Modern Architecture Style for Distributed Hyper Media System

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ABSTRACT

The advancement in the communication system leads to a new networking paradigm, SDN remains to be implemented for SG M2M communication scenarios and there hang about a number of challenges that need to be overcome. M2M communication protocols and standards provide a starting point for the broader development of SG communication networks that can be enhanced by abstracting high-level network functionalities. The aim of this paper to carry out an exhaustive work on the future SG communication networks and to propose solutions to identified limitations of existing communication networks. By the focus of this intention, the work first hub on the SG application modeling techniques based on the traffic requirements and power supply load profiles. To address the dynamicity of the traffic model and demand load curve, a series of analytical models and smart algorithms were developed. SG application models were developed and evaluated using a range of scenarios reflecting typical usage. Heterogeneous network architectures and efficient traffic models were developed to identify an appropriate wireless communication technology and to maximize the network performance for major SG applications. However, a careful observation of the communication networks ability to manage and control the diverse M2M communications reveals that the inadequate dynamic communication network configuration capability would be a problem for future SG applications. In a SG Neighborhood Area Network (NAN), wireless sensor networks (WSNs) will play a key role in the development of major SG applications. The application centric WSNs require complex configurations such as well-defined access techniques, transmission and security protocols. The SDN based WSN network must be robust enough to support the adaptive energy dispatching capacity of the modern power system. The proposed communication framework incorporates novel communication features to separate the control plane and data forwarding plane within the SG communication network. This includes detailed modeling of the control and data plane communication parameters to support both delay sensitive and delay tolerant SG applications. The unique SDN features offers a platform to accommodate maximum number of SG applications with highest controllability and manageability. The performance of the SDN based future SG network is evaluated using a simulation scenario that considers realistic user load profiles, wireless standards, the SG premises geographical area and the state of the art of the SG standards. The proposed application centric traffic modeling techniques, SDN based wireless communication framework and analytical models in this work can be adapted for research into other communication networks, particularly those that are begin developed for the Internet of Things and other forms of M2M communications. Also, due to the technology agonistic characteristics of the analytical and traffic models, they can be used in the development of various wireless networks, particularly those that focus on wireless sensor networks, more generally than the broader Internet of Things.

Keywords

Machine to Machine, SND, Heterogeneous network architectures wireless sensor networks.

1. INTRODUCTION

In the epoch of highly developed mechanization and broadband communications where every aspect of daily life can be positively affected by new applications; our power grids continue to be operated using antiquated technologies and systems. Although the traditional power grid has been an effective solution for more than 50 years, the future is uncertain as the shift from coal and gas to solar and wind occurs. As more efficient and lower cost batteries come onto the market, the opportunity for bi-directional electricity flows will grow and the open loop system, where power flows from the generation plant to the customer, will cease to be the norm. Also, a lack of situational awareness, poor visibility and control over the power grid is making it more vulnerable to disturbances such as blackouts and brownouts [1][2].

The advent of renewable energy and increasing use of various Distributed Energy Resources (DERs) have made it necessary for the power grid to facilitate bi-directional power flows. To stabilize operational parameters and balance load profiles to enable bi-directional energy flow capability, the existing power grid should be efficiently operated using enhanced control and monitoring technologies. The shift towards bi-directional energy flows and improved control and monitoring of the power grid has led to the evolution of the next generation power grid known as an Smart Grid (SG) and the technologies used to convert the existing
power grid into an SG must be reliable, scalable, interoperable, secure and cost effective.

Research into SG communication networks aims to identify an integrated approach that leverages communication technologies and standards while focusing on the management and control of systems found in the existing power grids. M2M communication protocols and standards provide a starting point for the broader development of SG communication networks that can be enhanced by abstracting high-level network functionalities. A one stop communication solution is yet to be developed that facilitates reliable and efficient traffic exchange between the different SG domains and supports the deployment of diverse communication network services and applications. Software Defined Networking (SDN) provides a separation of traffic control and the systems that transfer traffic across the network [17]. SDN is a novel approach to manage and control communication networks that provide a higher level of network functionality abstraction that is appropriate for SG use. SDN provides an efficient, secure, reliable, cheap and flexible topology for SG communications. An SDN based communication architecture for SGs provides the flexibility and low-cost necessary to support the transition from the existing power grids to SGs. Another feature of a potential SDN implementation for SG communications is the optional use of different communication technologies for traffic control and traffic transmission systems. Selection of the appropriate communication technologies will depend on the traffic model developed for each of the SG domains. Multiple applications can be incorporated utilizing SDN that has different traffic patterns, processing priorities, and data expiration times.

