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Internet of Things and 5G Solutions for development of Smart Cities and Connected Systems

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Abstract

Sustainable urban development will result in cities worldwide to evolve into smart cities by utilizing Internet of Things (IoT) technology implemented on 5G networks. This will provide people living in smart cities with a better Quality of Life by improving services and it will also lead to sustainable resource management and use. A literature study was done on the possibility of the development of smart cities in South Africa and the benefits it will provide, as well as, challenges that will be faced. The different elements used to develop smart cities, namely 5G, IoT and cloud computing, were investigated and discussed. The study focused on the application of smart transportation and smart health in the urban environment, as a technical revolution in these two domains will provide an opportunity to benefit the majority of people, irrespective of social status. It was observed that developing smart cities in the South African context will provide major benefits in the transportation and health sectors, which could lead to an improvement of the people lives and effective resource management.

Keywords: Smart cities, Internet of Things, 5G, security, sustainable development, cloud computing.

1. Introduction

Smart cities have become an increasingly popular topic of research and development for academics and industry worldwide. The overall aim of a smart city is to improve the quality of life and efficiency of services for inhabitants within the city and through that, establish smart communities [1], [2]. Smart cities will achieve this through the mass implementation of Internet of Things (IoT) devices that connect to one another, the Internet and cloud services. IoT will provide smart cities with smart governance, smart energy, smart environment, smart transportation, smart IT and communications, smart buildings, smart health facilities, smart

education and a general sensor connected environment [3], [4], [5]. Smart cities rely on large scale connectivity of the IoT devices, ubiquitous networking and Internet connection in order to achieve the full potential, efficiency and capability of smart communities [6]. This requires the necessary bandwidth and infrastructure to support the large scale connectivity and data transfer, which is a challenge with current cellular technologies. This is because it will not be able to support the smart city revolution, as frequency bands in use are already congested [4]. Therefore, 5G connectivity aims to become the foundation of IoT and Smart "Connected" Cities and Societies of the future and it aims to address the shortfall of previous mobile technologies [3].

Smart City implementation and testbeds do not only focus on improving developed cities and nations but also developing countries. India is currently starting with implementation of its 100 smart cities project, where the government aims to improve the citizens' quality of life within cities, by using the benefits of technology, to establish a smart ecosystem [3]. This provides a positive viewpoint for developing countries, like South Africa, to also utilize Information and Communications Technology (ICT) to build smart cities and smart societies, in order to benefit their citizens. In many ways India and South Africa are similar, where public transportation systems and infrastructure, public health system, municipal management environmental management, etc. are failing in a lot of regions as a result of inadequate resources and resource planning [7]. Societal problems of these 2 countries are also similar, as almost a third of the population of both countries live under the poverty line and the both countries have a problem with their education systems, as high school drop-out rates are experienced [8]. Therefore, successful application in countries like India, to address these shortfalls, will illustrate that South Africa can hugely benefit by participating in the next technological revolution, which is smart cities, using IoT technology implemented on 5G frameworks.

The paper is organized as follow, Section 2 discusses smart cities and the technology and concepts used to implement it. In Section 3 the application of smart transportation and smart traffic in South Africa is discussed. In Section 4 the application of the smart health domain is discussed in the South African context. Section 5 concludes the paper, highlighting key findings.

2. Smart Cities

Cities and urban environments worldwide are growing at a phenomenal pace, as a result of people migrating from rural to urban areas. This is a result of people trying to find work and to provide their families with a better quality of life, in terms of education and health care. It is speculated in [9], that over half of the human population already live in urban areas and by 2020, source [1] speculates this to increase to approximately 70%. South Africa is no different,

with the United Nations predicting that by 2030 71.3% of South Africa's population will be living in urban areas [10]. This poses a huge challenge regarding the sustainable development of the urban environment within South Africa. All these people will need to share resources and infrastructure, like transport systems and infrastructure, health facilities, water and energy services, other municipal and government services, etc. Therefore, the urban environment in South Africa needs to allow for the sustainable development of the smart cities [1].

