# State of the Art 3GPP M2M Communications toward Smart Grid

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## Abstract

Recent advances in wireless communications and electronics has enabled the development of machine-to-machine (M2M) communications. This communication paradigm has been expected as an automated control and report solution for smart grid. The smart grid enables customers and operators to utilize the collected usage information from a large number of meters with transceivers for efficiency and safety. In this paper, we introduce architecture, requirements and challenges of M2M communications for smart grid. We extract technical issues that should be resolved in M2M communications to support the smart grid via third-generation partnership project (3GPP) cellular networks. We then present the current state of the art of research results to deal with such issues. Finally, we outline the open research issues.


***Keywords:*** M2M communications, smart grid, 3GPP cellular network, features of M2M applications, research trend

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## 1. Introduction

Widespread use of mobile devices has enabled people to communicate with other people at any time and in any place [1]. Today, the appearance of gadgets and appliances with short-range transceivers extends the dimension of information and communication technologies to the communication with anything [1][2]. Machine-to-machine (M2M) is a technology for providing such communication between people and things, and between things themselves. In M2M communications, many machines exchange their information with each other with low cost, low effort, and low human interaction [3][4][5]. This information sharing increases machine intelligence, and then enhances efficiency in various applications, such as smart home appliances, fleet management tracking, healthcare, security and surveillance, and smart grid.

M2M communications have five general characteristics: *limited human control and interaction*, *the use of only packet switched networks*, *a potentially huge number of communicating M2M devices*, *low complexity and effort*, and *low traffic volumes per M2M device* [3][4]. Each application of M2M communication may have specific characteristics to fulfill its service requirements and features, e.g., low mobility for smart home appliances [4].

Smart grid is a major application where the characteristics of M2M communications can be fully utilized [6]. In the smart grid, electric grids with awareness assist utilities to produce, distribute, and consume power efficiently and intelligently [7]. To do this, the smart grid requires functionality, such as remote usage monitoring and reporting, two-way communications, remote supply control, and communications with individual meters. M2M communications can become solutions to control and manage a large number of electric grids located in a wide area via wireless infrastructures. M2M communications also can support smart meters for reporting accurate usage information of each electric grid to customers, energy distributors, and suppliers [6].

Recently, several researches have been done to utilize M2M communications in a smart grid [7][8][9]. They are based on a hierarchical network architecture, i.e., home area network (HAN), building area network (BAN), neighborhood area network (NAN), and wide area network (WAN). They introduce scenarios and requirements of M2M communication networks for smart grid applications. The work done in [7] and [8] explore the technical issues in HAN, and the work done in [9] present network planning algorithms for the efficient utilization of the limited radio resources in NAN. However, existing researches do not focus on the technical issues found in NAN and WAN, i.e., to manage and control the data transmitted from many HANs, as critical challenges in smart grids. We consider these research issues from various viewpoints (e.g., resource management, control, addressing, identification, etc.) in NAN and WAN.

For the wireless infrastructure of NAN and WAN in smart grid, the technologies of third-generation partnership project (3GPP) have taken attention due to its wide radio coverage and capacity to support an enormous number of devices. 3GPP introduces many technical requirements to facilitate M2M communications for smart grid via 3GPP networks [3][10].Thus, the following issues should be researched:

- Group based management need for a number of M2M devices.
- Optimal protocols between M2M devices and one or more M2M servers are required to connect communication links, exchange data, and authorize each other.

- Existing IP-addressing should be modified to communicate between M2M devices with private IP address and M2M servers with public IP address.
- A lack of M2M identifiers should be resolved by using identifiers within 3GPP system.
- Congestion controls of data traffic and control signaling in 3GPP user and control planes are required in wireless access and core networks.
- Management as traffic types, i.e., metering and management, is required.

In this paper, we introduce current such technical issues and research trends of M2M communications to provide smart grid service via 3GPP networks and present promising open research issues. The remainder of this paper is organized as follows. In section 2, we describe network architecture, requirements and challenges of M2M communications in a smart grid application. We discuss technical issues and research trends with future work to provide smart grid application using 3GPP M2M communications in section 3. Finally, we conclude the paper in section 4.

