Title	Research challenges in 5G networks: a HetNets perspective
Authors	Farooq, Muhammad O.;Sreenan, Cormac J.;Brown, Kenneth N.
Publication date	2016-03
Original Citation	Farooq, M. O., Sreenan, C. J. and Brown, K. N. (2016) 'Research Challenges in 5G Networks: a HetNets Perspective' 19th International Conference on Innovations in Clouds, Internet and Networks (ICIN 2016), 1-3 March, Paris, pp. 177-183. isbn:978-3-901882-81-4
Type of publication	Article (peer-reviewed);Conference item
Link to publisher's version	http://dl.ifip.org/db/conf/icin/icin2016/
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Download date	2024-05-22 20:53:36
Item downloaded from	https://hdl.handle.net/10468/5072

Research Challenges in 5G Networks: a HetNets Perspective

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***Abstract*—This paper highlights use cases, emerging machine type communication (MTC) technologies, ongoing research activities, and existing research challenges in 5G networks. 5G networks are faced with the following challenges: (i) handling large amounts of data, (ii) coping with different types of data traffic, i.e., human-type, machine-type, and combined-type (iii) connecting billions of machines, and (iv) severe resource limitations of devices. The ubiquitous nature of cellular networks make them the preferred choice for access networks, but a lack of communication resources is a problem. To address the resource scarcity issue, different wireless access networks may combine to form a heterogeneous network (HetNet) and hence become a single 5G network. For long-term success of 5G networks, we envision the following as important research outputs: (i) a scalable 5G network architecture that can handle a large number of human users and machines considering different constraints, (ii) a comprehensive quality of service (QoS) framework to satisfy heterogeneous users and machines requirements, (iii) a procedure for intelligent access network selection, and (iv) comprehensive inter-network handover mechanisms.**

***Index Terms*—5G Networks, HetNets, Machine-Type Communication, Quality of Service, Network Architecture.**

I. Introduction

The number of Internet users is on the rise due to the offered services: world-wide web, social networking, voice over IP (VoIP), video conferencing, video streaming, real-time multi-player gaming, to name a few. Mostly, these services are used by humans, therefore this form of data communication is termed as human-type communication (HTC). Moreover, with the advent of Internet of Things (IoT) it is predicted that billions of machines, for example, sensors, home appliances, video cameras, smart objects shall be connected to the Internet [1]. These machines communicate with each other without human intervention, therefore such form of data communication is termed as machine-type communication (MTC) [2]. Similarly, to accomplish different tasks machines and humans communicate, we term this type of communication as combined-type communication (CTC). MTC and CTC are essential for IoT and cyber-physical systems (CPS), a few examples of such systems are: intelligent transportation, smart homes, smart parking, critical control of remote devices, and waste management to name a few [3]. MTC and CTC can have an enormous impact on economy, and it is anticipated that by 2018 there will be 326 billion US dollar revenue opportunity in retail industry due of MTC and CTC [4]. Furthermore, the total MTC market by 2025 is estimated to be 30 billion connected devices, and about 7 billion will be connected through cellular network infrastructure [5].

This work is supported by the grant (SFI 10/CE/I 1853) from Science Foundation Ireland as part of CTVR.

One of the major goals of 5G networks is to ubiquitously handle a large amount of HTC, MTC and CTC data. Cellular networks are the preferred choice for access networks as the networks provide ubiquitous connectivity [6] and state-of-the-art networks support relatively high data rates, for example, long term evolution advanced (LTE-A) [7]. However, a large number of machines and other communication devices connected to the Internet raises a scalability issue, i.e., a network may not handle hundred of thousands of simultaneous connections [8]. Mostly, data traffic generated by humans and machines has different dynamics, for example, amount of data generated. Mostly, machines may only transmit a few bytes of data per unit time, however humans may initiate a large amount of data transfer. Similarly, HTC, MTC, and CTC can have different and diverse set of quality of service (QoS) requirements. A video streaming application requires bounded delay and packet loss, a sensor that is monitoring vital signs of a patient requires timely delivery and 100% reliability, and a command send by a human to a machine for critical control have stringent delay and reliability requirements.