The European Parliament defines a smart city as a city that aims to address public issues with the use of ICT based solutions, through a multi-stakeholder and municipality based partnership. Therefore, a strong cooperative environment is required in cities between government, civic organizations, industry and civilians, in order for the development of smart cities [9]. A benefit of smart cities is that they adjust their social, business and natural needs according to the available resources which results in improved resource usage and availability and results in the conservation of resources and the environment [9], [11]. This can benefit South African cities in many ways, as most resource reserves like water and electricity are under constant pressure, and maintenance of public infrastructure is not up to standard because of lack of personnel, funds and experience [12]. Therefore, South African cities can improve their resource management through the use of smart city infrastructure, reducing costs and improving the quality of services. Another benefit of smart cities, also applicable to South Africa, is that resource management greatly reduces the negative impact on the environment, especially as cities are growing, industries are expanding and power and resource consumption is ever increasing [5], [13].

Challenges of smart cities and the implementation thereof especially in the South African context includes getting the civilians to partake or make use of services implemented in typical Cities. Evidence was presented, which illustrates that smart cities deliver better value for its citizens and offer sustained success if citizens within the smart city project get involve into the project, compared to cases when only authorities and government engage in it [14]. The problem in South Africa regarding this challenge is that a sizeable portion of the population has an inadequate education and more specific, the Common Good First research found that in 2016 mobile and Internet usage was at 52% of the population [15]. This high digital illiteracy rate can prove difficult to attain citizen support for smart city projects. Another challenge in the implementation of smart cities is that the deployment is complex [14], especially when considering that cities in South Africa often have outdated infrastructure and that townships, which form large parts of the metropolitan areas, often lack the required infrastructure [12].

Smart cities have the potential to change the quality of life for citizens within South African cities as it can improve public services and address the service delivery shortfalls experienced. In order to understand how this can be achieved, elements of a smart city will be investigated

and application domains of smart cities, like smart transportation and traffic and smart health will be investigated. The vital elements of a smart city are Internet Of Things (IoT), 5G ubiquitous connectivity and cloud services [11]. These elements will be discussed in the following subsection.

2.1 5G technology as an enabler

The backbone of a smart city is large scale, ubiquitous connectivity so that IoT sensors and actuators, throughout the city, can connect to one another and the Internet [6]. This hyper connectivity poses a challenge as high bandwidth, low latency and an ultra dense connection of devices is required. Current and legacy mobile networks will not be able to fulfill the requirements of the smart city and IoT revolution. However, 5G is expected to address these challenges by providing ubiquitous, scalable connectivity for exponential growing IoT [1], and is expected to launch by 2020 [9], [13]. 5G technology will be the primary driver for IoT and the foundation of smart communities [1], [4], [6].

5G will aim to address the challenges of its predecessors by providing extremely high capacity, high bandwidth, robust integrity and low latency [4]. This will be achieved by enabling and improving Machine-to-Machine (M2M) communication, millimeter waves, massive Multiple Input Multiple Output (MIMO), small cell networks and beamforming, illustrated in figure 1 as the foundation of future 5G [13].

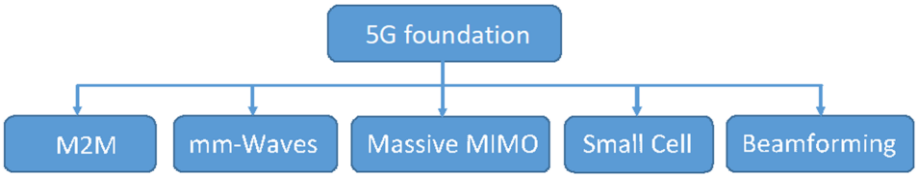

Figure 1: The foundational technologies and techniques of 5G.

