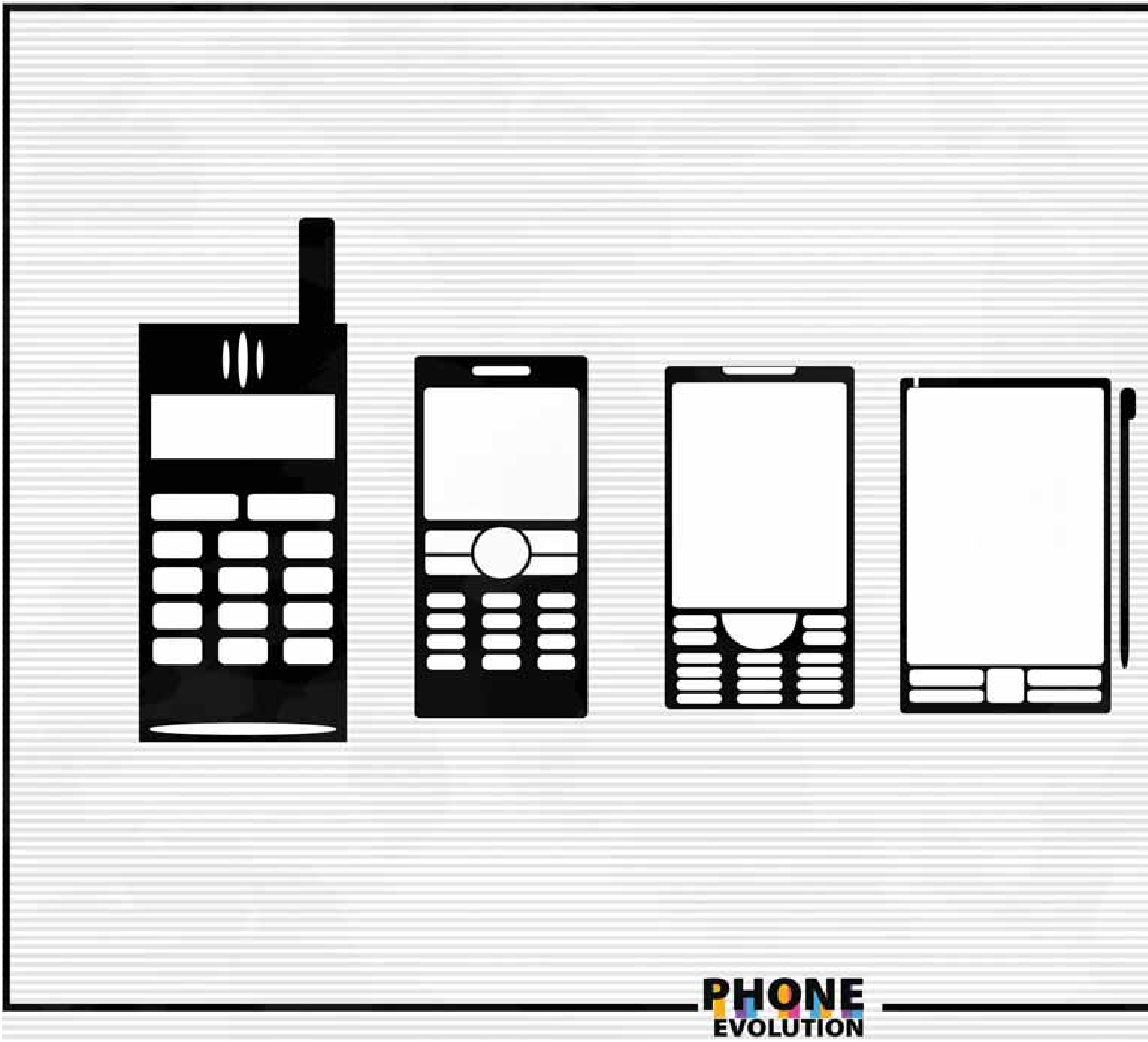
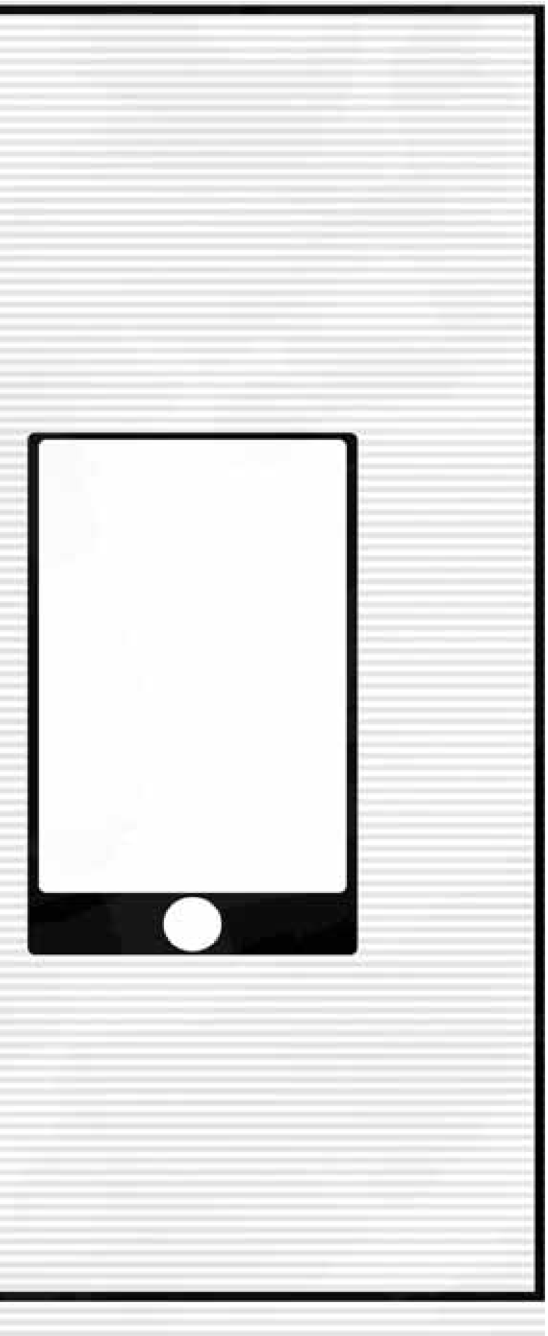