The use cases for HTC, MTC, and CTC are huge, and cellular technologies alone may not satisfy diverse QoS requirements of the huge set of use cases due to scalability and capacity issues. However, to address these issues different communication technologies can be combined to form a heterogeneous network (HetNet). The HetNet can not only address the stated issues, but can also connect devices with different communication technologies with a 5G network. But, this opens a bunch of issues for the 5G research community: a scalable network architecture, QoS framework, intelligent network selection, and inter-network handover algorithms to satisfy diverse HTC, MTC and CTC requirements.

The rest of this paper is organized as follows. In Section II, use cases for 5G networks are presented. MTC technologies are discussed in Section III. Major 5G research projects are discussed in Section IV. In Section V, sheds light on our vision of some future research challenges in 5G HetNets and their importance, and finally this research paper concludes in Section VI.

II. 5G Use Cases

In this section, different use cases for 5G networks are presented. We organize the use cases into three categories: HTC, MTC, and CTC use cases. Furthermore, based on QoS requirements of the use cases each category has two sub-categorizes: inelastic and elastic use cases. Inelastic sub-category contains those use cases that either require hard or soft QoS guarantees, whereas elastic sub-category contains those use cases that only require best effort service. Fig. 1 shows our different categorization of 5G use cases, and a few example use cases in each category.

A. HTC Use Cases

1) Inelastic HTC Use Cases:
Future networks need to satisfy users' demand for high definition (HD) multimedia content. The example HD multimedia contents are: interactive voice and video calls, conference calls, video streaming, interactive games, interactive on-line class rooms, TV, etc. The demand needs to be satisfied any-time, anywhere, with a range of mobility levels and communication standards (WiFi, WiMax, LTE-A, IEEE 802.15.4, etc). These use cases require different levels of QoS. HD video streaming application requires a loose bound on delay and reliability, whereas interactive gaming requires a tight bound. The networks should satisfy a range of QoS requirements for a huge number of users even in challenged network conditions.

2) Elastic HTC Use Cases:
The following are a few examples of elastic HTC use cases: web browsing, Email, social networking, online news, text and image messages, etc. Future networks need to provide more capacity to handle a huge number of users. The Internet connectivity should be available any-time, any-where, with a range of mobility levels and communication standards. The networks should support the huge number of users even in challenged network conditions.

B. MTC Use Cases

1) Inelastic MTC Use Cases:
Intelligent Roads: A set of sensors and video cameras are deployed alongside a network of roads. The sensors can control traffic lights, detect traffic rules' violation, traffic intensity, and accidents. The video cameras may start video streaming in case of an accident or violation. Moreover, the sensors can feed their sensed data to a global positioning system (GPS), and the GPS may then update different vehicles' route in a real-time. For an efficient network of intelligent roads, the data about accidents, road blocking, and video streaming need be delivered with some sort of QoS provisioning.

Inter-Vehicle Communications: Autonomous driving and intelligent intersections and traffic management need inter-vehicle communications [9]. This type of communication requires stringent reliability and timely delivery of data packets.

Patient Monitoring: Automatic health monitoring systems measure vital signs of remote and in-door patients. In most cases, the vital signs are transmitted to a server, and in case of an emergency the server alters an appropriate health facility. Due to the criticality of the task, the vital signs should be transmitted reliably, securely, and as early as possible.

Industrial Process Automation: Sensors monitor automated industrial processes, and report their readings to a controller. In case of abnormal readings, the controller issues a command to avoid a malfunction of the process. Therefore, reliable and timely delivery of sensors' readings and controller's commands is of vital importance for an efficient industrial processes automation.

Theft Control: Sensor-based systems can be used to detect products theft in supply chain and/or in stores. The information related to the theft needs to be transmitted reliably and in a real-time.

Smart Grid: Smart grid is emerging as an efficient solution for power distribution, identifying faults in the distribution systems, and to reduce carbon fuel consumption [10]. Sensors monitor different aspects of the distribution system, and report to a controller. An efficient smart grid should report faults and electricity thefts reliably, securely, and in a timely manner.

