5G THE FUTURE OF MOBILE COMMUNICATIONS

ANDY SUTTON, RAHIM TAFAZOLLI

Researching 5G – delivering the vision

5G technology is receiving lots of attention in the media even though the term 5G isn't formally defined yet; the formal definition will come from the International Telecommunications Union in the near future. There is, however, a significant amount of research on-going in the UK and elsewhere to develop candidate technologies to deliver the 5G vision of the future.

The 5G Innovation centre (5GIC) at the University of Surrey in Guildford, a key organisation within the UK, describes 5G as the next generation of mobile connectivity technologies that supports mobile broadband as well as networking of billions of devices. 5G will be a flexible infrastructure capable of handling ever-increasing demand for mobile data and providing connectivity for future technologies such as the Internet of Things (IoT). In one sentence; the 5GIC vision is "always sufficient rate to give users the perception of infinite capacity".

The mobile journey

Mobile technology has been on a rapid journey since the launch of digital cellular systems in the UK some 20 years ago. Work on Global System for Mobile Communications (GSM) started in 1982, prior to the introduction of 1st generation analogue cellular in the UK.

The goal of GSM was to provide a pan-European system with international roaming between member states, something which wasn't possible with country-specific 1st generation technologies. GSM delivered a standard which, in the early 1990s, was widely adopted, not just in Europe. The early GSM standards supported Short Message Service and circuit switched data, enabling users to connect laptops to external data networks. The increasing demand for data, and in particular Internet access, led to the development of General Packet Radio

Figure 1: Representatives from the University of Surrey, Ofcom and Founding Members at the official signing ceremony

