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Spectral Limitations and the Emerging Trends in Wireless Communication

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Abstract

The electromagnetic spectrum had long been found to support the transmission of information. In this paper, the authors provided a brief treatise on the stupendous growth of wireless communication appeal, as an alternative to wired communication, for long-distance communication. Specifically, the paper delved into how the radio portion of the electromagnetic spectrum emerged to support the transmission of information. A discussion of the profound progress that had been made in the field of mobile communication with the emergence of different generations leading to the, now, proposed 5G networks, with increasing capabilities intended to make life more meaningful in all areas of human endeavour, was also provided. Further consideration was provided on the finite nature of the radio spectrum, which became a challenge in the face of the consistently emerging wireless technologies and rapid deployment of such emerging technologies to match the exponential increase in transmittable information types and demand for such. The inadequacy of the traditional spectrum management approach, the fixed spectrum allocation, which, partly, accounts for the "scarcity of the radio spectrum" that accompanied the wireless communication growth was expounded. Finally, the various efforts made to confront these challenges and the techniques involved in the new approach to spectrum management; i.e. the dynamic spectrum access or sharing was discussed.

Keywords- ***Radio Spectrum, Spectrum Management, Spectrum Scarcity, Dynamic Spectrum Sharing, Dynamic Spectrum Access***

I. INTRODUCTION

The discovery, by Marconi, of the radio spectrum, a portion of the electromagnetic spectrum, spanning between 1GHz and 100GHz, to be capable of supporting information transmission, was quite a relief. This is because it created, yet, an alternative medium of long-distance information transmission, to that of cable and an opportunity for the emergence of mobile communication. This, not only broke the jinx of geographical separation on communication, it greatly, enhanced capacity. Decades after that realization, the emergence of cellular mobile phones, in the early eighties, seemed to have opened the door for a plethora of other services. Without much ado, it could be opined, without the risk of contradiction, that mobile communication has, indeed, revolutionized the way people communicate.

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The range of services offered, through wireless mobile communication, is enormous and continues to grow, while; the demand for each of these services has also been increasing exponentially, especially in recent years [1][2][3]. In the final two decades of the last century, the international telecommunication union (ITU) assigned more radio frequencies than the entire past decades of wireless communication history put together [4]. This explosive growth in demand for wireless services has, however, brought to the fore, the major challenge of wireless communication; scarcity of the radio spectrum. This is, expectedly, so because while the range of services and the demand for such services is continually growing the radio spectrum, the channel for the provision of the services, is finite.

Concurrently, the appeal of the wireless mobile technology spurs the global tendency to deregulate, liberalize, and privatize the telecommunication industry, particularly in the wireless mobile broadband [5], [6]. This has the effect of encouraging and making market entry easier for new telecommunication service providers [7],[8]. This, also, increases competition among the players, leading, to falling prices, which in turn, leads to further rise in demand [8], [9]. This lowering cost advantage, coupled with the possibility of easy and rapid deployment, accounts for its tremendous appeal, especially, in rural areas and developing countries, hitherto characterized by acutely low teledensity in the face of exorbitant costs of deploying wireline services.

These, coupled with the increasing acceptability and adoption of applications, such as the Global Positioning System (GPS), and Radio Frequency identification (RFID) tags have also placed a further burden on the finite radio spectrum[10], [11]. A fundamental factor that has made the challenges accompanying the growth in demand for mobile telecommunication services more pronounced, is the traditional command and control approach, used in radio spectrum assignment/allocation and management. To address the limitation of the traditional spectrum management technique, as well as the scarcity of the spectrum, a paradigm shift in spectrum management is being put in place to accommodate the ever-increasing demands for services and ensure ubiquitous information transmission with acceptable Quality of Service [12]. This paradigm shift is the introduction of several techniques collectively referred to as dynamic spectrum sharing or access DSS or DSA.

The rest of this paper is organized as follows: Section two, discusses the evolution of the successive generations of the wireless mobile communication technology, section three discusses some facts and trends in spectrum sharing, while section four discusses spectrum scarcity. In section five, we dovetailed into details of techniques involved in dynamic spectrum access in the sixth section we provided our position on the issue and the seventh section concludes it.