## 2. M2M Communications in a Smart Grid

Smart grid is one of the most popular applications of M2M communications. The smart grid increases the reliability of the entire power system and improves the quality of energy [11]. Individuals can reduce energy waste, industries can be stably supplied the energy with effective management for the power system, and nations can pursue green development by reducing the emission of green-house gases using the smart grid [6]. In order to achieve these advantages, all the entities in the smart grid applications should be able to interact smoothly by connections. First we describe the network architecture to support smart grids. Next, we introduce the appropriate technologies for each type of networks, and then, we map the network architecture to the 3GPP M2M communication model, which is our main interest. We then extract the smart grid requirements and the challenges when such requirements are fulfilled in M2M communication networks.

### 2.1 Network Architecture of Smart Grid using M2M Communications

Network for smart grid applications composes four functional entities: asset entity, data and control center, application entity, and distribution network as shown in **Fig. 1** [6]. Asset entities with smart meters that operate under gateways as concentrators measure information on consumption, demand, and quality of electricity. Gateways forward the data collected from the asset entities to the data and control center through communication networks. The data and control center manages the asset entities and the collected data and it interacts with the distribution network which is responsible for the management of power supply and delivery. In order to provide various smart grid services, the center also cooperates with the application entities, i.e., data recipient, bill entity, efficiency entity, and service provider.

M2M communications are utilized for exchanging data and for controlling messages between the functional entities of a smart grid. To enhance scalability and to provide various functions in each entity, hierarchical network architecture which consists of HAN, BAN, NAN, and WAN is considered [7]. Asset entity transmits its measured information to a gateway (or concentrator) via HAN. In order to forward the information to the data and control center, the gateways can build a NAN, and it can utilize a WAN. The data and control center is connected to the application entities or distribution network via public networks.

M2M communication technologies for HAN include Bluetooth (IEEE 802.15.1), Wi-Fi (IEEE 802.11), ZigBee (IEEE 802.15.4), and ultra wideband (UWB), which commonly have short-range connectivity and also incur low-cost [7]. Technologies for NAN and WAN that have long-range employ mobile communication technologies, i.e., 3GPP GSM, UMTS, LTE, WiMAX, etc. Several standard forums and organizations like, 3GPP, 3GPP2, IEEE, European telecommunications standards institute (ETSI) have surveyed M2M communication architectural models.

3GPP M2M communication architectural model consists of user equipment (UE) using machine type communication (MTC) application, MTC server, and 3GPP network entities involved in MTC [3][10]. **Fig. 1** shows the relation skip between a smart grid network and 3GPP M2M communication architectural model. The 3GPP M2M communication model covers three architecture models: direct model, indirect model, and hybrid model. In the direct model, the 3GPP operator provides direct communication where the MTC application directly connects to the operator network without the use of any MTC server. In the indirect model, the MTC server provider or 3GPP operator manages MTC communications. In the hybrid model, the data transmission in the user plan is used to the direct model, while the signaling in the control plan is used to the indirect model.

