Road to 5G: Key Enabling Technologies

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Abstract —The research on 5G systems is intensively conducted in order to deliver systems by 2020, driven by the exponentially increasing internet traffic, in addition to the emergence of new services and use cases with specific sets of requirements. This paper is a literature review on 5G requirements, use cases and standardization picture. It presents existing and new enabling technologies towards future mobile systems and discusses challenges they face following two aspects: wireless technologies and network technologies.

Index Terms—5G, key technologies, 3GPP standards, IMT-2020, advanced receivers.

I. INTRODUCTION

Mobile traffic has known a huge evolution in the last few years. On the one hand, mobile subscriptions are significantly increasing. For example, Ericsson Mobility report establishes that 44 million new mobile subscriptions were added globally in Q1 2019, resulting in a total of around 7.9 billion subscriptions worldwide. On the other hand, the mobile data traffic has also significantly increased due to new emerging applications and use cases. The growth is about 82% between Q1 2018 and Q1 2019 [1]. In particular, mobile video traffic and social networking traffic are currently dominating on smartphones and tablets, and it is forecasting a traffic growth in volume, as predicted by Cisco in Fig. 1, but also a redistribution of traffic dominance; smartphones are currently predominant in terms of generated mobile traffic, but the Machine-to-Machine (M2M) connections represent the fastest growing device/connection category, expected to grow from 11% to 31% of global mobile devices and connections between 2017 and 2021[2].

This rising demand of data volume and the diversity of requirements are leading the development of the fifth generation (5G) of mobile systems. Following the rule of a generation issuing every decade, 5G commercialization is expected by 2020. Intensive research has been conducted to make this technology available even before, targeting among other enhanced mobile broadband services and a wider range of Internet of Things (IoT) applications. The variety of research domains linked to 5G makes it necessary to situate actual needs and research choices about 5G technologies.

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This paper is a review of the 5G research trends from requirements and use cases to enabling technologies. The second section illustrates 5G standardization activities, objectives and applications. The third section elaborates key enabling techniques of wireless 5G access, and the fourth section gives an overview of 5G network enabling techniques. The last section gives some conclusions about current and future 5G research trends.

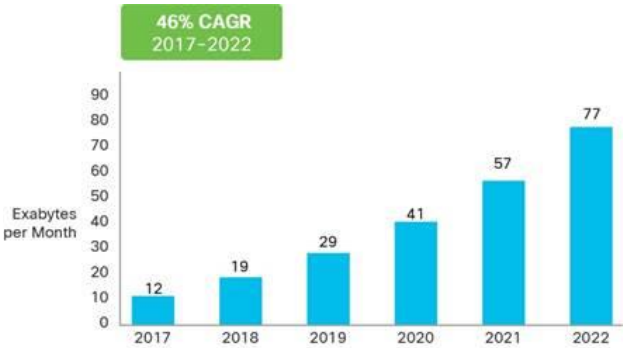

Fig. 1. Cisco forecast for mobile data traffic by 2022 (Source [2])

II. 5G REQUIREMENTS AND USE CASES

From a basic mobile voice system to advanced broadband services, mobile systems have known many evolutions, and the actual landscape is deploying 4G and pre-5G systems while developing 5G systems. In fact, Long Term Evolution (LTE) and LTE-Advanced (LTE-A) are deployed in many regions, and already provide better data rates. However, an increasing mobile data traffic with more user centric concept is needed. 5G research has been thus launched in 2013 and enhancements of current concepts and technologies, as well as new ones, are being proposed. A possible definition of 5G is given by the Next Generation Mobile Networks (NGMN) Alliance and describes 5G as “an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models” [3].

A. *International Mobile Telecommunications-2020 (IMT-2020)*

The 3rd Generation Partnership Project (3GPP) standardization has issued LTE Releases 8 and 9 which fulfill IMT-Advanced requirements and were considered as 4G, then downgraded to 3.9G while LTE-Advanced were considered as 4G [4]. As depicted in Fig. 2, next releases brought each an evolution for 4G, and LTE Release 13 has been almost frozen in March 2016 [5]. Actually, 5G standardization is based on functionally frozen specifications before 2020, authorized after evaluation as IMT-2020, and Release 13 and Release 14 are considered as a pre-5G or LTE-A Pro. 5G starts with Release 14 with new fundamentals, study and formalization of some selected specifications into standards in Release 15 (Phase 1) and Release 16 (Phase 2). The freezing date for Release 14 Radio Access Network (RAN) work program by 3GPP was in June 2017, and Release 15 standards are planned to be made operational at least in 2020. The Release 15 has been actually divided into three separate sections; an "early drop" working on the bulk of the initial 5G standard, including a "standalone" (SA) option for 5G in order to allow operators to deploy 5G without an LTE network. The second main drop of Release 15 was approved in June 2018, and the “late drop” in April 2019. The next release, Release 16, named also 5G phase 2, is expected to be approved in December 2019, and to include a wider range of technologies, like 5G in unlicensed spectrum and specifications for IoT technologies. Release 17 might include spectrum above 50GHz, enhancements for Unmanned Aerial Vehicles (UAV), options for 5G multicasts and broadcasts, IoT specifications for industrial sensors, and Artificial Intelligence (AI) and machine learning enablers for 5G network operations. It can be thus interpreted as 5G-Advanced [6].

Note that more particularly, 5G NR (New Radio), which is the New Radio Access Technology (RAT) developed by 3GPP for the 5G mobile network, started in 2015 and ended in September 2018, and focused on delivering the first set of 5G standards [6]. The first specifications were published in late 2017.

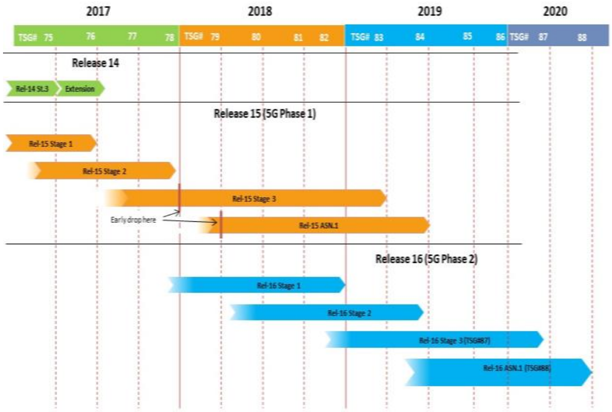

Fig. 2.The radio evolution in the present decade (Source: [4])

Commercial 5G networks already started to appear in some cities. The first ever 5G NR call on a commercial network was made in September 2018 with simulated smartphone device by Verizon, Ericsson and Qualcomm, while Verizon and Nokia completed the first over-the-air data transmission on a commercial 5G NR network in the same period [7]. Other examples are the recent switch on of 5G networks in many regions, such as cities in Australia by Telstra and in UK by EE in May 2019, and cities in Spain and Italia by Vodafone in June 2019 [8]. Estimations from [1] forecast that by 2024, 5G subscriptions will reach 1.9 billion, and 5G coverage up to 65% of the world's population.