M2M communication improves communication reliability and reduces overall latency. The current frequency bands used by mobile operators and devices are getting extremely congested and increasing IoT devices and service will just worsen this. Therefore, the millimeter wave spectrum will be utilized for 5G, as it has a lot of available capacity [6]. Millimeter waves are highly susceptible to attenuation, therefore, more small cell base stations will be implemented to increase network availability. Use of small cell networking will reduce energy usage of mobile operators and lead to higher density of devices that can be accommodated [4]. Massive MIMO provides an antenna configuration that allows improved carrying capacity of a base

station. Beamforming provides directionality to a signal, which increases the efficiency of base stations and reduces interference of signals. This allows a base station to function more effectively in the handling of higher amounts of network traffic [6].

5G technology and networks will provide many benefits, which includes higher data transfer than 4G networks, higher wireless area traffic capacity, reduced latency, device heterogeneity and energy efficiency [4], [6], [9], [13]. The higher data transfer effectively means IoT devices, such as cameras for surveillance, will be able to upload video streams much more seamlessly to the cloud. Access to large amounts of data will also be more seamless. Higher wireless area traffic capacity means that in dense urban areas the 5G network will be able to support more devices, which connect to each other and the cloud. This benefit is critical for implementing smart cities as a massive amount of devices will be continuously exchanging data. Reduced latency is vital for applications where real-time response is critical scuh as autonomous vehicles and medical procedures. The heterogeneous nature that 5G networks aim to offer will make IoT a reality, as different systems and devices will be able to connect and share data and resources [14]. Energy saving is a major benefit 5G network technology aims to provide. Through the design and implementation of 5G technology, it will be much more energy efficient [4], [6] than current technology, with source [9] estimating that an energy saving of up to 90% per service is possible with 5G. This will be a massive benefit for South Africa, moving into an energy consumption conscious future. In South Africa mobile operators, industry and governments have the opportunity to first change the major urban landscape, by implementing 5G networks as soon as it becomes feasible, and then focus on the rural areas [5]. This will result in a foundation for IoT and smart city implementation.

2.2 Internet of Things

Internet of Things (IoT) is defined by the European Information Society as "a manageable set of convergent developments in sensing, identification, communication, networking and informatics devices and systems" [16]. IoT will, with efficiency, connect billions of users in a short time period, therefore, it is crucial for the development of smart communities [1], [13]. IoT is considered to be the next evolutionary step of the Internet and it is speculated to become one of the critical driving forces of global economic development in the future [11]. Therefore, the impact of IoT on smart cities will be profound, as it will provide the platform for sensors and devices to seamlessly interact to create a smart ecosystem [34] with some of the applications illustrated in figure 2. In South Africa, IoT technology can be applied to a wide range of applications that benefit cities, like transport and traffic management, health care, education, government and municipal management, industry automation, etc.

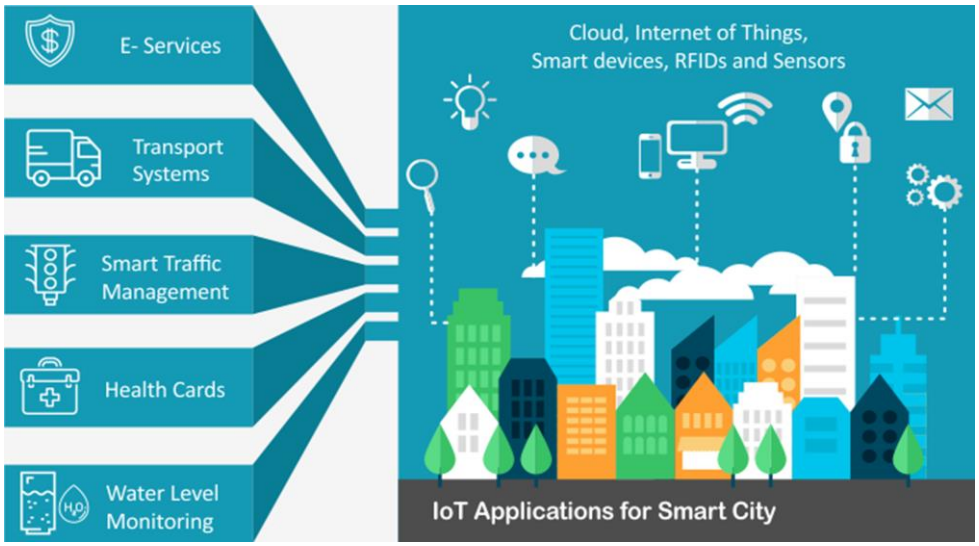

Figure 2: IoT applications for the Smart City environments [17].

