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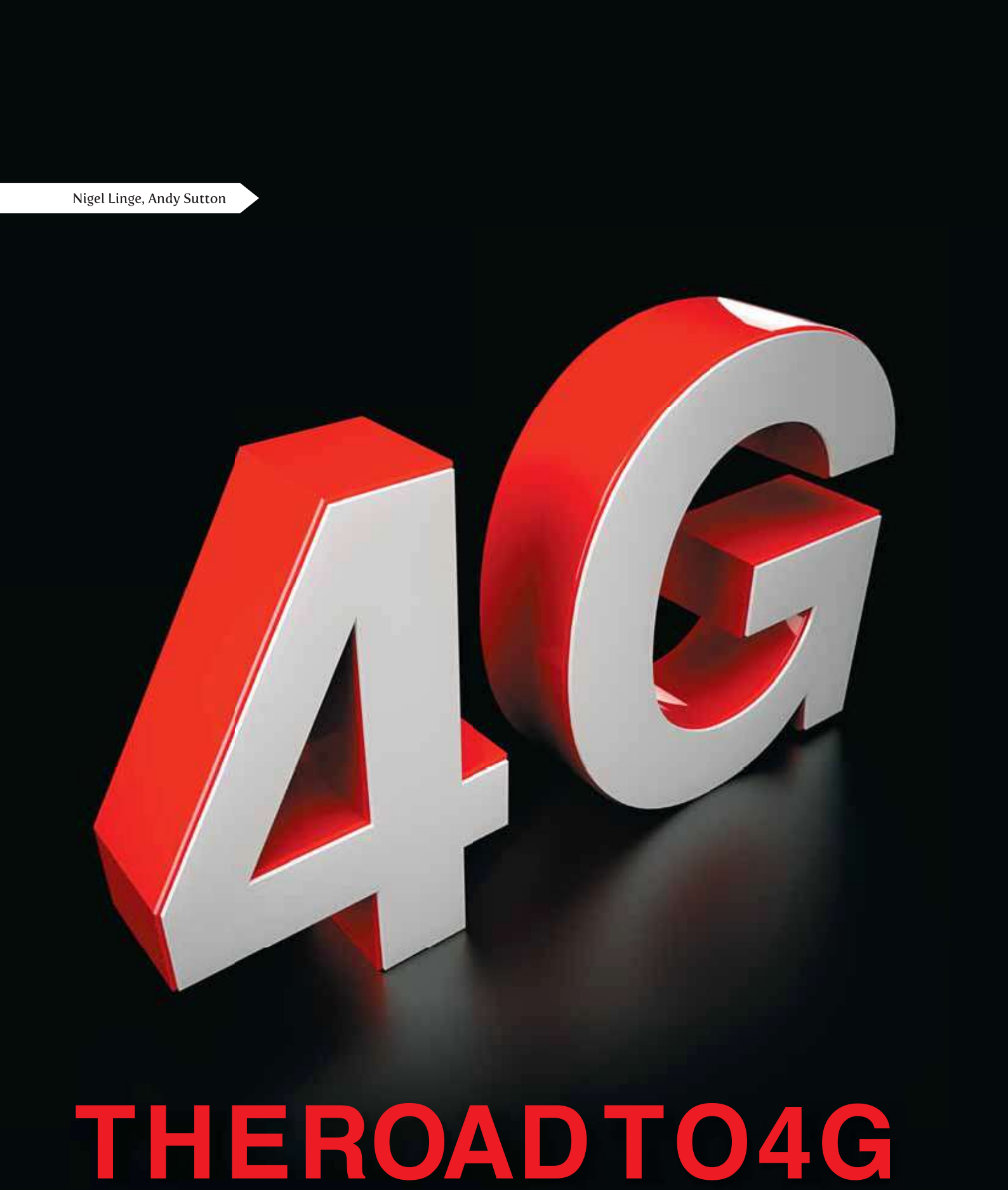

THE ROAD TO 4G

When Dr Martin Cooper of Motorola walked along Sixth Avenue in New York on 3 April, 1973, he entered the history books by becoming the first person to make a mobile phone call. But this is just part of the story. Nigel Linge and Andy Sutton examine the past, present and future of mobile technology.

