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Review Article

M2M Communications in the Smart Grid: Applications, Standards, Enabling Technologies, and Research Challenges

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We present some of the ongoing standardisation work in M2M communications followed by the application of machine-to-machine (M2M) communications to smart grid. We analyse and discuss the enabling technologies in M2M and present an overview of the communications challenges and research opportunities with a focus on wireless sensor networks and their applications in a smart grid environment.

1. Introduction

Smart grid (SG) networks will be characterised by the tight integration of a flexible and secure communications network with novel energy management techniques requiring a very large number of sensor and actuator nodes. The communications network will not only facilitate advanced control and monitoring, but also support extension of participation of generation, transmission, marketing, and service provision to new interested parties.

In order to realise the intelligent electricity network, machine-to-machine (M2M) communication is considered as a building block for SG as a means to deploy a wide-scale monitoring and control infrastructure, thus bringing big opportunities for the information and communication technology (ICT) industry. For example, smart metering in M2M can facilitate flexible demand management where a smart meter (SM) is a two-way communicating device that measures energy (electricity, gas, water, or heat) consumption and communicates that information via some communications means back to the local utility. With near realtime information available for example based on the flow of energy in the grid, different levels of tariff can be calculated and made available for the consumer, the consumer can make a smarter and more responsible choice. The information generated by SM therefore acts like "glue" allowing various components of SG to work together efficiently. There are also various large-scale wireless sensor and actuator networks (WSAN) deployed in SG (such as the electric power system generation, or home applications) in order to carry out the monitoring task, for example [1]. These WSANs with the collaborative and self-healing nature have an important role to play in realising some of the functionalities needed in SG. On the other hand, there is also cellular M2M where cellular technology plays an important role in M2M communications due to its good coverage, promising data rates for many applications, and so forth. However, in this paper, we mainly focus on WSAN where various short-range wireless technologies are used to support various M2M applications.

There are currently various standardisation activities in M2M communications with a conscious effort to deliver a harmonised set of European standards. The challenges and opportunities that smart metering and smart grids present to communications networks are significant and include interoperability, scalable internetworking, scalable overlay networks, and home networking with potentially much larger numbers of devices and appliances. The security and privacy aspects are also extremely important given the large amount of private data that can be exposed by smart metering alone.

In this paper, we discuss the applications of M2M communications to SG. We present a brief introduction

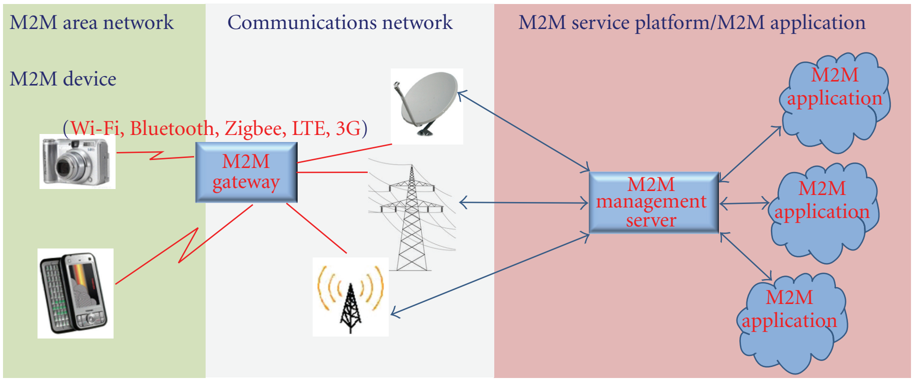

Figure 1: Architecture of M2M networks.

on M2M standardisation work in Section 2, and M2M scenarios and requirements in SG in Section 3. Further we discuss the enabling technologies in Section 4 and provide an overview of the communications challenges and research opportunities in Section 5, with a focus on WSAN and its applications in an SG environment. Section 6 is devoted to the conclusion of this paper.

