



SPACE ENABLED SMART AFRICA (SESA)

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ABSTRACT

Urbanization in Africa is growing at a rapid pace and so is the population growth. Cities in Africa are struggling to cope with the demand that urban migration brings. For example, Africa has over 60% of her population located in the urban areas. These urban locations are sprawling slums due to the massive influx of people and inadequate housing systems. The United Nations, through the Sustainable Development Goals called for a sustainable cities and communities.

This project is focus on using the smart city approach to tackle these urbanization issues. With the advancement in satellite application systems, smart cities can be enabled through space technology to address these urbanization and other issues affecting the African region.

Integrating space technology, such as communication, Earth observation, and satellite aided position timing & navigation application systems and small satellite technology, to the smart city paradigm could provide sustainable ways in which problems like digital division, over population, natural disaster, etc. could be managed and eradicated.

ACKNOWLEDGEMENTS

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Keep flying high.

CONTENTS

COVER PAPER	
DECLARATION	
ABSTRACT	
ACKNOWLEDGEMENTS	

Chapter 1

INTRODUCTION

1.1 Urbanization in Africa	3
1.2 Mega cities in Africa.....	4
1.3 United Nations Sustainable Development Goals	9
1.4 Agenda 2060	12
1.5 ICT trends in Africa	14
1.6 Satellite broadband coverage in Africa.....	17
1.7 Smart cities	18
1.8 Scope and objective of dissertation.....	19
1.9 Structure of dissertation	20

Chapter 2

SMART CITIES

2.1 What is a smart city.....	22
2.2 Smart city application	24
2.3 Integrated management	24
2.4 Public Services & Application	25

Chapter 3

COMMUNICATION NETWORKS AND DEVICE

Communication networks	38
------------------------------	----

3.1 Internet of Things (IoT)	43
------------------------------------	----

Chapter 4

ENABLING SPACE TECHNOLOGIES FOR SMART CITIES IN AFRICA

4.1 Space Mission Segment	59
4.2 Communication satellite	61
4.3 Satellite aided Position, Navigation and Timing systems (PNT)	67
4.4 Space aided earth observation satellites	71
4.5 Small satellites	75

Chapter 5

TOWARDS SPACE-ENABLED SMART CITIES IN AFRICA

5.1 Benefit of Smart cities for Africa	79
5.2 Challenges confronting the development of smart cities in Africa	81
5.3 Smart city initiatives in Africa	83

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Main findings	86
6.2 Conclusion	88

REFERENCES	90
------------------	----

LIST OF FIGURES

- FIGURE 1.1 CITY OF LAGOS, NIGERIA [4]
- FIGURE 1.2 CITY OF CAIRO, EGPYT [5]
- FIGURE 1.3 CITY OF KINSHASA, DEMOCRATIC REPUBLIC OF CONGO [6]
- FIGURE 1.4 CITY OF JOHANNESBURG, SOUTH AFRICA [7]
- FIGURE 1.5 CITY OF NAIROBI, KENYA [8]
- FIGURE 1.6 THE UNITED NATIONS SUTSIANABLE DEVELOPMENT GOALS [9]
- FIGURE 1.7 INTERNET USERS IN 2007 BY COUNTRY [15]
- FIGURE 1.8 NUMBER OF INTERNET USERS IN AFRICA BY COUNTRY [16]
- FIGURE 1.9 FORECAST OF PAST AND FUTURE MOBILE INTERNET SUBCRIBERS [17]
- FIGURE 2.1 VIRTUAL REPRESENTATION OF A SMART CITY [22]
- FIGURE 2.2 BLOCK ILLUSTRATION OF SMART CITY APPLICATIONS AND INFRASTRUCTURE [24]
- FIGURE 2.3 SMART INTEGRATED MANAGEMENT SYSTEMS [25]
- FIGURE 2.4 ELEMENT OF SMART GOVERNANCE [27]
- FIGURE 2.5 DEPICTION OF A SMART TRANSPORTATION [29]
- FIGURE 2.6 CONNECTING SMART BUILDING WITH SMART GRID [31]
- FIGURE 2.7 SMART EDUCATION BUILDING BLOCK [32]
- FIGURE 2.8 SMART BANKING [36]
- FIGURE 3.1 SELECTION PROCESS OF COMMUNICATION TECHNOLOGY [39]
- FIGURE 3.2 ADOPTION TRENDS OF WIRELESS TECHNOLOGY IN THE LAST THREE DECADES [40]
- FIGURE 3.3 WIRELESS COMMUNICATION TECHNOLOGY IN SMART CITIES [42]
- FIGURE 3.4 STAR TOPOLOGY OF WIRED COMMUNICATION NETWORK SYSTEM [43]
- FIGURE 3.5 INTERNET OF THINGS [44]
- FIGURE 3.6 IOT ARCHITECTURE [47]
- FIGURE 3.7 SENSING ELEMENTS AND ITS RELATIVE ELECTRICAL SIGNAL [48]
- FIGURE 3.8 SENSING DEVICE APPLICATIONS IN SMART CITIES [49]
- FIGURE 3.9 CHARACTERISTICS OF BIG DATA [51]
- FIGURE 3.10 BIG DATA TYPES [52]
- FIGURE 4.1 SPACE MISSION SEGMENTS [59]
- FIGURE 4.2 ECHO 1 COMMUNICATION SATELLITE [62]

FIGURE 4.3 DEPICTION AND WORKINGS OF A GROUND STATION TERMINALS OF A COMMUNICATION SATELLITE [63]

FIGURE 4.4 BLOCK DIAGRAM OF A SATELLITE TRANSPONDER [63]

FIGURE 4.5 A DEPICTION OF SATELLITE COMMUNICATION SYSTEM [65]

FIGURE 4.6 THE ARSAT-2 COMMUNICATION SATELLITES [67]

FIGURE 4.7 GLOBAL POSITIONING SYSTEM (GPS) OPERATIONAL CONTROL SYSTEM [68]

FIGURE 4.8 GLOBAL POSITIONING SYSTEM (GPS) SPACE SEGMENT TRANSMISSIONS [69]

FIGURE 4.9 GLOBAL POSITIONING SYSTEM CONSTELLATION [70]

FIGURE 4.10 GALILEO SATELLITE [71]

FIGURE 4.11 WAVE PROPAGATION OF AN OPTICAL SENSORS IN AN EARTH OBSERVATION SATELLITE [72]

FIGURE 4.12 THE ACTIVE PROCESS OF SYNTHETIC APERTURE RADAR [73]

FIGURE 4.13 LANDSAT 7 EARTH OBSERVATION SATELLITE [75]

FIGURE 4.14 STANDARD 1U,2U,3U [76]

FIGURE 4.15 THE ADRDUSAT [77]

FIGURE 4.16 ONEWEB SMALL SATELLITE SYSTEM [78]

LIST OF TABLES

TABLE 3.1. COMPARISON OF COMMUNICATION AND NETWORK TECHNOLOGY IN SMART CITIES [41]

TABLE 3.2. APPLICATION OF PRIVACY-ENHANCING TECHNOLOGY TO SMART CITY TECHNOLOGIES [57]

TABLE 4.1. EXAMPLES OF COMMUNICATION SATELLITE [66]

TABLE 4.2. EXAMPLES OF GNSS SATELLITES [70]

TABLE 4.3. EXAMPLES OF EARTH OBSERVATION SATELLITE [74]

TABLE 4.4. EXAMPLES OF SMALL SATELLITE. [78]

1 INTRODUCTION

The world population has seen significant growth over the past decades. An estimated world population of 2.6 billion in 1955 has increased to a record of 7.7 billion in 2018, as reported by the United Nations Population Division (UNPD). These records show that the world population increases by 1 billion people every 12 years. The reason for this increase is due to high fertility and birth rates, increasing urbanization and migration over this time period.

Africa holds 16% of the world's population, with about 1.2 billion people in the continent. There are 54 countries in Africa. The world population is estimated to increase to 8.5 billion by the year 2030, and up to 11.2 billion by 2100. More than half of this population growth will be in Africa, with the population growing at the rate of 2.55% annually between the year 2010 to 2015. By 2050 the African continent should see a growth of around 89.25% in population from its original population as at 2010-2015, as reported by the United Nations Population Division (UNPD)¹.

This sporadic growth in population around the African continent can be harnessed for development, but it could also quickly become very problematic if the right modalities to manage this growth are not implemented. China, for example, used the explosion in their population during the 40's to 70's, by taking advantage of the economy of scale, building infrastructures and industry with its vast amount of local human resources. Population growth has a direct effect on urbanization, and people tend to move to areas with better personal and basic amenities, such as clean water, electricity, transportation service, etc. The ripple effect of such movement resulted in an increase in demands for basic amenities.

The smart city concept can support urban development in Africa by providing sustainable amenities needed by its civil societies, such as smart government, smart learning (E-Learning), smart energy, smart transportation systems, etc.

¹ Un.org. (2015). *Population*. [online] Available at: <http://www.un.org/en/sections/issues-depth/population/> [Accessed 8 Dec. 2017].

1.1 Urbanization in Africa

Urbanization is defined as the gradual movement of people from rural to urban areas over a period of time. Urbanization mounts pressure on public infrastructure in Africa, such as increased demands for energy, housing, clean water, food, transportation infrastructure, social services, etc. Urbanization in Africa has digressed into illegal settlements and slums over the past decades. The Northern part of Africa has the highest urbanization rate of 47.8%, while Sub Saharan Africa has an urbanization rate of about 32.8% but a higher slum settlement rate of about 65%. Reasons for the high disparity of slums between these regions are based on issues such as the lack of basic infrastructures. As at 2010, only 20% of sub-Sahara Africa had access to electricity, 3% had access to fixed network broadband and 53% had access to mobile phones, 84% have access to clean water and 54% have access to sanitation. As at 2017, about 60% of African citizens do not have access to clean water and sanitation.

This rapid growth in the African population is caused by different factors such as high fertility rates, higher life expectancy, improved provision of basic amenities and the large number of young people living in the continent. In 2015 the number of youths aged 15-24 that lived in Africa was estimated to be 226 million. This accounted for 19% of the global youth population. It is projected that by 2030 the number of youths that will be living in Africa will increase by 42%. Africa's youth population is expected to grow over the coming decades and might surpass that of Asia by the year 2080.

Urban settlement in Africa will see a sharp rise by over 300 million people between 2000 and 2030. Nigeria, Democratic Republic of Congo, Uganda, Ethiopia, and United Republic of Tanzania are among the countries in the world that are expected to have among the highest population growth between 2017 and 2050.

By 2030, six of the world's mega cities will be situated in Africa. Cities like, Cairo, Lagos, Johannesburg, Luanda and Dar es Salaam, will see a significant rise in population, given that these cities are huge part of their country's economic capabilities. By 2030, cities like Lagos, Kinshasa and Cairo will be housing more than 20 million people, while Johannesburg, Luanda and Dar es Salaam will house about 10 million people. These levels of population growth will increase demands for better urbanization like real estate development, public services and infrastructure, etc.

1.2 Mega cities in Africa

A mega city is one whose inhabitants exceeds 10 million people. It is either a large metropolitan area, or the combination of several metropolitan areas in close proximity. African mega cities are usually found in the most populated countries in Africa.



Fig 1.1. City of Lagos, Nigeria².

Lagos: Lagos is the biggest city in Africa by population and it is situated in Nigeria, which is the most populated country in Africa, with about 200 million people. Lagos metropolitan area with a land mass of 999.5 km² and a GDP of \$ 136 billion in 2017, holds over 21 million people in total and provides 25% of the country's GDP. Lagos city grew in population from 1.4 Million people in 1970 to 21 million people in 2017. By 2050, the population of Lagos is expected to double and be among the top three mega cities in the world. Being the largest city in the continent, Lagos is hoping to become a smart city in the coming decades. With the ongoing development in infrastructure, high immigration and the growing younger population, the State of Lagos plans to harness these resources in other to promote and develop a technological and digitally driven city. Though about 66% of the population in Lagos lives in slums, the city is optimistic about using technology to change the status quo.

² The British Library. (n.d.). *Aerial view of modern-day Lagos, Nigeria*. [online] Available at: <https://www.bl.uk/collection-items/lagos-nigeria> [Accessed 2 Jan. 2017].



Fig 1.2. City of Cairo, Egypt³.

Cairo: Cairo is the second largest city in Africa and it is the capital city of Egypt, which has an estimated population of 89 million. The city Cairo has population of about 20.4 million and a land mass of 528 km² in 2016 and generated a GDP of about \$73 billion. Cairo is located along the Nile Delta and houses more than half of the country's population.

The city is referred to as the cradle of civilization. This can be associated with her being at the centre that connects routes to Asia, Europe and Africa. Cairo has seen significant growth over the past decades and this is due to the gap between death rate and birth rate of her citizens, as well as immigration. The death rate in Cairo for the past decade has been around 7 deaths per 1000 people and a birth rate of about 30 births per 1000 people. Cairo is a mega city with a growing population that is outpacing its growth in infrastructure and services.

³ Robert Harding, i. (n.d.). High Quality Stock Photos of "nile river". [online] Robertharding.com. Available at: <https://www.robertharding.com/index.php?lang=en&page=search&s=nile%2Briver&smode=0&zoom=1&display=5&sortby=1&bgcolour=white> [Accessed 3 Jan. 2017].



Fig 1.3. City of Kinshasa, Democratic Republic of Congo⁴.

Kinshasa: Kinshasa is the capital and largest city in the Democratic Republic of Congo, and has an estimated population of 7.8 - 11 million people. The country's total population is estimated to be 82.6 million people, though the specific population data are uncertain due to the conflicts that transpired in 1998 known as the "African cold war", where more than 90% of the soldiers died from malaria and other diseases. About 45% of the deaths were children under 5-years-old. Kinshasa has a land mass area of 9966 km² and a GDP of \$58.39 billion in 2016. The Democratic Republic of Congo is expected to double its population by 2030, therefore increasing the population in the city of Kinshasa. In recent times, the Democratic Republic of Congo has seen significant growth in population, with births per day reaching 1,835 and deaths per day reaching 438.

⁴ Nutritionandhealthcare.info. (n.d.). Bukavu, city of Democratic Republic Of The Congo in photos. [online] Available at: <http://nutritionandhealthcare.info/page/bukavu/democratic-republic-of-the-congo/default.html> [Accessed 3 Jan. 2017].



Fig 1.4. City of Johannesburg, South Africa⁵.

Johannesburg: The city of Johannesburg is the business hub of South Africa which has an estimated population of 54.9 million. The city housed 4.4 million people as of 2016. Greater Johannesburg, which covers the metropolitan areas of West Rand, Lenasia and 400 more suburbs which covers an area of 520 km², accounts for about 10.5 million people in 2018. Johannesburg is a continental financial business and industry hub. The city accounts for 17% of the country's wealth and was ranked the 27th largest economy city in the world according to the Johannesburg⁶ Department of Economic development. The population of the city grew rapidly during the 1896 gold rush, reaching a population of 400,000 by 1931 and doubled during the second world war. In 1950, the recorded population of Johannesburg was about 1,653,000 and in 2015 the city recorded an annual population growth of 2.14%.

⁵ view, J. (2010). Johannesburg CBD - Aerial View Stock Image - Image of portrait, city: 14146879. [online] Dreamstime.com. Available at: <https://www.dreamstime.com/royalty-free-stock-images-johannesburg-cbd-aerial-view-image14146879> [Accessed 4 Jan. 2018].

⁶ Africa.com. (n.d.). The 5 Busiest Cities in Africa - Africa.com. [online] Available at: <https://www.africa.com/the-5-busiest-cities-in-africa/> [Accessed 6 Jan. 2018].



Fig 1.5. City of Nairobi, Kenya⁷.

Nairobi: Nairobi is the capital city of Kenya. The country's estimated population is 51 million people in 2018, with Nairobi housing 4.4 million people. The city is one of the fastest growing cities in Africa and the most populated city in East Africa, with an average annual growth rate of 4%. The population of Nairobi was 137,000 in 1950 and the last official population census recorded in 2009, counted 3.5 million people. In recent years the city has grown to become a technology hub in the East African region. Being the most technologically savvy city for the past 2-3 years, it holds the record of the highest and fastest internet usage and speed in the continent with GDP of \$8.96 billion in 2016. Nairobi has been named "The most intelligent city" in Africa by the intelligent community forum 2 years in a row. The city still has one of the biggest slums in the world, with 22% of the ethnically diverse population living in. With a land mass of 696 km², the city is estimated to reach 7.1 million people by 2030 and this will be due to the high fertility rate in the country and immigrants in search of employment opportunities created by the city's recent development in technology innovations.

⁷ Art Gallery, G. (2006). Nairobi | Eastleigh & Eastlands District | Photo Gallery | Projects & Constructions - Page 4 - SkyscraperCity. [online] Skyscrapercity.com. Available at: <https://www.skyscrapercity.com/showthread.php?t=917220&page=4> [Accessed 3 Jan. 2017].

1.3 United Nations Sustainable Development Goals & Agenda 2063



Fig 1.6. The UN Sustainable Development Goals⁸.

The United Nations Sustainable Development Goals (SDGs) are built on the progress made by the Millennium Development Goals (MDGs) in 2012. These 17 goals were established to combat poverty, promote social inclusion and development, sustainable management of natural resources, and the ecosystem by all countries regardless of their developmental status. The overarching aim of these goals is to address issues surrounding, poverty, social development and natural resources that affects the world presently without hindering development for future generations.

The three main elements of the SDG's are Economic growth, Social inclusion and Environmental protection. These elements are all interconnected and need to be aligned together to achieve each of the 17 goals.

Economic Growth: For the economy to grow, poverty needs to be reduced and eradicated. The first Sustainable Development Goal is to end poverty in all forms everywhere in the world. Eradicating poverty is one of the biggest challenges in the World, especially in developing countries. The Johannesburg Plan of Implementation (2002), as proposed in the World Summit on Sustainable Development held in Johannesburg, South Africa in 2002, prioritized actions on poverty eradication. These actions include:

⁸ World business council for sustainable development. (2016). Connecting Business with the Sustainable Development Goals: WBCSD at the UN General Assembly High Level Thematic Debate on Achieving the SDGs. [online] Available at: <https://www.wbcd.org/Programs/People/Social-Impact/News/Connecting-Business-with-the-Sustainable-Development-Goals-WBCSD-at-the-UN-General-Assembly-High-Level-Thematic-Debate-on-Achieving-the-SDGs> [Accessed 4 Jan. 2017].

- ❖ improving access to sustainable livelihoods, entrepreneurial opportunities and productive resources;
- ❖ providing universal access to basic social services;
- ❖ progressively developing social protection systems to support those who cannot support themselves;
- ❖ empowering people living in poverty and their organizations;
- ❖ addressing the disproportionate impact of poverty on women;
- ❖ working with interested donors and recipients to allocate increased shares of Official Development Assistance (ODA) to poverty eradication, and
- ❖ intensifying international cooperation for poverty eradication

The United Nations Food and Agriculture Organization (UNFAO) listed Sub-Saharan Africa as the 2nd highest location with people living in hunger between 2014-2016. The number of people living in hunger is about 233 million, which covers 47% of the total population of the continent that lives below poverty line of \$1.90 per day or less. Hunger is caused by different factors in an economy. These factors include; poverty, corruption, conflicts, environment and population growth, etc. Poverty is one of the major reasons for hunger in Africa and it deprives people of basic amenities like access to clean water, food and shelter. Corruption is another cause of poverty in Sub-Saharan Africa where those in powerful political positions accumulate wealth through corruption and mismanagement. According to Freedom in the World's annual index in 2016, which measures the extent of people political rights and civil liberties, Sub-Saharan Africa has a very low freedom ranking. The non-government organization called, Transparency International stated that Sub-Saharan African nations have serious issues with corruption. Conflicts within nations and across nations in Sub-Saharan Africa are another major reason for hunger in the region. According to a World Bank report, countries with repeated occurrences of violence within the last three decades have 20% higher poverty rate than countries without such violence. Another cause of hunger is environmental issues such as deforestation, erosion, draught, fire hazard and desertification, amongst others. Increased poverty and hunger through the reduction of agricultural production and urban development also encourages violence.

1.3.1 Environmental protection

Protecting our environment is key to achieving the Sustainable Development Goals. With economic growth gaining some momentum within the past decade around the world, environmental pollution is still a huge problem, accounting for more than 19 million premature deaths annually. Major sources of pollution are food production, transportation vehicles, services, industrial, energy, waste and manufacturing pollution. The World Health Organization noted on 21 March 2014 that air quality is an issue that affects almost all regions across the globe and it is considered to be the “*world’s single greatest environmental risk to health*”⁹. The global death rate by air pollution from both indoors and outdoors sources is estimated to be 6.5 million people annually. Currently 9 out of 10 people inhale polluted air and about 2 billion children live in regions around the world with outdoor air pollution that exceeds the World Health Organization (WHO) guideline levels. An estimated 1.7 million children between age 1 – 5 years die from air pollution every year. Outdoor air pollution is mainly caused by the emission of fossil fuel burning through combustion in transportation vehicles, domestic solid fuel heating,

⁹ Who.int. (2014). WHO | 7 million premature deaths annually linked to air pollution. [online] Available at: <http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/> [Accessed 6 Apr. 2018].

coal burning for power generation and unregulated burning of waste products such as plastics.

Pollution comes with a significant economic cost due to its impact on health and welfare. Such costs include, but are not limited to; healthcare costs, damages done to the ecosystem and productivity loss, etc. The Organization for Economic Co-operation and Development (OECD) reported in 2016 that the welfare costs of diseases related to outdoor air pollution was estimated at \$3 trillion and \$2 trillion for diseases related to indoor air pollution. A report by the World Bank and Institute for Health Metrics and Evaluation in 2016, stated that the estimated global cost of diseases connected to air pollution was \$5.11 trillion. Pollution can be easily prevented or controlled through sustainable consumption and production practices. Such practice includes, prioritizing waste management and reduction, implementation of environmental policies, including multilateral environmental agreements between stakeholders that provides collaboration and funding for infrastructural development such as management control and pollution monitoring. The United Nations Resolution and Multilateral Environmental Agreements provide a global governance framework for targeted and time-bound actions in support of Sustainable Development Goals (SDGs) that are linked to the environment through the fostering of international partnership and sharing of technological experiences.

1.3.2 Sustainable Development Goal 11: (Sustainable Cities and Communities)

Making cities inclusive, safe, resilient and sustainable is the primary focus of SDG 11. Rapid population increase in cities is giving rise to urban slums, which is alerting nations around the world to start developing sustainable ways to combat these challenges. This goal was further expanded to ten targets as stated below:

- Provide housing that is affordable, safe and sustainable for urban dwellers by 2030.
- Provide affordable transport systems that are, sustainable, accessible and safe for all by 2030, through the improvement of road safety and the expansion of public transports systems to accommodate children, disabled and older citizens.
- Promote and develop inclusive and sustainable urbanization that involves integration and sustainable human settlement planning and management.
- Provide ways to protect and safeguard the world's natural and cultural heritage.
- Minimize all economic losses affiliated with nations Global Gross Domestic Product (GDP) caused by disaster such as flooding and make provision for the vulnerable and less fortunate.
- Minimize the per capita losses caused my environmental disasters on cities including but not limited to the air quality, water treatment etc.
- Provide eco-friendly environment that is inclusive and universally accessible to older persons, children and people with disabilities by 2030.
- Encourage ways to link positive environmental, social and economic impact between urban, pre-urban and rural areas through the advancement of both national and regional development planning.

- Adopt and implement of integrated policies and plans aiding sustainable ways of managing resources, inclusion, awareness, mitigation and adoption of climate change, implement disaster risk management making sure its in-line with the Sendai Framework for Disaster Risk Reduction 2015-2030 and holistic disaster management at all levels.
- Support less developed regions with financial instruments, advance technological and technical assistance, physical infrastructures using local materials, etc.

The United Nations held a conference on Housing and Sustainable Development titled “Habitat III” in Quito, Ecuador from 17th to 20th October 2016. This was the first conference held on urbanization since the inception of the 2030 Agenda for Sustainable development. The objectives of this conference were to assess accomplishments to date, secure renewed political commitment for sustainable urban Development, addressing poverty, identifying new emerging challenges and adopting and implementing the “New Urban Agenda”. This new global urban agenda is geared towards an innovative and new approach on how we build, manage and live in our cities. It was adopted by world leaders and has brought committed collaboration and partnership between private and public stakeholders, including government institutions, private sectors and civil society, etc.

1.4 Agenda 2063

Agenda 2063 is the strategic framework document adopted on the occasion of the golden jubilee in 2013 by the African Union (AU) and its precursors, the Organization of African Unity (OAU), to re-dedicated herself to the Pan-African Vision of “*An integrated, prosperous and peaceful Africa, driven by its own citizens and representing dynamic force in the international arena*” for the purpose of social-economic transformation of the African national and continental regions. This agenda is to facilitate and assist existing sustainable development initiatives in the continent and was supported by the New Partnership for Africa’s Development (NEPAD) Planning and Coordinating Agency (NPCA), the African Development Bank (AfDB) and the United Nations Economic Commission for Africa (UNECA). Agenda 2063 is made up of seven aspirations, namely:

1. A progressive and prosperous Africa based on inclusive growth and sustainable development.
2. An integrated continent, politically united, based on the ideals of Pan Africanism and the vision of Africa’s Renaissance.
3. An Africa with mature and good governance, democracy, respect for the law, human rights and justice.
4. A secure and peaceful Africa.
5. An Africa with strong rooted heritage, cultural identity values and ethics.
6. An Africa made by the people through self-development of the African continent, relying on the resources and potential offered by its people, especially women and youth and also caring for children.
7. Africa as a strong, united, resilient and influential global player and partner.