MOBILE NETWORK EVOLUTION WITHIN THE UK



ANDY SUTTON, NIGEL LINGE

Network architectures behind the mobile phone

This year the mobile phone celebrates its 30th birthday in the UK. But while the physical handset may take centre stage, where would it be without that all important supporting cast, the mobile network? Andy Sutton and Nigel Linge explore the evolution of the mobile network architecture from 1G to 4G and onwards to 5G.

In the first few seconds of 1985, Michael Harrison telephoned his father, Sir Ernest Harrison, using a Panasonic VM1 handset. This call to the Chairman of Vodafone was in effect the first one to be made on the UK's newly launched mobile phone network. A second network operated by Cellnet officially opened for business on 7 January that same year.

Thirty years have elapsed since that momentous week in January 1985 and our mobile phones have evolved from cumbersome bricks that could only make telephone calls to sophisticated smart phones that increasingly influence every aspect of our daily lives. But what about the telecommunication networks that lie hidden from view but which have made the mobile phone revolution possible? How have they evolved over this time to accommodate our massively changing demands of what a mobile phone should do?

1G: Analogue voice technology

The original concept for a cellular mobile phone network was first published in December 1947 by Douglas H. Ring in a Bell Labs memoranda entitled, "Mobile Telephony – Wide Area Coverage". However, it was not until 1973 that it became a practical reality when Dr Martin Cooper and his team at Motorola produced the first working cell phone [1]. These first mobiles and their networks used the Advanced Mobile Phone Service standard and were entirely based on non-encrypted analogue transmission. The Advanced Mobile Phone Service standard was modified for use within the UK where it became known as the Total Access Communication System (TACS). These first generation networks used Frequency Modulation on a 25kHz radio channel using 890-905MHz for transmission from the mobile and 935-950MHz for transmission from the cell's base station giving it a capacity of 600 channels for the transmission of voice and control signals. In August 1986 additional frequencies were released, thus extending TACS (ETACS) to cover 872-905MHz and 917-950MHz and to support 1320 x 25kHz channels.

