machine-to-Machine Communication)

1.3 Smart City Scenarios

Smart cities employ multiple technologies to improve the living standard of citizens, providing citizens better services in health, transportation, energy, education, public safety and security. These technologies include, but are not limited to, cloud computing, networking, SDN/NFV, big data, IoT and cybersecurity architectures. Figure 1.2 [57] lists possible smart city application scenarios, which are connected to data acquisition and storage center using communication infrastructure.

Figure 1.2 is divided into two parts. The upper part of the figure demonstrates different smart city scenarios. In each scenario, data generated by sensors is transmitted to data acquisition and storage center, which can later be used to analyze and process the collected data. Cloud services and artificial intelligence can be utilized to analyze the big data collected from these sensors. Based on this analysis, various decisions can be made for the benefits of smart city citizens. The lower part of the figure demonstrates pillars on which a smart city is built. These pillars play a vital role in building smart cities.

In the following, we will elaborate each application scenario and the communication infrastructure required.

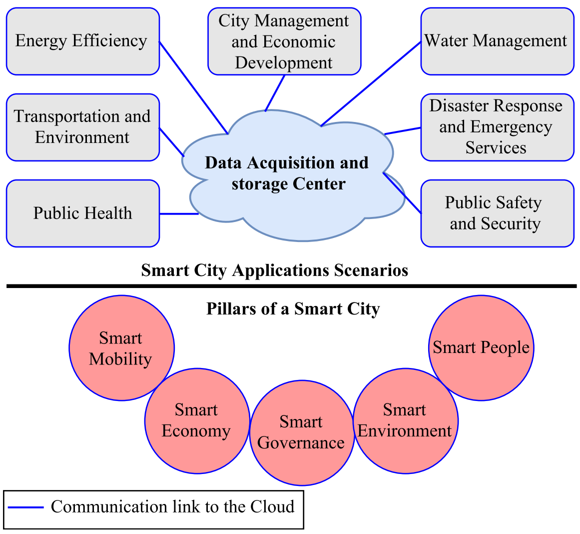

Figure 1.2 An abstract view of smart city applications and its pillars: the part above horizontal line represents various smart city application scenarios, which are connected to data acquisition and storage center through the Internet. The lower part of the figure represents different pillars of a smart city (adapted from [57]).

1.3.1 Public Health

The technology has changed the way the patients are treated in the modern world. According to some reports [58], the traditional ways of healthcare management are unable to handle the data of rapidly growing population in the world. There is a need to find smarter ways to handle this problem. The modern communication technologies and traditional healthcare processes can be integrated together in order to develop a better healthcare system. This includes wireless body area networks, communication networks, data analytics and humans. The sensors acquire health information such as heartbeat, blood pressure, blood sugar or any deterioration in health, which can be potentially transmitted, using communication technologies, to remote servers accessible by healthcare professionals for monitoring, diagnosis or treatment purposes.

Many localities/councils in Europe, Asia and America are working to provide innovative solutions for public health, making use of aforementioned technologies [59]. An overview of some of these solutions is provided below.

24/7 Social Care at Home. Technologies for social care include solutions for older and disabled citizens, which automatically notify concerned staff about the problem such as a fall or deterioration in health conditions. Using these solutions, the residents requiring social care needs can independently stay at their home, but could continuously be connected to 24/7 healthcare centers.

Wearables and Video Calling to Doctors. This includes solutions to remotely consult a real doctor using video conferencing. The patient can be remotely examined using wearable health patches [60] that have the ability to continuously monitor and transmit vital signs such as heart rate, muscle movement, brain activity, hydration level and temperature. Moreover, the prescription can also be automatically sent to a network of pharmacies for an automated delivery of medicine [59]. This could dramatically reduce the physical visits to public healthcare centers.

Remote Surgery (Telesurgery). The remote surgery allows people to access world leading expertise and healthcare services without travelling to the traditional healthcare facility. This can be imagined as a pool of experts, where any patient on earth can take advantage of being treated by the experts, provided that the Internet connection between the patient and the medical expert satisfies the latency requirements, necessary for carrying out the certain surgery.