The Agenda 2063 framework document was adopted by the African Union (AU) summit in January 2015 as the foundation for Africa's long-term social-economic and integrative transformation. The African Union Commission (AUC) was directed by the African Union (AU) to prepare the First Ten-Year Implementation Plan of Agenda 2063, i.e. 2013-2023. This 10-year plan provides the first of the series of 5 blocks over the next 50 years. The ten-year plan has the following pillars:

a) Flagship projects:

These are projects approved by the African Union (AU) summit and are parts of the 10-year implementation plans. These prioritized projects listed below are to be attended to immediately;

- 1) Integrated high-speed train
- 2) African virtual and E-University
- 3) Focus Areas in national/regional plans
- 4) African commodity strategy
- 5) Annual African Forum
- 6) Continental free trade area
- 7) African passport and free movement people
- 8) Grand Ina Dam Project
- 9) Pan African E-Network
- 10) Silencing the Guns
- 11) African Outer Space Strategy
- 12) Continental financial institution

b) Near-term national and regional development priorities

National plans for respective member states are reviewed as well as the strategic plans of the Regional Economic Communities (REC). Given that their focus area for development is included in the 10-year implementation plan, this review will make sure that the immediate priorities are aligned with the 50-year plan.

c) Continental frame work

The African Union Commission (AUC) has further developed the continental framework into different segments to support members states in their national development, as follows:

- 1) Comprehensive African Agricultural Development Program (CAADP)
- 2) Program for Infrastructure Development in Africa (PIDA)
- 3) African Mining Vision (AMV)
- 4) Science Technology Innovation Strategy for Africa (STISA)
- 5) Boosting Intra-African Trade (BIAT)
- 6) Accelerated Industrial Development for Africa (AIDA)

d) Agenda 2063 results framework

This framework is to include projects in the 50-year frame work document that are due in 2023 in the first 10-year implementation plan. They are listed below.

- 1) African Union Decision Plan
- 2) African Union Directives
- 3) African Union Plans of Action
- 4) African Union Plan of Treaties

1.5 ICT trends in Africa

1.5.1 Internet penetration in Africa

Internet penetration can be defined as the fraction of the population using or have access to internet connectivity in a specific demographic. Information and communication technologies have yielded positive economic impacts in Africa within the past decade and this is due to the mobile phone and broadband internet revolution. The Global System for Mobile Communication Association (GSMA), reported that mobile internet adoption is the core driver of ICT in Africa and its contribution to the Gross Domestic Product (GDP) of the Sub- Sahara Africa economy was 2.6% (\$37 billion) in 2016. More than 50% of these returns were generated by network operators.

Statistics released by “Statista” in 2017 shows that North America has the highest rate of internet and online penetration of 89%. The Atlantic Ocean Island nation of Bermuda has the highest internet penetration rate in the world as of 2015 amounting to 98%, followed by Western Europe with 87% internet penetration.

The increase in computer and smart phone accessibility has accelerated internet usage globally. In April 2017, the total number of mobile internet users was 3.4 billion and 93% of internet users now connect to the internet through a mobile device like a smart phone or tablet. Mobile internet access accounts for 51 % of all browser-based web traffic in 2017. While mobile internet access saw a surge within the past three years, laptop and desktop internet accessibility saw a decline of almost 20%, accounting for 40% accessibility in 2017 as reported by Global System for Mobile Communication Association (GSMA).

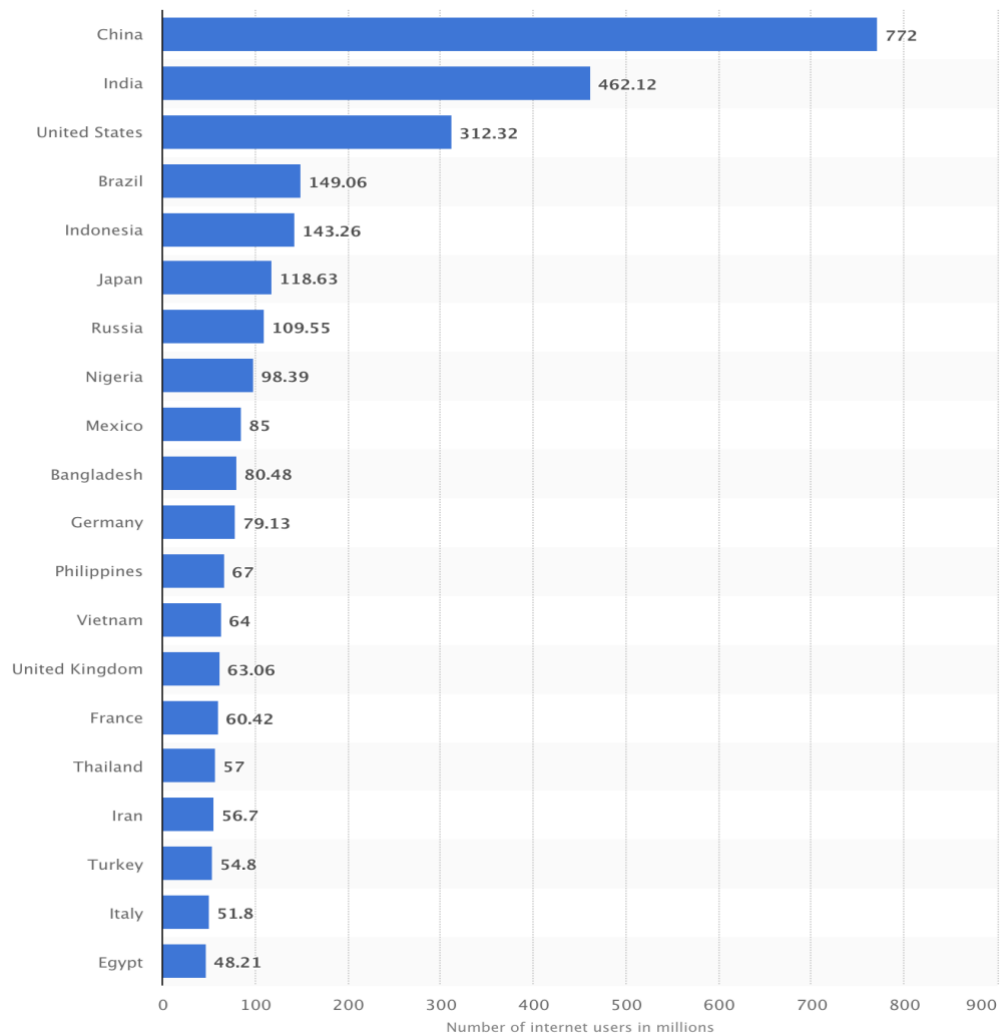


Fig.1.7. Internet users in 2017 by country¹⁰.

These findings show that connected devices such as mobile phones and tablets are now part of our everyday lives and drive the growth in Internet usage. Though internet connectivity is not yet evenly distributed around the globe, it has seen a significant increase over the past few years through mobile broadband connectivity.

1.5.2 Forecast on internet penetration in Africa

Africa is seeing some of the world's fastest growth in internet adoption, increasing by 20% each year from the previous year, with 435 million connections over a population of 1.272 billion on the continent in 2017 and accounting for an additional 73 million connections from 2016. This increase is mainly due to the adoption and lower costs of handheld devices such as smart phones, tablets and the infrastructure needed to facilitate such connections. In 2017 "*GSMA intelligence*" reported that by 2025 mobile internet penetration will be above 61% of the global population.

¹⁰ Statista (2017). Number of internet users in selected countries 2017 | Statistic. [online] Statista. Available at: <https://www.statista.com/statistics/262966/number-of-internet-users-in-selected-countries/> [Accessed 28 Apr. 2017].

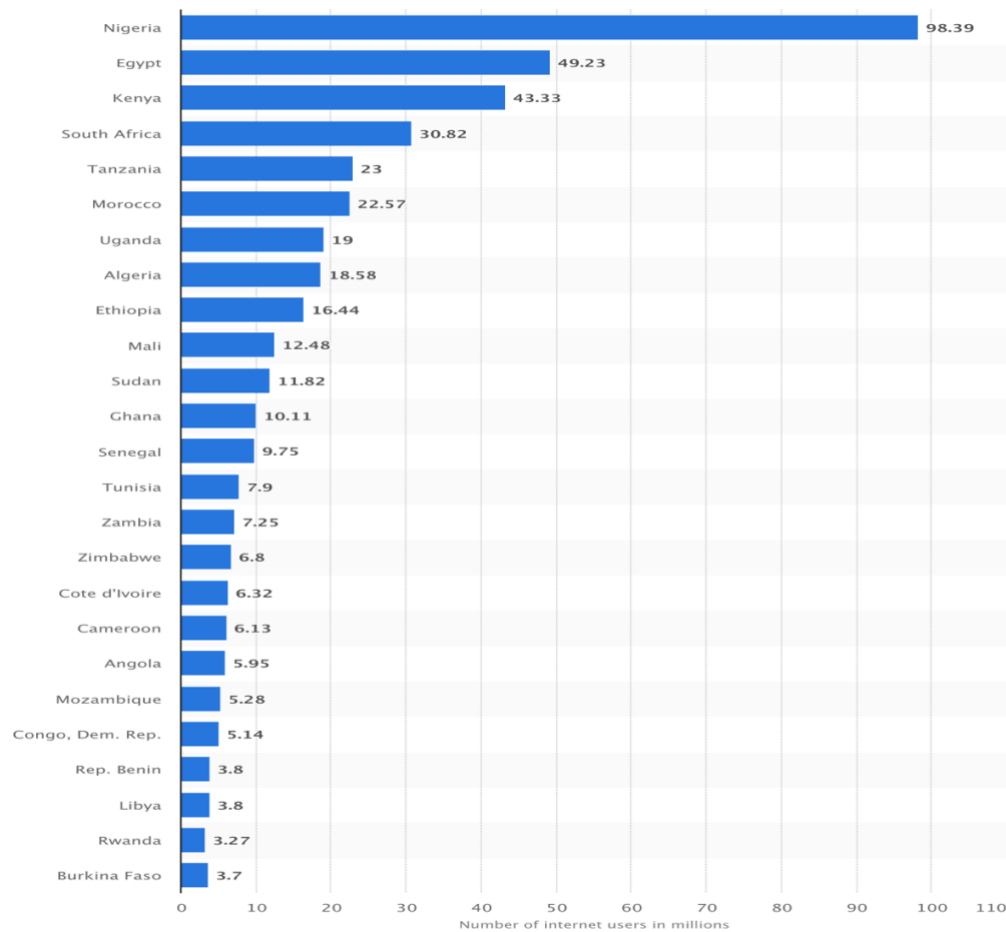


Fig 1.8. Number of Internet users in Africa by country¹¹ .

Nigeria has 98.39 million subscribers and this is due to the country's large population of about 200 million people, followed by Kenya, which has the highest internet speed in the region of over 13Mbps on average¹². Kenya has been the regional hub of technology innovations for the past three years and the major reason for this penetration is the adoption and increase of Internet provision, mainly from mobile internet broadband.

The speed of this mobile broadband differs with respect to location. The Akamai State of the Internet report in 2017 shows that the Netherlands and Singapore use above 50Mbps of internet speed on average per country, while other countries like India, Nigeria, etc. use an average of < 10Mbps internet speed. The Southern part of Africa has the highest rate of internet penetration in Africa, accounting for 51% of internet access in the region. Northern Africa records 49%, while Western Africa amounts to 39%. East

¹¹ Statista (2017). Africa number of internet users by country 2017 | Statistic. [online] Statista. Available at: <https://www.statista.com/statistics/505883/number-of-internet-users-in-african-countries/> [Accessed 24 May 2017].

¹² Waititu, J. (2016). Why Kenya is the leading in terms ICT in Africa | Mambo.co.ke. [online] Mambo.co.ke. Available at: <https://www.mambo.co.ke/kenya-leading-terms-ict-africa/> [Accessed 6 Jul. 2018].

Africa and Central Africa have the lowest internet penetration as of 2017 and account for 27% and 12%, respectively.

Fig 1.9 shows the percentage by population of mobile internet subscribers in selected African countries and the rest of the world in 2016 and a 2020 forecast. This Figure shows that due to the adoption of mobile broadband and handheld devices, the growth in Internet penetration, which is mainly fuelled by mobile networks, will increase to an average of 45% by 2020.

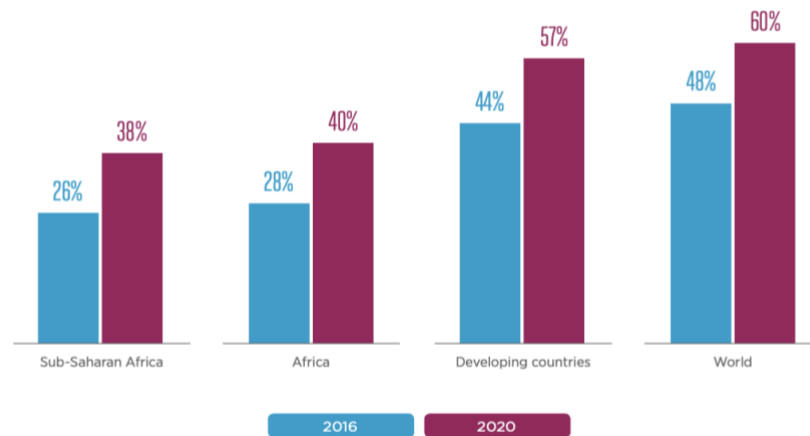


Fig.1.9. Forecast of past and future mobile internet subscribers¹³.

1.6 Satellite broadband coverage in Africa

For most of the last decade, satellites were the predominant means of providing international trunk internet bandwidth for Sub-Sahara Africa before the introduction of terrestrial transmission networks such as submarine cables and fibre optic cables. Although Africa uses the combination of satellite, submarine cables and terrestrial networks to provide broadband for the region, satellite broadband as a primary source of Internet connectivity has declined. This is mainly due to the cost of accessibility and network latency.

Satellite broadband distribution is still the most viable way to provide complete internet coverage across the African region and can be distributed to areas with no terrestrial infrastructure. The Commonwealth Telecommunication Organization (CTO) reported that *“Every square inch of the African continent is covered by satellite bandwidth”*.

¹³ GSM (2017). The Mobile Economy. [online] Gsmintelligence.com. Available at: <https://www.gsmintelligence.com/research/?file=7bf3592e6d750144e58d9dcfac6adfab&download> [Accessed 20 Aug. 2017].

Satellite broadband is distributed mostly through telecommunication satellites usually situated in Geostationary Earth Orbit with altitude around 35,768 km above sea level. The generated bandwidth is then linked down to Very Small Aperture Terminals (VSATs) where it is further distributed directly to the end users or through another terrestrial node. An example of such satellite is “*Intelsat 28*” which built by Orbital Sciences Corporation for Intelsat and was launched in 2011. It is a communication satellite located at 32.9^o East longitude and provides services such as internet connection, wireless backhaul and media applications to Africa, Europe and the middle Eastern countries.

The satellite industry is evolving rapidly, with new technological capacity such as High Throughput Satellites (HTS), wide-beam KU-band transponders, and small satellites for communication application, etc. With these emerging technologies, the adoption of satellite broadband distribution in Africa will continue to grow.

1.7 Smart Cities

The definition of a smart city varies with respect to the subject matter. After analysing more than 100 definitions, the International Telecommunication Union in 2014 defined “A Smart Sustainable City as an innovative city that uses Information and Communication Technology (ICT) and other means to improve quality of life, efficiency of urban operation and services and competitiveness, while ensuring that it meets the need of present and future generations with respect to economic, social and environmental aspect”. The Smart city concept generally involves the use of Information and Communication Technology such as but not limited to, wireless communication networks, Internet of Things (IoT), Cloud Computing, Big Data, Sensors, satellite applications and Artificial Intelligence (AI) to facilitate faster, reliable and smart decision-making for municipalities and ordinary citizens.

The United Nations Economic and Social Council (ECOSOC) reported in 2016 that Smart infrastructure in developing countries can provide ways to achieve leapfrogging in technology. With proper implementation and adaptation of ICTs, African cities can be turned into smart cities. The rise of smart cities is trending around the world and according to a list published by the National Geographic in February 2018, Singapore stands out as a country with cities that work smart. The residents and companies in the city-state of Singapore can monitor their energy usage, waste production and water use in real time. Cameras connected through the internet of things are used to monitor environmental sanitation in public spaces, crowd density and local traffic flows, to mention but a few of such applications.

The smart city concept can revolutionize urbanization in Africa. It can promote and support sustainable housing, cleaner environments, robust security and economic growth, which align with the United Nations Sustainable Development Goals if all the right modalities are implemented. With the smart city concept in play, communities can be resilient and sustainable through smart initiatives like, smart energy provision, smart security management, smart buildings, etc. In retrospect, the smart city approach can support progress toward the entire set of SDGs goals in regards to the African context.

1.8 Scope and Objective of Dissertation

The objective of this dissertation is to investigate how space technology can support and enable the Smart City concept in Africa. For example, Internet connectivity has become an essential commodity in our everyday lives, providing information and communication using standardized communication protocols through computer networks. With standard and robust internet connectivity, the continent can provide vast amounts of information and access to invaluable information resources that are necessary to foster the Smart city concept in the African region as well as to support the attainment of the United Nations Sustainable Development Goals (SDGS). Such supports include but are but not limited to sustainable housing and communities, quality education through E-learning, decent work and economic growth, etc.

Smart Cities are one of the ways Africa can *leapfrog* into the 21st century in terms of technology and innovation. This can be compared with the mobile phone revolution during the early 2000's, where mobile connectivity enabled the African continent to communicate and connect with the rest of the world, bypassing the traditional fixed-line networks that were not evenly distributed across the region. With the right implementation, a smart city concept can provide the same opportunities as the mobile revolution did. The core infrastructure of a smart city is based on information and Communication Technology (ICT), that involves the use of Big Data, Internet of Things (IoT), sensors, satellite communication networks, wireless and wired networks, etc. Most countries in Sub-Sahara Africa lack these amenities to operate a functioning smart city, but with sustainable and standard satellite application such as internet connectivity, the region can bridge this gap. There have been a number of projects working towards the provision of global internet connectivity, such as the, the *Oneweb* constellation project, *SpaceX* disposable satellites project, *Google project Loon* and the *Facebook Aquila* project. These projects are focused on global internet connectivity that is cost effective and sustainable, with a common vision of launching these small satellites, or solar powered balloons as proposed by Google, or an unmanned Internet broadcasting airplane "Aquila" spearheaded by Facebook to the Lower Earth Orbit (LEO), i.e. an altitude between 100km to 1200km above Earth surface. This approach differs from the traditional telecommunication satellites that are located 35,785km above the Earth's surface, hence reducing signal travel time to a ground station or individual consumers.

Africa can subscribe to this new space technology development which will bring low cost subscription and total network coverage in the region and support the smart city concept. This dissertation aims to connect the dots between space technology and the Smart City concept in Africa.

1.9 Structure of Dissertation

The remainder of this dissertation is structured as follows:

Chapter 2 takes us deeper into the smart city concept, discussing its core infrastructure, different kinds of smart city initiatives, its applications and ongoing smart city projects in Sub-Saharan Africa and other parts of the globe.

Chapter 3 focuses on space technology that can support the smart city concept in Africa. This chapter will discuss the characteristics of a communication satellites, Earth observation satellite applications, Position Navigation and Timing (PNT) satellite applications, as well as small satellites. Also, we will examine the connection between the emerging mega-constellations such as the *Oneweb* constellation project and small communication satellites and how these developments affect the smart city concept in Africa.

Chapter 4. will focus on the benefits of a smart city in Sub-Saharan Africa, and also consider factors affecting its implementation, such as government policies, technological know-how, cost of operations and implementation of needed infrastructure. Lastly, we will discuss the possible viabilities and vulnerabilities of the smart city concept in the African context.

Chapter 5. Will review the major findings from this research and provide some recommendations for future work.

2 SMART CITIES

2.1 Smart cities

There are numerous ways to define a smart city. Based on the scope of this dissertation, we will define a smart city as a city that invests in modern information and communication technology (ICT) infrastructure, advance space technology, human and social capital, to enhance the quality of life of her citizens, to support sustainable economic development, better decision making and robust management of her natural resources, etc. A Smart city can only be fully achieved by working in partnership with stakeholders in different forms, with focus on citizen participation.

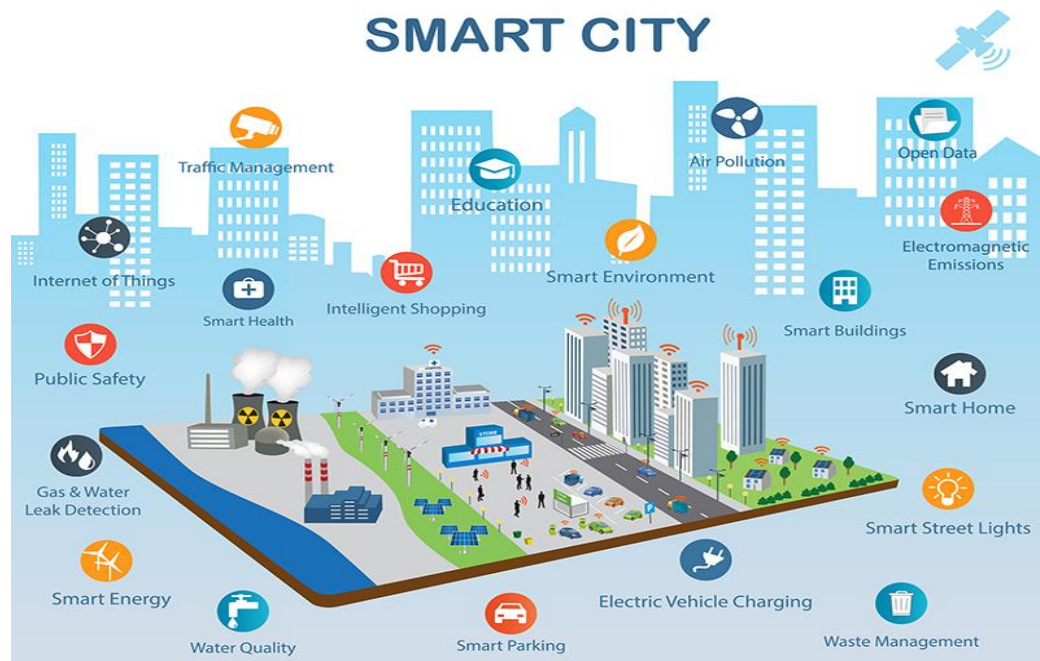


Fig. 2.1. Virtual representation of a Smart City¹⁴.

¹⁴ Depositphotos (2016). Smart city concept and internet of things. [online] Depositphotos. Available at: <https://depositphotos.com/126025652/stock-illustration-smart-city-concept-and-internet.html> [Accessed 2 Jan. 2016].

All cities are unique in their own way, ranging from geographical location to architectural infrastructure, etc. Though, most cities usually have similar objectives such as security, sustainability and wellbeing of their citizens. The rate at which cities can attain these objectives usually depends on their level of infrastructural development.

Smart cities rely on both hard and soft infrastructures. Hard infrastructures consist of physical transportation systems, good road networks, ICT infrastructures, such as internet connectivity, energy provision infrastructure, etc. Soft infrastructure has to do with governmental policies, leadership roles, community organization and innovative aspiration, etc.

Africa for example struggles with infrastructural challenges which can be attributed to lack of maintenance of already existing infrastructure or total neglect, the population explosion mounting pressure on existing infrastructure, non-existing transportation networks in most part of the region and irregularities in governmental policies. Compared to Western counterparts such as the United States of America or the European continent, Africa is still decades behind in terms of both soft and hard infrastructures. Though, Africa lacks these amenities, the region does have an advantage in technology adoption. This is because there is no existing infrastructure in most African countries and the high cost associated with maintaining old (legacy) infrastructure cannot compete with the implementation of modern technological amenities which are flexible and cost effective.

Information and Communication Technology (ICT) is the backbone of a smart city concept. Fig 2.2 shows a structural representation of the seven foundational areas that makes up the smart city infrastructure.

In the sections that follow, we will demonstrate the contribution of ICTs to each aspect of smart city applications and infrastructure.