Personalized Marketing: Based on a customer's digital identification (MAC layer address of the customer's communication device) and the customer's shopping trends, personalized real-time marketing can be carried out while the customer is roaming inside or near a shopping mall. Reliable and timely delivery of relevant promotions is curial in real-time personalized marketing.

Monitoring Structures: Sensors can be embedded into concrete structures, for example, high-rise building, tunnels, and over-head bridges. The sensors can send information about the structures' health. The information about any weakness in the structure needs to be reported reliably and in a timely manner to avoid damage.

2) Elastic MTC Use Cases:
Home Automation: Different devices inside a home collaborate to accomplish a task. A controller inside a home connected with a smart meter may schedule operating time of different electric appliance based on the following: electricity tariff, power required by the appliance, and total operating time of the appliance to complete a task.

Intelligent Waste Management: Sensors attached to waste bins can measure the level of bins' occupancy and the pollution caused by the waste. Collecting the waste using the information provided by the sensors can help to reduce pollution and energy consumption.

Intelligent Parking: Sensors attached to parking spaces can communicate with online servers to provide information about available parking spaces in a particular area.

Air Pollution Management: Sensors can be deployed in densely populated areas to measure air quality. The sensors can send their measurements to online servers. Applications on the servers can help municipal office to take appropriate steps for reducing the air pollution.

Public Transportation: Sensors can be attached to public transport vehicles. The sensors communicate the vehicles' location information to online servers, and the servers can automatically display the location information to people waiting

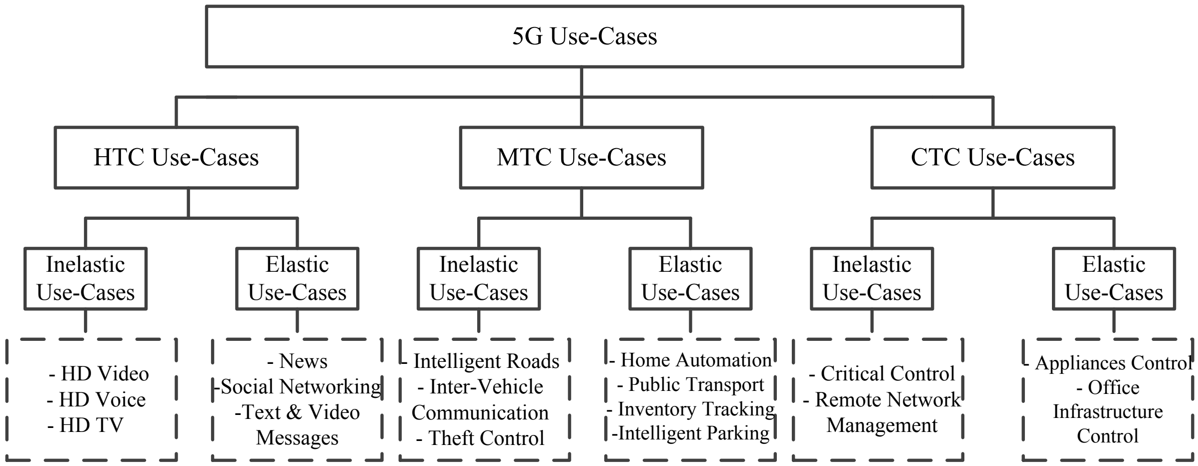

Fig. 1. 5G Use Cases Categorization and Examples

at different stations. This information can help to estimate the arrival time of a vehicle at a station.

Intelligent Vending Machines: Provide data to merchants, i.e., sales, products' sales trends, etc., and merchants can adjust prices and avoid unplanned stock-out.

Intelligent Replenishments: Intelligent shelves can help to analyse products' sales trends, moreover unplanned stock-out can be avoided.

Inventory Tracking: Micro-controller-based systems can be attached to products, and a controller at any-time can track a certain product in an inventory.

C. CTC Use Cases

1) Inelastic CTC Use Cases:
The following are examples of inelastic CTC use cases: critical control of remote devices and remote network management. These use cases may require a range of QoS requirements depending upon the nature of a task.

