Emerging Technologies and Initiatives in R&D on 5G Networks

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***Abstract*—With increasing demand for high data rate cellular links as smart phones become commonplace, the race has started to define which technologies will constitute the next generation (5G) wireless standard. In this paper, we attempt to identify some emerging technological trends which may influence the make up of the next generation wireless standard. Some of these technologies are already being considered in standards such as 3GPP LTE, while others are still in the development phase.**

I. Introduction

The evolution of the mobile phone over the past decade has changed a device of single functionality to one which can almost rival a laptop in terms of functionalities and computational power. This transformation, coupled with an expanding cache of bandwidth hungry applications have triggered demands for higher data rates. Mobile data traffic has been forecasted to grow more than 24-fold between 2010 and 2015, and more than 500-fold between 2010 and 2020 [1]. This has been shown in the brisk uptake of 4G contracts and has driven operators worldwide to deploy 4G networks. As 4G starts to take hold as the dominant technology in different geographical markets, the attention is now slowly turning towards future 5G technologies.

II. What is 5G?

While there have been frequent talks about 5G and what features it will have, the general consensus on 5G technologies are still fuzzy at best. To fully understand what 5G is, we need to take a look at previous generations of cellular standards. Starting from third generation (3G), the International Telecommunications Union - Radiocommunication Assembly (ITU-R), defines a set of technical criteria (such as bandwidth efficiency) for which a cellular standard will need to meet in order to be considered to be part of that cellular standard generation. There can be more than one set of standards which make up a cellular standard generation. For example, to be branded a 3G standard, a standard will need to satisfy the IMT-2000 requirements [2] set out by ITU-R. There were six different cellular standards which satisfy the requirements and were subsequently adopted (including Wideband Code Division Multiple Access (WCDMA) and Worldwide Interoperability for Microwave Access (WiMAX)) by ITU-R. In 4G, the requirements set out by ITU-R was named IMT-Advanced [3], and two sets of standards met these requirements and were adopted (3GPP Long Term Evolution-Advanced (LTE-A) and WiMAX Release 2). A key feature of 4G listed in [3] is its ability to support data rates of up to 1 Gbps in low mobility scenarios and 100 Mbps in high mobility scenarios. Initial steps have already been taken to formally define technical requirements of 5G. In early 2013, ITU-R Working Party 5D (ITU-R WP5D) initiated the development of a new recommendation [4] which will set out the new criteria for 5G standards. While we may not yet know what the technical criteria for 5G are, we point out several technologies in the following sections which can potentially be included in future standards.

III. Initiatives in Europe

Europe has traditionally been at the forefront of telecommunications activities, well supported by both the industry and the European Commission (EC). In October 2012, the University of Surrey announced a new £35 million 5G innovation centre to research 5G technologies [5]. At approximately the same time, the European Commission announced €50 million in funding to develop 5G technologies [6], part of which will fund the €27 million METIS project [7] as part of its Framework 7 research grants. The objectives of METIS project is to develop technologies which will improve mobile data volume density by 1000 times, increase the number of connected devices by 10-100 times, and increase per user data rate by 10-100 times, among other things.

In association with the start of the EC's Horizon 2020 research funding programme, the EC also set up a 5G Infrastructure Public-Private Partnership (PPP) [8]. The role of the PPP is to make recommendations and provide advice to the EC to prioritise the most relevant research areas and topics which will advance 5G research. This will influence funding calls within the Horizon 2020 programme. The public funding set aside for 5G PPP related calls within Horizon 2020 is around €700 million.

IV. Emerging Technologies

In this section, we identify some of the most potential technologies which may possibly be included in the future 5G standards.

A. Small Cells

As the demand for higher data rates increases, one of the solutions available to operators is to reduce the size of the cell. By reducing the size of the cell, transmit power can be reduced as the power lost through propagation will be lower. With smaller cells, capacity is also improved by increasing frequency reuse, and reducing the number of UEs per cell. Additionally, coverage can be improved by deploying small cells indoors where reception may not be good and offloading traffic from macro cells when required. This solution has only been made possible in recent years with the advancement in hardware miniaturisation and the corresponding reduction in cost. Additionally, changes to the functional architecture of the access network allowed data and control signals to tunnel through the Internet, enabling small cells to be deployed anywhere with Internet connectivity. Small cells can have different flavours, with low powered small cells (or femtocells) typically used in residential and enterprise deployments, and the higher powered picocells used for wider outdoor coverage or filling in macro cell coverage holes [9], [10].

