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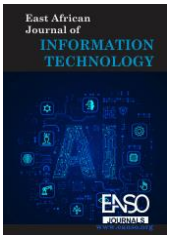

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Original Article

The Evolution of GSM Technologies into 5G and the Imminent Emergence of Transformative Telemedicine Applications: A Review

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ABSTRACT

Telemedicine is the delivery of health care services over a distance by health care providers using electronic technologies for the diagnosis, information exchange, treatment and disease prevention, injuries prevention, research and evaluation, and for continuing education for the health care provider. Telemedicine has been in existence since the 1960s, through telephone and video technologies. Over several decades, wireless broadband technology has become better with advancement with internet speed becoming almost ubiquitous. According to a telemedicine study by World Health Organization, 114 countries, that is, (59%) of member states, revealed that teleradiology has the highest rate of established service provision globally at (33%). Close to 70% of the countries indicated the need to know the cost and cost-effectiveness of telemedicine solutions, and above 50% needed to know about the infrastructure needed for telemedicine implementation while 60% needed clarification on clinical uses. With the evolution of Global System for Mobile (GSM) Communication services into 5G, it is the objective of this study to demonstrate how a combination of faster communication at lower latencies can be used to provide clinical support that overcomes geographical barriers using Information and Communication Technologies (ICT), with a goal of transforming healthcare service provision. A resultant prototype telemedicine application capable of medical diagnosis using artificial intelligence techniques demonstrates with the highest accuracy at 93.68% match. The medical similarity index of pathogens is captured from digital sources such as USB microscopes and scanners as medical images or specimens.

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INTRODUCTION

Information and Communications Technologies (ICT) offers great potential in addressing some of the challenges of Universal Health Care (UHC) delivery in developing countries. The use of ICT and other technologies in the health sector has given birth to the concepts of Telemedicine, Telehealth, Telecare, mHealth, eHealth and digital health, which are often used interchangeably (Norris & Morgan, 2002). The absence of alternatives to health care delivery in relation to accessibility and geographical disparities of healthcare facilities are some of the reasons why ICT implementation is necessary (Craig & Patterson, 2005). Based on the ICT potential, the World Health Organization (WHO) established the Global Observatory for eHealth (GOe) to review the benefits of ICTs in the health care sector for patients' wellbeing (Kay, Santos & Takane, 2010).

The term 'Telemedicine' was coined in the 1970s, to mean "healing at a distance" and it signified the use of ICT to improve patient outcomes by enabling healthcare and medical information access (Strehle & Shabde, 2006). The first published evidence of telemedicine can be tracked in the 20th century denoted by the transmission of electrocardiograph data over telephone wires (Strehle & Shabde, 2006). The modern Telemedicine, therefore, started in the 1960s largely driven by the military and space technologies (Kay, Santos & Takane, 2010). For example, the use of television to facilitate cross consultation between psychiatric institute specialists and the general practitioners at a state mental hospital. The rapid technological revolution from analogue communication channels to digital channels combined with drops in the cost of ICT has caused increased interests in telemedicine application by health care providers. The advent of the internet has further accelerated ICT advancements to exceeding heights such as web-based applications like e-mail, teleconsultations via the internet, and multimedia approaches such as medical imagery (*Figure 1*) and video. These, therefore, have led to exciting interests in the advancement of telemedicine applications that the developing countries may leverage on.

Figure 1: Mobile Teleradiology

Source: (Kay, Santos & Takane, 2010).

