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5G Road Map to Communication Revolution

Evon Abu-Taieh, Issam H. Al Hadid and Ali Zolait

Abstract

The goal of this chapter is to give researchers, practitioners, and students a pedestal to get a comprehensive look at the new technology of communication named 5G. The chapter will present an introduction that shows the importance of 5G to the different uses of the Internet. Then, the chapter will present two essential aspects: (1) 5G research in academia and real world and (2) timeline of Gs. Then, the chapter will discuss three aspects of 5G which are, namely, (1) Regulations, (2) security, and (3) the 5 enabling Technologies. Then, the chapter will discuss the real-life case of South Korea mobile carrier.

Keywords: 5G, millimeter waves, small cells, massive multi-input multi-output (MIMO), beamforming, full duplex

1. Introduction

The Internet is nonpareil like running water and electricity; it is a basic need in today's world. The influence of Internet on real life reached: Economics, politics, and social. Hence, it created an alternate reality for all factors in life: e-business, e-politics, social networks, e-learning, e-culture, security, Data Science, and Big Data.

In economics, the Internet created new type of trade, i.e., e-business and new products. Some of the e-business models ranged from e-payment, new tax rules, new currency, and borderless trading. New products are different products other than the physical and non-physical products. Non-physical products include movies, music, games, and computer programs. Internet created new trades that did not exist before ranging from delivery services of physical products like delivering food, cloths, etc. to delivering non-physical products like services. According to some reports, "online retail sales worldwide will exceed US$3.4 Trillion" [1] while costs of the first year of online retailing ranges from $644 to $31,000 according to eCorner [1]. Others [2] stated that online spending is expected to reach 8.8% of total retail price increasing from 7.4% in 2016. Also, Gorlamandala [2] stated that UK has the highest retail e-commerce sales with 15.6% followed by China with 11.5%. Cross-border is an issue reported by Gorlamandala [2] listing China with $245 million and Australia, Indonesia, Singapore, France, and Mexico as countries where e-commerce sale is in noticeable numbers. Another report by Deloitte [3] stated that Amazon.com ranked fourth as top 10 retailers in 2017 with $118.573 million retail revenues with a growth of 25.3 and 36.8% retail revenue from foreign operations. Amazon in the report [3] jumped two places to number 4. The report stated "Amazon is a consistent performer in the Fastest 50, having featured in the Fastest

50 since FY2004" [3] and stated "The increase in unit sales was mainly a result of Amazon's efforts to reduce prices for customers, shipping offers, increased in-stock inventory availability, and more product variety" [3, 4]. Even Walmart is competing with Amazon over online retailing. Walmart credited the increase in sales to integrate online system with traditional sales stating "Walmart has credited its efforts to integrate its store and digital businesses so that they feed off each other." [4]. Walmart online sales have risen to 63% [4]. Furthermore, according to Wahba [5], Walmart has acquired Flipkart.com with $16 billion deal, also teaming up with Google and Microsoft and Rakuten, JD.com.

Social networks include Facebook (2.3 billion active users [6]), Instagram (1 billion [7]), VKontakte, QZone (572 million [6], Odnoklassniki, twitter (330 million [6]), Snapchat (294 million [6]), Reddit (330 million [6], Linkedin (310 million [6]), and YouTube (2 Billion [6]). Communication software include Google Duo, FaceTime, Skype WhatsApp (1600 million [6]), Facebook Messenger (1.3 billion active users [6]), Viber (260 million [6]), WeChat (1112 million [6]), and QQ (823 million [6]). All allowed connectivity and trading views in cheaper and more accessible manner. Furthermore, most of these applications are for free and allow communication for free. Still, they compensate their cost with advertising using some sort of profiling to deliver advertisement message.

Politics was affected by the cyberspace. Best example is the effect of Facebook on politics. In fact in a study by Levy [8], the researcher stated "In the measured period, stories related to politics accounted for 36% of interactions among the top 100 Facebook stories" [9], while topics like soft/general interest (17%), death (11%), science (10%), hard/general (8%), and economics (6%) followed. In fact, some revolutions were based on Facebook interaction like 2011-Jan revolution of Egypt. Another example is the American presidency race in 2016 and the Russian INTERFERENCE issue.