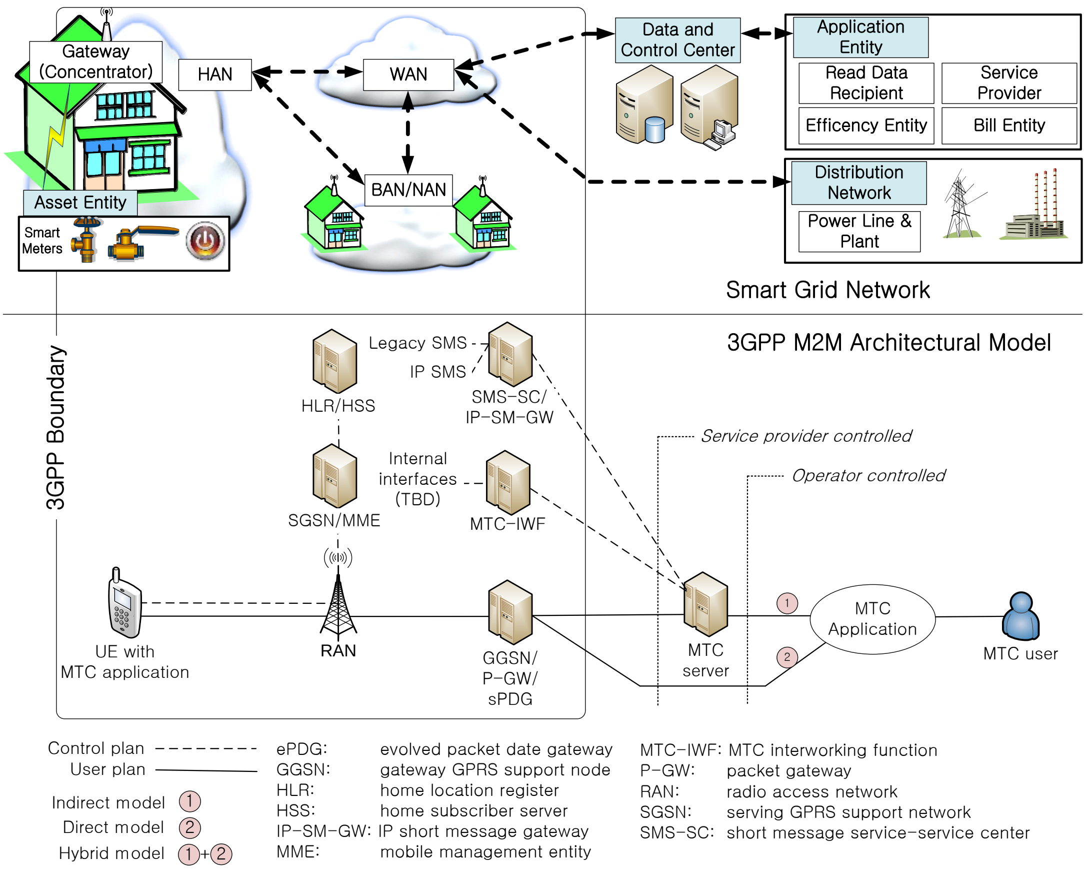


**Fig. 1.** Relation between smart grid network and 3GPP M2M architectural model

3GPP2 considers enhanced network systems with communication protocols for M2M applications, M2M communication adaptation, and wireless WAN [4]. IEEE 802.16 introduces basic and advanced system architecture model [5][12]. In the basic system architecture, IEEE 802.16 M2M devices can perform as aggregation points for non IEEE

802.16 M2M devices with different radio interfaces. In the advanced system architecture, IEEE 802.16 M2M devices can act as aggregation points for other IEEE 802.16 M2M devices. ETSI considers M2M system architecture with an M2M device domain, and a network & application domain [13]. An M2M device domain consists of M2M device, M2M area network, and M2M gateway. A network & application domain consists of access network, transport network, M2M core, M2M applications, network management functions, and M2M management functions.

## 2.2 Requirements for a Smart Grid

In order to extract the requirements of a smart grid, we first analyze the use cases of M2M communications in a smart grid and we categorize them into three parts: metered data monitoring, end-device management, and grid network management as **Table 1** [6]. Metered data monitoring is a set of use cases in which a smart grid server retrieves the information, such as consumption, demand, supply, and quality of power from the metering system. Use cases in end-device management category allow the control center of smart grid to manage a device or group of devices to improve network performance. The grid network management use cases focus on achieving effective generation, transmission, distribution, and consumption of the power in the entire grid network.

**Table 1.** Use cases of M2M communication in a smart grid

| Category | Use cases |
|---|---|
| Metered data monitoring | Obtain meter reading data |
| | Monitor power quality |
| End-device management | Facilitate demand-side response action |
| | Facilitate distributed generation action |
| | Enable or disable the end-devices of the smart grid system |
| Grid network management | Install, configure, and maintain smart grid system |
| | Manage the distribution network |
| | Manage the power grid efficiency |
| | Manage the outage data |
| | Interact with devices |

In order to support these use cases, entities in a smart grid should fulfill four requirements: remote monitoring and reporting, two-way communications, remote supply control, and communications with individual devices. Details of requirements are listed in **Table 2** [6].

