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A Survey of the Challenges and Opportunities towards Next Generation 5G Technology

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***Abstract*—5G networks lies in providing, enormously low latency, growth in base station capacity, and significant improvement in users' perceived quality of service (QoS), compared to current 4G LTE networks. This paper finds several developing technologies which will modify and define the future generations of wireless communication standards. Some of these technologies are at present creating their way into standards such as 3GPP LTE, while others are still in development. This survey provides an overview of wireless communications, reviews and recent contribution to the state-of the- art, additionally, we Will look at most of the relevant research challenges that these new technologies to be addressed in the future.**

***Index Terms*—5G, mm-wave, beam forming, channel model, C-RAN, SDN, HetNets, massive MIMO, SDMA, IDMA, D2D, M2M, IoT, QoE, SON, sustainability, small cell base stations, field trials.**

I. INTRODUCTION

Today and in the recent future, to fulfill the presumptions and challenges of the near future, the wireless based networks of today will have to advance in various ways. The use of mobile phones has increased rapidly in the earlier two decades, in terms of complexity of applications, their required capacities, little processing power to one with high resolution and heterogeneity of device types. So far, this trend has always been met by significant technological growths and will continue to increase. This transformation, coupled with an expanding cache of bandwidth keen applications have activated demands for greater data rates. Mobile data traffic has been estimated to grow more than 24-fold between 2010 and 2015, and more than 500-fold between 2010 and 2020 [1]. This has in turn pushed the uptake of 4G contracts and driven operators worldwide to deploy 4G networks. Looking back at the growth of 3G (UMTS, HSPA) and 4G (LTE, LTE Advanced) it is clear that these generations of mobile networks focused on creating new physical radio transmission schemes in order to meet new capacity requirements. From our point of view, 5G networks should consider both wireless and wired parts targeting a fully integrated solution. Furthermore, in order to address the user oriented challenges, we foresee a continued evolution of existing functions, e.g., network densification into ultra-dense networks and device to device Communications, as well as development of new

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functions such as moving networks and huge machine communications. This requires auto combination and self-management capabilities well outside today's self-organizing network features, which reflected in the architectural layer to complete their full potential. Furthermore, ultra reliable communications put very stringent latency and reliability requirements on the architecture. In this paper, we explain our perspective on such a 5G radio access network and focus especially on the arising challenges and new technologies that enable us to meet these challenges.

The rest of the paper is organized as follows: In Section II, we present the evolution of wireless technologies. Section III gives the vision and motivation of the 5G network. Section IV and V includes the detailed explanation of the heterogeneous networks and challenges. Section VI and VII contains software defined cellular networks and massive MIMO and 3d MIMO.

II. Evolution Of Wireless Technologies

In 1887, Heinrich Hertz implemented laboratory experiments which proved the existence of EM waves. From 1895 to 1901 Marconi investigated with a wireless telegraph system who built several radio telegraph stations in England and started commercial service between England and France in 1899. Marconi initiate the path of recent day wireless communications by sending the letter `S' along a distance of 3Km in the form of three dot Morse code with the help of electromagnetic waves. After this initiation, wireless communications have become an important part of present day society. Since satellite communication, television and radio transmission has advanced to pervasive mobile telephone, wireless communications has transformed the style in which society runs. The evolution of wireless begins here [2] and is shown in Fig. 1. It shows the evolving generations of wireless technologies in terms of data rate, mobility, coverage and spectral efficiency. As the wireless technologies are growing, the data rate, mobility, coverage and spectral efficiency increases. It also illustrates that the 1G and 2G technologies are work on circuit switching while 2.5G and 3G works on both circuit and packet switching and the next generations from 3.5G to now i.e. 5G are using packet switching. Along with these factors, it also differentiate between licensed spectrum and unlicensed spectrum. All the developing generations use the licensed spectrum while the WiFi, Bluetooth and WiMAX are using the unlicensed spectrum. An overview about the evolving wireless technologies is shown in fig 1:

1st Generation

The 1st generation was started initial from 1980's. All 1G cellular systems depend on analog frequency modulation for speech and data transmission and in-band signaling to move control information between terminals and the time-out of the network during the call. It has a data speed up to 2.4kbps. Major subscribers were Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), and Total Access Communication System (TACS). It has a lot of disadvantages like below average capacity, uncontrolled handoff, inferior voice associations, and with no security, since voice calls were stored and played in radio towers due to which vulnerability of these calls from unwanted eavesdropping by third party increases [7].