The first ever mobile phone call, made on that historic April day in 1973, used the DynaTAC (Dynamic Adaptive Total Area Coverage) mobile that Dr Martin Cooper and his team at Motorola developed. This had its roots in technology that dated back to the mid 1940s.

During WW2, Motorola pioneered the development of the walkie-talkie epitomised by the American military's SCR536. This two-way radio transceiver, with its push-to-talk feature that allowed one radio to transmit and all of the others in range to listen, may have been a long way from a mobile phone but the experience gained in developing it would prove to be extremely useful later. On 17 June 1946 a team of engineers from Bell Labs demonstrated the world's first telephone call using a car radio phone and by 1948 that service had been made available in 100 cities across America attracting 5,000 customers who were making 30,000 calls per week. A public radio telephone service was introduced into the UK by the Post Office for customers in South Lancashire on 28 October 1959. That service was controlled by the Peterloo exchange in Manchester with two radio base stations, one at Winter Hill and the other in Liverpool. This service was subsequently extended to London in 1965 with the opening of the Post Office Tower and was inaugurated when the Postmaster General made a telephone call to the TV presenter, Richard Dimbleby, who was travelling in his chauffeur-driven Rolls Royce.

However, these networks could not handle large call volumes and there were only a few radio channels available which severely limited the number of simultaneous calls that could be handled. A more elegant network design was proposed in December 1947 by Douglas H. Ring, an engineer working at Bell Labs. His technical memoranda entitled, Mobile Telephony – Wide Area Coverage, set out the basic principles of a cellular network in which the country is divided up into a series of small geographic areas called cells, each of which is controlled by a single radio base station. By keeping the transmitted power low, a key feature of this architecture was that frequencies could be re-used providing that no two adjacent cells used the same set of frequencies. Unfortunately for Bell Labs, the technology in 1947 was simply not capable of realising this vision and hence this is why the more primitive radio phone service was deployed.

In 1973 Dr Martin Cooper made the first handheld mobile phone call outside the Hilton on Sixth Avenue, New York.

One year after Dr Cooper's famous telephone call, the Federal

Communications Commission in the USA released part of the radio frequency spectrum to permit a larger scale experiment. But it was not until 1977 that Illinois Bell, the AT&T operating company for Chicago, installed a trial cellular network comprising 10 cells. The success of this network then led to the development of the American Advanced Mobile Phone System (AMPS) used by Illinois Bell in their first commercial cellular system which opened in October 1983. This used the frequencies 824 - 849MHz for transmission from the mobile and 869 - 894MHz for transmission from the cell's base station. Within these frequency bands, each voice call was allocated a 30kHz analogue radio channel using frequency division multiple access.

In Europe, mobile phone development was led by the Scandinavian countries, collectively creating the Nordic Mobile Telephony (NMT) network which was launched in Sweden and Norway in 1981 and Denmark and Finland in 1982. The first NMT network was based on 450MHz and hence became known as NMT-450 and this was followed in 1986 by a second network that used the 890 - 960MHz frequency band and became known as NMT-900.

The UK Government announced in 1982 that two licences would be offered for the provision of mobile phone network services. One of these licences was to be awarded to British Telecom working in partnership with Securicor which resulted in the creation of Cellnet, while the second was opened up for competitive bids. The successful bidder for this second licence was Vodafone (VOice and DAta over the teleFONE), a joint venture between Racal Electronics and Millicom. Both of these networks adopted a version of the AMPS system which became known as the Total Access Communication System (TACS).

