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Machine-to-Machine Communication and Research Challenges: A Survey

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Abstract In recent years, with the proliferation of machine-to-machine (M2M) applications into industries, M2M communications has attracted researchers in this prominent field of research. M2M communications has emerged to achieve ubiquitous communication among intelligent devices to monitor applications with little or no human intervention. The autonomous characteristics of M2M communications, which decrease the cost for human resource significantly, give impetus for the research of M2M communications in both industry and academic areas. This paper focuses on state-of-the-art M2M technologies, future challenges and envisioned opportunities. We have divided M2M communications into two categories, namely, capillary M2M and cellular M2M. In this paper, we provide a comprehensive study of M2M communications, including different categories and their challenges. This paper also investigates into the standards defined by the standardization organizations, such as IEEE, IETF, 3GPP for the multiplicity of M2M

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communications. At last, we analyze and discuss the key research challenges in M2M application designs.

Keywords Machine-to-machine communications · Capillary M2M · Cellular M2M · Wireless technology · Architecture · Gateway

1 Introduction

In the past few years, great progress has been made in information and communication technology (ICT), which has accelerated the development of numerous innovative applications. It is widely predicted that the number of embedded devices will increase tremendously and finally they will connect to the Internet as the internet of things (IoT) [1–3]. The rise of M2M communications is a key technology to realize it. M2M communications refer to a large number of low-power and low-cost embedded devices sharing information and making collaborative decisions with little or no human intervention. M2M communications have brought great potential opportunities for designing real-time monitoring and remote control applications, such as smart grid [4], e-health [5], transportation management [6], industrial automation [7], surveillance [8] and so on. M2M-enabled devices are expected to grow from 200 million in 2014 to tens of billions by 2020 [9].

The future goal of M2M communications is that an arbitrary smart device can communicate with any other smart device at anytime and anywhere. European Telecommunications Standards Institute (ETSI) has already proposed the high-level architecture for M2M communications [10]. This architecture consists of three domains: M2M *devices domain, Network domain,* and *Application domain*, as shown in Fig. 1. There are different embedded levels of intelligence in M2M devices domain, connectivity of which are usually provided by an ad hoc network. A huge number of convergent points such as network coordinators exist in *Network domain* in order to ensure the access between Internet and the heterogeneous access networks. The *Application domain* provides various control or management services.

M2M communications can be classified into two categories based on communication technologies used; capillary M2M communications [12] and cellular M2M communications [13]. Capillary M2M communications refer to mostly embedded, low-power, and low-cost design with short-range communication systems. While insights from academic research on wireless sensor networks (WSNs) can be used, capillary M2M communications are dominated by industry-driven standardized low-power solutions. In cellular M2M communications, long-distance transmission technologies and licensed spectrum are used.

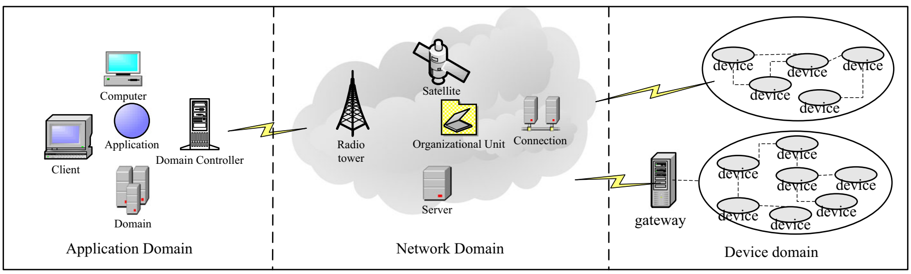

Fig. 1 High-level architecture proposed by ETSI for M2M application support [11]

For better penetration of M2M devices into the cellular market, it is envisaged that specific optimization for cellular M2M communications will be introduced in LTE-A [14].

In order to bring IoT and M2M communications into reality, it is critically significant to understand the current technologies and standardization activities in this area. Studies in these fields have emerged in recent years [15–18]. The IP-based standards for IoT has been reviewed and the challenges associated with each protocol stack are analyzed in [19]. The features and challenges of M2M communications in telecommunication networks are presented in [14, 20–22]. The work in [23] introduced the architecture and the standards of home M2M networks, and a practical example for home area M2M communications can be found in [11]. Unlike previous literatures, which focuses on one specific type of M2M communications and the research issues associated with it, we illustrate M2M communications on a broader scale by presenting the overall picture of M2M communications, in terms of different types of M2M communications, the latest standards and current research challenges.