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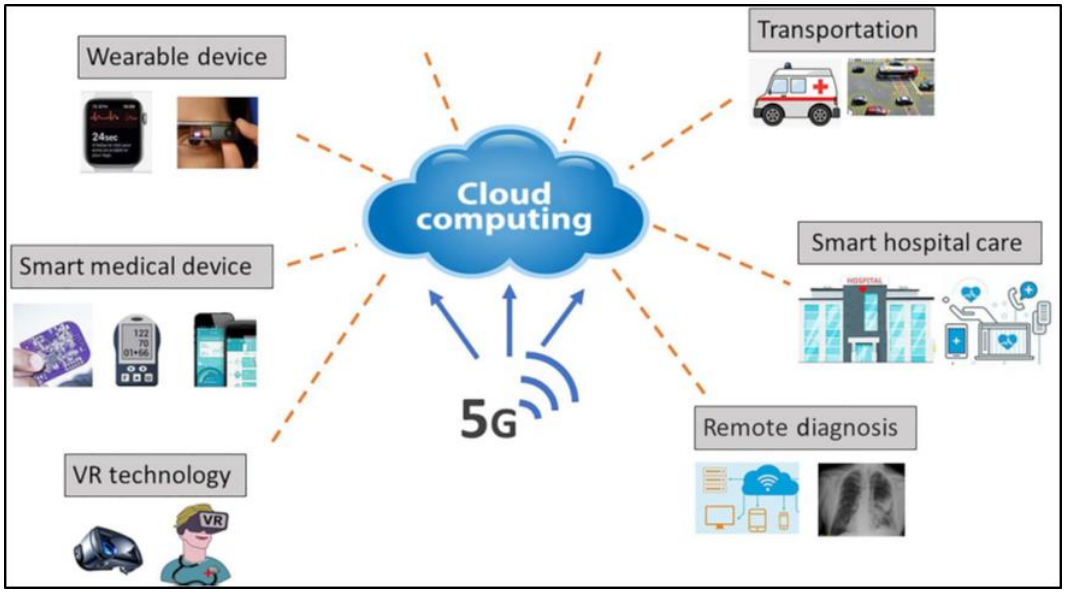
Human health is the key to human development and progress. Therefore, with a dysfunctional healthcare system, stakeholders are seeking ways in which they can ensure that universal health coverage is achieved. In a broader perspective, the fundamental objective of telemedicine is to improve the health of the people. The use of modern information technologies is to help integrate and coordinate the healthcare service delivery to ensure that there are improved patient outcomes (patient-centric), in terms of greater efficiencies, higher transparency levels and improved ease of access of services (Crock, 2016). Another issue is that healthcare is not personalized and doctors can prescribe medication based on population averages with very minimum data-driven strategies. It becomes even more costly to provide tailor-made treatment based on patient medical history. Accessibility of healthcare facilities is another notable challenge faced by the developing countries, more so, for patients from marginalised cadres such as persons with disabilities. The purpose of this paper was to illustrate how GSM evolution technologies in a multi-device environment enable telemedicine through the internet of things (IoT), artificial intelligence (AI) and machine learning (ML) and how it will restructure healthcare system in the near future.

5G refers to the fifth generation of wireless transmission technology. some of the important characteristics of 5G technology are good data transfer rates, latency, coverage, power and network energy usage with unique characteristics of high-speed data transfer rate, super-low latency (delay in the data transmission-response system), connectivity and capacity, and high bandwidth and durability per unit area, that is good for the healthcare sector (Li, 2019). Using 5G super bandwidth and the capacity to connect devices in an ecosystem in an intelligent network, 5G will serve as real-time interactivity for equipment and patients using speed, latency, coverage, availability and low power IoT services trade-off's (Li, 2019). *Figure 2* below illustrates some applications of 5G technology in healthcare.

Figure 2: Applications of 5G technology in healthcare.



Source: (Li, 2019)

The objective of this paper was to systematically review the literature on GSM evolution and its appropriateness as an enabler to telemedicine. The paper demonstrates how a combination of faster network communication and devices performing at lower latencies can be used to provide clinical support that overcomes geographical barriers using ICT through artificial intelligence telemedicine application capable of medical diagnosis.

