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Erratum

Format changes (various)

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Michael Love and Marwan Jamal

Introduction

The Internet of Things (IoT) is emerging as a primary enabler of the transformation to digital business services in today's economy (*Internet of Things*, 2016). IoT is a concept first attributed to Massachusetts Institute of Technology (MIT) Professor Kevin Ashton (Gabbai, n.d.) and can be defined as “a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” (ITU-T, 2012, p. 1). The “things” include a wide variety of digital devices that capture environmental and operational data from embedded sensors, transmit the data to a cloud platform, and permit users to use the data in a variety of ways as part of a business analytics approach to decision-making. In this sense, IoT is following a wider industry trend of harvesting data to create value as witnessed by the growth of companies like Google and Facebook.

However, adoption of IoT applications and services has not always been straightforward or predictable. Market surveys from the 2010-2012 timeframe estimated anywhere from 50 billion to 1 trillion IoT devices by 2020 (Nordrum, 2016). Current estimates are much more conservative. One survey estimated there were 7 billion IoT devices worldwide in 2018 and projects there will be 9.9 billion devices by 2020 (Lueth, 2018). These early estimates were way off due to a combination of technical, business, and social factors that required more time and effort in order to mature IoT business models and develop more use-cases (“IoT Decision Framework,” 2017). The first factor is attributed to advances in digital sensor and actuator technology. The second factor is attributed to the evolution of cloud and edge services. The third factor is related to advances in artificial intelligence and related services such as machine learning, natural language processing, and deep learning. The fourth factor is attributed to advancements in connectivity, specifically 5th Generation (5G) cellular services 5G services. Although 5G is still in its infancy, leaders need to understand the impacts that 5G will have on IoT projects. This paper will provide an overview of IoT architecture, an assessment of 5th generation (5G) telecommunications, and describe pertinent factors that leaders should consider when incorporating 5G services into IoT projects.

IoT Background and Reference Architecture

Early IoT architecture was built on the premise of Radio Frequency Identification (RFID) tagging to track and locate objects. This type of architecture was introduced to enable automated inventory and supply-chain tracking in a manner that eliminated the need for manual input. Companies such as Wal-Mart relied heavily on RFID technology to reduce warehouse inventories and speed up supply transactions. Over time, RFID technology evolved to incorporate digital sensors and devices that track and locate objects over the Internet. In today's business world, IoT plays a significant role as an enabler of the digital economy. One study estimated the revenue in 2019 for commercial IoT services at \$456 Billion with projected growth to \$1.4 Trillion in 2024 (“Commercial Internet of Things Benchmark,” n.d.) while another study estimated global IoT

revenue over \$840 Billion worldwide with similar growth patterns over the next 6 years (“Global internet of things (IoT),” 2018).

Reference architectures vary across the industry but all essentially seek to describe the ecosystem that consists of data sensors & actuators, platforms & gateways, communication channels, back-end infrastructure and services, and front-end applications and services. The Institute of Electrical and Electronics Engineers (IEEE) developed a three-tiered reference architecture that separates the architecture by: 1) sensing, 2) network and data communications, and 3) applications (Minerva, Biru, & Rotondi, 2015). 5G services support the second tier, networking and data communications, and serve as the transport layer that connects the raw data collected from sensors to the applications that enable data analysis and decision-making. *Figure 1* shows a depiction of the IoT reference architecture:

Figure 1: IEEE IoT Reference Model

5th Generation (5G) Cellular Telecommunications

The adoption of mobile cellular communications over the past two decades has increased dramatically while costs to install, operate, and maintain cellular technologies have steadily gone down. This growth can be attributed to innovation along three axes: cellular infrastructure, device hardware, and increased services. From 2000-2010, adoption rates of cell phone use in the U.S. grew from 62-82%. During that timeframe, new cellular technologies were introduced, starting with 3G data services in the early 2000’s and 4G/LTE services from 2009-2012. The advances in telecommunications were matched by improvements in battery life, design, and rich new features for end-devices. By 2011, cell phone use in the U.S. was reported at 83% and smart phone adoption was 35%. Those percentages increased to 95% for cell phone use and 77% for smart phone users in 2018 (“Demographics of Mobile Device Ownership and Adoption in the United States | Pew Research Center,” 2018).

5G cellular telecommunications represents the next leap in technology innovation for cellular services. Cellular service providers have a dependency on the electromagnetic spectrum that is managed through licenses for specific frequency bands. 5G has been engineered to operate in both existing and new frequency ranges. In the U.S., these frequency ranges are known as

Range I (450MHz-6GHz) and Range II (24-52GHz). 5G will also use larger frequency bands to transmit data for users, providing upwards of 100MHz per channel while 4G currently uses up to 20MHz per channel. These large channels are aided by an evolution in multiple input-multiple-output (MIMO) technology that will allow users to send and receive larger data at higher capacity as compared to previous cell technologies. This gives 5G the capacity for 10-100 times more bandwidth than 4G while using substantially less power and reducing latency to 1 millisecond or less. 5G will also support a host of additional advances in cell technology such as improved beam forming, spectrum efficiency up to 5 bits per second/Hz, and network slicing. Network slicing allows carriers to apportion bandwidth to subscribers and provide tiered service levels, thus providing price-points for different service levels. Network slicing will also improve service level agreements between customers and providers, as cell service has traditionally been classified as *best effort*. Best effort service treats all users and devices equally and is determined by characteristics such as distance from cell towers, local interference, and density of users on the tower and is primarily a by-product of limitation factors associated with mobile communications. With 5G, service providers will be able to guarantee services on par with wired telecommunications.