II. TRENDS IN WIRELESS CELLULAR MOBILE COMMUNICATION

The evolution of wireless cellular technology is being driven by a trinity of; scarcity of the radio spectrum [12], continuous increase in the quantity, quality and complexity of service demand [3], and need for better (efficient) utilization of the available scarce radio spectrum [13]. The changes and advancements in wireless technology, are aimed at meeting the ever-increasing expectations in quantity and quality of services. From one technological standard or generation to the next one, efforts are being made to address the shortcomings of an earlier technology/generation by the new technology/generation [14]. Since the drivers of this technological trend are dynamically changing, the technological evolution in recent times has been very rapid. This is because, before deployment (even, at times before conclusion and adoption), of a new standard or generation of technology, the requirements and hence researches for the next generation have begun. This myriad of issues, drive the evolution of wireless cellular mobile communication from the analog era, the first generation (1G), to the current generation, 5G

A. First Generation Networks (1G Networks)

The first-generation wireless technology was analog with the basic function of providing voice calls at 2.4kpbs [15], [16]. It employed the Frequency Division Multiple Access (FDMA). The first of such system in the world, was by the NTT (Nippon Telegraph and Telephone) in Japan, in 1980 ([16], [17]. Others that got launched were: the AMP (Advanced Mobile Phone), in the United States of America, Total Access Communication Systems (TAC) in the United Kingdom, and the Nordic Mobile Telephones in Eastern Europe. Russia launched theirs and became very popular in Europe [13]. The bandwidth allocated to the system, like the AMP, was 40 MHz within the 800 MHz -900MHz frequency i.e., using 869 MHz -894 MHz for the forward channel (Base Station to Mobile Phone) and 824 MHz -849 MHz for the reverse channel (Mobile phone to Base station). It was during this time that the 7-cell reuse pattern was adopted because directional antennas provided better cell reuse than the omnidirectional antennas. The basic features in 1G were hold, mute, redial, speed dial.

B. Second Generation Networks (2G Networks)

Unlike the 1G, the 2G uses digital data signalling and offered low bit rate data services, in addition to the traditional voice services, offered by the 1G. It uses the digital multiple access technologies, such as time division multiple access (TDMA) and code division multiple access (CDMA). It offers higher spectrum efficiency and more advanced roaming capability, compared with the 1G system. The Global Systems for Mobile Communications (GSM), first deployed in the early 1990s in Europe, was the earliest and most popular 2G technology. It operated in the 900 MHz and 1800 MHz bands, throughout the world, except in America, where it operated in the 1900 MHz band. In a bid to provide better services, it has undergone appreciable improvements, since its first emergence. The GPRS and EDGE, known as the 2.5 Generation (2.5G), are later variants of the GSM [16]. The 2G, which operates at higher spectral efficiency than the 1G, has the following advantages over the latter, (i) it can handle some data capabilities such as fax and short message services that are not possible with the 1G (ii) it operates at a higher data rate of up to 9.6 kbps. These additional capabilities were facilitated by the so-called 2.5G technologies, the GPRS, and EDGE. The GPRS provides theoretical maximum speeds of up to 171.2 kilobits per second (kbps) while with the EDGE, data rate up to 384 kbps, was achieved.

C. Third Generation Networks (3G Networks)

Packet or data transfer in the 2G networks, even in EDGE, is much like circuit-switched voice calls, with its attendant inefficiency. This is apart from the absence of a common standard, on a global level. Hence, the need for a system that is technology standard/platform-independent, with a globally unified network design standard, which gave rise to the 3G technologies. The technology defining requirements are set out in the IMT-2000 standard while the Third (3rd) Generation Partnership Project (3GPP) was responsible for designing the mobile system that implemented the standard. The equivalent European Telecommunication Standards Institute (ETSI) defined standard, in Europe, was called Universal Terrestrial Mobile System (UMTS). In America, its equivalent technology was referred to as CDMA2000 (Code Division Multiple Access-2000) [16], [17]. Compared with its predecessor, the 3G standard provides greater network capacity, owing to its significantly improved spectral efficiency, while offering a more diverse and advanced range of services. It also offers better mobility as well as a data rate of 14.4 and 5.8 Mbps, in the downlink and uplink respectively.