B. 5G Requirements

5G is expected to multiply mobile data traffic per area by a factor of 1000. The typical user data rate and number of connected devices is targeted to be 10 to 100 times higher, and battery life for low power devices to last 10 times longer with an End-to-End (E2E) latency reduced by a factor of 5. These targets are adopted in order to enable diverse use cases addressed by 5G, with requirements identified among others by a focus group of the International Telecommunication Union (ITU) for 2020 and beyond, hosted by ITU-Standardization Sector ITU-T. It highlights three main categories of use cases, based on the key considered services:

- Extreme mobile broadband (xMBB)
- Massive Machine-Type Communications (mMTC)
- Ultra-reliable Machine-Type Communications (uMTC)

Requirements such as delay, throughput, reliability, etc. are related to the targeted use cases. A summary of 5G requirements, as described in [9], is given in Fig. 3. Table I gives examples of applications related to requirements.

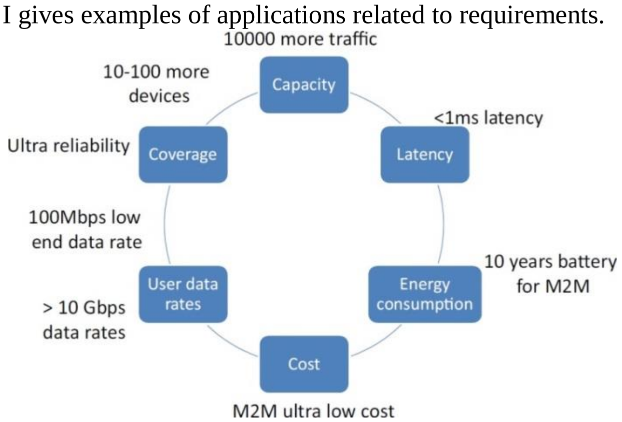

Fig. 3. Summary of key requirements for 5G

TABLE I: EXAMPLE OF 5G REQUIREMENTS (SOURCE: [10])

Requirement	Desired Value	Application example
Data Rate	1 to10Gbps	Virtual reality office
Data Volume	9GB/h (busy period) 500GB/month/user	Stadium, Dense urban information society
Latency	Less than 5ms	Traffic efficiency and safety
Battery Life	One decade	Massive deployment of sensors and
Connected devices	300000 devices/AP	Massive deployment of sensors
Reliability	99.999%	Teleprotection in smart grid network, Traffic efficiency and safety

C. 5G Use Cases

Current broadband services are expected to evolve significantly, as well as other emerging use cases that should be supported by 5G. NGMN presents eight use case categories through representative examples [3], as illustrated in Fig. 4. These categories can be described as follows:

- Broadband Access in Dense Areas : Pervasive Video, Smart Office, Operator Cloud Services, HD Video/Photo Sharing in Stadium/Open-Air Gathering
- Broadband Access Everywhere : 50 + Mbps Everywhere, Ultra-low Cost Networks
- Higher User Mobility : High Speed Train, Remote Computing, Moving Hot Spots, 3D Connectivity: Aircrafts
- Massive IoT: Smart Wearables, Sensor Networks, Mobile Video Surveillance
- Extreme Real-Time Communications : Tactile Internet
- Lifeline Communication : Natural Disaster
- Ultra-reliable Communications : Automated Traffic Control and Driving, Collaborative Robots, eHealth, Remote Object Manipulation (Remote Surgery), 3D Connectivity (UAV), Public Safety
- Broadcast-like Services : News and Information, Local Broadcast-like Services, Regional Broadcast-like Services, National Broadcast-like Services

Note that answering these promised use cases implies the enhancement of already used techniques as well as the use of new ones.

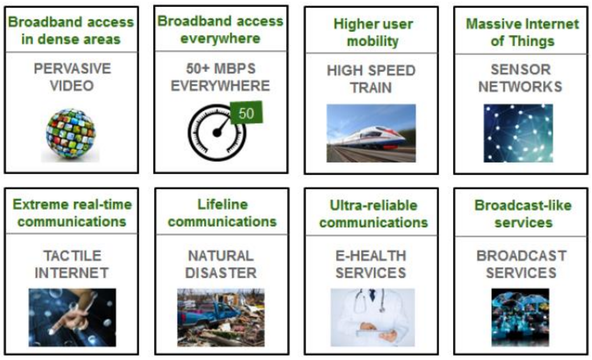

Fig. 4. 5G use case families and related examples (Source [3])

III. Wireless Enabling Technologies

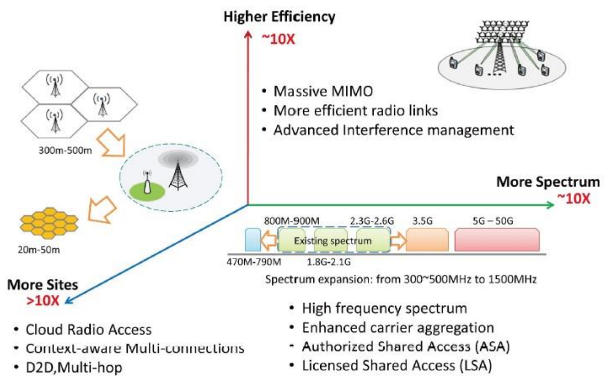

Fig. 5. Breakthrough in three different dimensions (Source: [11])

The fulfillment of 5G requirements implies a dramatic change in the design of cellular architecture and wireless technologies. The massive network capacity as well as the increased user experience required for 5G systems suggests researches in numerous dimensions, as illustrated in Fig. 5.

Following the requirements addressed for 5G, the RAN appears as one of the biggest challenges [12]. For instance, the increased required bandwidth leads to a reconsideration of the current use of already adopted mobile frequency bands and a better use of unlicensed spectrum, as the one of 5GHz, in addition to the move to millimeter wave (mmWave) bands. This implies a number of challenges allocating and re-allocating bandwidth, as the new system should provide a ubiquitous high-rate low-latency experience for network users. On the other hand, increased spectral efficiency and spectrum utilization, through new waveforms and advanced Multiple Input Multiple Output (MIMO) among others, is to be adopted. Extreme densification and offloading are also key factors of capacity enhancement. All these have taken into consideration the energy efficiency issue for all the system's components, as it becomes critical when the network goes denser. Network densification also positions solutions for virtualization and softwarization of the network as a must.

Note that 5G systems are meant to represent a convergence of existing systems with the integration of new techniques and components. As discussed in the previous section, the coming 3GPP releases, named as beyond 4G, include some key enabling techniques to address 5G requirements. Fig. 6 illustrates techniques evolution towards 5G.

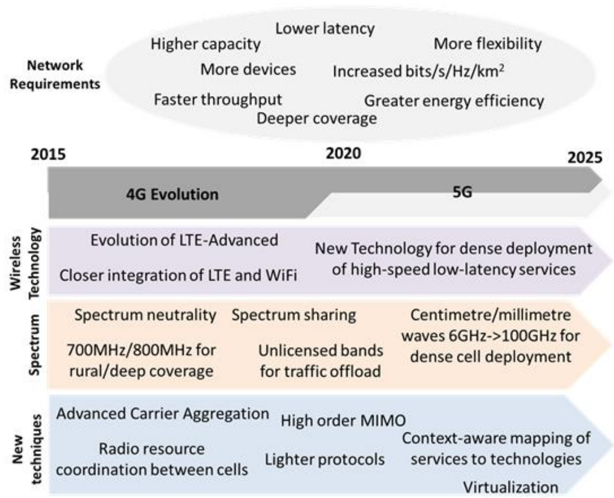

Fig. 6. Evolution to 5G (Source: [8])

In the following, 5G wireless enabling techniques are discussed through spectrum utilization, spectrum efficiency and densification issues.

