American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-1, pp-56-68
www.ajer.org
Research Paper Open Access

Evolution of Mobile Communication: Navigating and Addressing Concerns in 5G Deployments

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***ABSTRACT: The** evolution of mobile communication systems from the first generation to the current generation has resulted in substantial interests from researchers, service providers, government agencies and the general public. Many concerns have been raised about the proliferation of electromagnetic devices and their possible effects. This study explores the investigations and experiments that have been carried out on mobile communication systems, particularly the recent 5G deployment. The results show that the constraints and concerns can be generally classified into three broad groups which are health, aviation and incumbent services. The debate on long term health effects of non-ionizing electromagnetic radiation particularly those from 5G remains unresolved. However, mitigation techniques as well as regulatory recommendations have been outlined for safe interoperability with aviation and incumbent services. This study demonstrates the need for continuous investigation and improvements in experimental techniques in order to determine generally applicable standards for deployment and implementation.*

***KEYWORDS** 5G,Aviation, MobileCommunication Networks, Health, Fixed Satellite Service.*

Date of Submission: 02-01-2024 Date of acceptance: 15-01-2024

I. INTRODUCTION

Within the last five to ten years, the realm of Mobile Wireless Communication Networks (MWCN) has witnessed rapid expansion. The effectiveness of wireless communication has improved significantly, leading to the emergence of multiple progressive generations of cellular telephone technology, now serving billions of users [1]. This journey through generations began with 1G, which focused on voice calls but laid the foundation for subsequent advancements. The 2G era introduced digital phone communication and text messaging services. The advent of the Third generation (3G) brought multimedia capabilities and enhanced data transmission rates [2]. The 4G revolution, a significant leap beyond 3G, improved speed, reliability, Quality of Service (QoS), and data bandwidth.From 2010 to the present, 4G has dominated the landscape with its widespread adoption and user support. The dawn of the 5G era promises the Wireless World Wide Web (WWWW), building on the continuous evolution of each generation, introducing new techniques and features, leading to a surge in mobile users and the mobile phone industry [3]. The recent years have seen swift increase in the mobile technology sector, both with regard to advancements and number of subscribed users. There has been a notable shift from fixed lines to mobile communication, particularly with the transition to the modern era. By the end of 2010, mobile cell subscriptions had surpassed fixed phone lines by multiple folds, prompting increased attention on network planning and development services [4].However, the current 3G and 4G networks aren't optimally suited for the Internet of Things (IoT), which involves numerous pieces of equipment and tools communicating over the internet to streamline daily life [5]. In this context, all kinds of devices need to connect to the internet through high-speed connections, facilitating seamless communication among a multitude of devices. The imminent focus of 5G mobile communication lies in supporting the large-scale implementation of IoT, with billions of interconnected smart objects and sensors [6]. 5G has been specifically designed to handle the vast data influx associated with IoT. It empowers connectivity across billions of devices and paves the way for future innovations [4].As we look towards the future, mobile and wireless communication with five generations will continue to enhance connectivity, with traffic volume permeating every facet of society, fostering all-encompassing transformation. With the growing popularity of handheld mobiles, consumer requirements kept constantly increasing. Advancements in engineering and technology enabled the production of better and faster mobile phones with more functionalities [7]. These functional advancements are now used to characterize mobile phones in generations ranging from 1 to 5.

II. LITERATURE REVIEW

The initial generation of mobile communication networks, known as 1G, emerged during the 1980s and was characterized by its analog nature. It utilized analog radio signals operating at a frequency of around 150 MHz. The primary function of 1G was voice transmission, with modulation techniques resembling those of the Mobile Cell Phone System. The communication systems of this era employed frequency modulation (FM) for radio signal transfer, and traffic was multiplexed using a Frequency Division Multiple Access (FDMA) approach, which split up the available frequency spectrum into different access channels[8].However, the 1G generation had its limitations, being characterized by unreliability and lacking in security features. In light of these drawbacks, efforts were made to overcome these challenges, leading to the development and introduction of two systems: the Advanced Mobile Phone System (AMPS) and the Total Access Communications System (TACS). These systems aimed to address the shortcomings of 1G technology. Despite these improvements, the data speed of 1G systems remained relatively low, with rates reaching up to 2.4 Kbps [9].These networks offered basic mobility and basic services to subscribers. They relied on analogue technology using frequency division multiple access (FDMA) and presented many challenges in compatibility. Apart from low capacity and poor voice quality, there were also problems with network security and coverage.

The subsequent generation of mobile networks, known as 2G, saw the establishment of the Global System for Mobile Communication (GSM) standard in Finland in 1991. Notable advancements in 2G included the ability to encrypt calls and the introduction of digital voice calls, resulting in improved clarity and quality. A key feature of 2G was the capability to send text messages (SMS), followed by the introduction of picture messages and eventually voice and image messages (MMS) on mobile devices [10].Unlike its predecessor, 2G used digital signals for transmission rather than analog. It introduced the concept of Code Division Multiple Access (CDMA), whereby each user was assigned a unique code to communicate across multiple physical channels. This CDMA approach allowed for effective use of the available spectrum and facilitated communication for a larger number of users. Multiple access techniques like Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and CDMA were employed to accommodate increasing user demands.Around 1995, a transitional phase known as 2.5G emerged, which combined voice and data capabilities. This phase introduced advancements such as Enhanced Data rates for GSM Evolution (EDGE), which increased data transfer rates to a significant level. During this period, General Packet Radio Service (GPRS) was launched, featuring packetized switching capabilities that were well-suited for internet connectivity. Data rates of up to 64 Kbps were achievable through these technologies. 2G mobile networks incorporated digital technology and were launched in 1991 on the GSM standard. The network offered advanced mobility services such as roaming and introduced basic data services such as multimedia message service (MMS). They were able to handle more traffic, used digital encryption methods and emitted less power than their first-generation counterparts. Generally, 2G networks havegreater efficiency.