The concurrent operation of different classes of base stations, macro-, pico-, and femto- base stations, is known as heterogeneous networks (or HetNets). This is used to provide a flexible coverage area and improve spectral efficiency. Overlaying different classes of base stations can also potentially provide a solution for the growing data traffic, especially when the transport of data is optimised to take advantage of the characteristics of heterogeneous networks. 3GPP has identified various scenarios and requirements for the enhancement of small cells in [11].

B. Dual Connectivity

One of the key concepts underpinning the operation of enhanced small cells is the separation of the control plane and the user plane. The control plane provides the connectivity and mobility while the user plane provides the data transport. In such a scenario, the user equipment (UE) will maintain connection with two different base stations, a macro and a small cell, simultaneously. The macro cell will maintain connectivity and mobility (control plane) using lower frequency bands, while the small cell provides high throughput data transport using higher frequency bands [12], [13]. This is illustrated in Figure 1. An alternative version is the splitting of uplink and downlink across different classes of base stations.

The motivation behind this is that in the current standard (Rel. 8-10) cell specific reference signals are always transmitted regardless of whether there are data to transmit or not, and transmitters cannot be switched off even when there is no data to transmit. However, with the definition of a new carrier type [14], where cell specific control signals, such as reference and synchronisation signals, are removed, this is no longer the case. The macro cells will now provide the reference signals and information blocks, while the small cells, using the new carrier, can deliver data at higher spectrum efficiency, throughput, and energy savings. Additionally, they can now be switched off when there is no data to transmit. This can also provide additional benefits such as lower interference [4]. Such a scheme is expected to improve cell edge user throughput by up to 70 percent and reduce macro node energy consumption by 20 percent at low loads [12].

C. Multiple Radio Access Technologies

Although the 3GPP define heterogeneous networks as the concurrent operation of different classes of base stations, we believe that heterogeneous networks in 5G will be a mixture of different radio access technologies as well. This will include future wireless local area networks (WLANs) technologies which can offer seamless handovers to and from the cellular infrastructure, and device to device communications. Moreover, the additional radio access technologies can also concurrently provide higher throughput to users. This can already be implemented in part using the 3GPP Access Network Discovery and Selection Function (ANDSF) [15]. However, in situations where there is a high concentration of user terminals, offloading of data to WLANs may result in poor throughput, as WLANs are not well equipped to handle large number of users. This problem is recognised by the IEEE 802.11 Working Group, which has initiated a study group on High Efficiency WLANs (HEW) to tackle situations where there is a high density of access points and/or a high density of user terminals [16].

D. Device-to-Device Communications

Another approach to solving the highly dense network problem will be through Device to Device (D2D) communications, where each terminal is able to communicate directly with other terminals in order to either share their radio access connection, or to exchange information. Coupled with power control, D2D communications can reduce interference, especially in non-licensed frequency bands.

In 4G cellular communications, there are no provisions made for devices to communicate directly with nearby devices. All communications will have to be routed through the base station, and the gateway. This is extremely inefficient, especially when the devices are close by. In scenarios such as machine to machine (M2M) communications, where the number of devices involved can potentially be very large, it would be more sensible if devices can communicate directly with each other when necessary.

In unlicensed spectrum, devices can already communicate with each other outside of the cellular standard using technologies such as Bluetooth or Wireless LAN in *ad hoc* mode. However, these connections are susceptible to interference. On the other hand, using licensed spectrum will guarantee a certain level of quality of service if the connection is managed properly. These D2D communications will almost certainly require the base station to facilitate the connections to avoid intra-cell interference. The process to standardise this approach is already set in motion in 3GPP [17].