2.2 Smart city applications

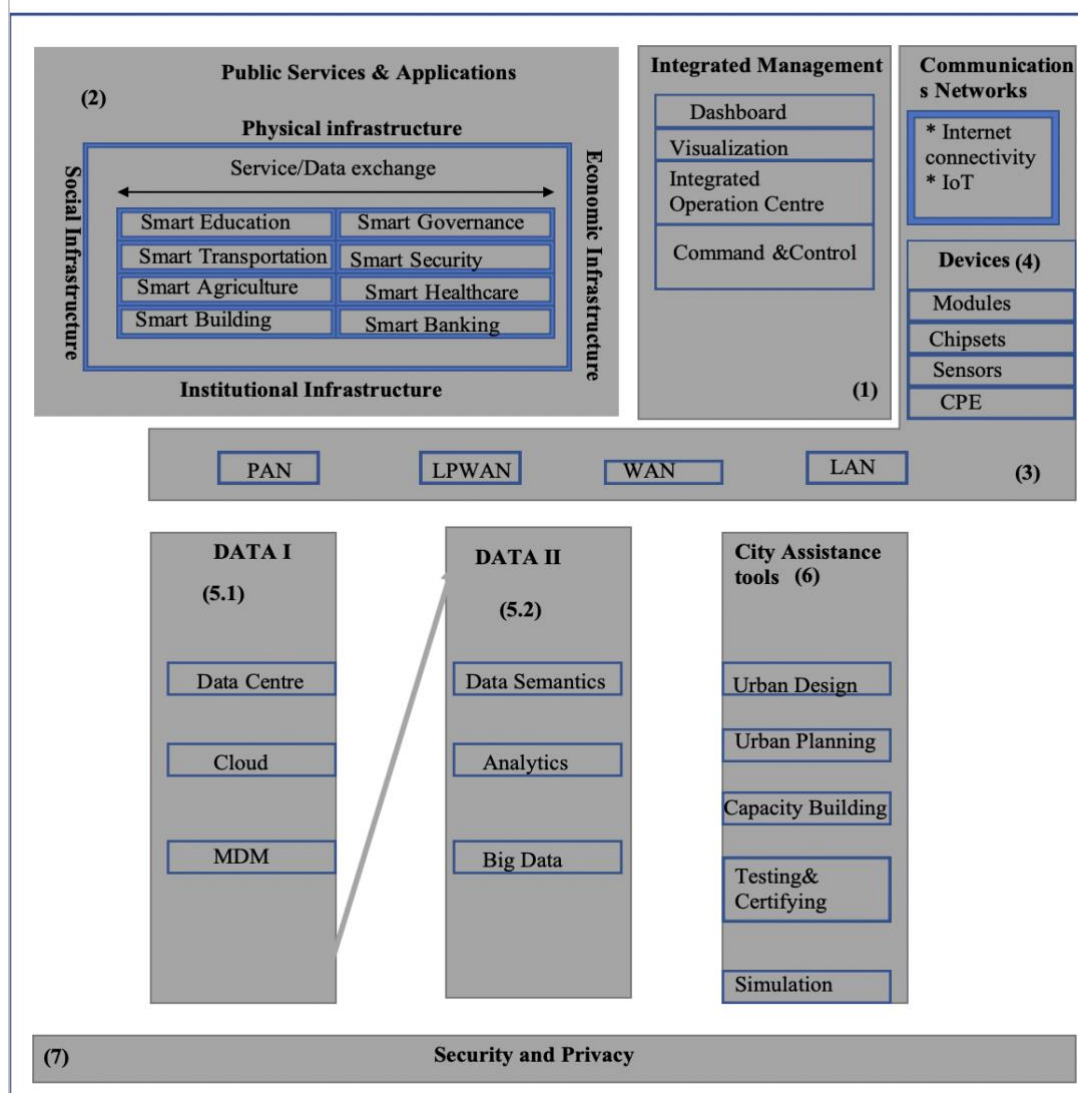


Fig 2.2. Block illustration of smart city applications and infrastructure¹⁵.

2.3 Integrated Management

This sector of the smart city infrastructure deals with integrating and managing a wide range of information provided by a city through, but not limited to, sensors nodes, cameras, satellite data, etc., in a single interface. These management tools consist of integrated operation centres, command and control centres, dashboards, and data visualization devices. The integrated management centres provide a single framework

¹⁵ tec.gov.in. (2015). ICT Deployments and Strategies for India's Smart Cities. [online] Available at: <http://tec.gov.in/pdf/M2M/ICT%20deployment%20and%20strategies%20for%20Smart%20Cities.pdf> [Accessed 14 Apr. 2017].

where all data from the smart city applications can be monitored and combined seamlessly. Fig 2.3 depicts the functions of the smart city Integrated Management Systems.

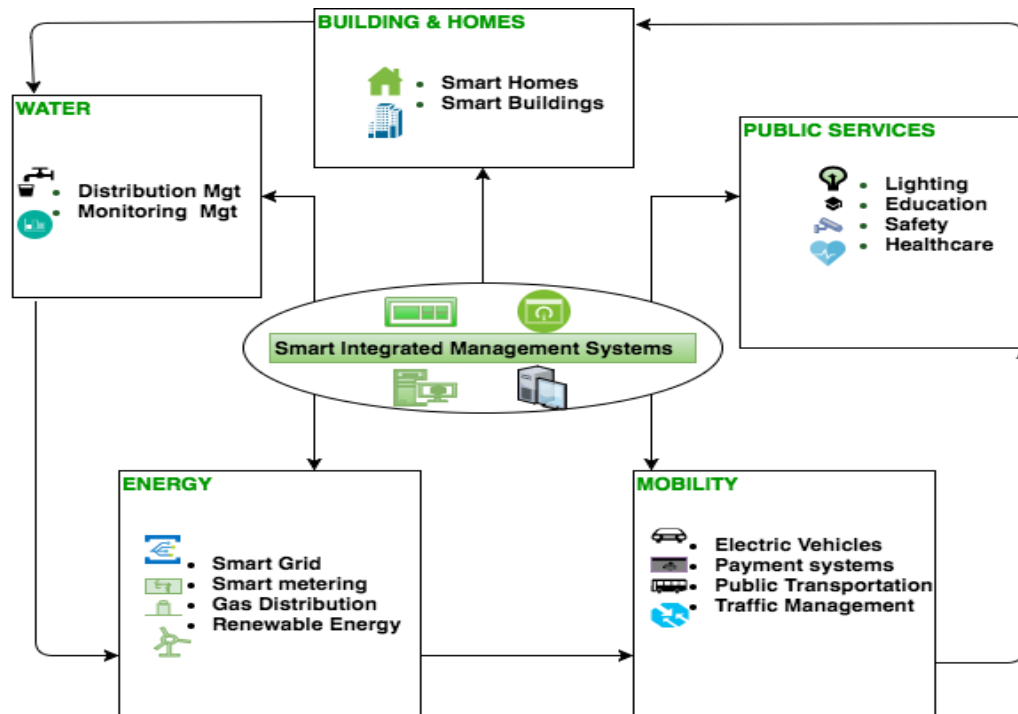


Fig 2.3. Smart Integrated Management Systems¹⁶.

2.4 Public Services & Application

This infrastructure applies to application solutions offered by the smart city concept. Information and Communication Technology (ICT) is the backbone of smart city applications. These technologies comprise, but are not limited to, the Internet, computers, wired & wireless networks, satellite communication systems, radio, cables, Geographic information Systems (GIS), instant messaging platforms, video conferencing, cameras and social media, etc. These technologies enable the following smart city applications:

- Smart Governance
- Smart Transportation
- Smart Building
- Smart Security services

¹⁶ Leinmiller, M. (2013). Smart Water: A Key Building Block of the Smart City of the Future. [online] Waterworld.com. Available at: <https://www.waterworld.com/articles/print/volume-29/issue-12/water-utility-management/smart-water-a-key-building-block-of-the-smart-city-of-the-future.html> [Accessed 25 Mar. 2017].

- Smart Education
- Smart Finance
- Smart Farming or Agriculture

Discussion on the properties and characteristics of some of the above-mentioned applications will be rendered as follows;

2.4.1 Smart governance: A Smart city needs smart administration and governance. The core aims of smart governance are to get the civil society more informed and involved, provide transparency between the public and government institutions, to promote accountability and connect all governmental institutions in a unified framework that allows free flow of data and information within the given institutions.

E-Governance can be categorized into these models: Government-to-Government (G2G), Government-to-Citizens (G2C), Government-to-Business (G2B) and Government-to-Employee (G2E).

Government-to-Government(G2G): This model encourages a transparent and a centralized or holistic environment within government agencies through Information and Communication Technology (ICT). The application of ICT reduces clutter through digital documentation as well as reducing corruption through transparency. It also provides ease of communication between government parastatals, etc.

Government-to-Citizens(G2C): This model facilitates direct communication between government and its citizens through different communication channels such as web portals, social media platforms, radio, newspapers and other technological forums. This model provide means for citizens to air their complaints or provide ideas on matters that affect them directly, giving the government insights on pressing issues affecting its citizens while providing applicable and impactful solutions in real time.

Government-to-Business (G2B): This model enables government to interact with businesses in real time and with ease. Entrepreneurship plays a significant role in a country's economic development and needs to be encouraged and supported by the government. These supports can be provided through E-government by having real time information on regulations, policies, investment opportunities, credit facilities, taxes, etc. Made readily available online to small and medium business owners. These provisions in real time can reduce risk factors such as, bottleneck policies, access to capital and red tape that affects entrepreneurship in a country. This model also provides public information such as real-time economic data and online transactions that can be used by business owners to forecast future business opportunities.

Government-to-Employee (G2E): This model can facilitate seamless interactions between government, employees and companies, through software systems rendered by Information and Communication Technology (ICT) providers. This model, can ease access and transactions such as, payrolls, medical allowances, pension schemes, bank

loans and provident funds, through online platforms. This model provides secured storage of personnel information such as bank account details, social security number and personal information, etc.

The interoperability mechanism of a smart government makes it unique compared to the traditional practice of today. Developed and developing countries around the globe are adopting E-government as part of their digital infrastructure. The positive impact of a smart government is limitless and as such should be one of the core aims of any smart city concept around the world, and Africa to be precise.

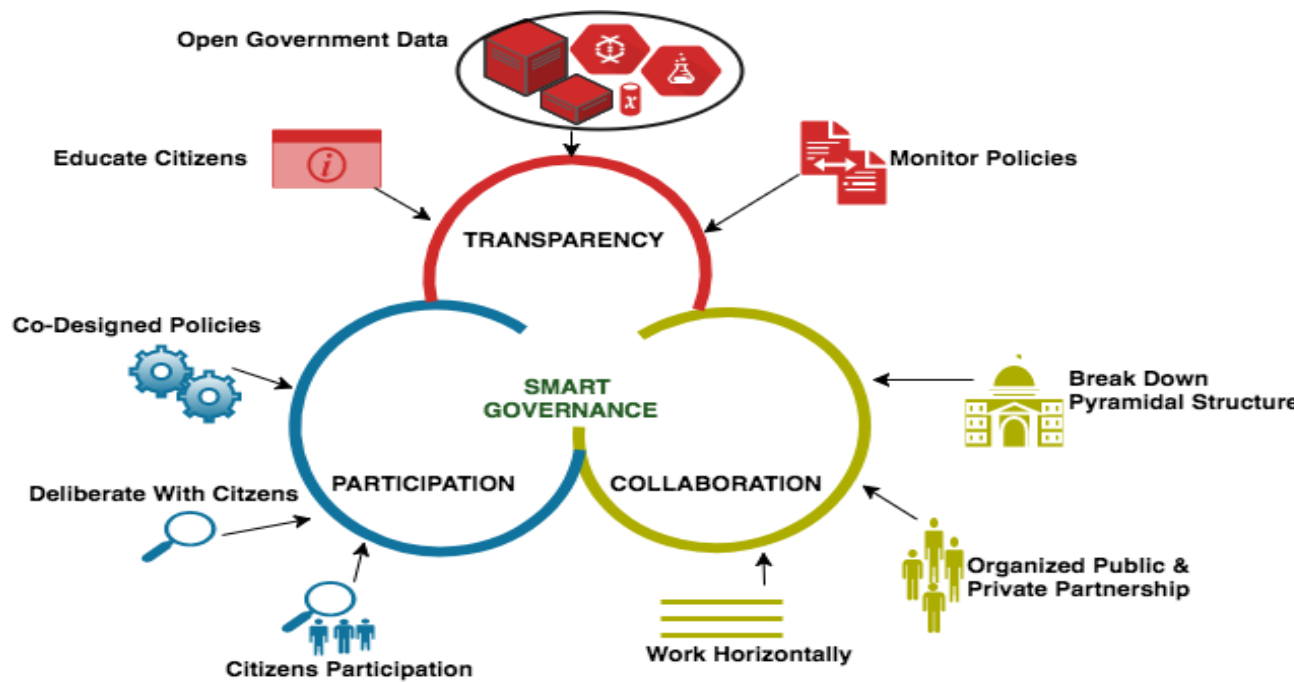


Fig 2.4 Element of Smart Governance.

2.4.2 Smart transportation: Transport in its various forms has a huge impact in the day-to-day lives of the residents of a city, from the environment to personal satisfaction and logistics.

The European Union (EU) framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport, adopted in 2010 defined a smart transportation or intelligent transportation systems as one “in which information and communication technology (ICT) are applied in the field of road transport, including infrastructure, vehicles and users, traffic and mobility management, interfaces of other modes of transport, etc.”

The core values of a smart transportation are; High productivity and efficiency, Improved safety, environmental friendliness and better quality of life.

Productivity and Efficiency: Traffic congestion lowers productivity and efficiency therefore increasing cost of labour, which further affects the entire economic system if approached from a macroeconomic perspective. The *Economist* published a report in 2013 stating that the expenses generated from traffic congestion in the United States, Germany, France and the UK amount to US\$200 billion each, and it is expected to reach US\$300 billion in 2030¹⁷, if the right modalities are not put in place. Smart transportation can provide real time data for monitoring traffic lights and road congestion through the application of ICT infrastructure. Sensors, cameras, GPS and other satellite systems are used to alert drivers or pedestrians on which routes are best to take during a traffic congestion. Mobile apps such as Uber, Lyft and Taxify, etc. are already changing the space of car ownership around the globe. This in turn reduces the number of cars driving through roads, hence reducing congestion.

Safety: Smart transportation is intended to reduce or avoid accidents through vehicle automation and connectivity. Autonomous vehicles have been making headlines around the globe. The vehicle-to-vehicle (V2V) and vehicle-to-Infrastructure (V2I) technology gives an automated vehicle the ability to communicate with its environment and other vehicles close to it. This prevents accidents caused by human errors, through collision avoidance systems technology, etc. An example of such an autonomous car is the Model S or the Model X, designed by Tesla, Inc. It is an electric vehicle with 360⁰ rear, side and forward-facing cameras for maximum visibility, 12 ultrasonic sensors and advanced hardware that is capable of providing Enhanced-Autopilot feature today and a full self-driving capability in the future. Intelligent transportation can reduce non-alcoholic related accident by as much as 80%¹⁸.

¹⁷ The Economist. (2014). The cost of traffic jams. [online] Available at: <https://www.economist.com/the-economist-explains/2014/11/03/the-cost-of-traffic-jams> [Accessed 2 Jul. 2018].

¹⁸ Washington Post. (2014). Direct communication between car computers may reduce accidents by up to 80 percent. [online] Available at: https://www.washingtonpost.com/local/trafficandcommuting/direct-communication-between-car-computers-may-reduce-accidents-by-up-to-80-percent/2014/02/03/b55e9330-8d1a-11e3-833c-33098f9e5267_story.html?noredirect=on&utm_term=.905c32fa1a9c [Accessed 11 April. 2018].

Environmental friendliness: Transportation is a major contributor to Green House Gas (GHG) emissions, and accounts for approximately 14% of global emission. Smart or intelligent transportation can reduce CO₂ emission through mobility management strategies. These strategies involve the implementation of renewable energy cars, i.e. electric cars, diversification of transportation means such as the provision of pedestrian partway and low-speed modes like bicycles and Segways. Information and Communication technology (ICT) is providing ways such as, car-sharing, ride-sharing (Carpooling), telecommuting and parking cash out, etc. to reduce the production and emission of Green House Gases (GHG). The emission of Carbon Dioxide is projected to increase in developing countries due to their high reliance on fossil fuel. The smart transportation initiative is a sustainable way to combat such ongoing issues.

Quality of Life: From an individual or personal perspective, the hours spent in traffic congestion are one of the biggest concerns to commuters. A report released in 2014 by “Tom-Tom”¹⁹ stated that the average commuter spends an extra 100 hours a year travelling during the evening rush hour alone. These are hours that can be spent in other more productive engagements, such as personal development or family quality time. With the smart transportation approach, using information and communication technology (ICT), these wasted hours can be better managed and organized.



Fig 2.5 Depiction of smart transportation²⁰.

¹⁹ Size, F. & WIRE, B. 2015. New TomTom Data Reveals Rush Hour Traffic Doubles Journey Times for Commuters. Businesswire.com.

<https://www.businesswire.com/news/home/20150330006108/en/TomTom-Data-Reveals-Rush-Hour-Traffic-Doubles>, [Accessed July 19, 2018.]

²⁰ Betancort, S. (2015). What is ITS and how it will change the way you move? [online] European Public Affairs. Available at: <http://www.europeanpublicaffairs.eu/what-is-its-and-how-it-will-change-the-way-you-move/> [Accessed 25 Sep. 2017].

2.4.3 Smart Buildings: A smart building is one that uses Information and Communication Technology to deliver intelligent building services such as: Illumination, physical security, thermal monitoring, domestic sanitation, air quality, fire safety, etc. Smart buildings might differ in designs but usually use the same integration process. All smart buildings are connected and responsive to a power grid through the connection of subsystems, which typically operates independently, these subsystems share information that optimizes the performance of smart building.

Building systems: Traditional buildings have a rigid flow of communication that is made up of complex mechanical devices. Most of these devices or subsystems are not interoperable usually due to proprietary issues. This makes the flow of communication protocols move in a certain distinct path. With a smart building, all devices and subsystems communicate seamlessly with each other optimizing performance and sustainability. An example of such system is using available data to regulate lightning or temperature within a building with respect to the occupants' activities.

People and technology: A smart building would be worthless without people making use of it. A smart building connects and provides intuitive tools that are designed to increase and enhance the efficiency of the people living in it. As smart buildings evolve, the sharing of information with each other will create room for innovation and future application, hence providing managers with tools and technology that will enable better security, comfort, safety and cost-effective impacts. An example of such a system is the "Amazon Alexa" device, which is voice enabled through an app. These devices can read up out weather report, emails, news channels, and search through google and other search engines for information, making life easier for the user or occupant.

Global environment: For decades, traditional building management systems have been automated to provide just enough energy to heat and cool a building to meet comfortable standards. This reduces decision making in an organization, since data produced from such management systems are all trapped within the building. With smart buildings, data can be gathered from a smart integrated management system that monitors all manufacturing or communication protocols within an organization or enterprise building. These data can be analysed and reported by a translation software (Middleware application service)²¹. These reports can be displayed on a web-based platform with visual snapshot features for managers or senior executives to make decisions on reducing and monitoring greenhouse gas emission, carbon foot prints, abnormality in maintenance costs, high energy usage, etc. All in real time.

Bottom line: There are several ways smart buildings can be cost effective and they all have to do with the efficiency in delivering optimization within the smart building subsystems. Optimization of ventilation and cooling equipment in a smart building uses the minimum amount of energy needed to provide comfort for its occupants. Smart buildings use shared information or data within and outside the building to learn patterns possessed by occupants to reduce energy usage when a building is not occupied or in use, therefore reducing energy wastage. Smart buildings use analytical algorithms to

²¹ Azure.microsoft.com. (n.d.). What is Middleware - Definition and Examples | Microsoft Azure. [online] Available at: <https://azure.microsoft.com/en-us/overview/what-is-middleware/> [Accessed 12 Feb. 2018].

predict and fix problems within their sub-systems before they escalate to more damaging issues. Lastly, a smart building can sell off its unused energy gained from load reduction, back to its power grid for profit. This can be achieved by altering its power usage with respect to signals received from the electricity market.

Smart power grid: Smart buildings can be connected to a smart power grid for efficient energy usage. Smart buildings can autonomously switch off unused devices or systems during peak periods and switch back on during off-peak periods, minimizing grid strains as well as reducing energy costs on the building. Smart buildings can also be programmed to interact with their environment, predicting weather forecast to trigger demand for energy from a smart power grid, depending on the predicted weather. i.e. if the weather is of very low temperature, a smart building can activate the heating system of the building, thus demanding for more power and verse-versa.

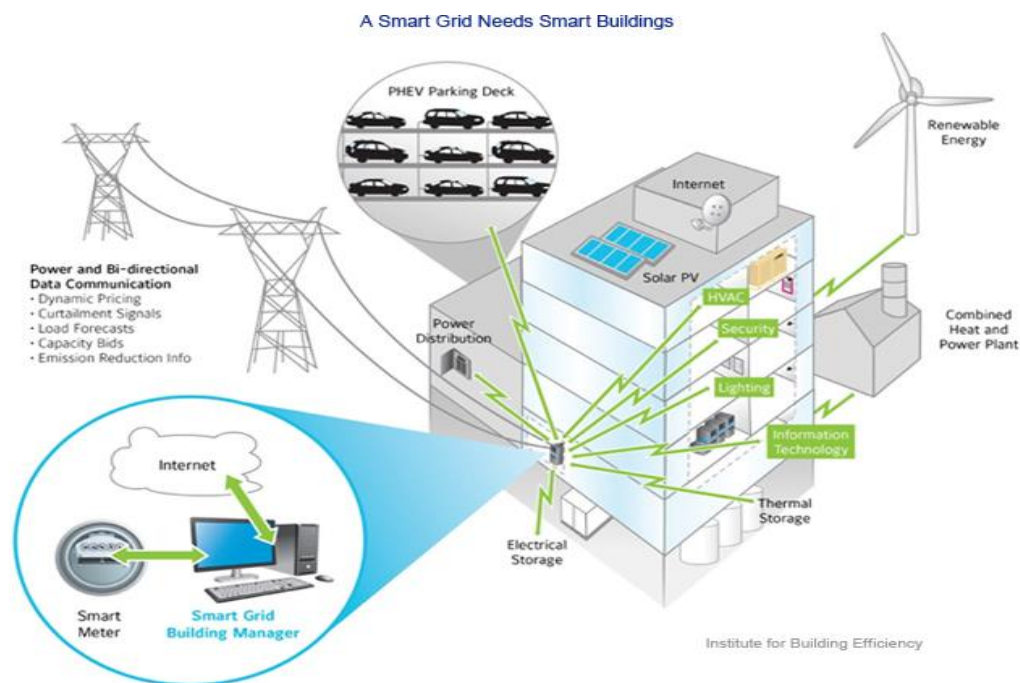


Fig 2.6. Connecting smart building with Smart grids²².

²² Buildingefficiencyinitiative.org. (2011). What is a Smart Building? | Building Efficiency Initiative | WRI Ross Center for Sustainable Cities. [online] Available at: <https://buildingefficiencyinitiative.org/articles/what-smart-building> [Accessed 10 Jan. 2018].

2.4.4 Smart Education: A smart education system is one that involves the use of technology in delivering educational services. Technology in this case functions as an educational catalyst that empowers both the teacher and student through digital learning and thus overcoming some of the difficulties with the traditional approach used in previous years. For example, with the rise of big data and the increased adoption of smart devices (mobile phone, tabs and laptops), educators are now equipped with innovative analytics such as educational data mining and learning analytics, enabling them to optimize and efficiently support or facilitate critical and practical research.

A Smart education framework is made up of three essential elements which are: **Teachers, Learners and Technology**. The presence of these elements encourages creativity, innovation, high quality of thinking and personalized learning environment.

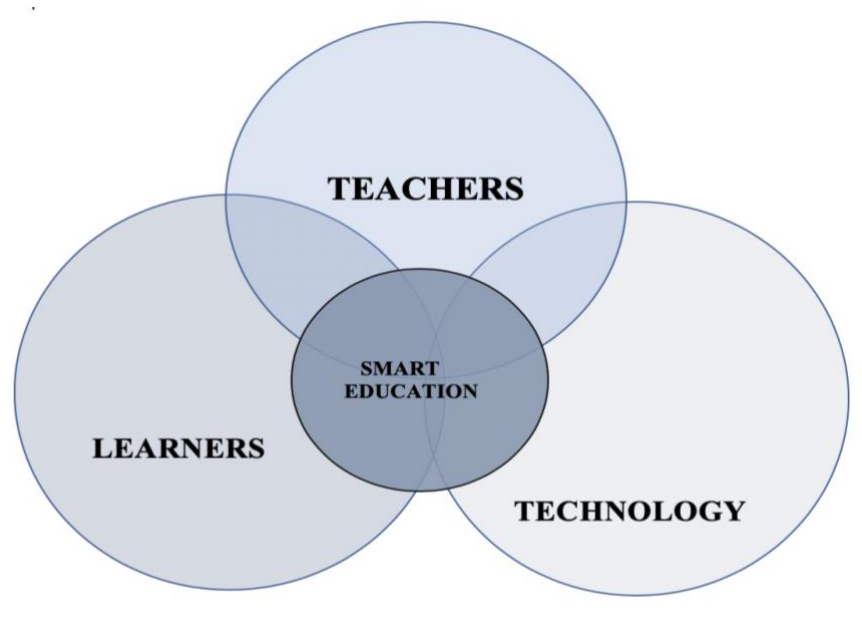


Fig 2.7. Smart Education building blocks²³.

Teaching presence: This can be defined as using student-centred, personalized and collaborative teaching models by a tutor or an instructor to design learning in a smart educational environment. This model uses technology to interact and encourage learning through direct feedback and instructions. Teaching presence in smart education can be conceptualized in three major components which are instructional design, technological support, facilitation and direct instructions.

Instructional design: Instructional design is an important element of both the traditional educational system and the smart educational system. They both include setting of learning objectives, organizing learning activities and providing professional guidance. Instructional models have positive impact in helping learners to achieve high level of cognitive presence, and changes as technology advances; hence there is no specific

²³ T. Hoel, Jon. Mason. (2018). Standards for smart education. [online] Available at: <https://link.springer.com/article/10.1186/s40561-018-0052-3> [Accessed 13 Jan. 2018].

structure to its delivery. All instructional designs have similar characteristics which are collaboration, student-centered, and personalized learning systems.

Technological support: This is another component of teaching presence that provides technological support to students. A teacher's confidence in technology utilization has a positive effect on students in a learning environment.

Facilitation and direct instructions: This component of teaching presence presents the teacher as a facilitator in the smart education framework. The teacher's responsibilities are, promotion of interactions, discussion and participation, etc. The teacher also provides direct instructions through scholarly and leadership roles.

Learner presence: This can be defined as the synthesizing of different types of information for the purpose of acquiring knowledge or improving and modifying existing skills in a smart educational environment. This is done by applying smart initiatives that involve proactivity, problem-based learning, inquiry style techniques and procedure, e.t.c. The traditional educational approach which usually involves passive processes where the teacher at one end provides a source of knowledge and learning materials to the learner at the other end who then consumes these resources passively and with constant repetition. This however, is now being changed by technology, using the digital context to promote individual abilities in learning.

Autonomous learning: Smart education promotes individuality in learning, which is considered as a more proactive way to acquire knowledge or skills. With technology involvement in education, a learner can match his or her cognitive stimuli to suit their personal interests and talents. Personalized or autonomous learning promotes flexible learning strategies such as proactive participation, intentional interactivity to both teachers and students based on their personal preferences and abilities. Using personal interest as a means for motivation, fosters creativity.