3G, or the third generation of mobile networks, brought about significant enhancements by utilizing advanced wireless technology to support high-speed data transmission. Introduced in 2000, 3G networks provided reliable and high-speed data transfer capabilities. A consortium called the 3rd Generation Partnership Project (3GPP) was established to facilitate the implementation of 3G mobile communication networks. This consortium continued its efforts to define a flexible system that adhered to the International Mobile Telecommunications-2000 (IMT 2000) standard. In Europe, the 3G network was referred to as the Universal Mobile Telecommunication System (UMTS) or Universal Terrestrial Mobile Systems (UTMS). These terms are aligned with the International Telecommunication Union (ITU) IMT2000 terminology for the third-generation system. Among the technologies introduced within this context were Code Division Multiple Access (CDMA) and the Enhanced Data GSM Environment (EDGE), both of which contributed to the development of 3G digital networks [11].3G networks offered significantly expanded data transmission capabilities, enabling data transfer rates of at least 2 Mbps. The key advancement was the ability to achieve data transmission speeds approximately three times faster than 2G networks. This increase in bandwidth and data transfer rate enabled the use of various internet-based applications, including audio and video streaming, file transfers, and IP-based services like Skype. 3G networks provided peak data rates ranging from 100 to 300 Mbps, allowing for more efficient and seamless data communication [12].Third generation networks were first launched in 2001 by Japanese operator NTT DoCoMo. It was based on W-CDMA technology and offered more data services, seamless roaming and better security than previous generations. The third-generation partnership project (3GPP) promoted faster implementation of 3G networks leading to advancements such as 3.5G and 3G+. This enabled increases in capacity and faster data speeds as described below:

- Up to 144kpbs for General Packet Radio Service (GPRS)
- Up to 384kbps for Enhanced Data rates for Global Evolution (EDGE).
- Up to 1.92Mbps for UMTS Wideband CDMA (WCDMA)
- Up to 14Mbps for High-Speed Downlink Packet Access (HSDPA)

The emergence of the fourth generation, 4G, marked a significant transformation in mobile communication networks, introducing greater bandwidths, enhanced security, and very fast data services access. The 4G technology is built upon the foundation of Long-Term Evolution (LTE), a standard for the fourth generation of wireless communication which was designed by the 3rd Generation Partnership Project (3GPP). The primary goal of 4G was to deliver improved versions of the advancements promised by its predecessor, 3G. These enhancements encompassed areas such as multimedia enhancements, video streaming, global connectivity, and seamless device compatibility. Notably, 4G aimed to provide an even higher level of performance, with speeds as per the International Telecommunication Union (ITU) standard reaching up to 100 Mbps [13].The first deployment of 4G occurred in Stockholm, Sweden, and Oslo, Norway, in 2009. This was achieved through the utilization of the Long-Term Evolution (LTE) 4G standard. The global rollout of 4G subsequently transformed high-definition video streaming into a reality for a multitude of consumers. 4G networks offer rapid mobile internet access, reaching up to one Gbps for stationary users. This advancement has paved the way for various applications, including online gaming, enabling video streams at better definitions, and remote conferences with improved video quality [9].Advancements in technology and an overwhelming demand for bigger and faster data resulted in the introduction of 4G using LTE, OFDMA and MIMO technologies. In 2008, the ITU-R set data rates for 4G at 100Mbps – 1Gbps depending on the mobility. 4G networks are completely IP based offering full telecom/Datacom convergence, very high speed and IP based mobility. 4G networks are an all IP based packet switched network with the ability to support more simultaneous subscribers, providing better spectral efficiency and smooth handovers across various networks.

The introduction of 5G technology, also known as the fifth generation, represents the forthcoming advancement in wireless mobile broadband technology, offering notable characteristics such as greater speeds, reduced delay, support for massive device connectivity, and energy efficiency. The current technological landscape necessitates robust support from 5G to accommodate various services and applications. The ongoing development of 5G is propelling wireless communication into a truly global World-Wide Wireless Web (WWWW) era. This generation is built on a unique concept that merges 4G and the Wireless System for Dynamic Operating Mega Communication (WISDOM), forging a novel paradigm in wireless telecommunication networks [12].5G's high-speed data transmission capabilities are underpinned by communication fundamentals, with short frequencies and wide bandwidth enabling more efficient networks. The allocated spectrum for 5G spans from 30 GHz to 300 GHz, facilitating communication over short distances with bandwidth exceeding 1 Gbps [14].In the face of growing demands for faster internet services from subscribers and the necessity to keep supporting novel applications, 5G mobile communication networks are built to address these challenges. These networks are poised to rise to the increasing demand for data from industry-based subscribers and emerging technologies such as communication between one machine and another. The proliferation of internet-connected devices, encompassing devices like smart watches, smart meters, and industrial sensors, contributes to the Internet of Things (IoT). The IoT extends mobile communication to interactions between people and devices, with applications like mobile health, smart vehicles, smart homes, industrial control, and environmental monitoring driving its exponential growth. This surge in IoT-generated big data will find its foundation in the 5G network and will be stored and processed in Cloud. The transformative impact of 5G extends across various sectors, and by 2020, an estimated 20 billion devices are expected to be connected [15].The practical application of 5G in daily societal life encompasses a broad range of scenarios, including mobile broadband services and IoT. Notable applications supported by 5G include charging mobile devices using heartbeat signals, achieving nanosecond-level labor timing, augmented reality (AR), video conferencing in real time with near zero delay, smart city applications, autonomous vehicles, education, virtual reality (VR), industrial automation, and healthcare [16]. 5G enables large-scale data broadcasting in the gigabit range, supports virtual private networks, and offers connectivity speeds of up to 25 Mbps with data bandwidth surpassing 1 Gbps, leading to exceptionally high upload and download speeds.Fifth generation mobile networks are expected to have higher capacity, greater speeds and better reliability [17]. It is described as the backbone for the internet of things (IoT) with the following requirements: tens of Mbps for users, 100Mbps in urban areas, 1Gbps for multiple simultaneous users, 100,000+ simultaneous connections, more efficient use of the spectrum, better coverage, enhanced signaling and reduced latency as compared with the previous generation. Figure 1 presents a summary of the process by which wireless mobile communication has evolved from the earliest generation to the current generation showing their period of introduction, technology and services offered.