**Table 2.** Requirements in the smart grid

| Requirements | Description |
|---|---|
| Remote monitoring and reporting | Metering systems in smart grid read the data of meters and provide the data to a designated smart grid server |
| Two-way communications | Metering systems retrieve the information about power quality, supply, demand, etc. and forward the data to a smart grid server. Smart grid server provides control, clock synchronization information to metering systems |
| Remote supply control | Smart grid server provides configurable parameters to metering systems to limit power supply |
| Communication with individual devices | Individual devices in home or building communicate with each other or the gateway to exchange energy management data |

## 2.3 Challenges of M2M Communications to Support a Smart Grid

M2M communications have different scenarios from existing mobile communications that provide human to human (H2H) services; a large number of M2M devices can communicate with M2M servers or other M2M devices without human control thus with low cost and effort. Besides, the challenges of M2M communications vary according to their applications [4]. The challenges of M2M communications are categorized and are listed in **Table 3**.

**Table 3.** Challenges of M2M communications [3][4]

| Challenges | Description for M2M devices |
|---|---|
| Low mobility | Rarely move or move only within a certain region |
| Time controlled | Send or receive data during only defined time intervals |
| Time tolerant | Can delay their data transmission |
| Small data transmission | Send or receive small amount of data |
| M2M device monitoring | Related events are monitored on system |
| Priority alarm | Issue a priority alarm in the events such as theft, vandalism or need for immediate attention |
| Secure connection | Require a secure connection between M2M devices and M2M server |
| Network provided destination for uplink data | Send all data to a network with destination IP address provided by M2M application |
| Infrequent transmission | Send or receive data infrequently |
| Group based M2M features | Be managed by a network as a group rather than individually<br>– Group based policing: A QoS policy is enforced on a group<br>– Group based addressing: M2M devices in a group send or receive the same message |

However, all requirements of a smart grid as shown in subsection 2.2 do not face with these challenges of M2M communications. Each challenge of M2M communications can be associated with each requirement of a smart grid as shown in **Table 4**.

**Table 4.** Association between challenges of M2M communications and the requirements of a smart grid

| Requirements / Challenges | Remote monitoring and reporting | Two-way communications | Remote supply control | Communicate with individual devices |
|---|---|---|---|---|
| Low mobility | | ● | | ● |
| Time controlled | | ● | | |
| Time tolerant | | ● | | |
| Small data transmission | ● | | | |
| M2M device monitoring | ● | | | |
| Priority alarm | | | ● | |
| Secure connection | | ● | | |
| Network provided destination for uplink data | ● | | | |
| Infrequent transmission | | | ● | |
| Group based M2M features | ● | ● | | |

## 3. Technical Issues to Support a Smart Grid in 3GPP Cellular Network

Many techniques have been considered to realize M2M communications in a smart grid. Unfortunately, Bluetooth, ZigBee, or Wi-Fi still have no network architecture to fulfill all the general characteristics of M2M communications [14]; these techniques can be utilized only in HAN [7][8]. Meanwhile, 3GPP cellular network can provide connections for M2M communications [14] and it can be used for BAN, NAN and WAN of a smart grid. Especially, 3GPP LTE-Advanced technology can be applied to the networks with various cell sizes, i.e., macrocell, picocell, and femtocell. If one technology can construct and manage connections for M2M communications in a smart grid, it would be desirable because of low-cost and low-complexity. Hence, to provide smart grid applications, we survey the technical issues, current researches, and the future work of 3GPP M2M communications.

### 3.1 Technical Issues

In the smart grid application, smart devices have low or no mobility until the reinstallation. In addition, many smart devices, such as meters, power distributors, and collecting gateways may exist on the same cellular network. The massive number of devices might transmit simultaneously in a certain period. Meanwhile, the smart grid server could perform group-based device management. It could send the same management message to all units of a group for efficiency. To provide the smart grid service with these features, existing 3GPP network should consider the technical issues as shown in **Table 5**.