D. Fourth Generation Networks (4G Networks)

Primarily designed for data, an all IP-based protocol, and Mobile broadband, the 4G significantly improved user experience and multi-service capacity. The All-IP technology ensures a unified platform for integrating existing technologies of older generations as well as Wi-Fi and Bluetooth [13]. This also ensures flexibility and a measure of freedom for users in their choice of service, with a reasonable quality of service, at an affordable price, anytime, anywhere. The implication of this is that data transfer will be less expensive and much faster [17]. The official standard or requirement of the 4G technology was defined as the IMT Advanced, by the ITU-T. Chief among the requirements for IMT-Advanced are:

i. Peak data rate of 1 Gbps for downlink (DL) and 500 Mbps for uplink (UL).
ii. Mobility up to 350 Km/h in IMT-Advanced.
iii. Support for scalable bandwidth and spectrum aggregation, with transmission bandwidths more than 40MHz in DL and UL.
iv. Backward compatibility and inter-working with legacy systems

E. Fifth Generation Networks (5G Networks)

The 5G standard is not only expected to be considerably faster than its predecessor, the 4G, it is also intended to provide applications with high social and economic value, leading to a ‘hyper-connected society’ in which mobile broadband communication will play an ever more important role in peoples’ lives. There are two distinct definitions of what the 5G is; a service-led view which defines 5G as an amalgamation of 2G, 3G, 4G, Wi-fi and other wireless communication technologies, to provide greater coverage and always-on reliability; and a second view, which defines it in terms of increase in the achievable data speed and multifold reduction, in end-to-end latency[18].

1) ***The ‘hyper-connected society’ view****:* The proponents of this, opined that 5G would be an amalgamation of pre-existing technologies covering 2G, 3G, 4G, Wireless-Fidelity (Wi-Fi), Bluetooth and others, to allow higher coverage and availability, thus, higher network density, in terms of cells and devices. The main distinguishing feature, as propounded by this view is greater connectivity, to facilitate Machine-to-Machine (M2M) communication, Device-to-Device (D2D) services as well as the Internet of Things (IoT). There could also be the need for a new low powered radio technology, as well as low throughput field devices with long duty cycles of about a decade year or more.

2) ***The new radio access view****:* This adopts the traditional approach of defining a wireless generation by setting specific key requirements/targets for data rates and latency, by which new radio interfaces can be assessed. This approach, otherwise referred to, as ‘generation-defining’, is based on the existing pattern of previous evolution or generation of mobile wireless communication technology. In a similar pattern, to the previous generations; 1G – 4G, where FDMA, TDMA/CDMA, WCDMA, and OFDMA were the respective defining radio access technologies, 5G is expected to have its unique radio access technology. This, therefore, provides clearly defined criteria for determining which technology can be referred to as 5G or not. DSA and software-defined radio and networking (SDR & SDN) are also proposed to be integrated into this new access technology, creating a clear deviation from the older generations.

Both views have been considered equally important in the growth and development of the 5G standard. Consequently, the defining requirements of the 5G technology are derived from both views: The main requirements can be summarized as the following:

i. 1-10Gbps connections to endpoints in the field
ii. 1-millisecond end-to-end round-trip delay (latency)
iii. 1000x bandwidth per unit area
iv. 10-100x number of connected devices
v. (Perception of) 99.999% availability
vi. (Perception of) 100% coverage
vii. 90% reduction in network energy usage
viii. Up to ten-year battery life for low power, machine-type devices.

