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5G Wireless Communications for Future Internet of Things: The Need for Free-Space Optical/Visible Light Communication Technology

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Abstract: *IoT networks have some important characteristics. Some key requirements of the IoT are low device cost, low deployment cost, high energy efficiency, high security and privacy, and support for a large number of devices. The LED-based OWC systems have all the great features required to support the IoT. The key technologies currently used for IoT connectivity are Zigbee, Bluetooth Low Energy (BLE), and WiFi. ZigBee is a low-cost, low-power, wireless mesh network standard that has been widely used for IoT applications. The Internet of Things (IoT) based on the tactile internet will also be an essential part of the 5G communication systems. Accordingly, 5G wireless networks will face numerous challenges in supporting the extensive verities of heterogeneous networks and in satisfying the mentioned service-quality-related parameters. Optical wireless communication (OWC), along with many other wireless technologies, is a promising candidate for serving the demands of 5G communication systems*

Keywords: 5G; IoT; Heterogeneous Networks; Optical Wireless Communication; FSO

I. INTRODUCTION

The Internet of Things (IoT) is transforming businesses and peoples' lives and will continue to ignite innovations in the future. It is expected that we will progress to tens of billions of connected devices globally over the next decade¹ that will generate multi-trillion dollars of economic value [2] across many markets forming the foundation of an interconnected world—or the Internet of Everything. In this vision of a connected world, cellular technologies will play a pivotal role – and they already have; 1G and 2G networks connected people via voice, and 3G and 4G extended connectivity to the mobile Internet with fast mobile broadband services as show in Fig.1

There are already more connected things than people in the world. Analyst firm Gartner reported that about 8.4 billion IoT devices were in use in 2017, up 31 percent from 2016, and this will likely reach 20.4 billion by 2020 [3] Another leading analyst firm, IDC, put worldwide spending on IoT at \$772.5 billion in 2018 -- up nearly 15 percent on the \$674 billion spent in 2017. IDC predicts that total spending will hit \$1 trillion in 2020 and \$1.1 trillion in 2021[4]

Today's IoT devices are connected on a wide variety of wireless technologies that might roughly fall into four classes of connectivity technologies: wired, short to mid-range wireless (from Bluetooth to mesh networking), long-range wireless (including cellular and Low Power Wide Area networking (LPWA)), and satellite. Within each class

are numerous specific technologies and standards. Another way to consider the IoT technology classes is by dividing them into short-range and wide-area connectivity segments. The former is typically enabled by unlicensed radio technologies, such as Wi-Fi, Bluetooth, ZigBee, and Z-wave. The latter consists of devices powered by cellular technologies (GSM, LTE, and 5G) as well as unlicensed low-power technologies, such as Sigfox, and Lora. These technologies offer different benefits and use cases. For this paper, the focus remains on the wireless cellular technologies of the global Third Generation Partnership Project (3GPP) standards, and in particular the foundation of 4G LTE for the future of 5G and the massive IoT.

To be clear, “massive IoT” refers to the tens of billions of devices, objects, and machines that require ubiquitous connectivity, whether mobile, nomadic, or stationary. To reach the massive scale as defined by 3GPP would mean at least one million devices per kilometer (km). Also, the mobile networks must efficiently support the simplest devices communicating infrequently that are ultra-energy efficient for the long term with ten-plus years’ battery life. However, the massive IoT does not have to wait for 5G scale deployments for success. 4G technology is supporting the massive IoT today.

According to the Ericsson Mobility Report - Q4 2018, there will be approximately 400 million IoT devices with cellular connections at the end of 2016 and that number is projected to reach 1.5 billion in 2022, or around 70 percent of the wide-area category. In 2018, mobile phone connections were surpassed in numbers by IoT devices [5] This growth is due to increased industry focus and 3GPP standardization of cellular IoT technologies.

Cellular IoT connections benefit from enhancements in provisioning, device management, and service enablement. Perhaps even more significantly, cellular networks also offer ubiquitous coverage, and unparalleled levels of reliability, security, and performance required by the most demanding IoT applications. 3GPP technologies such as 4G Long Term Evolution (LTE) can provide wide-area IoT connectivity—LTE is the most widely deployed and fastest-growing wireless technology with 3.7 billion connections worldwide at the end of 2018.6 With 637 LTE commercial networks7 worldwide as of April 2019, LTE will continue to expand its’ coverage and connections over the next decade forming the foundation for the next generation of wireless technology – 5G.

Fig.1 History of Cellular Technology

Fig. 2 5G Mobile Phone

II. IOT OVERVIEW

IoT, initially referred to as Machine-to-Machine (M2M), represents one of the key growth opportunities for telecommunication service providers and enterprises of various sizes in the next decade. IoT represents all devices that are connected to the internet and can communicate with other connected devices through wireless networks and embedded sensors, so it has an expanded market from M2M that has evolved over time and with technology development. That evolution will continue; whereas 4G has been driven by device proliferation and dynamic information access, 5G will be driven largely by IoT applications, a wide range of IoT use cases, Massive IoT (MIOT) deployment as well as more advanced solutions that may be categorized as Critical IoT. Fig.3 displays the applications for both M-IoT and Critical IoT technology and the differing requirements that are satisfied by each.