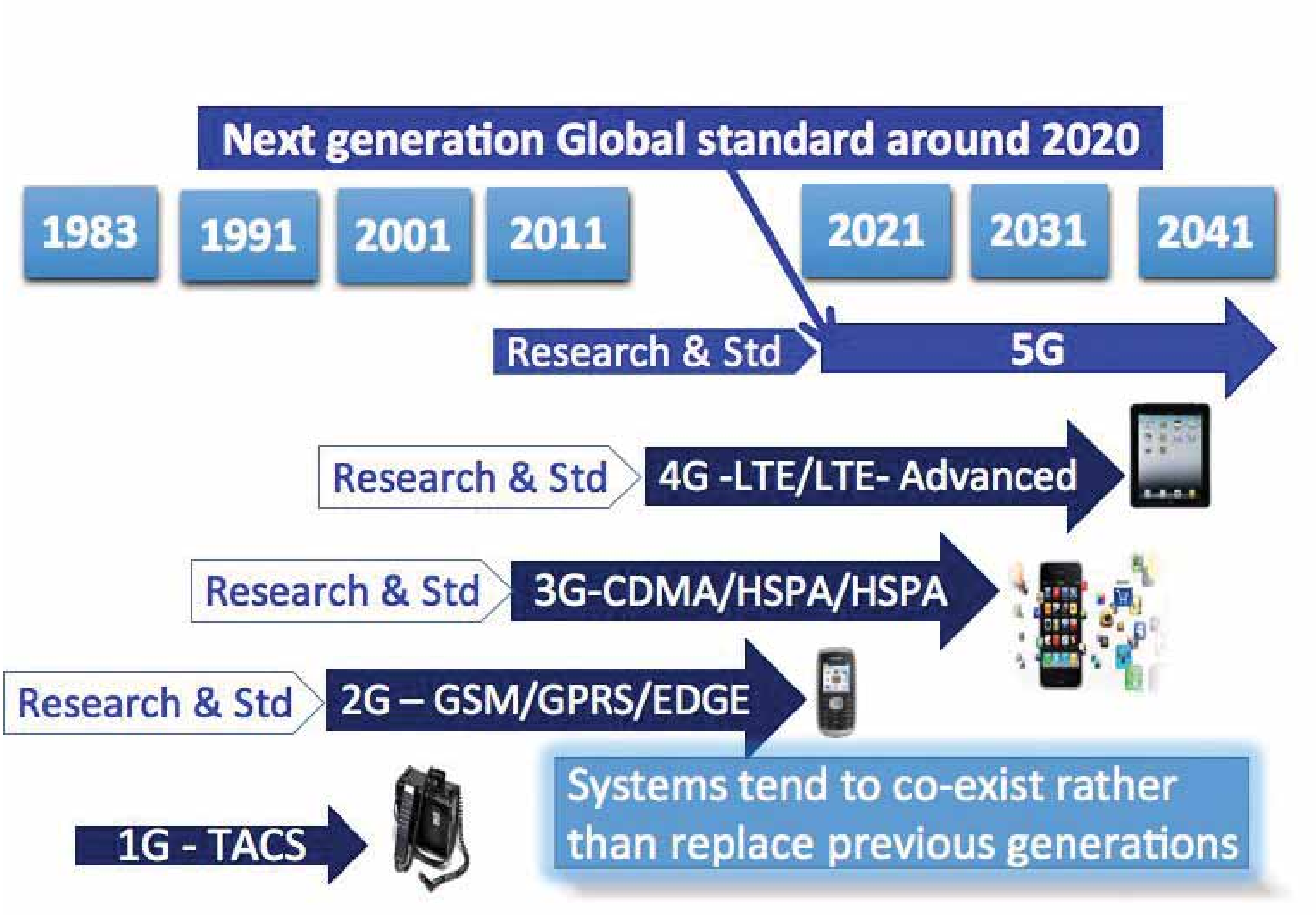

Figure 2: Wireless standards evolution

Service which introduced packet-switching capability to GSM running in parallel with the existing circuit switched network.

The introduction of 3G was based on the same architecture as GSM/General Packet Radio Service although with a new radio interface to support higher data rates and greater capacity. This was subsequently enhanced with High Speed Packet Access technologies.

The big change to cellular network architecture came with 4G or Long Term Evolution (LTE). LTE is an all-IP network with no circuit switching, voice is simply IP data with a high Quality of Service applied and implemented. This move to an all-packet-based system enables a much simplified network architecture and the use of an advanced Quality of Service and policy control framework enables a wide range of new and innovative services to be delivered.

5G is expected to be standardised by the year 2020 and will be commercially deployed a few years later. Although 5G will introduce new technologies, much will be an evolution of 4G LTE-Advanced and WiFi both of which are developing to offer ever greater peak and average user data rates and new and innovative services.

The shortening timelines between research and commercialisation is illustrated in Figure 2.

5G Innovation Centre

The 5GIC is the UK's only research centre dedicated to the next generation of mobile communications[1]. Bringing together leading academic expertise and key industry partners in a shared vision, it will help to define and develop the 5G infrastructure that will underpin the way we communicate, work and live our everyday lives. The founding members (see Figure 1) signed up to 5GIC in October 2013 during a ceremony hosted at the University of Surrey.

The new 5GIC building (see Figure 3) is due to open in September 2015. The 5GIC is part of the University's Institute for Communication Systems and will draw on the University's international renown in satellite and terrestrial mobile communication systems and IoT. The Institute for Communication Systems made a major contribution towards the development of 2G technology in the 1990s, 3G in the 2000s and 4G since 2010.

Research in the 5GIC will drive the delivery of a mobile communications and IoT

[1] See http://www.surrey.ac.uk/5gic

Figure 3: Artist's impression of the 5GIC

network capable of meeting tomorrow's needs. The focus will be on developing intelligent systems that work together to give the impression of unlimited data capacity, providing a network that is far faster (low latency) than today's 4G system, with greater energy-efficiency and reduced end-user costs.

Research will be conducted in close collaboration with 5GIC's members, including the major telecom service providers and mobile device manufacturers. 5GIC offers the UK's only large-scale test-bed, which will be used to prototype solutions, helping to define 5G as it moves towards standardisation in 2016. It also hosts dedicated specialist laboratories for network testing and management, and communications electronics.

The 5GIC is funded by £12 million from the Higher Education Funding Council for England and over £60 million co-investment from the Centre's Members (see Figure 4). 5GIC members represent many aspects of the evolving eco-system and new members are welcome.

Spectrum

Finding additional radio spectrum to allocate to 5G network is a key consideration; currently there are 46 bands available for LTE and this is likely to increase still further with 3GPP standards Release 13. Finding space for 5G is a challenge which will be addressed at the World Radio Congress 2015, particularly in the traditional cellular spectrum sub 6GHz bands (noting most cellular activities to date are limited to 2.6GHz and below). In addition to sub 6GHz spectrum there is interest in the use of higher frequency bands, including the millimetre wave bands above 30GHz; this is likely to be addressed at a future World Radio Congress.