The study of mobile communication networks is very important to ensure that the telecommunication sector in Nigeria and around the world continues developing accordingly. It is therefore no surprise that numerous authors and researchers have carried out various studies in relation to mobile communications networks. There are multiple studies that have been carried out over the years, however, only the relatively recent studies are presented in this article.[18] stated in their paper that mobile communication systems can be sustainably developed by merging together the related fields of communication and computing. They assert that such implementation will be made possible in the future due to the advent of fog computing. They went on to present an overview of fog computing enabled networks and included various metrics and parameters. They analyzed how heterogenous such network implementation will be using advanced telecommunication tools such as fog computing. They proposed a communication and fog computing network architecture which is both hierarchical and heterogenous and demonstrated much higher capacity than traditional networks.[19] compared various architecture of mobile communication networks and analyzed the survivability of the network. The authors presented different techniques that one could typically use to improve the probability of survival of a network. They also discussed methods that can be employed to mitigate failure in different parts of the network and what tools can be used to identify them. They also studied the use of optical fibre communication for providing interconnectivity between elements of the communication networks and described cost effective design and architecture while also considering network viability.[20] took a close look at the security systems in place for mobile communication networks. The authors stated that this has become necessary due to the popularity of the network and highly demanded data service access. They stated that due to the many changes that occur from one generation of mobile communication networks to another, it has become necessary to ensure that these systems are adequately protected.[21] stated in their publication the importance of studying how the mobile communication networks have evolved over the years particularly as it relates to the introduction of the fifth generation of mobile communication networks popularly known as 5G. They asserted that improvements in access schemes depend very much on the improvements in client stations. Their paper reviewed the differences in types, rates, applications and other features of the previous generations in a bid to clarify and compare fifth generation enhancements.[22] discussed the evolution of mobile communication as it relates to spectral policies. They noted the exponential increment in the utilization of mobile telecommunication services further stating that new areas of applications for example, internet of things (IoT) make up a huge portion. The introduction of 5G provides high capacity and low latency connections and thus mobile networks can support a wider range of services than in previous generations. They concluded that it has become necessary for regulatory bodies and organizations to develop novel regulatory requirements and frameworks for spectrum management. [23] conducted a study on how the fifth generation of mobile communication networks have impacted the growth of intelligence-based automation systems and digital industrialization as a whole. Their paper also presented a review of the development of various generations of mobile communication networks exploring the technologies involved, trends and challenges. The author also highlighted the importance of mobile communication networks in digitization.[24] conducted a comparative study of the evolution of different generations of mobile communication systems. Their paper discussed the various technologies implemented in different generations through the use of figures, graphs and tables.[25] investigated the evolution of wireless mobile telecommunications networks and its impact on sustainability. The authors focused particularly on optimization driven by big data and the mobile framework. They studied the significant points of 5G and the previous mobile technologies.[26] presented a review of cellular mobile technologies from first generation to fifth generation and massive MIMO. Their article focused on how mobile technologies have evolved and developed over time and discusses the significance and advantages of one generation over another.

