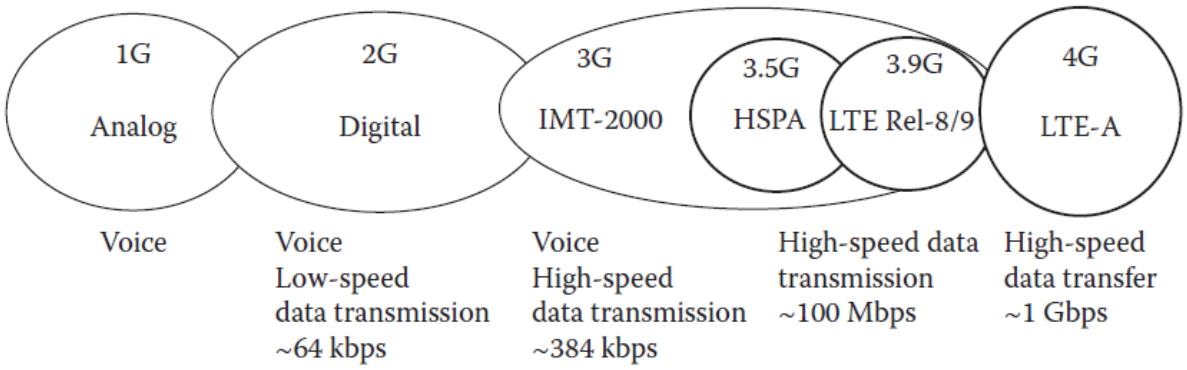

Fig 1: Mobile Communications System Evolution [1]

This section gives an overview of the evolution of mobile (cellular) communications from first generation (1G) to fourth generation (4G).

1.1.1 First Generation (1G)

The first generation of mobile phone systems to be launched were based on analogue technology. Commercial deployment started around 1981. By today's standards the performance was limited, the phones were bulky, and initially the coverage was poor. In addition to this, when the phone systems were first launched they were very expensive, which limited them to business use. Nevertheless, these phone systems marked a major milestone in telecommunications history. For their day, they represented a major step forward in technology, and they also established a market that grew well beyond the initial predictions. In fact, many of these systems quickly ran out of capacity as a result of the demand as the numbers of subscribers grew.

The three main systems that were launched were NMT (Nordic Mobile Telephone), AMPS (Advanced Mobile Phone System, also known under its specification number as IS-41) and TACS (Total Access Communications System). The NMT system was developed as a joint venture by Nordic countries with Ericsson, and Nokia playing a major part, although there were many other interested parties. This system was obviously used in Nordic countries, but was also employed elsewhere around the world. AMPS was focused on North America, but was also widely used around the globe. Similarly, TACS, developed by Motorola, was used in the UK as well as many other countries [2]

1G systems were launched in Ghana by Millicom Ghana Limited in April 1992 under the brand name Mobitel. The technology deployed by Millicom was TACS. Celtel Ghana Limited also launched AMPS in 1993.

1.1.2 Mobile Cellular Licence/ 2G

Due to challenges such as inadequate capacity, security and lack of roaming, research into second generation (2G) systems began leading to standardization of a number of them. Popular and most widely used amongst them is the GSM technology. The others were North America TDMA, PDC and cdmaOne/IS95. Unlike the 1G systems, 2G systems were mainly digital.

1.1.2.1 Global System for Mobile Communications (GSM)

GSM started as the Groupe Speciale Mobile. To make the brand global while keeping the same initials, this was later changed to Global System for Mobile Communications. The aim was to develop a digital mobile phone system that would support roaming across borders and also improve capacity over the analogue systems that were then in use. Call privacy and security were also high on the agenda [3].

The goals set for the system were tough, as no digital system had been launched before and neither had any attempts at roaming on this scale been considered. The original aim was to use spectra in the 900MHz region. Since then further bands have been used such as 1800MHz, 900MHz and, more recently, 800MHz. Originally the systems using the high-frequency bands were given the names DCS 1800 (Digital Communications System) in Europe and PCS 1900 (Personal Communications System) in USA. Now they are simply referred to as GSM 1800 and GSM 1900 respectively [3].