Note that all of the aforementioned applications impose different requirements on the communication infrastructure connecting them with the central services. For instance, social care and video calling do not demand stringent requirements of ultra low latencies. An uninterrupted Internet connection with sufficient throughput is enough for these applications. However, telesurgery imposes very stringent requirements on latency and reliability of the Internet connection. 5G networks can potentially fulfill the communication needs of a smart public health system as the network latency and reliability completely resonate with the requirements.

1.3.2 Transportation and Environment

The intelligent transportation system is an important part of smart cities, which not only affects the environment but also impacts the quality of life of the citizens. For example, in a densely populated city, automobile sharing, bicycle sharing, electric vehicles and robust local transport facilities can not only address the issue of CO_2 emission but also reduce traffic congestion in the city. All these facilities require an agile, robust and secure communication network to allow vehicles to communicate with each other, with the infrastructure and with the people.

The ubiquitous coverage of cellular systems makes it the most viable and trivial solution to solve the connectivity problem. Based on the cellular technology, many initiatives have been taken to increase safety on the roads. For example, eCall is a European initiative, which brings rapid assistance to the vehicles involved in accidents, by automatically informing E112 about the incident. The European Parliament has decided to make eCall mandatory to be included in all new cars sold in European Union, after April 2018 [61]. The prototype of the solution has already been tested with General Packet Radio Service (GPRS) and in-band signaling over cellular networks.

The cooperation between vehicles and intelligent mobility is one of the most powerful concepts of smart transport systems. It requires intelligent communication systems for wireless data exchange not only from Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) but also between other road users such as motorcyclists, cyclists and pedestrians. For this kind of communication, IEEE 802.11p has been proposed, which extends 802.11 in order to support the intelligent transport system. The amendments were approved and published under the name, "Amendment 6: Wireless Access in Vehicular Environments" [62].

Vehicle-to-everything (V2X) communication is one the most important parts of Intelligent Transportation System (ITS) that virtually connects vehicle on the road with almost everything in the proximity. V2X potentially changes the ecosystem of current transportation system. For example, some researchers believe that connecting vehicles with everything will extinguish the need of traffic lights on the roads [63]. Instead, a traffic network will adjust the smart traffic lights, bus routes, light rail systems and subways to optimize the traffic across entire city. For this optimization, the status of virtual traffic lights and cues can be delivered to the drivers and pedestrians via smartphones [63]. The potential benefits of this optimized traffic network include, but are not limited to, reduced traffic congestion in the city, reduced CO_2 emission in the environment, reduced wastage of fuel and consequently the less economic loss. The economic loss solely was about $121 billion in US for the year 2011 [63]. In addition, by virtue of communication among sensors empowered vehicles, cars can platoon themselves half a meter apart or less to stretch the road capacity and infrastructure.

Big data analysis will play a vital role in optimizing transportation of a smart city. For example, analyzing the "macroscopic behavior" of the traffic across city is one of the biggest challenges for traffic engineers and computer scientists. This includes route modeling and demand modeling of a transport system subject to behavior of vehicles and pedestrians in different weather conditions, sporting and entertainment events and office hours *etc.*. For this modeling, more sophisticated algorithms are needed based on big data approaches.

Other aspects of smart transport systems include the detection of toll evaders, driving on bus-only lane, red light crossing, over speeding using cameras, crime detection and security [64]. All these require communications to control center or among camera/sensors to correctly detect any misbehaving vehicle. Similarly, various services such as fleet management and PayAsYouDrive insurance currently use the GPRS system to transmit the driving style and vehicle health to insurance companies or car rentals. The use of 5G technology, in place of GPRS, will further improve the consumer experience with increased uplink speed and reduced latency [64]. This will help consumers to find an optimal route to the destination in real time.