All the previous indicates that Internet is becoming an essential part of life and the number of Internet users is increasing rapidly. In addition, according to GSMA [10], there are 5,177,676,750 unique mobile subscribers in the world with 9,418,683,350 mobile connections. The backbone of the Internet is communication. The communication technology must meet the demand for communication. End users need more communication speed and reliability. Hence, there is a need to develop communication technology. As such, the development of 5G mobile communication technology is a promising one.

5G is the fifth generation of mobile technology that promises increased speed and lower latency, higher capacity, and higher reliability capacity [11]. 5G will be reflected in a number of today's technologies such as smart cities, connected infrastructure, wearable computers, autonomous driving, seamless virtual and augmented reality, artificial intelligence, remote robots, drones, and Internet of Machines and Things (IoMT) [12, 13]. Yet to implement 5G technologies: there are three challenges that the implementation faces: Spectrum, infrastructure, and regulations. In the next two sections, the chapter will present two essential aspects: (1) 5G research in academia and real world and (2) timeline of Gs.

2. 5G research in academia and need of real world

The topic of 5G was discussed in (14,271) research paper in conferences indexed in ACM and IEEE. Furthermore, (4542) research paper was published in journals indexed in ACM and IEEE in the past 2 years discussed topics pertaining to 5G as shown in **Table 1**. Almost 27% of the publication was published in 2019. Furthermore, one can notice that there is a race in publication pertaining to 5G from

	ACM indexed research		IEEE indexed research	
Research in:	2019	2018–2019	2019	2018–2019
Proceedings	440	748	2985	13,523
Journals	82	144	1707	4398
Newsletters	22	47		
Magazines	7	10	293	1325
Reports		1		
Total	551	950	4,985	19,246

Table 1.
Research indexed in ACM digital library and IEEE Explore pertaining to 5G.

the huge number of publications (20,196). Also, one can notice that IEEE is super-seding ACM in the publications pertaining to G5.

3. Timeline of Gs

Communication technology progressed according to generations. The first generation analog communication started in the late 1970s and had a speed of 2.4 kpbs used for cellular telephones. Total access communication system (TACS), extended total access communication system (ETACS), and nordic mobile telephone (NMT) technologies were used in 1G. The main use was wireless phone call with high rate of phone drops and unclear voice.

The second generation used global system for mobile communication (GSM), general packet radio services (GPRS), and enhanced data rates for GSM evolution (*EDGE*) technologies with speed 56–64 kbps and 170 kbps when using EDGE. The second generation used digital technology rather than analog and the main uses were basic text, simple email, and snake game. The second generation included 2G, 2.5G, and 2.75G.

The third generation had four flavors: 3G, 3.5G, 3.75G, and 3.9G LTE. The speed reached 384 kbps and allowed Internet on the telephone and stream videos. 3G used universal mobile telecommunications system (*UMTS*) based on the GSM standard. While 3.5G used high speed downlink packet access (*HSDPA*) and high-speed uplink packet Access (*HSUPA*), followed by 3.75G which used high speed packet access (HSPA), an amalgamation of *HSDPA and HSUPA*. *3.9G used* long-term evolution (LTE) standard.

The fourth generation 4G and 4.5G LTE reached 1 Gbps and 100 Mbps using multiple-input, multiple-output orthogonal frequency-division multiplexing (*MIMO-OFDM*). The result of such generation is HD steaming and video chats response with 0.04 ms with speed 300 MHz–3 GHz.

The fifth generation is promising millions of simultaneous connections, nearly 0 response time, massive MIMO, three times faster than 4G, and 0.001 ms response time. In short, 5G promises to be 1000 times faster than 4G. The applications of 5G are IoT, smart cities, games, autonomous cars, remote robots, drones, healthcare, and global positioning systems (GPS). Quantum cryptography for 5G security [14] is required to answer for breach of privacy in IoT. IoT, a term coined by Kevin Ashton rather than the well-known terms "embedded Internet" or "pervasive computing," will be more affected by 5G technology. Examples of objects that fall within the scope of IoT include connected security systems, thermostats, cars, electronic appliances (microwaves, fridges, washing machines, dryers, and coffee

makers), lights in household and commercial environments, alarm clocks, speaker systems, and vending machines. In the next sections, the chapter will discuss the three aspects of 5G: (1) Regulations, (2) security, and technology.