2. M2M Standardisation Activities

2.1. M2M Architecture and Topology. M2M is unarguably a combination of various heterogeneous electronic, communication, and software technologies. The general architecture of M2M networks such as those being specified in ETSI TC (technical committee) M2M is shown in Figure 1. Other more detailed information of the M2M architecture can be derived from the on-going work in ETSI TC M2M. In reference to this architecture, M2M devices (intelligent and communication enabled) form an M2M area network; this could be from a small-scale home environment to a bigger environment such as a factory. The M2M area network is connected to the communication network such as satellite, power line, or mobile base stations through the M2M gateway. Through the communication networks, they are connected to the M2M management server on the M2M service platform and subsequently reaching the M2M applications (video for monitoring, online social networking, etc.) on the other side of the M2M management server.

2.2. ETSI M2M. The European Telecommunications Standards Institute (ETSI) Technical Committee is developing standards for M2M communications. The group aims to provide an end-to-end view of M2M standardisation, and will cooperate closely with ETSI's activities on next generation networks, and also with the work of the 3GPP standards initiative for mobile communication technologies. ETSI TC M2M is among one of the three European Standardisation Organisations which have been issued a mandate by the European Commission on Smart Metering (M/441). The TC M2M domain of coordination to answer M/441 includes providing access to the meter databases through the best network infrastructure (cellular or fixed) and providing end-to-end service capabilities, with three targets: the end device (smart meter), the concentrator/gateway, and the service platform. Further, smart metering application profiles will be specified including service functionalities. Figure 2 shows the responsibility area among CEN (European Committee for Standardisation), CENELEC (European Committee for Electrotechnical Standardisation), and ETSI on the M/441 mandate work.

A number of liaisons have also been established with other standardisation bodies, for example, CEN, CENELEC, DLMS UA, ZigBee Alliance, and other ETSI TCs.

2.3. 3GPP. Apart from ETSI, 3GPP is also active in M2M technology-related activities. In 3GPP M2M is also called machine-type communications (MTC) where work has been carried out on the optimisation of access and core network infrastructure, allowing efficient delivery of M2M services. 3GPP SA1 has already completed a technical report TR 22.868 in 2008 on "Facilitating M2M Communications in GSM and UMTS." They have now started a new work item on network improvement for MTC, in order to gather requirements to reduce the operational costs of supporting M2M services. 3GPP SA1 Services is working on the services and features for 3G systems. In release 10, they have produced "Service Requirements for Machine Type Communications (MTC) Stage 1." 3GPP SA 3 has started looking into the security aspects of MTCs.

2.4. IETF ROLL—Wireless Sensor Networks (WSN) and Internet of Things. IETF has created a set of activities related to sensor technologies and smart objects such as 6Lowpan and ROLL (routing over low-power and lossy networks). These efforts are aiming at bringing the Internet Protocol to sensors and M2M devices needed for building a monitoring infrastructure for SG. Working Group ROLL is focusing on RPL (routing protocol for LLNs) for low-power and lossy networks (LLNs) where the nodes in the networks are many embedded devices with limited power, memory, and processing resources. These nodes are interconnected by various wireless technologies such as IEEE 802.15.4, Bluetooth, low-power WiFi, and power line communication links. The emphasis of the work is on providing an end-to-end IP-based solution in order to avoid the non-interoperable networks problem.

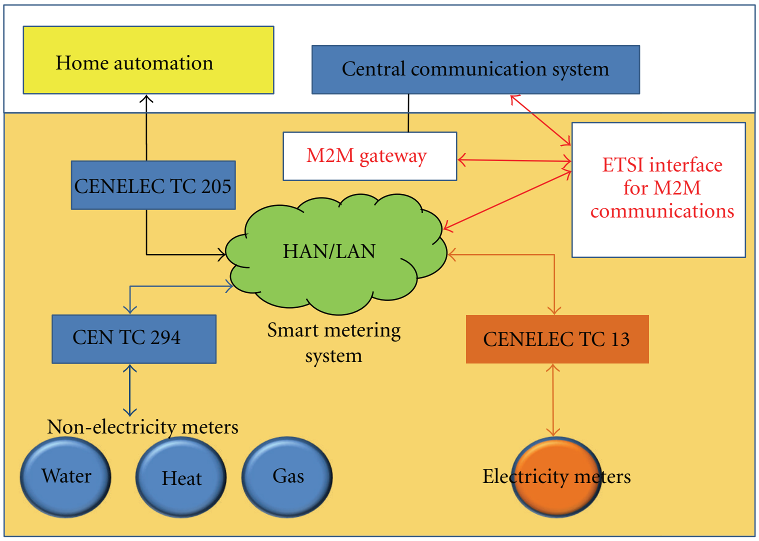

Figure 2: M441 responsibility split among CEN/CENELEC/ETSI.