Advertising traffic information through social media and mobile apps is another application of smart transportation systems. Mobile applications are cheaper and more real time than electronic displays, displaying possible congestions ahead. These kinds of applications are equally beneficial to transport authorities and Mobile Network Operators (MNOs) for business and economy perspectives, the consumers in the perspective of fuel consumption and time to reach the destination and the climate by emitting less CO_2.

1.3.3 Energy Efficiency

The communication technology can play a major role in improving the energy efficiency of smart cities. The energy we use in our daily life mainly comes from the burning of fossil fuels, which emits CO_2 in the atmosphere. ICT can potentially improve the energy efficiency in the following ways.

Smart Buildings. The intelligent building management system and wireless sensor networks can potentially help to control appliances of the building. The heating and cooling systems can be completely switched off when there is no one in the building. The entrance cameras can be used to detect any presence inside the building to turn on only specific appliances.

Smart Homes. The communication infrastructure helps residents to stay connected with their homes even when they are away. The smart appliances and smart meters give the consumers awareness about their energy consumption in real time. They can change their behavior towards energy use and save both money and energy.

The communication infrastructure, which is an essential component of smart cities, itself consumes energy. For example, 3G, 4G and 5G infrastructures, smartphones, tablets, sensor networks, cameras and monitoring displays consume energy. In the smart city planning, the energy consumption of ICT sector should also be well considered to improve the overall energy efficiency.

1.3.4 Smart Grid

The so-called smart grid is a major source of energy efficiency in smart cities, which harmonize the needs and capabilities of grid operators, electricity market stakeholders and consumers to manage power networks as efficiently as possible [65]. A smart grid uses communication technologies to connect smart meters, smart appliances and renewable energy resources with the control room in order to reduce the peak demand and better integrate energy from renewable resources into the power grid.

The renewable energy resources such as solar power and wind power are highly variable, and so require more sophisticated control system and energy efficient solutions to better integrate them into power grids. For this integration, communication technologies remain at the heart of smart grids. In communication, D2D and 5G networks will play an important role in realizing the communication needs of smart grids. For example, smart meters and other sensors nodes in smart grids can be locally connected to a D2D access point to give it an access to cellular networks. After this, Software-Defined Networking (SDN) techniques, such as network slicing, can be utilized to ensure the QoS required by the smart grids [66]. Concerning this, several solutions have been proposed in literature focusing on 5G networks as a communication enabler of smart grids [67–69].

The smart grid offers several benefits over traditional power grid networks, which includes, but are not limited to, the following.

Reliability. The smart grid makes the power gird more resistant against faults and engraves the process fault-detection and self-healing in the power network. This consequently ensures reliable delivery of electricity and reduces vulnerability against attacks and natural disasters.

Energy Efficiency. The smart grid makes the power network more energy efficient by including demand-side management, *i.e.,* Adjusting/balancing the load such that both consumers and electricity stakeholders get benefits. For example, at the consumer end, air conditioner can be turned off during short-term price spikes. At the stakeholder side, it reduces the truck rolls for meter reading and fault detection and recovery. The ultimate goal is to eliminate the redundancy in power grid networks and save energy and resources.

Flexibility. The smart grid enables bidirectional flow of energy, *i.e.,* the electricity from local renewable energy resources can be added to main power grid for the times when local demand is lower than production. This bidirectional flow of energy makes the network more flexible to save energy and also brings monetary benefits to the consumers that have their own local renewable energy resources.

1.3.5 Water Management

Water is one of the most important assets on our planet, which should be managed properly to avoid possible wastage of this natural resource. The communication sector can be potentially utilized to track or forecast the water level in the rivers and to identify more resources of fresh water. More precisely, technologies such as remote sensing, semantic sensor web, Geographical Information System (GIS), sensors and cellular networks can be used innovatively. Communication technologies provide a significant way to obtain real time information of various variables such as soil moisture level, rainfall, temperature and forecast about floods and storms.

The smart metering and sensing system help water management authorities in providing real time information about water usage and leaking in the water supply, thus providing better control over water management. This helps to manage the complete ecosystem of the water distribution network, from reservoirs to end users.