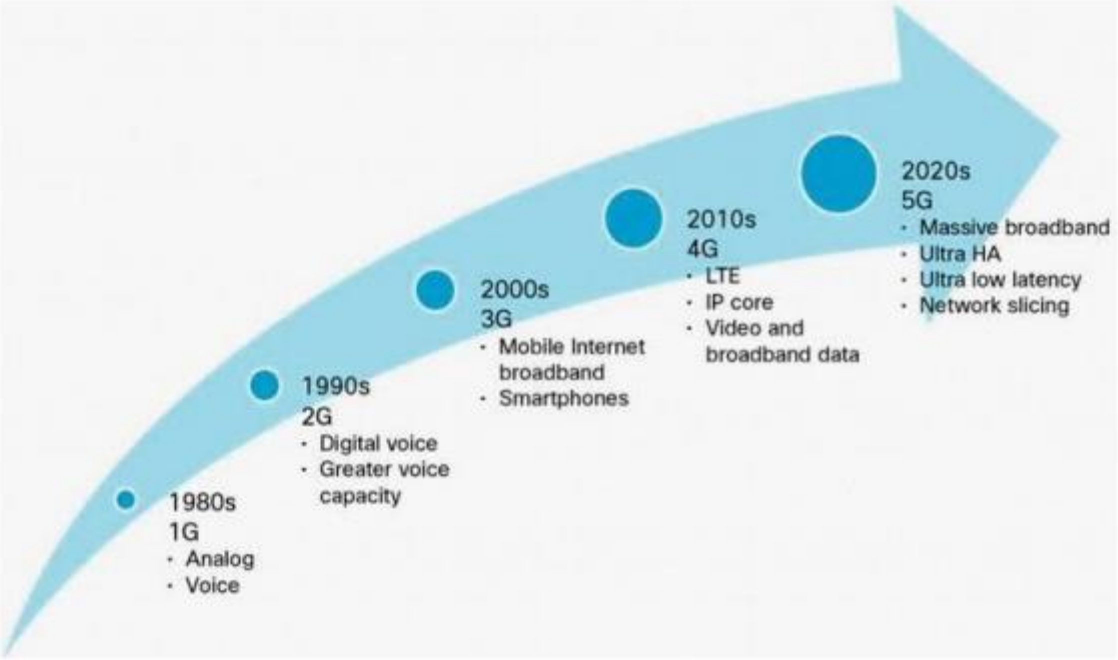

Fig. 1: Evolution of Mobile Communication [21]

III. FIFTH GENERATION NETWORKS CONSTRAINTS AND CONCERNS

5G, denoting the fifth iteration of wireless communication systems, signifies the latest progression in mobile telecommunications standards. Its applications encompass a wide range, extending from mobile broadband services to the domain of advanced automobiles and interconnected devices. The inaugural specification for 5G New Radio (NR) was concluded in June 2018 and subsequently integrated into the 3GPP Release 15 specification. Notably, players in the telecommunications industry such as infrastructure vendors, network providers, and device manufacturers have already developed new products utilizing 5G technology. The drive behind the creation of 5G emerged due to the rapid escalation in the need for wireless broadband that can effectively transmit video and content-heavy services. Additionally, the proliferation of the Internet of Things (IoT), where a multitude of smart devices communicate through the Internet, also played a significant role. To address these needs, 5G is designed to offer exceptionally high broadband speeds, extremely low latency, and ultra-reliable internet connectivity.The implementation of 5G networks and devices necessitates a significant departure from previous architectures, radio access technologies, and physical layer algorithms.The landscape of mobile access technology undergoes a significant transformation approximately every decade, with each successive generation introducing substantial improvements in performance. These shifts are driven by the escalating demands for capacity resulting from the explosive growth in data consumption, particularly due to video content. Video resolutions are also on the rise, and devices supporting 4K video require data rates as high as 15.4 Mbps per user using H.265 profile 5.1, accommodating features like 4K resolution at 64 frames per second and a Chroma ratio of 4:4:4[27]. Users are spending more time watching feature length television shows and film productions through stream services, hinting at a persistent trend with no signs of saturation. The demand for content is projected to surge beyond forecasts, leading to an estimated annual mobile traffic increase to 291.8 exabytes by 2019 [28].However, the utility of 5G (IMT 2020) goes beyond catering solely to mobile broadband systems. The technology is designed to also accommodate a varying range of applications within three main groups:

- Enhanced Mobile Broadband (eMBB): This category is reminiscent of current offerings but promises to perform extensively better and provide subscribers with more seamless experience. It encompasses various cases, such as large coverage areas and hotspots. Large coverage areas require smooth connectivity and improved mobile ability, delivering significantly enhanced user data rates compared to present offerings. In hotspot scenarios, the focus is on supporting large number of subscribers per area and exceptional ability to carry large data, albeit with required mobile ability limited to pedestrian speeds.
- Ultra-Reliable and Low Latency Communications (URLLC): This usage category demands strict levels of latency, reliability, and availability. Applications like transport systems with embedded intelligence, vehicle to everything (V2X) communication, healthcare procedures, smart grid applications, disaster management and relief, industrial manufacturing control systems, etc., fall within this domain [29].

- Massive Machine Type Communications (mMTC): This grouping encompasses applications defined by varying traffic patterns. While specifics may differ, one constant is the potential deployment of many devices transmitting comparatively minimal or maximal volumes of information that are insensitive to latency. These devices need to be economically feasible and affordable possessing extended battery life.