Fig. 3 Differing Requirements for Massive and Critical IoT Applications [14]

As the name Massive IoT suggests, 5G technology will enable a connected world numbering many billions of IoT devices. For example, research from Business Insider projects more than 64 billion IoT devices by 2025, up

from about 10 billion in 2018, and 9 billion in 2011[15]. The massive IoT is further demonstrated by Cisco predicts that by 2022 there will be 14.6 billion machine-to-machine IoT connections as demonstrated in Fig.4

Fig. 4 Global M2M Connection Growth.

III. 5G AND IOT GROWTH

With 5G deployments starting in 2019, the mobile ecosystem is becoming even larger, and more widespread, and extensive. Momentum is building in many markets as service providers accelerate their plans for a 5G rollout. In 2024, Ericsson projects that 5G will reach 40 percent population coverage and 1.5 billion subscriptions, making it the fastest generation ever to be rolled out on a global scale. This is driven by new, innovative solutions that reuse existing infrastructure and available spectrum. In parallel to the 5G rollout, cellular IoT is passing new milestones on its way to becoming the technology of choice for wide-area IoT applications. Boosted by strong uptake in North-East Asia, Ericsson predicts that cellular IoT connections are set to pass the 4 billion mark by 2024 [16] As explained in the Introduction, the IoT will comprise numerous technologies, including wireless technologies. This paper focuses largely on wireless Cellular IoT (C-IoT).

5G roll-outs provide mobility innovation and new levels of fixed/mobile convergence that will be impactful in driving the IoT market. Cisco forecasts that by 2022, 22 percent of global Internet traffic will come from mobile (cellular) networks (up from 12 percent in 2017); also by 2022, about 3 percent of global mobile devices/connections will be 5G-capable and nearly 12 percent of global mobile traffic will come from 5G [17]. Mobile carriers from around the world are beginning to introduce trial and commercial 5G networks with large-scale 5G deployments beginning in 2020, when mobile spectrum, standards, profitable business plans, and other operational issues are more fully developed. As of May 2019, there were commercial launches of 8 networks worldwide offering 3GPP standardized 5G technology, according to research firm TeleGeography [18] That number is anticipated to grow to about 25 commercial 5G networks worldwide by the end of 2019 [19]

5G mobile devices and connections will be over 3 percent of 12.3 billion global mobile devices and connections by 2022 – meaning over 422 million devices will be 5G capable. Nearly twelve percent of global mobile traffic will be on 5G cellular connectivity by 2022 generating 21 GB of traffic per month [20]

5G wireless communication is expected to offer high data rates and improved quality of service, and therefore IoT needs to be implemented in 5G architecture. FSO communication is the key technology that can offer high-capacity communication performance and therefore is the best choice for wireless communications for satisfying the fullest capabilities of 5G expectations offering 1 Gb/s or more speeds. The performance and coverage area of IoT will also be improved with high-speed FSO communication when 5G features are implemented in IoT. The requirements of IoT such as sensing data, processing, and connectivity can all be satisfied for IoT devices' signaling, security, omnipresent direction, power consumption, and bandwidth [5]. Techniques like device-to-device and M2M communications are useful to understand how IoT works as discussed in [5]. 5G, the next generation for mobile system technology using high data broadcast within the latest mobile operating system, provides high-resolution bidirectional connectivity. Visible light communication (VLC) technology can offer very high data rate communication using off-the-shelf LEDs as transmitters and avalanche photodetectors as receivers. How VLC and specifically Li-Fi (equivalent of Wi-Fi using light and VLC communication) can be integrated for IoT as shown in Fig.5

Fig.5 OWC networks for the 5G and IoT platforms [1]

IV. DRIVERS

IoT is the new game-changer for businesses and individuals and is considered to be the fourth industrial revolution by experts and scientists [21]. However, a revolution is often triggered by the rise and demand for certain driving factors. Similarly, IoT and its development are also backed by certain key components. Thus, if organizations want to prosper with IoT, they need to consider who and what is driving IoT and its innovation.

Fig. 6 IoT Defined [22]

Market drivers are the underlying forces and trends that make markets develop and grow. What are the drivers for the IoT? What are the trends that are impacting the mobile industry and also changing and expanding the IoT?

The drivers and trends that are contributing to the development of the IoT market defined in this whitepaper include 3GPP standards; expanded internet connectivity; high mobile adoption; low-cost sensors; large IoT investments; global application trends; the emergence of new mobile technologies; growing importance of automation and big data knowledge; Artificial Intelligence (AI) and Machine Learning (ML); Edge Computing and the Cloud; more use cases across vertical domains; security assurance; IPv6; and Open Source for 5G (Fig.7).

Fig. 7 IoT Drivers and Trends.

