International Journal of Electrical and Elecronics Engineering (IJEEE)
ISSN (P): 2278–9944; ISSN (E): 2278–9952
Vol. 12, Issue 2, Jul–Dec 2023; 1–10

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

5G COMMUNICATION TECHNOLOGIES AND NETWORKS

Cornelius A. D. Pahalson

Research Scholar, Department of Science, Plateau State Polytechnic, Barkin Ladi, Nigeria

ABSTRACT

The vast demand for wireless data transmission needs to be satisfied. Dramatic growth in wireless communications has created a shortage in the available radio spectrum. Wireless communications services for cellular phones, television, and broadband Internet access must compete with existing users in radar, government communications, scientific observations, and environmental monitoring. In the past few decades, mobile wireless technologies have experienced various generations of technology, namely from 1G to 4G. Current research in mobile wireless technology concentrates on the advanced implementation of 5G technology. Currently, The 5G term has yet to be officially used. 5G technology integrates all the wireless network types, thus gaining the needed network infrastructure (CR network). This paper is helpful for a researcher working in the wireless technology field.

KEYWORDS: *Evolution from 1G-4G, 5G Network Architecture, Need for 5G*

Article History

Received: ***10 Nov 2023*** **|** ***Revised:*** ***14 Nov 2023*** **|** ***Accepted:*** ***18 Nov 2023***

INTRODUCTION

With the development of digital technologies and micro-processing computing power in the late 1980s and today, enormous interest has emerged in digital cellular systems, which promise higher capacity and higher quality of services at reduced costs. Mobile cellular communications have historically undertaken four evolution stages or generations, shown in Table 1 [1]. Analog cellular systems belong to the first generation, where the primary service provided is voice. Second-generation cellular systems use digital technologies to providea better quality of service, including voice and limited data, with higher system capacity and lower cost. Third-generation cellular networks offer multimedia transmission, global roaming across ahomogeneous wireless network, and bit rates ranging from 384 Kbps to several Mbps. Worldwide migration to 3G is expected to continue through 2005 [2]. Meanwhile, researchers and vendors are expressing a growing interest in 4G wireless networks that support global roaming across heterogeneous wireless and mobile networks, for example, From generation cellular networks to satellite-based networks to high-bandwidth wireless LAN [2] [3].

Table 1: Evolution of Mobile Communication Systems

Property	1G	2G	2.5G&3G	4G
Starting Time	1985	1992	2002	210-2012
Representative Standard	AMPS	GSM	IMT-2000	UWB
Radio Frequency (Hz)	400M-800M	800M-900M	1800M-2400M	2G-8G
Bandwidth(bps)	2.4K-3K	9.6K-14.4K	384K-2M	20M-100M
Multiple Access Technique	FDMA	TDMA, CDMA	WCDMA	OFDM
Switching Basis	Circuit	Circuit	Circuit,Packet	Packet
Cellular Coverage	Large area	Medium area	Small area	Mini area
Service Type	Voice	Voice, limited data	Voice, data, limited multimedia	Multimedia

5G is the term used to refer to the next (fifth) generation of ubiquitous mobile telecommunications technology. Progress in mobile telecommunications is measured in 'generations' where, roughly every ten years, a new set of technologies represents a radical leap forward regarding the support needed for new services and applications. While in 2015, fourth-generation (4G) mobile technology is still being rolled out in Europe, work is already progressing on defining its successor, 5G, which is expected to be implemented starting in 2020[4]. 5G Technology stands for 5th Generation Mobile Technology. 5G mobile technology has changed the means of using cell phones with very high bandwidth. The user has never experienced such a high-value technology. Mobile users are very aware of cell phone (mobile) technology. The 5G technologies include all types of advanced features, which make 5G mobile technology the most powerful and in huge demand. Users can also hook their 5G technology cell phone with their Laptop to get broadband internet access. 5G technology includes a camera, MP3 recording, video player, large phone memory, dialing speed, audio player, and much more you never imagined. For children rocking fun, Bluetooth technology and Piconets have become in the market [5].