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The Mobile Transmission Evolution

Mobile communication has become more popular in the last few years due to the fast internet advancements from 1G to 5G in the mobile technology field. This reform is driven by compatible service transmission technologies such as increased numbers of telecoms customers. With the mobile cellular era starting in the 1980s, it has undergone a considerable change and massive growth (Meraj & Kumar, 2015). It is believed that with the coming of a 5G network, personal communication in a fully digital society will be addressed. The combination of faster communication speeds with low latencies (1 Gbps speeds and <10 ms latency) has the potential to transform healthcare through the provision of more robust datasets. This robustness seen in 5G communication is a precursor to the healthcare revolution. As per the previous trends of the societal transformation of 2G, 3G, and 4G, 5G will escalate these successes in supporting existing services and new services with new automation business models in an intelligent manner (Husenovic, Bedi & Maddens, 2018). The table below shows the mobile networks deployment dates, evolution speeds and latency.

Table 1: Evolution of mobile networks

	1G	**2G**	**3G**	**4G**	**5G**
Approximate deployment date	1980s	1990s	2000s	2010s	2020s
Theoretical download speed	2kbit/s	384kbit/s	56Mbit/s	1Gbit/s	10Gbit/s
Latency	N/A	629 ms	212 ms	60-98 ms	< 1 ms

Source: (Husenovic, Bedi & Maddens, 2018)

According to GSMA, the mobile transition into 5G is to provide boundless connectivity for all while delivering network innovativeness for optimal economics. Accelerated digital transformation across industry verticals through the transformed mobile broadband will drive the growth of the Internet of things (IoT) and critical communication services. *Table 2* below shows the paradigm shifts between cellular generations and their service impacts. The technology moves from 4G to Wi-Fi and Wi-Fi to LiFi. LiFi is an optical wireless broadband access technology that uses visible and infrared light spectrum in providing bi-directional transmission capability.

Table 2: 5G Paradigm shift into RF-LiFi Spectrum

Cellular Generations	**Paradigm Shifts**	**Service Pull**	**Impact**
1G → 2G	Analogue to digital	Mobile telephony	Revolution
2G → 3G	Small cell concept	Mobile internet	Evolution
3G → 4G	Small cell concept	Mobile internet	Evolution
4G → 5G	Multi-Access Network	Machine to machine communications	Evolution
Beyond 5G New radio	RF to light (LiFi)	LaaS, IoT and eMBB	Revolution

Source: (Sodhro & Shah, 2017).

Current Health Care Systems Challenges

Many organizations invest hugely in Information technology which has complex implementation processes, with lots of dynamics that could lead to implementation failures resulting into enormous time, effort, financial wastages, and risks to lives (Justice, 2012).

A great part of the population percentage who stay in rural areas, find it difficult to access specialists for good quality health attention at the right time. The specialists are usually located in town areas with a number of them covering only 20% of the population. As per the eHealth strategy report 2011-2017, 80% of clinicians serve 20% of the population. In as much as medical specialists are concentrated in urban centres and health care infrastructure suffers from imbalances in the

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regions and urban to rural areas with personnel shortage and lack of investment for this coverage. *Table 3* below shows personnel-to-patient ratios as per the Kenya eHealth strategy report 2011-2017 (MOMS & MOPHS, 2011). The huge imbalance between the patient and doctor ratio points to a desperate health care system. According to Watts et al, (2005), some of the challenges bedevilling healthcare in developing countries are so critical such as chronic illnesses, lack equipped amenities, and lack of enough skilled personnel.

Table 3: Personnel-Patient Ratio of Kenya

Workforce	Total	Approximate ratio of workforce per patient
Doctors	1513	1:26438
Dentists	169	1:236686
Pharmacists	283	1:141343
Clinical Officers - CO's	2104	1:19011
Nurses	16227	1:2465
Other Health Staff	9720	1:4115
Non-Health Staff	5615	1:7124
Overall	35631	

***Source**:* (MOMS & MOPHS, 2011)

WHO recommend minimum staffing levels of 2.3 practitioners per 1,000 populations while Kenya practitioners staffing levels are at 1.5 per 1,000 population. In order to achieve the WHO recommended levels, there is a need to increase the number of health care practitioners by 53% (WHO, 2006).