**Table 5.** Technical issues for smart grid in 3GPP cellular network

| **Technical issues** | **Objectives** | **Related work** |
|---|---|---|
| Group based management | − Provide easier mode to control/update/charge of M2M devices with low redundancy<br>− Save network resources assigned to individual M2M devices | [9][15] |
| Optimal protocols between M2M devices and one or more M2M servers | − Provide protocol to uniquely identify, authenticate, and authorize an M2M device or a group of M2M devices | [16] |
| Modified IP addressing | − Improve scalability for a large number of M2M devices in both IPv4 and IPv6 address space within 3GPP standards bodies<br>− Mitigate additional user plane latency, security threats, transaction, and messages for configuration | [10] |
| Resolution for a lack of M2M identifiers | − Resolve the shortage of identifiers by a large number of M2M devices | [3][10] |
| Congestion control | − Mitigate signaling and data traffic congestion from malfunctioning in M2M devices or servers, simultaneous attachments by many M2M devices, and recurring events in all M2M devices at the exact hour | [14][17] |
| Management as traffic types | − Provide signaling procedures in accordance with characteristics of metering or management traffic | [18] |

### 3.2 Current Research and Future Work to Solve the Technical Issues

Several research streams deal with technical issues in subsection 3.1. However, existing researches for each issue are not based on the 3GPP cellular network. To provide smart grid service via 3GPP cellular networks, solutions to resolve the technical issues should reuse existing 3GPP standards and minimize the impact on the 3GPP system. In this subsection, we introduce existing research and open research issues for each technical issue, as follows:

***Group based management:*** D. Niyato et al. proposed the grouping algorithm of concentrators to minimize installation costs and QoS provision when concentrators are newly installed or the system configuration is changed [15]. C. Wietfeld et al. proposed a greedy algorithm to achieve a maximum coverage with a minimum number of concentrators [9]. In the 3GPP networks, smart meters shall be managed as a group. Sometimes, they shall be individually controlled. Therefore, group based management should provide flexibility for individual and group based signaling.

***Optimal protocols for M2M devices and M2M servers:*** Y. Chen et al. proposed a reduced protocol stack using an M2M facilitator to efficiently minimize and transmit signaling traffic via the cellular network [16]. The M2M facilitator operates as the virtual interface between the M2M devices and M2M server and has a partial protocol stack of the M2M devices. The M2M facilitator performs the establishment and release of connection between M2M devices and M2M servers, instead of M2M devices. M2M devices can minimize signaling traffic by help of the M2M facilitator, and thus network congestion can be alleviated. In the 3GPP networks, smart meters should communicate with a smart gird server via the public land mobile network (PLMN) with optimal protocols for M2M communication. Optimal protocols for PLMN shall provide authentication and authorization for a smart meter, before the smart meter communicates with the smart grid server [10]. It should also support common service requirements, e.g., addressing, identifiers, charging, and security.

***Modified IP addressing:*** New IPv4 addressing mechanisms were introduced in [10]. M2M servers have an overlapped IP address pool. A gateway located between an M2M device and an M2M server obtains an IP address from the M2M server and then assigns the IP address to the M2M device and a packet data network (PDN) specific ID. The gateway indicates an M2M device with the PDN specific ID to the M2M servers. Then, the M2M server can know the IP address for the M2M device. IP addressing schemes for smart meters should consider three deployment scenarios. First, both the smart grid server and smart meter are assigned IP addresses in the same IPv6 addresses space. An IP address of a smart meter is assigned by the mobile network operator (MNO). Next, the smart grid server has a public IPv4 address while smart meters have private IPv4 addresses in an addresses pool possessed by MNO. Last, both smart grid server and smart meters have private IPv4 addresses. MNO assigns smart meters private IP addresses in the same IPv4 address space with the smart grid server. To overcome the limited number of IPv4 addresses, IP addressing schemes should use full private IPv4 addressing space and overlapping IPv4 address pools. In this case, IP address assignment can be handled by the MNO or controlled by the M2M communication enterprise providing for either static or dynamic addressing assignment.