Initially the UK Government announced that they had reserved two 25MHz frequency bands for TACS namely, 890 - 915MHz and 935 - 960MHz. However, only 15MHz of these channels was actually released. Therefore, TACS used 890 - 905MHz for transmission from the mobile and 935 - 950MHz for transmission from the cell's base station giving it a capacity of 600 x 25kHz channels. Vodafone was the first UK network to officially launch when comedian Ernie Wise made a mobile telephone call from St Katherine's Dock in London to Vodafone's offices in Newbury on the 1 January 1985. Cellnet launched shortly afterwards on 7 January, 1985; its network was centred on a single base station at BT Tower that provided coverage for the whole of Greater London.

> “The need for a single European standard for mobiles was identified as early as 1982.”

Motorola were especially influential in these early days which saw their iconic DynaTAC 8000 series of mobiles being replaced by the world's first flip phone, the Motorola MicroTAC and then the first clamshell phone, the StarTAC which was not only the world's smallest at the time but also weighed in at an extremely light 105g. These early days also saw Finnish company, Nokia, establish themselves as the world's second largest mobile phone manufacturer with the launch of their Cityman range of mobiles which was followed by the Nokia 101 candy bar design.

Owning a mobile phone at this time was expensive which meant that companies marketed the mobile to the business community showing the benefits of always being in contact with the office or your customers. The Motorola DynaTAC 8000X for example cost £2,500 to purchase. On top of this you had a monthly contract fee with your mobile phone network provider and had to pay call charges too, calculated on a per minute basis.

By the end of 1986 there were 100,000 mobile phone subscribers within the UK which doubled to 200,000 by the summer of 1987 and by the end of 1995, 7% of the UK population owned a mobile phone. The mobile phone also started to become accepted as part of society but these first generation analogue models had a major limitation; service stopped at the English Channel! Whilst mobile networks existed in all European countries, these were not based on common standards or frequencies.

EUROPEAN AGREEMENT AND THE MOVE TO DIGITAL

The need for a single European standard for mobiles was identified as early as 1982 when a working group was set up by the European Conference of Post and Telecommunications (CEPT) administrations to harmonise the public mobile communications systems in the 900MHz band. It was called Groupe Speciale Mobile (GSM) and first met in Stockholm in December 1982. The culmination of this group's 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. Signed in Copenhagen by telecommunication operators from 13 countries, this document would later be described by Chris Gent, the Managing Director of Vodafone, as ‘the most important document in the history of the mobile phone’.

The onward development of GSM was transferred from CEPT to the European Telecommunications Standards Institute (ETSI) and the final specification for his second generation network was to see a move from analogue to digital transmission.

The world's first GSM telephone call was made by the Finnish Prime Minister Harri Holkeri on the Radiolinja mobile network in Finland which he inaugurated on 1 July 1991. Within the UK a study suggested that demand existed to accommodate more mobile phone operators but there was insufficient spectrum to accommodate them. Therefore, an additional frequency band at 1800MHz (1710 - 1785MHz from the mobile and 1805 - 1880MHz from the base station) was made available for GSM.

Termed Personal Communication Networks (PCN) these new

networks were announced by Lord Young, Secretary of State for Trade and Industry, on 22 June, 1989, in the document, *Phones on the Move*.

Three PCN licenses were issued, although a merger between two of the license holders resulted in just two new network operators, these being Mercury Communications who created the One2One network and Hutchison Telecom who named their network, Orange. Within the UK, Vodafone launched the country's first 900MHz GSM network in July 1992 which was followed in September 1993 by Mercury One2One who launched the UK and world's first 1800MHz GSM network, known at the time as DCS1800. The other two network providers, Cellnet and Orange, launched their GSM networks in December 1993 and April 1994 respectively.

The first GSM-approved mobile phone for use within the UK was the Orbitel TPU900 which became available in 1991. In 1992, Motorola launched their first GSM mobile, the Motorola 3200 and Nokia launched their 1011 on the 10 November 1992. Most significantly, because GSM was a true pan-European standard, this created an economy of scale that attracted other manufacturers into the mobile market, such as Bosch, Siemens, Samsung, and AEG.