An ETACS network was designed to serve one purpose and that was to manage and handle analogue voice calls. These early networks did have several weaknesses: namely, call quality, the lack of security, and the fact that there was no common pan-European standard. Your UK mobile phone stopped working at the English Channel! That said, and despite the high cost of the handsets, 10 years after launch, seven per cent of the UK population were mobile users. However, the move to digital technology drove a massive uptake in mobile ownership and usage.

Cellnet closed their 1G ETACS network on 1 October 2000 and Vodafone closed theirs on 31 May 2001 thus bringing to an end the UK's 16-year era of analogue mobile networks.

2G: Going digital with pan-European GSM

Three years before the UK launched its first TACS network a working group was set up by the European Conference of Posts and Telecommunications to harmonise the public mobile communications systems in the 900MHz band. It was called Groupe Special Mobile (GSM) and first met in Stockholm in December 1982. At this point there was no guarantee that the GSM working group would decide upon a digital system, the key focus was to find a single, compatible system that could be rolled out across Europe and which could scale to the projected usage profiles. The culmination of this work was the publication on 7 September 1987 of a Memorandum of Understanding on the implementation of a pan-European 900MHz digital cellular mobile telecommunications service by 1991.

The UK Government announced that an upper 10MHz on the existing mobile bands (905-915MHz and 950-960MHz) would be reserved for GSM and not be released for further expansion of TACS. In addition and in response to the DTI Consultation Document "Phones on the Move", frequencies in the 1800MHz band (1710-1785MHz from the mobile and 1805-1880MHz from the base station) were also made available for 2G.

Architecturally, and as shown in Figure 1, the radio interface within each cell is managed by a Base Transceiver Station (BTS) which is the visible part of the network in the sense of it being the radio tower you see on roofs and by the side of roads. Each BTS is then connected via landline or point-to-point microwave to a Base Station Controller (BSC); with each BSC connecting several BTSs. The BSC is responsible for radio network management of, and call handover between, each BTS that it controls. Each BSC is then connected to a Mobile Switching Centre (MSC) via a Transcoder and Rate Adaptation Unit (TRAU) which is responsible for converting the 13kbit/s voice codec from the GSM-specific standards to that used on the 64kbit/s Public Switched Telephone Network (PSTN). Additionally the TRAU supports circuit switched data services. The MSC, for which there is likely to be more than one in the network, acts as the core circuit-switched exchange handling authentication, call setup and termination, billing, and mobile phone location tracking functions. The MSC also provides connectivity to the external PSTN.

The digital access network uses a combination of frequency division multiplexing in which the available

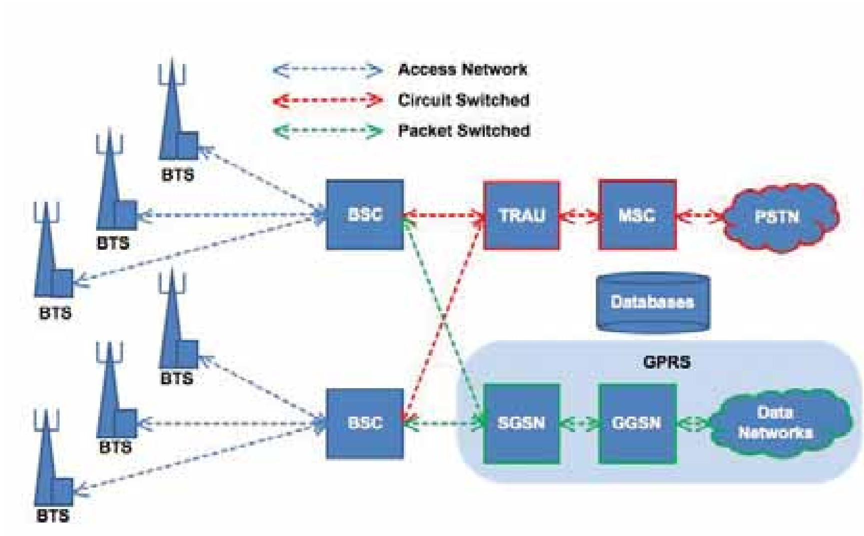


Figure 1: Network architecture of a 2G (GSM) and 2.5G (GPRS) mobile network

channels are spaced every 200kHz and time division multiplexing in which transmission within these channels is controlled on a strict time basis – hence, producing the GSM Time Division Multiple Access frame structure.