V. INTEGRATING HIGH BANDWIDTH FIBER WITH 5G AND INTERNET OF THINGS

The tremendous growth in connections and network traffic requires building infrastructure that can fulfill the upcoming demands on capacity and latency, both of which are essentials in high data rate wireless communications. Sensors embedded in devices and infrastructure will demand 5G wireless communication systems to integrate effectively [11]. 5G mobile networks will be needed to support IoT to connect potentially more devices with high bandwidth. 5G wireless networks will use fiber for backhaul and front haul to connect cell sites to the mobile control backbone. To fulfill the requirements of both 5G and IoT, an optical network as the backbone for the transport of those networks will be required to satisfy the high bandwidth and very low latency demands. The main emphasis is that micro data centers are integrated into 5G towers by fiber, which offers high capacity data transfer benefits [8]. The network accesses closer to the individual users, along city streets, in buildings, and everywhere in between can be possible using VLC technology, especially developing Li-Fi, which will serve as the conventional Wi-Fi except operating at visible wavelength. The flexibility and high bandwidth offered by VLC and Li-Fi are discussed in detail in another chapter. Furthermore, 5G across macro sites, in-building, and within small cells and integration with IoT are all possible using VLC and Li-Fi technologies.

TABLE I

Comparison of the performance metrics in various OWC technologies [13]

Issue	VLC	LiFi	OCC	FSO
Communication topology	Unidirectional or Bidirectional	Must be directional	Unidirectional	Unidirectional or Bidirectional
Communication Distance	20m	10m	60m	Greater than 10,000km
Mobility support	Optional Indoors	Must	Option	NO
Environmental effect	Outdoors: Yes	Outdoors: Yes	No	Yes
Interference Level	Low	Low	Zero	Low
Data Rate	10Gbps using LED and 100 Gbps using L.D	10 Gbps using LED and 100 Gbps using L.D	55 Mbps	40.665 Gbps
Security	High	High	High	High

VI. SECURITY IN VISIBLE LIGHT COMMUNICATION SYSTEM

VLC is a promising wireless communication technology through which baseband signals are modulated by an LED or diode laser. This is becoming a significant alternative to radio-based wireless communication such as Wi-Fi, Bluetooth, and similar devices. Because of several features, VLC data transmission networks (the so-called Li-Fi) provide an attractive and superior alternative to traditional wireless techniques [1]. The directivity and high obstacle impermeability of optical signals offer a secure way to transmit data within a closed indoor environment to make it difficult to intercept from outside. The classic security of confidentiality, authenticity, and integrity still apply to address the VLC secure communication. The three basic classes of VLC devices are considered in this section: infrastructure, fixed, and mobile. The infrastructure includes data streaming integrated with room light; fixed includes PC, laptops, other desktop appliances like printers, projectors; and mobile includes smartphones [12]. The four aspects of VLC communication with infrastructure, fixed, and mobile classes can be expressed as availability, confidentiality, authenticity, and integrity. Each threat level should be considered for each communication scheme to identify the areas of the highest threat level. A qualitative threat characteristic is discussed in [3]: low, medium, and high, based on the communication scheme's physical characteristics. A

qualitative classification of data transmission range (R), power (P), and radiation angle for communication (A) between mobile, fixed, and infrastructure devices can define some of the secure communication parameters as follows:

Jamming (J): $J = R/P$, Snooping (S): $S = P \cdot A$, Data Modification (M): $M = J \cdot S = R \cdot A$

Jamming is directly proportional to the communication range and it is easier to introduce a concealed transmitting device for a longer range. Snooping is directly proportional to the transmission power and the radiation angle and therefore with a wider and more powerful transmission beam, it is easier to oversee the communication link. Finally, the data modification risk is estimated as a product of the risks of jamming and snooping. In [3], qualitative estimations are described as follows: the mobile-to-mobile range is considered low (~10 cm), the fixed-to-fixed and fixed-to-mobile range is medium (up to 1 m), and all communications with infrastructure are considered high range (up to 3 m). For power, it is low for mobile devices, medium for fixed, and high when infrastructure is the sender. For mobile and fixed devices, the radiation angle is typically 30–60 degrees and is high when infrastructure ambient lighting is used.

The greatest risk of violating VLC security arises with infrastructure communication [9]. For example, for non-line-of-sight (NLOS) channel and line-of-sight (LOS) communication with infrastructure, snooping with an unauthorized receiver may be easily introduced without being recognized. One possible scheme for introducing jamming into the VLC infrastructure channel for the attacker is to use both directed and non-directed light sources from NLOS or LOS paths using optical beamforming. In some instances, given the channel capacity limitation [6], a signal source with sufficient transmitting power will be able to saturate the channel obscuring the data source. In conclusion, VLC infrastructure is not free from its security issues, and VLC infrastructure is particularly prone to data security risks

VII. CONCLUSION

This work aims to provide a conclusive investigation of the latest progress in research on VLC, which can be used as part of 5G wireless communication systems. Generation (5G) networks. VLC possesses several prominent features to address the highly demanding 5G system requirements for high capacity, high data rate, high spectral efficiency, high energy efficiency, low battery consumption, and low latency. However, this prominent performance is limited by the imperfect reception, since the line of sight channel condition may not always exist in practice.

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