Financials are also a challenge for the health sector and it is a risk in the rolling out of health-related information systems projects in third world countries. This is according to a study carried out by Pal et al. (2005), Xue and Liang (2007). The invent of 5G technology will not only help in providing cheap connectivity but will also aid in limiting costs related to transport, onsite staff training to online training and related health information systems innovations. 5G technology enabling telemedicine will aid in realizing universal health coverage (UHC) as evidenced in the national eHealth strategy policy paper report of 2011-2017, which identified ICT as a key driver for the improvement of healthcare outcomes. According to the Kenya National eHealth policy 2016-2030, successful eHealth systems such as telemedicine implementations are hindered by poor infrastructure, low literacy, inadequate technical expertise, unreliable power supply, limited funding, and lack of government involvement in most eHealth projects.

Infrastructure such as those that support the utilization of current internet technologies as well as supporting the operations of any health-related ICT project remains a constraint (WHO, 2010). Developing countries still have infrastructure challenges such as internet connectivity, which is still a problem (Kay, Santos & Takane, 2010).

The Role of Technology in Closing Healthcare Delivery Gaps

Technology disruption of the industry stems from the theory of disruptive innovation introduced by Christensen (2013). The theory provided clarification on the displacement of industry giants by lesser competitors and opening up channels for new entrants (Giovanisa & Athanasopouloub, 2018). Disruptive is a term used in the business and information technology literature to describe innovations that improve products or services and later lowering the cost of doing business to clients (Appiah, Ozuem & Howell, 2019).

The digital transformation happening in the healthcare industry will be as disruptive as that seen already in other sectors (Klewes, Popp & Rost-Hein, 2016; Valenduc & Vendramin, 2017). The traditional way of health care service provision is slowly being invaded by artificial intelligence, machine learning and internet of doing things.

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Healthcare systems running on AI, machine learning, or probabilistic models could provide therapeutic recommendations, prognosis learning, and real-time disease scoring. Diagnosis and treatment are today partially performed by medical histories and symptoms of the patient. ICT can perform better diagnosis and treatments by utilizing complex physiological and sensor data than a healthcare provider. It has also been argued that computers will replace 80% of what doctors can do in the future while providing accurate and fact-based clinical recommendations in a quicker way (Khosla, 2012).

The potential use of 5G technology (ICT) in healthcare in resources constrained environments such as the developing countries, has been emphasized by the World Health Organization report (WHO, 2010). For instance, telemedicine projects will help meet hitherto unmet health needs (Brandling-Bennett et al., 2005), thus impacting significantly and positively on healthcare. Telemedicine offers pragmatic opportunities for distant health care delivery in areas of evaluation, diagnosis, treatments and follow-ups (Croteau et al., 2005). It also offers an opportunity for patients to seek early treatment and to adhere to treatment schedules, thereby improving patient quality of life, reducing patient referrals, reducing travel cost and stress through information technology access. The provision of telemedicine services may also motivate health professionals to stay in remote health facilities, because of the support they will enjoy from the other health practitioners (Gagnon et al, 2006), thus providing a source of reassurance to both health professionals and patients in remote areas (WHO, 2010).

To demonstrate the use of telemedicine using GSM technology a mobile application software was developed with the capability of analyzing medical images, in a multi distributed telecommunications environment. Using artificial intelligence (AI) techniques of pattern recognition (that is, finding and extracting specific patterns in a given image), it has been shown that, with the evolution of GSM Technologies into 5G, a robust telemedicine capability can be a reality. *Figure 3* below, shows login screen to the mobile app, were different medical images (specimens), can be uploaded for similarity analysis. The resultant specimen comparison between parasite A and parasite B is 93.68% similar. This implies that the two specimens are closely matching. Assuming parasite A, is positive (primary) and parasite B is the new upload (under investigation), we can deduce that parasite B is also positive.