Wireless Sensor Networks (WSNs) have evolved utilizing ubiquitous wireless communication technologies that provide high-speed, low cost and secure M2M communication [18]. Among the contemporary communication technologies, WSN is particularly suited for use with SG communication networks because of its design for low energy consumption, easy deployment, and Quality of Service (QoS). WSN supports continuous innovation, reduced equipment costs, and open standards that reduce the need for a single vendor solution. For potential SG operators, WSN is an attractive alternative to wireline communication technologies for M2M.

In recent times, SDN has become a key focus for communication network research and development. Both academic and industrial experts are deeply motivated by the prospects of the SDN paradigm. The need to gain enhanced network controllability and manageability is the main driving force behind the initiative to convert existing networks to next generation SDN networks. Due to a separation between the data and control planes, SDN offers more manageable network features when compared with conventional networks. Rapid growth in data usage and the emergence of smart technologies has prompted an exponential growth in network device installation of over the past decade. Accommodating a large number of network services and applications is a challenge that is best met with the shift to SDN. Also, proprietary network equipment makes it difficult to implement hardware and software updates in a multi-vendor provisioned network. With SDN, the entire network can be controlled using a single secure monitoring and management platform. Also, SDN facilitates software updates, including network service updates, without directly intervening or physically configuring the network devices. The network can be configured, monitored and controlled using a hierarchy of SDN controllers regardless of vendor specific network devices. In most of the literature, SDN has been designed to utilize the OpenFlow protocol [19]. The OpenFlow framework was proposed by the Open Networking Foundation [20] to develop and test new control mechanisms for large networks. The framework defines a packet forwarding model, flow table generation and update mechanism. The protocol specifically establishes communication between the SDN controller and OpenFlow enabled switches. In an OpenFlow based SDN network, multiple flow tables can be installed or programmed onto a switch via the controller. Packets arriving at the switch match their header field information with the flow entries stored in the flow table. Packets are forwarded based on the action defined by the flow entry. In the case of a flow miss scenario, the switch sends a flow request to the controller and based on the flow command received from the controller the packets are forwarded to the destination. OpenFlow based SDN is one of the basic solutions derived from the wide horizon of the SDN paradigm.

In order to enhance the performance of the WLAN-WiMax HetNet a novel, WiMax ranging scheme is proposed. All the proposed models are presented with simulation results and analysis highlighting the key factors to design the communication network at different SG domains. Careful observation of the network manageability and controllability of the diverse M2M network reveals that the inadequate dynamic network configuration capability of the existing SG communication network would be the key bottleneck for the future SGs. Thus, a novel WSN based communication framework is presented exploiting the emerging SDN networking paradigm. The thesis further develops a comprehensive analytical model that includes optimization of the controller distribution to enhance the performance of the proposed communication framework in the NAN domain. Lastly, an application specific traffic model is presented utilizing the optimized controller distribution in the NAN domain showing the improvement in the overall performance of the SG NAN network.
2. LITERATURE SURVEY
An understanding of the SG architecture provides a guide as to the requirements for SG communication networks. Different standardization bodies and organizations such as the DOE [1], the State of West Virginia [32] and the National Institute of Standards and Technology (NIST) [33] have developed conceptual SG architectures. However, the IEEE 2030-2011 standard has been broadly accepted as the first industry standard with a SG architecture, and configuration and interoperability requirements [34]. Within the standard, an operational model called the SG, and Interoperability Reference Model (SGIRM) is proposed to deal with the interoperability issues among different components of the communication network, power system, and information technology platform. The SGIRM provides a guide to communication between SG generation, transmission, and distribution domains [35].

Modern SGs can be represented in three layers called the Electric Power System Layer, Communication Layer, and Application Layer. Interestingly, there could be numerous applications such as Automatic Meter Reading (AMR), AMI, DR, Outage management, EV charging, Asset Management (AM), pilot protection [36] and fraud detection developed and deployed via the Application Layer. Advanced intelligent modeling of the applications could resolve crucial interoperability issues. The Electric Power Layer comprises four domains including the generation domain, transmission domain, distribution domain and customer domain. A key challenge for SG in this layer is to provide two-way power flow between the different domains to balance energy demand and supply. The core of an SG exists in the Communication Layer and provides interconnections between all of the devices and corresponding systems.

The NAN connects customer premises to utility control centers via the AMI network. The primary functional device of an AMI is the Smart Meter, which supplies consumption information and performs quality monitoring. It can also be used as an interface for energy control when used in the HAN and exchange information via the AMI system. The AMI system supports various types of intelligent SG applications such as DR, DERs, EV charging, and energy consumption in home displays. The network topology for a NAN is shown in Figure 2.3 where all of the smart meters are connected to a Data Aggregation Point (DAP) that accumulates all the data received and transmits the data to a control center.