4. Frequency regulations

Regulation development is required for 5G to operate. Many countries have regulations and standards for the frequency use. Hence, for 5G frequency usage, a country must develop its own regulations and standards. In the USA, according to WIA [15], only 28 states passed legislations for small cell, 3 states introduced, and the rest enacted. Laws and regulations regarding the use of frequencies need time. Hence, many countries were caught unprepared for such shift. On the other hand, countries like South Korea (2019), China, and India (2018) were already deploying the technology.

5. Security: the Prague proposal

Security is a major issue in 5G technology. The Prague proposal is none binding agreement among 32 countries from Europe, North America, and Asia-Pacific that agree on a set of security guidelines in 5G network. The countries like South Korea, Japan, Australia, New Zealand, the US, Israel, and the UK stated that security of 5G networks is "crucial for national security, economic security, and other national interests and global stability" and stresses the importance of the development of "adequate national strategies, sound policies, a comprehensive legal framework and dedicated personnel, who is trained and educated appropriately" [16].

6. The 5G enabling technologies

There are two realms that enable 5G: the physical realm and technology realm. The first realm is the physical realm as shown in **Figure 2**. The physical realm vision is to increase data traffic measured as bits per second per squared kilometer, also called *Capacity*. Capacity is calculated by Eq. (1). Capacity is the multiplication of cell density, spectral efficiency, and available spectrum.

$$\text{Capacity}(\text{bit/s/km}^2) = \text{Cell Density}(\text{cells/km}^2) * \text{Spectral efficiency}$$
$$(\text{Bit/s/Hz/Cell}) * \text{Available Spectrum (Hz)} \qquad (1)$$

Nokia suggested to increase each element by 10×, while *South Korea Telecom* suggested to increase the first element by 56×, the second element by 6×, and the third element by 3×. In all cases, the first element c*ell density* can be increased by adding more access points per km^2. The s*pectral efficiency* can be increased by (1) increasing the number of antennas and (2) directing signals toward users. The third, *available spectrum*, requires the use of spectrums of 30–300 GHz, and hence, new hardware is designed and developed to handle such frequency.

The second realm is made of technologies: *Millimeter waves*, *small cells*, *massive multi-input multi-output (MIMO)*, *beamforming*, and *full duplex*.

To understand millimeter waves, one must go back in history to 1860s and 1870s when a Scottish scientist named James Clerk Maxwell developed a scientific theory that explained electromagnetic waves. The theory of Maxwell stated that electrical field and magnetic field can be coupled together to form electromagnetic waves.

"Heinrich Hertz, a German physicist, applied Maxwell's theories to the production and reception of radio waves. The unit of frequency of a radio wave—one cycle per second—is named the hertz, in honor of Heinrich Hertz" [17].

Millimeter wave is an enabling technology for 5G and refers to the use of super high frequency spectrum of 3.4 GHz. Such frequency may enable 5G technology to carry more amount of data, yet the distance is shorter, hence the need for more antennas per cell per km². The frequency is divided into three levels: very high, ultra high, and super high. The very high frequency ranges from 30 to 300 MHz and is mainly used in FM radio. The ultra-high frequency ranges from 300 MHz to 3 GHz and is used by TV and Wi-Fi, 2G, 3G, and 4G. The super high frequency ranges from 3 to 30 GHz [18] and is reserved to satellite broadcasting. Millimeter waves are called so because their length is 1–10 mm compared to tens of centimeters used in 4G technology [18]. mmWaves are attenuated by buildings, rain, and plants.