Figure 3: Mobile telemedicine app

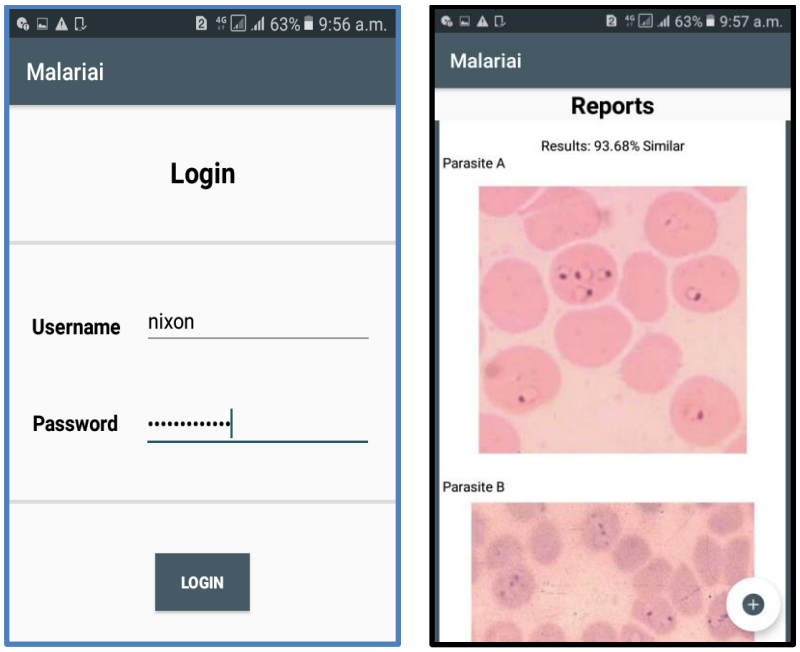

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Figure 4 below shows a comparison of two specimen images with slightly different stains. The analysis of the two samples for similarity is 73.98%, meaning the two specimens are slightly different as per the AI algorithms used.