2) Elastic CTC Use Cases:
Controlling different home appliances from within a house or over the Internet and similarly controlling and monitoring office infrastructure are examples of elastic CTC use cases.

III. MTC Technologies

MTC technologies can be categorized into personal-area, local-area, and wide-area. IEEE 802.15.4 and ZigBee are examples of personal-area technologies, IEEE 802.11 and its low energy consumption variant (IEEE 802.11ah) are examples of local-area technologies. These technologies are well-known, therefore in this section we focus on low-power wide-area (LPWA) technologies.

There are two categorizes of LPWA MTC technologies, namely: proprietary LPWA technologies and 3GPP standardized technologies. Table I shows a comparison of the technologies, all technologies are either already available at time of this publication or are expected to be available later in 2016. The technologies are developed with the following key objectives:

i) Long battery life
ii) Low device cost
iii) Low deployment cost
iv) Full coverage
v) Support for massive number of devices

A. Proprietary LPWA Technologies

1) SigFox: It uses ultra-narrow band (UNB) to connect different devices to the Internet using a cellular network architecture [11]. It operates in the globally available ISM band, hence reduce deployment cost. It uses UNB to satisfy the following objectives: scalable and high capacity network, low energy consumption, and simple antennas. Simple antenna design helps to lower the price of a device.

2) LoRa: It is used to connect different devices to the Internet using a cellular network architecture [12]. It operates in the globally available ISM band, therefore reduces deployment cost. It provides support for the following: bi-directional communication, mobility, and localization.

The data rate supported by the proprietary standards is very low and the transmission range is high, therefore the standards may not satisfy the QoS requirements of ultra dense deployments of machines.

B. 3GPP Standardized Technologies

1) NB LTE-M: It is a narrow band version of LTE optimized for MTC. It can share spectrum with an existing LTE network, hence no need for an additional hardware deployment. It targets those MTC use cases whose requirements can be satisfied by a low capacity network. The specifications for NB LTE-M are expected to be approved in Rel. 13. NB LTE-M will be different from LTE-M in the following aspects:

i) Reduced bandwidth of 200 KHz in downlink and uplink
ii) Reduced throughput
iii) Improved coverage

2) LTE-M: It is an optimized version of LTE with a relatively high capacity for MTC. It was first released in Rel. 12 in the fourth quarter of 2014. It can share spectrum with an existing LTE network, hence no need for an additional

TABLE I
LPWA MTC TECHNOLOGIES OVERVIEW

Attribute	SIGFOX	LoRa	NB LTE-M	LTE-M	EC-GSM
Range (outdoor)	<13 km	<11 km	<15 km	<11 km	<15 km
MCL	160 dB	157 dB	164 dB	156 dB	164 dB
Spectrum Bandwidth	Unlicensed 900 MHz 100 Hz	Unlicensed 900 MHz < 500 KHz	Licensed 7-900 MHz 200 KHz	Licensed 7-900 MHz 1.4 MHz	Licensed 8-900 MHz 2.4 MHz
Data Rate	< 100 bps	< 10 kbps	< 150 kbps	< 1 Mbps	10 kbps
Battery Life	> 10 years	> 10 years	> 10 years	> 10 years	> 10 years

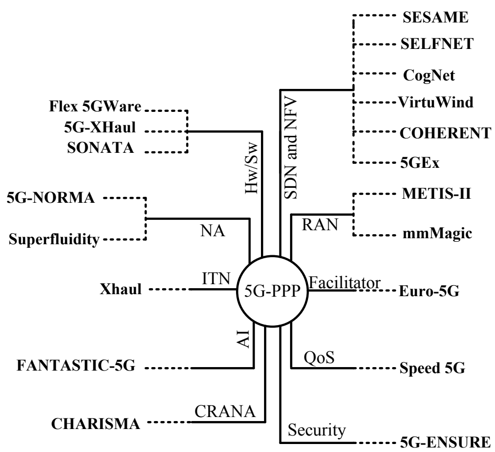

Fig. 2. Clusters of 5G-PPP Research Projects

hardware deployment. Further optimizations in terms of better coverage, higher battery life, lower complexity devices, and better discontinuation reception cycle are expected in Rel. 13. The specifications are expected to complete in 2016.