IoT is the critical success factor for the implementation of smart cities. Devices need to communicate with each other, through M2M communication, and with humans. This continuous exchange of data will allow businesses and cities, among other things, to automate processes, track metrics and improve performance and quality of service in the city [3]. A major benefit IoT technology could entail for South African cities is energy saving. South Africa still generates approximately 89% of its power with coal-fired power stations [18]. Therefore, the carbon footprint of its energy sector is high, but future IoT promises massive energy savings for the devices. Furthermore, test cases like the use of IoT to manage street lighting in Alba Iulia, Romania, illustrates energy savings of up to 80% [5], which can have a massive impact when applied throughout the cities of South Africa. Another benefit of IoT is that its application in cities greatly improves the maintenance and security of infrastructure [5]. Infrastructure, example street lights or water pipes, are monitored in real time and if breakdown or theft occurs the system reports it immediately, allowing authorities to respond much faster and get to the root cause. This can work effectively in South Africa, where public infrastructure issues are still manually reported and when authorities respond they often have to search for the source of the problem. This takes time, increases cost and in general is not as effective as required.

IoT promises a near-limitless range of possibilities for the future. However, currently there are some challenges that need to be overcome in the design of the devices and implementation of large IoT networks [14]. One of the major challenges for IoT networks and the scalability thereof is the need for network availability, reliability and higher bandwidth [5]. Current mobile networks will not be able to support the increase in IoT devices without the Quality of Service

being affected. 5G networks aim to solve this challenge, however, 5G is not rolled out yet. Another challenge experienced in the evolution of IoT, is the integration of devices communicating on different frequency bands. Again, 5G aims to solve this by integrating networks operating on different frequencies and allowing communication between all the devices [13]. IoT device challenges that are being investigated and improved is the battery life concerns, data and context awareness, device and data security, communication interference and device cost [13]. However, though thorough design and cautious implementation, many of these challenges can be overcome as illustrated in the Santander smart city implementation [14].

2.3 Cloud computing

Cloud computing enables ubiquitous, on-demand, convenient network access to shared pool of configurable computing resources [19]. The ubiquitous, on-demand nature of cloud like processing, storage and other services, is what makes it such a necessity for smart city applications. Cloud computing will reduce the cost, resource and energy consumption of classic decentralized systems [11], [20]. However, classic centralized cloud data model will not be the most effective solution for the smart city application, as it will increase latency and result in large volumes of data being transferred continuously to and from cloud resources [9].

The proposed structure for processing and data storage, in smart cities is a combination of centralized resources and distributed resources. Investigations have illustrated that combining centralized Cloud, Fog Computing and Edge Computing could deliver desirable results, in terms of energy saving, cost saving, lowest latency and high networking capability [9], [21]. Figure 3 illustrates the proposed structure of the combination of centralized and decentralized computing.

Firstly, some IoT devices/components make use of edge computing. This means the IoT device does a measure of its own calculation and processing, i.e. it converts sensor readings into human-readable data and adds a date- and location stamp to the data. Depending on the application this can, with efficiency, be performed by a low cost, low powered processor. This mitigates some of the Fog node and cloud server's load [21]. Fog computing, in simple terms, is placing cloud resources close to IoT devices and the data producers [20], [22]. This greatly reduces the latency of data transfer from edge nodes to central servers. IoT edge nodes send their raw or processed data to Fog nodes, where further processing can take place, example computing a regional traffic analysis of a few streets. The Fog node can then either forward all processed data or selected data to centralized cloud for further processing and/or storage. This reduces overall latency, data transfer rates and localizes a lot of traffic and processing. This model will benefit South African cities as often sections of a city consists of informal

settlements where there is a lack of proper cellular infrastructure. Fog computing nodes can process data locally and transfer important data to the central cloud, using limited connectivity. Furthermore, the cities will benefit by saving energy, cost and keeping data transfer loads from the IoT devices low.

