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Table of Contents

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Return to Table of Contents

Letter from the Editor

06 December 2020

Something interesting about taking over, and 5G
And some more
Happy Reading.
Enjoy!

Professor Periklis Chatzimisios, Editor-in-Chief, Member of IEEE Standards Education Committee

Periklis Chatzimisios, Editor-in-Chief, is a member of the IEEE Standards Education Committee (SEC) and serves as member of the Standards Program Development Board and the Education Services Board under IEEE Communication Society (ComSoc). Periklis is the Communications Chapter Chair of IEEE Greece Section and also serves as the Chair of ComSoc Technical Committee on Information Infrastructure and Networking (TCIIN), the Vice Chair of ComSoc Technical Committee on Big Data (TCBD) and an active member of the IEEE Future Networks (5G) Initiative.

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Return to Table of Contents

3GPP 5G CORE NETWORK: AN OVERVIEW AND FUTURE DIRECTIONS

27 November 2020
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Introduction
In 2015, the 5th generation (5G) mobile communication was officially approved by the International Telecommunication Union (ITU) as IMT-2020. Since then, 3GPP, the international organization responsible for 5G standards, is actively developing specifications for the complete 5G System (5GS). 3GPP Release 15 provides the first full set of deployable standards for the 5GS, and the evolution and expansion of 5GS are now being standardized in Release 16 and 17, respectively. The 5GS is designed to handle extremely high traffic from the vast number of devices more efficiently along with enhanced capabilities in providing real-time services, including mission-critical services, using a flexible architecture tailored to customer needs. This paper describes an overview of the 3GPP 5GS core capabilities and future directions.

3GPP 5G Standards Overview

3GPP started a preliminary study for the development of 5G specification in Release 14 and proceeded with the complete set of 5G specifications in earnest in Release 15 (late 2018) and Release 16 (mid 2019 for completion of 80% of features). In Release 15, 5G basic features including New Radio (NR), massive machine-type communications (mMTC), ultra-reliable low-latency communications (URLLC), vehicle to everything (V2X) phase 2, service-based architecture, etc., were defined as the 5G Phase 1 specification. In Release 16, additional features, for example, enhancing 5G system, industrial IoT, URLLC enhancements, are standardized as the 5G Phase 2 specification. As shown in Fig. 1, the 5G specification is officially scheduled to release its Phase 1 in June 2018 and, at the time of writing this paper, the Phase 2 specification is expected to freeze in June 2020 and complete in September 2020. Release 17 is scheduled to deliver in September 2021.

The scope of Release 15 covers both non-standalone 5G radio systems integrated with LTE networks and standalone 5G with a new radio system complemented by a next-generation core network (see Fig. 2). Release 15 also focuses on supporting enhanced mobile broadband (eMBB) among three 5G usage scenarios (eMBB, mMTC, URLLC) defined by ITU [1] with following capabilities:

- >10 Gb/s peak data rates for eMBB
- >1 M/km^{2}connections for mMTC
- <1 ms latency for URLLC

As the next major release for 5G specification, the 3GPP Release 16 provides an initial complete 5GS set of standards resulting from around 25 studies on various topics such as

V2X phase 3, 5G satellite access, network slicing, security enhancements [2], novel radio techniques and the IoT.

Release 17 targets further 5G system enhancements to expand the mobile ecosystem for supporting new services/protocols/devices, new spectrum bands and business models covering topics such as Multimedia Priority Service, V2X application layer services, 5G satellite access, and Local Area Network (LAN) support in 5G.

Benefit of 5G over 4G

What is 5G and how does it differ from 4G? This is a question that is paramount on the minds of the general public. When we speak of 5G we really mean 5G radio technology and not so much about the core network that is also an integral part of the entire 5G system. Currently, 4G radio technology is robust and matured, i.e., enhanced over the last ten years and widely deployed. The real benefits of 5G radio technology will take time to realize until it matures and is widely deployed in the next ten years. It should be noted that 5G isn't replacing 4G any time soon. In fact, both will coexist for many years and work together. 5G capable phones will support both 4G and 5G technology. Here is a list of key differences of 4G vs. 5G from a technical standpoint:

- Radio frequency spectrum – 3GHz vs. 30-300 GHz
- Spectrum efficiency – 3 times better (more bits per Hz)
- Data transmission/speed – up to 1 Gbps vs. 50 Gbps
- Lower latency – 50ms vs. 1ms
- Connection density – 10 times higher in 5G

The 5G radio's key benefits in the spectrum it operates in are higher speeds, less latency, and capacity for a larger number of connected devices along with less interference and better efficiency. One disadvantage in higher frequency band for 5G would be its broadcast range as signal does not travel long distance in higher frequency bands, and does not penetrate buildings very well. This will require large number of cell sites to be deployed for 5G. In the day-to-day experience, users will not experience a big difference using 5G technology, other than downloading videos faster. The biggest benefits of 5G will not be apparent right away but developments are underway to offer fancy features which we can't even foresee right now as 5G technology matures and is widely deployed. Unlike previous generations of mobile networks, 5G technology is expected to fundamentally transform the role that telecommunications technology plays in the society. The next section explains key features of 3GPP 5G standards.

5G Core Technology Features and Services

Some 5G key features to look into are new radio capabilities, network slicing, ultra-reliable low-latency communications, enhance security, high-capacity for large-scale internet of things devices, and enhanced core network using service-based architecture. These features allow operating more flexible and dynamic networks to uniformly enable user services with different needs. These 5G features enables supporting various value-added real-time services such as self-driving car, smart city, augmented reality and virtual reality (AR/VR), online interactive learning and 3D video.

5G Deployment Options: The integration of the new radio technology NR in 5G with the ones of the previous generation 4G Long Term Evolution (LTE) was studied in different options in 3GPP Technical Report (TR) 33.801 [3] with two general possibilities as shown in Fig. 2: Standalone (SA) options consist of only one generation of radio access technology, 4G LTE or 5G NR. Non-Standalone (NSA) options have both generations of radio access technologies (4G LTE and 5G) by means of dual connectivity. The most important options are for NSA the so-called Option 3 with the LTE eNB (i.e., evolved Node B) as master node and the 5G gNB, which is a 3GPP 5G Next Generation base station that supports the 5G NR, as secondary node, and both connected to the 4G core network (Evolved Packet Core, EPC). This allows a fast deployment in the operator networks that already deployed 4G LTE and from User Equipment (UE, the phone in 3GPP language) only a 5G radio needs to be added. The evolution in the core network to the 5G core is more difficult. For SA, the most important option is the so-called Option 2, where the 5G gNB is directly connected to the 5G core. While all 5G benefits can be used directly with this option, it is more beneficial with green field operators who start deploying 5G without any legacy network, since interworking with 4G requires much more effort.

Network Slicing using NFV: One of the new features of the 5GS, is call network slicing which enables operators to manage their network resources in unique ways based on customer traffic needs. The network slicing feature is an end-to-end feature which is supported both on the radio access network (RAN) and 5G core. It allows partitioning the network resources via creation of Network Slices (NSs) consisting of dedicated network resources that are needed to do the job, rather than using the entire network and wasting resources, as done previously when there was only a single monolithic network whose resources could not be partitioned resulting in under or over utilization of resources. For example, NSs can be created to address different requirements on functionality (i.e., priority, charging, policy control, security, and mobility), or different requirements on performance (i.e., latency, mobility, availability, reliability and data rates), or a NS can be created to serve only specific users (i.e., multimedia priority service users, public safety users, corporate customers, roamers, or hosting an mobile virtual network operator). The network slice behavior in terms of features and services can be described with the Slice/Service type as part of the slice identifier. So far there are four Slice/Service types specified [4] for eMBB, URLLC, mMTC and V2X [5].

The 5G network nodes can be virtualized and sliced through the use of cloud computing working in the same fashion as virtual machines (see Fig. 3). This concept is called network function virtualization (NFV) which has gained importance to allow operators to reduce capital expenditure (no need for dedicated hardware for the network nodes) and ability to tailor the network nodes easily through just software updates. The NFV standards are conducted by the ETSI NFV Industry Specification Group, founded in November 2012.

Service Based Architecture (SBA) – cloud native architecture: The SBA functionality is described in TS 23.501 [4] and the procedures are documented in TS 23.502 [6]. 5G SBA is based on technologies known from the internet, i.e., the Service-Oriented Architecture (SOA) and Representational State Transfer (REST). SOA consists of the three components Service Repository, Service Consumer and Service Provider. A Service Producer publishes its service(s) to the Service repository and a Service Consumer queries the Service Repository for a Service Provider for a specific Server. Then the Service Consumer queries or subscribes to events of the requested service. Network Functions (NF) of SBA can act according to one or more roles of the three, depending of the NF, i.e., they can consume a service from one NF but notify other NFs as a producer at the same time. Without going into details, SBA in 5G defines a variety of NFs as shown in Fig. 4, here are the most important ones: Access and Mobility management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Policy Control Function (PCF), Network Exposure Function (NEF), Network Repository Function (NRF), Unified Data Management (UDM), Unified Data Repository (UDR), Authentication Server Function (AUSF), Application Function (AF), Network Slice Selection Function (NSSF).

