Springer Link

Leveraging MMWAVE Technology for Mobile Broadband/Internet of Things

Transactions on Engineering Technologies pp 507-514 | Cite as

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Conference paper

Abstract

Today, almost every individual possesses at least one internet-connected device. According to Cisco, there were over 12.5 billion devices in 2010 alone. It has been predicted that 25 billion devices will be connected by 2015, and 50 billion devices by 2020; all contributing towards the Internet of Things (IoT). This rapid increase exposes the obvious need for enhancements in various underlying technologies. IPv6 for example, has been developed to provide 340 undecillion IP addresses, and 3GPP LTE and its further enhancements provides impressive high bitrates cost-efficiently. That been said, there is still a limit on the amount of data that can go through a frequency channel. Therefore, the surge in demand for data by the billions of devices emphasizes the need to re-visit spectrum planning. Beginning with a review on the success of unlicensed spectrum operations, this work looks into the potentials of complementing the licensed frequency bands with unlicensed by tapping into the advantages of millimeter wave access technology.

Keywords

IEEE802.11 Internet of Things (IoT) mmwave LTE Spectrum Unlicensed WLAN

1 Introduction

Spectrum is regarded as the life-wire of the telecommunications industry [1] but is also a very scarce and expensive asset. Therefore increasing the capacity of a wireless cellular network does not automatically imply increasing the bandwidth. LTE-Advanced (LTE-A), Release 10, supports bandwidth increase through Carrier Aggregation of its Release 8/9 carriers, yielding a maximum of 100 MHz bandwidth. However, there is still a limit on the amount of data that can go through a frequency channel. All cellular network providers, cutting across evolving generations of access technologies, are restricted to utilizing carrier frequencies within the 700 MHz and 2.6 GHz bands, referred to as the most valued spectrum [2]. Within this limited spectrum range, they all attempt to provide wireless high-speed data rates and low delay services to customers. Hence, the adoption of LTE has largely been dependent on refarming of spectrum previously provisioned for GSM [3, 4] so as to take advantage of the potentials of these frequency bands.

With the unending increase in demand for mobile data (as seen in Fig. 35.1) by increasing billions of devices, a looming shortage of bandwidth is envisaged in the near future. If this issue is not addressed early, the surge in demand for data will likely overtake the capability of the current wireless networks to meet the demand.

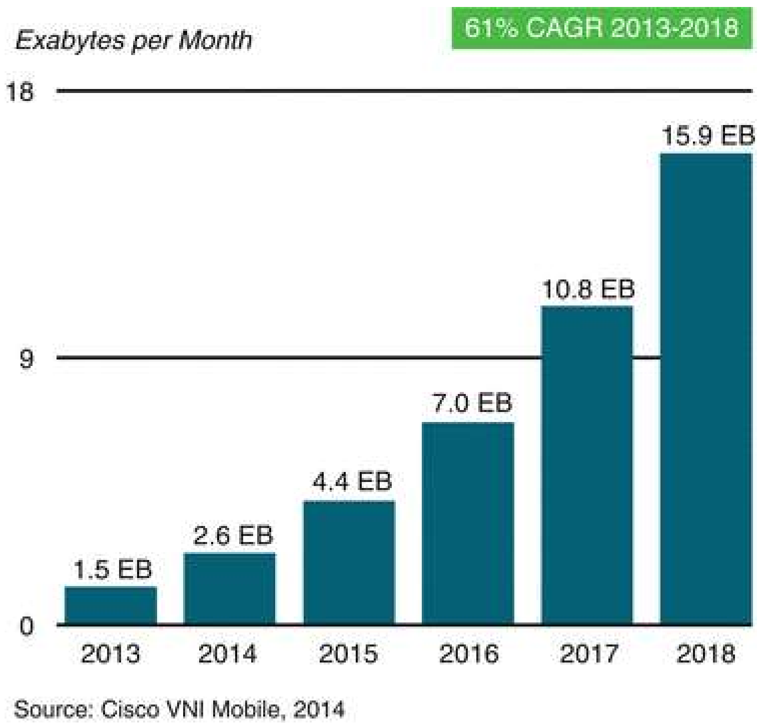

Fig. 35.1

Mobile data traffic growth [5]

At the ITU World Radio Conference (WRC) in 1992, 230 MHz of new radio spectrum was identified for IMT-2000 towards initial implementation and commercialization of 3G in the year 2000. Also, at the WRC in 2007, radio spectrums below 1 GHz and above 2 GHz were identified for IMT-A (4G) [6]. 4G only gained significant grounds in 2013/2014 with 331 LTE networks commercially launched, expected to get to 350 by the end of 2014 [7]. This gives an idea on the amount of time it takes for spectrum procurement and licensing after identifying potential spectrum, by the regulatory bodies. With the exponentially increasing demand rate for mobile broadband by the exponentially increasing devices, this time-line for spectrum licensing is unacceptable to meet the demand.