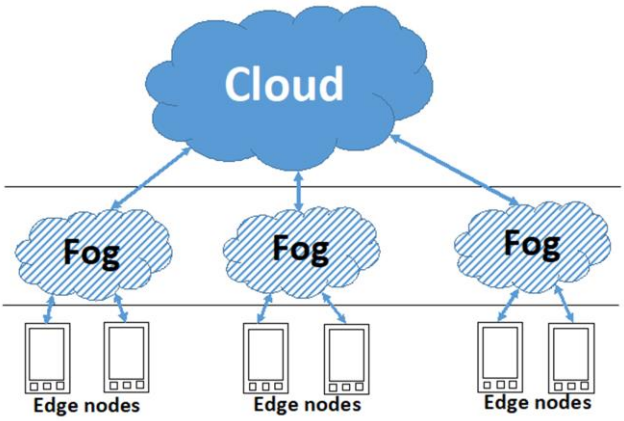

Figure 3: Basic concept of the proposed data processing and storage structure [22].

3. Smart transportation

Traffic and effective transportation is an issue in almost every city worldwide and also in South Africa [14]. Congestion on roads, looking for parking in the city, vehicle and passenger safety are all transport related issues citizens living in South African cities have to deal with on a daily basis. Smart, intuitive and efficient transportation systems [35, 36] are going to play a vital role in smart cities, in order to provide solutions to these issues [23]. In smart cities, IoT technology will be utilized to provide transportation with higher productivity, less vehicle accidents, lower travel times and better traveler experiences [24]. It is observed that smart transportation will play a major role in smart cities, therefore, some applications of smart transportation was investigated for the South African urban environment.

A major innovation that benefit smart cities and smart transportation [37] is autonomous vehicles. Autonomous vehicles transform transportation while the amount of self-driving cars on the roads are increasing [24], [25]. It is speculated that in the US alone, autonomous-vehicles will free up approximately 50 million hours, per year, for drivers [25]. The impact on cities, traffic and the economy will be profound, as people can spend more time at work and less in traffic. Vehicles will communicate with one another (vehicle-to-vehicle) and with infrastructure (vehicle-to-infrastructure) [9]. South African cities will benefit from this, as the autonomous vehicles will benefit road users by taking fast, more efficient routes, which will result in less

congestion on major roads and highways. This will result in increased road safety, as the human-error factor is removed and shorter drive times will be advantageous to the economy.

Automotive emissions are responsible for high levels of air pollution. Although standards and practices have improved vehicles' carbon footprints, the number of vehicles have increased and this out-weight improvements [23]. Research is being done into fitting vehicles with smart navigation systems, which communicate with one another and infrastructure. These systems will perform route planning to reduce travel time and CO_2 emissions [25]. This will have a positive effect on South African cities where air pollution is high and traffic congestion contributes to this. Finding parking in city centres and shopping centres in South Africa is another challenge. Citizens waste fuel, time and increase their carbon footprint by driving around to find parking [24]. Therefore, IoT devices can be implemented to allow people to reserve parking or to use a GPS system to guide a person to an open parking space. This will be done by communicating with devices in the area to prevent same vehicles from being assigned the same parking space. Therefore, through smart city benefits like eco-routing and smart parking, people will save time, cost and reduce their carbon footprint.

A good public transport system is critical for an efficient, well managed city. It reduces traffic congestion, pollution and travel costs for citizens [23]. In South Africa, almost 50% of the population depend on public transport to travel between home and work. The average traveling time to work, for public transport, averages between 1 and 3 hours [26]. The public transport is not regulated properly and lacks structure which technology can provide [27]. In India, a similar problem was experienced and researchers implemented a system where dynamic and static buses are used [23]. Static buses have fixed routes with fixed schedules that are provided to users at bus stops or on a mobile application. Dynamic buses have their GPS system configured to change routes based on traveler's destination, people that need to be collected from stops and traffic conditions. On average, this technique got travelers to their destinations much faster. Enabling public transport vehicles to communicate with one another and cloud computing systems will lead to an improved, safer travel experience for travelers [20]. It allows authorities and companies to monitor the vehicles and keep the drivers accountable and travelers updated on travelling times.