E. Massive MIMO

Another technology which is being considered is the use of a large array of antenna elements, several orders more

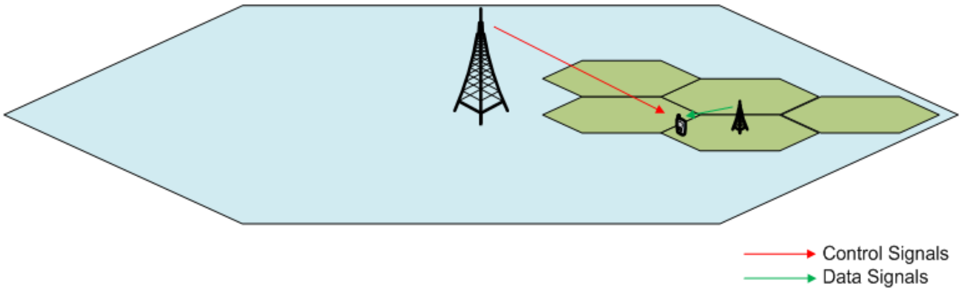

Fig. 1. Dual connectivity. The green link denote the high rate data link while the red link denote the low rate control link.

than the number in use today, to provide diversity and compensate for path loss [18]. Otherwise known as Massive Multiple-Input/Multiple-Output (MIMO), it also allows for high resolution beamforming and is especially useful at higher frequencies where antenna elements can be miniaturized.

Massive MIMO can purportedly increase the capacity by several orders and simultaneously improve the radiated energy-efficiency [19]. In addition, it provides large number of degrees of freedom, which can be exploited using beamforming if the channel state information is available. Another advantage of Massive MIMO is its energy efficiency, and each antenna element is expected to use extremely low power [20].

However, there are several research challenges which need to be solved before Massive MIMO can be incorporated into future wireless systems. Beamforming will require a large amount channel state information, and this will be problematic especially for the downlink. Consequently, Massive MIMO may be impractical for FDD systems, but can be used in TDD systems due to the channel reciprocity. Alternatively, limited feedback can be used [21]. Additionally, Massive MIMO suffers from pilot contamination from other cells if the transmit power is high, and will suffer from thermal noise otherwise [19]. Last but not least, there is a lack of channel models for Massive MIMO systems, without which, researchers will not be able to accurately verify algorithms and techniques.

Another interesting technique currently considered is 3D MIMO. This is sometimes considered as a special type of large scale MIMO which is only concerned with using the antenna elements for beamforming. While normal beamforming methods form beams in two dimensions, 3D MIMO allows beam control in both horizontal and vertical directions. This additional control allows for further sectorization within a cell. An example of sectorization created by 3D MIMO is illustrated in Figure 2. As with Massive MIMO, 3D MIMO requires new channel models [22]. Currently, 3GPP has started a work item on modelling 3D channels [23]. 3D MIMO will also require additional modifications to the feedback mechanism [24].

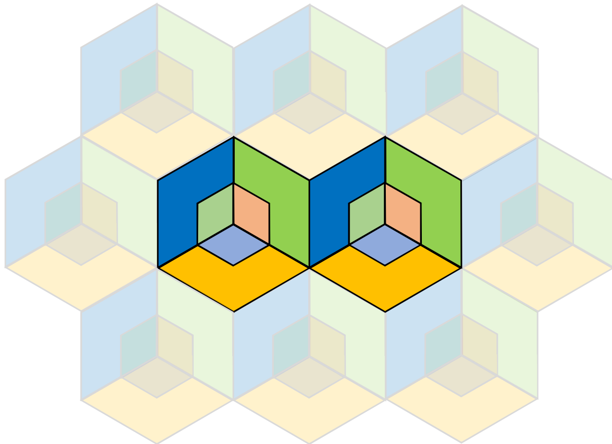

Fig. 2. Sectorization using 3D MIMO allows finer partition in the spatial domain.