Therefore, unlicensed spectrum is the quickest and potentially sustainable route of supporting this rapid growth/ network expansion. It may be integrated into the network to complement services offered through licensed bands.

2 Unlicensed Spectrum – Brief History

The electromagnetic spectrum represents the range of all frequencies possible for electromagnetic radiation. It is within this range that several applications are derived. Figure 35.2 illustrates a simplified electromagnetic spectrum chart.

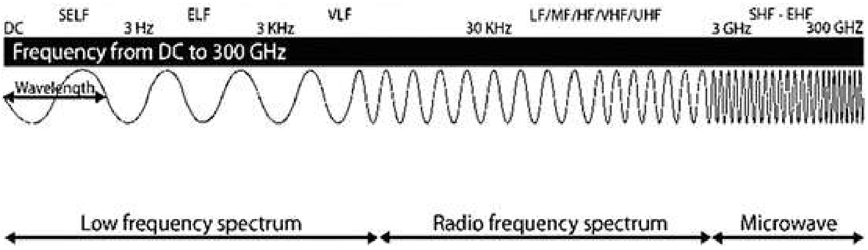

Fig. 35.2

The electromagnetic spectrum [8]

Wireless spectrum refers to the frequency range from 3 kHz to 300 GHz, where the United States (US) controls through the Federal Communications Commission (FCC), ownership and purpose of use of given sets of frequencies. When a carrier is said to be providing her services within a given frequency range, it means this carrier has obtained (through payment) a license to operate within the allotted frequency range in a given area.

In 1985, the US FCC decided to make available several bands of this spectrum for use without the need for a license. Spread Spectrum (SS) technology was used as the modulation technology – to spread the radio waves over a wide range of frequencies making the signals less prone to interferences [9]. This unlicensed spectrum found applications in extending the capabilities of existing hardware/services offered by the licensed spectrum.

2.1 IEEE802.11 Standards

In 1990, an IEEE committee called IEEE802.11 was set up to work on a standard to provide Wireless LAN services – by defining the over-the-air (OTA) interface between an access point and a wireless client, or between two or more wireless clients. By 1997, this standard was ready and published. It made use of the 2.4 GHz unlicensed spectrum, supporting a maximum data rate of 2 Mbps and channel bandwidth of 20 MHz. In a very short time, this data rate became too slow for many applications; the committee continued to work to improve the standard. The next standards released were the IEEE802.11a and IEEE802.11b. The former supported 54 Mbps data rate (due to OFDM as its modulation scheme) within a channel bandwidth of 20 MHz but an operating frequency of 5 GHz while IEEE802.11b supported 11 Mbps and operating on the 2.4 GHz spectrum. The IEEE802.11b standard was cheaper, covered more distance and could penetrate obstructions; hence, gained more popularity than the IEEE802.11a. By June 2003, another variant was released, IEEE802.11g; this was an improvement which combined the advantages of IEEE802.11a and IEEE802.11b. It supported maximum data rate of 54 Mbps but had an operating spectrum of 2.4 GHz. As the demand for higher data rates, number of devices connecting to access points and the need to access sophisticated services (such as interactive gaming and high-definition video streaming) increased, the IEEE802.11 WG was setup in 2007 to proffer solutions to the foreseen challenges. The target of this group was to increase the data rate of operations under the 5 GHz bands to 1 Gbps shared by devices connected to an access point while able to support 500 Mbps for a single link. The second target was to achieve single-link data rate of up to 1 Gbps in 60GHz spectrum. However, another variant, IEEE802.11n was released by October 2009. IEEE802.11n was developed to operate at both 2.4 and 5 GHz spectrum bands. It supports wider channel bandwidth up to 40 MHz, uses OFDM and multiple antenna techniques (MIMO) – offering up to 600 Mbps data rate. In response to the target for very high throughput in the Gigabit class, in January 2013, a new amendment to WLAN standards was approved – IEEE802.11ad (Wi-Gig). This standard was designed to operate at 60 GHz; however, it had a feature which enabled the connected devices transition between the 60 band to the 2.4 and 5GHz spectrum bands. This ensured constant connectivity using the best conditions. The IEEE802.11ad supports up to 7 Gbps but is easily obstructed by water, walls and other factors; hence is most applicable for room use. Furthermore, another WLAN standard, IEEE802.11ac (Gigabit Wi-Fi), was released in January 2014 – supporting up to 7 Gbps within the 5 GHz spectrum band. This standard uses OFDM for its modulation and supports flexible channel assignments adding bandwidths of 80 and 160 MHz to the previously existing bandwidths. It also supports smart antenna techniques, such as MU-MIMO (Multi-user MIMO) and also Transmit Beamforming technology. Table 35.1 below gives a summary of the IEEE802.11 Wireless LAN standards till date.