Smart Transportation can improve safety [27] for road users and improve emergency service response. IoT aims to create a smart, more coordinated network of emergency service response, which currently lacks innovation [24], [28]. The different departments within the emergency services have systems that do not always integrate, which results in chaotic, unorchestrated response of emergency service personnel [24]. Smart Cities aim to integrate these systems to improve emergency response and collaboration between departments. In Australia, police vehicles are fitted with dashboard cameras that upload video into the cloud and notify

authorities when unregistered or stolen vehicle number plates are picked up [24]. Smart Transportation will provide better coordination and response of emergency services, which is much needed in South African cities as these services are often uncoordinated and reactive rather than proactive.

4. Smart health

The purpose of Smart Cities is to improve the quality of live for the citizens living in the city. There is an increasing need for traditional healthcare system to evolve, as urban population sizes are increasing and the amount of healthcare professionals, in relation, is decreasing [29], [30]. IoT technology is used in the health environment to provide Smart health, by providing health related services, that are more efficient, cost effective and improves the decision making capability of medical professionals [16]. This is referred to as eHealth and it enables new prognosis capabilities, which aims to improve overall community health [31]. eHealth can improve the health services for people living in South African cities, as most of the challenges that eHealth aims to address (like cost effectiveness, high availability, preventative rather than reactive healthcare and sharing of information base) are challenges faced by the public health care system in South Africa. The fundamental use cases of eHealth are Remote Patient Monitoring, Personal Healthcare Data management, Remote Tele-health consultation, Location based services and Timing based services [31]. Some of these use cases will be discussed in more detail.

Remote Patient Monitoring is the most prominent use case of eHealth [31]. In traditional healthcare systems, patients go to clinics or hospitals to consult a healthcare practitioner. However, with increasing urban population and cost of consultation this is becoming a challenge. IoT-based wearable devices and sensors, which are attached to the body, implanted or woven into textiles, are becoming popular options for monitoring people's health by measuring physical parameters [29], [30], [32]. The sensor systems are capable of intelligence and can perform a general diagnosis, of which only abnormal cases are forwarded to a medical practitioner for evaluation. Figure 4 illustrates the basic concept of using IoT for Remote Patient Monitoring. It was found that using wearable eHealth devices at home, improves quality of life and overall it reduced hospital readmissions [16]. Remote Patient Monitoring reduce medical related costs by focusing on preventative measures and not reactive measures. Remote Patient Monitoring can benefit South African citizens, in cases where hospitals and clinics are often overcrowded and services are inadequate. The eHealth devices will allow citizens in Smart Cities to adapt their lifestyles to enjoy a better quality of Life and alert patients or medical staff when there is a medical emergency. It also provides a better home monitoring system for elderly

people and can notify authorities when there are problems, for them to respond more efficiently.

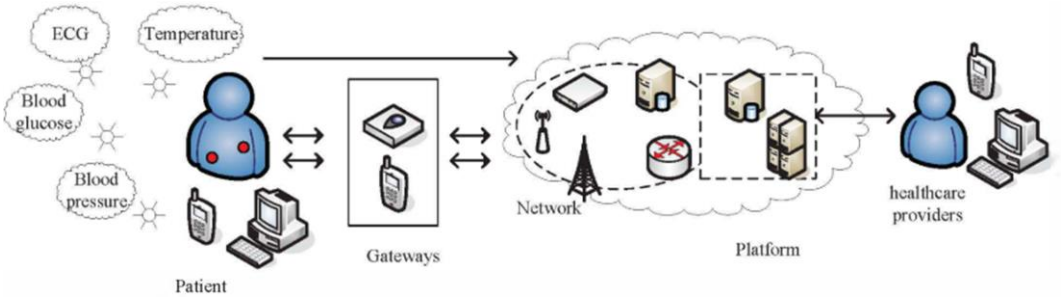

Figure 4: Concept of Remote Patient Monitoring using IoT [31].