The ICT sector can help to manage water resources more smartly in the following ways [70].

Water Resources and Weather Forecasting. The communication technologies help map water resources to identify the current water supply and its characteristics to determine future water demands for sustainable economy growth. The technologies like satellite-based remote sensing, GIS, Global Positioning System (GPS) are instrumental in carrying risk assessment on hydrological cycle of water, identify new water resources and analyze any environmental problems.

Irrigation in Agriculture and Landscaping. The sensor semantic web is usually used to collect the sensor information and observations using web technologies. This data can be analyzed to save water in agriculture. The wireless sensors can be placed at different locations in crops and in the soil to monitor the moisture level. The water valve can be automatically activated based on the sensors information to water the plants at the right time with the right amount of water. The sensors data is transmitted to the farmer using mobile networks, who can monitor the daily consumption of water.

Water Distribution Network. Sensors are installed throughout the water distribution network. These sensors are connected with control room using communication networks to help in identifying any leakage in the distribution network. The leakage is monitored in real time, which assists companies to take immediate remedies on problems detected in the distribution network.

Early Warning System to Meet Water Demand. Preservation of fresh water, flood management and water recycling are the key parameters to be analyzed to meet the water demands of smart cities. For the cities located near coast, there should be an early warning system to get the information about the water level in the sea. The sensors network is deployed near the coast to check the weather condition and water level. The extreme weather conditions and rise in the water level are communicated to control rooms using the cellular infrastructure.

1.3.6 Disaster Response and Emergency Services

The communication technologies can help greatly to save lives during natural disasters. According to a report [70], over 7000 natural disasters occurred worldwide, during 1980 and 2005, in which millions of lives were lost. Around 90% of those disasters were caused by weather and water related incidents such as cyclones, floods, tsunamis and droughts. The telecommunication can be used for weather forecasting, climate monitoring, detecting and mitigating the effects of natural disasters. The world weather watch from world meteorological organization divides the ICT into three core components.

Global Observing System (GOS). It provides measurements and observations of the atmosphere, at the ocean level, in the air and in the space.

Global Telecommunication System (GTS). It consists of telecommunication network and facilities to exchange real time data of meteorological observations between national meteorological and hydrological services.

Global Data Processing and Forecasting System (GDPFS). It helps in processing meteorological data and provides analysis, warnings and forecasts, which are generated by a network of meteorological centers. At the time of disaster, the network infrastructure also faces a communication breakdown. The disaster victims are no longer connected with the outside world. If communication infrastructure is not affected by the disaster, even then a lot of people try to connect with their family members in the affected areas, causing congestion in the network. However, D2D communication in 5G networks provides support to get the people connected in the time of disaster [28].

1.3.7 Public Safety and Security

Reliable and robust communication networks are fundamental for public safety agencies to guarantee Public Protection and Disaster Relief (PPDR). The networks such as TETRA and P25 are widely used by Public Safety (PS) agencies to respond in critical situations [71]. Such networks provide mission-critical voice services to enable communication between emergency first responders. However, the mega incidents such as 9/11 revealed the failure of such networks mainly due to interoperability problems. The PS networks of different municipalities are incongruent with each other. On the other hand, their narrowband nature does not permit high data rate multimedia services such as videos that are instrumental for providing effective PPDR.

In response to aforementioned problems, in 2012, the First Responder Network Authority (FirstNet) was created in the US to build, operate and maintain the first nationwide interoperable broadband wireless network for public safety [72]. The goal of Firstnet is to employ commercial cellular networks as a communication infrastructure for PS agencies nationwide. However, unlike narrowband PS networks, cellular networks provide non-mission-critical and often only one-to-one communication. The support for group communication remained very basic, meeting far less stringent constraints than those required for traditional PS networks.