In this paper we present a survey of different categories of M2M communications and recent development progress that have been made in M2M communications area. We first highlight the distinguishing features of M2M devices and M2M communications architecture defined by ETSI. Two categories of M2M communications, including capillary M2M communications and cellular M2M communications, are discussed in detail. The current standards of capillary M2M communications defined by IEEE and IETF, and the enhancement architecture of cellular M2M communications defined by 3GPP [24] are also presented, respectively. Then, we review the recent technologies of M2M communications with a focus on analyzing future research directions. Our aim is to provide a better understanding of current research and the progress till date in this field of research.

2 M2M Communications

The concept of M2M communication has changed over time. Initially, M2M communication referred merely to a set of sensors, which collect the information and transmit this information to a specific application. Nowadays, the meaning of M2M communications has become much broader. Any machine or device that can generate data or captures an event and is capable of transmitting this information to any other device via a wireless or wired communication network can be called M2M-enabled device and this process is called M2M communication. In addition, machines can make decision collaborative without human intervention. M2M communications are characterized by the autonomous characteristics, which provide comprehensive solutions to various monitoring and control applications. The distributed autonomous M2M devices are tiny and low cost computing devices, including sensors, actuators and other communication devices, and may operate in hash environment. Ubiquitous connectivity among M2M devices needs to be provided to support seamlessly communication among heterogeneous networks for M2M applications and services.

M2M devices should be equipped with many functions, which could be categorized as follows:

Data collection: A group of augmented sensors or RFIDs collects the raw data and generates the information.

Data processing: There should be a platform module responsible for analyzing and processing the data. After this procedure, only meaningful data will be transmitted.

Specific function: Unlike sensor nodes, M2M devices are usually actuators with their specific functions rather than just collecting the surrounding raw data and information.

Certain storage: The space of storage is determined by the proposed functionality of the device.

Distinctive address: Each M2M device will be assigned an inimitable identifier.

Information transceiver: This partition will connect M2M devices with the external world.

Power-supply system: Device can be powered either through a hardwired connection or battery supply.

Some of the major characteristics of M2M communications are as follows:

Multitude and variety: Owing to a large number of M2M devices and their enormously diverse Quality of Service (QoS) requirement, the huge amount of M2M traffic may lead the communication system overwhelmed. Meanwhile, the M2M traffic is usually sporadic and is device and application specific. These features bring unique challenges to the design of an efficient and reliable M2M system. Beside this, distinct address must be assigned to each device, which requires huge address space.

Self-organization: One of the main feature of M2MM2M communication is that the communication takes place with little or no human intervention. Thus, M2M devices are supposed to be self-sufficient which includes the capability of self-configuration, self-organization, self- healing, and self-management [23].

Reliability and robustness: Without humans' intervention, the failure of a M2M network element can propagate, which can lead to serious problems for the whole system. Moreover, due to the dynamic environment in which M2M devices work in, the robust feature of M2M communications has to be to ensure a reliable transmission.

Security and privacy: Highly sensitive and confidential data are handled by M2M network. However, it is difficult to detect network and system attacks because of the autonomous nature of M2M communications. Security vulnerabilities could result in privacy disclosure. An economical and convenient solution is required to ensure that M2M systems are secure.

In M2M communications, different access technologies and protocols are used to achieve ubiquitous connectivity among M2M devices with diverse QoS requirements, resulting in some unique characteristics, shown in Table 1.

3 Capillary M2M Communications

Capillary M2M communications refer to mostly embedded, low-power, and low-cost design with short-range communication systems. In capillary M2M communications, devices in one area are usually organized with a tree-topology or mesh network. Typically they are connected wirelessly but it is not necessary. And, the capillary network connects to a cellular network via a gateway. A simple architecture of capillary M2M communication is shown Fig. 2.

Capillary M2M communications system needs to fulfill the requirements to support large number of devices' interoperability with low power consumption, and handle burst and intermittent data transmission well in a high interference environment. These features need to be considered in the communication system design.