A digital mobile phone system naturally offered the ability to send data other than voice calls. One of these other digital services was the Short Message Service that allowed 160 character (7-bit) messages to be transmitted over the mobile phone signalling channel. Now more commonly called texting, the world's first text message is attributed to two Vodafone employees, Neil Papworth and Richard Jarvis, who sent their 'Merry Christmas' text message from a computer to a mobile on the 3 December, 1992.

Early mobiles could only receive text messages, but once the ability to transmit them became available there was an explosion in usage that has seen year-on-year increases until 2013, when the first ever decline - down 5% to 145 billion messages for the year - was recorded. However, within the UK the top texting days remain Christmas Day, New Year's Day, Valentine's Day and GCSE/A Level results day.

1. 1G analogue (ETACS) mobiles;

2. 2G GSM mobiles;

3. 2.5G (GPRS) and 2.75 (EDGE) mobiles;

4. 3G mobiles;

5. 4G v 3G speed test (Apple iphone 3Gs and Samsung Gala`xy S4).

The transition from first generation analogue to second generation digital networks also saw the mobile phone move from being the preserve of the business commercial user to become a must-have device for the domestic general user.

Mobile phones would soon be seen as an essential part of modern living, and for the UK, 1999 was a tipping point when a new mobile phone was being sold at the rate of one every four seconds and ownership doubled to 46% of the population, reaching 73% the year after.

Companies would soon start to market the mobile as a device that combined the convenience of being able to keep in touch on the move with a fashion item and entertainment centre.

Nokia was one of the first companies to recognise the desire for people to personalise their phones and turn them into entertainment devices. Released in 1994, the Nokia 2110 became the first to use the now famous, indeed iconic, Nokia ringtone.

The Nokia 5110 allowed people to change the phone's covers to reflect their mood or style, and the Nokia 6110 was the first to feature the cult mobile game, Snake. Consequently, whole new businesses emerged to support all of these features and capabilities.

A public radio telephone service, first introduced in 1959, was extended to London in 1965 with the opening of the Post Office Tower. The first call was made to TV presenter, Richard Dimbleby, travelling in his chauffeur-driven Rolls Royce.

DATA USAGE DRIVES BAND-WIDTH DEMAND

Further evolution of the mobile would see it acquire more and more functions normally associated with a computer.

It started with the IBM Simon released in the USA in 1994 and was then followed by the Nokia 9000 Communicator that combined email, word processor, diary, mobile phone and fully QWERTY keyboard, packaged as a clamshell form factor and released in 1996. Once a mobile began to adopt the functionality of a computer, there was a drive to find a new way of describing such devices. The Ericsson R380 released in 2000 was the first of this new breed to be marketed as a 'smart-phone'.

Despite a faltering start with mobiles such as the Nokia 7110, accessing the Internet from your mobile became a major driver for enhancing the data carrying capabilities of mobile networks. The General Packet Radio Service (GPRS) introduced a separate packet switched data network. The Base Station Controllers that managed the Base Transceiver Stations within each cell, had to separate voice calls from data, directing the data to a Serving GPRS Support Node that provided an interface to a dedicated and separate data transport network. This network then connected to the Internet via a Gateway GPRS Support Node. Data rates now increased from 9.6kbit/s to a maximum of 170kbit/s.

Cellnet launched the world's first GPRS (2.5G) network in June 2000, followed by Vodafone in April 2001, Orange in December 2001 and T-Mobile (the new owners of the one2one network) in June 2002.

An increase in data capacity resulted in corresponding further enhancements to the mobile. Screens became larger and moved from monochrome to colour, email applications became commonplace and perhaps most significantly, mobiles acquired a digital camera.