One primary limitation factor with cell technology has been the electromagnetic spectrum. 5G technology advances have shown the potential to increase bandwidth by using higher range frequencies. However, the trade-off for using new frequency ranges will require service providers to deploy substantially more cell sites. This is due to wave propagation properties inherent in the electromagnetic spectrum. As frequencies increase in the electromagnetic spectrum, the wave lengths shorten and are less capable to penetrate buildings and other solid objects. Therefore, 5G service operating in the Range II spectrum will require substantially more cell sites to cover the same area as 4G and earlier cellular technologies. A study by the Defense Innovation Board (DIB) (Medin & Louie, 2019) assessed global 5G frequency adoption and concluded that a majority of countries are investing in 5G Band I capabilities. The DIB study also recommended that the U.S. and Department of Defense (DoD) prioritize investments in 5G Band I capabilities over millimeter wave frequencies.

Combining 5G and IoT

From a service provider perspective, IoT represents an entirely new user demographic. Studies have shown that cellular user growth began to plateau by 2015 with the transition from 3G to 4G/LTE services. According to one study, growth in worldwide mobile phone users will increase marginally from 4.15 billion to a projected 4.68 billion in 2020. This represents an average yearly growth of 3.2% over existing 4G/LTE networks (“Number of mobile phone users worldwide 2015-2020 | Statista,” n.d.). However, IoT represents an entirely new class of user where one customer can potentially have multiple to hundreds of devices on the 5G network. This new infrastructure has the potential to exponentially increase the total number of IoT and mobile cellular devices on the network.

There are also several challenges involved with integrating 5G into IoT. The first are increased infrastructure demands. In order to achieve the maximum benefits of high bandwidth, low latency and superior performance, an entirely new grid of cell sites and access units must be installed. 5G services with millimeter wave technology operate at significantly shorter distances than previous generations of cell service, so more access points must be installed. Service providers can use existing infrastructure with lower frequencies in order to transition sites from

4G/LTE to 5G in order to gain some 5G capability without the full investment in millimeter wave frequencies. A second challenge is with malware and intrusion attacks. Smart phones that use 3G/4G/LTE services have typically experienced malware and intrusion attacks at a significantly lower level than other devices that communicate with the Internet due to non-IP based networking protocols supporting transport services. 5G, however, is an IP-based network technology that will expose 5G connected devices to common IP-based malware and intrusion risks such as denial-of-service (DOS and DDOS) and intrusion attacks. A third challenge is with standardized security and encryption of data from end-devices. Software and hardware solutions exist but have not been standardized across all carriers, hardware platforms or software applications. The larger challenge with standardization involves interoperability. In order for 5G to work seamlessly across carriers with device agnostic hardware and compatible software, a holistic approach should be considered. Hardware compatibility will determine interoperability between sensors, platforms and gateways.

Two primary hardware considerations are the type of sensor and type of encryption. Radio spectrum, hardware compatibility, and software standards each play an important role in supporting the 5G ecosystem. For example, 5G can operate over numerous frequency bands that require different radios and antennas for communication. Each hardware device will require radios and antennas to operate on frequency bands that are used by specific wireless carriers. In addition, software compatibility will be governed by 5G standards as well as industry partnerships. 5G standards are currently still being developed. The current standards developed through 3GPP provide a start for 5G deployment but still require additional input in order to account for all the challenges described here.

Recommendations for DoD

DoD Chief Information Officer (2016) provided a report on recommendations for IoT that cited uses for DoD fuel depots, smart buildings, executive vehicles, and battlefield situational awareness. Though this report did not address 5G specifically, it did signify the need for DoD to address IoT risks, some of which are common between IoT and 5G. For example, the report identified the “proprietary nature and isolation” of legacy sensors as limitations from attack. The DoD could choose to adopt proprietary technologies and maintain isolation of sensors in a modernized IoT context but doing so will have repercussions in terms of access to commercial telecommunications services and interoperability with standardized IoT platforms. A Government Accountability Office (GAO) report (2017) addressed security risks associated with IoT but did not address 5G telecommunications specifically. A number of risks identified in the report such as limited encryption, poor security in device design, and expansion of attack surface have implications that also pertain to 5G. In the future, it is important that reports like these address 5G telecommunications as a component of the IoT ecosystem. Senior leaders must understand the trade-offs between risks and capabilities in emerging transport technologies such as 5G in order to better understand IOT services.

The Defense Innovation Board study (2019) highlights several recommendations for the DoD that have impacts on 5G and IoT. First, the study points out that 5G has the potential to eliminate the need for separate local area and wide area network architectures by integrating both into a 5G wireless network architecture. Doing so will eliminate layers of networking that add significant cost, complexity, and latency to DoD networks. Lower latency will also allow the DoD to invest more in autonomous and remotely monitored systems, especially systems that require time-sensitive decision making. The DIB report highlighted hypersonic weapons and hypersonic

defenses as examples. The DoD can also increase efficiencies in supply and logistics operations through capabilities that monitor supply-chain operations from production to delivery in near real-time.

Conclusion

IoT devices and 5G cellular technology each offer benefits and opportunities to businesses and the DoD. By themselves, each will offer advances over existing legacy technologies. 5G will provide more bandwidth, lower latency, broader spectrum options, lower power requirements leading to longer battery times, improved service reliability, and latent security improvements. The challenges will be significant startup costs for new infrastructure, radios and access points, competition for new and existing licensed frequencies, current limits on millimeter wave technology in terms of range versus throughput, uncertainty of new standards, and interoperability of end-user products. IoT investments require thoughtful planning in order to provide continuous data packets from the sensor to the cloud. A number of existing technologies currently support IoT deployments but each has limitations with interoperability, security, and standardization. 5G, once standardized by 3GPP, will enable a common infrastructure that supports millions of devices securely at speeds previously restricted to wired communications and at extremely low latencies.

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