Vodafone launched the UK's first 900MHz GSM network in July 1992 whilst Mercury one2one launched the UK's and world's first 1800MHz GSM network in September 1993 with both of these being followed by Cellnet in December 1993 (900MHz) and Orange in April 1994 (1800MHz).

A digital transmission system inevitably allows the transfer of non-voice services and so it is at this time that the Short Message Service becomes a reality and people start trying to link their mobile phones to data networks, especially the Internet for which access to the web has now become a key driver.

During the 1990s, mobile operators experienced an increasing demand for data services for which the circuit-switched GSM network was not well suited. The parallel analogy here is how the demand for dial-up Internet at home drove advances in modem technology that eventually forced a move to adopt digital subscriber line (broadband) access. The solution for mobile, was to redesign the network to support packet-switched services using a General Packet Radio Service (GPRS). Data is transported over the access network on Time Division Multiple Access time slots giving data rates of tens of kbit/s. Within the BSC, these data streams are separated from voice and passed to a Serving GPRS Support Node (SGSN). This is then connected to a packet-switched core data network and onwards to external data networks, such as the Internet, via a Gateway GPRS Support Node (GGSN). BT Cellnet launched the UK's and world's first GPRS network in June 2000 followed by Vodafone in April 2001, Orange in December 2001 and T-Mobile (replacing one2one) in June 2002.

The provision of this always-on best effort data service (2.5G) continued to fuel a consumption of data services. It is at this time for example, that digital cameras are integrated into mobiles for GPRS facilitated multimedia messaging and the uploading of pictures to the web. Demands for increased data rates continued to grow, leading to the final evolution of the 2G networks to 2.75G and the introduction of Enhanced Data rates for GSM Evolution (EDGE) which offered rates of hundreds of kbit/s. This was achieved through a change in the radio access network and, specifically, the modulation and data coding techniques used on the radio interface. Apart from a need to upgrade the operators' core data network, the

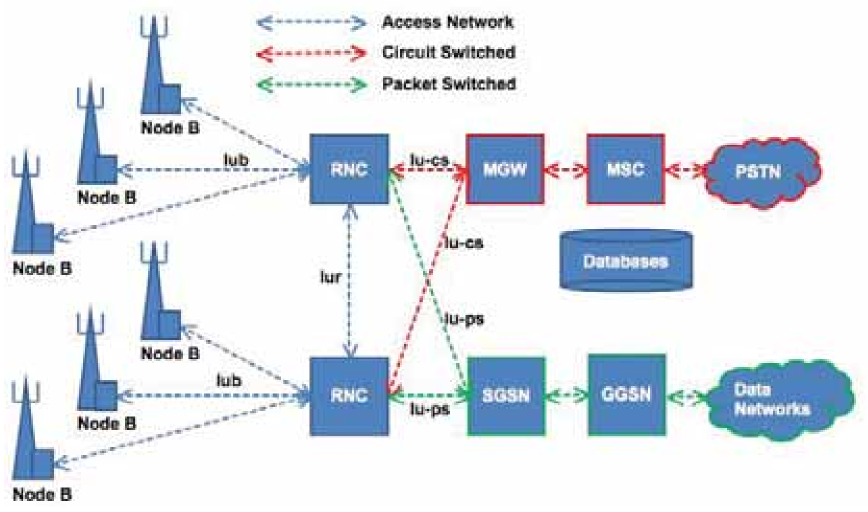


Figure 2: 3GPP Release 99 3G (UMTS) network architecture

architecture of an EDGE network is the same as that used by GPRS. Orange was the first in the UK to launch EDGE on 8 February 2006 but any further increase in data rate would only be met through a more substantial network re-design.

3G: Driving data rates upwards with UMTS technology

3G standardisation activities started in 1991 when ETSI established Special Mobile Group No. 5 to investigate options for the standardisation of Universal Mobile Telecommunications System (UMTS). As with GSM before it, the standardisation activities for this new generation of mobile communications technology started before the previous technology had launched commercial networks. By 1992 there was global agreement on the allocation of spectrum in the 2100MHz band for 3G networks and the first release of the technical standards appeared in the year 2000, these were known collectively as 3G Partnership Project (3GPP) Release 99. There was significant excitement about the potential of 3G to support new and innovative products and services for mobile operators. In many countries this spectrum attracted significant fees via auctions run by national administrations; the operators in the UK alone paid a staggering £22,477,400,000 for a piece of paper which allowed then to operate within an allocated slice of the 2100MHz band.