III. Spectrum Sharing and Management

The concepts of spectrum allocation, sharing, as well as its management are imperative with wireless communication in its entirety. The nature of the transmission path, being an unguided medium, unlike the cables and wirelines, used in wired communication, dictate that it be more controlled, and defined. The cellular communication technology makes this more pertinent for many reasons, chief amongst which is to prevent interference among competing transmissions of different players, in the airspace, and more importantly, to increase capacity, to meet the ever-emerging new technologies. Without proper management and coordination of modalities for usage and sharing of the radio spectrum, by different players, wireless communication would be in a perpetual state of chaos, as competing transmitters in their efforts to, successfully, transmit their signals within the ocean of other similarly intentioned players, fail in their efforts. In fact, this was the situation with radio communication, before the formation of the international regulatory body, the International Radio Telegraph Union (IRU) in 1906, which later transformed to the present day International Telecommunication Union (ITU).

At the National level, each member state of the ITU has its regulatory agency or organization that regulates the use of the radio spectrum within its territory for the different individual wireless communication services available. The spectrum regulation or management, simply involves setting out rules for the sharing of the radio spectrum or frequency, vis - a – vis, allocation of specific frequency bands for different services, determination of the transmitting parameters for each sharing operator and the geographical location, for which the rules are applicable [4] [29]. At the international level, the ITU sets out the different frequency assignments and operation parameters for the different wireless services. Subsequently, the National regulatory bodies, taking a cue from the ITU, grants rights or licenses to individual corporate entities, to have exclusive use of a certain portion of the spectrum, for a certain period and in some cases within a geographical range [19] [20]. This is the traditional command and control method of spectrum sharing. These entities could be commercial, governmental, or research organizations. However, it should be noted that the concept of spectrum sharing in wireless communication, is more than a simple administrative and regulatory task of frequency assignment and rules setting.

Spectrum sharing implies several users utilizing the same portion of the spectrum for different services [21]. The sharing could be in time, space, and frequency domains. Spectrum sharing is the concurrent usage of a given spectrum band in a given geographical area by several independent entities, leveraged through mechanisms other than traditional multiple and random-access techniques. These, defined the age-long traditional fixed spectrum sharing approach, in which corporate entities, (licensed users), are given exclusive rights of use of the portion of the spectrum, so allocated or assigned, for a period and a particular geographical region, by the relevant regulatory body. In Nigeria, the Nigerian Communication Commission (NCC) is the national regulatory authority responsible for spectrum management, in the case of point to point communication. The National Broadcasting Commission is responsible, in the case of broadcasting. Other examples include the Federal Communication Commission, (FCC) in the United States of America and the Office of Communication Ofcom in the United Kingdom. Due to the inadequacy of this approach in the face of the stupendous growth of the demand for radio spectrum, (earlier mentioned), a new class of spectrum sharing which involves a licensed user sharing its spectrum band with other users (Unlicensed) came into being. To be more precise, spectrum sharing might be administrative, technical, or market-based [4]. The various forms of spectrum sharing are as follows:

1) **Administrative Sharing:** This involves the regulator's approach to establish where sharing should occur and what are the rules that govern it. In addition, they define the sharing rules for radio system performance and applicable technical standards, equipment specifications, and equipment type approval [4]. They establish policies for spectrum allocation; establish

specifications that give support to spectrum-efficient technologies.

2) **Market – based Sharing:** This involves auctioning and spectrum trading the spectrum band. This method has proven more economical than administrative sharing. Spectrum auctioning involves the sale of spectrum license to transmit signals over a specific spectrum band. Then the successful licensee would consider services and technology to deploy [4]. The problem with this method is that it results in the hoarding of the spectrum.

3) **Technically Enabled Spectrum Sharing:** This involves technically efficient use of the spectrum band. The two determinants of technical efficiency are data rate and occupancy. Data rate quantifies the frequency of usage while occupancy quantifies how much constant and heavy usage of the spectrum over time [4]. The main spectrum sharing technologies are spread spectrum, dynamic spectrum access, and ultra-wideband and are broadly categorized into underlay and overlay technologies. The underlay technologies allow signals with low power signals to coexist with users with higher priority of signal power while overlay technologies allow different users to share spectrum by taking advantage of usage holes or gaps in the frequency, time, and space domain.

