**Understanding Technology Fragmentation in the IoT Market: Past, Present, and Future**

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We are currently standing on the brink of what many call the next industrial revolution, which promises us enormous economic and societal benefits by empowering ubiquitously connected objects, locations, and processes. The underlying technology trend to interconnect our surrounding physical objects (or, “things”), make them discoverable and addressable, as well as integrate them with the Internet infrastructure is commonly referred to as the Internet of Things (IoT). Located at the intersection of sensory, communication, networking, data storage, and information processing technologies, the IoT has the potential to produce a new wave of technological innovation and is expected to create over one trillion GBP of value-add by 2020.

The realm of the IoT is inherently reliant on the instrumental machine-to-machine (M2M) communications paradigm, which enables automated and autonomous devices (such as sensors, actuators, robots, and smart meters) to interact with each other, as well as with the Internet, while requiring minimal human involvement. As traditional voice service revenues continue to shrink, mobile network operators are increasingly interested in the M2M-powered applications to bridge in the growing revenue gap. Across such applications, M2M allows a device capture a certain event and communicate it through a network, or via another device, to an application, which may interpret this captured event and trigger an actuation based on it.

Early forms of M2M connectivity trace back to industrial supervisory control and data acquisition (SCADA) systems of 1980s, all being highly isolated and proprietary connectivity islands. Along the way of its rapid development, the IoT/M2M has embraced the legacy Radio Frequency Identification (RFID) technology (1980-…), as well as Wireless Sensor and Actuator Network (WSAN) technology (1990-…). Cheaper and more scalable connectivity, efficient cloud-based mass device management, as well as a plethora of devices with varying cost, performance, and power have all become the more recent catalysts of the IoT acceleration in the years that followed (2009-…).

Already today, the range of M2M applications is extremely broad, from wearable fitness trackers to connected cars, spanning the industries of utilities, transportation, healthcare, consumer electronics, and many others. However, we are only beginning to witness the true explosive growth of the IoT, with 10 billion M2M devices connected presently and 24 to 50 billion total connections expected within the following 5 years, as maintained by Cisco, Ericsson, and GSMA. Over the following decade, we may thus see our everyday furniture, food containers, and even paper documents accessing the Internet.

However, historical segmentation of the IoT markets, further plagued by the long-accepted paradigm of point technology solutions, hampers operator's flexibility, slows innovation, and makes it difficult to control costs. Consequently, the IoT of today is an unnecessarily complex and potentially vulnerable heterogeneous ecosystem, which embodies diverse connectivity between various types of networks across multiple communication technologies (such as ZigBee, WirelessHART, 6LoWPAN, legacy WiFi and Bluetooth, ISA100.11a, MiWi, BACnet, Z-Wave, etc.). The pressing challenge to construct a holistic connectivity infrastructure requires us to make radical changes to how M2M systems are built, deployed, maintained, and used.

While numerous legacy wired and wireless technologies were indeed helpful in creating a fertile soil for early IoT deployments, it has not been long before we as community confirmed many of them to be close to unsuitable in practice. A painful recent example is ZigBee equipment implementing the IEEE 802.15.4 standard together with the technical amendments ratified by the IEEE and the IETF. Low transmission powers of ZigBee radios led to very limited communication ranges and, consequently, to complex multi-hop network topologies in case of large-area applications. Such installations required higher densities of powered repeaters and gateways, which caused (i) excessive power consumption with batteries needing replacement every 1-2 years, (ii) poor reliability with hours of outage, and (iii) high maintenance costs.

The recent design efforts by IEEE 802.15.4e, IETF ROLL, and 6TiSCH have indeed been able to somewhat improve the multi-hop operations by tightly synchronizing the entire mesh network at virtually zero energy expenses, thus alleviating the battery drainage problem. The problem of short range, however, persists; and so does the problem of low reliability if lengthy outages under some operating conditions cannot be tolerated. While ZigBee may still be employed for some time, especially given that the control community has adopted much of its working principles within their de-facto standards of WirelessHART, ISA100.11a, etc., the major companies have already realized the very limited future potential of ZigBee-like solutions.

As the result, the field of IoT connectivity is now at a turning point with many promising radio technologies emerging as true M2M connectivity contenders: Low Power Wide Area (LPWA) networks (e.g., used by Sigfox); Low Power WiFi (e.g., used by Gainspan); and 4G/5G improvements for M2M systems (a.k.a. Cellular M2M, including NB-IoT). While there still remains a great deal of uncertainty regarding the viable business models, these afterthought solutions may be significantly more attractive for the prospective IoT deployments from both availability and reliability points of view.

In this study, our target is to comprehensively characterize these new M2M radio solutions as we carefully review the reasons, the current state, and the perspectives of the unprecedented technology fragmentation in the today's IoT market. Recently, we have completed an extensive research into the feasibility of the emerging radio technologies for M2M connectivity with unique system-level simulations as well as supportive analysis, and in this work we aim to systematically share our most essential learning. We firmly believe that these powerful solutions may potentially overcome the deficiencies in how M2M data is collected, stored, accessed, and shared. Ultimately, they may allow for a decisive transformation of the global M2M industry – allowing it to overcome its plaguing fragmentation, and thus enable a truly dynamic and sustainable next-generation IoT ecosystem.

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