3GPP UMTS technology was very different to the GSM technology of the day which necessitated the network operators to rollout a new network in parallel with existing 2G systems which was known as the UMTS Terrestrial Radio Access Network (UTRAN). 3G introduced a new radio interface technology based on Wideband Code Division Multiple Access (WCDMA) along with a new network architecture and broadband Asynchronous Transfer Mode (ATM) connectivity between the radio base stations, radio network controllers and core network nodes, circuit switched and packet switched as shown in Figure 2.

The Node B is the 3G WCDMA radio base station, based on a working name within 3GPP that stuck, and is used to manage the physical layer radio transmission and reception along with CDMA channel coding, micro diversity, error protection, and closed loop power control. It connects to the Radio Network Controller (RNC) via the Iub interface and handles the ATM traffic generation/termination over this interface. A number of Node B's and their associated RNC is known as a Radio Network Subsystem (RNS). A UTRAN may consist of one or more RNSs, most have many RNCs for scalability and therefore multiple RNSs within a UTRAN is common.

The RNC is the network controller which architecturally is the peer of the GSM BSC; however, it has much more functionality as the R99 Node B is a simple Layer 2 relay. The RNC is responsible for overall system access control, radio channel ciphering and deciphering, mobility management and radio resource management, including macro diversity. Additionally the RNC plays a key role in managing mobility due to the use of soft-handover in UMTS, hence the new Iur interface between RNCs.
The Media Gateway (MGW) manages

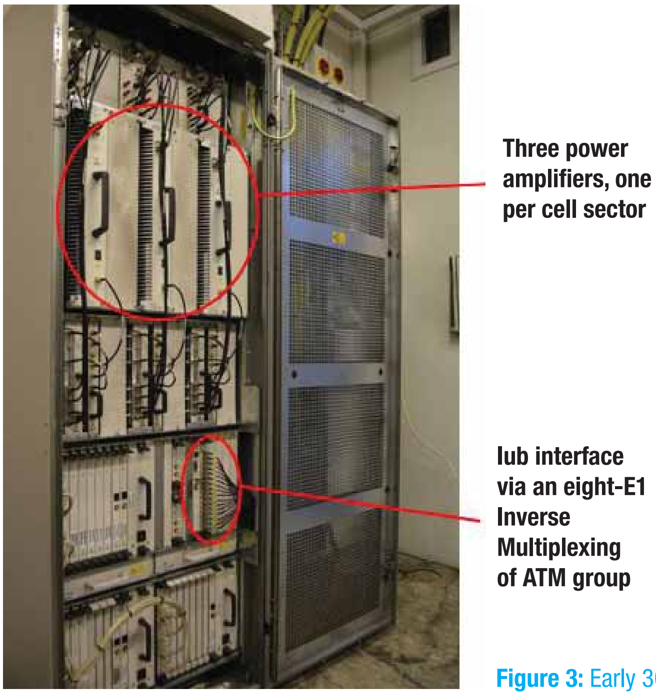


Figure 3: Early 3G WCDMA Node B

Figure 4: Cell site with multiple operator's antenna configurations for 2G and 3G

"3G technology has evolved considerably since launch. Key developments include: the introduction of an IP transport network layer to replace the ATM technology and high-speed packet access technologies which increase peak data rates to some tens of Mbit/s."

Figure 5: Multi-band cell site with 6-port cross-polarised antennas

transcoding and interworking between the 3G RAN and existing 2G circuit switched core network, although in reality many operators deployed parallel core networks for 2G and 3G which were integrated once 3G was proven and operating in a stable manner. The transcoding and interworking functions include termination of ATM traffic from the UTRAN via Time Division Multiplex interfaces, Adaptive Multi-Rate to ITU-T G.711 A-law Pulse Code Modulation transcoding and support of E1 Time Division Multiplex interfaces towards the MSC [2]. Figure 3 illustrates an early 3G WCDMA Node B. Note the eight E1 Inverse Multiplexing of ATM group offering a logical 16Mbit/s backhaul connection for the Iub interface and the size of the power amplifiers which are very linear Class A amplifiers required to support the Quadrature Phase Shift Keying modulation scheme.