IV. SPECTRUM SCARCITY IN WIRELESS COMMUNICATION

Availability of adequate frequency for wireless radio transmission has been a major challenge of wireless communication, since the first transmission by Marconi in 1895. This persistent problem has been a function of (1)- the existing radio technology at a specific time and (2)- the government regulatory policies. Through improved spectrum efficiency, spectrum/frequency re-use and better interference handling, the radio technology has evolved from having just one service/technology occupying the whole spectrum as in the days of Marconi to the present era of 5G. However, from the regulatory perspective, the useable radio spectrum has been almost fully allocated in practically every country of the world. This fact, coupled with the stupendous annual growth in demand for bandwidth-hungry services [1], [2], [3], gives rise to the spectrum scarcity phenomenon.

Figure 1, shows the frequency allocation map for the United States of America as of January 2016 [22]. As indicated on the map, every portion of the radio spectrum except for the lower frequencies (the white portion) has been allocated to a specific technology and/or designated for use by some government, organization, and commercial entities (licensed) or experimental and ancillary usage (unlicensed). This means there is little or no spectrum available for new services and technologies of the future.

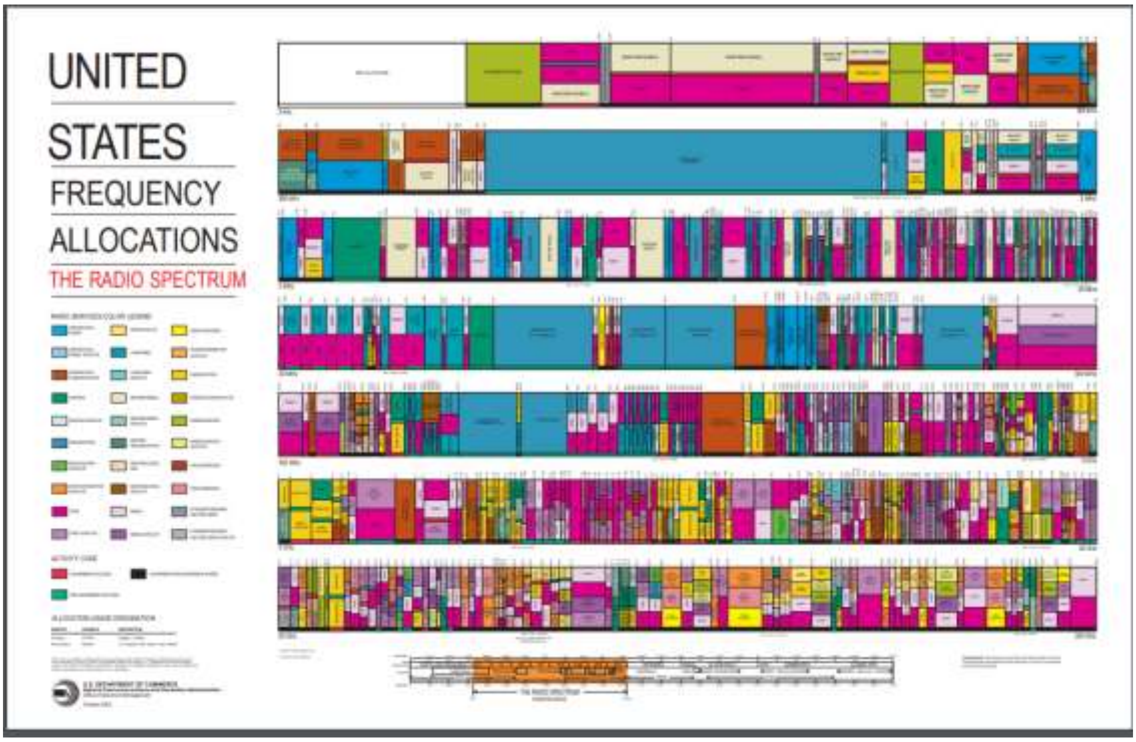

Figure 1. The United States Spectrum allocation Chart (2016)

This picture of frequency allocation is replicated in almost all nations of the world. Over the decades, a recurring solution has been re-farming of portions of the spectrum for use by new services or technologies. This method of evacuating existing occupiers from a portion of the spectrum and re-allocating same to new service/technology has not only been a relatively short term fix but is practically becoming more difficult today. Surprisingly, while these frequencies have been fully allocated, they have been grossly underutilized by the entities they were hitherto allocated to [23]. In fact, this has led to some school of thought to opine "spectrum scarcity is a fallacy or myth".