No official definition of 5G exists, but progress has already been made in setting targets, testing technologies, and defining applications for the new generation of connectivity. 5G is expected to integrate new radio access networks seamlessly with network technologies introduced by earlier generations of communications technology. It should allow billions of users and intelligent objects in the Internet of Things (IoT) to connect with networks; it should transmit vastly increased quantities of data with minimal delay; it should provide secure and reliable transmissions anywhere; and it should be more efficient, reducing the per-unit cost of data transported. Not all of the specific goals that experts have set for 5G may be realizable in the short term; however, for network operators to continue to meet customer demands effectively in the coming years, a new, radically improved generation of mobile wireless technology is needed[5]

The mobile and fixed wireless industries have grown tremendously over the past decades. Indeed, mobile has evolved from a niche technology, embodied by an analog 1G voice system, to a full-fledged internet on the move and end-to-end (E2E) digital 4G system. The evolution of mobile and cellular technologies has witnessed enhancement and optimization to various parts of the E2E communications systems over generations (e.g., 1G, 2G, 3G, 4G, and 5G). Still, broadly, these have been categorized into UE, radio access network (RAN), the core network (CN), and applications network (e.g., IP multimedia subsystem). In particular, evolution to5G networks will involve enhancements to various components of the network, including new air interface, virtualization, cloud RAN, SDN, and NS technologies[6].

MOBILE

The construct of the mobile network has undergone substantial transformations over the past years, but its segments largely remained unchanged. From a segment point of view, there is the mobile phone (in SDO language, referred to as "UE"). The UE connects to the base station (referred to as "evolved node B" or "eNB"). The base stations connect to form the RAN. These, in turn, connect to the CN, which exits into the broader internet via the serving and packet gateways.

One of the transformational changes was an E2E internet protocol (IP) architecture that allowed the mobile network to be treated like any other internet network. It has been hugely beneficial to the uptake of applications in the mobile space but also a severe challenge to the telecommunications ecosystem from a business point of view.

The latest technology changes that are substantially impacted are the introduction of Cloud-RAN functionalities, where a remote radio head is connected to a cloud server via a fronthaul. Centralizing some radio functionalities in a cloud close to the wireless edge has shown substantial cost savings and performance improvements. However, this still comes at a cost, as 5G will require a front-haul bandwidth that is very expensive to provide.

Figure 1: History of Cellular Technology [7]

Figure 2: 5G Mobile Phone [8]

FIXED

Fixed network elements play an instrumental role in the connectivity ecosystem but less so than in the past in the context of cellular systems. It is interesting to note that the interest in native usage of fixed networking assets is surging in the context of 5G.

CORE NETWORK (CONVERGED)

The core network aggregates the user traffic (via the user plane) and manages these data flows (via the control plane). While the user plane infrastructure has mostly stayed the same over the years in design, much of the control functionalities have been virtualized. The evolved packet core (EPC) can have its functions placed anywhere and even migrated via containers in real-time from one part of the network to another. The virtual EPC (vEPC) approach is also viable since it can "thin" the core networking infrastructure and bring packet gateways closer to the edge.

TRANSPORT NETWORK

The transport network, often all-optical, carries the data traffic E2E between the operators' packet gateways. It has traffic from internet service providers (ISPs) and other data sources.

It must be dimensioned to cater to the increased data traffic from wireless systems. Also, if 5G is to offer slicing capabilities, then slicing ought to be provided in the more comprehensive transport network, too; otherwise, the benefits of slicing will be eroded.