3. M2M in Smart Grid:M2M Scenarios and Requirements in SG

With the various functionalities that an M2M system could offer, it has been considered as one of the foundation ICT solutions on realising SG. In this section, first of all, we look into the basic architecture for SG and how the M2M architecture relates to this. This is followed by discussing two important M2M scenarios and exploring the related applications with WSAN in mind. Such understanding is essential when more detailed functional and technical requirements need to be developed. In particular, we look into how WSAN play a key part in delivering M2M applications in an SG context.

Figure 3 [2] shows the ETSI board of director architecture for SG which is formed by three main planes: Layer 1, the energy plane handles the energy related to production, distribution, transmission, and consumption, therefore includes a large amount of sensors, electricity storage systems, transmission, and distribution systems. This layer corresponds to the M2M area (device) network in M2M networks. Layer 2 is the control and connectivity layer which connects the energy plane to the service plane. This relates to the M2M communications network layer. Layer 3 is the service layer which provides all the SG-related services. This is related to the M2M service layer in the M2M network architecture. How to apply M2M architecture to SG networks will need to be further studied or standardised.

More recently, WSAN has been gaining popularity on becoming a promising technology that can enhance various aspects of today's electric power systems, including generation, delivery, and utilisation. This is due to the collaborative and low-cost nature of the networks (also without the need to construct a complex and expensive infrastructure). At the same time WSAN also has some intrinsic advantages over other conventional communication technologies, such as wide area coverage and adaptability to changing network conditions. However, different environments pose different challenges to a WSAN; for example in a harsh and complex electric power system environment, WSAN communication in SG applications faces significant challenges on its communications reliability, robustness, and fault tolerance. In this section, we study the role of WSAN in different M2M applications/scenarios in SG and discuss the different characteristics and challenges.

3.1. Home Applications and Smart Buildings. Wireless home networks (or home area networks (HANs)) are now becoming increasingly popular and have evolved from just computers to including all different types of electronic devices including home appliances and home entertainment systems such as TVs and audio. General applications include that of lighting control, heating, ventilation, and air conditioning control (HVAC) which requires WSAN in place to support the monitoring and also act as the wireless communication infrastructure. Further, they also provide a way to detect fluctuations and power outages. It also allows customers to control remotely the meter (such as switching on and off) enabling cost savings, and to prevent electricity theft. Other applications include demand response and electric vehicle charging.

Smart buildings such as offices rely on a set of technologies to enhance energy-efficiency and user comfort as well as for monitoring and safety of the building. The M2M technology and WSAN are used in building management system for lighting, HVAC, detecting empty offices and then switching off devices such as monitors, and for security and access systems.

The main requirement of the M2M devices in a home and office environment is their very low power consumption so that many devices can last years without requiring battery replacement. With the wide range of home/office devices that need to be networked, there is a need to support several different physical links. Among all the different networking