It’s important to classify the required communication technology suitable for SG applications within NAN and WAN. According to [37], wireless communication may be the only practical solution to support last mile communications in the distribution domain, which provides connectivity from smart meters to the AMI access points. Hence, to implement wireless communication network technologies in SGs, the IEEE 802.15 Task Group 4g (TG4g) was founded in December 2008 to define the Medium Access Control (MAC) and physical layer (PHY) protocols based on the IEEE 802.15.4 standard for wireless smart utility networks (SUNs) [38]. In this context, it would be interesting to investigate the possible exploitation of TV White Space (TVWS) cognitive radio to enable M2M communication in the NAN domain. TVWS has been extensively studied [39] specifically for SG applications and in general as a promising communication technology for smart meters. It can be a viable, although not yet fully standardized, solution for the SG ecosystem.

The Workforce Mobile Network (WMN) is used by the utility for maintenance purposes and to carry out daily operations. SG applications can be added to the WMN, for example, V2G or G2V load management capable systems and smart vehicles with power that might be returned to the grid using location update services via tracking and navigation based on the Global Positioning System (GPS) [41]. Through the WAN, WMNs may access both the NAN and FAN to collect various types of information from equipment installed at customer premises. IEEE 802.11s is devoted to the architecture and protocols of WMNs because the communication requirement of WMN will be similar to non-M2M communication services including the Internet, voice or video applications [42].

As a widely accepted SG standard, IEEE 2030 could be regarded as the major recent standardization effort. It defines the end to end SG architecture by integrating power systems with communications and information technology [43]. The IEEE P2030.1 and IEEE P2030.2 standards add to the detail provided in the IEEE P2030 standard. IEEE P2030.1 defines a knowledge based addressing terminology, mechanism, devices, and planning requirements for EVs and ITS applications. IEEE P2030.2 covers discrete and hybrid energy storage systems integrated with the electric power infrastructure [44]. Also, IEEE 1547 specifies the standards to interconnect distributed resources and renewable energy sources with the electricity grid.

3. NETWORK ARCHITECTURE OF THE SDN BASED NAN
The system design for the proposed framework considers the specifications released by the TG4g task group and was motivated by the potential for SDN based M2M communications across the NAN domain. Figure 1 shows the conceptual architecture of the SDN based NAN. The sensor nodes are deployed in the customer premises of an SG to create Home HAN, BAN or IAN. Overall, with several HANs, BANs, and IANs a single NAN is created. Within a NAN, the sensor nodes are connected to associated switches, and the switches are connected to centralized NAN controller that also serves the NAN gateways. Each switch associates themselves with the closest SDN controller to retrieve the packet forwarding instruction. Packet dissemination control information is guided via a set of rules called flow commands provided by the SDN controller. Furthermore, each NAN is attached to an SDN NAN.
controller, and all the NAN controllers are connected to single NAN domain controller which also acts as the gateway.

Figure 1 SDN based WSN to support NAN architecture

4. FRAMEWORK CONFIGURATION

SG NAN and FAN applications mostly fall under AMI or smart meter based and usually semi periodic in manner. For example, AMR, DM, EV charging/discharging, micro-grid management, etc. DR is responsible for balancing the load between generation plant and consumers via implementing diverse load control programs. The load control could be based on dynamic pricing of the energy units or more advanced technique of RLC. An example of well-known dynamic price programs is TOU, RTP, CPP, PTR. On the other hand, characteristics of an RLC program can vary based on properties such as interruptible loads, reducible loads, partially interruptible loads. More details on these DR programs could be found in [199]. DA [200] should be designed for providing near real time information on grid operation to better the monitoring and control within the distribution grid. With a large number of DERs, it becomes more important. Because by utilizing the distribution level devices such as voltage regulators, fault detectors, capacitor bank controllers (CBC), reclosers, etc. A DA system can enable useful applications like Volt/VAR control, fault detection cleaning, isolation and restoration (FCIR) and distribution system monitoring and maintenance. Volt/VAR control adjusts the voltage and balances the load factor to reduce the energy loss. In distribution monitoring and maintenance, sensor data is used to monitor the status (open/closed) of various distribution grid equipment. With FCIR, a section of the grid could be isolated if there is an occurrence of a fault and automatic restoration system can be set up to minimize service interruptions.

Table 1. SG application with NAN

5. COMMUNICATION MODEL

The first task towards developing the framework of the SDN based SG NAN using WSN is to determine the control and data plane characteristics. At the time of network initialization, flows are defined via the controller and stored in the switches. These flow commands are stored permanently in all switches until the corresponding applications are active in the network. As shown in Figure 2, there are two delay tolerant SG application packets generated from the IEDs and smart meters. Upon arriving at the switch, packets are placed into a flow lookup queue. If the flow is matched with a flow stored in the flow table, the corresponding switch forwards the packet to the desired destination by placing the packet into the immediate buffer queue. If the flow is not matched, the packet is sent to the nearest controller requesting a flow control instruction be assigned. After retrieving a flow command for the packet, the packet is placed into the buffer responsible for handling missed packets and forwarded to the destination at the earliest opportunity. Note that, flow commands could be modeled in such a way that switches can unicast, multicast or broadcast the packet based on the SG application specification.