Spectrum occupancy measurements, conducted worldwide, has confirmed the under-utilization of the radio spectrum. The report in [12] carried out a spectrum ccupancy measurement in Chicago, Washington, and other US cities, in all bands between 30 MHz and 3,000 MHz. The reported overall usages for the cities revealed a gross under-utilization of about 86.9% and 82.6% for the two cities investigated in the study. Similar works such as [13], [24] - [28], instigated a paradigm shift from fixed spectrum sharing to the dynamic spectrum sharing or access approach (DSA or DSS).

V. DYNAMIC SPECTRUM SHARING OR ACCESS (DSS OR DSA)

The realization that the radio spectrum, once referred to as "a natural common", free for usage by everyone, just as the air we breathe or the rays of sunlight, is, indeed, becoming scarce, brought about a critical re-evaluation of the traditional command and control fixed spectrum sharing approach. It became ironic that while the demand for spectrum is outgrowing the available supply, the already allocated spectrum is grossly under-utilized. The reason for this is the exclusive utilization right, given to licensees, (government or commercial) which forbids utilization of that portion of the spectrum by others, even whether, or not, the owners are utilizing them. This under-utilization has therefore created holes or gaps, otherwise referred to as ***white spaces*** in the supposedly already assigned frequency spectrum space. Spectrum holes or white spaces could be either spatial (relating to distance of geographical location) or temporal relating to time of existence of the holes).

The purpose of the DSA or DSS is to allow the utilization of a licensed spectrum, by other users (secondary users) other than the licensed owner (primary user) when or where it is not being used [19]. By adopting this approach to spectrum sharing, DSA simultaneously alleviates the challenge of spectrum scarcity and enhances spectrum utilization. This usage by unlicensed secondary users must however not compromise the quality of service of primary users. Cognitive radio CR was one of the front-runners of dynamic spectrum sharing. Extensive researches have been conducted and are still being ongoing, on numerous aspects of cognitive radio inspired network [30]. In recent times, other DSS schemes have been proposed, most of which are still at the infancy stage of development [31]. To prevent harmful interference to the operations of the primary users, secondary users had to employ mechanism(s) that enable them to determine, where and when to transmit. The mechanism for detecting whether or not a channel is free, for secondary use, is called spectrum sensing.

Spectrum Sensing Techniques

Spectrum sensing involves the measurement of various parameters which include, but not limited to, interference, noise, transmitting power, spectrum characteristics, and location characteristics, to enable a secondary user (SU) determine its availability for use, [30][31]. Spectrum sensing is broadly categorized into three main classes: non-cooperative (also known as transmitter detection or indirect spectrum sensing), cooperative, and interference-based sensing. [30][32]. Non-cooperative sensing is further classified into energy detection, matched filter detection, and cyclostationary feature detection.

1) **Cooperative or Collaborative Detection**: This method combines information from several opportunistic users in detecting the presence of the primary user PU. This sensing method can exist in three classes: Centralized coordination, Decentralized coordination, Decentralized Un-coordination [32][33].
2) **Interference-Based Detection**: This is a sensing method which controls the interference at the transmitter with the help of the radiating power generated. There are two types of interference-based detection techniques: Primary Receiver Detection Model and Interference Temperature Model [34].
   a. **Primary Receiver Detection Sensing Technique:** This sensing method relies on the primary receiver's local oscillator (LO) leakage power to determine spectrum availability or otherwise. This

could be implemented by the use of low-cost sensing nodes which will be located very close to the primary transmitter in order to relay information about the spectrum to secondary users [34].

b. Interference temperature Model Sensing Technique: In this method, the secondary users are permitted to transmit with lesser power than the licensed primary users. The SU transmit power is however restricted by the interference temperature level, so that there is little or no interference to the PU network [34].