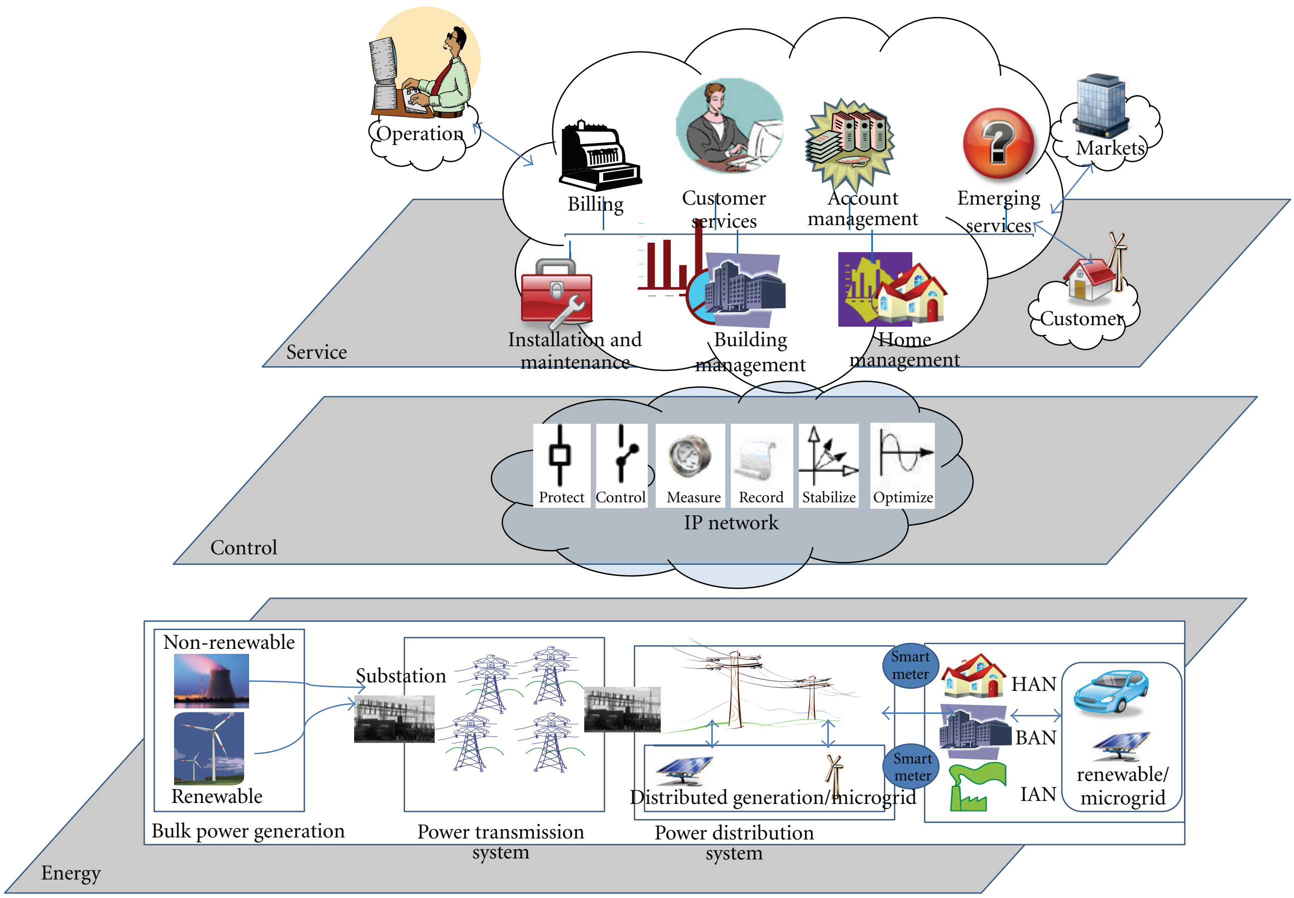

Figure 3: ETSI board of directors view on smart grid architecture including M2M network (adapted from [2]).

technologies, Ethernet, 802.15.4, Wi-Fi, Bluetooth, power line communications, and cellular all have a place in the home networking environment. The home M2M network will have to support all the different physical links and protocol stacks through the M2M gateway. The gateway also needs to be able to gather information on what processing and energy resources are available in the M2M devices (which are usually equipped with limited resources) and decide on how to disseminate data in a way that can optimise the resources. In general, the gateway capabilities include that of routing, network address translation (NAT), authentication, resource allocation, and so forth. Other more elaborate services or capabilities of the M2M gateway are ongoing work in TC M2M dealing with gateway reachability, addressing and repository, communication, remote entity management, security, history and data retention, transaction management, interworking proxy, and compensation brokerage. Smart building systems with WSAN are also expected to learn from the building environment and adapt the monitoring and control functions accordingly.