Future Directions

New studies have been proposed in 3GPP for Release 17 and work has started on them. Some of them are mentioned here which are proposed for enhancement of the 5G core network.

- **Proximity-based services**: To study applicability of direct mode device-to-device capability of the proximity-based service feature that is used in mission critical services, for commercial applications like virtual reality interactive services.
- **5G multicast-broadcast services**: To study the applicability of The Multicast/Broadcast Multimedia Subsystem (MBMS) feature of 3G/4G for supporting multicast requirements/use cases for cellular IoT, Public Safety, V2X etc.
- **Network automation for 5G**: To study applicability of the Release 15 functionality called network data analytics function (NWDAF) responsible for analyzing data of any part of the network, for enabling Artificial Intelligence related services.
- **Edge Computing in 5G**: To study the applicability of the mobile edge computing technology for improving response times for real-time applications based on URLLC, V2X, AR/VR, satellite access in 5GS, and content delivery network, etc., use cases.
- **Support of non-public private networks**: To study the applicability of the Release 16 feature called “Vertical LAN”, which offered specific industry (verticals) solutions for companies/factories like redundant transmissions and URLLC, to be available to private networks.
- **Enhancement of network slicing**: To study further enhancements of the Release 16 network slicing feature.
- **Support of satellite access**: To study the architecture enhancements in the 5G core for using satellite access in 5G.

Acknowledgment
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Return to Table of Contents

UAS TO UAS COMMUNICATION SUPPORT: WILL 3GPP 5G DELIVER ON ITS PROMISE?

30 November 2020

Kamesh Namuduri and Vara Prasad Karamchedu

Abstract

Unmanned Aircraft System (UAS) to UAS communication is an important element within UAS traffic management (UTM). It facilitates Beyond Radio Line of Sight (BRLoS) communications or using network assisted communications so that information can be shared among the aircrafts. While UAs to UAS communications can be implemented in many ways, this article focuses on the 3GPP-based solution. It provides a brief review of the technical specifications related to UAS communication support.

Introduction

An Unmanned Aircraft System (UAS) includes an Unmanned Aerial Vehicle (UAV) and a UAV controller. UAS to UAS communication is one of the central pieces of the UAS Traffic Management (UTM) system (see Table 1 for the terminology). Direct communication between UAVs will allow Beyond Radio Line of Sight (BRLoS) communications, enhanced situational awareness, and sharing of mission-critical information among the UAVs.

There are three primary ways to support UAS to UAS communications as illustrated in Fig.1: (1) through a terrestrial cellular network, (2) through a satellite network or by a direct communication without any supporting infrastructure, (3) using over-the-air direct communication strategies such as WiFi, Dedicated Short Range Communications (DSRC), Long Range (LoRa), IEEE 802.11p, L-band Digital Aeronautical Communications System (LDACS) air-to-air, Automatic Dependent Surveillance Broadcast (ADS–B)r their variants. Each of these radio technologies have their own advantages and disadvantages.

It makes sense to take advantage of cellular networking infrastructure which is available in every country with nation-wide coverage, to support UAS communications. According to 3GPP, ubiquitous coverage, high reliability and efficient quality of service management, robust security, and seamless mobility are critical factors to supporting UAS command and control functions [1]. However, performance requirements in terms of coverage, latency, and reliability need to be tested before cellular network supported UAS communication is adopted as a reliable option for critical communication needs such as "command and control" and for critical applications such as "detect and avoid".

This article outlines communication support services to UAS in 3GPP ecosystem. It discusses how 3GPP supports UAS communications and its performance requirements. This discussion is limited to the high-level 3GPP specifications that are relevant for UAS communications only.

UAS to UAS Communications

3GPP Release 16 outlines the technical specification for UAS support in the document titled "3GPP TS22.125" [2,4]. Fig. 1 depicts how a 3GPP network supports UAS communications. It illustrates how a C2 link can be established between a UAV controller and a UAV using a 3GPP Network, when the UAV is not within the communication range of its controller. It also depicts how a UTM system can be connected to UAV. When the UAV is within its communication range, a UAV is controlled by the UAV controller. The challenge is when the UAV is out of the communication range of the controller. It is when UAS-to-UAS communications becomes relevant. From a fundamental sense, a UAV is like a phone. Just like cellular service can reach our phones wherever we are, a UAV controller can communicate with a UAV if they are connected to the cellular network as shown in Fig. 1.

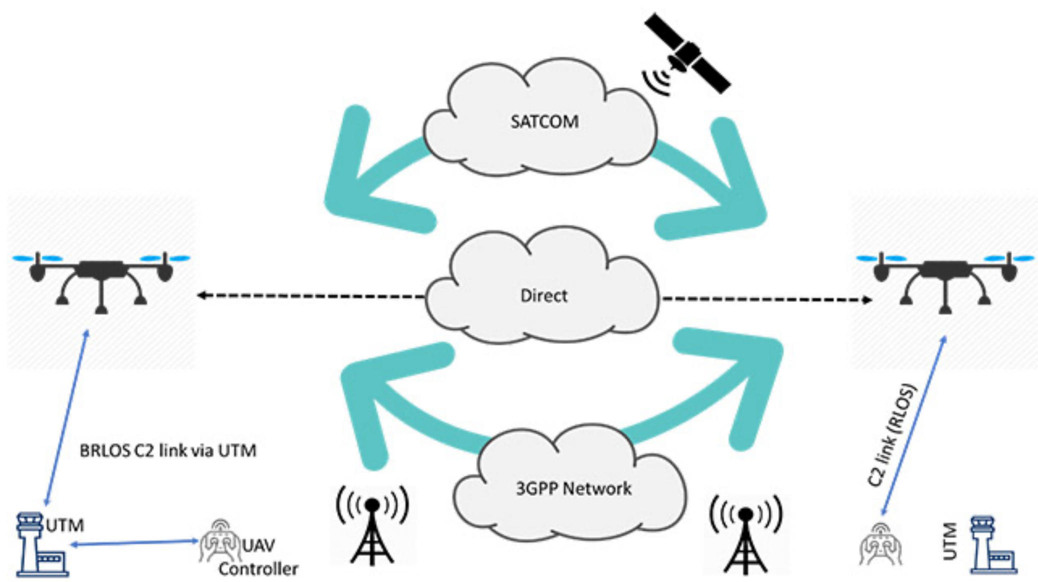

Figure 1: Options for UAS to UAS communication support

Table 1: Terminology

3GPP	Third Generation Partnership Project
5G	Fifth Generation Cellular Network
UAV	Unmanned Aerial Vehicle, same as Drone
UAS	Unmanned Aircraft System
UTM	UAS Traffic Management
C2 link	Command and Control
CNPC	Control and Non-Payload Communications
USS	UAS Service Supplier
UE	User Equipment (e.g., Mobile device)

3GPP separates UAS communication services into two categories: control plane and user plane. Control plane services refer to C2 communication services and control and non-payload communication (CNPC) services that are required for ensuring secure and reliable flight operations including navigation, telemetry, traffic control, and surveillance. C2 and CNPC data is time-critical and hence need to be shared in real-time to and from the UAVs. Data plane services refer to communication services to and from the payloads carried by UAVs such as a camera. Payload communication services are non-critical and hence do not need to be in real-time. 3GPP network supports both payload as well as non-payload communication services.

3GPP Support for Remote ID and Tracking

ASTM International recently (formerly known as American Society for Testing and Materials) released F3411 standard specification for Remote ID and Tracking [3]. Remote ID specification provides a means for a UAS to share its presence with other UAS as well as with personnel on the ground including law-enforcement agents. The specification defines the message format, methods, and minimum performance requirements for sharing Remote ID details. ASTM identifies WiFi and Bluetooth as potential means of communication support for implementing Remote ID. In future, other types of communication support including 3GPP, may be included.

Two types of remote ID are defined in this specification: broadcast and network. A UAS equipped with WiFi or Bluetooth radio can continuously transmit its Broadcast Remote ID data. Such a broadcast advertisement allows a UAS to discover other UAS within its vicinity and establish a connection with its neighbors. Broadcast Remote ID also allows devices on the ground to know the presence of a UAS within their vicinity. For example, a law-enforcement officer with a handheld device may receive the broadcast message to identify the UAS and verify if the UAS is legally allowed to fly in that area. Another use case is a passive application system which may use the Broadcast Remote ID for simply tracking and displaying the UAS position.

A Network Remote ID, on the other hand, is useful for systems and services such as UAS flight planning, coordination and deconfliction. For example, a UAS Service Supplier (USS) or a service provider will use Network Remote ID to establish a network connection with the UAS. Once a network connection is established, a UAS will be constantly in contact with the USS or service provider and share its current location. A USS or service provider can

also share airspace alerts with the UAS over the network connection or alternate routes in situations when the UAS cannot continue on its original route.
3GPP Release 16 lists the requirements for supporting transmission and reception of Network Remote ID messages [2]. For example, the 3GPP system is expected to enable a UAV to broadcast Remote ID data including UAV type, location, time, flight path, speed, and operating status to other UAVs in the vicinity can use this formation to avoid potential collisions.