Table 1 The distinctive characteristics of M2M communications

Category	Features	Explanation
Device type	Full function device (FFD) and reduced function device (RFD)	FFD can serve as a leaf or the network coordinator and it can establish the communication link as a router RFD cannot act as a network coordinator. It can only become the end node of the network
Distribution type	Decentralized distribution	The intelligent devices in M2M communications can generate the data and determine when to start the communication
Transmission rate	Different among nodes	The transmission rates of different types of devices vary a lot. The selection of the relay requires an efficient design to provide reliable and low-latency data delivery
Processing ability	Memory utilization/processor speed/database or knowledgebase	The intelligent device can process, aggregate, and compute the data before transmitting. This meaningful data can be transmitted directly to the application in the end-server without going through a gateway
Communication technology	One communication from different wireless technologies	Automatic communication among different technologies, such as global system for mobile communication (GSM), WiFi, and bluetooth and so on, can be achieved with the help of multiple physical (PHY) layer and medium access control (MAC) layer protocols
Major metrics	Energy consumption/throughput/end-to-end delay	The growing complexity of devices leads to increasing the energy consumption tremendously, which makes the critical usage of energy become essential
QoS requirements	Reliability/latency/packet delivery ratio/security	The reliability becomes the important issue because the human will not take part in the conduct of operation

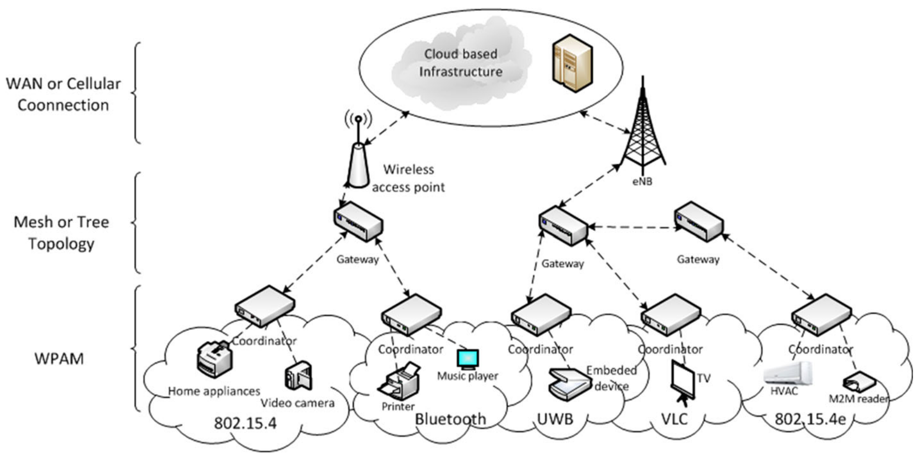

Fig. 2 A simple architecture of capillary M2M communication

3.1 Wireless Technologies for Capillary M2M Communications

Many factors have contributed in the rise of capillary M2M communications. For example, decreasing cost and increasing capabilities of sensors make the wireless sensor network (WSN) very common these days. In addition, some of the existing wireless communication systems can also be utilized in M2M communications. The popular communication technologies such as UWB [25], WiFi (IEEE 802.11) [26], Bluetooth [27] and ZigBee (IEEE 802.15.4) [28], can be used for connecting the intelligent appliances and gateways in capillary M2M networks. Another important factor is the emergence of more advanced softwares. For instance the software defined radio (SDR) [29] significantly improves the flexibility of wireless communication [30].

Currently, the IEEE 802.11 is one of the most popular wireless technology due to its support of high data rate, low cost and easy network deployment. However, with the rise of IoT and M2M communications, there are more and more competitors sharing the same spectrum. Since the increasing demand leads to high interference and low performance, technologies that can provide wireless local area access to support large-scale communication are in urgent need. Avoiding the crowded 2.4 GHz ISM bands, IEEE 802.11a uses the relatively unused 5 GHz, but the high carrier frequency results in a smaller effective range. Working at sub 1 GHz license-exempt bands gives the IEEE 802.11ah a significant advantage in providing large-coverage and low-power wireless connectivity to devices. Figure 3 illustrates the spectrum usage of IEEE 802.11a, and the 802.11ah following the US channelization standards [31]. IEEE 802.11ah can more easily penetrate through a wall as it operates at low frequency. Its coverage range can be up to 1 km covering more devices that can be reached within one-hop transmission [32]. Besides, in many countries the spectrum below 1 GHz is not fully utilized yet; thus devices operating with IEEE 802.11ah can work at a less congested frequency band. Moreover, enhancement has been made in the design of IEEE 802.11ah PHY and MAC layers to increase the system throughput, support large number of devices with low energy consumption and to improve

