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Review

Technologies and challenges in developing Machine-to-Machine applications: A survey

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ABSTRACT

Machine-to-Machine (M2M) communication is evolving day by day and expected to create an ecosystem of billions of electronic devices. This new class of communicating devices have very diverse traffic characteristics and pose unique challenges. The essence of this paper is to provide a survey of state-of-the-art communication technologies, architectures and development platforms, and explore their potential to support the growth of M2M applications. Thus, we review the networking techniques including wide area networks, grasping LTE, NB-IoT, EC-GSM-IoT, 5G, and other proprietary networks including SigFox, Lora, and Weightless. Furthermore the short-range capillary networks are also reviewed according to the facilities they provide for application development. Available application development protocols, cloud platforms, open source frameworks and middleware frameworks are discussed for facilitating M2M application development process. Altogether the investigation provides a broad perspective to a user for application development choices. In each section and in the end current challenges are discussed for future research work.

1. Introduction

With the advent of the Internet of Things (IoT), the future is predicted by having billions of machines, for example, sensors, home appliances, video cameras, and smart objects shall be connected to the Internet (Osseiran et al., 2014). These machines communicate with each other without human intervention, therefore such form of data communication is termed as machine-to-machine communication (M2M) (3GPP, 2012). M2M is essential for many smart city applications, i.e., intelligent transportation, smart homes, smart parking, and waste management to name a few (Pellicer et al., 2013). Different M2M applications have great potential to offer in many domains of life, whether that is health care, education, agriculture, automotive, and businesses (3rd Generation Partnership Project, 2012). The current growth of machine-to-machine (M2M) applications such as smart cities (Pellicer et al., 2013), smart community (Horten, 2014), smart healthcare (Amendola, 2014), smart grid (Fadlullah, 2011), smart building, and surveillance (Datta et al., 2014), etc., has resulted in a high density of devices posing a unique challenge to the capacity of current communication networks (Jermyn et al., 2015).

For developing applications there exists many considerations that should be taken into account when implementing IoT and M2M technologies and every aspect must be carefully considered, such as selection of suitable network connection, application development protocols, cloud platforms and available middleware frameworks. Each aspect has different properties ranging from cost and power consumption challenges. Considering the nature of devices and use cases for M2M communications, there are a number of requirements which need to be supported. The most fundamental issue is the support of extremely low power operations because the machines could be battery-less energy harvesting devices (Enocean) or battery powered sensors installed on bridges or high rise buildings at inaccessible locations (Cho et al., 2012), hence recharging or replacing a device's battery is very hard. At the same time, the device should remain functional for a number of years. Besides requirement of energy efficiency, interoperability is a big challenge in developing M2M applications because the devices are produced by various vendors and lack of standardization makes it extremely hard to enable interaction among the devices. Devices may communicate data in different formats, implement different application protocols and interface, that creates a challenge to streamline a smooth communication between different devices since there is no common middleware framework for M2M applications.

With respect to connectivity, there exist many telecommunication

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technologies which may provide a foundation for M2M communications and might be considered as the viable solutions with certain enhancements. In this context, 3rd Generation Partnership Project (3GPP) has proposed the amendments for M2M (3rd Generation Partnership Project, 2012) in its future releases and the Institute of Electrical and Electronics Engineers (IEEE) working group 802.11ah facilitates development of communication architecture feasible for M2M applications. In addition to existing standards by IEEE, commonly Enocean (Enocean), Bluetooth (Smart Bluetooth Low Energy,), ZigBee (Taylor and Alliance, 2011), and Thread (Wireless Thread) are usually employed in M2M devices network establishment. To address the interoperability issue, *oneM2M* (https://www.onem2m.org) was formed in 2012 by seven Standard Development Organizations (SDOs) from different countries to develop a widely accepted standard specification. *oneM2M* aims to develop a technology agnostic M2M architecture and specifications for the development of interoperable applications. These technologies address various issues of M2M communications and provide only partial solutions in terms of energy efficiency, coverage, reliability, scalability, and interoperability.

For application development whole scenario of available solutions should be present to user under current open issues. Till now there exist no survey that could grasp all the aspects of application development starting from network connectivity to middleware frameworks. This paper contributes towards fulfilling this gap and aims to provide the user with complete scope of available development technologies and elaborate existing challenges. The structure of this paper is as follows. Section 2 discusses the previous related survey papers and mentions the contribution of this paper, followed by Section 3 that reviews existing wide-area networks including LTE, NB-IoT, EC-GSM-IoT, and 5 G for M2M communications. Section 4 discusses the availability of proprietary networks infrastructure for M2M. In Section 5, a comprehensive review of state-of-the-art short-range communication techniques for M2M are presented. Section 6 presents available open source frameworks, cloud platforms, application development protocols, and middleware frameworks, those facilitate M2M application development. In Section 7 existing M2M communications challenges are discussed. Finally, conclusions are presented in Section 8.