Figure 4: 5GIC members

Requirements

5G will need to offer far greater capacity and be faster, more energy-efficient and cost-effective than anything that has gone before. The flexibility in support of narrowband as well as wideband and user-centric communications are salient features of 5G. Essentially, 5G will be a holistic framework for all our connectivity needs and it will need to be flexible enough to evolve, adapt and grow, just as the Internet has.

Greater capacity – 5G will significantly focus on users and their needs. The aim will be to give users the impression of unlimited capacity while juggling available resources. This will be achieved by (a) better prediction of user demand so that applications perform bandwidth-heavy tasks when the network is least loaded (effectively reducing latency when heavily loaded) and (b) better use of all available wireless networks' resources.

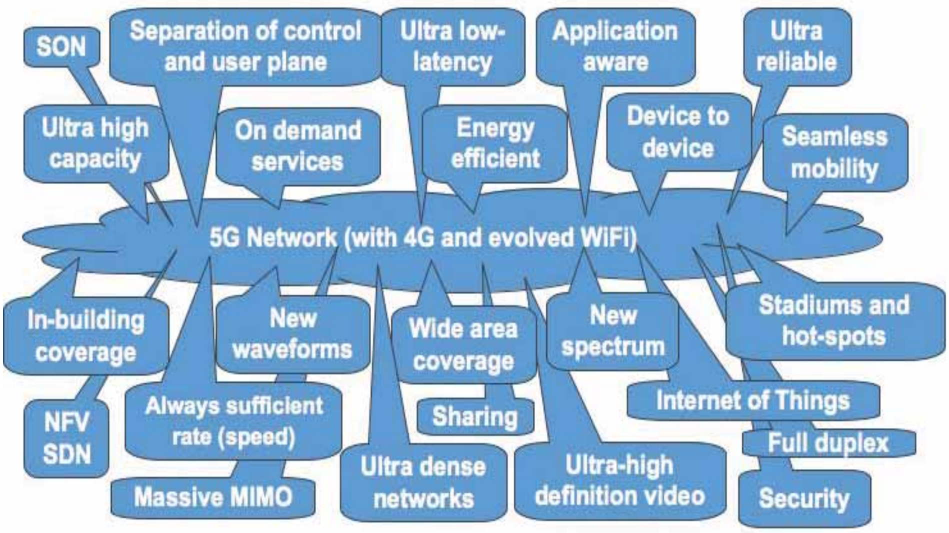

Figure 5: Some key 5G research topics

Devices and applications – The proliferation of smartphones is driving ever-increasing demand for mobile data – some predict it will grow a hundred-fold over the next decade. At the same time, we are just beginning to see the emergence of IoT, whereby billions of devices will become connected to help us achieve everyday tasks such as finding a parking space, or checking the fridge is stocked. In the future, many applications, from advanced gaming and wireless robots to autonomous vehicles, will require much lower latencies to enable very rapid reactions.

Cost-effectiveness – Although data could grow up to a hundred-fold, monthly bills cannot increase pro-rata if 5G is to become mainstream.

Energy efficiency – Reducing energy consumption will be another key focus, both to lessen emissions and to improve end-user benefits such as enabling longer battery life and providing innovative energy solutions for wearable devices.

Business models – There will be the need to support a wide range of business models. For example, as well as paying operators to provide users with coverage, users may be able to charge others for the coverage provided by Wi-Fi routers or femtocell home base-stations.

Research

Figure 5 details some key 5G research topics and these are explored further below.

The term ultra appears four times in Figure 5 signifying the scale of the challenges.

- ***Ultra high capacity*** – refers to overall area capacity requirements which differs by geo-type from dense urban, urban, suburban, rural to sparse rural. There should always be sufficient capacity to ensure the user has the perception of infinite network capacity. Figures, such as an initial 1,000-fold more capacity than LTE later rising to over 5,000-fold, are quoted.

- ***Ultra low-latency*** – is a key requirement for a number of reasons. Firstly today's higher layer protocols work better with lower latency. Secondly, low latency can enable a range of new and innovative use cases including immersive real-time video and the tactile web which introduces haptic feedback.

- ***Ultra reliable networks*** – are becoming a requirement for a number of reasons including the increasing reliance on mobile communications for personal and business activities as well as the increasing use of mobile networks to support machine-type communication and business critical applications. Applications, such as eHealth, smart transportation and critical infrastructure, will push the requirements for ultra reliable network to a new level.