2nd Generation

The 2nd generation was announced in late 1990's. Second-generation (2G) digital cellular systems establish the majority of cellular communication infrastructures unfold today. In part they helped fuel the transition of a mobile phone from luxury to necessity and helped to drive subscriber costs down by more efficient utilization of air interface and volume setting out of infrastructure components and handsets. Global Systems for Mobile communications (GSM) was the 2nd generation system, primarily used for voice communication and having a data rate up to 64kbps.2G mobile handset battery lasts longer because of the radio signals having low power. It also provides services like Short Message Service (SMS) and e-mail. Main geographical regions adopted different 2G systems, namely TDMA and CDMA in North America, GSM in Europe, and Personal Digital Cellular (PDC) and IS-95 [3], [7].

3rd Generation

Third generation (3G) phones were developed in the late 1990s and 2000s. The objective was to increase the data capability and speed. 3G phones were spell out by the Third Generation Partnership Project (3GPP) and later standardized by the ITU-T. Generally known as the Universal Mobile Telecommunications System (UMTS), 3G system is established on wideband CDMA that operates in 5 MHz of bandwidth and can produce download data rates of typically 384 kb/s under normal conditions and up to 2 Mb/s in some instances. Another 3G standard, cdma2000, was developed by Qualcomm. It uses 1.25 MHz bands to produce data rates to 2 Mb/s. Another version of cdma2000 is an upgraded IS-95 version. It is a 3GPP2 standard. It can transmit data at a rate to 153 kb/s and up to 2 Mb/s in some cases. The major disadvantage for 3G handsets is that, they require more power than most 2G models. Along with this 3G network plans are more expensive than 2G [3], [7]. Since 3G involves the introduction and utilization of Wideband Code Division Multiple Access (WCDMA), Universal Mobile Telecommunications Systems (UMTS) and Code Division Multiple Access (CDMA) 2000 technologies, the evolving technologies like High Speed Uplink/Downlink Packet Access (HSUPA/HSDPA) and Evolution-Data Optimized (EVDO) has made an intermediate wireless generation between 3G and 4G named as 3.5G with improved data rate of 5-30 Mbps [3]. Fig 2. Shows operating environment of 3G system.

4th Generation

The 4th generation has been defined but we are not in it, yet. Yes, some of the mobile carriers and the numerous phone and equipment manufacturers actually advertise 4G now. The proper definition of 4G as declared by the 3GPP and the ITU-T is something called Long Term Evolution-Advanced (LTE-A). The standard has not been completely done but primarily it is an improved and greater version of LTE that uses wider bandwidth channels and a larger number of MIMO antennas. A 4G system increases the principal communication networks by assigning a complete and reliable solution based on IP. Features like voice, data and multimedia will be imparted to subscribers on every time and everywhere basis and at quite higher data rates as related to earlier generations. Applications that are being made to use a 4G network are Multimedia Messaging Service (MMS), Digital Video Broadcasting (DVB), and video chat, High Definition TV content and mobile TV [2], [4]_[6].

5th Generation

More number of users increase in the demand of the accessibility, 5G with an advanced access technology named Beam Division Multiple Access (BDMA) and Filter Bank multi carrier (FBMC) multiple access. The concept of BDMA technique is illuminated by considering the case of the base station communicating with the mobile stations. In this communication, an orthogonal beam is assigned to each mobile station and BDMA technique will divide that antenna beam according to locations of the mobile stations for giving multiple accesses to the mobile stations, which correspondingly increase the capacity of the system [8]. An idea to shift towards 5G is based on current drifts, it is commonly assumed that 5G cellular networks must address more challenges that are not effectively addressed by 4G i.e. higher capacity, higher data rate, lower End to End latency, massive device connectivity, cheap cost and consistent Quality of Experience provisioning.