3GPP support for UAS-to-UAS Communications
UAS-to-UAS communications play an important role in decentralized traffic management, detect and avoid strategies, and other autonomous UAS operations. 3GPP support for UAS-to-UAS communications is critical for the success of unmanned air transportation of goods as well as people. As there will not be any signal lights in the skyways, UAS-to-UAS communications is the only means to avoid potential accidents in the sky especially during close encounters. Hence, 3GPP support for UAS-to-UAS communications is critical for the success of unmanned air transportation. According to Release 16 technical specification (3GPP TS 22.125) [4], UAV can make use of 3GPP system for direct UAV-to-UAV communication for transmitting and receiving messages with the following performance characteristics:

Table 2: 3GPP Specifications for UAS-to-UAS Communications [4,5]

Metric	Communication specifications
Relative Speed of UAS	320 kilometers per hour
Message payload	50-1500 bytes
Message frequency	10 messages per second
Communication Range	600 meters
End to end Latency	<=100 milliseconds

3GPP Release 17 includes technical report TR 23.754 for supporting UAS connectivity, identification and tracking [5]. 3GPP system is expected to support the following communication links: UAV-UAV, UAV-UTM, UAV-to-UAV controller. Each networked component is considered as a UE. This specification also includes authorization and authentication services.

Conclusions
Critical UAS communication services such as command and control, traffic management, and detect and avoid strategies require high performance in terms of communication range, reliability, and round-trip latency. 3GPP-based solution to UAS communication support is appealing primarily due the availability of existing infrastructure. Extensive flight experiments will reveal how well the key performance indicators defined in 3GPP technical specifications will be met.

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Biographies

Kamesh Namuduri received his B.S. degree in Electronics and Communication Engineering from Osmania University, India, in 1984, M.S. degree in Computer Science from University of Hyderabad in 1986, and Ph.D. degree in Computer Science and Engineering from University of South Florida in 1992. Over the past eleven years, his research is focused on aerial networking and communications. He is serving as the chair for two Standards Working Groups (IEEE 1920.1: Aerial Communications and Networking and IEEE P1920.2: Vehicle-to-Vehicle Communications for Unmanned Aircraft Systems). He is serving as the Chair for the IEEE Vehicular Technology Society’s Ad Hoc Committee on Drones. He is a co-editor for the book titled “UAV Networks and Communications” published by the Cambridge University Press in 2017.

Vara Prasad Karamchedu is an experienced telecommunication professional, with a unique combination of rich hands-on operational experience in Telecom and Cellular Network deployment/Maintenance blended with target driven, results focused Managerial experience. He has a deep understanding of market dynamics of public and private Telecom Networks over 45 countries in EMEA and Asia Pacific region (Fixed, Wireless, broadband access and long-haul transmission networks). His expertise includes Network Functions Virtualization (NFV), Software Defined Networking (SDN), 4G-LTE, LTE Advanced Pro, Public Safety and Critical Communications and 5G. At present, he is the Director of Technical Solutions and Business Development at Award Solutions EMEA Ltd, works in United Kingdom.

Return to Table of Contents

MULTI-CONNECTIVITY IN 5G NEW RADIO STANDARDS

30 November 2020

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Abstract

Multi-connectivity (MC) is a key enabler for 5G networks and beyond. It enhances the network performance for diverse use cases and across the metrics. With the user simultaneously connected to multiple nodes, MC increases transmission mobility robustness, reduces handover (HO) interruption time and increases the overall reliability of the network. Regarding standardization, MC has evolved from the LTE dual connectivity from 3GPP Release 12 to the 5G new radio (NR) multi-radio dual connectivity (MR-DC) paradigm currently being standardized for Release 16. With the consideration of fronthaul-based architecture and packet duplication features for MR-DC, among others, 5G networks (and beyond) are poised to deliver enhanced quality of service through increased throughput and reliability as well as reduced latency, HO frequency and probability of radio link failures. Further enhancements that aim to address the current challenges of MC operations are already being explored for Release 17 and beyond.

5G New Radio Evolution

Following the release of the first 5G new radio (NR) standard (Release 15 or 5G Phase 1) in mid-2018 by the 3rd generation partnership project (3GPP), several enhancements have been introduced by the cellular standardization body towards the 5G Phase 2 (i.e., the Release 16 which is expected to be finalized by June 2020). These enhancements are expected to further enable the three broad classes of 5G use cases: enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC) and massive machine type communications (mMTC).

For 5G NR Release 16, the enhancements are along two directions: (i) upgrading of existing features of previous releases, with respect to areas such as MIMO and beamforming, user equipment (UE) power saving, dynamic spectrum sharing (DSS), carrier aggregation (CA) and dual connectivity (DC)/multi-connectivity (MC), and (ii) enabling of new verticals and deployment scenarios with a particular focus on intelligent transport systems (ITS) and vehicle-to-anything (V2X) communications, positioning, industrial IoT and URLLC features, integrated access and backhaul (IAB) and NR in unlicensed spectrum. These features and scenarios will further enable 5G networks to deliver remarkable improvements across the performance metrics. To further advance the network capabilities, more enhanced features and newer scenarios are under consideration towards Release 17 and beyond [1].

Multi-connectivity Architectures in 5G NR

One of the key features of 5G NR enumerated earlier is multi-connectivity (MC). It refers to the concurrent use of multiple independent communication paths, nodes, access points (APs) or base stations (BSs) for data transmission to a UE. In MC mode, the UE accesses radio resources from multiple nodes that have distinct schedulers. The nodes could be of the same or different radio access technology (RAT) [2], [3]. The MC architecture is a very promising feature for 5G as it has been shown to enable the realization of the stringent constraints (high reliability, low latency and high throughput) for all the broad classes of 5G use cases, from eMBB that targets high-capacity applications (which Release 15 focused on) to the mMTC and URLLC applications which are the primary focus of Release 16. MC also enables ultra high speed and low latency communication (uHSLLC) that represents a mix of the aforementioned use cases.

While the throughput-oriented eMBB targets up to 1 Gbps user-experienced data rates, URLLC applications require 99.999% reliability for 32-byte packet size with 1 ms latency on the user plane (UP). This translates to a packet loss ratio (PLR) or block error rate (BLER) [2]. Industrial, automotive and health care application scenarios (such as industrial automation, autonomous driving, remote surgery, etc) require these stringent requirement to be met and MC is being extensively explored to facilitate delay-sensitive, error-free and/or ultra-fast communication for these applications [2], [4].

According to the 3GPP NR Release 16 standard [5], Multi-Radio Dual Connectivity (MR-DC) is the term that is generally being used for MC. Dual connectivity (DC) refers to the lower bound of MC where the UE is connected to only two APs. In the absence of MC/DC, the UE establishes a connection with only a node at a time (i.e., the legacy single connectivity case). Some of the earlier variants of MC approaches in 3GPP standards include carrier aggregation (CA [Release 10]), coordinated multipoint using joint transmission (CoMP-JT [Release 11]), dual connectivity (DC [Release 12]), LTE-WLAN aggregation (LWA [Release 13]) and MR-DC [Release 15] [2], [6]. The form, aggregation layer and scheduling policy of these MC techniques vary from approach to the other.

Building on the foundations from Release 15, MR-DC in Release 16 is a generalization of different possible configurations of DC where a multiple receive (Rx)/transmit (Tx) capable UE is configured to utilize resources provided by two different nodes connected via non-ideal backhaul, where one node provides NR access and the other provides E-UTRA (Evolved Universal Terrestrial Radio Access), or where both nodes provide NR access. One node acts as the master node (MN) and the other acts as the secondary node (SN). The MN and SN are connected via a network interface and at least the MN is connected to the core network, either the evolved packet core (EPC) or the 5G core (5GC).

In Release 12 (completed March 2015), 3GPP introduced the Intra-E-UTRA Dual Connectivity (or simply DC) which is the inter-site DC between two LTE BSs (i.e., same RAT) where both BSs are connected to the EPC. With the introduction of 5G NR, 3GPP introduced four configurations for MR-DC: one MR-DC with EPC (E-UTRA-NR Dual Connectivity (EN-DC)) and three MR-DC with 5GC configurations (i.e., NR-E-UTRA Dual Connectivity (NE-DC), NG-RAN E-UTRA-NR Dual Connectivity (NGEN-DC) and NR-NR Dual Connectivity (NR-DC)). The first three MR-DC options fall under the non-standalone (NSA) architecture involving two APs of different RATs while the fourth MR-DC option (i.e., NR-DC) represents the 5G equivalent of the LTE DC. These five DC architectures are illustrated in Figure 1. While the Release 12 DC (shown in Figure 1(a)) involves two nodes of the same RAT (i.e., LTE), NR DC involves two NR nodes. It should be noted that Figure 1(b) represents three sub-architectures depending on the different network nodes connected. The newest MR-DC configuration supported by 5G NR is the NR-NR Dual Connectivity (or simply NR-DC) shown in Figure 1(c). Unlike the other DC architectures, the UE in NR-DC is connected to two NR next-generation nodeBs (gNBs). We note that while the EN-DC in Figure 1b (i) is the current priority architecture by operators, NR-DC appears to be the ultimate migration goal for future deployment.