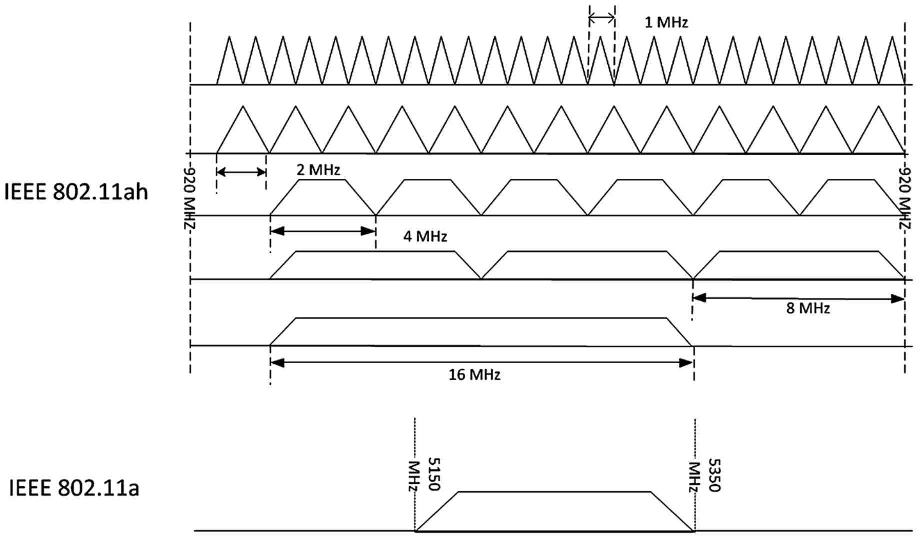

Fig. 3 Illustration of spectrum usage in IEEE 802.11a and 802.11ah

spectral efficiency [33]. These features make the IEEE 802.11ah a promising technology for M2M communications.

Visible light communication (VLC) [34] is another fast emerging technology that offers a large bandwidth and minimum electromagnetic interference. It can also achieve high data rate for short-range communications. These features of fast, safe, secure and no radio frequency radiation make the VLC another promising technology for M2M communications.

3.2 Standardization Activities of Capillary M2M Communications

To keep the installation simple and coverage seamless, many organizations are working to make standards for capillary M2M communications. A number of standards targeting to different protocol layers have been released. Here, we list the most popular ones as shown in Table 2.

IEEE makes enhancement for the PHY and MAC layers, which aim at enhancing the performances with respect to wireless communications, e.g., throughput and energy consumption, for M2M communications. Important features of IEEE 802.15.4 [35] include extremely low-power consumption techniques with low duty-cycle, collision avoidance using Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA) scheme and reservation of guaranteed time-slots. The IEEE 802.15.4e working group (WG) caters for enhancement on the IEEE 802.15.4 MAC protocol to make it suitable for industrial requirements. Channel hopping is used to mitigate interference and multipath fading, increase the network capacity and improve reliability. Other important features of IEEE 802.15.4e are the extremely low operation costs and technological simplicity without sacrificing the flexibility. Currently IEEE 802.11b also operates in the ISM band of 2.4 GHz, leading to interference from IEEE 802.15.4 [36]. Figure 4 shows the spectrum usage in IEEE 802.15.4 and 802.11b.

IETF makes effort to provide efficient M2M data management. IETF charters the 6LoWPAN (IPv6 over Low Power Wireless Personal Area Network) WG to standardize how to use IPv6 in IEEE 802.15.4 radios [37]. The features of 6LoWPAN are much different from previous link technologies such as WiFi or Ethernet. In 6LoWPAN, an adaptation layer can be built up with an IP-based architecture. 6LoWPAN is characterized by small packet size, low bandwidth, star and mesh topologies and large number of devices. The two major focuses of 6LoWPAN WG are to find out how to bring IPv6 datagrams into IEEE 802.15.4 frames and perform IPv6 neighbor discovery functions in an overlapping broadcast domain network [38]. As usual, fragmentation will be done in the adaptation layer due to much larger frame size from upper layer compared to the maximum

Table 2 Standards for capillary M2M at different protocol layer

Protocol layer	Standard
Application layer	COAP
Transport layer	UDP
Network layer	RPL
Adaptation layer	6LoWPAN
MAC layer	IEEE 802.15.4e
PHY layer	IEEE 802.15.4