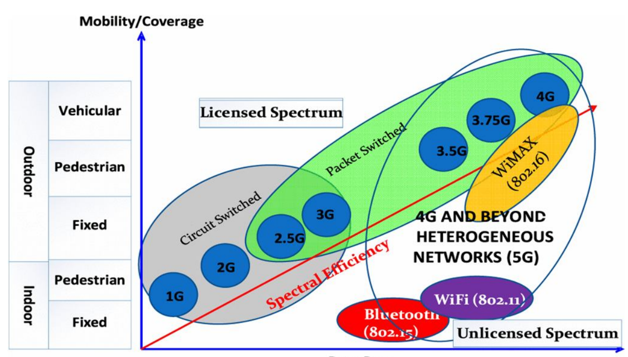

Figure 1. Evolution of wireless technologies.

III. 5G: VISION AND MOTIVATION.

The combined effect of emerging mm-wave spectrum access, hyper-connected vision and new application-specific requirements is going to trigger the next key evolution in wireless communications, 5G wireless communications imagine magnitudes of increase in wireless data rates, bandwidth, coverage and connectivity, with a massive reduction in round trip latency and energy consumption. It points out that the first standard is expected to mature by 2020. Group Special Mobile Association (GSMA) is working with its

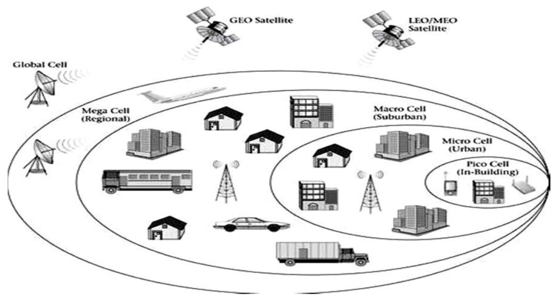

Figure 2. 3G Operating Environments

partners towards the ultimate shaping of 5G communication. Blending the different research initiatives by industries and academia, eight major requirements [7], [10], [11] of next generation 5G systems are identified as:

1 ~ 10 Gbps data rates in real networks:

This is almost 10 times increase from traditional LTE network's theoretical peak data rate of 150 Mbps.

1 ms round trip latency:

Almost 10 times reduction from 4G's 10 ms round trip time.

High bandwidth in unit area:

It is needed to enable huge number of connected devices with higher bandwidths for longer durations in a specific area [10].

Enormous number of connected devices:

In order to realize the vision of IoT, emerging 5G networks need to provide connectivity to thousands of devices [10].

Perceived availability of 99.999%:

5G envisions that network should practically be always available.

Almost 100% coverage for 'anytime anywhere' connectivity:

5G wireless networks need to ensure complete coverage irrespective of users' locations [10].

Reduction in energy usage by almost 90%:

Development of green technology is by now being considered by standard bodies. This is going to be even more crucial with great data rates and massive connectivity of 5G wireless [10].

High battery life:

Reduction in power consumption by devices is fundamentally important in emerging 5G networks [10].
With these above eight requirements, wireless industries, academia and research organizations have started collaborating in different aspects of 5G wireless systems. Ericsson [13] expects 5G development should start in a backward compatible way with existing 4G LTE networks. This will help in continuing services using the same carrier frequency to traditional devices. Ericsson is also collaborating with South Korean market leader SK Telecom, for demonstrating 5G networks at 2018 winter Olympics. METIS (Mobile and wireless communications Enablers for the Twenty-twenty (2020) Information Society) and HORIZON 2020 are the major 5G research project initiated and funded by the European Union (EU). To deploy 5G in alignment with the market demands, 5GPPP is working for early agreements with major stakeholders for multitenancy and single digital market.

IV. HETEROGENEOUS NETWORKS

A.Small Cell:

As the more requirement for greater data rates increases, one of the solutions available to operators is to reduce the size of the cell. By decreasing the size of the cell, spectral efficiency of area is improved through higher frequency reuse, while transmit power can be reduced such that the power lost through propagation will be lower. 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 miniaturization and the corresponding reduction in cost. Small cells can have different flavors, with low powered femto cells typically used in residential and enterprise deployments, and the higher powered picocells used for wider outdoor coverage or filling in macro cell coverage holes. 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[1].