Regarding the NR-DC, two sub-architectures are being explored. The first is the Xn-based NR-DC architecture (illustrated in Figure 1(c)) where the sublayer used for the routing or aggregation (i.e., the PDCP sublayer) is located in each gNB in a distributed fashion. Here, one gNB acts as the MN/MgNB while the other gNB acts as SN/SgNB). The second NR-DC architecture is the fronthaul split-based approach (shown in Figure 2). For the second approach, the PDCP sublayer is located in a centralized unit (CU) in the cloud while all (sub)layers below the PDCP are located in each gNB distributed units (gNB-DUs). One gNB-DU serves as the master cell group (MCG) while the other gNB-DU serves as the secondary cell group (SCG) with both DUs connected to the same gNB-CU [5].

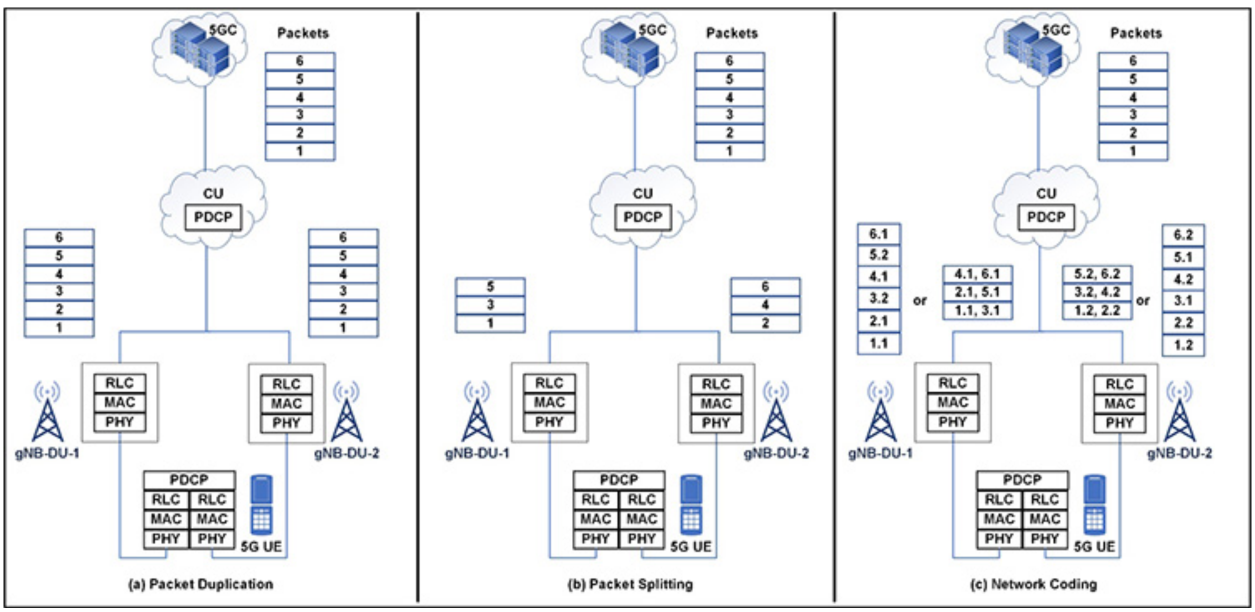

Figure 1: Dual Connectivity architectures (Xn-based framework)

Significance of Multi-connectivity

The principal aim of MC is to exploit the diversity of the simultaneous connection to different communication nodes in meeting the system performance requirements. Using MC, three main types of diversity could be exploited:

1. spatial diversity as the case with multiple antenna systems (whether intra-site/co-located or inter-site/distributed/cell-free massive MIMO),
2. frequency diversity such as the case with DC over multi-frequency heterogeneous network (e.g., multi-band HetNet involving sub-6 GHz macrocell and millimeter-wave (mmWave)/terahertz (THz) small cells), and

3. radio access technology (RAT) diversity where the different RATs involved could be from different standardization bodies (e.g., LTE-WiFi Aggregation (LWA) which was introduced in 3GPP Release 13 and completed in March 2016) or from the same body such as the 3GPP LTE and NR combinations or MR-DC [2].

To enhance 5G networks' performance (with respect to improved reliability, reduced latency, increased throughput or a combination of these), three approaches have been identified in exploiting the diversity capabilities of MR-DC with respect to packet operations:

1. Packet Duplication (PD) where the same packets are sent from the different nodes as illustrated in Figure 2(a). Here, reliability is increased due to the use of multiple redundant links. Also, latency is reduced with the elimination of packet re-transmission and the immediate processing of packets. Overall, PD reduces the frequency of handover, improves mobility robustness and reduces the probability of radio link failure (RLF) as the packets are available at both nodes. However, these gains are at the expense of throughput loss due to increased traffic load.
2. Packet Splitting (PS) where different packets are sent over the different paths as shown in Figure 2(b). The PS approach leads to increased throughput as the UE receives packets from multiple nodes. PS also reduces latency if each packet is sent on the faster of the two links. However, PS does not improve reliability as no redundancy is introduced by the approach.
3. Network Coding (NC) where different subsets of a packet/combinations of packets are sent on the different paths as shown in Figure 2(c). With subsets, the latency is reduced due to transmission of shorter packets, but the reliability is not increased. With a combination of packets, reliability is increased but the latency may be increased depending on the packet arrival rate and the need for queuing of packets or otherwise.

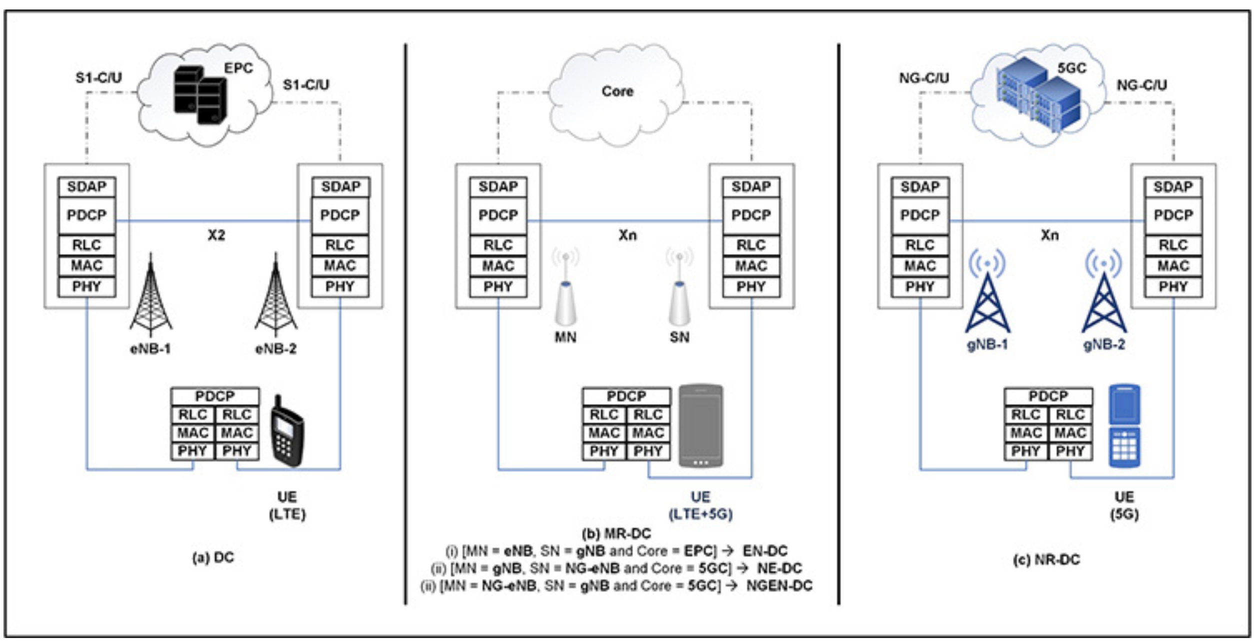

Figure 2: Packet operations for NR-DC (Fronthaul split-based architecture)

Packet Duplication in NR-DC

The 3GPP has adopted PD for both the control plane (CP) and the UP packets in 5G NR employing DC [5]. As earlier illustrated in Figure 2(a), PD is particularly aimed at meeting the URLLC requirements. Furthermore, a dynamic control option is also introduced where PD can be adaptively activated or deactivated based on the link conditions or network resource availability. When PD is deactivated, the network falls back to single connectivity (usually in conditions where single connectivity is sufficient to satisfy the latency and reliability requirement). The network resumes DC operations when PD is activated.

PD using the conventional Xn-based DC approach would require duplicate data packets to be forwarded from one AP to the other via the Xn interface which can render the system inefficient in the case of high congestion and/or latency. Using the fronthaul split-based approach, however, data is multicast from the centralized PDCP layer to the APs which avoids the Xn interface concerns. In the event of RLF on any of the transmission paths, PD facilitates the re-transmission on the alternate path(s) thereby reducing the overall interruption time and latency [4].

