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Network layer inter-operation of Device-to-Device communication technologies in Internet of Things (IoT)

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ABSTRACT

The goal of the Internet of Things (IoT) is to create an integrated ecosystem for devices to communicate over the Internet. To achieve this goal, efficient inter-operation is needed among Device to Device (D2D) communication technologies that make up the ecosystem. Currently, these technologies operate in vertical silos with different protocols. We explore the challenges associated with the integration and interoperability of these D2D technologies by focusing on network layer functions such as addressing, routing, mobility, security and resource optimization. We identify the limitations of the current TCP/IP architecture for D2D communication in the IoT environment. We also discuss some of the limitations of the 6LoWPAN architecture and *describe how it has been adopted for D2D communication.* Finally, we present solutions to address the limitations we have identified for the network layer functions as applicable to D2D communication in the IoT environment.

1. Introduction

Over the years, communication between humans as well as communication between human and devices has evolved a lot. The ubiquitous deployment and use of devices of all kinds have made device to device communication increasingly important. Today, various types of devices are either attached to humans (for interaction or monitoring) or operate on their own (for control or automation). These devices are personal electronics, home appliances, health monitors, smart vehicles, industrial sensors and actuators.

The Internet of Things (IoT) ecosystem is a platform that enables these uniquely identifiable devices with Internet connectivity capability, so that they can transmit information between each other and with humans. It is a complex, vast and rapidly expanding ecosystem that enables global seamless ubiquitous intercommunication between devices.

Seamless ubiquitous connectivity between devices has been fueled by the need for easy access to data, which can be processed and utilized to provide improved services for applications such as smart grid, health monitoring, home area networking, building automation and vehicular communication and telecommunication [1]. Thus, almost all devices ranging from health monitors, sensors, industrial automation devices, vehicles and home appliances now possess Internet connectivity capability which has increased the adoption and proliferation of the IoT. Several forecasts predict that by 2020, the number of everyday objects/devices (things) that will be connected to the Internet will reach about 50 billion [2]. Fig. 1 shows how the number of connected devices continues to rise significantly in comparison with the world's population. The increase started with the proliferation of consumer devices (e.g., smartphones, tablets, laptops, TVs and home appliances). However, over time, most connected devices deployed will be in industrial and public sectors (e.g., RFID tags, soil monitoring sensors, building sensors, street lights, and smart meters).

The strong interest in IoT began with the emergence of smart phones, which have been used to create new applications/services that are generating new revenue streams. Subsequently, more device manufacturers got motivated to develop even more smart devices to support emerging applications and services such as mobile-money and mobile crowd-sensing (where data is collected for decision and policy making). The IoT also promotes new business models for telecommunications (e.g., pay per use) [1]. Semantics and intelligent sensing coupled with learning algorithms can also be used to develop new applications. For example, a smart device can use semantics to infer user's intentions and

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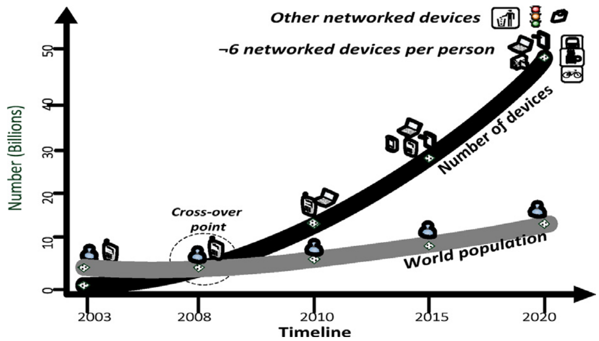

Fig. 1. Growth of connected devices [2].

provide services based on the inferences without user's involvement. Such an application can be provided by a smart home entertainment system that has the ability to determine which service(s) to provide according to the user's preferences.

New paradigms stimulating the rapid deployment of IoT include Software Defined Networking (SDN), Information Centric Networking (ICN), Network Functionality Virtualization (NFV), Bluetooth Low Energy (BLE), Nearby Field Communication (NFC), and Wireless Fidelity-direct (WiFi-direct). Fog networks and big data analytics are also emerging concepts advancing the adoption of IoT [1].