New Carrier Type

One of the key concepts for 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 [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 3GPP standard 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 [3], where cell specific control signals, such as reference and synchronization 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 [4].

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 Network (WLAN) technologies which can offer seamless handovers to and from the cellular infrastructure, and device to device communications. This will lighten the burden on cellular networks and shift load away from the treasured licensed bands. At the same time, it 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) [5]. 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 a large number of users. This problem is recognized by the IEEE 802.11 Working Group, which has initiated a task 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[1].

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 unlicensed 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, Zigbee 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[1].

V. Challenges Of Heterogeneous Networks

Inter-cell Interference:

One of the biggest problems for HetNets is inter-cell interference. This is especially problematic with unplanned deployment of small cells, where the operators have little or no control of the location of the small cell. Additionally, the concurrent operation of small cells and traditional macro cells will produce irregular shaped cell sizes, and hence inter-tier interference, which will require advanced power control and resource allocation to avoid inter cell interference.

Distributed Interference Coordination:

In deployment of access points where there are little or no coordination, such as between WLANs, distributed interference avoidance will be required. This will be increasingly crucial as more devices access unlicensed spectrum to complement their throughput.

Efficient Medium Access Control:

This is particularly relevant for dense deployment of access points and user terminals where the medium access is distributed, such as that of WLANs. In such situations, the user throughput is low, latency is high, and hotspots will not be able to complement cellular technology to provide a high throughput. Existing medium access control will need to be redesigned for such an environment to optimize the channel usage.

Device Discovery and Link Setup:

In non-network assisted device discovery in D2D communications, there could be issues when there is a large number of devices around. Additionally, setting up and maintain links with more than one party can prove to be difficult, especially when operating in the same frequency.

VI. Software Defined Cellular Networks

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 Open Flow system [10], 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. Currently in both academia and industry, a clear definition of SDN is still lacking. Nevertheless, according to a standardization body of SDN, Open Networking Foundation (ONF), the SDN architecture (as shown in Fig. 3) has the following features [11]

- Directly programmable: the network control plane is logically centralized and decoupled from the data plane. Network intelligence resides in software-based SDN controllers that maintain a global view of the network.
- Open: SDN simplifies network design and operation via open standards-based and vendor- neutral APIs (northbound and southbound).
- Agile: Network operators can dynamically configure, manage, and optimize network resources and adjust traffic flows to meet changing needs quickly via dynamic and automated SDN programs.

Recently, there are also growing interests in both academia and industry to apply SDN to mobile 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. Therefore, we believe that wireless or cellular SDN could be a possibility in future wireless networks. 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 [1].

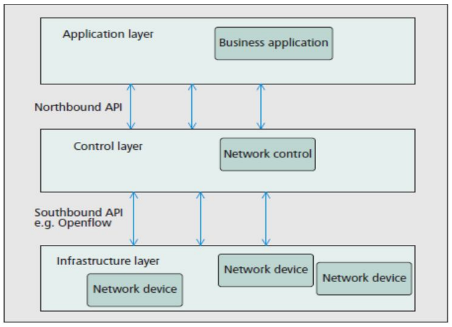

Figure 3: The SDN Architecture.

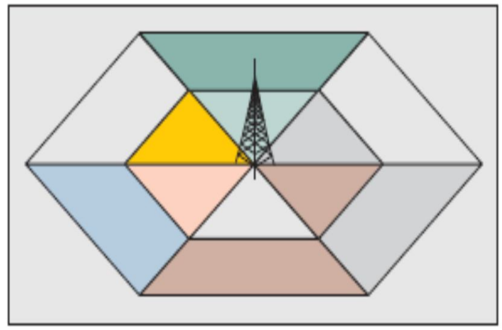

Figure 4. Possible sectorization for 3D MIMO

Challenges Of Software Defined Networking

Wireless SDN is still at its infancy. There are number of outstanding issues to be resolved before it can realize its full potential. Firstly, further development is needed to apply SDN concepts at network infrastructure level, e.g. introducing SDN into carrier networks. For example, there is currently no consensus yet on how the programmable switch can be achieved in the best way (in terms of performance and flexibility trade-off). Secondly, global standardization is still on-going and a unified cellular programmable interface for implementing SDN infrastructures has yet to emerge. In particular, the standard development of a reliable Network Operation System (Network OS) that provides unified access to computing, storage and network resources is crucial for SDN implementation in a multi-vendor environment. Finally, security in SDN is an open problem [1].