The system has been a considerable success, far outstripping the take-up by any other network beforehand or currently available. Part of the success of the GSM system is that the standard has rigorously defined the whole system.

The standard was generated and controlled under the auspices of European Telecommunication Standards Institute (ETSI), thus generating a truly international standard which, most manufacturers and service providers adhered to. In this way, not only did global roaming become a reality; it also meant that manufacturers could cater for a global market and benefit from economies of scale. The running of the GSM standard has now been passed to 3GPP, the organization that is also controlling the Third Generation (3G) UMTS (Universal Mobile Telephone Service) [3].

Second Generation Mobile Telephony services was launched in Ghana in 1996 by Scancom PLC Limited under the brand name Spacefon. The system deployed was the GSM.

1.1.2.2 General Packet Radio Service (GPRS)

As mobile phone technology became more widely used, it became obvious that data services would become the next major generator of revenue. Although many second-generation systems were able to carry data, it was only at very low rates. For GSM, the maximum rate was 14.4 kbps. Efforts were therefore made at boosting data speed over networks. The first was the High Speed Circuit Switched Data (HSCSD) which, even though was never widely deployed because it did not make efficient use of the resources of networks, enabled data rates of up to 64 kbps by combining time slots.

Most data transfer occurs in a 'bursty' fashion. The transfer occurs in short peaks, and then remains calm for a while, meaning the channel remains dormant while its capacity could be used to transfer data for other users. To overcome this problem the General Packet Radio Service (GPRS) was devised using packet data that enables a far greater level of efficiency than using a circuit switched scheme where a complete circuit is devoted to a user. [3]

For the GPRS network structure to provide packet-based services, the core network structure had to be upgraded from the GSM mode. Data from the BSC is routed through a Serving GPRS Support Node (SGSN), which forms the gateway to the services within the network, and then a Gateway GPRS Support Node (GGSN), which forms the gateway to the outside world. These elements form what is known as the Public Land Mobile Network (PLMN) [3].

The SGSN serves a number of functions for mobiles with data services. It enables authentication and then tracks the location of the mobile within the network and ensures that the quality of service is of the required level [3].

1.1.2.3 Extended GPRS (EDGE)

EDGE, Enhanced Data for Global Evolution or for Enhanced Data for GSM is a further evolution of GSM, enabling the attainment of higher data rates using substantially the same network equipment. Although effectively an upgrade to GPRS, the core network capability remains virtually unchanged, allowing migration to the new standard. [3].

EDGE offers a significant speed improvement over GPRS which though can only be achieved under ideal conditions; like when signals in both directions are sufficiently strong. This normally entails the mobile being reasonably close to the base station. Once a mobile starts to move, variations in signal strength are normally experienced which degrades the quality of the link [3].

1.1.2.4 North American TDMA

While the second-generation GSM digital cellular system was being introduced in Europe, a different technique that although digital and using Time-Division Multiple Access (TDMA) techniques with different requirements was being developed in the US. With no further frequency allocation from the FCC to accommodate a new cellular system, very heavy investment in AMPS technology was deployed over vast areas of the US. There was the need therefore to ensure that any digital systems that was developed would be as compatible as possible with AMPS. That meant designing a system that could use the existing AMPS channels to allow a smooth transition from AMPS to TDMA. During the changeover, both AMPS and TDMA could co-exist in the same area.

1.1.2.5 Pacific Digital Cellular (PDC)

Japan's second-generation TDMA cellular system known as PDC is very similar to NA-TDMA. PDC stands for either Pacific Digital Cellular or Personal Digital Cellular. The standard was defined by Japan's standards organization RCR, now ARIB. The first service was launched in March 1993 by NTT DoCoMo, and by 2003 had over 61 million subscribers. The system is used nowhere else in the world, and is now being phased out with the advent of 3G services. Japan rolled out UMTS and CDMA2000 after PDC.