3.2. Power Distribution Systems. An SG being the emerging next-generation electric power system, offers improved efficiency, reliability, and safety by allowing smooth integration of alternative energy source as well as automated control and modern communication technologies [3]. Traditional electric power systems rely on wired communication for monitoring and diagnostic purposes. However, these systems require expensive cables to be installed and maintained on a regular basis. Therefore, there is a need for a cost-effective solution that would enhance the management process of the electric power systems.

WSAN has an important role to play in this area due to its low cost, flexible, and collaborative nature for aggregated intelligence. They are capable of monitoring the critical parameters of the equipments in SG and provide a timely feedback to enable the SG system to respond to the changing conditions. This enables SG to function in a reliable way with self-healing capability. The role of sensors in various parts of the SG power distribution system cover a wide range of transmission systems, substations and distribution systems. A WSAN-based wide area network (WAN) electric energy substation monitoring system plays an important role in ensuring the health of the power subsystems (transformers, circuit breakers, etc.) and transmission lines, and improving the observability and reliability of power systems [1].

WSN provides the capability for wireless automatic meter reading (WAMR) for electric power distribution systems with the benefit of reduced operational cost, online pricing, and remote monitoring for asset protection. The challenge in WAMR is reliable two-way communications between the electric utilities and customer's smart metering devices.

One of the major roles of the WSAN in a power distribution system is voltage quality management (VQM). With the growth of nonlinear time variant loads due to various existing and new applications, the distortion and disturbances on the voltage signal have become increasingly a significant problem. In a VQM WSAN, ideally each node can assess the information of performance of the monitored site, by using local information for computation, also the global performance of the monitored grid section by using local information exchanges between its neighbour nodes. With these features, the node could detect local voltage quality anomalies [4].

Some of the requirements of WSAN solutions in SG in a power distribution system are as follows. Highly scalable: the network should be able to scale to hundreds and thousands of devices and many could be communicating at the same time. High reliability: many of these power automation systems are expected to maintain good reliability that will last at least 20–30 years once installed. Other requirements include being able to handle range and obstruction issues as the harsh environment in a power distribution system could affect the link quality and range. Further, there could be various hardware and infrastructure obstructing the communication of the WSAN.

3.3. Other Applications. Other M2M applications cover a wide variety of domains from sales and payment, fleet management, telemetry, e-health applications, to security and surveillance.

4. Enabling Technologies

4.1. Short-Range Wireless Technology. Short-range wireless technology (SRWT) is becoming increasingly popular for ubiquitous WSAN connectivity in various instrumentation, monitoring, and measurement systems. In the context of M2M communications, SRWT plays a crucial role in terms of communication of the M2M devices with little or no human intervention. Such devices will proliferate in various environments with different applications up and running such as home security sensing, lighting control, and health monitoring. There are many challenges in designing such M2M networks which will be described in the later section. In this section, we survey the various potential SRWT for M2M networks and their respective features. In summary as shown in Table 1 (adapted from [5]), IEEE 802.15.4-based protocols such as 6LowPAN and ZigBee are suitable for low power and low data rate applications, also with less stringent range requirements such as sensor networks applications, whereas the IEEE 802.11 (Wi-Fi) protocol is well suited for higher data rate applications (also supporting longer range) including audio and video streaming-related applications. Bluetooth, on the other hand, is suitable for short-range and low-data-rate peer-to-peer communications.

4.2. Networks and Protocols. An efficient routing mechanism in the M2M networks decides how efficient the data can be transported from one end to the other. There are various challenges on applying existing routing protocols to these M2M networks due to some inherent characteristics of the networks such as

(i) Long sleep cycles

(ii) Low power nodes

(iii) Changes to the radio propagation environment

(iv) Changes of topology (mobility of nodes, nodes in sleep mode).