Though only PD has been standardized for 5G NR Release 16 (basically targeting URLLC applications), it may not be suitable for throughput-oriented eMBB or more importantly uHSLLC (i.e., eMBB+URLLC) applications requiring high throughput alongside low latency and high reliability. Therefore, an adaptive framework which dynamically switches from one diversity scheme to the other (PD, PS and NC) is required. In such adaptive networks, PD, PS or NC (for reliability, throughput or latency, respectively) would be activated based on the requirement for performance optimization in future networks. Finally, we note that the DC architecture could be extended to the true MC case with more than two Tx nodes to further exploit the diversity gains in future releases and that several other features and operational enhancements will be introduced in future standards (Release 17 and beyond).

Conclusion

MC enables cellular networks to meet the stringent performance requirement of next-generation applications and use cases. The user in MC mode can access resources from multiple nodes, exploit the diversity of the different nodes and harness gains from features such as packet duplication at the nodes to increase throughput, reduce latency and/or improve reliability. MC also guarantees connectivity to the network during handover thereby facilitating mobility robustness and enhanced overall quality of service. As a result, the MC feature has seen progressive enhancements from 3GPP Release 12 up to the current Release 16 standard. However, despite the significant gains, there are still a number of challenges and open issues for MC operations. These open issues include, among others, the choice of the most beneficial layer for MC operations, need for optimal scheduling policies in multi-cellular multi-user systems using shared spectrum and the need for reduced signaling overhead. These concerns are anticipated to be addressed in future standard releases

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Return to Table of Contents

THE 5G STANDARD – A PARADIGM SHIFT IN WIRELESS ACCESS TECHNOLOGY

30 November 2020

Suresh Borkar and Ahmed Khan

Abstract

5G is a paradigm shift into the domain of handling massive Machine Type Communication (MTC) traffic for supporting the Internet of Things (IoT) network in addition to providing significantly higher performance for traditional voice. data, and video applications. It utilizes a Cloud based Radio Access Network (C-RAN) and a Core. The C-RAN has unique capabilities including a Non-Orthogonal Multiple Access (NOMA) scheme, massive Multiple Input Multiple Output (MIMO) antenna array system, user oriented steerable beams, and operations in the mmWave frequency region. There is additional research needed to ensure safe operation of the 5G system so that it will not have adverse effect on humans, animals, vegetation, and the environment while operating in the mmWave spectrum. 5G core provides the framework for creating flexible services based on Network Slicing. Network slicing allows customization and optimization for “individual” applications and services based on use of cloud based Software Defined Networking (SDN) and Network Function Virtualization (NFV) capabilities.

Introduction

As we enter the era of intelligent applications and services including smart cities, smart energy, smart transportation, and smart health among others. 5th Generation (5G) Wireless is a key advanced access enabler for the associated Internet of Things (IoT) network. The intent of this paper is to provide the framework for 5G technology in terms of its evolution from 4G standard, the technological advances provided in implementing the standard, and unique expansion of its operation to the new mmWave frequency region. The primary issues being addressed in this paper can be paraphrased as

- How is 5G different from 4G Long Term Evolution (LTE) and what value does it offer?
- What are the technical advances in 5G?
- What actions can be taken to mitigate the health and other adverse effects of mmWave operations?

How is 5G different from 4G and what value does it offer?
4G LTE cellular technology is primarily targeted towards human-oriented voice, data, and video applications [1, 2]. Narrow Band-IoT (NB-IoT) and LTE Cat M1 (LTE-M) were key initiatives by the 4G LTE technology to address Low Power Wide Area Network (LPWAN)-oriented applications [3]. The upcoming 5G technology is a fundamental paradigm shift from 4G LTE [4,5]. In addition to handling human-oriented voice, data, and video-based applications at significantly higher performance and functionality, 5G is being designed to address Machine Type Communication (MTC) applications in the IoT space [6]. Architecturally, 5G uses 4G hardware as the foundation. Capabilities are formed in terms of adaptable software functions based on "cloudization".

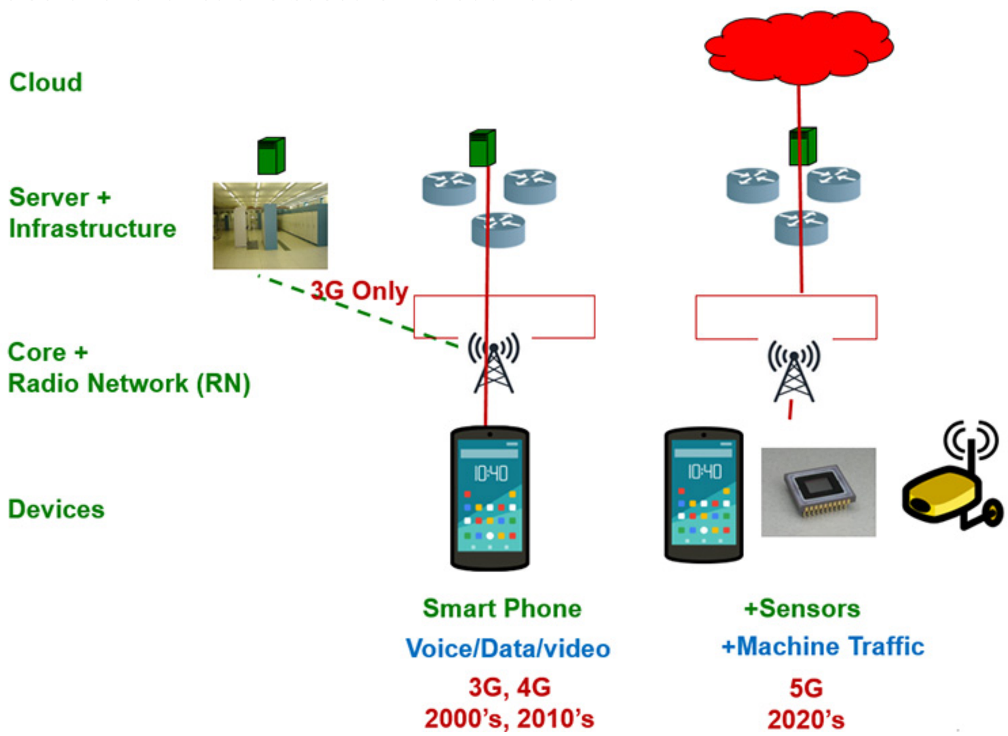

Figure 1: Cellular Wireless Evolution
The Key Performance Indicator (KPI) improvements in 5G in reference to 4G technology are summarized in Figure 2.

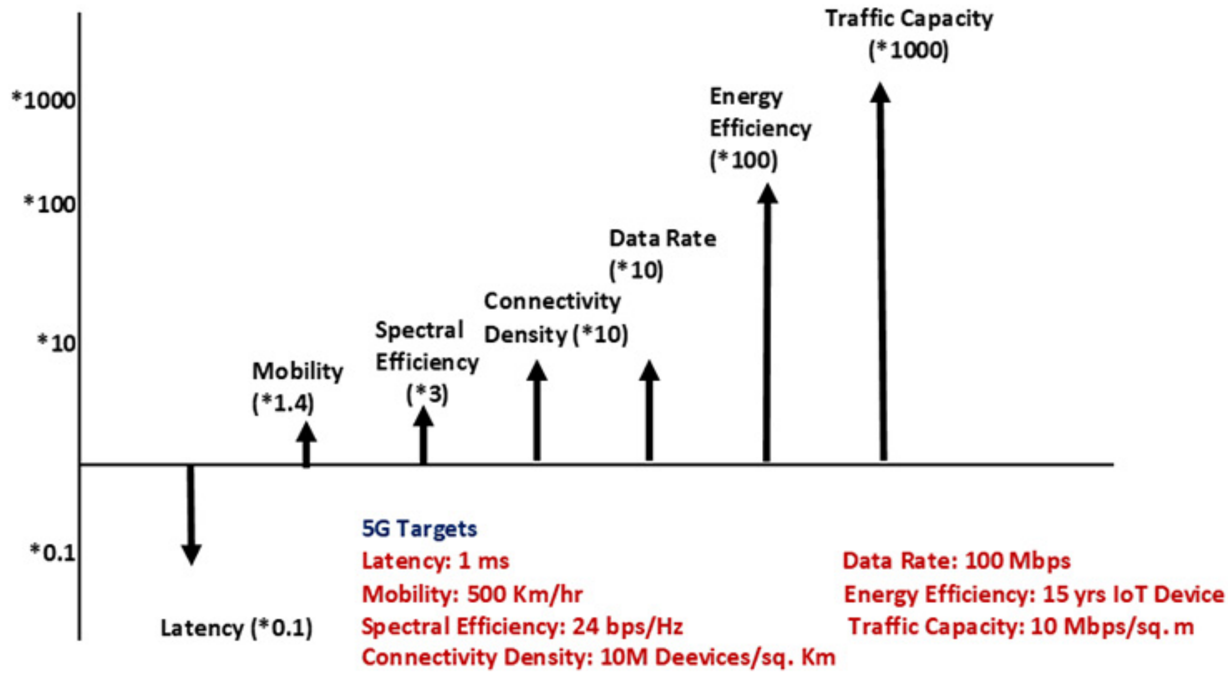

Figure 2: 5G Key Performance Indicators (KPI) with respect to 4G

What are the technical advances in 5G?
5G builds upon the key capabilities in 4G by providing several major improvements. Particular attention is placed on mmWave operations to handle mmWave operations. These include:

- High path loss due to higher carrier frequency,
- Deterioration in propagation characteristics due to environmental issues, e.g., humidity and rain, and
- Susceptibility to blockage.