3) EC-GSM: It is extended coverage GSM, an optimized version of GSM for MTC. It is being standardized in GERAN Rel. 13, and specifications are expected to complete in the first quarter of 2016. It can operate in a shared spectrum with existing LTE and GSM networks. It targets those MTC use cases whose requirements can be satisfied by a relatively low capacity network.

The data rate supported by the 3GPP standards are higher compared to the proprietary standards, but the data rates are not high enough to satisfy QoS requirements of a huge set of MTC and CTC use cases.

IV. 5G RESEARCH PROJECTS

A. 5G-PPP Research Projects

Fig. 2 shows ongoing 5G-PPP research projects. Detailed information about the projects can be found in [13].

i) The 5G research projects based on software defined networking (SDN) and network function virtualization (NFV) aim at addressing the following challenges: network self management, novel applications and services inside access network infrastructure, quality of experience, efficient resource management, novel control framework, and collaboration among multiple operators.

ii) The projects related to radio access network (RAN) aim at addressing the following: spectrum management architecture, air interface harmonization, agile network management, cross-air-interface system access and mobility framework, and radio access technology for millimeter Wave (mmWave) band.

iii) Speed 5G project focuses on QoS and aims to address the following: resource management, traffic allocation in a HetNet, and load-balancing across spectrum.

iv) 5G-Ensure aims to get rid of 5G security concerns by developing a 5G security architecture. The architecture will be shared and agreed upon by different 5G stakeholders.

v) CHARISMA aims to develop a cloud radio access network architecture (CRANA) with the following objectives: low-latency and enhanced spectral and energy efficiency.

vi) FANTASTIC-5G aims at developing a multi-service air interface (AI) for below 6 GHz frequency using a modular design. The following are the project's objectives: flexibility, scalability, versatility, efficiency, and future-proofness.

vii) Xhaul aims at developing an integrated transport network (ITN). It integrates backhaul and fronthaul networks that consist of high-capacity switches and heterogeneous transmission links. The project's objective is to handle anticipated large volume of data in future 5G networks.

viii) The projects focusing on the design of novel 5G network architecture (NA) aim to address the following issues: network customizability, cost and energy efficiency, ensuring stringent performance, API driven architecture, and scalability.

ix) Some projects focus on developing hardware and software components for 5G networks. Hardware components are being developed with the following objectives: enable massive MIMO for mmWave, increased capacity, reduced energy footprint, scalability, and modularity. Software components main focus is to enhance a developer's efficiency.

B. Celtic-Plus 5G Projects

Fig. 3 shows 5G research projects that are being carried out under the umbrella of Celtic-Plus [14].

i) The aim of project MUSCLES is to extend the idea of femtocell to out-door scenarios. MUSCLES will develop mobile small cells, and these cells can be deployed on the fly to dynamically, effectively, and efficiently utilize spectrum. The small cells will work in collaboration to form a mobile cloud, and the cloud will ubiquitously provide caching services for multimedia applications. Moreover, the mobile cloud will possess the following characteristics: proactive data caching, self organizing network, and content-awareness.

ii) The aim of project ReICOvAir is to provide reliable communication for industrial process automation over the air. After

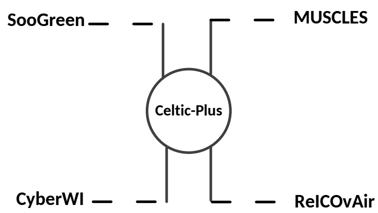

Fig. 3. Celtic-Plus 5G Research Projects

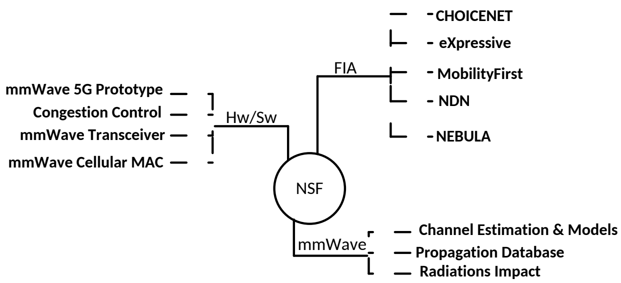

Fig. 4. Clusters of NSF Research Projects

gathering requirements from industry, the project will deliver a comprehensive software and hardware testbed solution that will demonstrate reliable industrial process automation over the air.