IV. 5G AND HEALTH

The debate on the health effects of non-ionizing radiation to human health has been going on for several years with no end in sight as different researchers from different industries have different ideas. The stance of the telecommunication industry is quite clear; non-ionizing radiation is safe for use within the defined limits. However, health experts have stated that the effects of long term exposure are something that cannot be fully understood at the present time. They have presented epidemiological studies such as in [30] as well as experimentation on non-human subjects to prove their case leading to the World Health Organization (WHO) classification of non-ionizing radiation as “potentially carcinogenic” which means that it can possibly cause cancer. It is important to note that this classification is also given to a multitude of daily used substances such as coffee and is by no means a definitive answer to the ongoing debate.Seasoned researchers have conducted studies on radiation exposure and found that radiation exposure did not exceed safe levels. [7] conducted field trials in 2G and 3G networks in order to compare the electromagnetic radiation emanating from user equipment at various relative distances. While the results showed that the radiation exposure was well below the internationally specified safety limits, they noted that the exposure values were dependent on the distance from the device. However, they did not consider the duration of exposure. This is expected of any time varying electromagnetic field. They also found that the 2G network had generally larger values of electric and magnetic field strengths than the 3G networks however they declined faster with respect to distance. It is Important to note that their findings showed that all the recorded data were well below the safety limits as specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).With the advent of 5G networks, the discussion continues to be held among many quarters. In the year 2020, there were widely spread conspiracy theories propagated through social media and modern-day social influencers which blamed the erection of 5G base stations as a direct cause of the COVID-19 pandemic. These claims were largely unfounded and have mostly been dispelled as untrue. However, the debate on 5G base station location and effect on the population remains unresolved.[31] reviewed various research works reporting on experiments aimed to investigate possible biological effects of exposure to non-ionizing radiation such as those in 5G networks. The authors noted that most of the studies reviewed had generally poor control methods and the techniques used in assessing the level of exposure were said to be of low quality. They also noted that many of the biological effects could not be replicated independently. They stated that while many results included heating effects from high radio frequency energy, the epidemiological studies did not reveal any glaring evidence that points towards serious health effects such as carcinoma, infertility and other illnesses. They concluded that it is important to continue monitoring wireless telecommunication network exposure levels for possible long-term effects. They also noted the need for improvement in the methodology used in such studies. [32] noted that the introduction of 5G services will result in an increase in the number of high-powered devices hence they questioned the potential health impact. The authors reviewed over 90 studies on in vivo and invitro experimentation and observed an 80% response to exposure and 58% demonstrated effects in in vivo and invitro studies respectively. However, they were unable to find any constant relationship between exposure time or frequency and effects. They concluded that the available data was insufficient to provide any meaningful conclusion and thus called for the need for further research. [33] discussed concerns raised in Poland on possible safety hazards arising from the implementation of 5G networks. They noted that it is important to investigate not only thermal effects but also indirect and long term hazards. The authors also stated that many nations have no protection criteria or recommendations for this range of frequencies. They concluded that while current data does not support the argument on definite health effects due to 5G exposure, it is necessary to take precautions as there is some data that indicates adverse health impacts on humans.[34] developed a general method for studying personal exposure to radio frequency electromagnetic fields particularly to be implemented in 5G studies. Their proposed protocol takes account of the auto-induced exposure from personal devices as well as from the service providers network devices such as base stations. Their study was based on results from existing simulations carried out by other researchers as well as from documented test site measurements. They used an activity-based approach and were thus able to introduce a systematic means of evaluation. They concluded that their protocol addressed the main setbacks experienced in carrying out personal exposure measurements in 5G networks.

V. 5G AND AVIATION SAFETY

The deployment of 5G communication networks across the globe has led to many concerns with regard to the impact of interference on radio altimeters. Over the last twelve to 18 months, there have been new directives and policy updates from national aviation authorities, particularly the FAA, addressing the controversy on radio altimeter compatibility with 5G networks.In the United States, wireless broadband deployment was delayed after high level talks and further restrictions were placed on 5G transmitters in and around certain airports with low visibility. Canadian authorities restricted 5G deployment around 26 airports along with other measures to ensure aviation safety [35].The research, testing and debates between the telecommunication sector and aviation industry has resulted in the formation of specialized groups to address the subject matter. One of the recently established groups is the Joint Interagency Five G Radar Altimeter Interference (JI-FRAI) group. The group consists of inputs from the Department of Homeland Security (DHS), Department of Defense (DOD), Federal Communication Commission (FCC), airlines and avionics manufacturers amongst others [36]. Current airworthiness directives suggest that radar altimeters found on older Boeing 747 models could produce abnormal data in the presence of 5G interference. These anomalies may result in erroneous Autoland messages and thrust lever adjustments while an aircraft is still in flight [37]. Pilots, engineers and airline companies are actively testing and updating their policies as results become available.The Institute for Telecommunication Sciences (ITS), a subsidiary of the National Telecommunications and Information Administration (NTIAA) had started conducting tests to ascertain the exact power levels of radiation from 5G base stations that will impact on an aircraft. Viavi Solutions have developed software that models and simulates specific conditions to determine whether or not a radio altimeter will fail in the presence of 5G interference.Several network operators and airline manufacturers are working together to study 5G interference as part of the radio Technical Commission for Aeronautics (RTCA) Special Committee 239. SC-239 was established in 2020 and was responsible for the first official report proposing potential interference of 5G wireless systems with radio altimeters [38].A few companies are focused on developing new standards for radio altimeters that will provide better immunity in 5G and even 6G environments using Digital Signal Processing (DSP) technology and internal filtering. [39] analyzed the landing approach scenarios that were considered in other studies of 5G radar altimeter interference. The author included multipath propagation as well as scattering as opposed to earlier studies which considered only line of sight propagation. He stated that it is critical to include multipath analysis as interference levels were seen to exceed the safety margins. The results highlighted the need for multipath, site specific analysis for accurate assessment of the degree to which 5G emitters may interfere with radar altimeters.[40] stated that 5G interference could degrade the acceleration performance, increase landing distance and cause possible runway excursion. They stated that in worst case scenarios, electromagnetic interference can result in an aircraft running off the end of the runway. Thus, electromagnetic interference issues can directly impact airlines, airplanes, passengers, aviation authorities and network providers. The authors suggested measures that could be used to reduce the risk of interference such as regulations that deal with 5G antenna power and orientation as well as placing buffer zones around airports.[41] simulated an aircraft landing through 5G emissions coming from a base station at close proximity to the airport. The author stated that simulation offers a relatively low-cost method to efficiently test and validate radar altimeter parameters with respect to the 5G base station parameters. He used the Ansys HFSS along with the electromagnetic interference toolkit to model wideband interference potential. The results showed that spurious emissions from 5G base station were responsible for in band interference in radar altimeters. The author suggested possible measures for mitigating the EMI effects such as creating a ‘keep off’ zone, limiting antenna pointing angles, reducing base station transmitter power and others.[42] stated that in late 2021 and early 2022, there were concerns from the aviation industry that aircraft altimeters would be impacted by 5G networks. The authors noted that so far, there have been no confirmed cases of interference between 5G and aviation. They noted that the International Telecommunication Union as well as other national governments have constantly studied the 3,5GHz range for over a decade. They stated that ensuring the coexistence of different technologies is the basis of effective spectrum management and therefore, it is important to ensure safe coexistence between 5G networks and adjacent frequencies.[43] studied the compatibility between 5G base stations and radio altimeters in Japan. The authors investigated the behaviors of radar altimeters in the presence of interference from 5G signals with results showing a similar tendency for vulnerability as had been reported in previous studies. They suggested that high power 5G base stations should not be installed within 200m of the airplane route.