These have significant impacts. Coverage is significantly reduced, typically to a 1 Km range and may have major gaps. There is significant attenuation in the range of 10^{-4} db/m and 10^{-2} db/m around 25 GHz and 60 GHz regions respectively and almost continuous attenuation of 10^{-2} db/m for rain rates higher than 25 mm/hr [7]. Devices which are not in line-of-sight cannot be accessed. There is limited in-building penetration which does not allow devices like meters inside the building or in the basement to communicate with the network.

The major advances provided in 5G Wireless are summarized in Table I.

TABLE I: 5G Technological Advances

Characteristic	Technological Advance	Comments
Customer Experience Improvement	Priority Management	Quality Class Identifier (QCI) Based User Traffic Bearer
	Network Slicing	Customization and optimization for "individual" application based on use of Cloud based Software Defined Networking (SDN) and Network Function Virtualization (NFV) capabilities
	Multi Radio Access Technologies (RAT) support – 4G, WiFi	Interworking and interface with 4G LTE and WiFi Radio Networks
Latency Improvements	Reduced Transmission Time Interval (TTI) (0.1 ms)	Number of Consecutive symbols for one Transmission in time domain
	Mobile Edge Computing (MEC)	Coordinated data computing between the cloud, the edge core / Radio Network, and the device
	Flexible Slots	Fast UL/DL turn-around and scalable slot durations
	Cyber Security	Multi domain security and trust models to handle Network and Edge Processing security vulnerabilities, User identity threats, and device data risks
Mobility Improvements	Split between Control and User Planes	Specialized user planes for different applications
	Efficient Handovers	Separate radio networks during Handovers
High Data Rates	Improve Spectral Efficiency	Higher 256 / 512 Quadrature Amplitude Modulation (QAM)
	Carrier Aggregation	Combine two or more carriers even in different bands into one data channel
	Higher Frequency bandwidth	Up to 100 MHz in sub 6 GHz and 500 MHz in mmWave Operations
Traffic Capacity Improvements	Non Orthogonal Multiple Access (NOMA)	Scalable-OFDM (SC-OFDM) Using Power domain techniques
	Channel Dependent Scheduling	Allocate time frequency resources to user with highest Channel Quality
	Multiple Input Multiple Output (MIMO) Antennas	Use time and space diversity to handle path loss, manage interference, and increase coverage
	Steerable Beams	Use MIMO to focus energy into narrow beam directed towards mobile User Equipment (UE)
Coverage Improvements	Fast Link Adaptation	Match modulation, coding and other signal and protocol parameters to the conditions on the radio link
	Coordinated Multi Point (CoMP)	Cooperatively enhance the signal from two different radio networks
	Mesh Networking	Use individual routers / nodes and gateways for a consolidated interface to the radio network
Energy Efficient Operation	Reduce power consumption during UE idle mode	Use Power Save Mode (PSM) and extended Discontinuous Reception (eDRX) techniques to reduce power transmission
Reliability	Advanced Channel Coding	Multi Edge- Low Density Parity Check (ME-LDPC) and CRC-Aided Polar (CA-Polar) codes for user plane data transmission and Control Physical Channel integrity
	Hybrid-Automatic Repeat reQuest (HARQ)	Improve transmission integrity via combining multiple error detection coded packets

What actions can be taken to mitigate the health and other adverse effects of mmWave operations?

An area of concern in mmWave propagation is the uncertain environmental and health impact of mmWave radiation. Figure 3 shows how the cellular operations both in the sub-6 GHz and mmWave frequencies form part of the overall Electromagnetic spectrum.

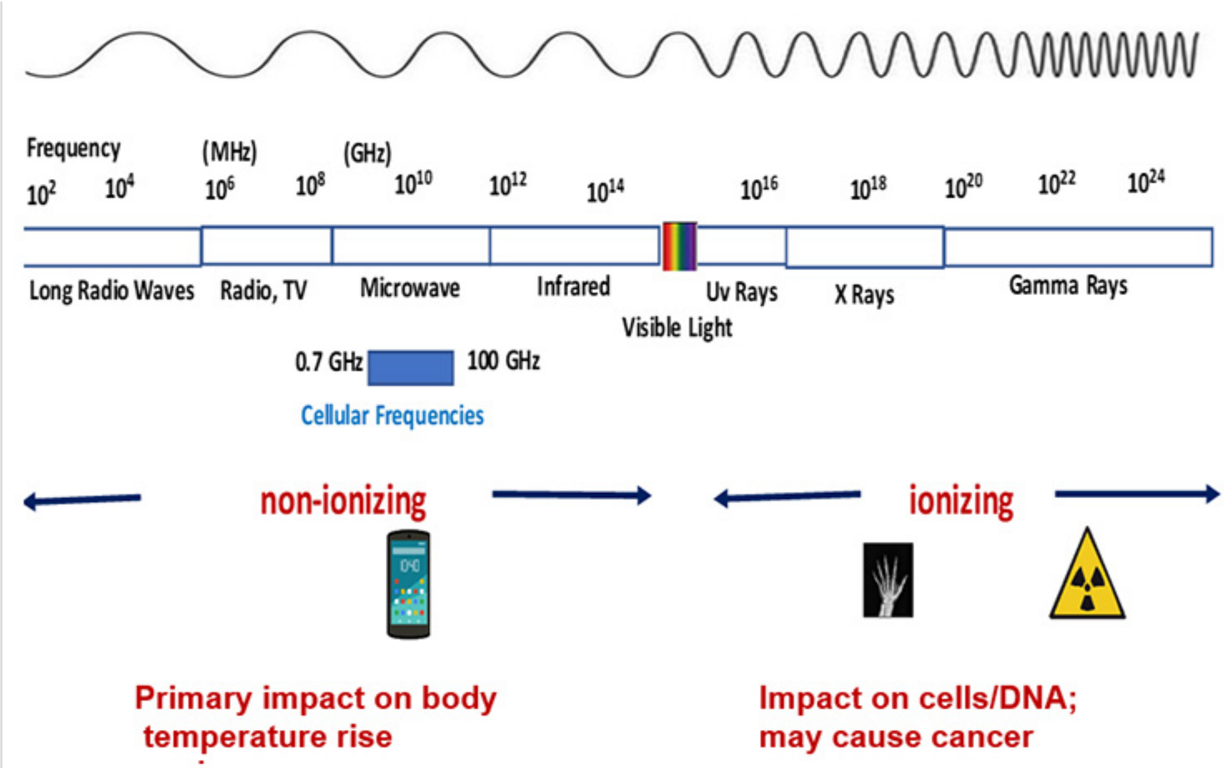

Figure 3: Health Impact of EM Spectrum

In the frequencies in which the cellular systems operate, the effect on human body is non-ionizing implying that the energy is able to knock the electrons to a higher state, i.e. thermal energy, but not knock electrons out of orbit. In the sub-6GHz frequency range, EM waves penetrate up to tissues just below the skin. The measure used is Specific Absorption Rate (SAR) with the International safe limits being defined as 0.08 W/Kg for the whole body with more stringent localized limits [8]. This results in mobile devices and base stations limited to 6 W and 500 W power radiation respectively. Experience of 30+ years has indicated no adverse health outcomes due to exposure within these safe limits thus repudiating the notion that mobile phone use can cause brain tumors. This applies to all cellular generations including 5G for operations in the sub-6GHs frequencies.

For the 5G operation, the primary concern is exposure to mmWave radiation. At these frequencies, instead of penetrating the skin, the absorption of the incident energy is confined to the upper two epidermis and dermis layers of the skin [9] (see Figure 4).