Sharing of health related information, which related to Personal Healthcare Data management is critical in the evolution of health services. This consists of collecting and storing data from health-related IoT devices interacting with a person and observations and health records produced by medical professionals [30]. This will produce large volumes that will be stored and processed in clouds, which can be used in conjunction with Big Data analytics to provide forecasting and health prediction services [33], [32]. Health related services will become more proactive and less reactive. This could benefit the South African health sector, in that most patients will get proactively treated, preventing conditions or diseases from worsening, resulting in lower cost per patient and less fatalities. Another factor of the use case, is connecting future health systems to one another and integrating these systems with legacy systems, using a common interface [33]. This allows medical professionals to access all patient data from a common system, which allows much more informed decisions to be made and the forecasting analytics to perform predictive analysis on patient data. The sharing and managing of personal health care data will benefit the health sector in South African smart cities, providing better services and an overall improved quality of life for citizens.

Remote service provision or Remote Tele-health consultation is the provision of services to a remote location, using ICT solutions. This will greatly benefit low income areas in South African cities where health facilities, like hospitals and clinics, are not available or are lacking adequate services. This will allow a medical professional, with adequate experience, to aid another medical professional or clinical worker, who lacks the skills or experience, to assist or treat a patient using the required technology [31]. It also allows medical procedures to be carried out remotely, which will save time and cost for medical specialists [30]. Another service that remote areas and clinics will benefit from, is the access to specialist information and knowledge bases [16]. Often low income and rural areas in South African lack enough medical professionals or medical staff with adequate knowledge. This enables specialist knowledge to

be shared with medical staff in these areas, to equip them to make informed decisions. This will cost much less than constructing health facilities and employing sufficient medical professionals and can provide a comparable service [16].

There are some challenges and risks that will be experienced with the implementation of smart health. One of the major challenges and risks in smart health is security of data. The IoT technology will, in most cases, transmit the patient health-related data wirelessly and then store it in the cloud. This makes the data vulnerable to a privacy breach or malicious attacks if proper security is not implemented [16, 38]. Therefore, the underlying systems will need strong security, that will ensure confidentiality and data integrity. Another challenge for delay sensitive applications will be low latency [22]. This includes health monitoring for a critical patient and performing a remote medical operation over a network or the Internet. The smart health systems will also need to be highly fault tolerant and provide high availability as health is a critical sector and if systems are down, it can result in dire consequences [29]. These challenges can be overcome and the risks lowered with proper design and implementation of the Smart Health systems.

5. Conclusion

The development of smart cities in South Africa is vital for sustainable urban development, as the population sizes in the cities are increasing and traditional service delivery models are not evolving fast enough. It was observed that smart resource management is becoming critical, as these larger urban populations have to utilize the same, or in some cases, fewer resources and services. This was discussed by investigating the transport sector and urban traffic, as well as the health sector in South Africa. Furthermore, it was discussed that IoT technology implemented on a 5G foundation will provide the framework for developing these smart cities. The implementation of the IoT technology on a 5G foundations in these investigated applications pose a series of challenges including practical implementation, cost of implementation, and stakeholder and citizen commitment among others. However, the benefits that smart cities offer for the South African context, like smart resource management, energy efficiency, long term cost saving, improved services, etc. will definitely out-weight the challenges.

It was also discussed that smart transportation and traffic in smart cities will have the opportunity to benefit the community, as it will reduce costs, decrease pollution, reduce traffic congestion and result in an effective transport system that will increase economic output. This is critical in South African cities where the populations are increasing and public transport is lacking structure and efficiency, resulting in increased traffic congestion. Smart health has the

possibility to evolving the public health sector in South African cities by providing Remote Health Monitoring, shared information services and remote health services to citizens. This will increase accessibility to health services, reduce the overall cost of the services and result in a more proactive health system, compared to the current reactive health system. Therefore, it can be observed that the implementation of smart cities, in the South African context, will improve the quality of life and efficiency of existing cities and create smart communities, which will lead to the sustainable development of the urban environment.

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