VI. 5G AND INCUMBENT SERVICES

Since the planned introduction of the 5th generation of mobile communications, there have been several discussions about potential interference issues that may arise due to its expected high power and high coverage density. In the years following its announcements, several industry players have conducted experimental research into potential interference that these services may cause for already existing communication services in select frequency bands. Therefore, this resulted in several publications from researchers, network providers, satellite operators, regulatory bodies, unions and many others. Some of the most recent publications are therefore reviewed in this section highlighting particular work that has been done on addressing concerns of 5G networks interfering with the operation of fixed satellite service earth stations both within and outside the 3.5 GHz frequency bands.[44] discusses the significance of the C-Band (3.4 - 4.2 GHz) in satellite services, especially Fixed Satellite Service (FSS) above 3.6 GHz. The C-band's broad coverage and weather resistance make it an effective communication solution, and it has also been considered for deployment in 5G cellular systems due to its mid-band nature combining signal reach and capacity. However, satellite service providers show concern with regard to potential interference from 5G systems affecting their services. The author's article presented a study of interference for 5G cellular systems that are operational in the sub 6 GHz for various conditions including adjacent and co-channel interference. It analyzes how impactful out-of-band emissions, Low-Noise Block (LNB) saturation, and Active Antenna Systems (AAS) are to terrestrial base transceiver stations (BTS). Techniques for coexistence are proposed and evaluated to help regulators and stakeholders understand the impact and potential solutions of deploying 5G in C-band alongside FSS services.[45] introduces a method to assess the coexistence potential of currently available satellite services and planned 5G cellular services in the millimeter-wave band. The study extends the interference reception area of a satellite receiver using geospatial terrain data, providing a more accurate assessment of interference. IMT-2020 (5G) systems are placed in the coverage region according to ITU parameters, and interference is analyzed for a Fixed Satellite Service (FSS) satellite and an Earth Exploration Satellite Service (EESS) passive sensor. Results indicate that FSS protection criteria are met, but EESS sensors may require more frequency spacing or mitigatory approaches for protection.[18] investigated the coexistence of 5G based Internet of Things systems and fixed-satellite services (FSS) at 40 GHz. Their study focuses on accurate interference estimation relying on mm Wave propagation parameters. The resulting outcomes of the simulations reveal that interference stemming from the 5G IoT system towards FSS ground stations can be effectively managed to stay below the prescribed protection thresholds. This is achieved by taking into account deployment characteristics such as antenna patterns, Earth station (ES) height, and the separation distance. The study presents a promising approach for co-channel coexistence in the mm Wave spectrum bands. [46] discusses the coexistence challenges occurring in 5G new radio (NR) deployments and incumbent fixed satellite service (FSS) operations in the C-band and Ka-band. The study examines how the utilization of suggested 5G antenna and radio transmission models in various implementation environments affects how the coordination and exclusion areas around FSS Earth station (ES) receivers are defined. The shape of these zones is influenced by changing gains in spatial antenna and varying transmission models.[47] explored the possibility of utilizing non-geostationary orbit (NGSO) satellites to access 5G New Radio (NR) enabled mobile stations (MS) in millimeter-wave (mm Wave) bands, specifically Frequency Range 2 (FR2). The paper investigates this from regulation standpoint also considering the user equipment parameters, space segment, link budget, and system perspectives. It describes potential challenges and forthcoming research necessities in this field of study, considering the coexistence of NGSO satellites and 5G NR systems.[48] presented a study focusing on the integration of Low Earth Orbit (LEO) satellite systems with the 5G New Radio (NR) to provide support for various 5G service requirements such as Massive Machine-Type Communications (mMTC), Ultra-Reliable Low-Latency Communication (URLLC) and enhanced Mobile Broadband (eMBB). The study surveys the opportunities, technical issues, and proposed solutions for integrating terrestrial mobile and satellite networks. It introduces a technique for managing mobility to reduce overhead due to signaling and minimize interruption of service when one satellite is handing over to another.[49] proposes a novel bandpass frequency selective surface (FSS) design to mitigate electromagnetic interference resulting from fifth generation (5G) mobile communications on the fixed satellite system in the C-band frequencies. The design comprises multiple layers with metal square loops and slots, resulting in a sharp sideband response. The FSS exhibits a flat passband in the range of 3.7-4.2 GHz but still maintains out-of-band effective shielding below 6.5 GHz. The prototype's measurements align well with simulation results, demonstrating its effectiveness in suppressing interference. [50] investigates co-channel interference from the 5G system to the Fixed-Satellite Service (FSS) earth stations in the frequency band ranging from 3400–3600 MHz The study employs Monte Carlo simulations to evaluate interference distribution due to 5G interfering base stations, considering factors such as antenna models, power control, path loss models, link calculations, and system scheduling. Their study suggests a minimum distance between 5G base stations and FSS earth stations to meet protection standards, emphasizing factors like angle between the FSS earth station receiver's main axis and the direction of the interfering base transceiver station's signal, the number of 5G base stations, and their transmitting power.[51] introduces collaborative mobile edge caching techniques which use underlay spectrum sharing and coordinated multiple point tools to increase efficient utilization of the spectrum in 5G systems. The strategies involve joint transmission (JT) opportunities and leverage caching schemes to enhance cache hit rates, decreasing backhaul traffic and the time taken to access content. The paper also proposes coordinated quality-of-service (QoS) aware allocation of resources schemes to maximize coordinated beamforming (CBF) spectral efficiency, while considering constraints like transmitting power, power of interference between systems, and QoS requirements for each subscriber. The study considers a scenario where a cell-based network is in coexistence with a fixed satellite service earth station in the C-band, highlighting the efficiency of the suggested caching and resource allocation techniques. [52] discusses the compatibility and coexistence of the fifth generation (5G) mobile communication network with operating frequencies in the 24.25–27.5 GHz frequency band with other adjacent wireless applications. The paper specifically focuses on assessing adjacent channel interference (ACI) between Land-Earth Station in Motion (L-ESIM), 5G base transceiver stations (BTS), and mobile stations (MS) with operational frequencies in adjacent frequency bands. Using the minimum coupling loss (MCL) approach, the study evaluates the impact of the geostationary orbit fixed satellite service's (GSO-FSS) frequency band of 27.5–29.5 GHz on the 5G radio access network from L-ESIM. The research determines the lowest distance of separation required to ensure the maximum acceptable interference levels, providing insights to ensure coexistence and compatibility between the systems.