A. Spectrum Utilization

5G is a convergence of existing and new systems with new air interface. New waveforms, multiple access technologies, modulation and coding schemes, etc. are being proposed.

a) Spectrum allocation

5G is a heterogeneous network and its spectrum is expected to be a combination of established and new bands, with a major challenge being to integrate the various bands. The focus is then on spectrum utilization in addition to spectrum efficiency. Some of the spectrum below 6GHz is thus being re-purposed for use with newer technologies, in particular for Non-Line-Of-Sight (NLOS) requirements.

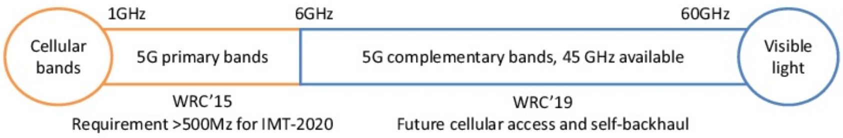

Fig. 7. 5G will aggregate sub 6GHz and above 6GHz

The new spectrum below 6GHz has been allocated for mobile communication at the WRC 2015, and is the primary band of 5G, while the band above 6GHz, considered as complementary 5G band, is expected to be allocated at WRC 2019 [13] (October), as illustrated in Fig. 7. In WRC-15, ITU through its ITU-R, studied 5G mobile broadband systems in the 24.25-86 GHz range and prepared the decisions for WRC-19. On the 3GPP Release-15, the NR-U work item supports both the existing 5GHz unlicensed band and the new "greenfield" 6GHz unlicensed band, and other unlicensed and shared spectrum bands, including mmWave, can be expected in coming releases [14].

In fact, frequency bands for 5G present different propagation characteristics and available bandwidths, which must be considered for system design. Decisions taken at WRC-15 do not consider though studies of bands below 24.25 GHz, while the 27.5-29.5 GHz band is not on the ITU-R list for WRC-19, even though several countries were intending to use all or parts of it. As a result, mobile industry ought to find solutions for early deployments of 5G, where parts of the range 3.1-4.2 GHz are actually seen as such. The 600 MHz (US) and 700 MHz (Europe) bands are also being considered in some countries for early 5G services deployment by Mobile Network Operators (MNOs).

Note that the backhaul spectrum for 5G networks also needs to be considered; the increasing capacity needed for backhauling has already driven the shift towards higher frequencies about a decade ago, when the 26 GHz, 28 GHz, and 32 GHz bands were introduced. 70-80 GHz band is also interesting and enables capacities in the order of 10 Gbps or more over distances of a few kilometers. The appropriate band depends, among others, on the national spectrum regulation authorities and on the regional climate. In fact, microwave backhaul has traditionally used frequencies from about 6GHz to 86GHz, while mobile broadband networks frequency bands are, or will be, ranging from about 450MHz to about 5GHz, for which WRC-15 added some new bands for 4G mobile broadband use. The emerging techniques of spectrum sharing and flexible spectrum use between mobile radio access and microwave backhaul are thus key enablers for 5G.

b) Carrier Aggregation (CA)

As stated, 5G is expected to present a convergence of existing and new systems. The multi Radio Access Technologies (multi-RAT) requirements for 5G imply the need to aggregate, for the same end user, RATs possibly operating on different bands. More efficient use of the fragmented and crowded spectrum can be made that way and needs to use coordination and load balancing between different RATs. Furthermore, asymmetric uplink and downlink aggregation provides carrier allocation flexibility. The concept of CA has already been proposed for LTE since 3GPP Release 10 in the case of LTE-LTE aggregation of inter and intra band contiguous carriers. Intra-band non-contiguous CA has been presented in Release 11, and CA using both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) band for Release 12. A CA method using 5 GHz WiFi bands, called Licensed Assisted Access, is presented in Release 13, and 5G standardization starting from Release 14 defines more cases following the 5G adopted bands [15]. Some challenges have to be solved in this case for configuring the Internet Protocol (IP), coordinating interference and time synchronization. In addition, resource scheduling over the aggregated bandwidth has to be optimized and may use advanced tools, such as game theory [16].

c) MmWave

New spectrum is allocated to face expected congestion of wireless technologies. MmWave frequencies could be used to augment the currently saturated 700 MHz to 2.6 GHz radio spectrum bands for wireless communications [17], [18]. Compared to currently used bands, little knowledge about cellular mmWave indoor and outdoor propagation environments with high users' density is available. In fact, the rather hostile propagation environment at these frequencies, in addition to hardware equipment costs, limited their use so far. The emerging techniques using large antenna arrays should allow though narrow beams to communicate, and novel transceivers hardware designs are needed to realize such functions and enable mmWave use. As an example, New York University (NYU) and NYU-Poly through their NYU Wireless research center are conducting research to create new technologies and fundamental knowledge for future mmWave wireless devices and networks [19]. Fig. 8 illustrates the position of 5G mmWave expected frequencies in regards to future bands (24.25-27.5 GHz, 27.5-29.5 GHz), in addition to first phase lower 5G frequencies.

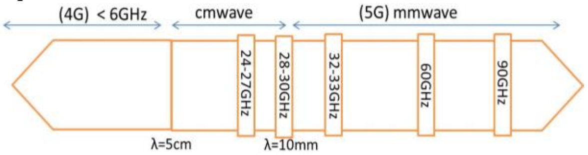

Fig. 8. MmWave frequencies for 5G

Note that Samsung demonstrated the world's First 5G mmWave Mobile Technology in May, 2013 using adaptive array transceiver technology over mmWave frequency bands for outdoor cellular and studying device feasibility and densification [12]. Many other mmWave systems have also been demonstrated since then, as it is the case for Huawei [20]. A more accomplished 5G pilot system was demonstrated in 2018 Winter Olympics [21].

B. *Spectrum Efficiency Issues*

The enhancement of existing techniques, in addition to new ones, such as new waveforms, multiple access technologies, modulation and coding schemes, etc. are being proposed to meet 5G requirements.

a) Massive MIMO

Massive MIMO is considered as one of the most important techniques for 5G Radio Access. Based on multiple antennas, MIMO is already used in LTE and LTE-A, and provides considerable diversity/capacity gains. The use of multiple antennas at the Base Station (BS) helps to focus the energy to form beams towards the device. Unlike LTE and LTE-A, the large amount of antennas, defining massive MIMO, can make it possible to serve many users in an accurate way. As described in [22], when combined with other 5G key enablers, essentially small cells and mmWave, massive MIMO can provide significant capacity gains to meet the expected explosion of data traffic demand. A new architecture is required then to realize the Full-Dimension MIMO (FD-MIMO) [23], and the use of massive MIMO can enable other key proposed technologies such as Beam division. As illustrated in Fig. 9, massive MIMO can be used to serve users but also for backhauling [24]. Note that the equipment of BSs with a large number of antennas may not be applicable to all types of antennas. On the other hand, BSs with a very variable number of antennas will have to coexist, and even take advantage of this diversity to prevent interference. The channel estimation is also critical for massive MIMO as the channel state information (CSI), though important for beamforming, can imply large overheads.

b) Channel modeling

In order to enable many of the physical layer techniques for 5G, accurate radio propagation models are needed. The expected bands to be used, especially above 6GHz, are not addressed by current models. Thus, new field measurements and ray tracing are needed for channel modeling, and research is already conducted for mmWave characterization in several environments [18].