1.1.2.6 cdmaOne/IS-95

While spread spectrum techniques had been used for many years in military circles, and primarily for covert communications systems, it was not until 1989 that the idea of using direct sequence spread spectrum techniques in the form of a code division multiple access scheme was proposed to the Telecommunications Industry Association in the US. As there was already another second-generation technology being developed, the industry did not want competing technology to be introduced. Accordingly, the first CDMA networks were not launched in the USA, from where the idea had emanated. Instead the first network was launched in Hong Kong in 1994. The US launched its first network in 1996 [5].

Using direct sequence spread spectrum techniques to provide access to technology was quite revolutionary. It was a major leap in technology over the original FDMA schemes used for the first-generation networks, the TDMA systems being rolled out as GSM in Europe, and the NA-TDMA system in the US. CDMA relies on the use of different orthogonal spreading codes to differentiate between the different mobiles accessing the system. Although the signals all occupy the same frequency channel, the system is able to decipher each signal by applying the correct code to correlate the incoming signal and decipher it [5].

MOBILE NETWORK OPERATOR	DATE OF FIRST ISSUE OF LICENCE
Ghana Telecommunications Company Limited (Vodafone) formerly Onetouch	2nd December, 2004
Scancom PLC (MTN Ghana) formerly Spacefon	2nd December, 2004
Millicom(Ghana)Limited formely Mobitel	2nd December, 2004
Airtel Ghana Limited formerly Westel	31st October, 2006
Glo Mobile Ghana Limited	17th July, 2008
Kasapa Telecom Limited (Kasapa)	2nd December, 2004

1.1.3 Universal Mobile Telecommunication System (UMTS)/3G Licence

UMTS, the Universal Mobile Telecommunications System, is the third-generation (3G) successor to the second-generation GSM-based technologies, including GPRS, and EDGE. Although UMTS uses a totally different air interface, the core network elements have been migrating towards the UMTS requirements with the introduction of GPRS and EDGE. In this way, the transition from GSM to UMTS does not require such a large instantaneous investment [6].

UMTS, which uses wideband CDMA (W-CDMA), has had a long history. Even as the first 2G systems were being rolled out, it was clear that these they were deficient and that new technologies capable of providing new services and facilities would be required. This explains why the World Administrative Radio Conference started to reserve spectrum allocations for new services in 1992 [6].

Next, the International Telecommunications Union began defining a system while the International Mobile Telecommunications System 2000 (IMT2000) started to take shape. To manage the new standard, the Third Generation Partnership Programme (3GPP) was formed as a global co-operation between six Organizational Partners (ARIB, CCSA, ETSl, ATIS, TTA and TTC)

from Japan, China, Europe, the USA and Korea. The establishment of 3GPP was formalized in December 1998 with the signing of The Third Generation Partnership Project Agreement [6].

The original scope of 3GPP was to produce globally applicable technical specifications and technical reports for a third-generation mobile telecommunications system based upon GSM core networks and the radio access technologies that they support. Later the scope of 3GPP was increased to include the maintenance and development of the GSM Technical Specifications and Technical Reports, as well as derivatives of GPRS and EDGE [6].

While 3GPP undertook the management of the UMTS standard, a similar committee was needed to oversee the development of the other major 3G standard, namely CDMA2000. This committee took on the name 3GPP2, and the standards bodies that were represented included ARIB, TTA, CWTS and TIA [6].

1.1.3.1 High Speed Packet Access (HSPA)

The maximum data transfer rate for UMTS is 2 Mbps. With Wi-Fi and other technologies, including wired ADSL links, providing much higher maximum download speeds and at lower cost, there was a need to ensure that UMTS did not fall behind and as a result lose business. To address this, the high-speed data packet access technology was introduced into UMTS. Additionally, trends showed the volume of packet switched data rising and overtaking the more traditional circuit switched traffic. Using the new High Speed Downlink Packet Access (HSDPA) scheme, it is possible to achieve peak data rates of 10 Mbps within the 5-MHz channel bandwidth offered under WCDMA [6].