5G TECHNICAL REQUIREMENTS

The Next Generation Mobile Network (NGMN) defines the following requirements that a 5G standard should fulfill [9]:

- Data rates of 10s of Mb/s for 10s of thousands of users
- Data rates of 100 Mb/s for metropolitan areas
- 1 Gigabit per second (Gb/s) simultaneously to many workers on the same office floor
- Several hundreds of thousands of simultaneous connections for wireless sensor
- Significantly enhanced spectral efficiency compared to 4G
- Improved coverage
- Enhanced signaling efficiency
- Significantly reduced latency compared to Long Term Evolution (LTE)

5G TECHNOLOGIES

5G will almost certainly introduce a new radio interface, which defines the frequency, channel bandwidth, and modulation scheme used to communicate between a mobile device and a wireless base station [4].However, it is also expected to integrate legacy radio access technologies such as those used by 4G and wireless local area networks. Thus, 5G represents a convergence of previous generations, the first time a new generation will incorporate, rather than replace, its predecessors.

5G networks will operate on a range of radio spectrum bands. In addition to the traditional sub-3 gigahertz (GHz) bands (where additional spectrum will be allocated in the 700 megahertz (MHz) band to mobile communications), 5G will exploit higher frequencies of radio spectrum in the millimeter-wave range (roughly 20 to 300 GHz) which can provide greater bandwidth, although over shorter distances. Nevertheless, most commentators agree that sharing by different operators of currently authorized and licensed bands and unlicensed bands will be necessary to make the most efficient use of the spectrum.

Devices and network base stations will employ multiple antennae(known as multiple inputs/multiple outputs or MIMO antennae),as shown in Figure 1,that allow multiple simultaneous connections to be set up to increase bandwidth, minimize errors, and optimize data speed.

To support a high density of connections and large bandwidth, 5G wireless networks will be heterogeneous, comprising large and small cells (so-called depending on how many areas they cover) using different technologies. Small cells are needed to provide coverage in very dense urban areas; using a high-frequency spectrum, they can provide much higher capacity transmissions and increased energy efficiency (beams can be directed, but high-frequency waves can have problems penetrating vegetation and buildings). Small-cell base stations can be designed to configure themselves automatically about nearby cells to reduce interference and simplify installation.

Coordination of traffic and spectrum will be more complex as users move between small-cell coverage areas, with communications reverting to the primary 'macro' cell if they move out of the small cell's range. Transmissions in a 5G network may also eventually pass from one user device to another or cell to another before being transmitted onto the network.

With 5G, the time and cost of network service deployment for network operators should be reduced. Virtualization techniques [10], which separate the services and capabilities offered by a system from its underlying infrastructure, should make it faster, easier, and cheaper for operators to put new network services using cloud-based servers in place. Energy efficiency is also a requirement for operators deploying many more stations in small cells and users with increasingly sophisticated devices and power-hungry applications. As a result, 5G should help network providers and users reduce their carbon footprints, bring down costs, and increase battery life [11]

5G ARCHITECTURES

Standards bodies still need to define 5G requirements, but various groups are analyzing the possibilities of what might constitute 5G for network deployments in 2020 or beyond. Figure 2 shows the transformation of networks, moving from today's LTE-Advanced networks to future LTE-Advanced and eventually 5G networks [4]

The overall 5G architecture and its impact on (i) Mobile Networks, (ii) Physical Networking and Computing Facilities, (iii) Service and Infrastructure Management and Orchestration, and (iv) Hosting and Deployment Systems.

5G networks are conceived as extremely flexible and highly programmable E2E connect-and-compute infrastructures that are application- and service-aware, as well as time-, location- and context-aware. They represent:

- Evolution in terms of capacity, performance, and spectrum access in radio network segments; and
- An evolution of native flexibility and programmability conversion in all non-radio 5G network segments: Fronthaul and Backhaul Networks, Access Networks, Aggregation Networks, Core Networks, Mobile Edge Networks, Software Networks, Software-Defined Cloud Networks, Satellite Networks, and IoT Networks.

5G Architecture enables new business opportunities meeting the requirements of a large variety of use cases as well as enables 5G to be future-proof using (i) implementing network slicing in a cost-efficient way, (ii) addressing both end-user and operational services, (iii) supporting softwarization natively, (iv) integrating communication and computation and (v) integrating heterogeneous technologies (include fixed and wireless technologies).