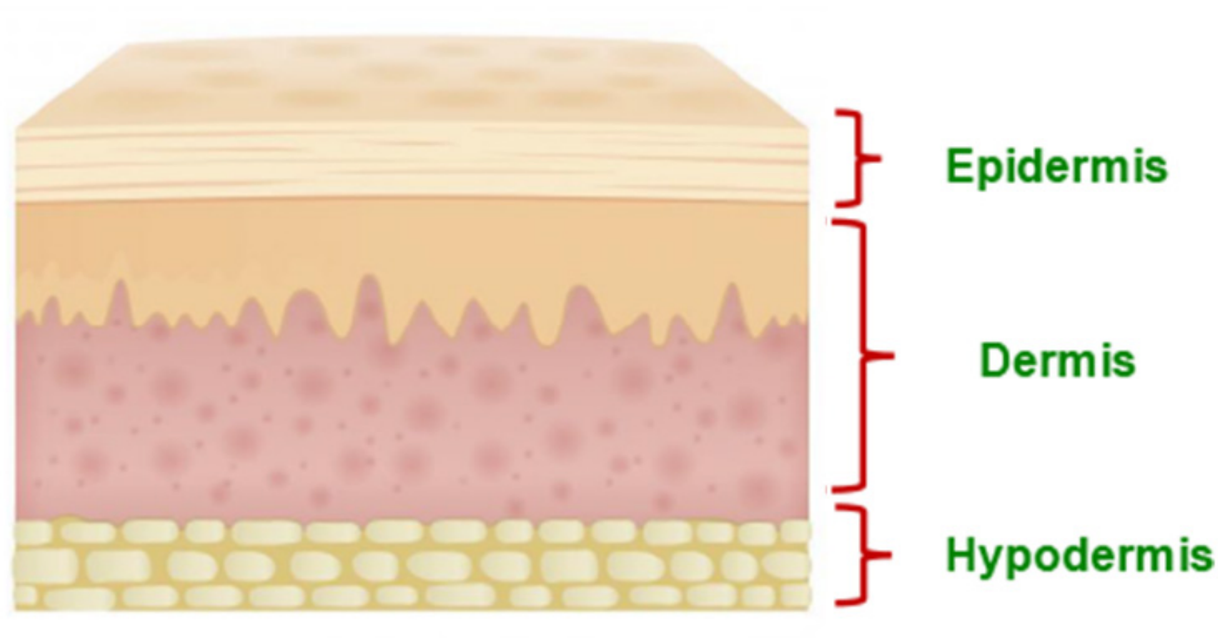

Figure 4: The three Primary Skin Layers

At these frequencies, sweat glands become conductive resulting primarily in reflection of the incident mmWaves. Clearly, excessive incident power in the mmWave region will cause body temperature to rise and may cause burns and thermal injury to eye. IEEE has defined maximum allowable body temperature rise of 1^0 C for safe operations [10]. It may be noted that mmWaves are currently used safely in airport security scanners and in selected satellite communications applications. So the primary issue to be addressed is "what the safe level of operations is for 5G base stations and devices not to cause harm to humans, vegetation, and environment".

The current literature has produced varying estimates on the expected MTC traffic and inconclusive inference on detrimental effects of mmWaves on humans and environment. Hence there is lack of consensus on safe limits of operations. As of October 2019, over 250 scientists, engineers, and doctors from 43 nations have sent a petition to United Nations (UN) expressing their concern on the possible detrimental effects of mmWave spectrum operations [11]. Similar concerns have been expressed by the American Academy of Pediatrics.

To mitigate these concerns, the key step required is for the research community to continue their research on what the safe limit is for 5G operations in the mmWave region and then for the regulatory agencies to mandate these limits. The seriousness of this limit is likely to arise in the next 4 – 5 years as the number of IoT devices increases.

Concluding Remarks

4G and 5G wireless systems support multimedia applications in sub-6GHz frequency range. In addition, 5G is a new paradigm in wireless access supporting massive MTC Traffic for IoT based intelligent and advanced applications. 5G allows interface to multiple Radio

Access Technologies (RATs) including 4G and WiFi. 5G expands operations into the new domain of mmWave operation with operating frequencies extending to 100 GHz. It is designed to address key issues of propagation loss and coverage gaps via use of advanced techniques like MIMO, steerable beams, mesh networking, and relay and dense networks. There is continued concern especially about its biological impact in terms of skin temperature rise in humans and adverse effects on vegetation and the environment. This requires further studies to determine the safe power radiation limits for base stations and devices. All stakeholders of wireless technologies ought to take steps to calm the concerns of general public by educating them about the traits of 5G technology and its potential impacts on society. The evolutionary path of 5G towards 6G entails ultra-high fidelity virtual reality, integrated network with satellite systems for global coverage, a potential nanocore for a global network, and ubiquitous wireless intelligence enabling intelligent services to follow the users seamlessly.

Terminology

CA-Polar: Cyclic Redundancy Check-Aided Polar CoMP: Coordinated Multi Point C-RAN: Cloud based Radio Access Network eDRX: extended Discontinuous Reception HARQ: Hybrid-Automatic Repeat reQuest IoT: Internet of Things KPI: Key Performance Indicator LTE: Long Term Evolution LTE-M: LTE Cat M1 MEC: Mobile Edge Computing ME-LDPC: Multi Edge- Low Density Parity Check MIMO: Multiple Input Multiple Output MTC: Machine Type Communication NB-IoT: Narrow Band-IoT NFV: Network Function Virtualization NOMA: Non-Orthogonal Multiple Access PSM: Power Save Mode QAM: Quadrature Amplitude Modulation QCI: Quality Class Identifier SAR: Specific Absorption Rate SC-OFDM: Scalable-Orthogonal Frequency Division Multiplexing SDN: Software Defined Networking TTI: Transmission Time Interval UE: User Equipment

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Return to Table of Contents

STANDARDS FOR ENERGY EFFICIENT VIRTUALIZATION, CONTENT DISTRIBUTION AND BIG DATA ANALYTICS IN BEYOND 5G NETWORKS

30 November 2020

Jaafar M.H. Elmirghani, Hatem Alharbi, Azza Eltraify, Sanaa Hamid Mohamed, Barzan A. Yosuf and Taisir E.H. El-Gorashi

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Abstract

Power consumption in communication networks and the supporting computing systems continues to increase due to the increase in traffic and processing requirements, and due to the relatively slower improvements in energy efficiency. Future networks are expected to continue to move computing algorithms and capabilities into the network including increased use of analytics, machine learning and intelligence applied to big data in the network, with content caching and virtualization. This level of flexibility in networks can lead to substantial power savings of up to 86% by being able to move content to where it is most popular. This article summarizes the key features of five new IEEE standards currently being developed to improve the energy efficiency of networks beyond 5G.

Introduction

The traffic in access and core networks continues to grow driven by new applications of the Internet of Things (IoT), machine to machine communication, high definition video, high data rate mobile traffic – such as in 5G and beyond and the increasing use of machine learning and artificial intelligence applied to big data carried by the network [1]. Traffic is currently growing at 30% – 40% per year on average [1] and if the current trends are sustained, this can lead to traffic doubling every two years, increasing by 30x in 10 years and 1000x in 20 years. The power consumption of the networks and the clouds and edge processing in the network can increase therefore by corresponding amounts. This led to the 1000x energy efficiency challenge in future networks. The solution to this challenge was originally pioneered by the GreenTouch consortium of 50 industrial and academic member organizations [2]. If the networks energy efficiency can be improved by 1000x, then in 20 years, networks can consume the same amount of energy as today while carrying 1000x more traffic. GreenTouch is a research consortium comprised of industry, academic and non-governmental experts that are united by the same goal of transforming communication and data networks, paying special attention to reducing the power consumption of ICT devices, platforms and networks. The GreenTouch consortium established the GreenMeter as a measure to assess the energy efficiency improvements it achieved in relation to its 1000x improvement target.

Concurrently, a number of tools migrated from computing to networking including virtualization, caching and analytics. These tools can be used to improve the energy efficiency of 5G networks and beyond. For example, content can be cached near end users to reduce the journeys up and down the network when accessing content, thus resulting in power savings [3]. Virtualization can help improve resource utilization, thus resulting in power savings [4] – [6]. Furthermore, analytics can help learn about the network and optimize its operation in addition to learning about the user and hence optimizing the services [7], [8]. Figure 1 shows a network architecture which includes the core network, metro network segments and the access networks supported. It provides processing capabilities in the access layer in the form of access fog units, in the metro layer in the form of metro fog and in central clouds connected to core network nodes.