Table 35.1

Summary of IEEE802.11 standards

	802.11	**802.11a**	**802.11b**	**802.11g**	**802.11n**	**802.11ad**	**802.11ac**
Year	1997	1999	1999	2003	2009	2013	2014
Frequency	2.4 GHz	5 GHz	2.4 GHz	2.4 GHz	2.4, 5 GHz	60 GHz	5 GHz
Data rate	2 Mb/s	54 Mb/s	11 Mb/s	54 Mb/s	600 Mb/s	7 Gb/s	7 Gb/s
Modulation	DSSS, FHSS	OFDM	DSSS	DSSS, OFDM	OFDM	SC, Low power SC, OFDM	OFDM
Channel BW	20 MHz	20 MHz	20 MHz	20 MHz	20, 40 MHz	2.16 GHz	20, 40, 80, 160 MHz
Adv antenna technology	N/A	N/A	N/A	N/A	MIMO	Adaptive Beamform-ing	MU-MIMO, Beamfor-ming

2.2 Bluetooth

In 1998, the Bluetooth Special Interest Group was formed with the aim of developing a standard to allow pairing of devices for the purpose of data transfer and sharing. The first standard was released in 1999 and several improvements have followed in subsequent years. Like some Wi-Fi standards, Bluetooth operates in the 2.4 GHz frequency band but transfers data over shorter distances (100 m). It engages FHSS as its modulation technology at 1,600 hops/s. It was intended for personal area networks but is starting to fit into more sophisticated applications such as sensors for health and in-vehicle systems [10]. In 2011, enhancements called Bluetooth Smart and Bluetooth Smart Ready were introduced.

2.3 Radio Frequency Identification (RFID)

An RFID is a wireless device with two components: a tag and a reader. The reader emits and receives data and identity information through radio waves from the tag. RFID tags can either be passive (powered by readers) or active (powered by batteries). Being subject to local regulations, RFID also operates on four major unlicensed frequency bands: 125–148 kHz, 13.56 MHz, 915 MHz and 2.45 MHz.

The use of unlicensed spectrum by these reviewed technologies and others has led to several applications in industrial and medical equipment, inventory systems, remotely-controlled car door openers or garage door openers, wireless keyboards and very many others. Therefore, devices using unlicensed spectrum keeps increasing as innovators come up with new use cases. Also, CEA research found that of all installed number of tablets/smartphones with cellular capabilities, only about half of the owners subscribe (pay) for cellular internet connectivity [11]. Today, as the IoT ecosystem expands to Internet of Everything (IoE), through increasing number of communicating devices, processes, people and data, the unlicensed spectrum cannot but play the vital role as the backbone through which bits of information are transmitted from one device to another.

However, it is obvious that majority of these technologies rely on spectrum bands within the Low Frequency (LF) and a bit of Super High Frequency (SHF) bands. Due to this growing vast majority, existing bandwidths have become insufficient. Therefore, researchers are beginning to consider the Millimeter Wave (mmwave) bands i.e. the 30–300 GHz spectrum, not only for wider bandwidth availability but gigabit speed for mobile broadband connectivity. The IEEE802.11ad standard operating at 60 GHz frequency, already presents some of the potentials of this spectrum with a 2.16 GHz bandwidth and up to 7 GHz data rate.

3 Millimeter Wave (MMWAVE) Technology

The mmwave frequencies are actually a part of the frequencies referred to as microwave frequencies; they represent frequencies further into microwave frequencies. As mentioned earlier, the mmwave frequencies are within the 30–300 GHz frequency bands, although, the industry considers mmwave frequencies to be from 10 GHz [12]. Due to the high frequencies, wider bandwidths are available resulting in multi-gigabit speeds. However, as frequency increases, received power drops unless offset by an increase in a combination of transmit power, transmit antenna gain and receive antenna gain. In other words, the high frequencies consequentially result in shorter wavelengths, therefore, shorter range capabilities. Mmwave propagation also faces challenges such as shadowing, in NLOS applications. Taking 60 GHz as an example, Fig. 35.3 is a plot of the free space pathloss in dB, showing increasing pathloss as the range increases.