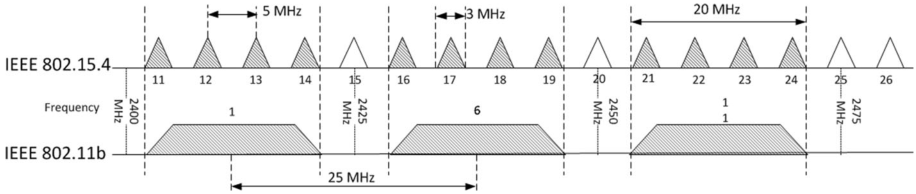

Fig. 4 Illustration of spectrum usage in IEEE 802.15.4 and 802.11b

packet size in the lower layer. Header compression is designed to avoid the overhead of data and reduce energy consumption.

In addition, routing over low-power and lossy links (ROLL) WG makes the necessary adaptations of IPv6 for network using IEEE 802.15.4. ROLL standardizes the IPv6 routing protocol for Low Power and Lossy Networks (RPL) [39, 40]. RPL is designed to support reliable and efficient interoperability among the devices from different domains of M2M networks. With the help of RPL, the network topology is formed in an optimized way given particular objective. RPL is designed to support applications across various scenarios, such as home automation, urban environment, industrial control, and building automations.

IETF also defines the Constrained Application Protocol (CoAP) [41], which allows small, embedded and power limited devices to communicate interactively over the Internet. The CoAP is an application layer protocol which translates to Hyper Text Transfer Protocol (HTTP) [42] to integrate with the web. The CoAP is an extremely important web protocol specialized to M2M communications. The IETF Constrained Restful environment (CoRE) WG [43] has done the major standardization work for this protocol.

4 Cellular M2M Communications

In cellular M2M communications, long-distance transmission technologies and licensed spectrum are used. Cellular based M2M communications have the advantage of better coverage and lower network deployment cost. However, existing cellular networks are designed for human-to-human (H2H) communications [44]; thus facilitating M2M communications into cellular networks creates diverse challenges.

4.1 Architectural Enhancements of Cellular M2M Communications

Although, there are many standards defined by different organizations, the 3GPP [45] is the leading organization which standardizes the network architecture for cellular M2M communications. One of major contributions of 3GPP in standardizing cellular M2M communications is that the introduction of Machine Type Communication (MTC) [46]. For cellular M2M communications, two additional network elements in LTE-A are the MTC device (MTCD) and MTC gateway (MTCG). The MTCG is an important part of M2M communications as it is responsible for allocating bandwidth to MTCDs. It also manages the power consumption among MTCDs. A MTC user means a legal entity that uses cellular terminals for M2M communications.

A simple architecture of cellular M2M communication is shown Fig. 5. The four stages of communications in MTCD-related transmissions are as follows:

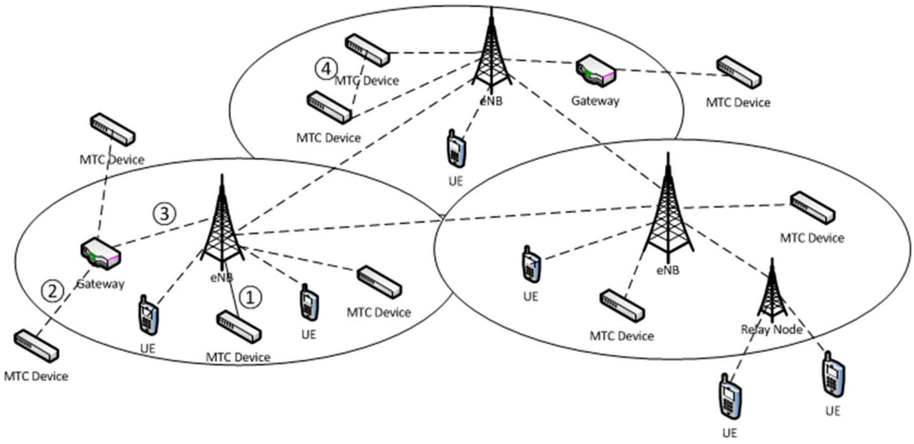

Fig. 5 A simple architecture of cellular M2M communication

Transmission between MTCD and eNB: The MTCDs use the licensed spectrum for direct communication with eNB. Therefore, MTCDs and UEs competes for this shared spectrum and it is also causes interference. Congestion is a big concern due to large number of devices joining the network. The eNB may overwhelm or even brake down due to huge amount of data transmission by MTCDs in case the cellular architecture is not well designed.