Many low-power protocols such as Zigbee uses the AODV protocol from RFC 3561 [7] as its routing protocol. Under the AODV protocol method, nodes in the network that are not part of an active communication do not maintain any routing information or participate in the periodic routing table exchanges as required in the algorithm. The routing paths are established on an on-demand basis, so only nodes that are awake will be involved in the process. The node that initiates the process will be responsible for most of the computational work in the routing protocol, which includes collecting and evaluating the responses to the route request sent and making decisions on the route with the lowest network cost which could be the path with the smallest number of hop counts or the path with the largest remaining battery power of the nodes.

Another solution proposed in the literature is [6] which is suitable for a long-term environment monitoring network with low duty cycles. The routing is done by allowing the network nodes to sleep most of the time and reviving them whenever the gateway is performing a bulk data download. The low-power node upon waking up would send a probe message to its neighbour to check for any potential communication and the gateway would calculate the network paths using the reachability information collected.

The IETF RPL protocol will enhance the advanced metering infrastructure (a network of smart meters) with IP routing characteristics such as dynamic discovery of network paths and destination, ability to adapt to logical network topology changes, equipment failures or network outages, independence from data link layer technologies, and support for high availability and load balancing. In [8], an RPL-based routing protocol for advanced metering infrastructure (AMI) in SG has been proposed, aiming to enable realtime automated meter reading and realtime remote utility management in the AMI.

5. Challenges and Research Opportunities

Having discussed the various scenarios and its challenges of WSAN in SG, in this section, we elaborate on the various topics of research interests that demonstrate great potential for further studies.

(1) *Gateway Design.* The gateway plays an important role in interconnecting various network devices and sensors in an application scenario. There is a need to cater for the different characteristics of the devices in the gateway. For example

Table 1: M2M short range wireless technology (adapted from [6]).

	802.15.4 (ZigBee/6LoWPAN)	Bluetooth/Bluetooth low energy (LE)	802.11 (Wi-Fi)
Max data rate	250 kb/s	3 Mb/s (enhanced) 1 Mb/s (basic or LE)	22 Mb/s (802.11 g) 144 Mb/2 (802.11 n)
Indoor range	10 m–20 m	1 m, 10 m and 100 m classes, 5–15 m (LE)	45 m
Power	Low	Medium low (LE)	High
Battery life	Years	Days years (LE)	Hours
Frequency band	2.4 GHz 868 MHz and 915 MHz	2.4 GHz	2.4 GHz, 3.6 GHz, and 5 GHz
Channel access	CSMA/CA (non-beacon based) or superframe structure (beacon based, non-contention)	Frequency hopping or CSMA/CA	CSMA/CA
Applications	Smart appliances Smart meters Lighting control Home security Office automation	Voice Smart meters Data transfer Game control Health monitoring (LE) Computer peripheral (LE)	Networking between WAN and customer premises (M2M area networks) Digital audio/voice

in a home environment, there will be devices that have different requirements on power, distance, data rate, and are running different communication protocols. Other issues are security capability, communication selection capability, and so forth. Software-defined radio technologies have been proposed in [5] as a solution to the home M2M gateway architecture enabling the gateway to function at multicarriers and multibands which can communicate simultaneously with different protocols, on different frequencies and in different frequency bands.

(2) *Harsh Environment.* This is a common problem for certain WSANs in SG such as those operating in the power system environment. The WSAN may be subject to strong RF interference, and also harsh physical environment such as corrosion and high humidity. These may cause the network topology and wireless connectivity to change when certain nodes fail or the measurements are not suitable for drawing good conclusions. Wireless channel modelling and link quality characterisation are some of the important work [9] when designing a reliable WSAN in the smart grid in such harsh environment as the power system designers can make use of such model to predict the performance of the network.

(3) *Service Differentiation.* In order to enable efficient prioritisation of certain applications that have some critical requirements to meet such as those belonging to protection and control functions, the WSAN must be able to support quality of service (QoS). For example, an alarm notification for the electric power systems will require immediate attention hence requires a realtime communication; other periodic reporting activities would require reliable communications.