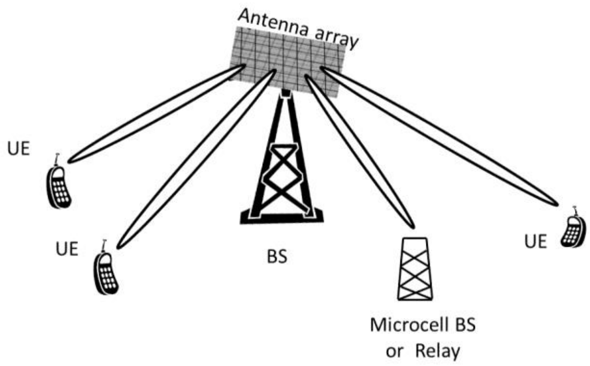

Fig. 9. BS using Massive MIMO to serve UEs and relays through beams

As highlighted in [25], the new channel model is an extension of the existing 3GPP 3D channel model. In addition, the frequency range handled by the model should be up to 100 GHz with a multi-band characteristics evaluation, and supports different mobility cases and large channel bandwidths. Many research activities are conducted to respond to these requirements. In particular, 3GPP RAN Meeting held in Busan Korea in June 2016 approved the first standard for the mobile broadband 5G high-frequency (6-100 GHz) channel model, considering existing and new scenarios. The ongoing works use new coordinate systems and antennas models, and consider mainly modeling of Pathloss, LOS probability, penetration, fast fading and blockage. A survey on approaches, models and measurements for 5G mmWave channels, considering massive MIMO channels and human body blockage, can be found in [26].

c) Signal waveforms

LTE is based on multicarrier modulation, namely Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Division Multiplexing (SC-FDMA) [27], which allowed a good spectrum efficiency over past techniques. However, the use of Cyclic Prefix (CP) reducing spectral efficiency, the large sidelobes caused by the rectangular pulse shaping and implying considerable Out Of Band Emission (OOB) as well as the high Peak to Average Power Ratio (PAPR) all suggest possible enhancement of multicarrier current techniques.

A first example of waveform candidates is filtered OFDM, which suggests filtering the signal in order to remove OOB emissions [28]. Filter Bank based MultiCarrier-Offest Quadrature Amplitude Modulation (FBMC-OQAM) modulation is another adaptation of OFDM, where no CP is required, enhancing thus spectrum efficiency [29]. Filtering in FBMC-OQAM is applied on a sub-carrier basis both at transmitter and receiver which, along with OOB reduction, makes the signal more robust against Inter-Symbol Interference (ISI), Doppler effect, synchronization imperfections, spectrum fragmentation, etc. Other resulting properties include self-equalization, which can reduce the number of unused subcarriers, and blind channel tracking, reducing pilot contamination and thus enhancing massive MIMO functioning. On the other hand, the orthogonality is relaxed from the complex field using QAM to the real field using OQAM, which may re-question some orthogonality techniques used for CP-OFDM, such as Alamouti Space time coding.

Universal Filtered Multi Carrier (UFMC), also called UF-OFDM, applies a subband filtering instead of subcarrier filtering as in FBMC-OQAM [30]. The choice of the subbands and of the filter is flexible so to achieve the desired OOB radiation and in-band distortion. As a result, the use of a prefix depends on filters design.

Similarly, Generalized Frequency Division Multiplexing (GFDM) also aims to provide a flexible multi-carrier technique through additional degrees of freedom compared to OFDM. It uses adjustable pulse shaping filters on a subcarrier basis to control OOB emissions. Furthermore, data symbols are grouped both in frequency and time dimensions, with a group size being also an adjustable parameter. The use of a CP may be needed in this case. The filtering flexibility implies however self-created interference, which is dealt with using receiver methods and iterative interference cancellation [31].

Comparison of such techniques has been elaborated through different studies, as by METIS project in [32]. A qualitative comparison of mentioned waveforms is given in Table II.

TABLE II. COMPARISON BETWEEN GFDM, FBMC, UFMC

	GFDM	FBMC	UFMC
PAPR	Low	High	Medium
OOB	Very low	Low	Low
Spectral efficiency	Medium	High	High
Processing complexity	Medium	High	High
CP	Yes	No	No
Orthogonality	No	Yes	Yes
ISI/Multipath distortion	Medium	High	High
Synchronization requirement	Medium	Low	Low
Effect of frequency offset and phase noise	Medium	Medium	Medium
Latency	Short	Long	Short
Ease of integration with MIMO	Yes	Yes	Yes

Note that 5G NR adopted still OFDM based waveforms with 5 different subcarrier spacings: 15 kHz, which is same as LTE, 30 kHz, 60 kHz, 120 kHz, and 240 kHz, with possible use of either normal CP or extended CP.

d) Multiple access

As OFDMA was successfully used for 4G as a multiple access technique, it may survive for 5G, but considering enhancement of the multicarrier modulation to be adopted. With the use of massive MIMO in a dense network context, multi-user MIMO (MU-MIMO) can be enabled through Spatial Division Multiple Access (SDMA) that uses multipath properties to multiplex users in the spatial dimension. The communication between the BS and the User Equipment (UE) can use an orthogonal beam, dividing antenna beams according to locations of the UEs [33]. In order to achieve higher capacity, Non-Orthogonal Multiple Access (NOMA) schemes are also proposed in [34]–[36], which allows more than one user to share the same subband without coding/spreading redundancy, breaking thus orthogonality. The receiver implements then joint processing to separate users' signals, aided by subcarrier and power allocation algorithm to maximize the offered rates [37]. NOMA flavours include among others Resource Spread Multiple Access (RSMA) and Sparse Code Multiple Access (SCMA) [5], [9], [38]. In fact, RSMA, based on Low Density Spreading CDMA, spreads user signal with appropriate channel coding, instead of simple repetition, depending on the demanded rate. On the other hand, SCMA uses a low density spreading with multi-dimensional constellations. The dimensions are partially used by one user and zero padded for the resources to be used by other users [39]. For both cases, NOMA principle of multiuser interference cancellation is used at the receiver. Up to now, 3GPP NR has specified flexible technology framework that can be tuned to enable a wide range of 5G scenarios, and more specifications are expected for Release 16 [40].