New data encoding algorithms pushed the data carrying capacity of 2.5G upwards to 470kbit/s with the launch of Enhanced Data Rates for GSM Evolution (EDGE), sometimes called 2.75G. The first network to launch with EDGE was Orange on 8 February, 2006.

3G AND THE £22 BILLION AUCTION

Data continued to be the driving force behind further mobile development and the next major advance came in the form of Universal Mobile Telecommunications System. This 3G network operated at 2.1GHz and introduced a new radio interface based on Wideband Code Division Multiple Access, a new radio access network and broadband connectivity between network elements which enabled data rates up to 384kbit/s. However, the most significant point about 3G was the introduction of a different frequency band and hence, the requirement to award new licences to operate at these frequencies. A competitive auction was instigated in April 2000 and collectively five mobile operators bid a total of £22.47 billion to acquire these licences. Vodafone, Cellnet, Orange and T-Mobile were joined by new entrant Three.

The price paid for these licences was not only costly in terms of money, but also resulted in delay before commercial services could be launched. Three launched a fledgling service in March 2003, followed by Vodafone in April 2004, Orange in July 2004, Cellnet (now rebranded as O2) in February 2005 and T-Mobile in October 2005.

Early 3G mobiles such as Motorola's A830 and Nokia's 7600 were noticeably larger than their predecessor 2G models. By 2006 the 3G smartphone was increasingly of a slider form factor with a

conventional telephone style keypad and colour screen, exemplified by the Nokia N95. What few people realised was that the world of the smartphone was about to undergo a revolution in 2007.

On 7 January, 2007, Steve Jobs announced that Apple were entering the mobile phone market and, by considering the mobile as a computer first and phone second, brought a whole new insight to handset design. The Apple iphone proved to be a truly disruptive piece of technology that redefined mobile phone design and introduced the world to the app - despite the fact that the first model was only a 2G device.

Steve Jobs announced that Apple was entering the mobile phone market on 7 January, 2007.

3G had to evolve to address the ever growing demand for mobile data; HSDPA (High Speed Downlink Packet Access) was introduced to provide a best effort, high speed data downlink channel which made use of a higher order modulation format known as 16QAM, (Quadrature Amplitude Modulation) and adaptive coding, as well as having access to QPSK (Quadrature Phase Shift Keying) modulation, as per the original 3G radio interface. Over the following years the 3G downlink and uplink continued to evolve with downlink capability reaching 21Mbit/s with the introduction of 64QAM and evolving still further with channel aggregation capabilities known as dual cell.

AND SO TO 4G

As experienced with all previous generations of mobile communications technology, there is approximately a 10 year development cycle from concept to live network services. This cycle was not significantly different with 4G; the plan was first conceived in 2004 as the next step in the evolution of the 3rd Generation Partnership Project (3GPP) radio interface to deliver Global Mobile Broadband. The plan was driven by the work of operator-led organisation the Next Generation Mobile Networks Alliance, which specified the plan based on some key criteria which included clearly defined performance targets, clearly defined economic targets, improved use of radio spectrum and simplified system design.

4G mobile communications arrived in the UK on 30 October, 2012, with the launch of EE, a new brand from Everything Everywhere (the company formed by the merger of Orange UK and T-Mobile UK back in 2010). Everything Everywhere, now renamed EE, received permission from Ofcom to refarm (a term used for spectrum reallocation) some of their 1800MHz spectrum from 2G GSM to 4G Long Term Evolution (LTE) use. This enabled EE to launch a service prior to the auction for new mobile spectrum in the 800 and 2600MHz bands.

Launching 4G in the 1800MHz band meant that antennas, feeder cables and low-noise amplifiers in the receive path could be reused thereby enabling a fast and effective roll-out of 4G to the UK. In fact the roll-out was one of the fastest in the world to date and is still on-going to increase geographical coverage and in-building penetration. Since the 4G spectrum auction there have been 4G roll-out and service launches from O2, Vodafone and Three, while BT also purchased some spectrum in the 2600MHz band, therefore ensuring a very competitive 4G landscape for the benefit of UK consumers.