Transmission between MTCD and MTCG: The frame structure and the data rate of different MTCDs varies a lot. The MTCG usually comes with a certain computational capability, which aggregate and process the data sent by MTCDs. This prevents the eNB from becoming overwhelmed. For efficient data exchange, the MTCG can allocate bandwidth and power resource intelligently to MTCDs. The communication between MTCGs and MTCDs usually relay on the short-range communication technologies, such as ZigBee and Bluetooth.

Transmission between MTCG and eNB: The MTCG and eNB use licensed spectrum for communication. A bidirectional link is used for communication in this process. To minimize the interference during communication, Orthogonal and shared resource allocations techniques are proposed [47].

Peer-to-Peer (P2P) transmission between MTCDs: The communication technologies used in capillary M2M can also be applied to P2P communications, which will not cause interference to H2H communications.

4.2 Features of Cellular M2M communications in 3GPP

To avoid sophisticated hardware implementation, a promising solution is to make use of existing infrastructure of cellular networks. 3GPP has already developed the access class barring (ACB) and overload protection schemes to provide stable individual access to the eNB [48]. Some literatures also investigate other access control schemes to access the cellular channels for large number of MTCDs. 3GPP Release 10 [45] identifies the features required for cellular M2M communications, which includes low mobility, packet switching, addressing, time controlled and time tolerant, identifiers, congestion control and overload control, subscription control and security. Release 11 [49] and beyond makes improvements and enhancements on cellular M2M networks including the methods to support high-speed packet-switching, identify efficient addressing and messages routing. Some of the important features from Release 10 are as follows:

Low/No mobility: Since most MTCDs are static, the tracking mechanism can be made less complicated to save the mobility signaling power.

Time tolerant: Some MTC applications can tolerate latency of several milliseconds to several minutes [14]. Diverse QoS performance perplexes the design of radio resource allocation schemes.

Time controlled: The periods of reporting signal is predefined. The receiving and transmitting of MTCDs only take place within one access grant time interval (AGTI).

Small data transmission: Most MTCDs sporadically transmit small amount of data to eNB.

Group based MTC: By grouping multiple MTCDs with similar QoS performance requirements, only a few physical resource blocks are required to transmit them, thereby alleviating congestion and overload problem.

5 Research Challenges

M2M communications consist of large number of highly diverse devices resulting in many research challenges. In M2M communications, optimization of energy, total cost and reliability are some of the active research areas. There are many research problems which need to be thoroughly analyzed and solved to achieve an efficient, reliable, and robust M2M communication system. Some of the key research challenges are as follows:

5.1 Heterogeneous Network Design

M2M communications exchange data frequently between different networks such as WSNs, wireless personal area networks (WPAN) and cellular networks. This heterogeneity poses specific set of challenges that should be addressed for an efficient M2M communication system such as data acquisition and data exchange between different networks needs to be seamless. Till today, Internet is used as an intermediate network for the data exchange between different networks. For example, data collected by a node in a WSN cannot be passed directly to a terminal of a cellular network directly. It reaches to Internet via the sink node of WSN and then passed to the terminal of a cellular network. This way of data exchange reduces the M2M communication system efficiency. Today, hierarchical signal exchange is used among different networks and the heterogeneous networks should converge towards the architecture of a flat network in future to minimize the overhead of signaling. Another challenge in M2M communication system is the access control schemes as different networks use different schemes and require coordination among them. For example, scheduling is used in WSNs while access scheme of the cellular network is the random access control. These differences in the access control schemes need jointly optimized design of protocol stack for the coordination of time to access the channel among different networks.