VII. Massive Mimo And 3D Mimo

Another technology which is being considered is the use of a large array of antenna elements, several orders more than the number in use today, to provide diversity and compensate for path loss [7]. Otherwise known as Massive Multiple- Input/Multiple-Output (MIMO), it also allows for high resolution beam forming 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 [8]. In addition, it provides large number of degrees of freedom, which can be exploited using beam forming 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 [8]. However, there are several research challenges which need to be solved before Massive MIMO can be incorporated into future wireless systems. Beam forming will require a large amount of 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. Additionally, Massive MIMO suffers from pilot contamination from other cells if the transmit power is high, and will suffer from thermal noise otherwise [8]. 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 [1].

Another interesting technique currently considered is 3D MIMO, which allows for 3D beam forming. This is sometimes considered as a special type of large scale MIMO which is only concerned with using the antenna elements for beam forming. While normal beam forming 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 **Fig. 4**. As with Massive MIMO, 3D MIMO requires new channel models. Currently, 3GPP has started a work item on modelling 3D channels [9].

Challenges of Massive/3D MIMO

Channel Estimation/Feedback: Currently, time division duplexing scenarios are considered for massive MIMO due to the prohibitive cost of channel estimation and feedback. Even for time division duplexing to work, channel calibration for Massive MIMO can prove to be a feat. New methods of channel estimation and feedback schemes will need to be proposed for massive MIMO to achieve mainstream status. Fast Processing Algorithms: To deal with the massive amount of data from the RF chains, extremely fast algorithms to process these data will be required. Pilot Contamination: Massive MIMO suffers from pilot contamination from other cells. Work around for this will be required for Massive MIMO to deliver its promised performance.

VIII. OTHER TECHNOLOGIES

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

Millimeter 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 millimeter wave frequencies to evaluate their feasibility for use in future networks. However, the characteristics of higher frequencies 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. We believe that millimeter wave frequencies holds the most promise, and there are already on-going efforts to make this a possibility. In [15], millimeter 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.

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) [17]. 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-utilized spectrum to be more effectively used and also solve the problem of quality of service for the primary user.

Big Data

Like in many other market sectors and industries, big data will also bring about lots of challenges and opportunities in 5G wireless. First of all, cellular networks have to provide efficient infrastructure support for this data deluge. For example, the future M2M or Internet of Things (IoT) applications will generate a vast amount of data. As discussed previously, this proves to be a major technical challenge for RANs. Secondly, new network architectures may emerge from the necessity of running big data applications. There is close synergy between cloud computing, software defined networking, and Network Function Virtualization (NFV). A convergence of these technologies can be envisaged to form highly robust and reliable 5G platforms for big data. Thirdly, making informed decisions and extracting intelligence from big data is an extremely important and yet non-trivial task. For example, cellular operators can make use of various customer network access data to reduce churn rate and seek new revenue opportunities. The smart grid, as another example, can be seen as a huge sensor network, with immense amounts of grid sensor data from various sensors, meters, appliances and electrical vehicles. Data mining and machine learning techniques are essential for efficient and optimized operation of the grid.

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 the LTE Positioning Protocol (LPP) [18]. Accuracy improvements to the currently available methods will certainly open opportunities for more location based applications.

IX. CONCLUSIONS

In this paper, we have provided an overview of some emerging technologies which may make up future 5G wireless networks. We have also described some research problems which these technologies present. This survey provide a comprehensive review of cellular evolution towards 5G networks. We begin with pointing out the new architectural paradigm shift, associated with the design of radio network layout, air interfaces, smart antennas, cloud and heterogeneous RAN. Subsequently. This includes understanding of new physical channels, novel antenna design, beam forming and massive MIMO. Novel emerging applications, like D2D and M2M communications, IoT and Software Defined Radios form the major driving force behind 5G.Finally, we point out major existing research challenges and identify possible future research directions. We believe that our survey will serve as a guideline for major future research works in 5G wireless communications.

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