These qualities give 5G networks several advantages. One is a high degree of flexibility. They serve highly diverse types of communication – for example, between humans, machines, devices, and sensors - with different performance attributes. They also enforce the necessary degree of flexibility about capability, capacity, security, elasticity, and adaptability, where and when needed. 5G networks represent a shift in networking paradigms: a transition from today's "network of entities" to a "network of (virtual) functions." Indeed, this "network of (virtual) functions," resulting, in some cases, in the decomposition of current monolithic network entities, will constitute the unit of networking for next-generation systems. These functions should be able to be composed on an "on-demand" or "on-the-fly" basis. A research challenge consists of designing solutions that identify a set of elementary functions or blocks to manage network functions, while today, they are implemented as monolithic. [17]

Further advantages emerge in management, controlof systems, and resources. 5G networks enable uniform management and control operations that are becoming part of the dynamic design of software architectures.

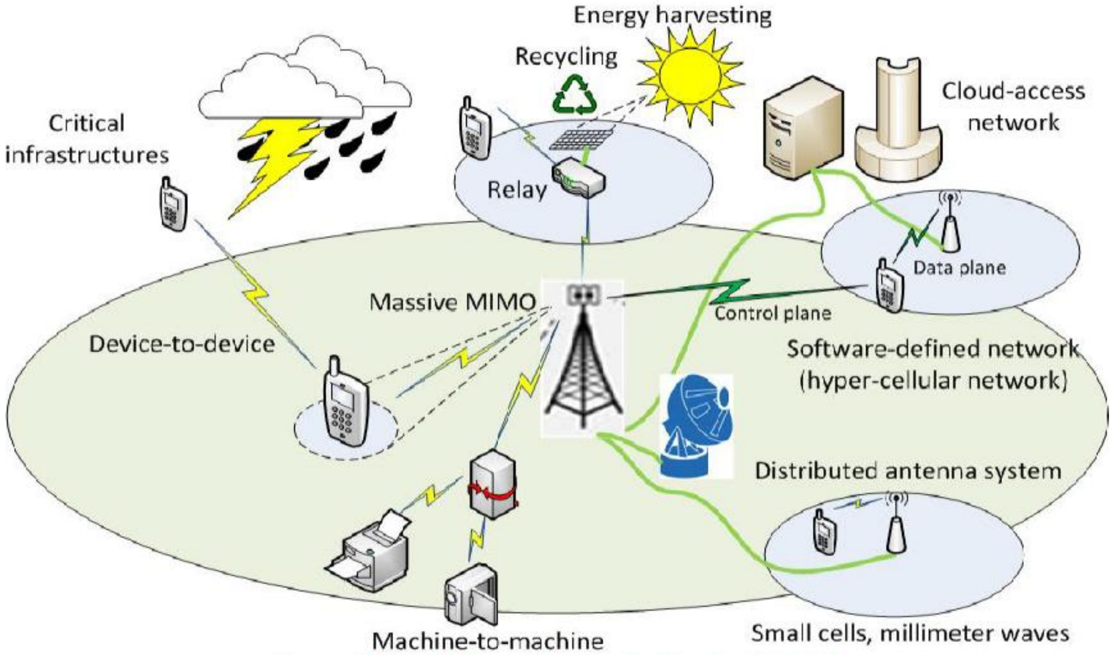

Figure 3: Revolutionary Technologies for 5G [12].

Small Cells (Increased Area Spectral Efficiency) [15]

- Heterogeneous networks, microcells < 1 km, picocells < 100 m, femtocells < 10 m, energy harvesting networks
- Software-defined network, separate data, and control planes (phantom cell, hyper-cellular network, macro-assisted smallcell)
- Cloud radio access networks (centralized baseband), distributed antenna systems
- Cooperative communication (coordinated multipoint, relaying)

Massive MIMO (Increased Area Spectral Efficiency)

- The number of antennas is much larger than the number of devices.