F. *Software Defined Networking*

In parallel with the development of software defined radio (or cognitive radio) in wireless communications, Software Defined Networking (SDN) has gathered momentum in the networking industry in the past few years. The concept of SDN originates from Stanford University's OpenFlow system [25], which enables abstraction of low level networking functionality into virtual services. In this way, the network control plane can be decoupled from the network data plane, which significantly simplifies network management and facilitates the easy introduction of new services or configuration changes into the network.

Recently, there are also growing interests in both academia and industry to apply SDN to cellular networks. The main motivation behind this is that SDN may help cellular operators simplify their network management and enable new services to support the exponential traffic growth envisaged for 5G networks. Similar to the programmable switches in wired SDN networks, programmable base stations and packet gateways are envisioned in cellular SDN architectures with extensions such as network virtualization on subscriber attributes and flexible adaptation of air interfaces [26]. Here we list a number of SDN research issues and challenges pertaining to our discussion of enabling 5G technologies.

With the evolution of cellular networks towards HetNets and small cells, network management is becoming extremely complex. With network virtualization, SDN provides network operators with a set of open interfaces that can be used for specifying network control policies and rules. This effectively shields the complexity of physical hardware from network management functionalities and eases the management task. However, radio resource management (e.g. scheduling) very often requires low level or cross layer information to optimize system performance. This requires that the SDN architecture has clear semantics and channels to pass on this information to relevant components in the system.

Future 5G applications may have diverse characteristics and quality of service (QoS) requirements. For instance, M2M traffic has very different latency, throughput, and priority features compared to Human to Human (H2H) traffic. The same can be said for real-time video traffic and usual web browsing data traffic. The flexibility offered by SDN can enable fine-grained resource control (e.g. based on subscriber attributes) to enhance user quality of experience (QoE) while in the meantime maximizing network utilization.

At the moment, the wireless industry has yet to reach a consensus on a unified view of future 5G network architecture. Some favor a more distributed network architecture with self-organizing capability, while others have advocated more centralized cloud-based access networks (e.g. China Mobile's C-RAN). The development of cellular SDN is somewhat orthogonal to this ongoing evolution as it provides an open, flexible, and programmable middleware solution that can be used in different network architectures. Two important issues are scalability (to support a large number cells and huge number of devices) and robustness (to provide a reliable abstraction without negatively impacting the flexibility). It is also worth mentioning that another important development closely related and yet complementary to SDN is Network Function Virtualization (NFV) [27]. NFV makes use of standard IT virtualization techniques to consolidate various network hardware and functions onto industry standard data centers, switches and storage.

G. Machine to Machine Communications

As the enabling technologies described above continue to develop apace, fuelling the growth of service coverage and capacity, new use cases and applications are being identified, their emergence demanding yet more of our global networks. Many of these new business areas involve autonomous communication between devices, whether these devices are components in a smart energy network, intelligent home appliances or vehicles and infrastructure in an integrated transportation system. Indeed, we are already seeing examples of these "machine to machine" (M2M) devices: consider the latest generation of in-car satellite navigation ("sat-nav") devices with their integral cellular modems, downloading traffic information updates invisibly in the background. These new applications have the potential to cause a step-change in the size of the telecommunications market.

There are several challenges specific to M2M communications, not least of which are the autonomous operation and often restrictive power, size and complexity requirements. The typical M2M traffic is also quite distinctive: having spent the past decades optimising our networks, from the highest level servers to the lowest level PHY channel codes, to support the characteristic traffic flows linked to speech, browsing and messaging, we are now faced with a different breed of traffic: short, periodic (or aperiodic) telemetry bursts and machine-generated updates. The distribution and nature of these M2M traffic flows do not sit readily within the current network architectures, so extensions and modifications are required. The technology extensions developed and deployed to support these M2M applications have been appearing in a relatively ad hoc and piecemeal fashion, in specific standards bodies and/or organisations with particular technical or regional remits. Clearly, this vertical approach, while getting solutions out to market quickly, is not ideal in the long-term. There are areas of commonality in M2M solutions where consistent, standardised and open horizontal approaches will help develop the economies of scale and interoperability that will lead to a truly global M2M market.