Collaborative learning: Smart education is providing collaborative means in learning environments around the world. In as much as individuality in learning is becoming more dominant within the smart education space, technology in education such as online sharing tools (for example; Google drives, skype, WhatsApp, etc.) are creating ways for social-emotional benefits. Collaboration using smart education, such as team-work participation through online sharing tools provides competence, sense of belonging and enhances one's collaborative roles in the society.

Efficient Technology User: Smart education requires efficient use or know-how of the technology it provides. Without understanding how the presented technology works, a learner cannot fully participate in the smart education environment. With the implementation of technology in the educational system, learners are getting equipped with knowledge such as computer self-efficacy; a process where one can be "judged on their capability to use a computer". This new generation of learners is already getting acquainted to these technologies and they are considered to be more technologically

skilled than their predecessors. They are known in the international community as “digital natives”²⁴.

Technology Presence: This can be defined as the enabling element between learners and teachers in the smart city framework. Technology facilitates and creates the environment for smart learning. This is conceptualized in three different categories which are but not limited to, connective, ubiquitous and personalized.

Connective: Technology in the smart education framework provides an important feature which is connectivity. Technology application in smart education, facilitates collaborative and seamless interaction between teachers and learners as opposed to traditional ways of studying, where interactions between students and teachers are limited to face-to-face conversations. Now with technology presence, a more flexible learning approach is being experienced across different educational platforms virtually anywhere with internet access. For example, Web 2.0²⁵ which involves social networks, blogs, podcasts, google drives, etc. Is providing numerous ways for interaction and collaboration within the educational space with less regards to physical location.

Ubiquitous: Technology presence in the educational framework gives flexibility in accessing educational resources. With the emergence of portable mobile devices, cloud computing and internet accessibility within the educational space, learners and teachers can access information needed from anywhere, any time and from numerous devices or access points. Ubiquitous access to learning through technology presence also provides instructional models for educational purposes e.g. WhatsApp messaging, skype and e-mail communications, etc.

Personalized: Technology presence in the smart education frameworks facilitates various means for personalized education. With the support of big data and learning analytics, students can personalize their learning patterns to suit their day-to-day activities as well as interests and competence. This concept of personalized learning as a characteristic of technology presence has moved learning away from being confined in a classroom to a place where learning can be done proactively and from anywhere suitable.

The combination of teachers, learners and technology presence forms the core structure of the smart education frame work. Through smart education, collaboration within the educational space will have no boundaries or barriers. These parameters (Teacher, learner and technology) complement each other to provide smarter ways to educate ourselves and future generations while contributing to the smart city concept.

²⁴ PALFREY, J. and GASSER, U. (2008). Born Digital. [online] Pages.uoregon.edu. Available at: https://pages.uoregon.edu/koopman/courses_readings/phil123-net/identity/palfrey-gasser_born-digital.pdf [Accessed 12 Jun. 2018].

²⁵ An, Ph.D, Y. and Williams, K. (2010). Teaching with Web 2.0 Technologies: Benefits, Barriers and Lessons Learned. [online] Itdl.org. Available at: http://www.itdl.org/journal/mar_10/article04.htm [Accessed 19 Aug. 2018].

2.4.5 Smart Banking: Smart banking or digital banking has been the topic across the banking industry for over a decade, and some argued that its already here. “*Today, the fastest growing financial services organizations in the world are, without exception, technology-based providers, not incumbent banks or institutions. From Ant Financial, Alipay and WeChat in China, M-Pesa in Kenya, Paytm in India, Kakao in Korea, and more. Technology allows much faster scale on much thinner margins, but it is fundamentally about a key element in the future of customer-centric banking – the removal of friction*²⁶”. With long-term strategic planning around all dimensions of the banking system, a bank can be fully digitalized.

With the advancement in digital technology, the banking sector has experienced a shift from traditional banking methods to a smarter banking system. Banks are becoming more flexible, mobile, collaborative and interactive. With the emergence of internet broadband connectivity and the mobile revolution, banking institutions are using technology to enhance user services and experience through customer feedback. These feedbacks are obtained with methods based on interactions, expectations, recommendations, engagement, experience, etc. Smart or digital banking has no fixed definition, but can be categorized in two-dimensional parts in the banking infrastructure, namely the internal dimension and the external dimension

Internal dimension: The internal dimension has to do with the back-end operations of the banking infrastructure, such as financial analytical software, computer hardware, Enterprise Resources Planning (ERP) software, Human Resources (HR), Risk management, Treasury, etc. As consumers of banking services become more “digitized”, banks are constantly trying to improve engagements with these loyal customers to stay ahead of the curve. The combination of services such as Application Programming Interfaces (APIs) with banking payment systems, provides seamless banking transaction experience for both the customers and Financial institutions. This is one of several ways e-payment services are revolutionizing the banking and financial industry. Banks are infusing emerging technology such as Artificial intelligence (AI) and Machine Learning (ML) in their banking operations for fraud prevention, to manage, predict and mitigate risks such as, credit risks, market risks, operational risk, etc. An example of such an application is the Contract Intelligence (COiN) software, developed by JPMorgan Chase. The software provides a platform where banking legal documents are analysed and important data points and clauses are extracted through pattern recognition algorithms. This software reduces a work load of 12,000 commercial credit agreements that usually takes 360,000 hours to just few seconds²⁷. Another software is “feedzai”, a software platform that uses robust Machine Learning to fight and detect financial crimes, by using extensive and big data to detect complex fraudulent patterns in real-time.

Smart or digital back-end operations of banks are changing rapidly with the emergence of new technologies. The impact of technology applications is prompting financial institutions to start building their own technological incubators or collaborating with other Fintech firms to stay ahead of the digital revolution. The internal dimension is not

²⁶ Brett King, Founder/Chairman (2018)- Moven, Author of Bank 4.0 Available at: <https://www.oracle.com/a/ocom/docs/dc/digital-demand.pdf>

²⁷ Sennaar, K. (2018). AI in Banking - An Analysis of America's 7 Top Banks. [online] TechEmergence. Available at: <https://www.techemergence.com/ai-in-banking-analysis/> [Accessed 15 Aug. 2018].

limited to just the technological applications but also involves leadership, talent management and other human resource paradigms.

External dimension: The external dimension has to do with the front-end operations of a bank such as, business operations, customer-centric services, other banks, regulations, etc. The external dimensions of a bank or financial Institution (FI) focus mostly on the customer's experience by creating an Omni-channel combined platform such as, online, mobile and social media services. This facilitates continuous, consistent and real-time feedbacks which are used by banks or financial institution to provide effective user experience for her customers. It has been debated by financial industry experts and practitioners that, the main building blocks of digital or smart banking are highly based on providing customers with the best services available on the market. In terms of regulations and other banks, digital banking is paving ways in which communication between banking and financial industries can be seamless while sharing information that can support ethical practices and accountability within the banking and financial industry.

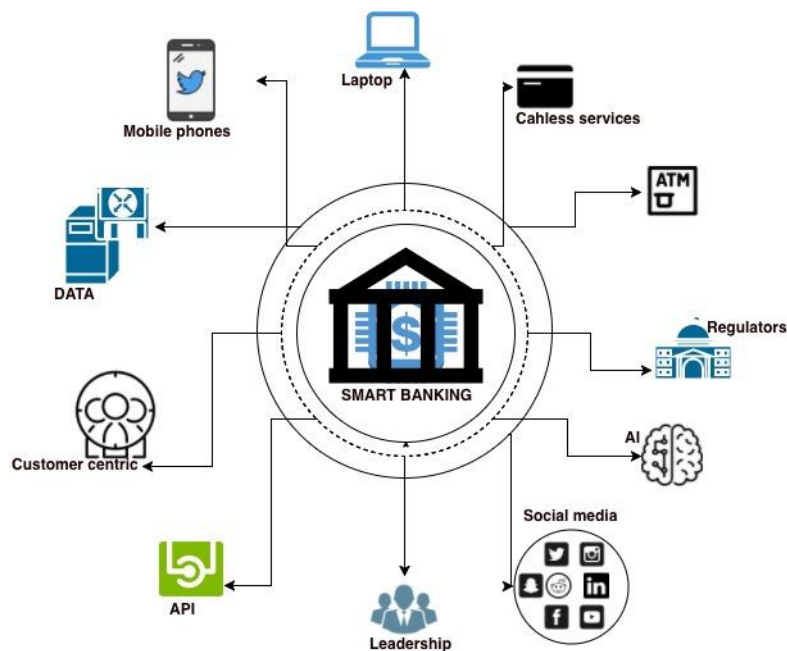


Fig 2.8. Smart banking.

As the world becomes more digitalized with the emergence of Internet broadband connectivity and the lower costs of smart devices, industries and citizens across Africa and the rest of the globe are adapting to these new technologies or risk being left behind in the digital future. People are becoming more comfortable in carrying out their financial operations online as opposed to bank walk-ins or face-to-face appointments. This is because banking services aided by technological devices and application platforms provide flexibility, shared experiences, personal needs and individual control, etc. These services are mostly supported by smart or digital initiatives to combat and improve issues such as, e-payment and transaction systems, customer query mitigation, portfolio management, regulations, data analytics and education, etc. An example of

such an initiative is M-Pesa, which is mobile banking application of low value accounts that enables the transfer of electronic funds via smart devices. This application was developed by Vodacom and was launched in 2007 by its affiliate *safaricom* located in Kenya and it is activated through Subscriber Identification Model (SIM) cards. The application converts physical funds into electronic funds from vendors or retailers of this service, which can then be transferred to other mobile accounts using a designated Personal Identification Number (PIN). M-Pesa has expanded beyond Kenya into other countries around Sub-Saharan Africa, and this is due to its high rate of adoption which can be attributed to the App's seamlessness in functionality and execution²⁸. Other initiatives are individual banking applications, open banking sources, etc.

Block-chain technology is another trending application which is changing the financial industry's landscape. A block-chain is a decentralized growing list of records called blocks which are written using cryptography programming language. These blocks have a timestamp, cryptographic hash of the previous blocks and transaction data. What this means is that, this program can record a transaction between two or more parties efficiently, permanently and in a verifiable way that cannot be deleted or tampered with. The block-chain technology platforms are decentralized by design and do not have a central controlling system. "The block-chain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value"²⁹. The block-chain technology was first applied by an unknown person or persons called "Satoshi Nakamoto" on the so-called "Cryptocurrency" ledger known as *Bitcoin*. Different sectors of the banking and financial industry are testing projects relating to the block-chain technology on business enterprises around the world. Application of the block-chain technology can reduce costs and transactions drastically. According to Santander, the world banking sector will save about \$20 billion by 2022 with the implementation of block-chain technology³⁰.

²⁸ Mas, I., & Ng'weno, A. (n.d.). Marketlinks.org. <https://www.marketlinks.org/sites/microlinks/files/resource/files/Three%20Keys%20to%20M-PESA%27s%20Success.pdf>, October 23, 2018.

²⁹ Tapscott, D., & Tapscott, A. 2017. What is Blockchain Technology? A Step-by-Step Guide for Beginners. Blockgeeks. <https://blockgeeks.com/guides/what-is-blockchain-technology/>, September 1, 2018.

³⁰ InnoVentures, S. 2015. The Fintech 2.0 Paper: Rebooting Financial Services. Santanderinnoventures.com. <http://santanderinnoventures.com/wp-content/uploads/2015/06/The-Fintech-2-0-Paper.pdf>, August 10, 2018.

3 COMMUNICATION NETWORKS AND DEVICES

Communication networks are a fundamental building block of a smart city. Communication networks in a city connect all hardware and software infrastructure with technology such as sensors, controllers, cameras, people, wired and wireless networks, etc. for the purpose of collecting and processing valuable streams of information and data from its city's environs. These data are used to facilitate a better understanding of how the city functions in terms of the environment, governance, economy and society, etc. The selection process for a smart cities communication networks requirement is quite difficult and complex, since all smart cities have their own unique communication and network requirements in which different factors are considered before it is deployed. The main influencing factors for sustainable communication networks in a smart city can be categorized as follows

Regulatory and Standards: The technological standards for the design and manufacturing of technologies equipment and devices are awarded and licensed by international standardization bodies such as. The International communication Union (ITU), Institute of Electrical and Electronic Engineers (IEEE), etc. For any communication network device to be used and deployed, approval from these bodies are needed. However, the national regulatory bodies have the final control on the use of infrastructure and standardization of devices in their respective region. To design a wireless network infrastructure in a particular country for example, one needs to know how much spectrum is available before designing because most of these spectrum slots are either unavailable or occupied. A vendor or communication network provider needs to be licensed by a regulatory body before their communication network technologies can be deployed.

Technical criteria: This has to do with the choice of technology used in a smart city communication network system and it depends mainly on the end application and quality of services rendered. Technical criteria such as throughput or bit rates, network capacity, interoperability, jitters, delays and network security are some of the important factors that are considered before implementing a communication network system. For example, with the emergence of big data and cloud computing, cyber or network security

needs to be guaranteed and robust ensuring all data are confidential and accessible to only authorized entities. Also, the authenticity and integrity of such data are assured in order to avoid data manipulation while guaranteeing the availability of data on request. Another example is the interoperability of devices and software applications from different developers and manufacturers. A standard protocol ensuring free flow of data across different technologies such as intelligent communication systems, transportation systems, lighting and heating systems, etc., is another technical criterion to consider.

Strategic decisions: These decisions have to do with strategizing how investment by operators or communication network system providers can yield maximum returns over time with the lowest cost possible and how it can affect the operating country's economy. Basically, strategic decision focus on the return on investment for both private and public stakeholders and how a country can be affected by these investments economically. For example, communication network devices such as sensors that are deployed in large scale needs to be manufactured with the lowest cost possible, i.e. the operating and capital expenditure such as but not limited to, maintenance cost, energy consumption, battery life, installation cost, equipment costs, etc. has to be cost-effective while implementing a communication network system.

Fig 3.1 shows the selection process and technical criteria for strategic decisions on communication technology for smart city applications.

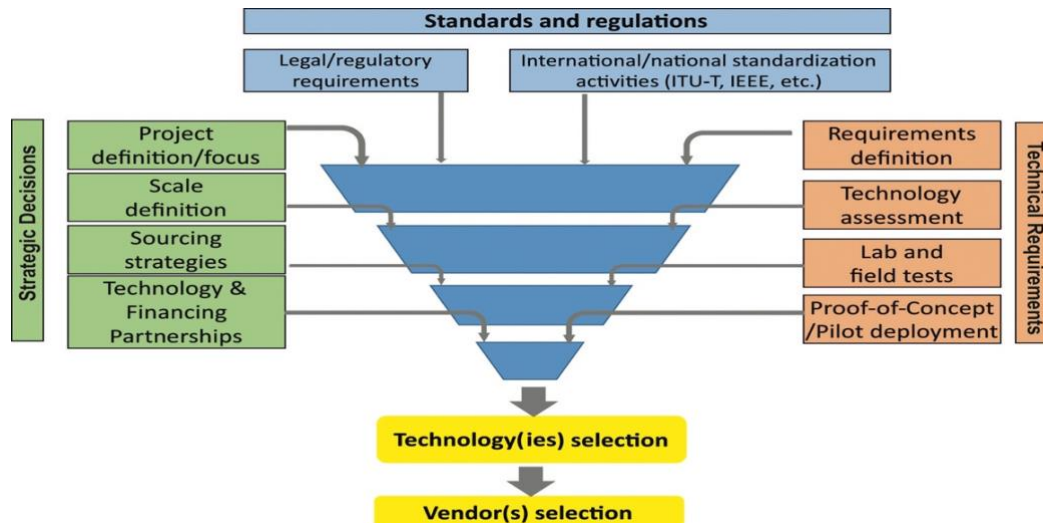


Fig 3.1. Selection process of communication technology³¹.

Communication networks in a smart city involve multiple deployment and connecting technology such as, public, wireless and wired communication network solutions. These technologies are often times combined to undertake collaborative tasks for maximum output.

³¹ Haidine, A., El Hassani, S., Aqqal, A. and El Hannani, A. (2016). The Role of Communication Technologies in Building Future Smart Cities. [online] IntechOpen. Available at: <https://www.intechopen.com/books/smart-cities-technologies/the-role-of-communication-technologies-in-building-future-smart-cities> [Accessed 26 Oct. 2018].

Wireless technologies: Wireless technologies facilitate wireless connections among different devices across all area coverage. The most used wireless technology for communication networks in smart cities presently is the mobile communication system, and its adoption since inception has increased significantly over time. Fig 2.10 shows the adoption cycle of mobile wireless technology in the last three decades.

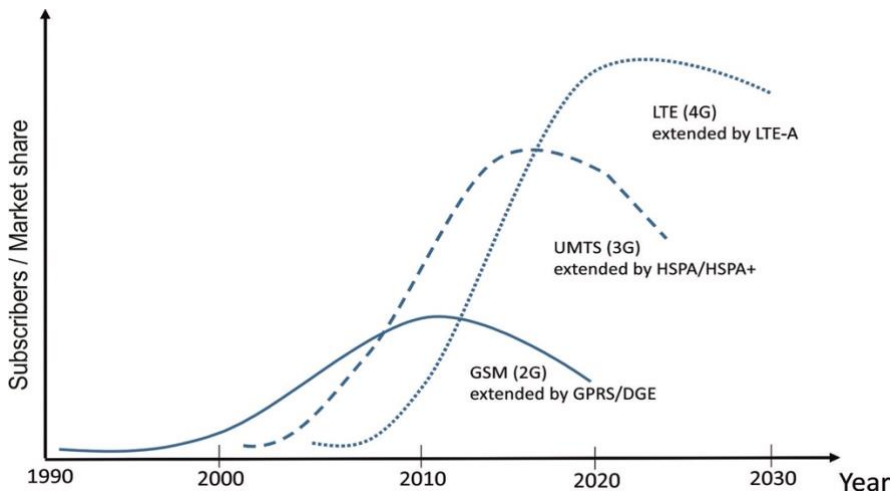


Fig 3.2 Adoption trends of wireless technology in the last three decades³².

The usual standards for wireless technologies that are used in smart cities are, IEEE 802.15.1, IEEE 802.15.3, IEEE 802.15.4, IEEE 802.15.6, IEEE 802.11, IEEE 802.16. IEEE 802.11. Each standard differs in area coverage capabilities that can be used for different applications in a smart city. For example, IEEE 802.15.1,3,4, & 6 standards which are used within close proximity like smart transport or smart homes, have shorter range than the IEEE 802.11 or IEEE 802.16 standards which are commonly used for longer range applications such as, smart grids. Wireless technology for smart city communication networks can be classified in, but not limited to four categories; Wireless Personal Area Network (WPAN), Wireless Local Area Network

(WLAN), Wireless Metropolitan Area Network (WMAN) and Global Area Network (GAN), etc. Wireless Personal Area Network (WPAN) technology falls within the IEEE 802.15 standard and it is used to connect devices centered around an individual work or personal space like an office or a living room. Examples of WPAN base technologies are Bluetooth, ZigBee, infrared communications, etc. Wireless Local Area Network (WLAN) technology operates on the IEEE 802.11 standard with wireless distribution technology connecting two or more devices that uses high frequency radio waves by method of Orthogonal frequency-division multiplexing (OFDM) within a small area coverage. An example of WLAN base technology is the Wireless-Fidelity (Wi-Fi) networks. Wireless Metropolitan Area Network (WMAN) technology is based on the IEEE 802.16 standard of operations and are used for connecting point-to-point or point-

³² Haidine, A., El Hassani, S., Aqqal, A. and El Hannani, A. (2016). The Role of Communication Technologies in Building Future Smart Cities. [online] IntechOpen. Available at: <https://www.intechopen.com/books/smart-cities-technologies/the-role-of-communication-technologies-in-building-future-smart-cities> [Accessed 26 Oct. 2018].

to-multipoint networks with individual nodes across a long area coverage. An example of WMAN based technologies are fourth generation (4G), Long-Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) networks, etc. Global Area Network (GAN) technology like WMAN, operates within the IEEE 802.16 standard and composed of different or multiple interconnected networks such as but not limited to, Wide Area Networks (WAN) and Local Area Network (LAN) which covers an entire geographical area. An example of a global area network (GAN), is the Internet broadband connectivity from a communication satellite. Table 3.1, shows the comparison of the different technology used in a smart city.

Communication Technology	Standards/Regulations	Frequency	Range (Approx.)	Data rates	Topology
WiMAX	3GPP	3.5 GHz	50 km	75 Mb/s	Point-to-multipoint, mesh
Bluetooth	IEEE802.15.1	2.4 GHz	1-100 m	1 Mb/s	Point-to-point
ZigBee	IEEE802.15.4	2.4 GHz	9-21m	25 0kb/s	Mesh
Wi-Fi	IEEE802.11 (a/b/g/n/p/aka/a)	2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz	100m	1-5 4Mb/s	Star
LTE	3 rd Generation Partnership Project (3GPP)	2.5 GHz, 5 GHz, 10 GHz	20-30km	30Mb/s(DL) 75Mb/s(UL)	Star
Internet	Internet Engineering Tax Force (IETF)	L-band	Global coverage	1Gb(DL) 500Mb/s(UL)	Point-to-point

Table 3.1. Comparison of communication and network technology in smart cities

Fig 3.3 shows different kinds of wireless technology found in a smart city communication network.

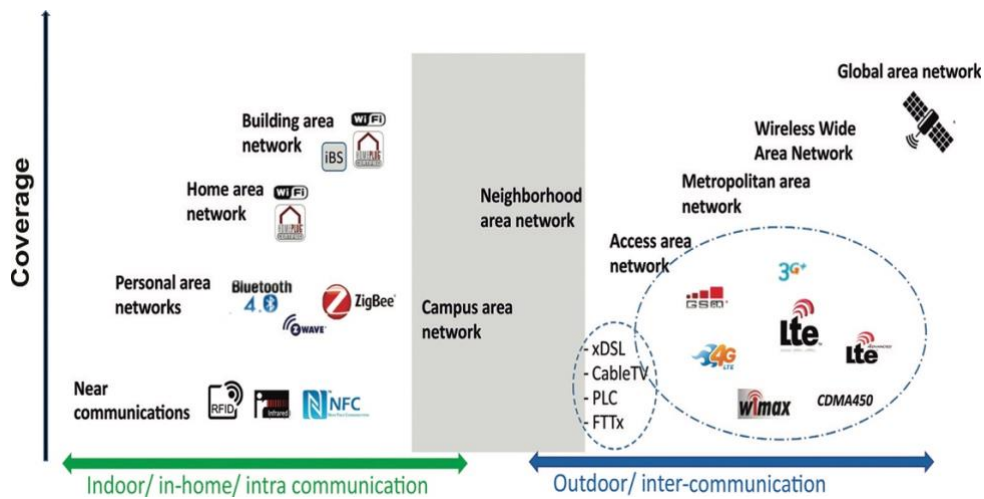


Fig 3.3 Wireless communication technology in smart cities³³.

Wired Technologies: Wired communication networks work mainly on Local Area Network (LAN) technology. A wired network is the connection of one or more devices together through Ethernet cables and it is as important as wireless technology in a smart city communication and networking platform. It provides robust and stable connectivity with respect to bit rates and Bit Error rates, and immunity against external interferences like electromagnetic-waves that in contrast might affect signals in a wireless communication network system. Interference such as reflections, refraction and path loss in a wired communication network are negligible because most of its infrastructure are direct cable connections which are insulated before implementation. The Local Area Network (LAN) in which wired technology is based on, operates within the IEEE 802.3 standards series, the available bandwidth of 200MHz, which carries a data rate speed of about 10Mb/s and above. An example of wired communication technology is the fiber-to-the-home (FTTH) networks for internet connectivity that is usually distributed by digital subscriber line (DSL), power line communications (PLC), cable TV(CATV), etc.

The common disadvantage of a wired communication network technology is its lack of ease in implementation. This cost a lot in terms of needed infrastructure, deployment and accessibility. The most common topology used in dispatching a wired communication network is the Star network system approach which usually have a central system that propagate the flow of communication from its central hub node to one or several devices.

Fig 3.4. Shows how a wired communication network is distributed in a star network system. Other distribution methods are, the bus networking system and the ring networking system.

³³ Haidine, A., El Hassani, S., Aqqal, A. and El Hannani, A. (2016). The Role of Communication Technologies in Building Future Smart Cities. [online] IntechOpen. Available at: <https://www.intechopen.com/books/smart-cities-technologies/the-role-of-communication-technologies-in-building-future-smart-cities> [Accessed 26 Oct. 2018].

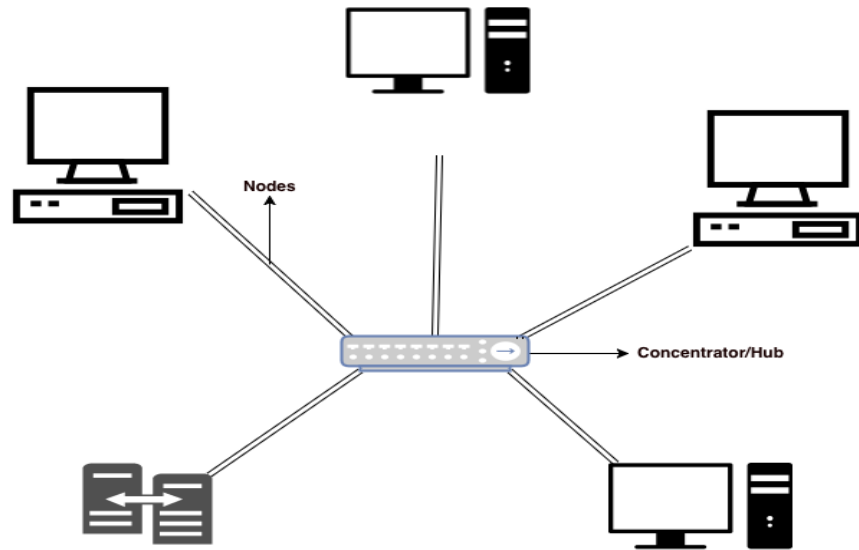


Fig 3.4. Star topology of a wired communication network system.