e) Channel coding

The use of new spectrum, new waveforms and multiple access techniques, the diversity of use scenarios and devices needing rate adaptability and decoder flexibility implies the need of appropriate channel coding in 5G context. The turbo codes used in 3G and 4G cellular systems have been rediscussed at 3GPP level, and were replaced in 5G NR by Low Density Parity Check (LDPC) and polar code in 5G, following the channel conditions. In fact, turbo codes must have component codes finely designed to maximize free distance, in addition to a good interleaver design, while LDPC codes are patent-free and less complex per iteration. LDPC codes don't require a random interleaver and have a lower error floor. In addition, the use of non-binary version of LDPC codes can enhance the performance especially for small and medium packet lengths, even though they are more complex [41]. Enhancement of LDPC codes can also include spatially coupling (SC-LDPC) using convolution and a windowed decoding for complexity reduction. The other adopted codes, polar codes, were relatively recently proposed by Arikan [42]. These codes give a constructive technique to achieve channel capacity with bounded complexity. They are suitable for multi-terminal environment and are constructed recursively via Kronecker products. However, the disadvantage of polar codes however lays in its rather high latency due to the inherent nature of the code construction. Note that polar codes were pushed for 5G systems notably as they were adopted for Huawei demonstration [13], while sparse regression codes were subject of a European project that ended in 2018 [43]. Huawei announced achieving 27Gbps using polar codes [44], and discussions in 3GPP identified it as 5G enhanced Mobile BroadBand (eMBB) channel coding scheme in the RAN1 (wireless physical layer) 87 meeting [45]. Generally, as compared in [46], the interest of these advanced codes depends on the context use; instead of considering capacity-approaching for point-to-point Additive White Gaussian Noise (AWGN) channel gains as in 3G/4G, transmission techniques, such as the waveforms, multi-antenna processing and network coding are considered for 5G. Nonetheless, optimization in accordance with multiple aspects is sometimes conflicting [47].

C. Network Densification

a) Ultra Dense Network (UDN)

Future 5G networks are meant to support the extremely heavy traffic forecasted for the coming years. This leads to a rethinking of the system design. Not only spectrum efficiency will have to be improved, as for previous evolutions from generation to generation, but a substantial network architectures redesign, through densification, will be necessary.

Cellular infrastructure densification was applied since the second-generation voice-oriented systems in order to enhance capacity or performance of an already deployed system through cell splitting and sectorization. Ultra densification for future networks has a more important role, while providing an extreme and user-centric reuse of system bandwidth on the spatial domain, and improving propagation conditions by reducing the distance between the end user and the BS.

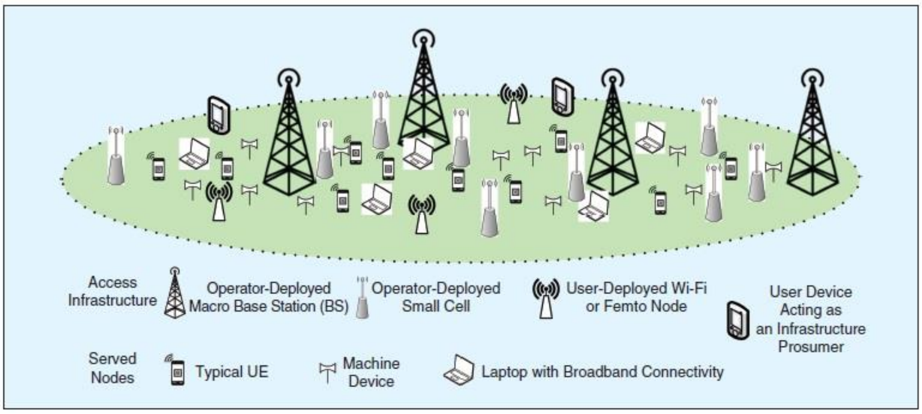

Fig. 10. UDN infrastructure composed by operator- and user-deployed heterogeneous serving ANs (source [41])

The densification considers operator-deployed infrastructure elements as well as user-deployed access nodes (ANs) and mobile user devices, as illustrated in Fig. 10, where multiple types of users and machines act as served nodes, and disruptive devices act as prosumers. For a given area, the number of serving and user nodes is of the same order. UDN imply an increased spatial reuse of system resources, a large node density and irregular deployment. This deployment is challenging in terms of interference, design and choice of density, network-wise coordination, load balancing, etc.

In fact, it is critical while densifying preserve the cell-splitting gains, in particular with the constraint of low power BSs. The limitation caused by interference in such networks has also to be carefully handled, especially for mmWave channels. In addition, there should be a fine optimization of users and BSs association in such heterogeneous multi-RAT using performant concepts, such as game theory, and models for mobility support such as virtual cells. The localization of nodes has thus to be handled as it is an input for that optimization. The deployments should be designed taking into account the possibly high cost of a dense infrastructure.

Cell-edge effect is an issue for UDN. In fact, densification challenges mobility and interference, and solutions adopted for LTE (Coordinated MultiPoint (CoMP)), CDMA (soft handover) or Wimax (fast cell selection) have to be replaced by an adequate system with ideal backhaul. A possible solution, among others, is the smooth cell virtualization [48].

The backhauling in a dense network is also a challenging issue, as discussed in [24], and it is proposed to use self-backhauling as a cost-effective solution. Given a dense deployment network, self-backhaul nodes can also provide traffic offloading and cell split using content prediction and caching techniques.

b) Cloud-Based Radio Access Network (C-RAN)

Network densification is a key enabler of 5G networks. This implies a heavy radio processing to be handled by the BSs. Cloud-based Radio Access Networks (C-RANs) is adopted in 5G RAN to handle such amount of processing. In fact, C-RAN decouples the BaseBand processing Unit (BBU) from the Remote Radio Heads (RRHs), allowing thus a centralized processing and assignment of radio resources. The BBU part can be moved to a pool, or more generally to the cloud, in order to optimize resource utilization. The transmission of radio signal is then performed by RRHs based on computed signals from the cloud. The BBU pool is a virtualized cluster connected to the core network through the backhaul. Each RRH is connected with the cloud BBU pool via a fronthaul. Cloud based computation makes RRHs cheaper and simpler, allowing more scalability and densification opportunities. It also reduces the delay for inter-cell coordination and permits more joint optimization of processing, e.g. for cooperative interference management, scheduling, CoMP, etc. [49]. C-RANs can also be self-organizing, where intelligent smart cells are deployed in the area covered by a macro BS, and can also enable advanced clustering and coordination schemes to enhance mobility and handovers. Moreover, C-RAN has to adapt to Heterogenous Network (HetNet) context, leading to H-CRAN. In such networks, different types of nodes, including Low Power Nodes (LPN, e.g., pico BS, femto BS, etc.) and high power nodes (HPN, e.g. 4G BSs) may have to cooperate using the same computing pools, and solutions to solve inter-tier interference improve joint processing gains. The H-CRAN is illustrated in Fig. 11.

Note that CoMP, already used in LTE, is adopted and enhanced for 5G, as it is a tool for interference combating in case of multiuser, very likely to happen in a UDN, in addition to the enhancement of coverage, cell edge throughput, and/or system efficiency [51], [52].