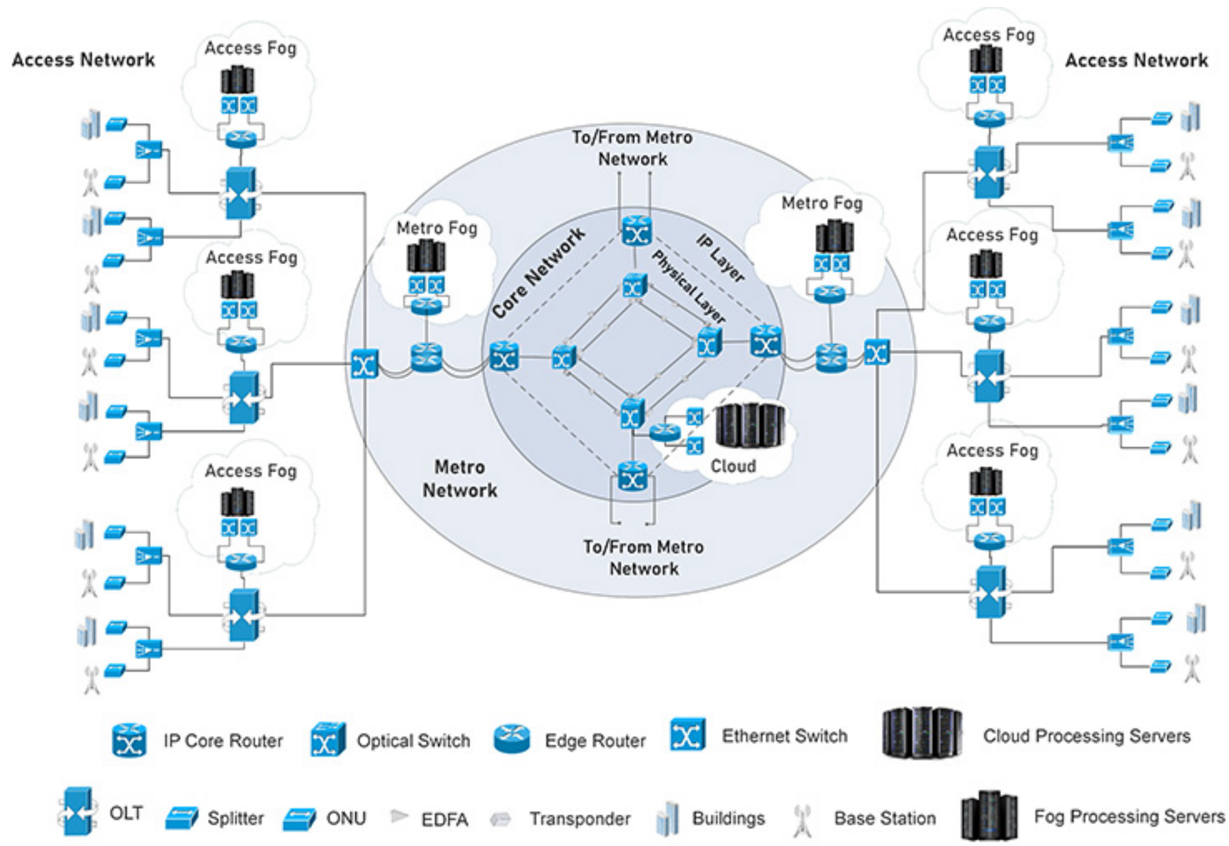

Figure 1: Energy Efficient Network Virtualization and Content Distribution in Beyond 5G Access

The IEEE is developing a number of standards for energy efficient operation of networks in the presence of virtualization, content caching and big data analytics which can be understood by referring to the architecture in Fig. 1. The standards are IEEE P1925.1, IEEE P1926.1, IEEE P1927.1, IEEE P1928.1 and IEEE P1929.1 [9].

This article summarizes the key features of these five new IEEE standards currently being developed to improve the energy efficiency of networks beyond 5G.

The Standards

In many network segments, the traffic may not fill a transponder capacity or alternatively may just exceed the capacity of a single transponder, which calls for the use of two transponders. In both cases the unused transponder capacity leads to energy wastage. An alternative is to use mixed line rates where transponders operating at different data rates are used. These may include transponders operating at 10 Gb/s, 40 Gb/s, 100 Gb/s, 400 Gb/s and beyond. There is thus a correct combination of transponders that results in power consumption minimization. A similar result can be achieved if the transponders used adaptive line rates based on optical orthogonal frequency division multiplexing (OFDM) [2], [10]. The IEEE P1925.1 "Standard for Energy Efficient Dynamic Line Rate Transmission System" focuses on the energy efficiency of these systems by introducing the architecture and mechanisms needed to enable the use of an optimal combination of line rates to accommodate the traffic while reducing power consumption by up to 55% in the examples considered [10].

User content generated at the edge of the network can aggregate and form big data streams. If such big data streams are transmitted to cloud data centres in the core network in Fig. 1 for processing, then significant power may be consumed. A key observation however is that users are generally interested in the knowledge embedded in the big data and not in the data stream itself. Consider an example where a heart rate monitor measures and transmits big data (due to its complex waveforms and multiple measurements) to a central data centre for processing. This data will hopefully repeatedly indicate that the person is fine for the next 30 years for example. Therefore, sending the full data may be redundant. Instead the big data stream can be processed at the edge of the network to extract incidents, i.e. knowledge, and transmit these incidents when the person needs help instead of transmitting the full data. The network therefore carries knowledge and not data. This form of big data edge processing can reduce latency and can save power (a saving of 52% in the example in [11]) by reducing the amount of data flowing in the network. This has to be done while paying attention to the key attributes of big data which include its Volume, its Velocity (meaning that it can be time sensitive and fast changing), its Variety (coming from multiple sources and sensors) and its Veracity [7], [8], [11]. This concept is introduced in IEEE P1926.1 a "Standard for a Functional Architecture of Distributed Energy Efficient Big Data Processing".

The network in Fig. 1 can be virtualized to provide network slices to different users and different applications in an energy efficient manner. A user may request a network virtual slice that contains dedicated access to part of the capacity of core routers, core optical switches / multiplexers and demultiplexers, as well as dedicated access to part of the capacity of the fibre links interconnecting these nodes. In this way resources can be consolidated in the network which can lead to power savings of up to 60% [4]. In addition, the slice may contain certain computational and storage resources at the core network clouds and further computational and storage resources at the metro fog and access fog and the interconnecting networks [4] – [6]. Orchestrating these network resources in an energy efficient manner is the subject of IEEE P1927.1 "Standard for Services Provided by the Energy-efficient Orchestration and Management of Virtualized Distributed Data Centers Interconnected by a Virtualized Network".

In several scenarios user computations may be carried out in virtual machines. Virtualization is employed in the cloud-fog architecture to satisfy the needs of the users to rapidly grow and shrink the usage of the data centre physical resources. Several logical entities (called virtual machines) are created by abstracting the datacenter resources in an efficient and isolated manner. The creation of these virtual machines can support multiple applications, which run on a shared hardware while being logically isolated from each other. It is usually preferable to place such virtual machines in the architecture in Fig. 1 as close to the end user as possible [2], [5]. For example, in the access fog processing units. As time progresses, users in a different part of the network may become interested in the services provided by this virtual machine while the original users may no longer be interested in the virtual machine due to time differences between the two user groups and work / entertainment switch over for example. In this case the virtual machine can be migrated to near the new set of users. In other cases, users interested in a given virtual machine may be at remote ends of the network. In such a case it may be necessary to replicate the virtual machines in a manner that minimizes power consumption with power savings up 64% [2]. Finally, the hardware over which the virtual machine is implemented may have power consumption that is proportional to the load placed on the virtual machine. Here, it may be possible to slice the virtual machine and make several copies of the virtual machine, where all the copies collectively consume an amount of power equal to that consumed by one large virtual machine that runs all the tasks. This optimized, energy efficient placement of virtual machines is the subject of IEEE P1928.1, a "Standard for a Mechanism for Energy Efficient Virtual Machine Placement".

Finally, video represents, by some estimates, over 80% of the overall traffic volume in networks. A large part of the video traffic consumed is attributed to a small number of very popular videos. For instance, a video library that has few hundred million videos, may have 50 to 100 videos that account for 80 percent of the requests, the well-known heavy tail Zipf distribution. If these few videos are cached locally, in the access fog or metro fog in Fig. 1 instead of being stored in the central cloud, then the network power consumption associated with retrieving these videos from the central library can be decreased by up to 86% [3]. The addition of network video caching hardware increases the overall hardware power consumption. This is tensioned against the power saved as a result of caching. As such an optimum video cache size exists that results in power minimization in the network [2], [3]. The IEEE P1929.1 standard "An Architectural Framework for Energy Efficient Content Distribution" addresses this problem.

The five IEEE Energy Efficient standards currently being developed to improve the energy efficiency of ICT are summarized in Table 1.

Standards (all of which can work with other standards)	Methodology	Energy Savings	Network Segment			Mechanisms Explained
			Access	Metro	Core	
IEEE P1925.1	optimum use of correct combination of line rates [1].	31% – 55%, in selected example			✓	Mixed line rates and Optical OFDM techniques are utilized to enable elastic optical networks to support heterogeneous traffic demands by enabling rate and modulation adaptive bandwidth allocation.
IEEE P1926.1	progressive processing of big data leading to reduction of traffic flow [10].	47% – 52%, in selected example	✓	✓	✓	Knowledge is extracted from big data streams by processing the data at the source, edge, and intermediate processing nodes, thus leading to reduced latency and energy consumption.
IEEE P1927.1	Optimized virtualization with server packing and minimum hop routing [4].	60%, in selected example	✓	✓	✓	Virtualization is used to allow for on demand allocation of processing and networking resources in cloud networks which results in improved utilization of resources and thus leading to power savings.
IEEE P1928.1	Virtual machine migration, replication and slicing [2].	56%- 64%, in selected example	✓	✓	✓	End user computation requests are encapsulated by Virtual Machines that may be placed in fog units as close as possible to the end user subject to factors such as migration, replication and slicing.
IEEE P1929.1	Optimum placement of content [3].	86%, in selected example	✓	✓	✓	Knowledge of content behavior and popularity is used to optimally store cached versions in fog nodes closer end users, and cache hit ratios are maximized to minimize energy use.

Table 1 A summary of the methodologies, power savings, network location and mechanisms used in the five standards currently being developed.

The work in [2] shows how the measures captured in these five standards can be used together to result in a power saving of 315x. The balance of the 1000x power saving sought was achieved by GreenTouch through additional savings in the RAN and wireless interface.

Conclusions and Future Work

A number of standards are being developed to improve the energy efficiency of future big data networks, content distribution networks, and virtualized networks. The standards take into account the network architecture, the hardware and the algorithms needed to orchestrate, manage and provision the networks. It has been shown through optimization techniques that, it is possible to achieve substantial amounts of power savings that can be as high as 86%. Future work will address the expected increased use of machine learning, and intelligence in networks to improve energy efficiency, and to provide a better fit between the users, services and network.

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Return to Table of Contents

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Return to Table of Contents

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Return to Table of Contents

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Return to Table of Contents

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Return to Table of Contents