***Resolution of a lack of M2M identifiers:*** In [10], the shortage of M2M identifiers used for remote configuration was discussed. 3GPP introduces a remote configuration scheme based on short message service (SMS). However, M2M devices only using packet-switched networks cannot use unique subscription identifiers, e.g., mobile subscriber integrated service digital network numbers (MSISDNs) [3]. Thus, solutions are required to support remote M2M device configuration without MSISDNs. A network operator should provide unique identifiers without MSISDN of smart meters or a group of smart meters. The identifiers can be classified into internal and external identifiers. Internal identifiers are used as subscription related identifiers for mobility procedures, charging, etc, within the 3GPP network. External identifiers are used by smart grid servers that are outside the 3GPP network. For operators and users of smart grid services, globally unique external identifiers shall be supported. The 3GPP network should be able to translate the internal identifier into an external identifier.

***Congestion control:*** Synchronized smart meters, which simultaneously send messages in a certain period, can aggravate the congestion situation. Therefore, it is necessary to simplify the signaling process and to develop methods limiting signaling traffic for efficiency. In order to achieve this, S.-Y Lien et al. proposed a group-based resource management mechanism for the M2M device access on radio access network (RAN) and QoS guarantee in [14][17]. In the proposed mechanism, M2M devices are grouped by QoS parameters such as the packet arrival rate, maximum tolerable jitter, and the acceptable probability. When the maximum tolerable jitter is violated, a base station allocates the radio resource to each M2M group by the unit of radio subframe in the proposed mechanism.

The conventional research is mainly focused on data traffic congestion at the radio access network. However, in the case of the smart grid, data traffic from great number of devices is converged to the corresponding smart grid server via the 3GPP core network, such as an evolved packet core (EPC). Outbreak points of congestion can move from the radio access network to the core network and smart grid servers. The core network congestion may frequently occur if many smart grid devices transmit their data simultaneously with time synchronization. Therefore, it is necessary to study both congestions on the radio access network and that in the 3GPP core network to relieve the traffic jam by limiting or distributing data traffic.

***Management of traffic types****:* G. Cherian et al. introduced traffic characteristics of reverse link (RL) and forward link (FL) in the smart grid [18]. RL and FL traffic are generated in M2M devices and M2M servers, respectively. Characteristics of the RL traffic are different from the FL traffic in terms of payload size and reporting period. However, these characteristics are not mainly considered in existing researches. In order to efficiently manage the data traffic in a smart grid, we introduce these characteristics according to the traffic type and it is as shown in **Table 6**.

**Table 6.** Smart grid traffic characteristics

| Type | Characteristics |
|---|---|
| Metering traffic | Periodic or scheduled transmission (optional event-driven) |
| | From device-side to central server |
| | High data rate |
| | Busty transmission of small size data |
| Management traffic | Event-driven |
| | From central server to device-side |
| | Delay sensitive |
| | Multicasting or broadcasting transmission |

The types of data traffic in a smart grid are classified into metering and management traffic. Metering traffic is data sent from smart grid devices to the smart grid application server by the uplink transmission. This data traffic includes measured values, such as the power usage, demand, quality or event-reporting such as an outage. Metering traffic generally has a bursty characteristic and is caused periodically or based on pre-defined scheduling. Management traffic containing control information to manage devices and network entities for system efficiency is transmitted from the smart grid server to each device or device groups. Management data is generated by server-generating events and is transmitted through multicasting or broadcasting. Metering traffic may cause congestion to the network by bursty transmission, while management traffic requires transmission with minimized delay and addressing methods. Therefore, optimization for the smart grid communication is performed by analyzing and reflecting each traffic characteristic.

## 4. Conclusions

M2M communication is in the spotlight as the next revenue business; smart grid service, one of the M2M applications, also attracts attention. Smart grid is an application that enables the power grid to minimize the wasted energy by controlling demand and supply in the power grid with a combination of power grids, communication networks and control centers. Many countries and energy corporations have aimed to reduce environmental pollution by decreasing the emission of greenhouse gases by smart grid under the slogan of green development. To support the smart grid service in 3GPP cellular networks, it is important to resolve technical issues caused by the smart grid characteristics that differ from cellular communications, i.e., group based management or congestion control. Research, for example, protocol stack simplification or concentrator optimization, has been presented. However, it is necessary to diversify research directions. In the future, the 3GPP network would provide smart grid services effectively when in-depth studies for each technical issue are performed.

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