Millimeter Waves (Larger Bandwidth)

- 30-300 GHz, wavelength 1-10 mm.

Smart Devices and Device-Centric Connectivity [19]

- Distributed services.
- Device-to-device (D2D) connectivity.
- Local caching.
- Advanced interference rejection.

Machine-to-Machine (M2M) Communications [13]

- Critical (e.g., vehicles) and massive (e.g., sensors) deployments.
- Minimal data rate with very high link reliability virtually all the time.
- Very low latency and real-time operation.
- Long battery life > 10-15 years.

5G APPLICATION AND SERVICES, REQUIREMENTS, AND CHALLENGES

A more ubiquitous, higher capacity, higher density, and more efficient 5G network will enable new applications and business models. There are many possible applications to which 5G connectivity can significantly contribute. It is also interesting to note that most of the needs of the applications can be served with the current networks; however, the element of human interaction (or lack of it) demands guaranteed latency and makes most of the 5G requirements critical. [14]

- Ultra-high-definition, such as 4K and 8K, and 3D video.
- Realizing the tactile internet—real-time, immediate sensing, and control, enabling many new applications.
- Automotive, including autonomous vehicles, driver-assistance systems, vehicular internet, infotainment, inter-vehicle information exchange, and vehicle pre-crash sensing and mitigation.
- Monitoring critical infrastructures using long-battery-life and low-latency sensors, such as transmission lines.
- Smart transportation uses data from vehicles, road sensors, and cameras to optimize traffic flow.
- Mobile health and telemedicine systems rely on high-resolution, detailed medical records, imaging, and diagnostic video availability.
- Public safety, including broadband data and mission-critical voice.
- Sports and fitness enhancement through biometric sensing, real-time monitoring, and data analysis.

Requirements

The following are the requirements of future wireless generations [4]

- Local IMT Small Cells.
- Design for MIMO.
- Design of Flexible Spectrum Usage.
- Data Rate Latency.
- Machine Type of Communication.
- Multiple RATs.
- Prioritized Spectrum Access.
- Network-Assisted D2D communication.

Challenges of HETNET [20]

- Inter-Cell Interference.
- Distributed Interference Coordination
- Efficient Medium Access Control.
- Device Discovery & Link Setup.

Features of 5G Technology

5G technology offers high resolution and bi-directional large bandwidth shaping for crazy cell phone users [21].

- The advanced billing interfaces of 5G technology make it more attractive and effective.
- 5G technology also provides subscriber supervision tools for fast action.
- The high-quality services of 5G technology are based on policy to avoid errors.
- 5G technology provides large data broadcasting in Gigabit, which supports almost 65,000 connections.
- 5G technology offers a transporter-class gateway with unparalleled consistency.
- The traffic statistics by 5G technology make it more accurate.
- Through remote management offered by 5G technology, a user can get a better and faster solution.
- Remote diagnostics is also a great feature of 5G technology.
- The 5G technology is providing up to 25 Mbps connectivity speed.
- 5G technology also supports virtual private networks.
- The new 5G technology will take all delivery services out of the business prospect
- The uploading and downloading speed of 5G technology is touching its peak.

- The 5G technology network offers enhanced and available connectivity to just about the world.

CONCLUSION

Developing the fifth-generation mobile communications system 5G forwards the provision of high speed, space high capacity wireless communication services. In 5G, the aim is to widen the bandwidth of the transmission signal by using frequency bands higher than those of existing frequency bands.