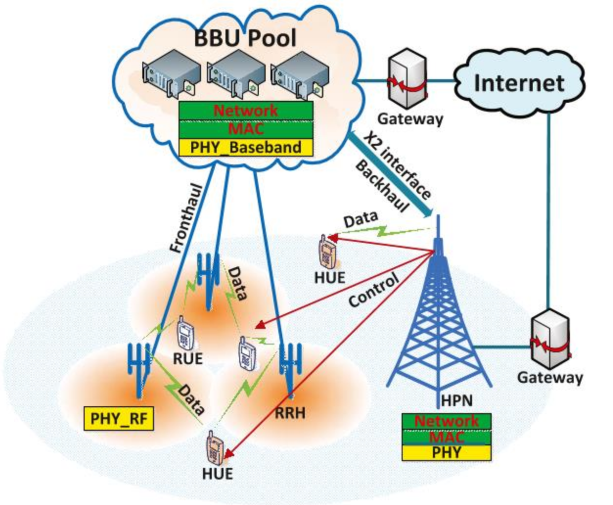

Fig. 11. H-CRAN: Heterogeneous cloud radio access networks (source ([50])

D. Energy Efficiency

Network densification is an effective method of increasing system capacity and coverage. In parallel, increased power consumption is expected. Thus, energy efficiency is a central challenge for 5G systems, due to the diversity of expected applications. In fact, the device battery life has to be lengthened and the overall energy efficiency of the network has to be improved. A solution can be energy harvesting from environmental energy sources for example. The variability of available energy levels over time, locations, weather conditions etc. presents however a challenge for Quality of Service (QoS) constrained wireless applications. Another solution can be the harvesting of energy from ambient radio signals: RF-powered energy-harvesting networks (RF-EHN) [53], [54] are actually a hot topic. The energy efficiency from a network side is also to be optimized. For example, it is proposed to reduce the energy consumption of BS in a smarter way, through cellular partition zooming for example, where the BS can zoom in to maintain the coverage area according to actually present users, and zoom out to sleep mode to save energy [55]. Other optimizations are proposed for the whole network, including core, fronthaul, backhaul, etc. [56].

IV. Network Enabling Technologies

Given the diverse 5G requirements, 5G networks need to be carefully designed in order to provide enough flexibility to meet all these requirements in an efficient and cost-effective fashion. This is to say, emerging use cases and support for vertical markets, multi-tenancy and multi-service, fixed-mobile access networks convergence, etc. imply a new ecosystem and need thus orchestration functions to serve resources to multiple logical networks. Many challenges arise when insuring evolutivity of the network to multiple future technologies along with a flexible resource sharing through cross-domain orchestration. In fact, multiple logical networks, known as network slices, are needed for 5G. This new network view can be possible using Mobile Edge Computing (MEC) technique for concurrent instantiations of the network. Required capabilities can be enabled through Software Defined Network (SDN) and Network Function Virtualization (NFV). In addition, the expected 5G architecture positions security and privacy as a major issue. Views and techniques being developed to meet 5G network requirements can be found in the white paper issued by the 5G Infrastructure Public Private Partnership (5G PPP) Architecture Working Group [57], where the 5G PPP is a joint initiative between the European Commission and European ICT industry. This section presents some logical and functional aspects and techniques of 5G architecture.

A. Network Architecture

Cellular networks are evolving to a multi-radio access technology (multi-RAT) and multi-layer heterogeneous network. At the same time, emerging mobile use cases make the current network architecture relatively incompetent to address current and future requirements. The network flexibility is a central objective in 5G architecture design, which suggests, as pointed in [58], the usage of a multi-service and context-aware adaptation of network functions, adaptive decomposition and allocation of mobile network functions, software-defined mobile network control, and joint optimization of mobile access and core network functions. A split in logical core and RAN is also necessary to allow evolution of both RAN and Core and to insure more deployment flexibility. This is illustrated by the adoption by the European Telecommunications Standards Institute (ETSI) of separation of User Plane (UP) functions and Control Plane (CP) functions, and modularization the function design, e.g. to enable flexible and efficient network slicing [59].

Similarly, NGMN presents a 5G architecture comprising three layers and a management entity: the infrastructure resources layer, the business enabling layer and the business application layer, in addition to an E2E management and orchestration entity to configure and supervise all three layers according to the demands of the requested services or business model. The architecture is based on central cloud and comprises typically multiple data centers which may be very distant, connected to each other or to the central cloud or edge clouds through wide area network (WAN) among others. Fig. 12 illustrates this topology as viewed by the project 5G NOvel Radio Multiservice Adaptative network architecture (5G NORMA), which is one of the 5G PPP projects under the horizon 2020 framework [60]. Note that control and data planes have to be separated as network densification increases overhead of control signaling while requiring a high capacity of the backhaul, especially for small cells and Device-to-Device (D2D). As suggested in [61], low layer functionalities will be provided by Radio logical network while a network cloud provides all higher layer functionalities in a way that avoids functionalities redundancy. In addition, functions can be dynamically deployed in the network cloud through SDN/NFV.

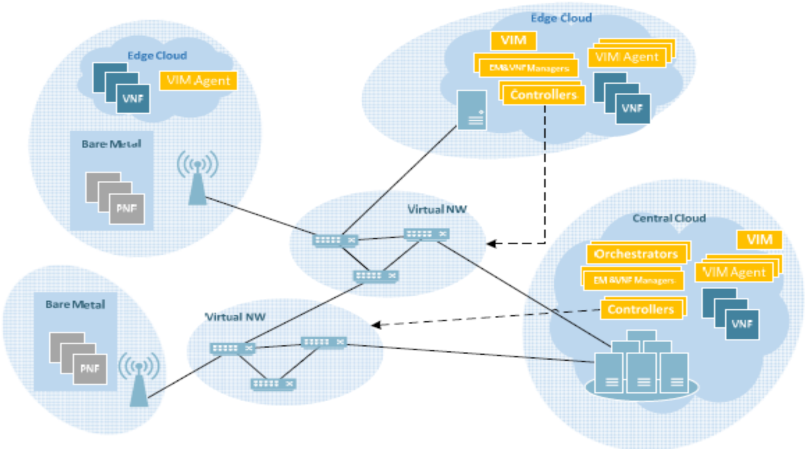

Fig. 12. 5G NORMA topology view on architecture (Source [51])

B. NFV/SDN

Virtualization facilitates resource sharing among many operators. As there is a need to decouple hardware from software and to move network functions towards software, and assuming separation between control and data, NFV is one of main 5G architecture drivers, ensuring network adaptability and making it easily scalable [59]. With simpler operation, new network features are likely to be deployed more quickly. NFV enables in fact sharing common resources through abstraction of physical resources to a number of virtual resources. It uses automation mechanisms in order to accelerate scalability following the increasing network demand. An example of wireless network virtualization is illustrated in Fig. 13.