Figure 4: Comparison of two medical images for similarity - A

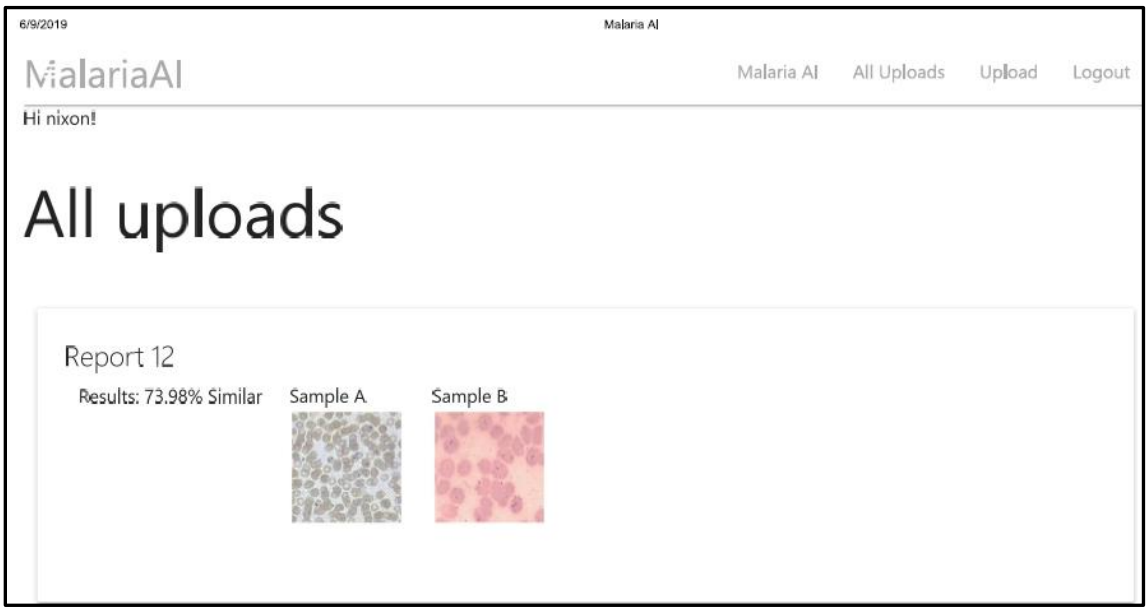
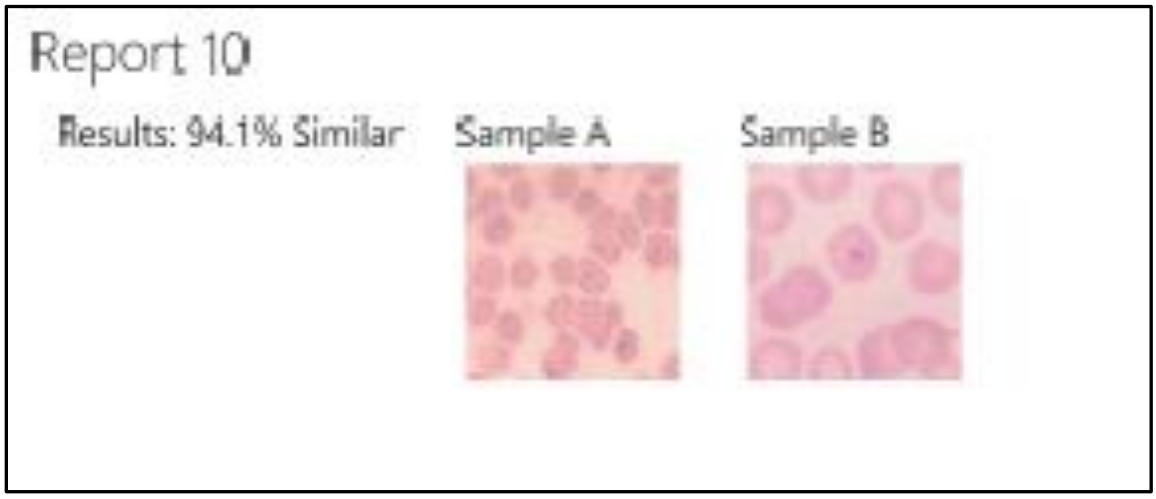


Figure 5 below shows a comparison of two specimen images which are slightly similar. The analysis of the two samples for similarity is 94.1%, meaning the two specimens are almost similar as per the AI algorithms used. this means sample B is positive assuming sample A was the benchmark.

Figure 5: Comparison of two medical images for similarity - B



The above mobile application prototype has shown that given a robust medium of communication such as 5G, telemedicine and other eHealth tools will be possible. A study by Market Research Future indicates that telemedicine market will grow at a compound annual rate of about 17% through the year 2023. 5G technology will enable health providers to transmit massive files from X-rays, MRIs, and other medical images. This will enable people and machines to make critical decisions about a patient's health quicker with more information.

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CONCLUSION

This paper has presented an overview of the evolution of GSM Technologies into 5G and its impact on the emergence of transformative telemedicine applications. It has been reported in many studies that, information communication and technology is one of the ways in which universal health coverage can be enhanced. The use of 5G wireless technology has the capability to transform healthcare sector by augmenting human capacity and reach rapidly by allowing things like resource pooling, virtualization of high-performance systems of telemedicine and several internet of things (IoT) tools. 5G characteristics such as broadband, low latency and ubiquitous access, will enable integrations of patients and medical practitioners through ICT innovations.

With the new terminal devices, such as smartwatches, wearables, virtual reality devices, smartphones and tablets, patient's habits and expectations are likely to change in view of the interactive nature of the media devices. The need to deliver healthcare services anywhere, anyhow and anytime as opposed to patients moving physically to health facilities is likely to gain momentum with faster internet speeds of 5G networks.

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