- ***Ultra dense networks*** – will be demanded in certain geographical areas by means of a contiguous layer of small pico-cell coverage. These will deliver significant area capacity density through spatial re-use of spectrum resources along with tight scheduling coordination between adjacent cells and the macro base station layer.

Energy efficiency is important. An objective is to deliver the capacity and performance benefits without consuming any more energy than current cellular systems. There are many research areas which will contribute to this goal from more efficient radio interface technologies, smart antennas, simplified network architecture to predictive mobility management. In-building solutions will play their part thereby avoiding the need for radio transmission through external windows, the glass of which often has thermal properties which would otherwise significantly attenuate the signal.

In-building solutions, along with stadiums and hot spots, present unique challenges to the design and implementation of cellular radio systems. Buildings vary considerably from residential premises, which range from large multi-tenant dwellings to single detached houses, to offices, shops, warehouses and entertainment venues. The in-building solutions will differ and must be tested against a range of use cases. Stadiums present a particular challenge in that they are empty most of the time but, when an event takes place, some tens or even a hundred thousand people all want to use their smartphones and other connected devices.

Although ultra dense areas with ultra high capacity demands are a major focus, another key driver is to extend coverage to all parts of a country, irrespective of geo-type. Rural coverage is essential and therefore wide area coverage building on 4G coverage, which itself is being extended to more and more rural communities, is a 5G requirement and will be a focus of 5G research. This could include techniques such as relays and mesh networks through to device-to-device communications. Device-to-device use cases will also play a key role in a wide range of applications from critical communications to local hubbing and aggregation of an ever-growing range of connected objects which form the IoT. Device-to-device communications will find application in and between vehicles, which may share traffic information, provide collision avoidance information and/or assist with the control of autonomous vehicles/self-driving cars.

Related developments

There are several hot topics running in parallel with 5G today including Networks Functions Virtualisation and Software Defined Networks[2]. The former enables a flexible 5G architecture so that networks (rather than network operators) can place particular functionality in specific nodes for a given scenario allowing the distribution of functionality across a network to be altered based on requirements. This intelligent reconfiguration of functionality will be controlled by advanced Self Organising/Optimising Network algorithms that link with the network operators' Operational Support Systems/Network Management Systems to provide real-time resource optimisation. The span of this reconfigurable network functionality will range from dynamic allocation of spectrum assets to the placement of content at appropriate cache locations based on specific real-time demands. One of the main drivers for content caching is the growth in video content consumption on or via mobile devices. EE recently stated that 67% of all data traffic will be video content by 2018 rising to 76% by 2030. One of the drivers for this significant increase will be the adoption of ever higher rate video codecs such as 4K Ultra High Definition TV[3]. To address this demand from a radio perspective, there is on-going research into full-duplex radio, which allows transmission and reception of signals on the same frequency at the same time, effectively doubling spectrum efficiency.

Partnerships

From a business perspective we are likely to see a number of new partnerships as the 5G eco-system evolves building on some of the network-sharing models we see today but involving a much wider eco-system. For example, lampposts can be used to accommodate small pico-cells and thereby offer an opportunity for revenue generation for local authorities. Offering greater digital connectivity can enhance the appeal of an area and therefore, by partnering with network operators, it is possible to enhance the cellular network to the mutual benefit of all parties. Similarly, the integration in-building solutions and maybe even external antennas into buildings from the outset could be an opportunity for construction companies.

5GIC work areas

To deliver this vision, 5GIC has identified seven key work-areas:

Content, user and network context – This addresses the capture, analysis and utilisation of context data related to various players, such as content objects, end users and devices in the 5G network ecosystem, as well as the network itself. Such comprehensive context information can be used to intelligently control the network resources in order to achieve "perceived Infinite Capacity". To this end, a content- and context-aware network architecture and its supporting protocols and mechanisms will be developed with a control framework for holistically supporting both multimedia content and IoT-based applications.

New physical layer – This focuses on an air interface design for dense small cells with higher spectral efficiency, reduced latency, relaxed synchronisation requirements and higher energy efficiency. Topics include new wave forms (including non-orthogonal and enhanced orthogonal wave forms), massive multiple input, multiple output, use of larger bandwidths and flexible implementation of spectrum aggregation, different duplexing methods, and the capability for Device-to-Device communications.