In order to support public safety requirements in commercial cellular networks, third Generation Partnership Project (3GPP) is working to enhance the LTE features. In this context, several initiatives are taken under different working groups. These initiatives include, Proximity Services (ProSe) and group communication in release 12 [73], Mission Critical Push-to-Talk over LTE (MCPTT) in release 13/14 [74] and

Mission Critical Video over LTE (MCVideo) and Mission Critical Data over LTE (MCDATA) in release 14 [75, 76].

1.4 Discussion

All of the aforementioned smart city scenarios are divergent in terms of their requirements for latency, mobility, network reliability, network resiliency and other properties. Integrating such heterogeneous applications in a communication infrastructure is not a trivial task. The communication infrastructure, fully supporting IoT and smart city applications, should include following aspects, which are also a primary goal for realization of 5G networks [5].

1.4.1 Multiple Radio Access Technologies (Multi-RAT)

Supporting multi-RAT in licensed and unlicensed bands is one of the fundamental requirements of 5G networks. This allows 5G to fully utilize the entire frequency range from sub-6 GHz to 100 GHz [5]. To enable multi-RAT, the concept of Single Radio Controller (SRC) is introduced, which is an intelligent solution to automatically decide among available radio access technologies such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), LTE and WiFi [77].

1.4.2 Virtualization

The communication requirements of different smart city applications are different from each other. For applications like telemedicine and remote patient care, latency is very important, while applications like waste management simply require a reliable internet connection without having stringent requirements on latency. In order to support these varying requirements of smart city applications, the architecture of 5G networks should be service-oriented [78]. The service-oriented network architecture can be realized by "network slicing", where each service can be handled by its own network slice. To better manage the network slicing, virtualization is the best way, which uses SDN and NFV as enabling technologies. The SDN controller can configure and build network slices for each service in demand. This allows operators to rapidly set up services and scale them in response to changing demands.

1.4.3 Distributed/Edge Computing

IoT devices generate an unprecedented amount of data, which needs to be processed and analyzed in the cloud to act on it. For example, the connected vehicles in V2V communication not only communicate with each other but also interact with the sensors on stoplights and bus stops to get traffic updates and rerouting alerts. All these communications need lots of data to be processed, which is done in the cloud. After processing the data from different sources, the result is sent back to vehicles to avoid potential accidents. However, there might be a chance that by the time data makes it way to the cloud, the opportunity to act on it might be gone (*i.e.,* too late). Moving the computing capabilities closer to IoT (at the network edge) is regarded as a potential solution to handle this problem of quick responsiveness for many smart city applications such as driverless cars, smart lighting, security cameras and monitoring ill patients [79]. This concept is known as edge computing or fog computing.

1.4.4 D2D Communication

Cellular networks are mainly designed for Human-Type Communication (HTC) to support higher data rates and larger data sizes, while MTC in IoT typically exchanges smaller data packets. For example, the minimum size of a radio resource block that can be allocated to a device in LTE-A could be actually too big for the need of IoT applications. On the other hand, large energy consumption required by cellular communication is a major barrier in terms of its adoption as a connectivity platform for IoT applications in smart city scenarios [80]. D2D communication is considered as a viable solution to solve aforementioned problems.

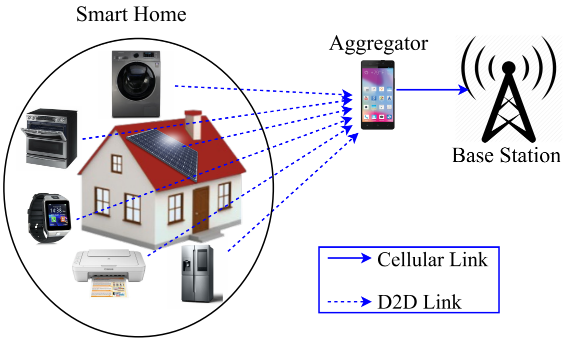

Figure 1.3 D2D communication as an aggregator for IoT traffic: home appliances are connected with a smartphone over D2D link. The smartphone aggregates traffic from different sensing nodes and sends it to base stations when it has sufficient data to be transferred.