Figure 2. Message between network devices

6. ALGORITHM

The algorithm for Application classifier module at the application layer of the cluster switch is
In the control plane of the SDN-based NAN, SG applications could be configured and modified via the controller. The primary task of the controller is to provide flow control messages to the switches. Inserting new applications or updating applications is carried out by the controller. First, updates are disseminated to all other controllers, and then updates are pushed to the application-classifier module of the switch. Considering the fact that the proposed framework operates in WSNs, an association process of the controller to the SDSW is handled based on the Received Signal Strength Indicator (RSSI) and Round-Trip Time (RTT). Theoretical details on the controller association process could be found in [203].

7. SDN BASED DISTRIBUTION GRID ARCHITECTURE

In order to enable distributed control over a large area, a sector-based grid topology has been considered. The grid topology selection for cluster communication was influenced by the configuration of the power distribution system. According to [204] distribution systems are mostly radial where a certain number of service transformers are connected to a single feeder. A sample of a distribution network architecture. A service transformer of 50 MVA can usually provide ten service drop connections [204]. Based on this estimation, if a radial system consists of 108 service transformers, it can provide connections to 1080 smart meters. Thus, it can be assumed that the average number of smart meters in each sector would be around 10–11. The simulation scenario was varied with a different seed value, and total 100 runs were considered to provide results that included average and 95% confidence intervals.

8. PERFORMANCE ANALYSIS

The proposed communication framework of SDN based WSN for SG NAN was implemented using Castalia [204]. To derive accurate and realistic performance of the model, a popular suburb named Fitzroy from Melbourne, Australia has been considered. It is assumed that all of the houses in this suburb have smart meters installed. Based on simulation parameter on the transmission power the whole area has been divided into 96 sectors each covering (100X100 m2). It’s found that with a transmit power of 4.5dBm the maximum line of sight distance can reach up to 300m [36]. Based on the observation there are approximately 1000 Smart Meters uniformly distributed within this suburb. Thus, the relationship between the processing time and a number of the switches per controller based on the derived equation of the optimized number of distributed power to the home premises. Smart meters and IEDs are installed at each home and aggregate data for further processing. The meter data is sent to the corresponding switches and forwarded to the appropriate authority to enable various SG applications.

Figure 3. Distributed Network Architecture

The relationship between the processing time and a number of the switches per controller based on the derived equation of the optimized number of distributed
controllers and switches. Among the actively running SG applications, delay sensitive applications require maintaining strict delay boundary of processing time. Keeping this requirement in mind, the simulation model considered the average delay of 110 ms (average delay requirement of delay sensitive applications) as the minimum required processing time to determine the optimum number of controllers. Based on the analysis, it has been identified that the number of switches that can be handled by a single controller would be about 30. Accordingly, the considered topology of WSN would require four controllers in total if each sector of the NAN is equipped with a single switch. To evaluate the performance of the proposed model in the worst conditions, the second scenario of the simulation model considers no flows defined for any SG applications. Thus, each time a new application packet arrives at the switch, it is forwarded to the associated controller to get assigned with the new flow type. After successful initialization of flows, the packets are forwarded to the corresponding destinations.

![Graph 1](image1.png)
![Graph 2](image2.png)
![Graph 3](image3.png)

Figure 5 Delay profile of different applications and total average delay in the Best-case and Worst-case scenario, and flow processing time

8. CONCLUSION
In the proposed SDN based NAN communication framework, a group of IEDs and smart meters form clusters, and a single switch handles each cluster. For large WSNs based NANs, the maximum network throughput and efficiency (e.g. packet success rate) would rely on the optimal number of switches that will be deployed in the distribution grid. Also, robustness of the communication system would depend on intelligent implementation of distributed controllers in the control plane. The mathematical model presented in this chapter determines the optimized number of switches and controllers within the NAN. The minimum number of distributed controllers in a NAN domain is derived and presented graphically. Additionally, this chapter presents a novel SDWSN based G2V load management scheme appropriate traffic models to support the SG during the off-peak hour through efficient Valley filling technique. It’s evident through simulation based analysis that the proposed SDN based G2V communication model can successfully support the load management application. Furthermore, a range of simulation models are presented to here to demonstrate the feasibility of the proposed SDN based NAN communication framework for AMI applications. The simulation study considered optimized number of distributed controllers derived from the proposed mathematical model. Simulation results on the AMI traffic in SDN based NAN shows the average delay and success rates of a predefined number of smart meter operation in the NAN domain.

9. REFERENCES


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