The use of power line communication is being adopted all over Europe to build the core of a smart power grid with the use of automated metering infrastructure (AMI). Examples of such project are the IBERDROLA in Spain and the G3-PLC that is developed in France.

The communication network system in a smart city cannot be fully realized without the combination of both wired and wireless communication technology. Since all communication cannot be provided by a single means it is therefore important to factor in both wired and wireless technology when designing the communication network system in a smart city.

3.1 Internet of Things (IoT)

The Internet of things (IoT) is a newly adopted paradigm and was first coined in 1999 by members of Radio Frequency Identification (RFID) development community. The Internet of things is defined as the network of physical objects that involves wired and wireless connection of systems and devices for communicating, gathering, analysing, sharing and transferring of data that are based on stipulated internet protocol. These analysed data are used for the purpose of smart monitoring, securing, tracing, positioning, reorganizing, process control and administration, etc. The Internet of Things (IoT) is an innovative internet technology that is changing the way we record and communicate with different entities within our environment. It is changing in such a way that we can now get real time data on every day entities such as food, electronics, vehicles, animals, people, water, etc. These were things that was impossible to communicate with in the past, but with the emergence and support of cloud computing, Internet of Things applications are reaching new revolutionary heights. One of the major

goals of the Internet of Things (IoT) is to have things connected anytime, anywhere, with anything or anyone seamlessly through any network paths and services.

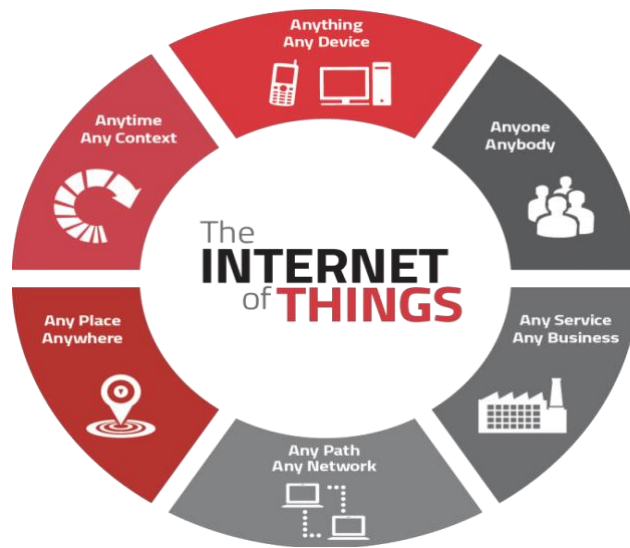


Fig 3.5 Internet of Things (IoT)³⁴.

Internet of Things (IoT) is enabled by multiple communication and network technology that comprises of both software & hardware appliances. Examples of such technology are but not limited to, sensor networks, wireless networks, such as, LTE, LoRaWAN, 2G-4G networks, GSM, GPRS, RFID, WI-FI, Bluetooth, ZigBee, microprocessor and microcontroller. Each enabling application have its own standards and regulatory policies, depending on what devices or communication network technology is being applied within an IoT system. The regulatory organizations responsible for setting standards for the Internet of Things span from International Telecommunication Union (ITU), Global standard 1 (Gs1) to the Internet of Things Standard Global Initiative (IoT-GSI) and the Industrial Internet Consortium (IIC). Supported by the ITU, the Internet of Things Standard Global Initiative (IoT-GSI) proposed two recommendations: the ITU-T Y.2060 which provides the overview of all concepts regarding to IoT and the ITU-T Y.2061 which describes the machine interface used in Internet of Things (IoT) applications.

The technology enablers below can be considered or used for implementing an IoT system in a smart city if:

- (I) The technology used to connect “things” can acquire and store contextual data.
- (II) The technology enabled “things” can process, transfer and analyse contextual data.
- (III) The technology enabled “things” can improve security and privacy.

³⁴ Donaldson, J. (2016). RFID Is Set to Lead The Internet of Things Movement. [online] Mojix - Test. Available at: <http://test.mojix.com/rfid-internet-of-things-movement/> [Accessed 13 Jan. 2018].

3.1.1 Characteristics of an IoT system:

The Internet of Things possesses different characteristics but the fundamental ones are as follows: Things-related services, Interconnectivity, dynamic change, enormous scale, heterogeneity and safety.

Things-related services: The Internet of Things provide things-related services within the constraints of things such as the semantic consistency between physical and their associate virtual things. What this means is that IoT objects have the ability to provide consistent reports of data or information between a physical device and its gateway devices through virtual displays, etc.

Interconnectivity: This is the main function of an IoT system, being able to connect multiple devices to provide a seamless and useful data output. The internet of things has the ability to connect everything to the global information and communication infrastructure.

Dynamic changes: The operations and state of devices can change dynamically in an IoT system, such as, off/on, sleeping/waking, connected/disconnected, etc. as well as the number of devices in the system.

Enormous Scale: The number of devices that will be operating and communicating with each other in an IoT system will be larger than the devices presently connected to the internet. With the growing application of IoT systems, the ratio of communication produced by device-to-device will be greater than that of human-to-device.

Heterogeneity: Devices in the IoT systems are heterogeneous in that they are made up of different hardware and software that uses different network protocols but can still interacts with other devices using different networks.

Safety: With the ability to combine multiple network protocols and devices, the Internet of Things (IoT) attracts multiple security threats and attacks such as confidentiality, authenticity, accessibility and integrity breach. Hence a robust security within the IoT system is paramount.

3.1.2 Internet of Things (IoT) architecture:

The architectural model of an IoT system is mainly made up four layers: Application layer, Service and application support layer, network layer and device or sensor layer. Each of these layers composed of both management and security capabilities that are part of its operating functions.

Application Layer: The application layer of an IoT model comprises of different smart application within our environment and space. Examples of such applications are smart transportation, smart building, smart healthcare, etc.

Service and Application support layer: The service and application support layer consist of two kinds of supportive capabilities which are generic and specific in nature. The generic support capabilities are typical or common capabilities that are used by different IoT applications such as the capacity to store and process data. The specific support capabilities as the name implies are those that are not generic and are used for IoT applications that are not diversified but specific to a niche.

Network Layer: The network layer consists of two main capabilities which are transport & networking. The networking capabilities provide the control functions of the IoT network connectivity such as, access control functions, authentication and accounting control functions. The transport capabilities focus on providing transportation for IoT applications and services with specific data information as well as IoT- related control and management functions.

Device Layer: The device layer can be categorized in two major capabilities which are, direct and indirect interactions with the communication network of an IoT system. Direct interaction has to do with gathering, processing and uploading of data and information directly without using gateways such as API's, etc., from the communication network. Indirect interactions use gateway capabilities to enable the gathering and uploading of data or information from the communication network. Sometimes ad-hoc networking of devices is constructed and implemented in an IoT system for increased scalability of a communication network. The device layer also exhibits gateway capabilities to support devices connected through different kinds of wired and wireless technology by supporting multiple network interfaces.

The management capabilities in an IoT system operate in all layers of the IoT architecture and it can be categorized into but not limited to generic and specific management. Generic management capabilities involve device management such as, diagnostics, remote device activation/de-activation, firmware and software updates, etc., local network topology management such as, point-to-point network, star network, etc., and traffic congestion management, such as network over flow conditions, time-centric and real-life data flows. Specific management capabilities are tailored with application-specific requirements such as, mobile payment, smart grid, etc.

Security capabilities are also divided into, generic and specific security capabilities. Generic security capabilities are independent of applications and involves authorization and authentication at all layers on the IoT architecture, i.e. the application, network and device layers. Specific security capabilities on the other hand, are specific in nature, designed for a designated IoT system. All layers have different security capabilities. For example:

Application layer: Application data confidentiality, signalling integrity protection, privacy protection, security audit and anti-virus, are all part of the security capabilities of the application layer.

Network layer: Authorization, authentication, network data confidentiality and integrity protection are all security capabilities of the network layer.

Device layer: Device integrity validation, access control, data confidentiality, authentication and authorization are all security capabilities of the device layer.

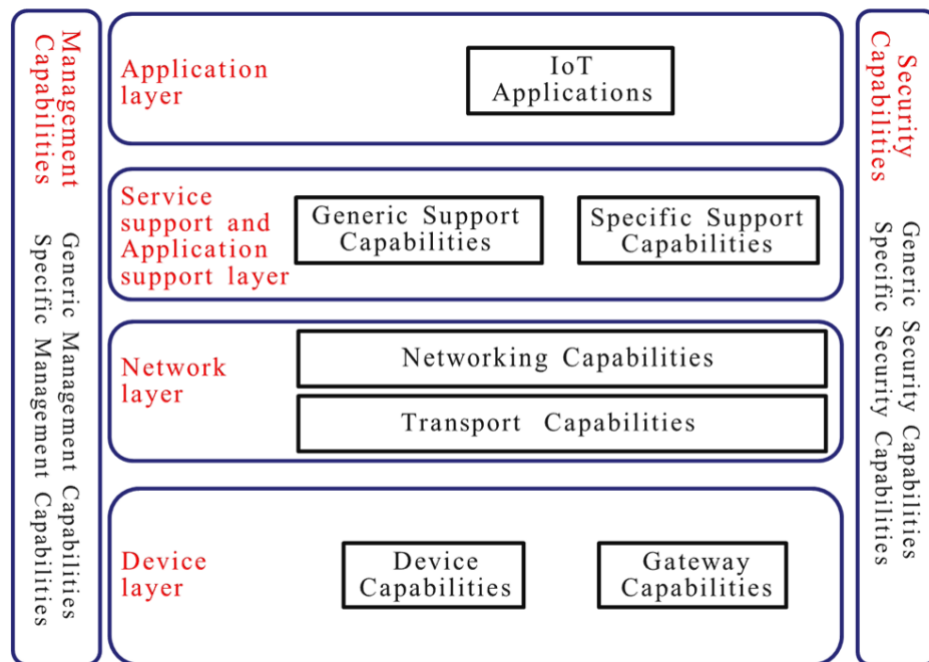


Fig 3.6. IoT Architecture³⁵.

3.1.3 Sensor classification:

Physical sensors: Physical sensors as the name implies measures physical attributes such as temperature, weight, length, pressure, electricity, sound, etc., in form of stimulus and then converts these measurements to produce electrical signals through a communication network system.

Chemical Sensors: Chemical sensors are used to measure qualitative and quantitative changes in an environment through chemical reactions. Chemical sensors are used to measure and classify specific set of chemicals.

³⁵ Torkaman, A. and Seyyedi, M. (2019). Analyzing IoT Reference Architecture Models. [online] Ijcsse.org. Available at: <http://ijcsse.org/published/volume5/issue8/p1-V5I8.pdf> [Accessed 7 Jan. 2018].

Figure 3.7. Below depicts the propagation sequence of a typical sensing device.

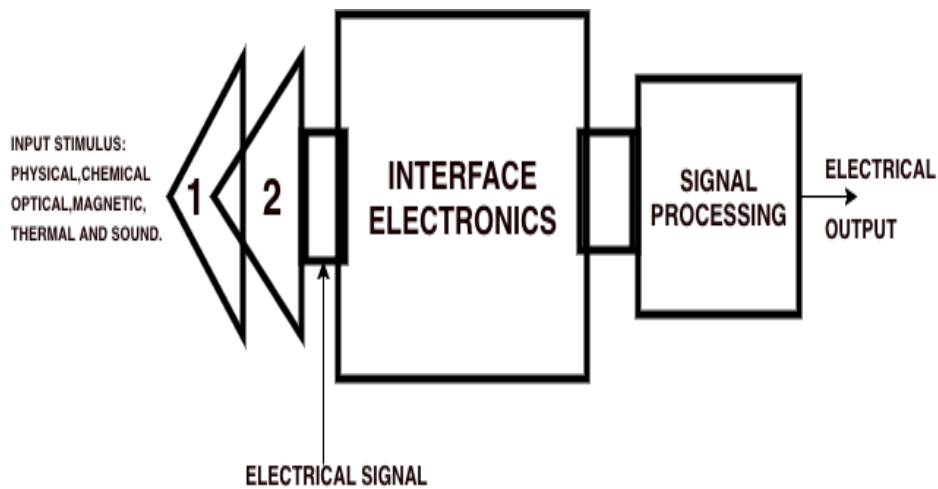


Fig 3.7 Sensing elements and its relative electrical signal³⁶.

Sensors used in a smart city are usually associated with the Internet of Things (IoT) applications such as: Proximity, temperature, pressure, optical and humidity sensors.

Types of sensors:

Proximity sensors: Proximity sensors are used to detect all kinds of motions. These sensors are used in cars and other mechanical appliances to navigate through obstacles, hurdles and routes. This type of sensor uses electromagnetic radiation such as radar, radio, and infrared signals, etc., to detect motion directions. Application of the proximity sensor can be found in cars, roads, airport, museums and business organizations. Examples of proximity sensors in IoT systems are, Doppler effect sensors, magnetic sensors, capacitive proximity sensors, etc.

Temperature sensors: Temperature sensors are one of the most commonly used sensors in a smart city. This sensor uses different methods to observe and quantify the temperature of an object or an environment such as physical contact with the sensing device or detecting radiant energy that emits from gas or liquids within the sensor's environs. Application of a temperature sensors can be found in almost all industries. Examples of temperature sensors in IoT systems are, Resistance temperature detector (RTD), Negative Temperature Coefficient (NTC), thermocouple, etc.

³⁶ Torkaman, A. and Seyyedi, M. (2016). Analyzing IoT Reference Architecture Models. [online] Iosrjournals.org. Available at: <http://www.iosrjournals.org/iosr-jbm/papers/Vol20-issue1/Version-4/J2001045560.pdf> [Accessed 17 Jan. 2018].

Pressure sensors: Pressure sensors as the name implies are used for measuring pressure which are usually of gas and liquid. Pressure sensors like temperature sensors are among the most commonly used sensors. The sensor determines the pressure of an entity (liquid or gas) based on the imposed pressure of same entity and then converts such impulses in the form of electrical signals as an output source. Pressure sensors are mostly used indirectly to measure gas/fluid flows, speed, altitude, water levels, etc. Examples of pressure sensors in IoT systems are, barometers and pressure gauges.

Optical sensors: Optical sensors are used to measure electromagnetic energy such as lights. This sensor uses the photoelectric effect mechanism by converting received light energy into electrical signals. Optical sensors are passive in nature and required an external source of energy most of the time. Applications of optical sensors are usually found in mining operations, pharmaceutical companies, oil refineries, etc. Examples of optical sensors in IoT systems are, photovoltaic cells, LED sensors, Light Amplification by Stimulated Emission Radiation (LASER) sensors, etc.

Humidity sensors: Humidity sensors are used to measure and sense the amount of water or moisture in the air of an environment. This sensor measures changes that alters the resistance or capacitance of the air around it and then calculate and convert these measurements to electrical signals as output. The three main types of humidity sensors are capacitive, resistive and thermal humidity sensor. Applications of these sensors are sterilizers, incubators, respiratory supporting systems, soil moisture monitoring, etc. An example of the humidity sensors in IoT systems is the hygrometer. Figure 3.8 Shows some implemented application that are carried out by sensors used in the Internet of Things (IoT) system within a smart city.

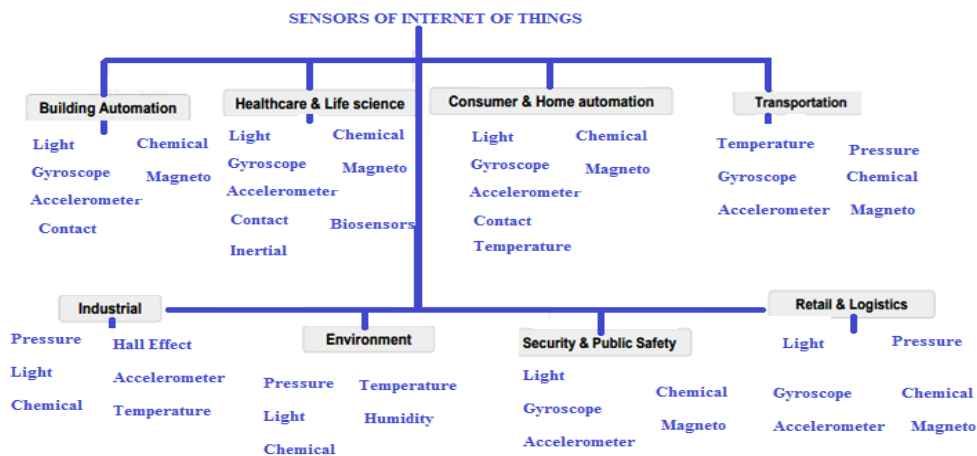


Fig 3.8 Sensing device applications in smart cities³⁷.

³⁷ Torkaman, A. and Seyyedi, M. (2016). Analyzing IoT Reference Architecture Models. [online] Iosrjournals.org. Available at: <http://www.iosrjournals.org/iosr-jbm/papers/Vol20-issue1/Version-4/J2001045560.pdf> [Accessed 17 Jan. 2018].

When using sensors in smart cities some factors need to be considered before implementation. These include cost, accuracy, environmental impacts and range of all sensors that will be used in a particular project.

3.1.4 Data, Security and Privacy

Data management and analysis is a fundamental driving force in building a successful smart city. Without a robust data management system, cities will struggle with interconnecting information and providing a sustainable living environment for her citizens. The kind of data used in a smart city can be classified into: structured & unstructured data from enterprise, big data, machine-to-machine data and open data sources.

Structured data: Structured data are organized in formatted field within a record or file which includes database and spreadsheets so that its contents can be addressable for effective analysis and processing. Structured data comprises of several characteristics such as but not limited to:

- (i) Consistency in order
- (ii) Well organized
- (iii) Easy to search and query
- (iv) Easy to access and understand

Structured data are usually stored in a database as mentioned earlier and its mostly in tabular form, with rows and columns that defines its attributes. An example of a structured database is, excel spreadsheets with labelled columns and rows.

Unstructured data: Unstructured data as the name implies are disorganized set of data that are non-tabular, dispersed and cannot be arranged into pre-defined fields. The unstructured data is a contrast to the structured data and possess opposing characteristics when compared with it, these characteristics are:

- (i) Inconsistent in order
- (ii) Unorganized
- (iii) Needs additional pre-processing
- (iv) Hard to access and query

Unstructured data is actually not completely disorganized, it just needs extra iterations or rummage to make sense out of the data presented. Examples of unstructured data are but not limited to, web pages, miscellaneous e-mails, and documents spread around different locations.

Big Data: Smart cities use and generate massive amounts of data from different sources within and outside the city to make smart and better decisions for future growth. Big data is a term used for both structured, unstructured data and open source data that are too complex for traditional processing methods to efficiently deal with or analyse. The importance of big data analytics in smart cities is ambiguous and facilitates the process of gathering, storing and managing all streams of data in a smart city.

Big data can be characterized in terms of the three “Vs”, which are: Volume, Velocity and Variety.

- (i) Volume: This refers to the amount of data being managed.
- (ii) Velocity: This refers to the rate at which data flows from and within various data sources which are usually continuous and large in size.
- (iii) Variety: This refers to data generated from multiple data or diverse sources in the form of structured and unstructured format.

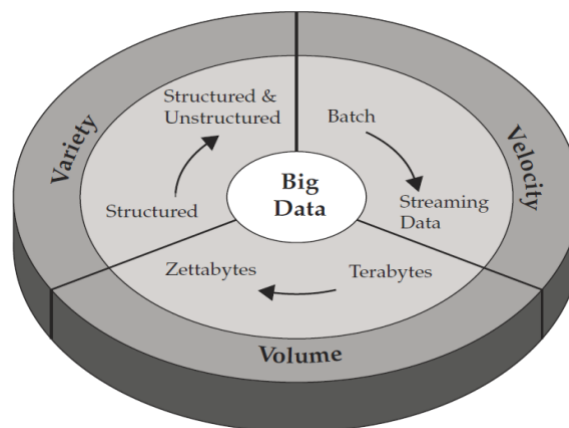


Fig 3.9. Characteristics of Big Data³⁸.

There are different types and sources of big data, from financial transactions to social media correspondence, from satellites images to sensors spread across a city. Therefore, it is paramount that all these types of information and data should be integrated for analysis and data management. As mentioned before, there are two main types of data that makes up a big data, which are structured and unstructured data sets. Fig 3.10 describes the different types and sources of data.

³⁸ Grobelnik, M. (2012). Big Data Tutorial - Marko Grobelnik - 25 May 2012. [online] Slideshare.net. Available at: <https://www.slideshare.net/markogrobelnik/big-data-tutorial-marko-grobelnik-25-may-2012> [Accessed 13 Jan. 2018].

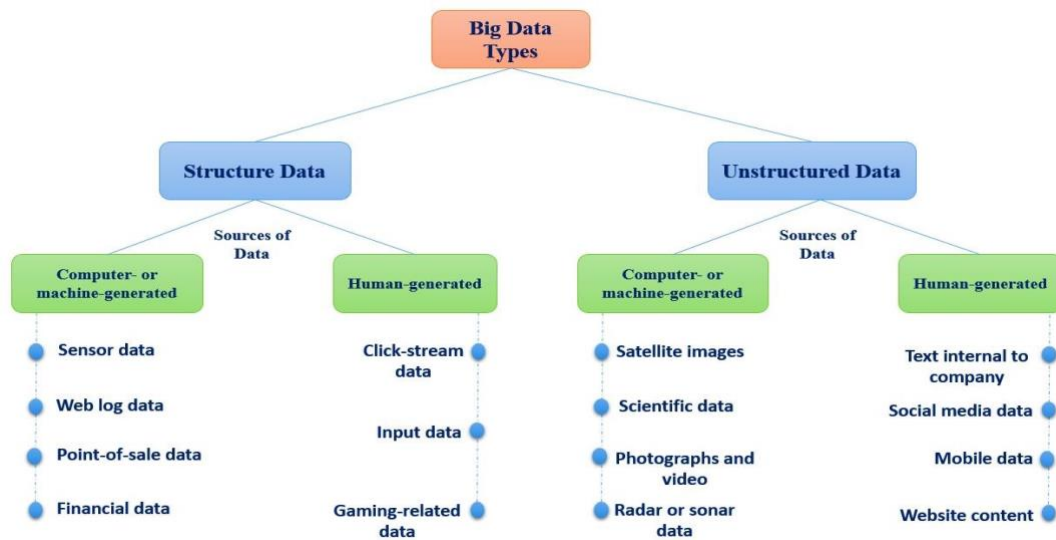


Fig 3.10. Big Data Types³⁹.

Big data can be applied in all areas of a smart city and used to answer questions like, what to do? and when to do it? data has often played an integral part in helping make these decisions. Big data can be applied in areas such as healthcare, traffic management, manufacturing management, etc. The data used in these applications adhere to all characteristics associated with big data which are volume, variety and velocity.

With the evolution of computing and storage technology, high volumes of data which could not be stored or processed before can now be done with these innovative technologies. With the emergence of cloud computing, large data can now be stored, processed and managed by a remote server hosted over the internet such as virtual machine storage, etc., rather than having to build and maintain computing infrastructure locally. Innovations like MapReduce, Big table, and Hadoop are changing the landscape in data processing and management, these technologies have the capability to manage and process massive volumes of data quickly, more efficiently, cost-effectively and in real-time.

Big data is still in its early stage in terms of understanding and investigating both its technical and business requirements. Therefore, there is need for more research in understanding and exploring the critical issues that can be resolved using big data. Big data analytics will support the smart city concept in Africa by analysing and predicting data generated by smart devices connected through and across different channels in a smart city.

³⁹ HADI, H., AHMAD, A., HADISHAHEED, S. and SHNAIN, A. (2015). BIG DATA AND FIVE V'S CHARACTERISTICS [online] Iraj.in. Available at: http://www.ijar.in/journal/journal_file/journal_pdf/12-105-142063747116-23.pdf [Accessed 6 Jan. 2018].

Security and Privacy: A Smart city as we know by now involves high degree of network connectivity to facilitate seamless communication within its infrastructure. This high degree of connectivity is usually associated with potential vulnerability such as cyber-attacks and unauthorized access to restricted data or information, etc. Another reason why a smart city might be prone to attacks is that most of the technology applications and devices used in smart city applications are from multiple sources and manufacturers who usually have back door access on their proprietary product. This subsequently encourages intrusion and vulnerability to security and privacy of a smart infrastructure. So therefore, it is important to factor security and protective measures from the ground up, when building a smart city.

Security and privacy are closely related terms and there is almost no privacy without security. Privacy in a smart city depends on the security placed to safeguard all systems and sub-systems within its infrastructure. For example, if devices in smart homes are compromised or accessed by unauthorized parties, the occupant of such homes can be spied on, or the home can be accessed physically by these intruders hence invading all sort of privacy that comes with the comfort of a home. Some of the attackers and data sources found within the smart city concept are:

Involved parties: Involve parties includes manufacturers of devices (Smart phones, vehicle, smart watches, etc.), software developers and authorized users with malicious intent.

Third parties: Third parties have to do with neither manufacturers nor service providers, they are usually external attackers with no direct authorization to sensitive information, but do have access through other channels such as social engineering, fake identities and pretence.

Service providers: Service providers include companies, government and agencies that provides utility services ranging from, cloud computing, internet broadband connectivity, smart meter readings, location-based providers, etc. Most of these agencies or institutions have access to delicate and private data which without consent might exploit for personal gains and incentives.

Privacy and security breach in smart cities are usually linked to four sources namely;

Observable data: This source of attack is mostly passive and involves eavesdropping or spying on both wired and wireless communication nodes. To access such data, attacker needs to be physically present at the intended location where communication can be compromised.