3) **Non-cooperative detection or transmitter detection sensing or indirect spectrum sensing:** This technique is based on the ability of the SU to determine feeble signals from a PU transmitter. The challenge with this method is that the SU does not have accurate information on the status of the primary receivers because there is no signalling between them. Different types of non-cooperative sensing techniques exist, few of which are highlighted below:

a. **Energy Detection(ED)**: This method compares the measured received signal strength indicator (RSSI) value with a pre-defined energy threshold to determine whether the spectrum is free or not [32]. ED is the most widely used sensing technique adopted by both industry and academia due to its less complex computation and no need for prior knowledge of signal strength [30][31][32]. There are, however, several limitations of this method, some of which are (i) difficulty in distinguishing between SU and PU, (ii) Noise power unpredictability and (iii) its unsuitability to spread spectrum system.

b. **Matched filter Detection:** When the transmitted signal parameters are known *a priori*, this method is best suited for detecting licensed or primary users. [30][31][32]. The advantages of the matched filtering detection method, over other methods, include its short detection period and very low complex computational requirement. However, it is very sensitive to non-additive Gaussian white noise (non-AWGN) [[30][31][32], also its software defined radio will require having a receiver each for every primary user.

c. **Cyclostationary feature detection:** This method exploits the periodic nature of modulated signals, hopping sequences, cyclic prefixes etc in detecting the received primary signal. The associated properties of periodic signals such as spectral correlation make it easy to separate noise and interference, which are stationary processes, from the actual signal of the PU. However, fore-knowledge of the PU is essential for the method's accuracy [30][31][32][34]. Its limitations include very high computational complexity, inefficiency when the short-time variation of the spectrum is considered and high measurement error.

d. **Wavelet Detection**: this technique is more suitable when checking for unoccupied frequency channels in a wideband system. One of its drawbacks is that it requires a high sample rate to achieve the needed accuracy and speed in scanning the entire band for vacant channels [32].

e. **Swiss Army Knife (SAK) Detection**: This approach works by incorporating all different spectrum sensing methods, depending on which method works best for a sub-band. This improves the overall performance of the detector [32].

VI. SCARCE SPECTRUM OR INEFFICIENT SPECTRUM MANAGEMENT AND UTILIZATION?

The command and control approach to frequency assignment implies exclusive right of access to the assigned spectrum by whoever the assignee is, every time and everywhere. This, as noted earlier, does not put into consideration the period when, as well as portions of the geographical area where, the licensed owner of the spectrum is not transmitting, hence rendering the spectrum unutilized. Several examples of this abound in all countries of the world, especially in such spectrums for public and private usage. It is also seen to lesser extents in some bands licensed for commercial usage. This will be addressed from two perspectives.

The first perspective will be based on the spectrum occupancy measurements, done across the world. Examining the finer details of the work in [12], shows that in the 806 MHz – 904 MHz frequency band, the utilization is about 55%. This is rather surprising, considering the fact that, this is one of the cellular bands, which usually have higher traffic than other bands. Moreover, this result was obtained for a highly populated city and in a technologically advanced country, Chicago, in the United States of America. Another result from this work shows an underwhelming utilization of just 20% between 2300 MHz – 2360 MHz. This frequency range falls in the frequency band that has been identified as one of the IMT (international mobile telecommunication) Band. In fact, the 3rd generation partnership project (3GPP) christened it LTE Band 40 [35]. If the bands with expectedly high traffic are experiencing such level of under-utilization, the extent of the under-utilization in bands with lesser traffic demand would be significantly higher. Similarly, the authors of the work in [36] reported an average of 4.5% utilization, within the frequencies 80 MHz and 5850 MHz in Singapore. It should be noted that these occupancy measurements did not take into account, the large chunk of spectrum used as guard bands that are neither allocated nor utilized by any service provider but are reserved to prevent inter-operator and inter - technology interference.