Because of the nature of the previously explained millimeter waves, small cells are needed. "**Small cells** are portable miniature base stations that require minimal power to operate and can be placed every 250 m or so throughout cities" [18] shown in **Figure 1**. Again, due to nature of small cells and all the interference that will be produced another technology is introduced named Beamforming. Small cells consist of small radio equipment and low-powered antennas about the size of a pizza box or backpack that can be placed on structures such as streetlights and the sides of buildings or poles. Small cells are divided into three major categories based on the coverage area, power consumption, the number of users, backhaul, application,
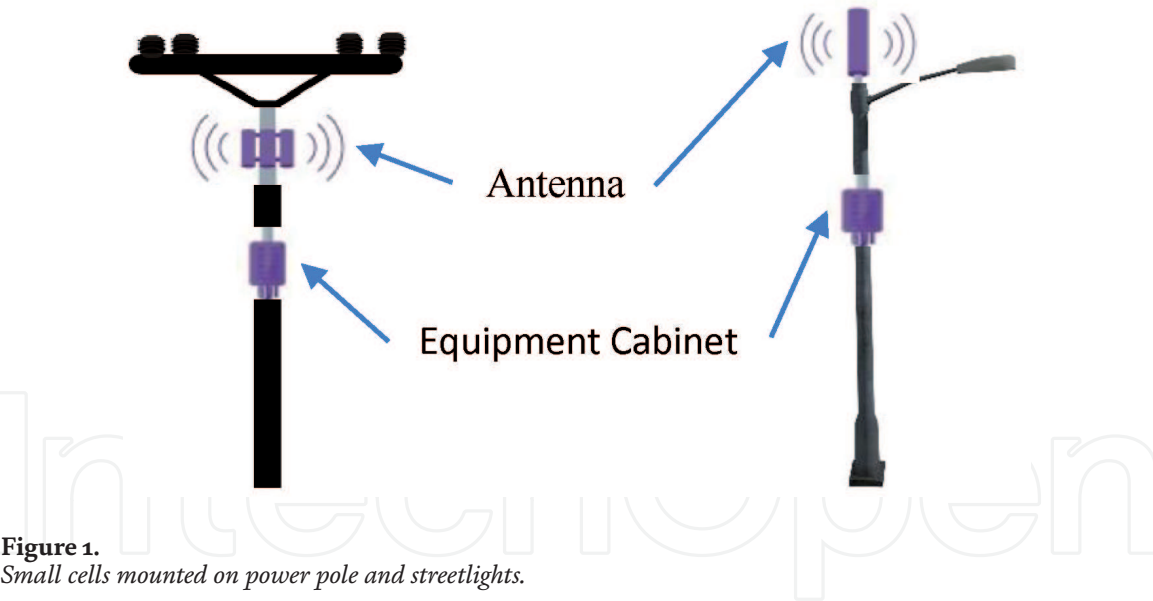

Figure 1.
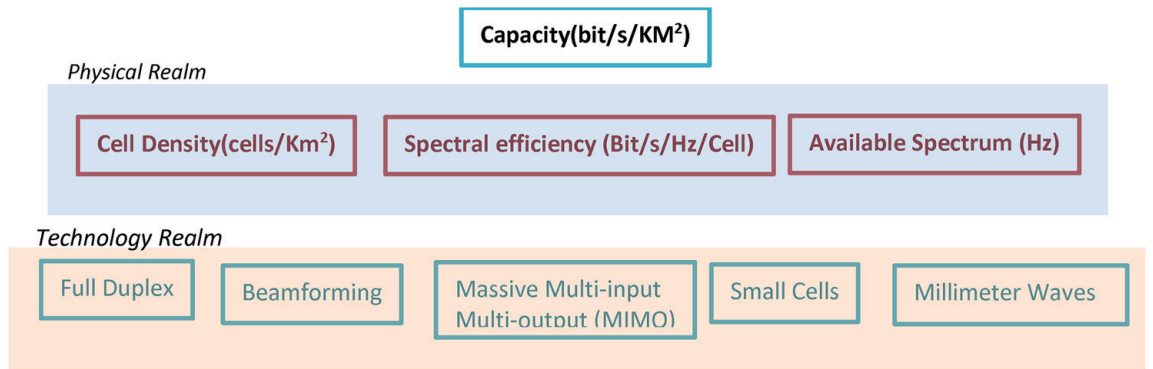*Small cells mounted on power pole and streetlights.*

Figure 2.
Realms of 5G.

and cost: Femtocells, picocells, and microcells [19]. The coverage area of femtocell is 10–50 m, while picocell covers 100–250 m and microcell covers 500 m–2.5 km. The power consumption of femtocell is 100 mW, while picocell consumes 250 mW and microcell consumes 2–5 W. The number of users for femtocells ranges from 8 to 16 users, picocells 32 to 64 users, and microcells up to 200 simultaneous users. The backhaul of femtocells and picocells is made of fiber connection, while for microcells, fiber connection and microwave links. Femtocells and picocells are for indoor usage, while microcells are for outdoor usage. Regarding cost, both femtocells and picocells have low cost in comparison with microcells which have medium cost.