It was to this end that the "oneM2M" Partnership Project (PP) was formed during 2012, to develop global, access-technology agnostic Service Layer specifications for M2M, in the same mould as 3GPP. This international body was formed by Standards Development Organisations (SDOs) from across the world: ETSI from Europe, ATIS and TIA from the USA, TTC and ARIB from Japan, CCSA from China and TTA from South Korea. Each of these SDOs already had interests in (and, in many cases, solutions for) different aspects of, and variations on, M2M systems: for example, the ETSI Technical Committee M2M had already produced an entire tranche ("Release 1") of technical requirements and specifications. These existing standards range from architectural descriptions to interface definitions, such as service layer interactions with common cellular access systems such as those developed by 3GPP and 3GPP2 (who are already developing and releasing extensions to their recommendations to support M2M traffic).

After this first year, the oneM2M participants (delegates from 200+ participating member companies and interested parties) have compared, merged, down-selected and harmonised "best of breed" contributions and proposals from around the world. The biggest challenges have often been finding common ground and vocabulary between different proposals. The architecture is based around Common Service Functions (from Device Management to Session Management) residing within Common Service Entities (CSE), with interfaces between the CSE and the applications above and the underlying network services below clearly defined. The current feeling is that both service- and resource-orientated architectures on the key CSE interfaces should be supported. The system is designed adopting the REST philosophy (a "RESTful" system). That is, the system is stateless, with uniquely addressable entities. Furthermore, the system must have well-defined interfaces between client and server, and between layers, to allow independent development and evolution of components.

Communication flows based around request/response interactions are also defined, and protocols for the different interfaces are being identified and scoped. The key, top-level documents have already been finalised and agreed, and are now under change control processes. Work continues within the different Working Groups to finalise and agree the remainder. The group is anticipated to deliver a first release in the middle of 2014.

H. Other Technologies

Apart from the above technologies and applications, there are also the following technologies can also potentially impact 5G.

1) Millimetre Wave: An obvious way of increasing the throughput will be through bandwidth expansion. However, the available bandwidth below 6 GHz is limited, and re-farming analogue TV spectrum will not sufficiently meet the burgeoning demand. Already, there are efforts to look beyond 6 GHz and also at the millimetre wave frequencies to evaluate their feasibility for use in future networks. While millimetre wave frequencies are well known to suffer from high path loss, this is not significant at the lower frequencies. However, their characteristics are not well studied, and measurement campaigns and channel modelling for different scenarios and environments will be required before transmission technologies can be designed for them. In [28], millimetre wave frequencies of 28 GHz and 38 GHz are extensively studied to understand their propagation characteristics in different environments, paving the way for their use in future wireless systems.

2) Shared Spectrum: Although cognitive radio was often touted as a solution to the problem of frequency spectrum shortage, it is seldom adopted as there are always concerns about the impact on the primary user or license holder of the spectrum. An alternative solution proposed which can potentially solve this dilemma is Authorized Spectrum Access (ASA) also known as Licensed Spectrum Access (LSA) [29]. The concept of LSA is to allow authorized users to access licensed spectrum based on certain conditions set by the licensee of the spectrum. This would allow under-utilised spectrum to be more effectively used and also solve the problem of quality of service for the primary user.

3) Indoor Positioning: While indoor positioning itself does not improve throughput or coverage, it has large implications on various applications and the quality of communications. Accurate positioning of user terminals can provide the network with additional information that can help in resource allocation and quality of service improvement. It can also enable a plethora of applications, including position based handover, resource allocation, and location based services.

Currently, 3GPP LTE has several positioning methods, including Cell ID (CID) and Enhanced Cell ID (ECID), as well as Assisted Global Navigational Satellite Systems (A-GNSS). It is also able to position using the Observed Time Difference of Arrival (OTDOA) method. All these are enabled through the Enhanced Serving Mobile Location Centre (E-SMLC) using LTE Positioning Protocol (LPP) [30].

V. Conclusions

In this paper, we have provided some information on recent developments on 5G research. We have also listed some emerging technologies which may make up future 5G wireless networks. While there is still much uncertainty over which technologies will eventually make up 5G, we hope this paper may help shed some light on what is coming soon.

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