Repurposed data: These are data that have been used for a specific purpose, but are then reused without formal consent from its source or origin. Most of these activities are carried out by service providers who use personal information of their clients to provide

not only the designated services required but also, incentivize these information or data for their personal or corporate gains.

Published data: These are usually consensual and publicly available data. This includes statistical data released by governmental institutions, individuals, corporate entities, etc., through open data sources that are readily available to the public. Such data can be correlated with other information that can be used by attackers for intrusion purposes or otherwise.

Leaked data: These are data that are meant to be private but have been compromise and released by unauthorize entities to the public. Attackers acquire such data through social engineering, software flaws, abuse of authorized access, etc. Leaked data are commonly used to dent the reputation of a person or entity connected to the content of data released.

3.1.5 Data security and privacy protection:

Perfect protection of private data in smart cities is impossible. However, the combination of different types of privacy technologies such as “Privacy Enhancing Technology” (PET), can help mitigate and manage most of these security issues. There are several ways data can be protected and secured in a smart city; Data Minimization, Differential Privacy, Data Anonymization, Encryption, Homomorphic Encryption, Zero-Knowledge Proofs, Secret Sharing, Pseudonymous/Anonymous Digital Credentials, Secure Multi-Party Computation, Private Information Retrieval. Table 3.2 shows the application, solutions and enabling technologies that supports data privacy in a smart city.

PET	Technology	Privacy-Securing Solutions
Data Minimization	Ubiquitous Connectivity	Uses minimal permission for mobile apps, restricts third-party libraries.
	(Participatory)Sensor Networks	Isolate sensors from other systems, separate entities that ask for and receive sensor readings.
	Wearable devices	Reduce time and location granularity on device, extract relevant features on device, discard raw data.
	Internet of Things	Process data for smart metering on device, discard raw data.
	Intelligent Vehicles	Process data for toll pricing on device, discard raw data, require cooperation of multiple entities to de-anonymize vehicles.
Differential Privacy	Open Data	Release noisy aggregates of data, e.g., public transport data.
	(Participatory)Sensor Networks Internet of Things	Obfuscate locations with planar Laplace noise. Apply noise to smart meter readings.
Data Anonymization	Ubiquitous Connectivity	Change device identifiers frequently to prevent fingerprinting, randomize browser fingerprints.
	Open Data (Participatory) Sensor Networks	Release only data that satisfy anonymity, diversity, invariance, or closeness. Ensure anonymity of sensor and spatial-temporal readings.

	Internet of Things	Cluster IoT data streams and only release clusters that are anonymized.
Encryption	Ubiquitous Connectivity Wearable devices Internet of Things Cloud Computing	Ensure correct usage of SSL/TLS with static analysis and dynamically linked libraries, Secure public Wi-Fi with WPA2, use anonymous communication to protect metadata. Avoid storing encryption keys on device, use cryptographically enforced role-based access control. Use identity-based encryption for private service discovery. Use attribute-based encryption for access control.
Homomorphic Encryption	(Participatory)Sensor Networks Internet of Things Cloud Computing	Aggregate sensor readings from multiple participants privately. Aggregate data over multiple participants, e.g. energy consumption. Privately process data at third parties.
Zero-Knowledge Proofs	Internet of Things Intelligent Vehicles	Enforce honesty of device for local processing, e.g., for smart meters. Enforce honesty of vehicle for local processing, e.g. for electronic tolling.
Secret Sharing	Open Data (Participatory) Sensor Networks Internet of Things	Use privacy-preserving data aggregation. Enforce anonymity of sensor readings cryptographically.

	Wearable devices	Aggregate data over multiple participants privately. Use secure distributed data storage.
Pseudonymous/Anonymous Digital Credentials	Smart Cards Intelligent Vehicles Cloud Computing	Authenticate users without identifying them. Use short-lived pseudonyms for car-to-car communication, preserve backwards-privacy when revoking pseudonyms, eliminate mapping between short-term and long-term identifiers. Authenticate users based on attributes instead of identities
Secure Multi-Party Computation	Cloud Computing	Process data with private inputs, e.g. genomic tests, Perform privacy-preserving data mining over distributed datasets.
Private Information Retrieval	(Participatory)Sensor Networks Cloud Computing	Ensure query privacy in location-based services. Hide access patterns to remote files and database.

Table 3.2. Application of Privacy-Enhancing Technology to smart city technologies.

4 ENABLING SPACE TECHNOLOGIES FOR SMART CITIES IN AFRICA

Space satellite technology applications have been a part of our everyday lives, soon after the first satellite called Sputnik1 was launched into space by the Soviet Union in October 1957. Space satellite technology applications have become an indispensable infrastructure that everyone now relies on. These applications stretch from weather monitoring and telecommunication to Earth observation and Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS). According to the United Nations Office for Outer Space Affairs (UNOOSA), there were 4,857 satellites orbiting the planet as at April of 2018 and according to the Union of Concerned Scientists, only about 1,980 of these satellites are active.

Satellite technology is playing and will continue to play an active role in the smart city concept around the world, providing several application opportunities. For example, satellite application data can be used to monitor and assist in urban designs/planning and development, as well as monitoring and providing directions for autonomous vehicles. Presently, satellite communication technology is assisting with telecommunication applications such as internet broadband connectivity, GPS application, etc., through wireless communication networks in smart cities around the world. With the growing demand for effective and innovative solutions in city development, space technologies such as satellite applications will be a key enabler in providing these solutions.

The term “satellites” is derived from the word “*satelles*” which means servant in Latin. This term entered into scientific use in the 16th century, when Galileo established that the Earth rotates around the sun, while the moon rotates around the Earth acting like a satellite roving around it. It was not until the 1940’s the young science fiction author,

Arthur C. Clarke was credited for conceiving the application of communication satellites based on an article written by him, and published in *Wireless World* magazine in 1945 specifically describing a worldwide communication satellite network.

4.1 Space Mission Segment

Before we go into different types of satellites and their applications, we need to discuss how these satellites get to outer space and how they communicate and send their signals from outer space down to Earth and vice-versa. The operational concept of a space mission mostly depends on the mission types and may vary for different missions. These missions are usually divided in three segments which are: Ground segment, Space segment and User segment.

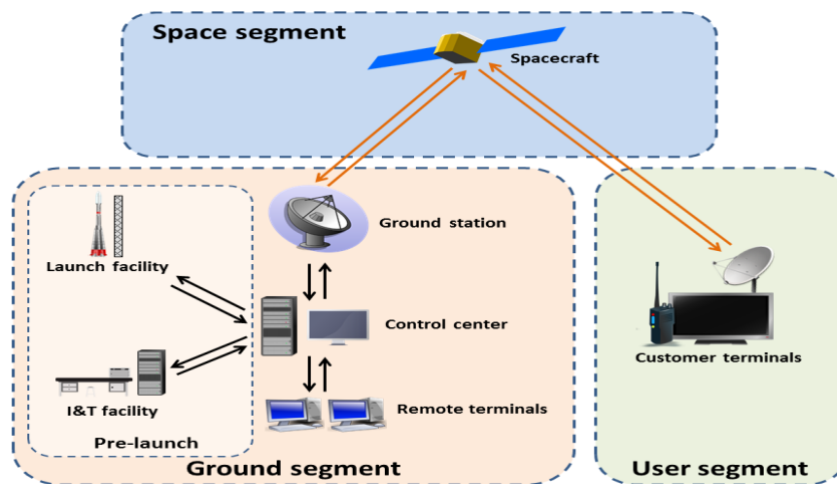


Fig 4.1 Space mission segments⁴⁰.

Ground segment: The ground segment of a space mission contains all the ground-based elements needed by operators and support personnel to manage a spacecraft. The ground segment enables the processing and distribution of satellite data to all involve parties. All ground stations have similar primary elements which are, ground stations, mission control centres, ground network, remote terminals, spacecraft integration and test, launching facilities, etc. The architecture of all ground stations is basically the same, and consists of elements such as:

Antenna systems: These antennas are used to track and receive data from the satellite.

RF equipment: The radio frequency equipment interacts directly with the antenna systems. The RF equipment receives down-link frequency carrier from the antenna

⁴⁰ En.wikipedia.org. (n.d.). Ground segment. [online] Available at: https://en.wikipedia.org/wiki/Ground_segment#/media/File:Ground_segment.png [Accessed 6 Nov. 2018].

through a receiver and then sends a modulated up-link frequency carrier from the TT&C equipment back to the antenna by means of a transmitter.

Mission data recovery equipment: This stores and processed data before sending same data to the end user.

TT&C equipment: The Telemetry, Track and Command equipment is used to receive, track, command, monitor and send telemetry data from and to the satellites in orbit.

Data-user interface: This interface connects the mission data recovery equipment with data users.

Mission control centre: These centres are where all the ground station elements and the interconnection between them is being managed.

Launch vehicles: All satellites get to outer space via launch vehicles. All launch vehicles are usually made up of rockets which propels a satellite payload from the Earth's surface through into outer space. Different types of rockets are used to launch a payload to space, example of such rockets is the intercontinental ballistic missiles (ICBM), which is the most common used rocket till date, sounding rockets, etc. These rockets are usually expendable, which means they are used one time and then destroyed during the re-entry phase after launching into outer space. However, in recent times companies such as SpaceX have developed reusable launch vehicles (Falcon 9) which will reduce the cost of space mission when it goes mainstream.

Launching facilities: A launching facility is one of the most important elements in the ground segment and consists of a launch vehicle integration area, launch pad, fuelling system, range safety, etc. There are different launch sites around the world but the most commonly used ones are, Guiana Space Centre, Kourou, French Guiana., Cape Canaveral Air Force Station, Florida, Mojave Air and Space Port, Vandenberg in California United States., Baikonur Cosmodrome, Kazakhstan, Russia, Satish Dhawan Space Centre, India. Broglio Space Centre (San Marco), Malindi, Kenya., and Centre interarmées d'essais d'engins spéciaux (CIEES), Hammaguir, Algeria.

Space segment: The space segment has to do with the satellite launched into outer space and its features. Such as satellite bus, payload, orbital position, satellite up-link and down-link, etc. The characteristics of these features depend on the type of satellite being launched into space. For example, a communication satellite usually has transponders, sensors, solar panels, control antenna, navigation payload, reaction control, thermal control, propulsion system, etc. Communication satellites are usually found in the Geostationary orbits (GEO) as well as the middle Earth orbit (MEO) and typically use a down and up link frequency within the C band and the K_u band range.

User segment: The user segment consists of antennas, receivers and processors that provide useful data for processing and distribution to the end user.

4.2 Communication satellites

Communication satellites are the most launched satellites in orbits today, providing internet connectivity, television broadcasting, telecommunication, etc. The development of communication satellite application technology has played a huge role in revolutionizing the transfer of information and means of communication globally, enabling long-distance communications in areas that couldn't be reached before and have difficulties getting communication links due to poor infrastructure and other factors. Remote areas that were unreachable before can now have banking services, distance education and telemedicine delivered to them via these enabling space technology.

The world's first communication satellite capable of sending and relaying signals to several places on Earth was a giant balloon-like satellite called Echo 1. This satellite was built and launched by the United States of America through the National Aeronautics and Space Administration (NASA) in August 12, 1960 in Cape Canaveral. The Echo 1 satellite, formerly named Echo 1A, was located at 1,609 km above the Earth's surface and acted as a passive reflector of up-link signals sent from a ground station on Earth. Echo 1 was made up of a 31,416 square-foot sheet of Mylar plastic balloon that was covered with 1.8 kg of reflective aluminium coating, it also contained inflating chemicals and two radio tracking beacons that were powered by five storage batteries and 70 solar cells. The balloon used for this satellite weighed about 59.8 kg. The first coast-to-coast call using satellite technology was made by Echo 1 from one researcher to another as test as well as the first image transmitted via a satellite. The Echo 1 burned up during re-entry in May 24th, 1968.



Fig 4.2. Echo 1 communication satellite⁴¹.

Communication satellites can be categorized in three segments as discussed earlier, which are:

Ground segment of a communication satellite: The ground segment of all communication satellites consists of the Earth surface area-based terminals that uses the communications capabilities of the space segments. These terminals are divided into, fixed terminal, transportable terminals and mobile terminals. Fixed terminals as the name implies are ground stations that are usually fixed in a permanent position while accessing the communication satellites in space. Examples of such fixed terminals are small terminals mounted on buildings and are used for broadcasting satellite signals. Transportable terminals are ground stations than can be moved from one place to another but once on location, it remain fixed during transmission with the satellites. Examples of such terminals are satellite news gathering trucks that are movable and fixed while communicating with the satellite for broadcasting. The mobile terminals, as the name implies, are ground stations that are movable even during transmission with the satellites. Example of such terminals are mobile phones, submarine systems, etc.

⁴¹ Space.com. (2010). 1st Communication Satellite: A Giant Space Balloon 50 Years Ago. [online] Available at: <https://www.space.com/8973-1st-communication-satellite-giant-space-balloon-50-years.html> [Accessed 27 Dec. 2018].

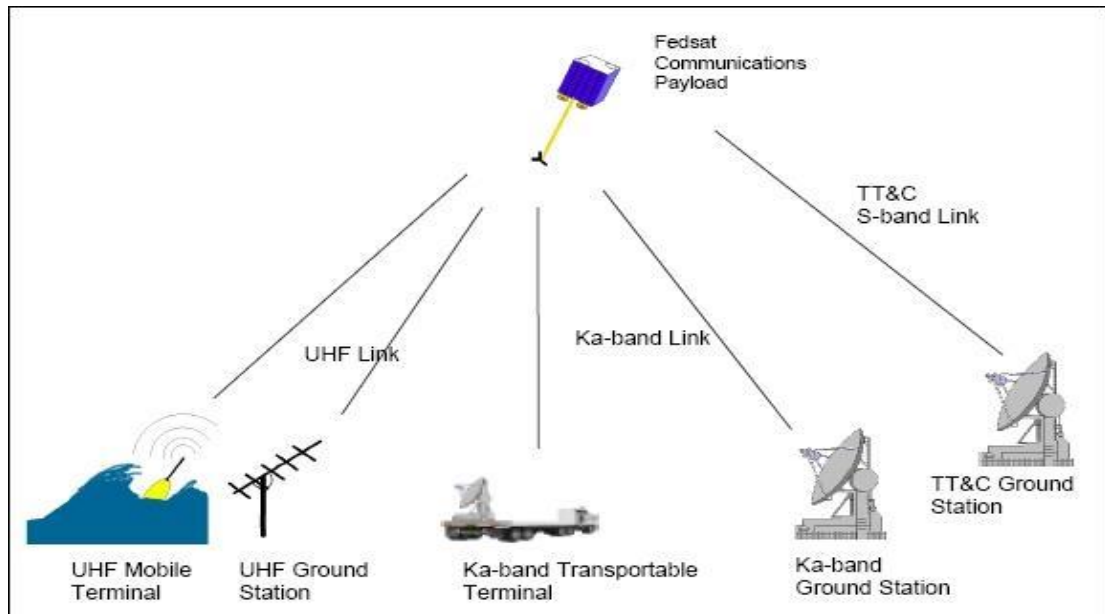


Fig 4.3. Depiction and workings of ground station terminals of a communication satellite (FedSat)⁴².

Space segment of a communication satellite: The space segment of a communication satellite has to do with its space bus, orbital position and frequency allocation, altitude control, thermal control, ground station, etc. Most communication satellites have a space bus that contains location for payloads and provides power, propulsion and other sub-systems needed for the operation of a communication satellites. Payloads in most communication satellites consist of transponders, antenna and switching systems. Transponders are devices that receives and transmit radio signals at a prescribed or designated frequency range. They are basically two types of transponders which are, the bent pipe transponders and the regenerative transponders.

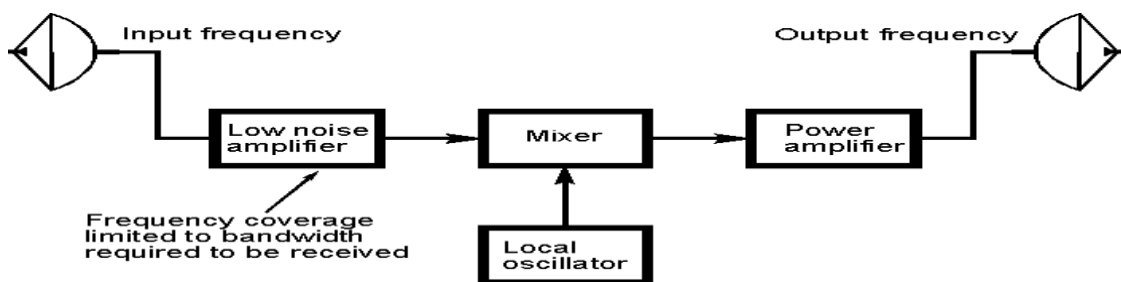


Fig. 4.4 Block diagram of a satellite transponder⁴³.

⁴² J. Kramer, H. (2019). FedSat - eoPortal Directory - Satellite Missions. [online] Directory.eoportal.org. Available at: <https://directory.eoportal.org/web/eoportal/satellite-missions/f/fedsat> [Accessed 1 Sep. 2018].

⁴³ Poole, I. (n.d.). Communications Satellites Technology: Radio-Electronics.Com. [online] Radio-electronics.com. Available at: https://www.radio-electronics.com/info/satellite/communications_satellite/communications-satellite-technology.php [Accessed 5 Oct. 2018].

Power provision in a communication satellite system depends on the payload functions and requirements but do have similarities with other satellite system. It usually consists of solar panels that uses solar cells to generate power from the sun at the right angle. Other sources of power are onboard batteries such as Lithium batteries, Nickel-cadmium batteries, etc. This supports power provision when the solar panels on the space bus or payload is out of range from the sun. All satellites system needs some means of movement or propagation while in outer space. After a satellite has been launched to orbit, one needs to be able to control and navigate same satellite to its nominal orbital position, hence a designated propulsion system is paramount. There are basically two types of propulsion systems which are, chemical propulsion and electrical propulsion systems. Chemical propulsion systems use chemical rockets and propellant to navigate a spacecraft, why electrical propulsion systems use electrical energy to change the velocity of a spacecraft in orbit.

Communication satellites are usually located in the geostationary (GEO) orbit which is a circular orbit located at above 34,000km above the Earth's equator and rotates synchronously with the Earth's rotation. The satellite at this position appears to be in a fixed position in the sky when observed from the Earth surface. The geostationary location has an orbital period equivalent to that of Earth which is one sidereal day, i.e. 23 hours, 56 minutes, 4 seconds. This means all satellites in the GEO orbit have a larger coverage area when compared to other orbital locations Its almost a fourth of the Earth's surface. Communication satellites in GEO encounter issues such as latency problems and since they are usually cantered above the equator, broadcasting signals to near polar regions are difficult. Other orbits such as the Lower Earth Orbit (LEO) which is about 500 to 1600 km above the Earth surface and the Medium Earth Orbit (MEO) which is about 8500 km to 18,000 km above the earth surface do accommodate communication satellite but not as much as the geostationary orbit. Lastly, the High Earth Orbit (HEO), is a non-circular orbit that operates within the elliptical orbit. HEO has a maximum altitude similar to those of the GEO and a minimum altitude similar to LEO. Most High Earth Orbit (HEO) are used for coverage in high latitude locations.

Frequency allocation is carried out by the International Telecommunication Union (ITU) and most, if not all communication satellites are allocated frequencies based on satellite communication market. These markets are divided into Fixed Satellite Services (FSS), Mobile Satellite Services (MSS) and Broadcast Satellite Services (BSS). Fixed satellite services (FSS) provide services such as telephone calls, television signals, etc. Commercial Fixed Satellite Services (FSS) are allocated frequencies in the C band (6/4 GHz), Ku band (14/12 GHz) and sometimes Ka band (30/20 GHz), why the military or defence Fixed Satellite Services (FSS) uses UHF band (320MHz / 240MHz) X band (8/7 GHz) and Ka band (30/20 GHz). These frequencies are used to provide services for satellites with a clear line of sight to the receiving antenna and a 3-6 dB of link margin. Mobile Satellite Services (MSS) are allocated a frequency within the lower VHF, UHF bands which are, (137MHz, 400/432 MHz, 1.6/1.5 GHz, 2.0 GHz, 2.5/2.6 GHz) bands. These frequencies are used to render services for mobile terminals that are mostly in motion and needs to have frequencies that are more tolerant when being used since they are usually out of sight to the satellite and 10-22 dB link margin. Broadcasting Satellite Services (BSS) are allocated frequencies in the 18/12 GHz bands by the International Telecommunication Union (ITU) and are used to provide Direct Broadcast Satellite (DBS) services around the world. Broadcasting Satellite Services (BSS) are received by user terminals with sizes ranging from 0.8 meter to 0.33 meter.

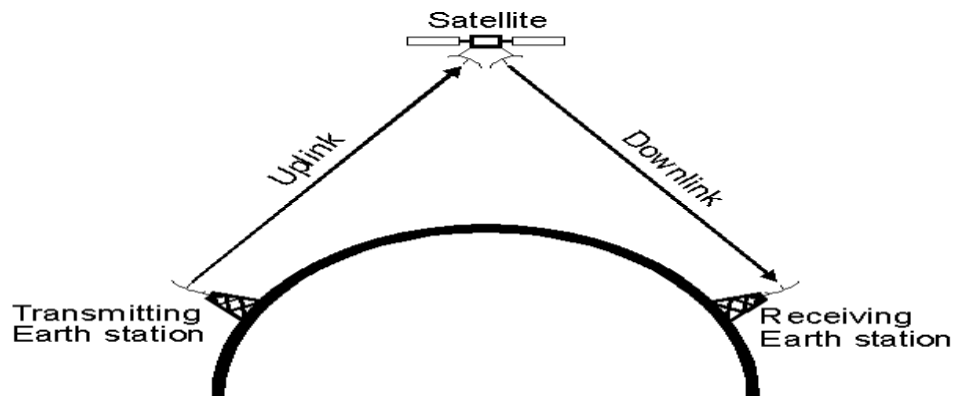


Fig. 4.5. A depiction of satellite communication system⁴⁴.

User segment of a communication satellite: The user segment in a communication satellite system, consist of the end user and costumers of the product generated by a communication satellite. For example, user segment can be telecommunication operators, internet service providers, direct-to-home satellite television, radio broadcasting, military services, and civic society, etc.

There are about 792 communication satellites in space presently and Table 4.1 shows some of these communication satellites and their respective characteristics.

⁴⁴ Poole, I. (n.d.). Communications Satellites Technology: Radio-Electronics.Com. [online] Radio-electronics.com. Available at: https://www.radio-electronics.com/info/satellite/communications_satellite/communications-satellite-technology.php [Accessed 5 Oct. 2018].

Satellite Name	Orbit	Operator	Frequency band	Status	Uses	Power	Launch mass/Kg
ARSAT-1	GEO/7 2° West	AR-SAT	24 IEEE K _u Band (with capacity up to 1152 MHz)	Active	Television services, telecommunication, data transmission, etc.	3.5kW	2,985 kg
Bangabandhu-1	GEO/1 19.09° East	BCSCL	40 K _U -band & C-band (with capacity up to 1600MHz)	Active	Television services, telecommunication, data transmission, etc.	6kW	3,309 kg
ATS-6	GSO	NASA	C, S, L, UHF and VHF bands	Inactive	Education, Direct broadcasting, etc.	645W	930kg
Badr-1	LEO	SUPARCO	435 MHz/145MHz	Inactive	Education, military, science & technology, etc.	12.5W	52 kg

Table 4.1. Examples of communication satellite.

Communication satellites as discussed earlier play a huge role in the smart city concept around the world. For example, satellite communication applications provide telecommunication capabilities, internet broadband connectivity and direct television broadcasting which can be integrated into a smart city to support all communication networks (Local and wide wireless networks) imbedded in its infrastructure.



Fig 4.6 The ARSAT-2 communication satellite⁴⁵.

4.3 Satellite aided Position, Navigation and Timing systems (PNT)

Positioning Navigation and Timing (PNT) satellite systems, is a combination of the implied names (PNT) distinct capabilities. Currently, there are 121 Positioning, Navigation and Timing (PNT) satellites in Earth orbit.

Positioning: This is defined as the ability to accurately determine the location of an entity in two or three dimensions when required.

Navigation: This is defined as the ability to determine current and intended position anywhere in the world from sub-surface to surface and then to space, through the application of speed, orientation and correction to course.

Timing: This is defined as the ability to acquire and maintain a precise and accurate time around the world from a standard universal time system.

When the constituent capabilities of these three entities (PNT) are combined globally with map, weather, and traffic data, etc., the product is what is known as Global Navigation Satellite System (GNSS). An example of the GNSS is the Global Positioning

⁴⁵ Spaceflight101.com. (Undated). ARSAT-2 – Ariane 5 VA226 – Spaceflight101. [online] Available at: <http://spaceflight101.com/ariane-5-va226/arsat-2/> [Accessed 4 Oct. 2018].

System (GPS) manufactured by the United States, the GLobalnaya NAVigatsionnaya Sputnikovaya Sistema (GLONASS) manufactured by the Russian federation and the BeiDou Navigation Satellite System (BDS) manufactured by the People's Republic of China and the Galileo System manufactured by Europe.

Ground segment of PNT aided satellites: The ground station of a Global Navigation Satellite System (GNSS) is quite common with other spacecraft mission systems. It comprises of a master control station, a backup master control station, networks of four ground antennas and a globally distributed monitor station. The master control center (MCS) is responsible for monitoring the satellite bus and payload status, satellite maintenance and anomaly resolution, detecting and responding to failures, etc. The master control centre operates 24hrs a day, every day of the year.

Fig 4.7 is a diagram representing an overview of a typical GNSS operational control system and its functions.