The first stage of the upgrade was to increase the data rate on the downlink channel, where typically more data is transferred. This resulted in the HSDPA technology whose key to operation was the use of an additional form of modulation. HSDPA was the first to be implemented because most of the data are transported in the downlink direction. However, to support applications such as Voice over IP (VoIP) video-conferencing and some of the other new ideas that required high-speed data transmission in both directions the High Speed Uplink Packet Access (HSUPA) was introduced as part of Release 6 of the 3GPP specification. This employs many of the same features found in HSDPA known as High-Speed Packet Access (HSPA). [6].

UMTS was first launched in Ghana in 2008 by Zain Communications Ghana Limited (now Airtel).

1.1.3.2 CDMA2000

With lS-95 established and very successful, it became necessary to upgrade the system with a high-speed data capability to enable it to carry much faster data and thereby enhance the revenue growth. The approach adopted by those developing the CDMA technology from cdmaOne/lS-95 was to have a system in which there was a well-defined migration path forward but with full backward compatibility. As a result of this the IS-2000 standard was developed to enable higher 3G data rates. Within CDMA2000, a number of further developments were included in the hope that as more areas moved towards 3G standards thus making the old AMPS systems obsolete, it would be possible to have systems operating on a wider bandwidth. This allowed new standards for systems that use the single channel bandwidth (IX) as well as those that would use three times the bandwidth (3X) [7].

CDMA2000 IX has been designated a 3G standard, and is widely deployed with operators in all continents of the world. Like cdmaOne, IX is widely deployed in North America and the Asia Pacific regions as well as many other countries around the globe [7].

MOBILE NETWORK OPERATOR (3G)	DATE OF FIRST ISSUE OF LICENCE
Scancom PLC (MTN Ghana)	23rd January, 2009
Ghana Telecommunications Company Limited (Vodafone) formerly Onetouch	11th December, 2008
Millicom(Ghana)Limited	26th January, 2009
Airtel Ghana Limited	26th January, 2009
Glo Mobile Ghana Limited	26th January, 2009

1.1.4 Broadband Wireless Access (BWA) – 4G Licence

LTE is one of the primary broadband technologies based on Orthogonal Frequency-Division Multiplexing (OFDM), which has currently been commercialized. In 2005, LTE and System Architecture Evolution (SAE) study items were set up in 3GPP. Both operators and manufacturers were keen to push these study items because they were facing competition from other technologies such as WiMAX [1].

Operators were looking for significant improvements compared to UMTS releases that provided an architecture that was better suited to the shift from circuit-switched communications toward packet data and a radio technology that enabled spectrum re-farming. LTE Rel-8 provides high peak data rates of 150 Mbps (2x2 MIMO) on the downlink and 75 Mbps on the uplink for a 20-MHz bandwidth and allows flexible bandwidth operation from 1.4MHz up to 20MHz. LTE Rel-8, which is mainly deployed in a macro/micro cell layout, provides improved system capacity and coverage, high peak data rates, low latency, reduced operating costs, multi-antenna support, flexible bandwidth operation, and seamless integration with existing systems. The LTE network architecture is designed with the goal of supporting packet-switched traffic with seamless mobility, QoS, and minimal latency [1].

The first LTE network in Ghana was launched by Surfline Communications Limited in 2014.

MOBILE NETWORK OPERATOR	DATE OF FIRST ISSUE OF LICENCE
Surfline Communications Limited	12th June, 2013
Blu Telecom formerly G-Kwiknet	13th June, 2013
Telesol Limited	3rd July, 2017
Ghana Telecommunications Company Ltd. (Vodafone Ghana)	19th March, 2019
Scancom PLC (MTN Ghana)	21st June, 2016