New entrant, Three, was the first to launch their 3G network in March 2003, followed by Vodafone in April 2004, Orange in July 2004, O2 (re-branding of BT Cellnet) in February 2005 and finally, T-Mobile in October 2005.

Depending upon the mobile operators' strategy they either deployed dual-band cellular antennas which supported GSM and UMTS in either a space or polarisation diversity configuration or, alternatively, chose to deploy separate antennas. Figure 4 illustrates a tower with two mobile operators adopting these different strategies. The antennas that stick up from the head-frame are TETRA antennas and therefore not relevant here; the panel antennas on the top head-frame are dual band antennas (1800MHz and 2100MHz). The lower installation consists of separate antennas for 900MHz GSM and 2100MHz UMTS; the 3G antennas being the smaller of the two given the mathematical relationship between frequency and wavelength.

3G technology has evolved considerably since launch. Key developments include: the introduction of an IP transport network layer to replace the ATM technology and high speed packet access technologies which increase peak data rates to some tens of Mbit/s. Some UK mobile network operators have now re-farmed some of their 900MHz spectrum for UMTS use.

4G: All IP network with LTE and LTE-Advanced technology

Work on 4G standardisation started in 2004, just as 3G started to take-off. 4G refers to Long Term Evolution (LTE) and LTE-Advanced technologies (strictly LTE-Advanced if considering actual ITU-R definitions of requirements however LTE is commonly known as 4G). Spectrum for 4G is not as simple a story as it was for 2G or 3G. In fact at the time of writing there are some 42 frequency bands defined by 3GPP for LTE with three more in process so far in the next standards release (Release 13). Not all of these bands are available in the UK although the recent spectrum auction has added 800MHz and 2600MHz bands to those previously available for UK cellular services. Figure 5 illustrates a multi-band antenna system supporting 2G, 3G and 4G services. 4G introduces a revolutionary

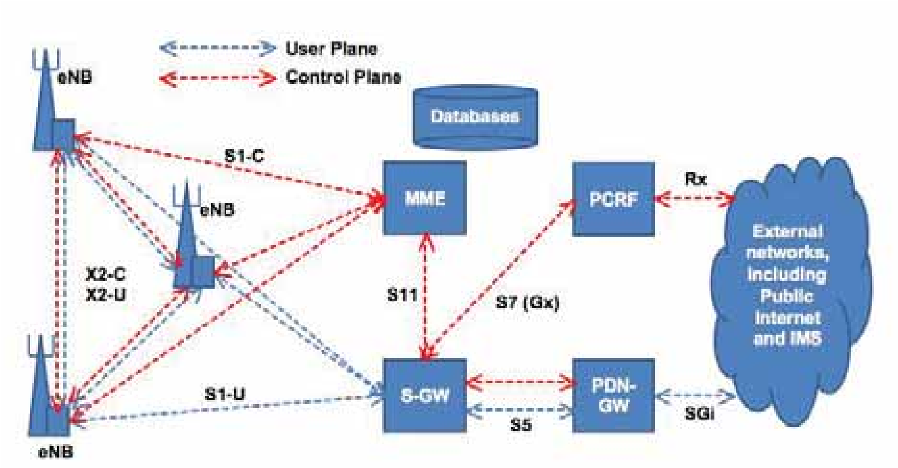


Figure 6: 3GPP Release 8 4G (LTE) network architecture

approach to network architecture; it is an all-IP-based network and for the first time offers no traditional circuit switching.

The 4G network introduces another new radio interface technology, this time based on Orthogonal Frequency Division Multiple Access. As mentioned the 4G network is all-IP therefore all interfaces are Ethernet-based while Carrier Ethernet provides the network connectivity. There is a complete implementation of separation of user and control plane, an approach we first encountered in 3GPP Release 4 back in 2001. The network architecture which is shown in Figure 6 looks quite different to 2G and 3G networks and makes use of a robust QoS framework to provide a range of differentiated services, including support for IP Multimedia Subsystem signalling and voice over IP, the combination of which provide what is known as Voice over LTE.