2. Related work

M2M communications has been reviewed extensively in the literature (Matson et al., 2011; Pereira and Aguiar, 2014; Ghavimi and Chen, 2015; Biral, February et al., 2015; Condoluci et al., 2015; Dawy et al., 2016; Palattella et al., 2016; Andreevy et al., 2015). In Matson et al. (2011), infrastructure-based M2M is discussed, with the focus on artificial-intelligence based communication devices. European Telecommunication Standard Institute (ETSI) architecture is discussed with regards to mobile devices including smartphones in Pereira and Aguiar (2014). Existing work in this domain also discusses scenarios of smartphones acting as gateways and how data aggregation is performed in M2M networking architecture. In Ghavimi and Chen (2015), the authors discussed M2M deployment scenarios for a LTE/LTE-A network. The article highlighted the challenges faced by the M2M communications such as random channel access, congestion and diverse random access overload control in LTE-A networks. The problems related to resource allocation and their solutions are presented in Biral (February et al. (2015), which also discusses issues with current cellular networks to accommodate M2M communications. Communication options besides 3GPP standardization are discussed in Condoluci et al. (2015), the literature explores 5 G networks for MTC and discusses the design options for femtocells. Cellular networks are a promising communication feature for M2M networks, which is explored in the literature (Dawy et al., 2016). The article (Palattella et al., 2016) investigate in detail the perspective of 5 G technologies for the IoT, it covers the topic by considering both the standardization and technological aspects. With respect to the latest publications, the work (Andreevy et al., 2015) reviews the market-changing effect of the IoT, that is based on the architecture of M2M communications to amalgamate ubiquitous of various actuators, sensors, and smart meters over a wide range of businesses. Also, the paper reviews most of the prominent existing M2M radio technologies, while keeping attention towards the 3GPP cellular network. However, all of these studies only investigate the communication side technologies such as infrastructure-based network for M2M application which is not sufficient information source for application development.

The core objective of this paper is to provide complete scope of M2M application development, starting from available connectivity options that includes a comprehensive survey of all the variants of both infrastructure-based (Fantacci et al., 2014) including the latest NB-IoT, EC-GSM-IoT, other popular proprietary networks such as SigFox, Lora and Weightless and infrastructure-less (short-range) potential communication network techniques by considering both M2M communications and device characteristics. Furthermore, current challenges of application development, available protocols, cloud platforms, middleware frameworks and open source frameworks for applications are discussed. As there exists many challenges, each one is also discussed in a separate section, these include open issues such as energy efficiency, scalability, cost, portability, data handling and security in different communication technologies. The investigation in this paper can help in making the right choice for a typical use-case of M2M application. This is the first paper that provides an extensive survey on M2M communications architectures, technologies, protocols, and application development.

3. Standard Wide Area Networks

Communication is the most fundamental challenge in M2M interaction to realize cyber-physical systems. Machines may have very diverse requirements in terms of bandwidth, energy efficiency, coverage, mobility, and reliability. There are various existing technologies which address these issues and many new specialized wireless technologies have been developed for low power small devices or machines. For our discussion in this paper, infrastructure refers to those networks that are deployed in wide areas using fixed base station nodes and centralized server. In this section, we discuss the infrastructure-based technologies that include Long Term Evolution (LTE) based on cellular communication architecture, Narrowband IoT (NB-IoT), Enhanced Coverage EGPRS (EC-GSM-IoT), and Worldwide Interoperability for Microwave Access (WiMAX). Table 1 lists the specification of other latest LTE releases for MTC.

3.1. LTE cellular networks

Cellular networks are one of most commonly available wireless networks for communication between human-to-human and computer-to-computer. The current 4th generation of 3GPP project based on cellular architecture is known as LTE-A (3GPP LTE) that supports very high data rates at downlink and offers flexible radio resource management schemes. LTE is recently enhanced to LTE-Advanced (LTE-A) and LTE-MTC (LTE-M), and the latter enhancement tries to support M2M. LTE-M has more advantage over cellular IoT that works over reframed 200 kHz band of GSM but does not support shared spectrum. LTE-M can work on the 200 kHz band reframed from GSM and operates over a shared spectrum of LTE architecture. These latest LTE releases are capable of operating on the normal architecture of LTE and offering services to M2M devices through upgrading the baseband software on the base stations. The enhanced version of LTE supports both time division duplex (TDD) and frequency division duplex (FDD) modes using 1 ms of subframe structure. By using a short subframe, latency can be minimized significantly for real-time critical applications. The high-level LTE network architecture comprises of the following components: 1) User Equipment (UE), 2) Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and 3)