(4) *Packet Loss or Errors and Variable Link Capacity.* In WSAN, the perceived level of interference and bit error rates affects the attainable capacity of each wireless link [9]. Also, the wireless links exhibit a varying characteristic over time and space due to various reasons such as obstructions and noisy environment in an electric power system. Therefore the capacity and delay at each link vary from location to location and could be bursty in nature. This poses a serious challenge to providing QoS in the system. There have been a wide range of methods proposed in the literature based on MIMO (multiple-input and multiple-output) communication and smart antennas that can be exploited to improve the network capacity in a noisy environment.

(5) *Resource Constraint.* The resources required in a sensor node can vary from application to application in terms of energy, memory, as well as processing power. In general, limited battery power is the main resource constraint that requires various communication protocols for WSAN to provide high energy efficiency. Energy efficient protocols such as routing solutions are needed where WSAN are usually expected to function over years without having to change the battery. The routing technique also has to take into account the long sleep cycles, changing radio environment, change of topology, and the limited processing power.

(6) *Security.* Security for WSAN in SG is an essential requirement in order to ensure that the whole system functions smoothly and safe from any sorts of attack and intrusion. This covers a wide range of solutions targeting threats such as denial-of-service, eavesdropping on transmission, routing attacks, flooding for generation plant security, data centre security, WAN security, identity management, access control,

and so forth. Conventional centralised IT network security models are not directly applicable to the highly distributed and low-cost devices in M2M communications networks due to the need for dispersed and decentralized methods.

(7) *Self-Configuration and Self-Organisation.* As the topology of the sensor nodes in a WSAN changes due to sleep mode schedule, mobility or node failure, there is a need for self-configuration and self-organisation to make sure that the network functions as normal. Therefore, fault diagnosis is essential for the hardware as well as software in the infrastructure. Failure analysis or predictive maintenance makes sure that the system has the ability to identify failure (assisting quick failure remedy), predict failure and recover from fault/failure. Intelligent diagnosis methods such as those that filter and reason the mass information related to an alarm, helps quick understanding of the nature of the fault and localised the fault. Various machine learning techniques such as artificial neural network have been proposed in [10, 11] for power system fault diagnosis and alarm information processing.

(8) *Data Processing.* With the large scale development of WSAN in SG, there are a large amount of information collected over time. There is a need to intelligently combine or aggregate, fuse or infer these data in order to draw conclusion on what action is needed or how to configure the parameters in the system for optimum functionality. The other benefit is for increased energy efficiency by better match of supply and demand. For example, the authors [12, 13] proposed using artificial neural network for load forecasting which is important for demand response. Data processing can also help achieve improved security and reliability by fast response to unusual events and in the case of energy shortage. For example, methods for traceback and traceability for malicious activities in critical information such as methods proposed in [14] to examine relevant attributes features at intermediary stages of data transaction in the infrastructure. This is followed by finding the maximum occurrence features pertaining to characteristics of normal and abnormal transactions. These attributes are mined using hybrid data mining algorithms in order to identify unique classes in the traceability matrix for security and privacy.

(9) *Reliability.* Reliability can be tackled from multiple levels such as the communication link level and the system level. The system needs to be able to cope with the harsh environment and adaptively work out the best way to cope with node failure and link variability.

(10) *Middleware and APIs.* Advanced application programming interfaces (APIs) help to enable implementation of optimisation algorithms and efficient management and configuration of networks, open interfaces to enable independent software vendor, device manufactures, and telecoms operators to implement their services. Open APIs provide the means for third parties not directly associated with the original equipment manufacturers to develop a software component which could add functionality or enhancements to the system. On the other hand, smart energy management solutions require access to more information ideally from different service providers and devices implemented by different vendors. Such information should be available and presented in a usable format to interested parties. Further, timing and specific configuration of measurements and controls are also critical for dynamic scenarios. Since support for different technologies and some level of cooperation over administrative boundaries are required, proprietary or widely simplified interfaces will not be sufficient in these scenarios. This situation can be improved by standard generic API definitions covering methods and attributes related to capability, measurement, and configurations. The design of such APIs should be technology agnostic, lightweight and future-proof.