4G is very different when compared with previous generations of mobile technology; there is no traditional circuit switching domain. Circuit switching is the technique that has been in use since the invention of the switched telephone network. But 4G is packet switched only, therefore voice must be carried as voice over IP, a trend we're also seeing on fixed networks. Prior to this voice over IP capability, or, voice over LTE (VoLTE) as it's more commonly known, operators have implemented a technique known as circuit switched fall-back in which a 4G device is pushed to 3G or even 2G, as necessary, to make or receive a voice call. It is anticipated that VoLTE will be launched in the UK during 2014.

Smartphones are now available covering all of the UK 4G frequency bands and these new devices offer a true mobile multi-media experience.

Data rates on 4G are typically some tens of Mbit/s in the downlink (from network to device) and often quite similar in the uplink (device to network), where up to 50Mbit/s is possible. Typically latency in 4G networks can be as low as 40 or 50 milliseconds, compared to 100+ milliseconds which is common on 3G. Consequently, video consumption on 4G is already significantly higher than on previous generations of mobile technology due to this improved performance.

As 4G evolves with a technology known as LTE-Advanced (LTE-A), even higher peak and average data rates will be possible. Indeed, EE recently demonstrated in London the use of LTE-A carrier aggregation which aggregates two downlink 20MHz channels to create one logical 40MHz channel delivering speeds of up to 300Mbit/s. In fact London, the city where the UK's first mobile phone call was made over 40 years ago, can now claim to be the fastest 4G city in the world!

AUTHORS' CONCLUSIONS

The mobile communications industry has evolved at a remarkable pace, from large analogue bricks which could only make phone calls, to today's high-end smartphones which are effectively hand-held computers with full multi-media capability. The pioneering work between the 1940s and 1970s laid the foundation for the cellular networks we know today while ETSI's bold move in 1982 started something quite amazing and fundamentally changed the way people communicate and access information forever.

Looking forwards, 2G, 3G and 4G will likely co-exist for several years however the future is 4G with 5G coming along as and when appropriate. Given the typical 10-year development cycle, it is good planning to start 5G research now as 4G networks launch. The UK is determined to play a key role in 5G research and development with recent funding from central Government and industrial partners leading to the creation of the 5G Innovation Centre which is run by the Centre for Communications Systems Research at the University of Surrey.

ABBREVIATIONS

AMPS	American Advanced Mobile Phone System
CEPT	European Conference of Post and Telecommunications
EDGE	Enhanced Data Rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
GPRS	General Packet Radio Service
GSM	originally Groupe Speciale Mobile, now Global System for Mobile Communications
LTE	Long Term Evolution
LTE-A	LTE Advanced
NMT	Nordic Mobile Telephony
PCN	Personal Communication Network
QAM	Quadrature Amplitude Modulation
TACS	Total Access Communication System
VoLTE	Voice over LTE

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Nigel Linge is Professor of Telecommunications at the University of Salford. He is an electronic engineer by profession who specialises in computer networks and their applications and has research interests that cover location and context based services, communication protocols, the delivery of multimedia applications, network design and the use of networks for sensing. In addition, he takes a keen interest in telecommunications heritage and is active in public engagement. In 2013 he was chosen as the presenter of the ITP's Family Christmas Presentations for which he delivered his lecture entitled, Your world in your hand at five venues around the UK. Nigel is a Chartered Engineer and Chartered IT Professional, a Fellow of both the Institution and Engineering and Technology and British Computer Society and a member of the ITP and the ITP's Editorial Board.

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Andy is a research mentor and industrial partner of the 5GIC at the University of Surrey, Andy also holds the post of Visiting Professor at the University of Salford and EE were a co-sponsor of the 2013 ITP Family Christmas Presentations.