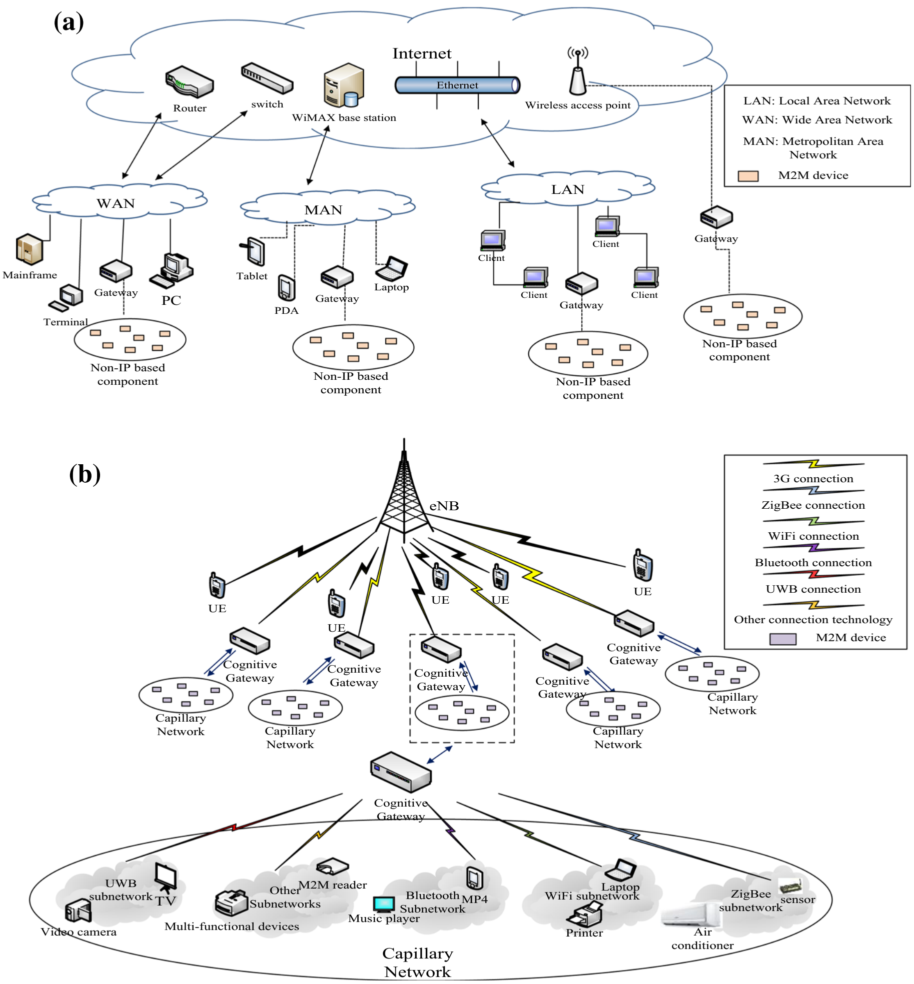

Fig. 6 Cognitive gateway architectures: **a** Networks with gateways that connect the Non-IP and IP based components; **b** networks with gateways that connect capillary and cellular M2M communications

5.2 Design of Cognitive Gateway

5.2.1 Networks with Gateways that Connect the Non-IP and IP Based Components

In order to remotely monitor and control the M2M devices, a secure and efficient way is to interconnect the M2M devices with IP-based network. Figure 6a shows the interoperability of M2M devices that is provided with the multiprotocol gateway. The gateways can provide secure, scalable, energy efficient, and reliable capabilities to a telecommunication network. It can also be used to efficiently bridge telecommunication networks with local connections, such as local area network (LAN), wide area network (WAN), and metropolitan area network (MAN). Conventional schemes that connect the Non-IP based devices with the external IP networks are not sufficient to provide robust, low-latency and reliable transmissions. Therefore, traditional proxy-type gateway cannot bridge different networks to achieve a direct communication as the internal networks still use the native protocols. This problem is solved with a rather traditional solution in which every internal node is assigned an IP address. This solution requires data fragmentation at the gateway due to diversity of the length of packets, especially with the utilization of the 6LoWPAN standards. Further research is required on M2M gateways in order to make them cost and energy efficient and has seamless connection between internal nodes and external networks.

5.2.2 Networks with Gateways that Connect Capillary and Cellular M2M Communications

Most of the M2M applications require data exchange between capillary and cellular M2M networks. For example, smart grid needs efficient and reliable data exchange between these two networks. Interoperability of devices and network convergence are highly required for these heterogeneous networks. In both capillary and cellular networks the frame structures and signaling schemes varies a lot, which perplexes the complexity of the design of the heterogeneous network. A cognitive gateway that is equipped to support multiple standards of wireless communication technologies can establish the communication link with the incompatible radio in an automatic manner. Therefore, it is required to connect these networks in a way which is flexible and scalable for their seamless operation. Figure 6b shows a gateway that connects capillary and cellular networks. A cognitive gateway improves throughput, extend the convergence and helps diverse devices to communicate smoothly between different networks. It also helps in providing in better access control and QoS management services [50]. Therefore, it is essential for a gateway to be robust and designed carefully in order to be integrated with capillary and cellular M2M network to achieve greater energy conservation and better system scalability.