The eNB is an evolved Node B which is the 4G radio base station. The eNB is an intelligent node as most of the functionality of the network controller now resides within the base station (there is no standalone network controller in 4G), making the base station responsible for procedures such as mobility management. To implement the necessary procedures the eNB has to communicate with other eNB's that are adjacent to it with this communication taking place over the X2-C interface while any traffic forwarding is mapped to the X2-U. An X2 user plane is required to support certain mobility scenarios to ensure a seamless experience for the end user.

The S-GW is the Serving Gateway which together with the Packet Data Network Gateway (PDN-GW) provides user plane services to the 4G subscriber. These functions include; local mobility anchor for inter eNB handover, mobility anchor for inter-3GPP mobility, idle mode downlink packet buffering, packet routing and forwarding along with Differentiated Service Code Points (IP QoS) marking and charging. The PDN-GW functions include User Equipment IP address allocation via Dynamic Host Configuration Protocol functionality, per-user based packet filtering, Differentiated Services Control Point marking, data rate enforcement and lawful intercept.

“ The eNB is an intelligent node as most of the functionality of the network controller now resides within the base station. ”

The Mobility Management Entity (MME) is effectively the control plane functions of the SGSN. Functions include: signalling and signalling security, inter-node signalling for mobility between 3GPP access networks (e.g. 4G handover to 3G), tracking area list management, paging, S-GW and PDN-GW selection along with authentication and bearer establishment and management. Additionally the MME manages roaming connections towards the home Home Subscriber Server (an evolved Home Location Register).

The last node to consider is the Policy and Charging Rules Function (PCRF) which provides policy control data such as service data flow detection, QoS, prioritisation and flow base charging information to traffic handling nodes. Additionally the PCRF terminates the S7/Gx interface for home network services.

The first 4G network to launch within the UK was that provided by EE (formed from the merger of Orange and T-Mobile) in October 2012. In this particular case, permission had been granted from Ofcom to launch 4G services over their existing frequency spectrum and hence, their network launched prior to the official 4G auction. Vodafone and O2 launched 4G in August 2013 followed by Three in December 2013.

The latest developments in 4G have focused on Carrier Aggregation which is an LTE-Advanced technique that enables several carriers to be logically bonded together to offer higher peak and average data rates along with greater system capacity. Recent UK demonstrations of CA have included three component carriers and achieved peak data rates above 400Mbit/s which was achieved by use of 20MHz in the 1800MHz band combined with 20MHz and 15MHz in the 2600MHz band [3]. To ensure backwards compatibility with early 4G terminals the maximum bandwidth of an individual component carrier is 20MHz.

AUTHORS' CONCLUSIONS

During the last 30 years the UK's mobile phone networks have evolved considerably, from offering basic voice telephony in urban centres to providing high speed IP-based mobile broadband over a wide area. The move to digital communications started with GSM, a technology which revolutionised mobile communications on a global basis, and has continued through UMTS towards the current LTE-Advanced solutions. It is only possible to highlight a few topics relating to these technologies in this article and the reality is that mobile operators manage GSM, UMTS and LTE networks as one operational network today which requires complex converged designs alongside detailed network planning and optimisation. The rollout of LTE, introduction of truly multi-layered heterogeneous networks and evolution towards Network Functions Virtualisation will drive future innovations in network architectures and technologies as we move towards 5G [4] and the Internet of Things.

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ABBREVIATIONS

ATM	Asynchronous Transfer Mode
BSC	Base Station Controller
BTS	Base Transceiver Station
EDGE	Enhanced Data rates for GSM Evolution
ETACS	Extended Total Access Communications System
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Groupe Special Mobile
Iub	Interface between UMTS Node B and RNC
Iur	Interface between UMTS RNC's
Iu-cs	Interface between UMTS RNC and Circuits Switched Core
Iu-ps	Interface between UMTS RNC and Packet Switched Core
LTE	Long Term Evolution
MME	Mobility Management Entity
MSC	Mobile Switching Centre
PCRF	Policy and Charging Rules Function
PCU	Packet Control Unit
PDN-GW	Packet Data Network Gateway
PSTN	Public Switched Telephone Network
RNC	Radio Network Controller
RNS	Radio Network Subsystem
SGSN	Serving GPRS Support Node
TACS	Total Access Communication System
TRAU	Transcoder and Rate Adaptation Unit
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

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