IoT devices can be clustered together based on their proximity. A smartphone can aggregate the traffic of the cluster to the cellular network to improve communication and energy efficiency [80]. As an example, Figure 1.3 presents a smart home scenario, where smart appliances are connected with a cellular network through an aggregator. Direct D2D communication is considered as a connectivity mechanism between smart appliances and the aggregator.

Enabling IoT with D2D communication encounters certain challenges, such as interference management, resource allocation, security, trust, and pricing. Along with these challenges, network operators require new business models to answer "pay for what" questions [81]. The device, which acts as an aggregator or a relay in D2D communication, will deplete its resources (such as battery, processing, storage, and communication). This requires innovative business models that can provide incentives to the devices acting as aggregators or relays. An IoT operator, for the cases when a device is acting as an aggregator, can provide these incentives, as in this case an IoT operator is the main entity that is responsible for providing and managing the local connectivity. On the other hand, a mobile network operator can provide incentives to the devices acting as relays in licensed bands, as in this case network operator is mainly providing resources for connectivity.

However, from the point of view of IoT and mobile network operators, a business model is required to generate revenues. The case of IoT operator is comparatively simpler as it provides connectivity to a constrained and local environment *e.g.,* a smart home or a smart building. While, in the case of network operators, the business model for IoT can be comparatively complicated as it is already relying on roaming and other agreements in the ecosystem. However, SDN can be adopted to reserve special data pipes for IoT traffic based on their requirements. In doing so, the network operators can charge premium rates to IoT customers based on their QoS requirements and the resources they use. This flexibility of creating a service-oriented network for IoT applications is not easy to implement with other competing technologies (mentioned in Section 1.1) with same ubiquitous coverage as of mobile networks.

1.4.5 Big Data

IoT devices for different smart city applications generate a massive amount of data. The analysis and mining of this data is a significant step towards making a city smart [82]. Machine Learning (ML) and Artificial Intelligence (AI) techniques are used to analyze the data. As an example, IoT devices and advanced ML and AI techniques could be used to observe the spread of life-threatening Zika virus in urban environments. Drones could be used to identify standing waters and observe Zika infected Mosquitos. The mobility traces of smartphone reveal how humans are moving around the city. These traces along with the data collected from the drones can be processed and analyzed using ML and AI techniques to find clues on how Zika or other life-threatening diseases spread in the community [83]. With the help of IoT and big data ecosystem, municipalities can provide their citizens insights and information regarding these diseases.

1.4.6 Security and Privacy

Security is one of the most important elements to be considered in smart city applications prior to any implementation, such as web-based technologies for cities. For example, in a recent demonstration, Chinese students hacked a Tesla electric car and opened its doors while the car was on move on the road [64]. Moreover, some students demonstrated a hack for Toyota Prius and Ford Escape vehicles, which affected the steering and braking systems. Similarly, in a smart home, a malicious user can falsely control the communication and harm the appliances by forging possible instructions. Turning on the gas burner and a small lamp near it can potentially trigger fire in the home. To solve these security problems, end-to-end security should be inherently embedded in the network architecture of 5G cellular systems across all domains and layers.

Privacy is also a major concern in smart cities, where every sensor transmits some data, which can be private to citizens [84]. Privacy becomes a more critical issue when it comes to IoT as smart cities may deal with sensitive personal data such as health care information collected by wearable devices. This includes collection, transmission, processing, and sharing of sensitive data without appropriate privacy protection. Users may not be willing to expose their data to others, which hinders the processing and sharing of health data and users' experiences.

1.5 Conclusion

In this chapter, we provide a survey and useful considerations in the design and deployment of communications infrastructure for smart city applications. The chapter first reviews the current literature in the field of 5G and D2D communications with a reference to IoT integration. We identify the current trends in the designing of 5G networks and discuss possible integration of IoT and D2D communications. The chapter presents different application scenarios in smart cities with their communication needs. Finally, we highlight the enabling technologies of future communication infrastructure from the perspective of smart city integration.

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