5.3 Group Control

In cellular M2M networks, a large number of MTC devices having diverse requirements on Quality-of-Services need to get support from eNB. However, the structure of the current frame for LTE network is not well suited for small data transmission as it is designed for the transmissions of multimedia data with a large size with the goal of achieving high throughput. Therefore, allocating radio resource to M2M communications in LTE networks is a complex task. Group control [14] has been proposed, which provides an efficient solution to solve the random access and efficient allocation of radio resource for MTCDs in cellular M2M networks. However, further research needs to be done to explore optimal grouping which can save energy and cost.

5.4 Robust Connectivity

Due to the tremendous amount of M2M traffic, the uplink of M2M channel has a higher risk to become overloaded. Both WLAN and cellular network can serve as backhauls for WSNs. However, such backhauling opportunity is not always available and it needs smart data delivery schemes among heterogeneous systems.

In M2M communications, devices are usually operated in a dynamic and lossy environment. In other words, it comes with high interference and unreliable links. Another challenge is the intermittent connectivity, which leads to uncertainty for network management and communication delays. The duration of connection and transmission delay limit the data delivery ability during a connection opportunity. In order to achieve robust connectivity in M2M communications, we should have solutions to minimize the probability of collision and reduce communication delay. Thus, we need to find solutions to optimize node discovery process, and develop time critical MAC protocol and reliable routing protocol.

5.5 Limited Storage

Normally smart devices used in M2M communications are storage-constrained with a small buffer. Thus, packets may be easily dropped from devices. Meanwhile, in order to save power, some smart devices may break their wireless link connectivity when they do not need to transmit data. Therefore, initiating communication with the sensor nodes at an arbitrary time is difficult. With high probability, data will be lost if the connectivity is not built up on time. We have to improve the storing capabilities of smart nodes in an energy efficient manner. One way is to equip the smart node with the ability of data fusion and aggregation, which means pre-process the data in the smart node or smart sensor. In this way, nodes only need to store meaningful data. However, on the other hand, such ability might consume extra power.

5.6 Co-channel Interference

H2H and M2M communications share the time and frequency resources, which results in serious co-channel interference, degrading the QoS. This also brings the demand for efficient use of limited radio resources due to increasing number of M2M devices. Therefore, spectrum management becomes a major issue in realizing M2M communications. Cognitive radio technology that can reuse the licensed spectrum holds a promising solution for this problem. However, it may still bring interference to each other. Another important research topic is interference mitigation schemes to avoid or minimize the co-channel interference.

Besides, the unreliability of wireless channels adds more difficulty in minimizing the co-channel interference. Channel fading, shadowing and multipath fading, results in uncertainties of wireless channels to decrease the link reliability. In addition, MAC and routing protocols are usually designed without considering the uncertainties of the channel conditions. This is an another important challenge for M2M communications.

5.7 Realize Energy Efficiency

M2M communications have severe constrains in terms of energy, memory and computation ability. Smart devices are usually battery-powered and have to run complex computational processes. The computational complexity perplexes the energy depletion problem, and the replacement of tremendous number of batteries needs expensive logistics. Decreasing the expense of power consumption becomes a major headache in M2M communications. Several energy saving schemes have been proposed for M2M communications, e.g., compressing the transmission messages to save the transmission power, energy efficient routing protocols to reduce the overall transmission power, sleep mode to minimize energy consumption.

6 Conclusion

The effectiveness of M2M communications requires ubiquitous connectivity among M2M devices and efficient transmission of meaningful information between intelligent devices and applications. In the future, the M2M applications will become worldwide and an essential part of our life. However, to make these promises a reality, M2M communications need to successfully deal with various technological challenges. In this paper, we have provided a survey of recent M2M research and standardization activities, and highlighted the aforementioned challenges and future research directions foreseen.

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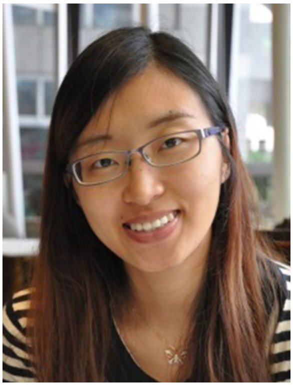

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