"*Beamforming* is a traffic-signaling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process" [18]. The major goal of beamforming is to steer a signal from communication towers and small cells to the telephone while avoiding the obstacles like building and trees, hence reducing the line drops or disconnection. "Beamforming is typically accompanied with beam steering/beam tracking. With beam steering, a transmission is dynamically adapted (i.e., steered) both vertically and horizontally by utilizing a steerable two-dimensional antenna array. By beam steering, a highly focused beam, a stronger radio signal with higher data throughput is delivered over a greater distance using less energy. The result is spectral efficiency enhancement, capacity gain, cell edge throughput gain, and mean user throughput gain" [20]. There are three types of beamforming: analog radio frequency (RF) beamformer, baseband digital beamformer, and hybrid beamforming methods; the latter is most used in 5G according to Ahmed et al. [21]. One the other hand, the traditional baseband digital beamforming (DB) requires one distinct radio frequency (RF) chain per antenna. While baseband digital beamformer has many drawbacks like the high-power consumption and high cost of mixed-signal and RF chains according to Ahmed et al. [21, 22]. The researchers of Ahmed et al. [21] conducted a comparison between digital and analog beamforming according to the following: degree of freedom, implementation, complexity, power consumption, cost, inter-user interface, and data streams. The researchers found that digital beamforming has high degree of freedom, complexity, power consumption, cost, and inter-user interface, while analog beamforming was low in the same criteria. In implementation criterion, digital beamforming used ADC/DAC while analog beamforming used phase shifters. And the data stream digital beamforming is multiple, while the analog beamforming is single. The same source lists four advantages of hybrid beamforming: (1) enabler of mmWave massive MIMO, (2) less cost for hardware and (3) operation, and (4) energy efficiency. Ali et al. [23] added two more advantages: (5) Improved spectral efficiency and (6) increased system security. Ali et al. [23] listed the following algorithms used in beamforming: least-mean-square (LMS) [24]; recursive-least-square (RLS); sample matrix inversion (SMI) [24]; conjugate gradient algorithm (CGA); constant modulus algorithm (CMA); least square constant modulus algorithm (LS-CMA); linearly constrained minimum variance (LCMV); and minimum variance distortion less response (MVDR).

MIMO is the technology used by 4G and stands for multiple-input multiple-output. While 4G base stations have a dozen ports for antennas that handle all cellular traffic: eight for transmitters and four for receivers, 5G can handle hundreds [18] and is duped as *massive MIMO*. To achieve such goal, 5G must install more antennas which will produce more interference, hence the need to beamforming. Massive MIMO systems will utilize beamforming.

Full duplex is the technology that allows a transceiver to send and receive data simultaneously [18]. To achieve such goal, researchers must design hardware that will allow antennas to send and receive simultaneously. "To achieve full duplex in

personal devices, researchers must design a circuit that can route incoming and outgoing signals so they don't collide while an antenna is transmitting and receiving data at the same time" [18]. "*One drawback to full duplex is that it also creates more signal interference, through a pesky echo. When a transmitter emits a signal, that signal is much closer to the device's antenna and therefore more powerful than any signal it receives. Expecting an antenna to both speak and listen at the same time is possible only with special echo-canceling technology*" [24].

7. Current situation—South Korea

Currently, 5G is facing many challenges to be implemented; the following is the case of South Korean mobile carrier. On the 20th of March 2019, South Korean mobile carrier (SK Telecom) announced using quantum cryptograph technology for the security of 5G network. SK applied quantum number generator (QRNG) technology of ID QUANTIQUE (IDQ) for 5G subscribers to prevent hacking and eaves dropping. SK invested $65 million into IDQ and plans to expand the use QNRG. Furthermore, SK wants to apply quantum key distribution (QKD) technology in April/2019 [14, 25].

8. Conclusion

There are many publications and published research (20,196) that pertain to 5G technology. This chapter gives researchers, practitioners, and students a pedestal to get a comprehensive look at the new technology of communication named 5G. The chapter first gives an introduction about the increasing need for 5G technology. Then, it shows the amount of research conducted and indexed in ACM and IEEE. Next, the chapter shows the development of telecommunication technology from first to fourth generation. The chapter discusses three important aspects of 5G: Regulations, security, and the five enabling technologies. The five enabling technologies included two realms: physical realm and technology realm. The physical realm included discussion of capacity, cell density, spectral efficiency, and available spectrum. On the other hand, the second realm is made of technologies: *Millimeter waves, small cells, massive multi-input multi-output (MIMO), beamforming*, and *full duplex.* The seventh section presented current situation—South Korea mobile carrier.

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