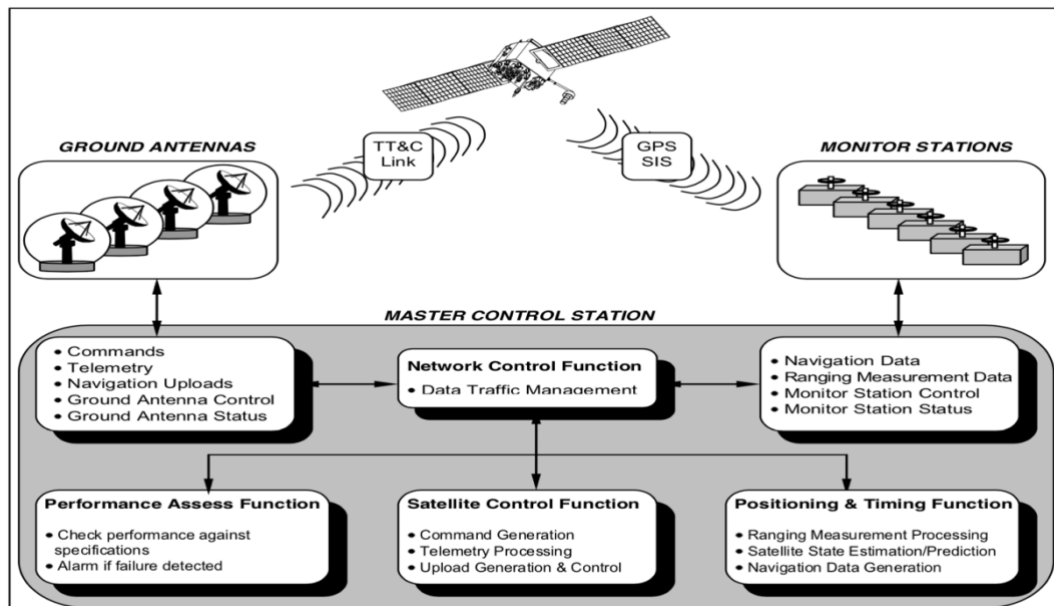


Fig. 4.7. Global positioning system (GPS) operational control system⁴⁶. (SIS = signal-in-space)

Space segment of PNT satellites: In discussing the space segment of a Global Navigation Satellite Systems (GNSS), we will focus on the Global Positioning System (GPS) manufactured and launched by the United States of America since 1973. The GPS was initially developed for military service but was commercialized in the 1980s by president Ronald Reagan. The global positioning system (GPS) is a network of 31 satellites orbiting the Earth at an altitude of 20,000km and orbital radius of about 26,600km as of February 2016. This constellation uses 24 active satellites with four satellites each in six

⁴⁶ Gps.gov. (2008). [online] Available at: <https://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf> [Accessed 2 Dec. 2018].

different orbital planes to locate or navigate for precise locations, while the remaining act as supporting satellites in case of emergencies.

The GPS uses the trilateration process in finding and locating precise points. Trilateration is the process of determining the relative or absolute location of a point with measurement such as distance and time, using geometry. For example, four or more satellites in the GPS constellation are always within line of sight from any location on Earth; this provides data which is used by the GPS satellites to calculate and determine pinpoint positions using the trilateration process. The payloads in the GPS satellites have a helix array antenna and transmit signals on the L-band subsystem which modulates around L1 (1575.42 MHz) and L2 (1227.6 MHz), between the satellites and the ground station. The GPS constellation is a combination of both old and new satellites, this includes the Block IIA (2nd generation, "Advanced"), Block IIR ("Replenishment"), Block IIR-M ("Modernized"), Block IIF ("Follow-on"), GPS III, and GPS III F ("Follow-on"). Fig 4.8 depicts the GPS transmission process in the space segment.

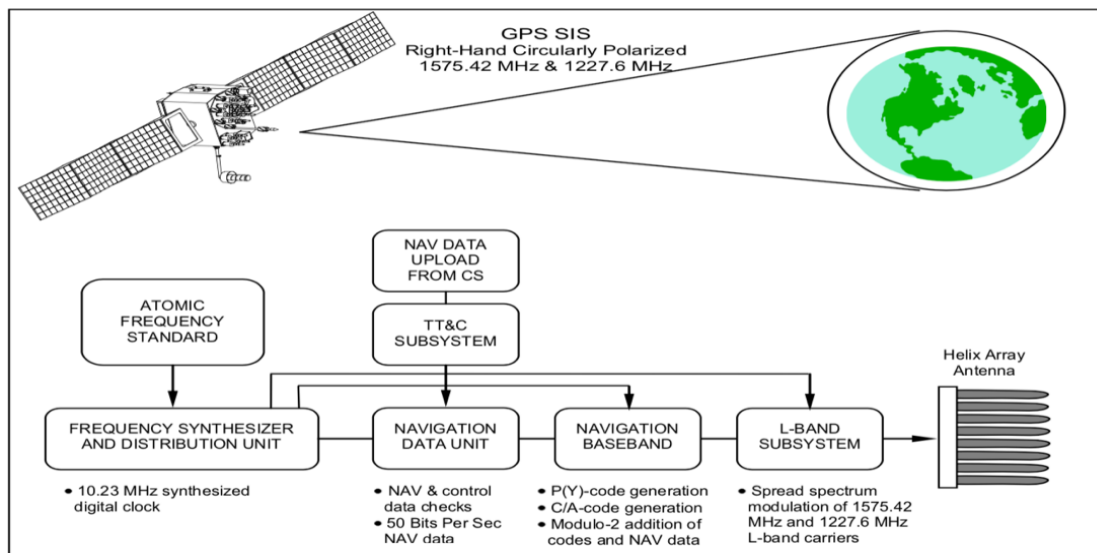


Fig. 4.8 Global Positioning system (GPS) space segment transmissions⁴⁷.

User segment of PNT aided satellites: The user segment of a Global Navigation Satellite System (GNSS) such as the Global Positioning System (GPS), consists of numerous applications. For example, like the internet, GPS application has become part of our everyday lives and an essential tool of the global information infrastructure. GPS technology application has increased productivity in a wide range of industries around the world such as farming, banking systems, communication networks, mining, construction, military, power grids, urban planning, surveying, etc. GPS technology applications are also found in autonomous vehicles, medical facilities, weather forecasting, as well as in package deliveries and emergency response.

⁴⁷ Gps.gov. (2008). GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE PERFORMANCE STANDARD. [online] Available at: <https://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf> [Accessed 2 Oct. 2018].



Fig 4.9. Global Positioning System (GPS) constellation⁴⁸.

Examples of some Global Navigation Satellite System (GNSS) and some of their characteristics are given in the table below.

Name of Satellites	Orbit/Height	Operator	Frequency band	Status	Launch mass/Kg	Uses	Number of Satellites
GLONASS-K	3xMEO/ 19,130km	Roscosmos	L-band/ (L1OF/L2OF) (1602.0 MHz/ 1246 MHz)	Active	750 kg	Military, Navigation, Farming, etc.	26
Galileo	3xMEO/ 23,222km	GSA, ESA	L-band/ E1(1575.42 MHz), (E5 (1191.795 MHz), E5a (1176.45 MHz), E5b (1207.14 MHz)) & E6 (1278.75 MHz)	Active	675kg	Navigation, Search and Rescue, Military, etc.	30
BeiDou Navigation Satellite System (BDS)		GEO, IGSO, MEO	L-band/ 2491.75 MHz	Active	1,000 kg	Disaster monitoring, short message services, navigation, military, etc.	4

Table 4.2. Examples of GNSS satellites.

All smart cities need the application of Global Navigation Satellite Systems (GNSS). In smart cities around the world, the GPS application for example provides ease at which people navigate on their day to day movement, and has provided opportunities for businesses around mobile applications such as Uber, Taxify, etc. The idea of autonomous vehicles is mainly based on Position Navigation and Timing (PNT)

⁴⁸ Vectors. (Undated). Diagram of global positioning system vector image on VectorStock. [online] VectorStock. Available at: <https://www.vectorstock.com/royalty-free-vector/diagram-of-global-positioning-system-vector-7682707> [Accessed 16 Sep. 2018].

applications. The extent at which the PNT satellites can support a smart city entirely depends on one's imagination.

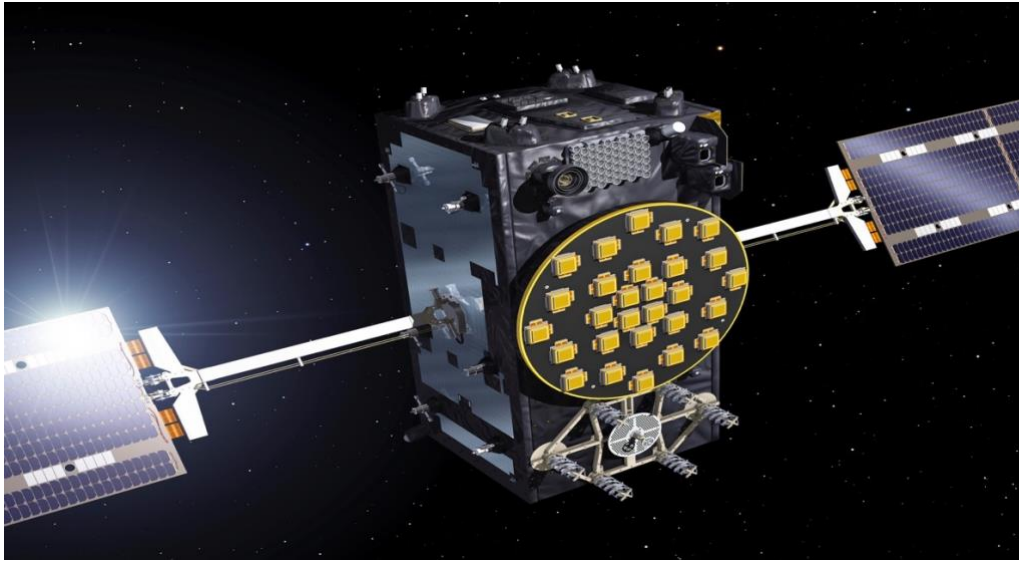


Fig 4.10. Galileo Satellite⁴⁹.

4.4 Earth observation satellites

Earth observation satellites are satellites with remote sensing technology. Remote sensing is the science of capturing or obtaining information without physical presence by method of satellites, airplanes, drones or balloons. There are 661 Earth observation satellites currently in space. Earth observation satellites differ other satellites based on factors such as, mission types, orbit types, payload types, spectral characteristics. etc. Earth observation satellites are equipped with different and several kinds of sensors that varies from optical sensors, active sensors to passive sensors. Sensors also provide valuable data. For example, the first artificial satellite Sputnik 1 which was manufactured and launched by the Soviet Union in 1957, sent back radio signals that was used by scientists to study the ionosphere. The United states sent their own remote sensing satellite the following year called the Explorer 1 in 1958, which helped with the discovery of the *Van Allen* radiation belts. The United States also manufactured and launched the first earth observation satellite (Television and Infrared Observation Satellite (TIROS 1)) capable of capturing images in 1960.

Ground segment of Earth observation satellites: The ground station of an Earth observation satellites consists of control, tracking and managing stations where data from the satellites are being received, on-board components such as the sensors are being monitored, orbit and altitude can be controlled, etc. Data received from on-board components of an Earth observation satellite are stored either on the on-board memory bank or transmitted through a receiving antenna to the ground station where it is archived

⁴⁹ Graham, C. (2018). What is Galileo and why is Britain set to build a rival satellite system? [online] The Telegraph. Available at: <https://www.telegraph.co.uk/news/2018/12/01/galileo-britain-set-build-rival-satellite-system/> [Accessed 9 Oct. 2018].

in the cloud, hard disk or magnetic tapes. These data received are then processed by correcting distortions which ranges from geometric, radiometric to Doppler frequency shift and after which same data are distributed to their designated end users. The launching section for an earth observation satellite is similar to every other satellite mission.

Space segment of Earth observation satellite: The space segment of an Earth observation satellite consists of its remote sensing capabilities and on-board devices. This includes optical, passive, and active sensors. The portion of the Earth's surface seen by a sensor on-board an Earth observation satellite is known as *swath*. All these sensors can be used to observe water distribution, ground surface temperature, sea surface temperature, cloud conditions, etc.

Optical sensors: These sensors use the reflection of sunlight, Earth's radiation, near, medium and thermal infrared rays to observe and operate in an Earth observation satellite. Optical remote sensing systems are categorized into but not limited to four types based on their spectral bands which are, Panchromatic, Hyperspectral, Multispectral, and Super-spectral imaging system.

Passive microwave sensor: These sensors use reflections of microwaves from an object to observe and operate in an earth observation satellite. An example of a passive microwave sensor is the microwave radiometer that records and receive natural microwave emission from the Earth.

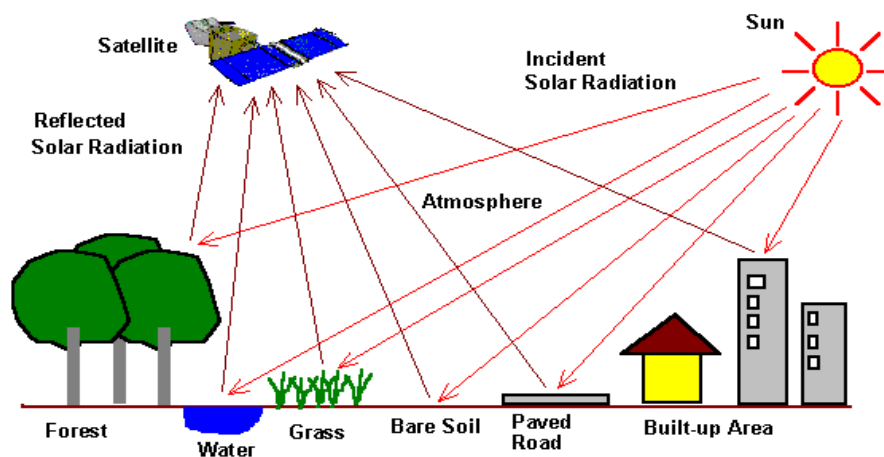


Fig 4.11. Wave propagation of an optical sensors in an Earth observation satellite⁵⁰.

Active microwave sensors: These sensors generate and transmit their own microwave signals to a target and then receive and use the reflected microwave signals to observe and operate in an Earth observation satellite. An example of an active microwave sensor is the radar altimeter that sends out microwave signals in form of pulses and receive and

⁵⁰ Liew, D. (2001). Principles of Remote Sensing - Centre for Remote Imaging, Sensing and Processing, CRISP. [online] Crisp.nus.edu.sg. Available at: <https://crisp.nus.edu.sg/~research/tutorial/optical.htm> [Accessed 27 Oct. 2018].

record the scattered reflected micro wave signals onboard or on the ground station. The Synthetic Aperture Radar (SAR) imaging also applies the radar principle to form an image by transmitting a pulse signal from the antenna onboard the Earth observation satellite and then using the time delay of the reflected signals from the Earth surface in measuring the microwave energy.

Earth observation satellites use microwave bands ranging from K_a , K_u , X, C, S, L, P and a frequency range of 26.5-40 GHz, 12-8 GHz, 8-12.5 GHz, 4-8 GHz, 2-4 GHz, 1-2 GHz, 0.3-1GHz, respectively. The orbital location of earth observation satellite depends entirely on the satellite purpose and mission. The orbit location can be either LEO, MEO, GEO or HEO.

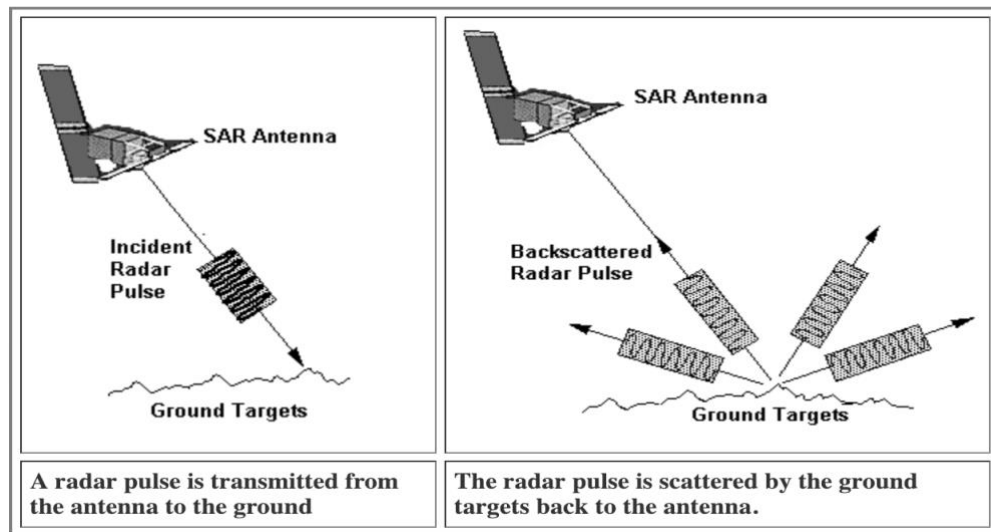


Fig. 4.12. The active process of Synthetic Aperture Radar (SAR)⁵¹.

User segment of Earth observation satellites: the user segment of an Earth observation satellites are as numerous as other satellite applications. Earth observation satellites are used for disaster monitoring, land management, mapping, maritime services, agricultural services, etc. Data generated from remote sensing satellite can be used for global warming warnings, images for simulations and educational purposes, etc.

Some examples of Earth observation satellites and their characteristics are listed in Table 4.3 below.

⁵¹ Liew, D. (2001). Principles of Remote Sensing - Centre for Remote Imaging, Sensing and Processing, CRISP. [online] Crisp.nus.edu.sg. Available at: <https://crisp.nus.edu.sg/~research/tutorial/mw.htm> [Accessed 22 Oct. 2018].

Name of Satellites	Orbit	Operator	Spectral band	Status	Launch mass/Kg	Uses	Power	Sensors
Landsat 7	Sun-synchronous	USGS / NASA	15m panchromatic band (8 band)	Active	2,200kg	Earth imaging	1,550 W	Enhanced Thematic Mapper Plus (ETM+)
Sentinel-2	Sun-synchronous	ESA	Multi-spectral (13 band)	Active	1,140 kg	Land and sea monitoring, sea ice observation, ships detection, etc.	1,700 W	multi-spectral instrument, VNIR
BILSAT-1	Sun-synchronous	TÜBİTAK UZAY	Multi-spectral (4 band), S-band, UHF/VHF	Inactive	130 kg	Disaster monitoring, Urban development, Agriculture, Hydrology, etc.	Solar cells batteries (6W, 50W, 12W)	VNIR, high-resolution panchromatic sensor
ADEOS I	Sun-synchronous	NASDA	26 GHz Ka band, 2 GHz S band.	Inactive	3,500kg	Global warming, Depletion of the ozone layer, deforestation	5,000 W	AVNIR, optoelectronic radiometer

Table. 4.3 Examples of Earth observation satellite.

Earth observation satellite in the smart city concept are as important as every other type of satellite application system. Remote sensing capabilities of an Earth observation satellite can be used for weather monitoring, urban planning and mapping, smart farming, smart security, energy monitoring. Data generated from remote sensing satellites can be used to monitor animal and human migration, maritime services, etc. The application possibilities of an Earth observation satellite in the smart city concept are endless.

Data from Earth observation satellites are used on GPS applications around the globe. Interestingly Earth observation satellite data are available through government agencies such as, NASA, SANSa, ESA, etc. for education, business and public services.



Fig 4.13. Landsat 7 Earth Observation Satellite⁵².

4.5. Small satellites

Small satellites or SmallSats are satellites with low size and mass under 500kg. Though, all satellites with mass under 500kg can be classified as small satellites, they can be differentiated based on their unique size and mass. The number of small satellites in space as of 2015 was between 163-212, and was predicted to exceed more than 500 satellites by 2019. Examples of such satellites are: Minisatellites (100-180kg), Microsatellites (10-100kg), Nanosatellites (1-10kg), Picosatellites (0.01-1kg), Femtosatellites (0.001-0.01kg). The first satellite (Sputnik 1) launched to space can be regarded as a small satellite as it weighed about 83kg, which was followed by the Explorer 1 that weighed about 14kg.

Most small satellites are built based on the CubeSat standard developed in 1999 by Prof. Jordi Puig-Suari and Prof. Bob Twiggs from California Polytechnic State University and Stanford University respectively⁵³. The initial motivation to building a CubeSat was to provide affordable access to space for academic institutions such as universities, high schools, middle schools, etc. CubeSats are satellites designed based on some certain criteria that control factors such as, size, weight and shape. The standard requirement

⁵² Landsat.usgs.gov. (n.d.). Landsat 7 | Landsat Missions. [online] Available at: <https://landsat.usgs.gov/landsat-7> [Accessed 28 Oct. 2018].

⁵³Nasa.gov. (2017). [online] Available at: https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf [Accessed 10 Sep. 2018].

to build a CubeSat helps reduce both cost of production and launching for interested companies and organizations. CubeSats come in various sizes and shapes that are based on the standard CubeSat units represented by 1U and usually comes in a 10 x 10 x 10 cm cubic units. In recent years and the advancement in small satellite technology, units with bigger sizes ranging from 1.5U, 2U, 3U, to 6U have become popular. A CubeSat application varies and depends on the intended satellite mission which ranges from Earth observation and remote sensing to communication satellite applications. Due to their diverse applications, CubeSats can be launched to several orbital locations.

Fig .4.14 shows an example of the 1Unit, 2Unit and 3Unit types of CubeSats.

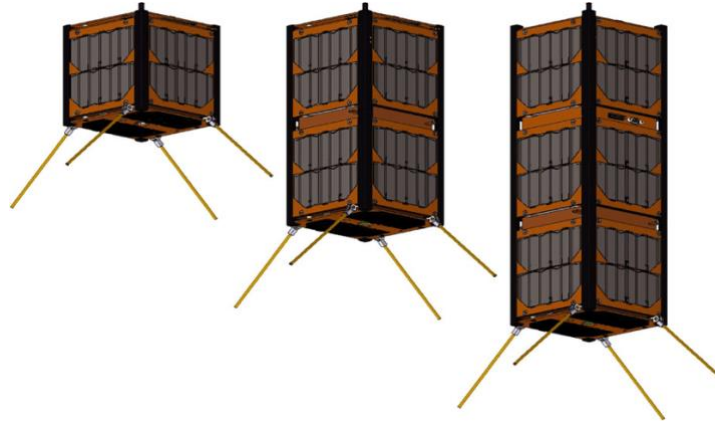


Fig. 4.14. Standard 1 U ,2U & 3U CubeSats⁵⁴.

Ground segments of Small Satellites: The ground segments of small satellites are similar to those of other satellite application systems, which consists of control centres with antennas, open source software packages, altitude control mechanisms, etc. Though small satellite launching capabilities are similar to other satellite application launching systems, they usually piggyback on larger spacecraft mission due to their small sizes, which in turn reduces the cost of launching. However, small launching vehicles, large CubeSats deployers and orbital manoeuvring systems can also be found on in most ground stations.

Space segments of small satellites: The space segments of small satellites consist of different kinds of payloads depending on the satellite mission. These payloads carry devices such as multi band sensors, Commercial off-the-shelf (COTS) based sensors, High Definition (HD) capabilities, etc., high-gain antennas, laser communicators. Small satellites such as CubeSats uses frequency bands within the VHF, UHF, X-band, IR/visible frequencies, etc., and have data rates in range of 10Mbps in S band, 500Mbps in X band and 1-2 Gbps in K/K_u/K_a band. The power subsystems of small satellites carry power packs such as thin packs of lithium ion batteries, solar panels and solar cells. While the propulsion systems are made up of gas thrusters, pulsed plasma thrusters, solid rocket motors, etc. Some of these propulsion systems are still in the testing phase and new developing approach like chemical and electrical propulsion systems are being

⁵⁴ KL Oi, D., Ling, A., Bedington, R., Bai, X., Truong-Cao, E., Chuan Tan, Y., Durak, K., Zafra, A. and Grieve, J. (2016). Nanosatellite experiments to enable future space-based QKD missions. [online] researchgate.com. Available at: https://www.researchgate.net/figure/U-2U-and-1U-CubeSats-Isometric-CAD-drawings-of-3U-2U-and-1U-CubeSats-respectively_fig2_310823793 [Accessed 2 Aug. 2018].

proposed. In terms of structure and materials used in building a small satellite, CubeSats have a defined modular standard as discussed earlier. But other small satellites such as microSats and miniSats still uses customized building standards. With the development of disruptive technology such 3-D printing, a more sustainable and reliable small satellites designs can be achieved.

Fig 4.15 shows the inner workings and content of a small satellite known as ArduSat, which is a 1U Nanosatellite based on the CubeSat standards.

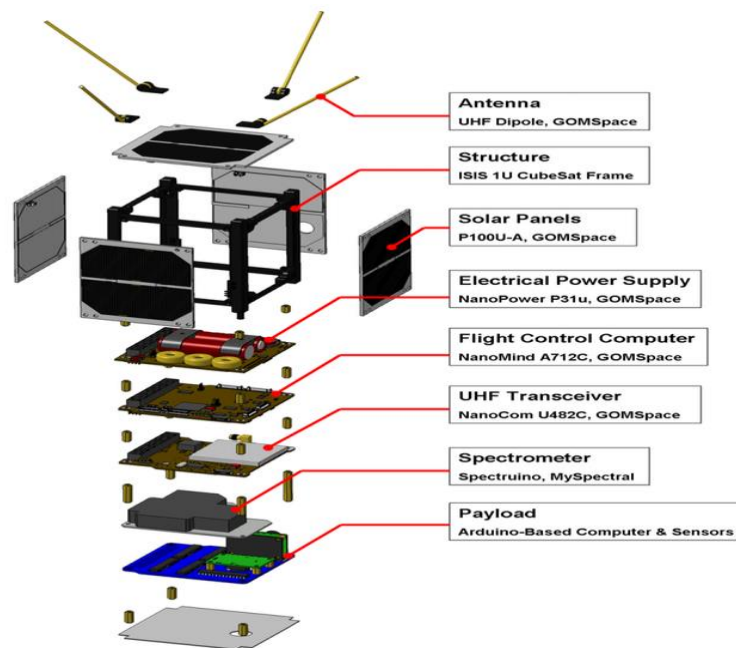


Fig. 4.15. The ArduSat (1U configuration)⁵⁵.