REFERENCES

1. *Sun J.-Z., Sauvola J. and Howie D. (2001). "Features in future: 4G visions from a technical perspective," in Proc. IEEE GLOBECOM'01, vol. 6, San Antonio, USA, Nov. 2001, pp. 3533–3537.*
2. *Varshney U, and Jain R. (2001). "Issues in emerging 4G wireless networks," IEEE Computer, vol. 34, no. 6, pp. 94–96, June 2001.*
3. *Zahariadis T, and Kazakos D.(2003). "Revolution toward 4G mobile communication systems," IEEE Wireless CommunicationsMagazine, vol. 10, no. 4, pp. 6–7, Aug. 2003.*
4. *Analysis Understanding 5G: Perspectives on future technological advancements in mobile, GSMA Intelligence, 2014.Available at: https://gsmaintelligence.com/research/?file=141208-5g.pdf&download.*
5. *Aleksandar, T and Toni, J. (2011). Functional Architecture for 5G Mobile Networks International Journal of Advanced Science and Technology Vol. 32.*
6. *L. Wei, R. Q. Hu, Y. Qian, and G. Wu. (2014). Enable device-to-device communications underlaying cellular networks: challenges and research aspects. IEEE Communications Magazine, 52(6):90–96.*
7. *Ms. N. D, Ms M. P., Ms. K. P. (3013). 5G WIRELESS TECHNOLOGIES 4G auction is not over, but time to start talking about 5G" International Journal of Science, Engineering and Technology Research (IJSETR) Volume 2, Issue 2.*
8. *Akhilesh, K. P, and Ompal Singh. (2012). 5G Technology – Redefining wireless Communication in upcoming Years" International Journal of Computer Science and Management Research Vol 1 Issue 1 Aug 2012 ISSN 2278 – 733X.*
9. *Schulz, Pet al., (2017) "Latency Critical IoT Applications in 5G: Perspective on the Design of Radio Interface and Network Architecture," in IEEE Communications Magazine, vol. 55, no. 2, pp. 70-78,*
10. *Ali Yazdan et al., (2017). Energy-Efficient Massive MIMO," IEEE Microwave Magazine, Vol. 18, No. 5.*
11. *C. I, Rowell. C, Han, S, Xu. Z, Li, G Pan, Z. (2014). Toward green and soft: a 5G perspective. IEEE Communications Magazine, 52(2):66–73*
12. *N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Sukhavasi, C. Patel, and S. Geirhofer. Network densification: the dominant theme for wireless evolution into 5G. IEEE Communications Magazine, 52(2):82–89, 2014.*
13. *C. Anton-Haro and M. Dohler. Machine-to-machine (M2M) Communications: Architecture, Performance, and Applications. Elsevier, 2014.*

14. *Han. B, Gopalakrishnan. V, Ji. L. and Lee, S.(2015). Network function virtualization: Challenges and opportunities for innovations. IEEE Communications Magazine, 53(2):90–97, 2015*
15. *Chandrasekhar. V et al., (2008). Femtocell networks: A survey, IEEE Communications Magazine, pp. 59-67, September 2008.*
16. *Hossain. E, Mehdi. R, Hina. T, and Amr A. (2014). Evolution Towards 5G Multi-Tier Cellular Wireless Networks: An Interference Management Perspective." arXivpreprint arXiv:1401.5530*
17. *Rost, P.Banchs, A. Berberana, L Breitbach, M. Doll,M. Droste, HMannweiler, C. Puente, M. A. Samdanis, K. and Sayadi, B. (2016). Mobile Network Architecture Evolution towards 5G," in IEEE Communications Magazine, vol. 54, no. 6, June 2016.*
18. *EU PROJECT METIS-II, 5G RAN Architecture and Functional Design White Paper, https://metis-ii.5g-ppp.eu/wp-content/uploads/5G-PPP-METIS-II-5G-RAN-Architecture-White-Paper.pdf*
19. *NGMN Alliance, "5G White Paper", March 2015 https://www.ngmn.org/5g-white-paper.html*
20. *Fernando, N. Loke, S. W, and Rahayu, W. (2013). Mobile Cloud Computing a Survey,Future Generation Computer Systems, vol. 29, no. 1, Jan. 2013, pp. 84–106.*
21. *M. Dohler, T. Mahmoodi, M. Lema, and M. Condoluci, (2017) "Future of Mobile," EuCNC*