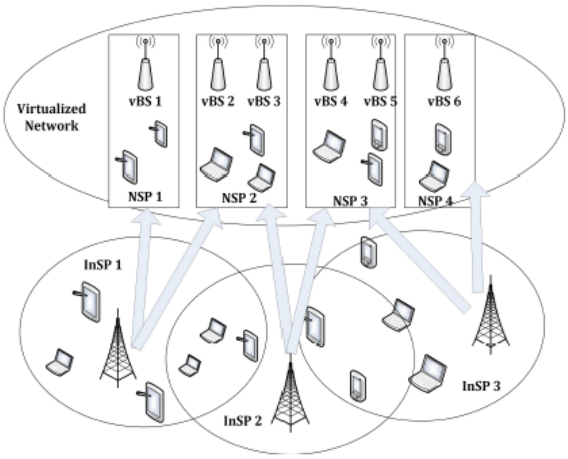

Fig. 13. An example of wireless network virtualization (Source [62])

Basically, NFV installs network function software in virtual machines deployed in a virtualized commercial server, not in dedicated network equipment individually. RAN works thus as edge cloud while Core works as core cloud. Connectivity among virtual machines located in edge and core clouds are provisioned using SDN. Actually, NFV/SDN allow network linking to the cloud to enable the suggested ultra-flexible network architecture, as illustrated in Fig. 14.

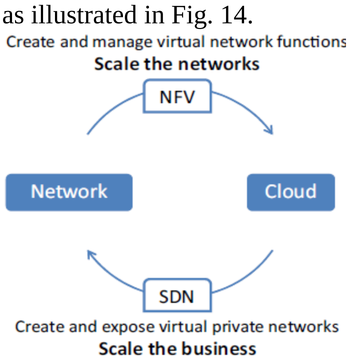

Fig. 14. NFV Vs. SDN (Source [63])

SDN fits into the NFV paradigm and can enable the orchestration of the NFV physical and virtual infrastructure resources, through supporting provisioning and configuration of network connectivity and bandwidth. An example of SDN components is illustrated in Fig. 15.

Note that in addition to programmability, flexibility, adaptability and capabilities, NFV/SDN can allow among others Operational EXpenditure (OPEX) and Capital EXpenditure (CAPEX) reduction, speedy service creation and deployment, efficient service life-cycle management, energy consumption reduction, and improved quality of experience for users. Along with SDN, NFV can offer, in addition to an increased throughput, a better Quality-of-Experience (QoE) for the end users, improving thus capital efficiencies vs. dedicated hardware implementation solutions, flexibility in assigning functions to hardware, scalability, resilience and resource sharing, operational efficiencies, power efficiency, service innovation through software based deployment, migration to newer technologies by isolating part of the network, granularity of assigned resources, workload migration, automation and operating procedures mutualization, decoupling of functionality from location [64].

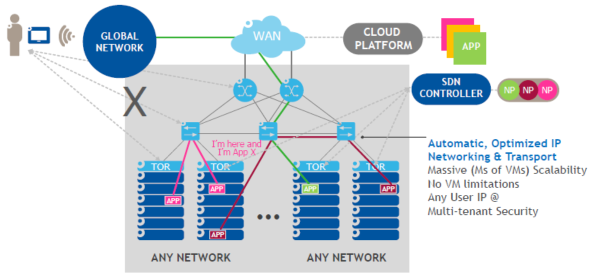

Fig. 15. SDN Components descriptions (Source [54])

C. Network Slicing

The new 5G ecosystem needs to provide communication services for multiple applications with different requirements. In fact, 5G is meant to serve a variety of devices with different characteristics and needs, like mobile broadband, massive IoT, and mission-critical IoT, each requiring different types of features and networks in terms of mobility, charging, security, policy control, latency, reliability, etc. Using the same physical infrastructure, multiple logical networks will be needed, known as network slices. Network Slicing is a network technique, initially for the core network but extended to an E2E concept including also RAN part. Network slicing enables the delivery of services with differential performance characteristics.

For example, massive IoT service connecting immobile sensors measuring temperature, humidity, precipitation, etc. to mobile networks does not require advanced mobility features, critical in serving mobile phones. On the other hand, mission-critical IoT service, like remote controlled robots or autonomous driving, requires, unlike mobile broadband service, a very low E2E latency. It can't be cost-effective to build a dedicated network for each service. Instead, network slicing can define multiple logical networks over a single physical network. The physical network is sliced up into different virtual E2E slices following on the service requirements. Each slice is made of a number of network functions and given radio access technology parametrization, combined together for a given use case and/or business model. The slice is logically isolated and is assigned dedicated resources. The isolation of slices separates error propagation between slices. Note that virtualized network functions are placed in different locations in each slice (i.e. edge or Core cloud) depending on services, and therefore customized by operators.

D. Mobile Edge Computing

The expected network density and application diversity, which may lead to congestion, can be alleviated through Mobile Edge Computing (MEC), mainly standardized by ETSI, 3GPP and ITU-T. The management of cloud-based applications, either for 4G or future 5G networks, can also be improved through MEC. In fact, MEC provides Information Technologies (IT) and cloud computing capabilities within the RAN in close proximity to mobile subscribers, and thus accelerates responsiveness for content, services and applications demand, enabling ultra-low latency, high bandwidth and real-time radio network information, particularly useful for context-related services. Examples of MEC use cases include [56]:

- RAN-aware content optimization in terms of cell load, link quality, etc. so to increase optimization and QoE.
- Dynamic content optimization, particularly video, distributed video analytics and video management.
- Distributed Content and DNS Caching to save backhaul and transport and enhance QoE
- Augmented Reality (AR) content delivery, providing local content caching and local object tracking with a minimized Round Trip Time (RTT) and optimized throughput, all critical in AR QoE.

An illustration of QoE improvement through MEC is illustrated in Fig. 16.

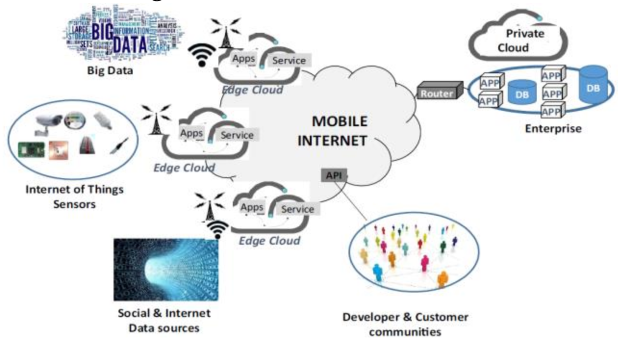

Fig. 16. Improved QoE with MEC in close proximity to end users (Source [65])

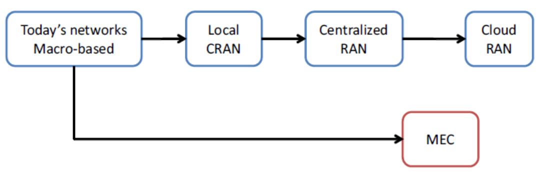

Fig. 17. Cellular network evolution to Cloud RAN and MEC (Source [66])

Note that MEC is related to cloud as illustrated in the Fig. 17. In fact, Centralized RAN process centralizes baseband processing capabilities while cloud RAN implements baseband processing capabilities in distributed locations. On the other hand, MEC introduces new processing capabilities in the BS for new applications, with a new functions separation and a new interface between BBU and RRU.

A demonstration for a 5G mobile edge proof of concept was conducted by Ericsson and Vodafone in their approach of 5G commercialization. The test considered remote machine vision in the manufacturing vertical, and succeeded to showcase a ’5G Smart Network Edge’ with an enhanced efficiency in machine vision with low latency, serving to guarantee a detection rate from the cloud system [67]. In parallel, 5G system specifications provide new functionalities that serves as enablers for edge computing, which can be found in [68]. MEC currently deployed in LTE networks is connected to the user plane and designed as an add-on to a 4G network in order to offer services in the edge, but 3GPP designs MEC in 5G in order to map onto Application Functions (AF) using services and information offered by other 3GPP network functions, following the configured policies. Other enabling functionalities are also defined for flexible MEC deployments [69], [70].