User Segments of Small Satellites: The user segment of small satellites is very broad and this is because small satellites can be applied to most if not all satellite application missions. Some of the small satellite applications found in the user segments are weather monitoring, internet broadband connectivity, disaster management, urban development, agriculture, education, etc.

Small satellite constellations are another trending development in satellite applications in recent times. A satellite constellation is the combination of two or more satellites working in concert. There are several satellite constellations in existence today and most of them are found on the medium and lower Earth orbit. The GPS constellation system is an example of one of the existing constellations out there. An example of a small satellite constellation is the OneWeb constellation. The company founded by Greg Wyler is proposing to have a constellation of about 882 satellites that will provide cheap and accessible global internet broadband connectivity. These satellites will be placed in the Lower Earth Orbit (LEO) and the Medium Earth Orbit (MEO), with an altitude up

⁵⁵ Kickstarter. (2012). ArduSat - Your Arduino Experiment in Space. [online] Available at: <https://www.kickstarter.com/projects/575960623/ardusat-your-arduino-experiment-in-space> [Accessed 30 Oct. 2018].

to 1,200km and have a satellite internet broadcasting capacity of up to 7.5 Gbps. Frequency distribution from the satellite will be the Ku band in Fixed Satellite Services (FSS) with down and up link frequencies between 10.7-12.75GHz/14.0-14.5GHz. The satellites will be launched on the Soyuz launching vehicle developed by the former Soviet Union, which has a launching success rate of 98%. The Soyuz launch vehicle will be the primary deployment vehicle for the OneWeb constellation satellites, carrying 30 satellites per launch. The ground terminals consist of portable hand-held antennas that can be placed on top of cars or on the roof of a building, and includes Wi-Fi/LTE/3G/LMR.

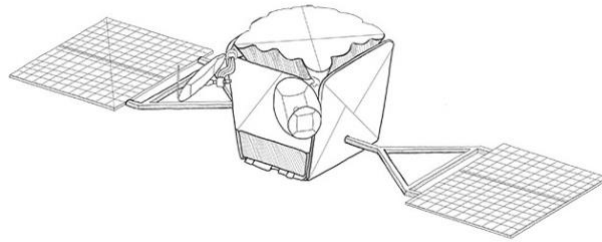


Fig. 4.16. OneWeb Small Satellite System⁵⁶.

Other small satellites and their different properties are listed in Table 4.4 below.

Name of Satellites	Orbit	Operator	Data rate	Status	Launch mass/Kg	Uses	Power	Sensors
Picard	LEO	CNES	625 kbit/s, 2.6 Gbit/day	Inactive	120kg	Solar research	185W	Sun sensors
DEMETER	LEO	CNES	X-band transmitter 16.8 Mbit/s;	Inactive	130kg	ionospheric perturbations, seismic, and volcanic activity.	70 W	Star sensors, sun sensors, magnetometer

Table 4.4. Examples of small satellite.

Small satellite technology is disrupting the space industry. The reason for this disruption is due to its modular approach to design using COTS components, which in return reduces the cost of production, operation and launching of small satellites. Small satellites can be applied to the smart city concept in all areas, ranging from telecommunication, weather monitoring to urban planning, internet broadband connectivity and education.

⁵⁶ Jacobs, D., Wyler, G., Enders, T., Finkelstein, O., Salinas, R. and Clavel, A. (2016). OneWeb. [online] Oneweb.world. Available at: <http://www.oneweb.world/> [Accessed 8 Sep. 2018].

5 TOWARDS SPACE-ENABLED SMART CITIES IN AFRICA

As briefly discussed earlier, Africa is still in the very initial stages in terms of smart city implementation. But with the rapid development of space technology, such as the OneWeb constellation project for example, and with proper negotiations through public-private partnerships, African countries can subscribe to such services and tap into the limitless resources the internet provides while developing their needed infrastructure. Space-enabled smart cities through satellite applications in Africa are already here. We use satellite applications every day to make smart choices, such as, taking an Uber cab for a late dinner as opposed to driving back late at night tired or intoxicated and also, Intelligent Transport Systems (ITS) are enabling self-driving cars, Mobility sharing, geolocation of people and vehicle, by means of satellite navigation technology applications.

5.1 Benefit of Smart cities for Africa

The smart city concept if fully implemented, will benefit every industry in the intended smart location in Africa. From education, agriculture, government, financial services, to security, urban planning and development, military services, disaster management, etc. Smart cities foster smart citizens, so as cities get smarter so do their citizens. Digital solutions as explained, have the potential to disrupt traditional urban services by creating new network nodes that encourage new investors and stakeholders. Smart initiatives such as smart metering is helping with good energy management. The Internet of Things (IoT), blockchain, etc., are giving opportunities for job creation in Africa by creating an entrepreneurial environment for her citizens. Blockchain technology implementation which is based on decentralization, transparency and anonymity, will bring accountability in industries and institutions, support digital crowdfunding and provide clean energy across Africa.

The population growth in Africa is exploding rapidly and so is urbanization. Nigeria for example has over 200 million people living in the country. If the economy of scale approach is applied properly, this population increase can be an advantage for socio-economic development when approached from an economic perspective. But this can also be a problem if the population growth and urban migration in the country is not properly managed and mitigated. With Smart city implementation, urban planning can be accurately and feasibly mapped out to suit the country's population expansion. With satellite remote sensing applications for example, feasible and sustainable housing can be developed to address urban migration. As stated by *Joan Close* the Nairobi-based United Nations (UN) director of UN-Habitat, in Quito in Ecuador on October 2016. "Africa has a huge opportunity to address the new challenges of urbanization. It's a wave

and it's a process. They should devise strategies that focus on the capacity of urbanization to generate prosperity. The big question is how to direct this process, and with which objective and vision. I urge people in African and their governments to take urbanization as an opportunity and as a tool for development"⁵⁷

African cities are well positioned to benefit from the smart city initiative based on the following reasons;

Telecommunication: Telecommunication technology growth and development within the past decades have revolutionize how we communicate. As discussed earlier in this dissertation, with advancement in the mobile telecommunication industry in Africa, most people are now connected and communication within the African context is becoming seamless. Also, banking activities are becoming easier and more accessible due to these advancements in telecommunication technology. Examples of such developments are fintech mobile applications that are developed and used in Africa, e.g. (mPesa), the mobile banking app developed in Kenya. The smart city initiative in Africa can take advantage of the digital data already being gathered and foot print within the telecommunication space by applying such data for the advancement of smart city applications.

Young population: Africa has the youngest population in the World and the figure will most likely double by the year 2045, according to *African Economic Outlook* report in 2012. In Africa, 75% of the population is under the age of 25. Most of these young millennials are ICT savvy and aspire for interconnectivity, reliable and smart transportation, sustainable food and housing, etc. These young and bubbling youths are a great asset to the smart city paradigm in Africa. Being tech savvy, they probably have the skills to develop and apply applications that will promote and support the smart city initiative.

Limited legacy infrastructure: The infusion of newly developed and smart Information Communication Technology (ICT) systems in legacy infrastructures attracts huge costs. With this in mind, Africa can easily implement smart technology from the ground up without the extra costs involved to break down an old infrastructure or merge both the old and new infrastructure. Africa is still a developing continent and most infrastructure such as, telecommunication cable lines, efficient transportation, irrigation, educational and housing systems are redundant or unavailable. However, with the smart city initiative, Africa as a continent can bridge the digital divide currently affecting it.

Entrepreneurial mindset: Most African citizens which comprise more than 50% of youths between the age of 18-40 years, have an entrepreneurial spirit. The reason for this entrepreneurial mindset can be attributed to the lack of government support such as employment provisions, basic human necessities (sustainable housing, clean water, effective transportation system, etc.), and other factors. With such an entrepreneurial

⁵⁷ Kanhema, N. (2016). Urbanization is a tool for development | Africa Renewal Online. [online] Un.org. Available at: <https://www.un.org/africarenewal/magazine/april-2016/urbanization-tool-development> [Accessed 13 Dec. 2018].

mindset, if empowered and supported with the right tools and motivation, the outcome will make Africa a powerful hub for creative innovations.

The benefits of smart cities for Africa are obviously numerous and cut across all industries in retrospect. However, implementing these modalities to support development of smart cities in the African continent also comes with several challenges.

5.2 Challenges confronting the development of smart cities in Africa

There are several factors that can impair or slow the process of making Africa a smart continent and these range from, immaturity in government practices, lack of funding, technology know-how, to lack of basic infrastructures such as sustainable energy and power supply. If these issues surrounding smart city implementation in Africa are not properly and urgently dealt with, the situation across the continent is bound to get worse. The main factors affecting smart cities in Africa are:

Telecommunication Issues: With the rapid advancement in telecommunication technology around the globe, Africa as a continent still lacks in establishing a core telecommunication infrastructure, especially Internet broadband connectivity, which is a basic household commodity in developed continents such as Europe. Telecommunication infrastructure plays a key role in the communication network systems of a smart city. The communication network system in a smart city range from wireless communication networks (e.g. for the IoT) to Wired communication networks (LAN) such as fiber optic cable network, etc.

Inadequate Infrastructural Issues: Africa still faces serious infrastructural deficiencies across all industries, organizations, institutional and governmental sectors, etc. The chief executive officer of the New Partnership for Africa Development (NEPAD), Dr. Ibrahim Mayaki stated that “only 38% of the African population has access to electricity, the penetration rate for internet is less than 10%, while only a quarter of Africa’s road network is paved”⁵⁸. Smart cities are built on these basic infrastructures. For instance, car sharing in a smart city needs good and paved roads to thrive, and smart farming requires electricity to yield maximum production rates. The inability to provide adequate infrastructural needs is one of the main reasons there are drawbacks in fully implementing smart city initiatives in Africa.

Environmental Issues: The environment in Africa is deteriorating fast and this can be attributed to excessive pollution. Indoor air pollution alone affects about 90% of African population with an estimated 600,000 deaths per annum. This in return discourage urban migration in certain part of Africa, which relatively hinders the implementation of smart city initiatives in the region.

⁵⁸ Mayaki, I. (n.d.). Why infrastructure development in Africa matters | Africa Renewal Online. [online] Un.org. Available at: <https://www.un.org/africarenewal/web-features/why-infrastructure-development-africa-matters> [Accessed 2 Nov. 2018].

Citizen engagement: Smart cities cannot succeed without citizen inclusion. Having the technology is just one part of the whole concept of a smart city, the other part is getting the citizens to participate in the smart initiative being implemented or presented. Technology can offer the means for digital and creative solutions but should stay as a means to an end at the service of citizens. Africa is slow in including her citizens in smart decision making and will rather embark on a smart project based on the decisions made by government parastatals.

Rule of Law: High crime in any location on Earth will always discourage growth. Africa has one of the highest incidences of crime rates around the world, which limits the amount of foreign investment needed for economic growth. Such investment can be monetary, technological, skill and knowledge know-how, etc. One of the reasons for the low level of investment is attributed to the fact that the rule of law does not prevail in Africa and African countries are usually rated at the bottom of the scale of perceptive indicators in terms abiding to the rule of law. The smart city initiative is regarded as a form of development that will involve, public, private and foreign investors and stakeholders. With the high levels of crime rate in the African region, the smart city initiative will be handicapped or non-existent.

Skills shortages: Shortage of technical skills is another factor that is affecting the full implementation of the smart city concept in Africa. Lack of basic and adequate educational systems in most parts of the region is one of the main reasons for the shortage of skills and technical know-how. Another reason for the shortage of skills is brain drain. According to the World bank, “At the beginning of the 21st century, more than 130 million people live outside the country of their birth, and that number has been rising at about 2% a year. Cross-border migration, combined with the “brain drain” from developing to industrial countries, will be one of the major forces shaping the landscape of the 21st century. “A brain drain can hamper a developing country’s ability to harness modern agricultural and industrial technology. Some countries in Sub-Saharan Africa have lost one third of their skilled workers.⁵⁹” Technical-know how is paramount in the smart city initiative. Instruments and tools used in operating a smart and sustainable city require technical, managerial and administrative professionals and experts.

Government bureaucracy: Government regulatory and policy frameworks are an important factor that influences innovation in different industries in a given country stretching from technological, agricultural, educational to mining, security and finance. Government policies in Africa are unstable, lack focus, change regularly and the quality of regulatory frameworks is poor. This in return affects technological innovation in the shut run. With the lack of technological innovation caused by bottleneck policies in Africa, the implementation of smart initiative in the region will be hampered.

⁵⁹ Openknowledge.worldbank.org. (2000) Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/5982/WDR%201999_2000%20-%20English.pdf [Accessed 11 Nov. 2018].

Data issues: Readily available data is needed for the implementation of any smart city in the world. The emergence of big data has supported and provide means for optimization in industries and institutions around the globe. These data acquired need to be gathered, processed and distributed in a secure manner through a management control centre. Africa as a continent still lacks behind the rest of the World in data management and security. Most data from the region is either not available or non-reliable, which negatively affects the implementation of smart city initiatives.

Coordination: A smart city needs an excellent coordination to thrive. In a smart city each department ranging from the management control centre to the site operators needs to have adequate means of communication and coordination. This kind of seamless coordination is lacking in Africa and hence affects the implementation of smart cities in the region.

Funding: The smart city initiative comes with financial commitments which the African continent struggles with due to problems like mismanagement, corruption, etc. Africa struggles with a lot of issues such as hunger, poverty, health, environmental degradation, etc. and tends to prioritize these life-threatening issues over technological advancement, hence government in the region invest more into these prioritized issues. Getting funding for projects such as the smart city concept in Africa will be coming more from the private sector rather than an equal contribution from both public and private sector stakeholders. The private sector will drive smart city initiatives because they make good business sense. The role of the government is to ensure a positive climate for business.

Energy/Power Issues: Smart cities cannot exist without the presence of a power grid. Power availability and distribution in Africa is deficient with only 20% of her population having access to electricity⁶⁰. Nigeria for example has about 5,000 MW of on-grid power generating capacity to supply a population of over 200 million people. The energy and power supply conditions in Africa still cannot satisfy the majority of her population and consequently, is not creating room for the smart city initiative to thrive in the region.

Using space technology to promote and support smart cities in Africa will benefit the continent in several ways as mentioned in this chapter. With the rapid development in small satellite communication applications, space technology will reduce the cost for the integration of smart initiatives such as, disaster management, weather monitoring and security in Africa.

5. 3 Smart city initiatives in Africa

The smart city paradigm around the world is at its primal stage in terms of development and requires adequate infrastructural support to achieve its full potential. For example, Africa as a continent has no established smart cities yet, such as that of Singapore or

⁶⁰ Dr. Mkhwanazi, (2003). [online] Sustainabledevelopment.un.org. Available at: <https://sustainabledevelopment.un.org/content/documents/nepadmkhwanazi.pdf> [Accessed 10 Nov. 2018].

Barcelona who are way ahead in in establishing smart initiatives. However, there have been numerous smart initiatives taking place around the African continent, these initiatives include; The Casablanca Smart city expo, Nigerian Smart Cities Initiative, Smart Africa blueprint initiative, etc.

Casablanca Smart city expo: This was a two-day conference held from April 18th to 22th, 2018. The conference took place in the city of Casablanca, which is located in Morocco. The conference brought together 85 speakers that included private stakeholders and government parastatals from around Africa and the world at large. The conference was programmed around civic technology, sustainable development, common public space, new technology, urban innovation, etc., and was organized under the name “Liveable cities and urban social innovation”⁶¹. The claim of this program was to exhibit how the city of Casablanca is moving towards the smart city concept, where social and sustainable urban management and development for its inhabitants can be realized through smart innovative technologies. These developments range from smart urban planning, smart education, smart health, e-governance, renewable energy, smart economy, etc.

One of the main focal points in the Casablanca smart city expo, is the inclusion of citizens in the development of a city digital infrastructure. It was proposed by the former mayor (*Jordi Hereu*) of Barcelona, stating that “in a Smart City project, citizens must be considered as actors of the transformation”. His visions and approach stretch from planning, sharing, holistic agreement between all stakeholders involve including citizens, and long and mid-term vision projects. One of the smart approaches carried out by the city is the “Wecasablanca” which focus on information or data sharing of the city to investors, academia, visitors and partners. The idea is that with such sharing approach, the city will attract tourism, economic opportunities, exposure and community identity.

Nigerian Smart Cities Initiative: The Nigerian government acknowledges the importance of smart cities and its application in developing a sustainable and living environment. Nigeria have been involved in numerous smart city initiatives in recent years, such as the Eko Atlantic project. This is an innovative residential and business development located on the Victoria island. It stretches across three and the half square miles of land reclaimed from the Atlantic Ocean in Lagos state, Nigeria. This project is estimated to provide over 250,000 residences and create job opportunities for more than 150,000 people. The managing director of the Eko Atlantic David Frame commented that “We are finding ways and means to produce a city that will reach international standards and create opportunities for recreational facilities as well as providing a core business centre and a good place to live right on the coast of Lagos”⁶².

Other examples of smart city initiatives in the country are the implementation of Delta state SMART CITY initiative in all State-owned Tertiary Institutions, The Successful

⁶¹ Smartcityexpocasablanca.com. (2018). REPORT 2018 LIVABLE CITIES AND URBAN SOCIAL INNOVATION. [online] Available at: http://www.smartcityexpocasablanca.com/wp-content/uploads/2018/10/SMART_CITYEXPO_2017-VF-compressed.pdf [Accessed 7 Oct. 2018].

⁶² Vladimir Duthiers and Teo Kermeliotis, C. (2012). Lagos of the future: Megacity's ambitious plans - CNN. [online] CNN. Available at: <https://edition.cnn.com/2012/08/22/business/lagos-urbanization-regeneration-infrastructure> [Accessed 13 Aug. 2018].

installation of the Calabar metropolitan dark fibre optic network infrastructure, and the recent partnership between Huawei and the Nigeria government to help build and support the application of digital technologies in the country.

Smart Africa blueprint initiative: The smart Africa blueprint initiative encompasses partnership between African government parastatals, regulatory bodies, private stakeholders, etc. Examples of these partners include, African Union (AU), International Telecommunication Union (ITU), World Bank, Electrical Contractors Association (ECA), African Development Bank (AfDB), Global System for Mobile communication (GSMA), Internet Corporation for Assigned Names and Numbers (ICANN), etc. The initiative was organized to provide leadership for the advancement of socio-economic development in the African region through Information and Communication Technology (ICT) applications. The smart Africa Manifesto document was first adopted in October 2013 by few African heads of state that includes Rwanda, Uganda, Gabon, Kenya, Chad, South Sudan, Senegal, etc. at the summit held in Kigali Rwanda on the 28th to 31st of that same year.

The smart manifesto consists of 5 pillars that reflect five key principles that ranges from, policy, access, e-government, private sector/entrepreneurship to sustainable development. These pillars are built on four enablers which are, communication and advocacy, innovation, resource mobilization and capacity building. The idea is that, if all of these enablers are combined and implemented efficiently with the five pillars, Africa as a continent will improve in economic growth and job creation for her citizens.

Other smart projects elsewhere in Africa include; The Braamfontein wireless Mesh project in Johannesburg, South Africa., M-Pesa a mobile application that facilitates financial transactions in Nairobi, Kenya., K-Lab which provides technological hubs for start-ups such as TorQue a company that offers customized software for small and medium enterprises in Kigali, Rwanda., Nandi mobile and MoTeCH are two startups that offers technology for the community health sectors in Accra Ghana. WinSenga is an award-winning mobile application that performs ultrasounds on pregnant women and can also detect the heart beats of a foetus. This app was made by three students of the Makerere University located in Kampala, Uganda. Cloudpress⁶³ a cloud-based marketing platform that allows brands to create and share products to customers virtually. Instabug is a software company that reports bugs, crashes, user survey, etc., for mobile applications with over 25 million users worldwide. Both applications were built in Cairo Egypt. The free public Wi-Fi zones to be established by the Dakar initiative in Senegal is another smart initiative being carried out in Africa. Lastly, Qelasy is an electronic device in form of a tablet that was pioneered by the Ivorian entrepreneur Thierry N'Doufou. The device provides access to the entire educational curriculum in digital format across the country of Côte d'Ivoire.

The concept of smart city in Africa is growing at an enormous pace and with proper planning and implementation the African continent can mitigate its issues as well as provide a sustainable environment for her citizens through smart technology

⁶³ Moyo, M. (n.d.). Top Tech-Savvy Cities in Africa - Africa.com. [online] Africa.com. Available at: <https://www.africa.com/top-tech-savvy-cities-in-africa/> [Accessed 7 Sep. 2018].

6 CONCLUSION AND RECOMMENDATIONS

6.1 Main findings

Africa has all the advantages to start working towards sustainable and smart cities for the future. There is a rising urban migration in Africa and this is mainly due to the population explosion and other factors in the region. All the mega cities in Sub-Sahara Africa have a population exceeding 10 million people, with Lagos (*Nigeria*) topping the list with over 21 million inhabitants. These cities struggle with the daily influx of people and with providing the basic amenities needed for sustenance.

In 2012, the United Nations proposed the Sustainable Development Goals (SDG), a 17-point agenda to help tackle a wide range of issues ranging from poverty, hunger, to social inclusion and sustainable management of natural resources by all countries irrespective of their development status. In 2013 the African Union (AU) through Agenda 2063, proposed 7 aspirations that are similar to the SDG goals but focus mainly on the African continent. Though there has been some development in some areas of these goals and aspirations, the African continent has not seen much impact from such development. For instance, internet access in Sub-Sahara Africa is still ridiculously low and expensive. However, some selected countries like South Africa, Kenya and Nigeria are making head-way to expand their internet connectivity coverage. As electronic mobile devices become cheaper over time, access to smart devices in Africa exploded and revolutionized the telecommunication industry. People can now stream, take pictures and send it through their hand-held devices.

The smart city paradigm is the combination of several smart initiative such as smart governance, smart education, smart banking, smart transportation, etc., all working together seamlessly to create a fully implemented smart city. The smart city infrastructure is made up of several communication systems that consist of both wired and wireless networks, management integration systems that holds the control centre of a smart city, data centres that utilize big data for smart decision making, a privacy and security system that protects and holds sensitive data and information, etc. Wireless communication networks are the most widely used network system in smart cities and it is made up of Bluetooth connections, Wireless Area Networks, Internet broad band connections, Wireless Fidelity Wi-Fi networks, etc. These wireless communication networks are already being and can further be supported by satellite application systems.

Satellite applications will play a vital role in achieving a fully functional smart city. Applications such remote sensing are already being used to enforce security measures in smart and sustainable cities around the world. Communication satellites are providing direct to home services as well as internet broadband connectivity. The GNSS applications systems is already a core infrastructural tool in the smart city ecosystem that provides navigational capabilities for vehicles, airplanes, marine transport and military services. Small satellite technology is disrupting the space industry by providing standards that are cost effective and efficient. Such standards are the CubeSat Unit design, cheaper launching means, such as piggybacking on other space mission due to their sizes, etc. Small satellite constellations are another disruptive idea that is being promoted by small satellite technology. There are institutional bodies that assign the means such as radio frequencies (RF) bands with which these satellites and communication networks connect with each other. These application satellites are manufactured and launched into space through the Space Mission and Design process. These processes are broken down into the Ground segment, Space segment and the User segment. With each segment playing their key roles on a given space mission.

Space applications towards smart cities in Africa provide a lot of benefits such as accessible internet connectivity, open source data from Earth observation satellites, etc. There are several ways that the smart city initiative will benefit the African continent. These benefits range from urban development, disaster management, digital banking system to power grid optimization and security. There are several challenges that affect the implementation of smart cities in Africa as well. These challenges include, inadequate infrastructure, lack of technical know-how, government policies and bureaucracy, lack of funding, lack of energy distribution, etc.

Conclusion

There is as yet no complete functioning smart city, but some countries are way more advanced than others in the implementation of smart city initiatives. Examples of these countries are Spain (Barcelona, Madrid), Singapore, United States of America (New York City, San Francisco), and the United Kingdom (London). These leading smart cities have the basic infrastructural requirement to foster a smart city and with that innovation and creativity is certain.

Developing a smart Africa with the support of space technology, has revealed that the majority of the African countries cannot have a fully operating smart city in the short-term period. This is because the required infrastructure needed to facilitate such smart projects are not available or they are completely neglected. However, with recent developments in space technology such as the OneWeb small telecommunication satellite constellation and the proposed SpaceX small satellite constellation, Africa can piggyback through a public-private partnership with these technology providers. By subscribing to such technology, Africa will gain access to cheaper and more reliable internet broadband connectivity. A robust and cost-effective internet connectivity alone in the Africa region, will provide educational opportunities through smart learning & teaching, global access to different industries and markets, entrepreneurial opportunities, etc. The internet has opened borders across countries all over the world and people transact, socialize, work, study, and literally live most of their lives relying on the internet today. Africa can start leapfrogging hurdles such as, but not limited to; (a) Access to standard educational materials, (b) Communication barriers (c) rigid financial systems and (d) Access to the global markets, etc. African countries can use such internet access to acquire information and data that will support and provide them with resources that can be used to start building their own inclusive and enabling smart city infrastructures. These resources are: technical know-how through skill acquiring e-learning platforms, and exposure to innovative technology that can be mirrored and integrated to the African context.

Small satellite technology is another smart initiative the African continent should start investing in because it is cost-effective and reliable. Being able to raise funding for technological innovation and development is a hard and complicated issue in the African region, so embarking on cheaper space missions will be an ideal way to start building the long overdue space infrastructure the continent of Africa deserves.

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