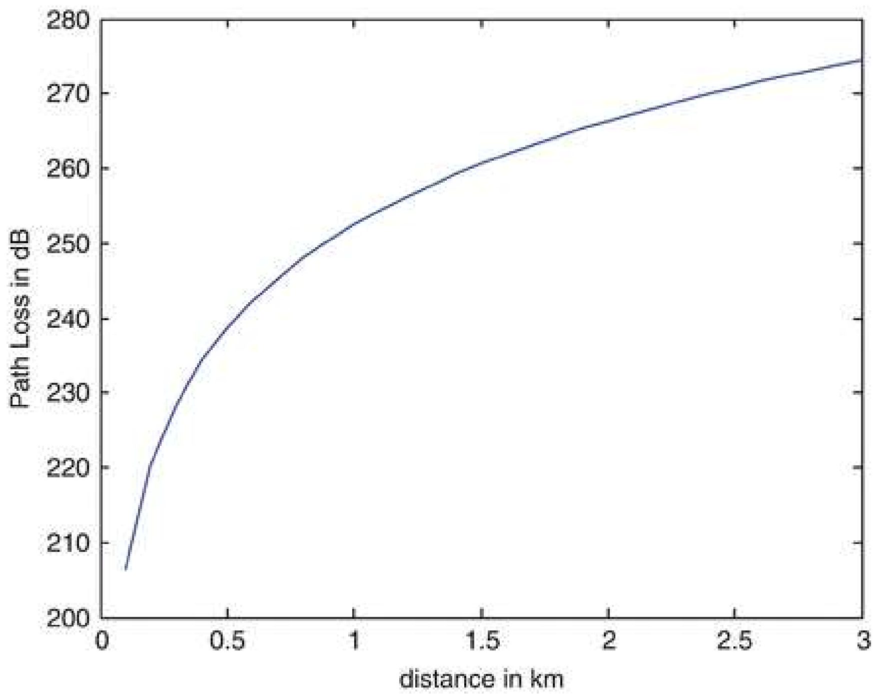

Fig. 35.3

Free space pathloss at 60 GHz

It is a common myth that propagation at mmwave frequencies suffers severe attenuation due to rainfall and the atmosphere (oxygen) but experiments in real-life scenarios have shown that neither of these factors significantly affects propagation at certain mmwave frequencies. Also, with advancements in IC technology – enabling smaller antenna elements for operations in the mmwave frequency bands coupled with high gain and steerable antennas at the mobile and access points/base station [13], mmwave technology is able to support kilometres of range. The shorter wavelengths also enable advanced antenna techniques such as Massive MIMO and adaptive Beamforming. With these technologies, mmwave has great potentials in radio astronomy, mobile communications and wireless backhaul, satellite-satellite link, and other applications [14].

There is also ongoing research in implementing a fully integrated mm-wave overlay system over the existing cellular system [15].

3.1 Performance at MMWAVE Frequencies

The following frequency bands have been identified and analyzed extensively to be suitable for adoption to deliver multi-gigabit data rates offering up to multi- gigabits in bandwidth too [12, 14, 16, 17]: 23, 28, 38, 40, 46, 47, 49, and 60 GHz and E-band frequencies (70, 80 and 90 GHz). Some of these bands have been studied to obtain some propagation characteristics.

In [14], the authors identified potential mmwave frequency bands and also presented their respective available bandwidths. The 60 GHz band is said to be available worldwide, with 5 GHz bandwidth common to several countries. However, it suffers about 20 dB/km pathloss due to the atmosphere. At 70 GHz (E-band frequency), light rain causes 1 dB/km attenuation while heavy rain yields 10 dB/km attenuation. In [12, 17], studies were carried out on 28 and 73 GHz bands, for a cell size of 200 m in a densely populated urban environment, and transmitters were situated at rooftops of up to five stories high buildings. It was observed that at 73 GHz, heavy rainfall yielded 2 dB attenuation while 28 GHz bands yielded 1.4 dB attenuation. It was also observed in [16] that atmospheric absorption has no significant effect on 28 and 38 GHz frequency signals within the 200 m cell size. Penetration losses were also observed: they were seen to be way higher for outdoor propagation than indoors, hence the need for access points for effectual handoffs into buildings. At 73 GHz, a symbol rate of 1.536 Gsym/s was obtained with peak data rate of 15.7 Gbps using MIMO.

4 Conclusion

Mmwave technology has been proven by researchers to be a viable and potential solution to enhance capacity and data rate for full support of the IoT ecosystem and future mobile broadband needs. The size of bandwidth future communications require is domiciled at these high frequency bands. With appropriate supporting technologies, the flaws of mmwave frequencies can be circumvented. The strength of mmwave frequencies has been authenticated by the introduction of IEEE802.11ad.

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Cite this paper as:

Oshin O., Oni O., Atayero A., Oshin B. (2015) Leveraging MMWAVE Technology for Mobile Broadband/Internet of Things. In: Yang GC., Ao SI., Gelman L. (eds) Transactions on Engineering Technologies. Springer, Dordrecht

- DOI https://doi.org/10.1007/978-94-017-9804-4_35
- Publisher Name Springer, Dordrecht
- Print ISBN 978-94-017-9803-7
- Online ISBN 978-94-017-9804-4
- eBook Packages Engineering