[53] explores the sharing studies between the IMT-2020 networks (5G networks) and already available systems in the 28 GHz band, particularly in adjacent channel and co-channel situations. The study uses simulations to assess compatibility and interference between the IMT-2020 technology and satellite services operating in the same spectrum, known as the Fixed Satellite Service (FSS) in the Ka band. The paper considers both Geostationary Satellite Orbit (GSO) and non-geostationary satellite orbit (NGSO) scenarios, providing insights into the possibility of joint and safe existence of 5G with satellite systems in the 28 GHz band. [54] presents the initial findings of the 5G-ALLSTAR project, which is focused on developing solutions for enabling a shared spectrum in the context of allowing multiple connections between 5G cell-based services and satellite systems. The paper starts by discussing the spectral bands suitable for the systems in the interim and also in the immediate future. The authors then introduce two channel models: a model based on ray tracing and a stochastic model based on geometry, both of which can simulate scenarios that involve land based and non-land-based networks. The paper proceeds to outline three approaches investigated for managing interference in the project: signal processing, beamforming, and radio resource management. These approaches aim to optimize spectral efficiency and coexistence between the cellular and satellite systems.[55] examines interference in 5G systems and point to point fixed services in the 26 GHz band. The study analyzes the current spectrum usage in Brazil, including deployed services within the proposed band. The authors evaluate the co-channel interference caused by 5G networks on fixed services under various conditions such as the number of cells, location based on geography, effect of propagation, and height of the antenna. The results provide insights into the lowest distance of separation required for deploying a 5G network ensuring that no interference is affecting the existing fixed service.[56] explores the issue of interference in 5G networks and the fixed satellite service (FSS) in the C-band. The paper focuses on the Chinese context and evaluates the level of interference in a practical system deployed by China Unicom. Factors including the location of 5G terminals, the load level of 5G base stations and the angle between 5G base stations and FSS antennas impact the level of interference. The authors propose a solution to mitigate interference by including a filter for the FSS receiving antenna. They evaluate the filter's passband in a laboratory setup and validate its effectiveness against real-world interference scenarios. The results suggest that using a filter with sufficient suppression in the 5G spectral range can significantly reduce the separation distance between 5G base stations and FSS earth stations, thus avoiding coverage gaps in the 5G network. [57] discusses the integration of legacy satellite communication systems into the 5G ecosystem, emphasizing the impact on microwave filter technology. Traditionally, satellite and terrestrial networks had limited integration due to commercial and technological factors. However, as satellites become part of the 5G infrastructure, the application of microwave filters in these novel systems is expected to evolve. The paper explores uses of filter techniques with respect to satellite to terrestrial 5G systems, addressing potential challenges as well as opportunities that arise from this integration.[58] addresses the potential interference issues between satellite services and 5G networks, as their spectrum allocations may overlap. The paper evaluates the worst-case interference situation in terrestrial Base Stations (BS) and satellite Earth Stations (ES) in the context of 3.4 GHz operations. It considers various parameters such as ES height, BS height, terrain, variation in time, and change in location. The goal is to provide recommendations for path loss based on ITU-R P.1546-5 in order to mitigate potential interference and ensure effective coexistence.[59] focuses on the evolving landscape of spectrum regulation and the increasing availability of unlicensed and shared spectrum bands for mobile communication. The paper proposes a coordinated shared spectrum framework as a potential approach for next generation cellular standards. This approach aims to enhance spectral efficiency in densely populated networks, emphasizing throughput, delay reduction, and resource fairness between operators. The proposed framework seeks to optimize network performance through dynamic sharing based on varying traffic demand, potentially leading to significant gains in multiplexing efficiency compared to static spectrum allocation schemes. [60] conducted an analysis of coexistence in 5G New Radio (5G NR) and Satellite Television Receive Only (TVRO) in the C-Band. The study involved practical test beds with analog and digital TV channels from a parabolic dish receiving antenna focused on a geostationary satellite, as well as a 5G NR link operating at 3.55 GHz. The analysis was based on varying the 5G power level and vertical polarization to assess the impact on TV channel quality. Measurements of RF and IF signal spectra were shown, indicating possible interference issues arising from the deployment of 5G base stations near TVRO subscriber locations. The paper highlighted the importance of managing coexistence, particularly given the significant number of TVRO users in Brazil and C-Band satellite users in the United States. They suggested the use of low-cost filters at the first stage of amplification to reduce the separation distance from 12.02km to 672.6m.[61] addressed the challenge of 5G interference with C-band radio and television services in the context of China's new infrastructure development. The paper analyzed the interference principles of 5G and presented strategies to mitigate 5G interference. The goal was to ensure the continued progression in measures to mitigate interference from 5G.[62] introduced a new method for shared satellite spectrum with terrestrial mobile 3-dimensional (3D) in-building small cells, referred to as femtocells. This technique aimed to address spectrum scarcity and improve data access indoors. The paper detailed the suggested spectrum sharing method, including co-channel interference considerations due to satellite user equipment in the small-cell coverage area. The almost blank subframe (ABS)-based enhanced intercell interference coordination (eICIC) technique was used to enhance quality-of-service (QoS) for both small cell and satellite user equipment. The paper derived capacity at the system level, efficient use of the spectrum, and energy efficiency performance indicators for the suggested method, taking into account different building coverage scenarios. The study demonstrated the superiority of the suggested technique with regards to energy efficiency and spectral efficiency relative to fifth generation (5G) network requirements and existing techniques. The paper concluded by discussing the implementation of the radio resource scheduler and outlining the importance, challenges, and further research directions of the suggested spectrum sharing method. [63] highlighted the importance of preparing for the commercial deployment of 5G technology by 2020, according to the timeline set by the International Telecommunication Union (ITU). Several leading countries had already begun tests and preparations to roll out their 5G networks in alignment with the ITU timeline. Given Indonesia's substantial growth in internet and mobile phone users, there was an urgency to hasten the implementation of 5G services within the country. To facilitate this process, the study focused on assessing the practicability of 5G proposed bands in Indonesia and exploring potential scenarios for sharing spectrum with incumbent systems. The study's outcome indicated the following findings:

i. Low Band (700 MHz): Sharing spectrum between 5G and analog TV on the 700 MHz band was not feasible due to the requirement of a distance of separation equal to 20 km. This implies that coexistence between these services in the low band would be challenging.

ii. Middle Band (3.5 GHz): Sharing spectrum between 5G Base Stations (BS) and Earth Stations (ES) of Fixed Satellite Service (FSS) in the 3.5 GHz band could be achieved. However, it required a distance of separation of 10 km when the angle of elevation of the ES antenna is set to 20°.

iii. High Band (28 GHz): Sharing spectrum between 5G Access Points (AP) and FSS was feasible in the 28 GHz band. No protection distance was required when the angle of elevation of the ES receiver is set to 20°. However, a distance of separation equal to 5 km was necessary when the ES antennas were set at elevation angles of 0° and 10°.

Overall, the study's findings provided insights into potential spectrum sharing scenarios for 5G deployment in Indonesia and underscored the importance of considering protection distances to ensure effective coexistence with existing services.

VII. CONCLUSION

Mobile communication networks as we know them today have seen exponential growth and improvements over the past decades. As with all technological advancements, there have been numerous concerns about potential hazards being introduced by the implementation of new systems and new technologies. The fifth-generation networks are no exception to these concerns. In particular, concerns have been raised on possible health effects, aviation threats and coexistence with existing services such as fixed satellite services. Over the years, multiple researchers have continued to study these interactions closely and investigations are still ongoing.After careful analysis of the currently available data, one can summarize as follows:

Health —As with all other services in the non-ionizing spectrum, current investigations have not been able to show any adverse health effects from 5G to human health, at least not with the required degree of certainty to warrant mitigation efforts. However, there is an abundance of results from experiments, investigations and epidemiological studies that seem to suggest possible long-term effects and thus it is necessary for such studies to continue while service providers and users encourage safe practices when dealing with these devices.

Aviation — Studies from the aviation industry seem to suggest that the implementation of 5G has an adverse effect on some avionics within adjacent channels particularly radar altimeters which play a critical role in aviation safety. These concerns have led to precautionary regulations and recommendations to be implemented while regulatory agencies continue to monitor the interaction. Although many telecommunication providers and stakeholders maintain that there is little to no potential for harmful interference, the use of proper signal processing techniques and the application of filters have been suggested as measures to mitigate any harmful effect and maintain consumer confidence.

Satellite service — The interaction of 5G base stations with other incumbent services has led to concerns about possible interference. This has resulted in close monitoring of the coexistence between these two services by industry experts, researchers, stakeholders, government agencies and regulatory bodies. The output of current research in this area has been very conflicted with some resulting in large separation distance recommendations; others resulting in the need for frequency relocations; and others showing no cause for concern. This points to the need for continued monitoring, research and investigations in order to reach a consensus on regulatory requirements.

This study has shown that the exponential growth in wireless communication networks from first generation to the present generation, while laudable, has led to many concerns which must be addressed to enable full utilization of the scope of possibilities and use cases offered by 5G technology.

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