Many IoT applications involve the pervasive aggregation of data from devices in order to manage the physical world [3]. Predictive analytics and real-time optimization models can be applied to such data for the creation of the wealth of knowledge that will enable a "smart world", which is the main goal of the IoT [1]. However, this data collection and analysis are possible if the data can be accessed over the Internet. To achieve this goal, interconnectivity and interoperability are required among different types of heterogeneous devices that co-exist in the IoT ecosystem. Most IoT devices are expected to be self-configuring and adaptive thereby reducing human intervention. As such, Device-to-Device (D2D) communication is expected to be an intrinsic part of the IoT ecosystem. Typically, D2D communication involves direct short-range communication between devices without the support of a network infrastructure (e.g., base stations or access points). In D2D communication, devices co-operate to exchange information among each other via multi-hop transmissions. Most applications/service in the IoT ecosystem will be realized by D2D communication networks such as the Digital Enhanced Cordless Telecommunications Ultra Low Energy (DECT ULE), Zigbee, Bluetooth Low Energy (BLE), Power Line Communication (PLC), Radio Frequency Identification (RFID) and Near Field Communication (NFC) [4]. However, these are proprietary communication technology standards, which have existed in vertical silos. Besides, they were designed for applications that did not require Internet connectivity for devices.

Although D2D communication will be predominant in the IoT, yet much of the attention on D2D communication has focused primarily on the Long Term Evolution (LTE) cellular network. Cellular networks are a part of the IoT ecosystem, but most D2D communications will be carried out by devices such as sensors and actuators. Since diverse IP and non-IP technologies will co-exist in the IoT, it is vital to understand the integration challenges that need to be addressed at the network layer in order to enable seamless ubiquitous connectivity among D2D communication devices in the IoT.

Basically, the IoT ecosystem's platform can be divided into three levels namely, the sensing level (for data generation), communication level (for device connectivity and data transmission) and management level (for data collection, storage, processing and management) [5]. The sensing level includes mobile or stationary devices that can generate data in various formats while the communication level includes existing and emerging wired or wireless communication networks. At the management level, data collection, storage and analysis technologies are needed.

1.1. Main research contributions and organization of this work

With reference to the communication level and a focus on D2D communication in the IoT, (a) we highlight some inherent limitations of the current Internet-based protocol stack; (b) we provide some insight into the inter-operation issues, limitations of some D2D technologies including the adoption of IPv6 over Low power Wireless Personal Area Networks (6LoWPAN); (c) we identify some open issues of 6LoWPAN and recommend solutions for them; and (d) we present the challenges and solutions for network layer inter-operation protocols for D2D communications.

The remainder of this paper is organized as follows. Section 2 discusses the limitations of the TCP/IP architecture that makes its implementation on resource constrained D2D communication devices problematic. Section 3 focuses on inter-operation approaches, the adaptation of 6LoWPAN in some D2D technologies and its limitations. In Section 4, proposed solutions that address the network layer protocol challenges for D2D communications are presented. Finally, Section 5 concludes the paper.

2. Implementation challenges of the TCP/IP architecture for D2D communication in IoT

Generally, devices in any communication network use a set of rules (protocols) for data transmissions [6]. The TCP/IP architecture is the framework that underpins the communication rules within the Internet. It breaks down data transmission between any two devices into five functional layers, namely: the physical, data-link, network, transport and application layers. Many networking technologies have been developed based on these functional layers. As data moves between layers, extra framing and control data is added to the main data. Such additional information requires processing and thus incurs substantial processing power and memory capacity. However, most of the IoT devices cannot meet this requirement. In addition, D2D communication in the IoT is characterized by the heterogeneity and mobility of a plethora of devices. Thus, the ecosystem will have to be scalable to enable the reliable transmission of information between devices [7]. However, the TCP/IP protocols for the Internet are not designed to support the high level of scalability, high amount of traffic and mobility presented by the IoT ecosystem [7]. They are significantly limited in satisfying these new requirements [8].

In this section, we identify and discuss the design features of the TCP/IP architecture that make it difficult to implement on D2D communication devices in the IoT environment.

2.1. Limitations of the TCP/IP architecture for IoT

The TCP/IP protocol stack cannot enable optimized D2D communication in the IoT because of its built-in properties and operations such as:

2.1.1. TCP/IP protocol stack is heavyweight

The TCP/IP stack requires high bandwidth, processing power, battery power and memory. It needs resources such as sockets and buffers to achieve its goal. These resources, however, consume memory and battery power [9], which are limited resources on highly constrained IoT devices [10]. Usually, a TCP/IP stack stores any packet received in a network buffer before it is accessed by the upper layer protocol. Likewise, any data to be sent is also placed in such buffers before transmission. IoT devices may not have enough