Light Media Access Control and Radio Resource Management – The aim here is to improve the radio resource usage in heterogeneous networks consisting of macro and dense small cells by better co-ordination amongst the cells to improve spectral efficiency, controlled latency and/or lower energy usage. Work will also cover efficient Light Media Access Control protocols for smart and adaptive use of radio resource with low overheads, solutions for self-configuration and user mobility management for small cell networks, and wireless front- and backhaul for small cell networking and local access.

Multi-cell joint processing – An important characteristic of mobile systems is the overlap between nearby radio cells. This becomes more prevalent as we move towards increasingly dense and heterogeneous networks. With ever increasing signal processing capabilities, the overlap can be managed to reduce interference, or to actively combine signals across multiple cells to boost capacity and data rates. The research is on utilisation of interference to our benefit rather than fighting it.

Antennas and propagation – Wireless systems require reliable, compact, efficient and intelligent antennas both at base stations and wireless devices. In the 5G era such devices could take the form of any "thing" – not just traditional mobiles. Each device will be used in different ways, in different environments and at different frequencies, and will therefore have highly variable propagation characteristics and need to be modelled appropriately.

[2] See The Journal Vol 8 Pt 2 for more information on Networks Functions Virtualisation and Software Defined Networks

[3] See The Journal Vol 8 Pt 3 for more information on 4K Ultra High Definition TV

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Research will deliver novel intelligent antenna designs to assist in meeting the 5G capacity demands, whilst also characterising the radio propagation environments in which such antennas will need to operate. In a number of cases, the propagation environments can be exploited in a way that maximises wireless data and takes full advantage of the available spectrum.

System architecture and coexistence – In the 5G environment, a new radio system architecture with a logical separation between the ability to establish network availability and to provide functionality or service could bring many benefits. Work will define how such a system architecture could really work, and the potential performance of this arrangement. Work will also develop systems with self-optimisation/organisation capabilities, and investigate dynamic spectrum sharing schemes to enable the coexistence of users supported by different systems as well as operation of both licensed and license-exempt bands and their impact on Media Access Control and Radio Resource Management.

Test-bed and proof-of-concept – An important mission 5GIC is to undertake technology implementation and performance evaluation. Proof-of-concept for selected ideas will be implemented on bench test-beds and/or on a campus-wide test-bed to verify the core ideas. The aim is to test innovative algorithms and analyse their performance when applied to a practical system and scenarios. This way, the pros and cons for each scheme can be identified and fed back to optimise the overall design. Key 5G technology solutions will be demonstrated in national and international workshops.

AUTHORS' CONCLUSIONS

5G takes mobile communications way beyond mobile phones and tablets through to an ever-growing and diverse range of devices or things.

Sensor networks will collect huge amounts of data which will be mined and processed to enable intelligent decisions to be made; for example, in support of an intelligent transportation system. 5G will intelligently understand the demands of users in real time, dynamically allocating network resources depending on whether the connected device need voice or data connectivity.

ABOUT THE AUTHORS

Andy Sutton
EE Principal Network Architect
Andy has responsibilities for EE's radio access network architecture evolution and mobile backhaul strategy and architecture. He has 30 years of experience within the telecommunications industry, mainly in radio access, transmission and transport network strategy, architecture and design. During the last 20 years in the mobile industry, Andy has worked for Orange, France Telecom Group, H3G and EE. He is a Chartered Engineer, Fellow of both the Institution of Engineering and Technology and British Computer Society and a Member of the ITP. Andy is a research mentor and industrial partner of the 5GIC at the University of Surrey, and holds the post of Visiting Professor at the University of Salford.

Rahim Tafazolli
Director, Institute for Communications Systems and 5G Innovation Centre (5GIC), University of Surrey
Rahim has published more than 500 research papers in refereed journals, international conferences and as invited speaker. He is the editor of two books on *Technologies for Wireless Future* published by Wiley's Vol.1 in 2004 and Vol.2 2006. He is currently, board member of many national and international research and innovation initiatives He was appointed as Fellow of WWRF (Wireless World Research Forum) in April 2011, in recognition of his personal contribution to the wireless world as well as heading one of Europe's leading research groups.

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ABBREVIATIONS

5GIC	5G Innovation centre
GSM	Global System for Mobile Communications
LTE	Long Term Evolution
IoT	Internet of Things