The second perspective is better illustrated with the case of the CDMA technology in Nigeria, licensed to operators like Multi-Links Telkom, Reliance Telecommunications (RELTEL), Starcomms, Intercellular Nigeria, Visafone, etc. While on the NCC frequency allocation table [20], a large chunk of the spectrum was allocated to these operators, for a very long period of time, however, in so many geographical areas, they are not being utilized. This is in part, due to the inability of the CDMA operators to extend their services to many places as the competing technology, GSM, did. In places where their services are, the quality is below what the GSM networks offer. The result is that these frequencies which are very suitable for wireless mobile broadband remain unused or waisted, even, as the whole world talks about spectrum scarcity. A similar scenario occurred with the inability of NITEL, the 5th licensed GSM service provider to utilize its assigned spectrum in the GSM 900 and GSM 1800 as well as the UMTS band. The company could not sustain meaningful business operations for decades while their assigned band remained inaccessible to other service providers that could use the spectrum. These examples show the gross inadequacy of the command and control approach to spectrum management and a major cause of the challenge christened ‘spectrum scarcity’ in wireless communication.

Based on the aforementioned, it is obvious that the real plague of spectrum availability is not scarcity of the radio spectrum but the inadequacy of the spectrum management technique and the consequential ineffective utilization by spectrum license holders. The authors of this paper cannot but agree with the school of thought that says spectrum scarcity is a myth [23],[37]. Rather than the present spectrum allocation approach, efforts should be made to ensure that dynamic spectrum access is regulated and coordinated, by the ITU and the national regulatory authorities, in each member country. The existing approach might be retained for critical national and public safety services such as radio – astronomy or elsewhere, where there is a need for international or global standardization, to ensure seamless and harmonious operation by different countries [38]. Hence flexibility and dynamism in the usage terms and conditions set up by the regulatory authorities should pave way for the rigidity and static control of the legacy command and control spectrum allocation and frequency assignment.

Furthermore, the understanding of the relation between the spectrum and the radio waves and the devices used for their transmission (the transmitters and receivers) need to be put in the right perspective. The notion of scarcity of the spectrum is brought about by the understanding that the spectrum is a separate entity or commodity, through which radio waves are transmitted. The truth is that unlike the wired/cable communication, the radio wave is the medium of transmitting itself. i.e., to say, the radio wave is not different from the spectrum. Hence, spectrum assignment is not the allocation of some concrete or tangible asset but a granting of authorization to operators or technologies to operate with some specific characteristics. In this regard, the transmitters and receivers have been given permission to tune their circuitry to operate within the range of the allocated frequency [23].

In a similar way, the main reason for the present command and control approach, prevention of interference from and to different users of the spectrum, need to be construed from the sophistication and design of the transmitting and receiving devices as well as the underlying technologies. The first radio transmission by Marconi utilized the entire available radio spectrum and covered an area of more than 160, 000 million square meters [37]. Sixteen years later, spectrum efficiency improved by about a trillion-fold. Another 47 years down the line, the achieved improvement is about an additional 100 million fold. The introduction of the cellular concept provided a further ten-fold increase. Subsequent successive advancement in access technologies from TDMA-FDMA-WCDMA-OFDMA and now NOMA (non-orthogonal multiple access) further provide multiple fold increase in spectrum efficiency. Antenna techniques such as active/smart antennas, MIMO (massive input massive output), beamforming, etc. are also improving the efficiency of utilizing the spectrum further. These technologies and many others have proven more than efficient in improving interference handling and ensuring reliable and efficient communication between different users of the spectrum. The existing fact has shown that it is high time to abolish the notion of spectrum scarcity and embrace the challenge of taking advantage of the emerging and future technologies to foster an environment of spectrum abundance in wireless communication.

VII. CONCLUSION

The plethora of emerging technologies in wireless mobile communication posed challenges to humanity, given that the spectrum remains limited in supply, leading to the issue of spectrum scarcity. The bourgeoning demand for the radio spectrum, consequent upon this emergence of new technologies, dictates that new spectrum management techniques be adopted, away from the existing command and control. The goal is to provide enough spectrum to meet demand without compromising on quality of service. The industry and research centres have been confronting this challenge, through technological innovations. Particularly handy, is the realization that assigned radio spectral - spaces were being underutilized. This raises the prospective ideas of spectrum sharing as encapsulated in the notions of cognitive radio and the associated DSA and DSS. In addition, it will become necessary to consider the amenability, through technological adaptation, of other bands being, presently considered difficult/impossible for use.

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