(11) *M2M Computing Platform.* With the deployment of large-scale M2M networks and its various applications to be provided, there needs to be a way to control and manage these devices as well as to work on the data or make the data available efficiently for a different purpose. Cloud computing has been regarded as one of the potential technology to be leveraged for M2M computing. The cloud, a combination of IT virtualisation by combining Internet, information and communication technology, and various resources (hardware, development platforms), makes it easier to deliver the M2M applications as services (through the Cloud) virtually. This allows flexible IT management and data sharing across the platform and resources can be dynamically reconfigured according to the variable load allowing optimum resource utilisation. For example, a commercially available cloud platform for M2M applications is Sierra Wireless AirVantage Cloud Platform [15] which enables M2M solution providers, system integrators and network operators to rapidly develop, is deploy and operate M2M applications and services.

(12) *Multi-Radio Support and Spectrum Efficiency.* Multiple communication technologies and standards are being deployed to support communications in different parts of SG. For example, Bluetooth could be used for the communications between meter and end customer devices. On the other hands, ZigBee and IEEE 802.11 could be used for smart meter interfaces in the home and local area network. In order to manage and support all these different communications, there needs to be multi-radio support functionality in the SG. Also, radio spectrum scarcity is an increasingly important problem due to the rapid growth in the telecommunication service industry. One of the proposed ways of managing the spectrum efficiently is a solution such as using the unoccupied television spectrum, also known as the white space, has been proposed by the Federal Communications Commission (FCC). As this is no longer the static spectrum allocation case in the conventional way, there needs to be an efficient secondary spectrum management strategy. Company such as NEUL [16] has developed M2M communications network solutions which operate in TV white spaces.

(13) *M2M Protocols.* There are various scopes for M2M protocols research such as reliable (i.e. delivery-guaranteed),

delay-guaranteed, rate-efficient, and energy-efficient protocols design. Energy-efficient protocols such as routing and transmission protocols are needed where WSAN are usually expected to function over years without having to change the battery. The routing technique also has to take into account the long sleep cycles, the changing radio environment, changes of topology, and also the limited processing power. The existing leading transmission protocol, that is, TCP/IP is known to be inefficient for M2M traffic with low data volume as there are redundant and overhead which therefore is not energy efficient for M2M communications. Therefore, protocols redesign for M2M communications needs to be explored.

(14) *Optimal Network Design.* As an M2M network consists of an interconnection of a number of devices and systems together, there is a need to design the network to minimise the cost of M2M communications while still meeting the QoS requirements. Placement of gateway, number of M2M devices supported in a clusters, and so forth are some of the related topics [17].

6. Conclusion

There has been no doubt that M2M communication plays an important role in realising the next-generation smart electrical system, SG. In this paper, we have looked into various on-going M2M standardisations-related activities which have shown the growing momentum of M2M in becoming the one of the important ICT solution for SG. We highlighted the work carried out in organisations such as ETSI M2M, 3GPP, and IETF ROLL to draw attention on the set of topics of interest among various stakeholders on M2M in SG picture. Next, we studied a selection of challenges and requirements of M2M application/scenario and WSAN in SG. We then focused on the technical details of M2M communications, which covered a wide range of topics, M2M architecture and topology, various short-range wireless technology, and networks and protocols. Having extensively discussed the above topics, we provided our view on various research opportunities in this topic. We believe that data processing, security, reliability, middleware and APIs, M2M computing platform, multiradio support and spectrum efficiency, M2M protocols and optimal network design are some important and interesting topics that can be looked into in the future work.

Although the roadmap of worldwide smart grid deployment is still not clear, it is almost certain that the future intelligent energy network empowered by advanced ICT technology will not only be as big as the current Internet, but also change people's lives in a fundamental way similar to the Internet. On an even larger scale, the notion of Internet of things will connect trillions of objects and the whole world will become an extremely large-scale wireless sensor network. As M2M communications is an underpinning technology for this vision, we therefore envisage that M2M will be an exciting research area for communication engineers for many years to come.

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