iii) CyberWI project proposes to provide security solutions for industrial Internet. The project considers the following use cases: building automation, industrial control systems, traffic applications, health care, and banking. Based on these user-cases the project will focus on intrusion detection, access control, secure data transfer, and security testing tools.

iv) SoGreen project proposes to model energy consumption of emerging applications, for example, multimedia applications and smart grid. Moreover, the project proposes to work on optimization of mobile access networks for energy consumption.

C. National Science Foundation's Research Projects

Fig. 4 shows projects supported by the US national science foundation (NSF). Detailed information about the projects can be found in [15].

i) The Future Internet Architecture (FIA) projects intrinsically focus on developing a new architecture for the Internet. The aim is to design an architecture that can effectively handle future applications. FIA projects are based on the following ideas: innovation in the core of the network, give users a choice to select different services offered by the network's core, application specific API for different types of applications, dense mobile networks with multiple base stations and access points with overlapping wireless footprint, content distribution networks (CDN), trustworthiness in CDN, named data networking, and secure cloud computing.

ii) mmWave projects focus on developing the following: a spatial and temporal channel models through extensive measurements both for in-door and out-door communication environments, spatial channel estimation, mmWave radiations biological effects, and a database of mmWave propagation. As per the information available at [16], the database contains the following: power delay versus time profile plots and pre-measurement statistics, for example, excess delay, root mean square delay spread, and path loss for all mmWave studies performed by both New York University wireless research laboratory and its partners.

iii) The projects related to the hardware category aims at developing a mmWave-based experimental setup for 5G networks, moreover a project in this category also focuses on designing and developing an energy-efficient mmWave-based transceiver. In the software category, a project is focusing on designing a stochastic congestion control protocol for high end-to-end throughput in next generation cellular networks. The primary objective is to optimize the protocol for the following: an emerging new class of applications and mmWave-based access networks. There is another project that is focusing on designing and developing a cellular MAC layer for mmWave-based cellular networks.

Current 5G research projects cover a range of important research issues. But, additional research work is still required for the following especially considering HTC, MTC, and CTC use cases: a scalable network architecture, a QoS framework, an intelligent access network selection, and inter-network handover.

V. 5G Research Challenges

We envision the following as the important future research challenges in 5G networks.

A. A Scalable Network Architecture

To enhance the network's capacity and handle the growing number of connected communication devices, femtocells are used in LTE-A networks [7]. A femtocell connects devices present in a small geographical area, for example, office building to the core network using a home eNodeB (HeNB). Only using femtocells is not enough to handle dense deployment of MTC devices along with HTC because the cells operate in the same cellular frequency spectrum. Secondly, as the state of different connections is maintained in the network, the scalability issue still exists.

To handle a huge amount of data generated by different types of devices and to provide the Internet connectivity to heterogeneous devices, different access networks can be used either separately or in an integrated manner with a LTE-A network. To address the LTE-A network's capacity and scalability issues different access networks should not only connect to LTE-A's evolved packet core, but also provide their own back-haul link to the Internet. This arrangement is feasible as most cellular network provides operate and manage their separate network to provide the broadband Internet connection facility. Research efforts are required to standardize new interfaces between the LTE-A network and different types of other available access network technologies. To further handle the scalability issue, different entities that aggregate multiple machines data and communicate with a core network on behalf of the machines are required. Machines using a low-power communication standard may connect to the core network through a gateway. There can be multiple gateways, and depending upon the network's condition a machine may switch between different gateways. Therefore, to update a machine's current point of attachment a standard signalling interface between different gateways and/or the relevant entities in the core network needs researchers' attention. NFV can be used to define different interfaces between heterogeneous access networks, gateways, and relevant entities in a network's core. The architecture for 5G networks needs to be robust enough to handle a range of mobility levels while satisfying QoS requirements of different emerging communication types.