E. Self-organizing Networks (SON)

5G networks are meant to provide a heterogeneous and dense structure, seen as a “network of networks” with different types of access technologies to create a seamless user experience. Use cases like autonomous driving and tactile internet, in addition to more traditional voice and data applications, need a fundamental change in the way networks are managed, with a much more automation and dynamic predictive resource allocation. SON technology is seen as an important enabler of these requirements. The Release 7 of the Small Cell Forum, having among others 3GPP and NGMN as partners, focuses on SON technology as a 5G enabler, which is defined over “Hetnets multi-environment-multi-technology, multi-domain, multi-spectrum, multi-operator and multi-vendor” which can be deployed for 4G networks following best practices that smoothen a later transition to 5G [71]. Due to the expected density, the optimization of the network structure can be complex. SON aim thus to automate the configuration of network settings, which provides an easier deployment and operation in addition to a better performance due to the dynamic way the process goes. An illustration of SON deployment process is given in Fig. 18.

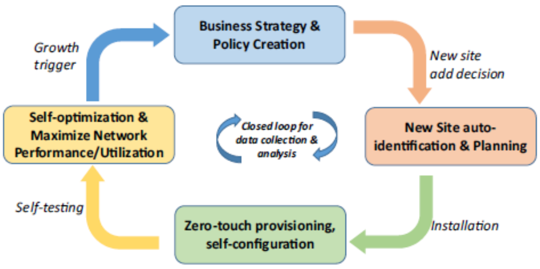

Fig. 18. Ideal deployment process with closed loop automation (Source [71])

The features provided by SON for LTE are [71]:

- Self-configuration: basic backhaul and interface configuration, automatic inventory and software update, automatic neighbor relation, handover paths definition, cell identifiers assignment.
- Self-optimization: load balancing, mobility robustness, access robustness, frequent handover and interference mitigation, coverage capacity optimization, signal strength and quality, minimization of drive testing, crowd measurement reports optimization, energy saving, handover forwarding.
- Self-healing: cell outage detection, cell degradation detection, cell outage recovery, cell outage compensation, recovery from cell outage compensation.

SON should provide in addition more robust solutions in a 5G dense networks for interference management, following the deployment scenarios and required QoE. An example of already issued solutions that enable SON is the recently published Application Programming Interface (API) for physical layer and Medium Access Control (MAC) layer [72].

F. Device to Device Communications (D2D)

Another approach suggested to solve high-density cellular network is D2D communication. In fact, in voice-centric systems, parties establishing communication are supposed to have no spatial proximity a priori, contrary to some situations for data communication where several collocated devices would like to wirelessly share content or interact. In this latter case, it can be more efficient to adopt a Proximity-based Device-to-device communications. Moreover, this communication ability may be used to enhance capacity and coverage when devices act as transmission relays and set up multi-hop communication links. D2D plays an important role in 5G applications. However, the following issues have to be addressed in 5G, as they already present challenges in 4G:

- Direct discovery: In 4G systems, the Evolved Packet Core (EPC)-level Proximity Service discovery solution is adopted, which relies on the location services requiring five stages: UE registration, proximity request, location reporting, proximity alert and direct discovery. This implies an increasing in complexity and delay.
- Interference management: as devices act as relays, there are constraints on distance, scheduling and emission power in regard to BS and primary cellular UEs, as shown in Fig. 19.
- Direct communication: In 4G systems, physical channels of direct communication links reuse physical uplink shared structures, which reduces the dynamic range requirements of power amplifiers

due to high PAPR. 5G systems on the other hand may use frequency resources dispersed in several frequency bands. New multi-carrier modulations and CA techniques have to be used, and D2D communication link in this case has to be redesigned.

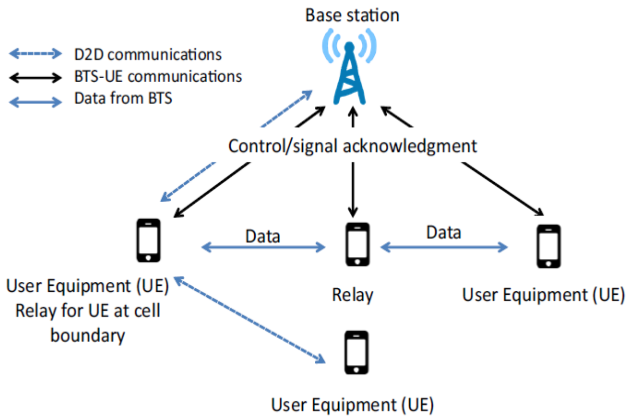

Fig. 19. D2D typical scenario (source [73])

G. Fog Computing

The ultra dense networks paradigm implies a huge amount of data to transmit. For some applications, data needs to be centralized and may use cloud computing. This “cloud model” can be extended to the edge Fog networking, which is a system-level horizontal architecture distributing resources and services anywhere along the continuum from Cloud to Things. Fog and Cloud fusion can provide a device and service consolidation in addition to an optimization of life-cycle management of tenants and virtualized services, enhancement of data policy management and integration of applications and data management. A unified orchestration for Fog and Cloud can enforce service and security and integrate the entire IoT verticals. Fog computing nodes are typically located away from the main cloud data centres, at the edge. Theyare wide-spread and geographically available in large numbers and can provide applications with awareness of device geographical location and device context. In addition, cloud computing on fog nodes enables low and predictable latency. A comparison between fog and conventional cloud is given in [74] and summarized in Table III.

TABLE III : COMPARISON BETWEEN FOG/EDGE AND CONVENTIONAL CLOUD COMPUTING (SOURCE:[75])

	Fog computing	Cloud computing
Target users	Mobile users	Internet users
Service type	Limited localized information Services related to specific deployment locations	Global information Collected from worldwide
Hardware	Limited storage, compute power And wireless interface	Ample and scalable Storage space and Compute power
Distance to Users	In the physical proximity and Communicate through single-hop wireless connection	Faraway from users And communicate Through IP networks
Working Environment	Outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls,etc.)	Warehouse-size building with air conditioning systems
Deployment	Centralized or distributed in regional areas by local business (local telecommunication vendor, shopping mall retailer, etc.)	Centralized and Maintained by Amazon, Google, etc.

V. CONCLUSION

5G systems present an evolution of existing systems, including releases meant for LTE, LTE-A and LTE-A pro as well as a revolution introducing completely new techniques along with new use cases targeted for future networks. The development of 5G new techniques and standards aims to fulfill a number of requirements much more demanding than for previous systems. Every day brings new ideas, achievements, Proof-of-concepts and demonstrations enabling 5G systems. This paper presents a picture of research and standardization landscape of 5G systems development. It also presents some of the most important key technologies heavily studied for 5G, such as massive MIMO, C-RAN and SON, which promise to fulfill 5G requirements announced by International Mobile Telecommunications (IMT)-2020 and NGMN Alliance.

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