B. A Comprehensive QoS Framework

Different HTC, MTC, and CTC emerging applications have different and diverse QoS requirements. Effective industrial process control systems can require delay in a range of few milliseconds to several seconds [17]. An effective patient monitoring system requires low delay and 100% reliability, and video surveillance system requires bounded delay and packet loss rate [18].

Simultaneously satisfying QoS requirements of HTC, MTC, and CTC applications is a challenging task that needs to be addressed by 5G networks. The QoS support offered by LTE-A standard lacks a mechanism to map a large set of HTC, MTC, and CTC applications' QoS requirements to different QoS classes. A comprehensive study is required that outlines different QoS requirements of emerging communication types. Afterwards, a set of rules needs to be defined that can map different types of data to different QoS classes available in LTE-A. A research is also required to identify those QoS requirements that can be satisfied through class-based QoS provisioning, and those that can be satisfied through flow-based QoS provisioning. Similar research is also required for other access network, for example, IEEE 802.15.4, WiFi, and WiMax. Invariably, QoS requirements must be satisfied on end-to-end basis, therefore in future ultra-large scale deployment of MTC devices may require an extension to Internet QoS architectures. In access and core networks SDN can help to satisfy QoS requirements of emerging communication types.

C. Access Network Selection

Nowadays, multiple wireless access network technologies, for example, LTE, WiFi, and bluetooth are supported by user equipments (UEs). Therefore, in HetNets a UE should select an access network that can provide the best service [19]. In 5G networks, the goal of supporting a large amount of data activity from heterogeneous devices with varying QoS requirements requires revisiting the access network selection problem. Ultra-dense deployment of MTC devices and their atypical traffic pattern may randomly congest an access network. If the access network is transporting a mission-critical application's data, the random congestion can make the application useless due to a missed delay deadline or lost data packets. Hence, the need to re-visit the access network selection problem considering the challenges raised by HTC, MTC, and CTC. This may require using a range of metrics for an access network selection, for example, available bandwidth, back-haul network's capacity, number of connected devices, ability of a network to satisfy QoS requirements, etc. Identification of events after which an access network selection algorithm should re-execute for different types of communications need to be researched. A network selection algorithm should also deal with the ping-pong problem; due to higher available bandwidth most devices switch from a LTE network to a WiFi network, thus the available bandwidth in the WiFi network becomes lower than the LTE network and, therefore the devices switch to the LTE network, hence a ping-pong. Wireless sensor nodes with dual communication interface are also emerging, therefore designing energy-efficient access network selection algorithms is also important.

D. Inter-Network Handover

Handover is inevitable, and there are three cases for an inter-network handover to take place: (i) an access network device malfunctions, (ii) user mobility (non-availability of a current type of access network at a new location), and (iii) there is another access network that may offer better service. The causes (ii) and (iii) for inter-network handover are peculiar to 5G Hetnets. There are a number of challenges involved in such a handover: specifying appropriate metrics to determine a better access network for HTC, MTC, and CTC, energy-efficient handover signalling, and smooth and fast handover.

VI. Conclusions and Future Work

5G networks are envisioned to support a huge amount of data activity initiated by HTC, MTC, and CTC. The ubiquitous nature of cellular networks makes them the preferred access network choice, but we shed light on the limitations of the networks to satisfy the requirements of 5G networks. We advocated the use of HetNets, as they not only help to enhance a network's capacity, but can also connect devices using different communication technologies. Moreover, we categorized different ongoing 5G research projects and briefly highlighted their objectives. Finally, we presented our vision of different existing research challenges and their importance for the long-term success of 5G HetNets keeping in-view ultra-large scale deployment and atypical traffic of MTC. In future, our research lab aims at focusing on the research challenges highlighted in this paper.

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