# The Monitoring Network Architecture in the Neighbourhood Area of the Smart Grid

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**Abstract:**
The Smart Grid has three main characteristics, which are to some degree antagonistic. These characteristics are: provision of good power quality, energy cost reduction and improvement in the reliability of the grid. The need to ensure that they can be accomplished together demands a much richer ICT monitoring and control network than the current system, which is centrally controlled. In this paper we discuss our design choices for building a communication network alongside the power network. We examine the existing communication technologies and justify our choice for selecting one of these technologies as the most appropriate method of communication in our proposed architecture. We focus particularly on the neighbourhood area sub-grid. Since visualisation tools for monitoring the neighbourhood area of the power grid are currently lacking, we present a visualisation tool we have developed for this system.

**Keywords:**
Smart Grid, Neighbourhood Area Network, Monitoring, Wireless Technology, Visualisation Tool.

## 1. Introduction

The Smart Grid utilises diverse technologies such as power system automation, control, and communication to enable, real-time interoperability between electricity consumers and providers. This system intends to improve efficiency in decision-making systems which rely on resource availability and economics (Reed et al., 2010).

According to the U.S Department Of Energy (DOE) (Miller et al., 2008) desirable characteristics of the Smart Grid have been identified as; self healing, consumer friendly, reliable with good power quality, and resistant to cyber attack. In addition, it should be able to accommodate all storing and generation options, and enable new services and markets. To achieve these features we face challenges at each different layer of the system. One of the vital challenges is a lack of predictive real-time system controls, which is the focus of our research. Based on successful applications in the water distribution network (Khan *et al.*, 2010) we provide an architecture for integrating sensing, computation, and decision making to monitor and predict the future state of the power grid in real-time.

In a traditional electricity grid, there was only a power distribution network and the whole system lacked monitoring of the state of the grid, except at a centralised level. As shown in Figure 1, Smart Grid is considered to be an integration of a power network and a communication network. The power network, responsible for transmitting electricity from generation points to the clients, consists of three sectors; generation, transmission, and distribution. Our current proposal for such a communication network, responsible for providing communication between different sectors in a power network, has three tiers. These are known as: (1) wide area network (distribution), (2) neighbourhood area network (metering), and (3) home area network (consumers). Until now most work has focused mainly on wide area and home area communication networks (1 and 3). By contrast we have particularly investigated the monitoring of the neighbourhood area network (also called local area network (LAN)) in the distribution network of the power grid. The communication network at this level of the Grid is very underdeveloped, and it suffers from a lack of monitoring and predictive real-time system control. Thus, providing such communication architecture at the neighbourhood area of the sub grid will be an important contribution to the overall ICT architecture of the Smart Grid.

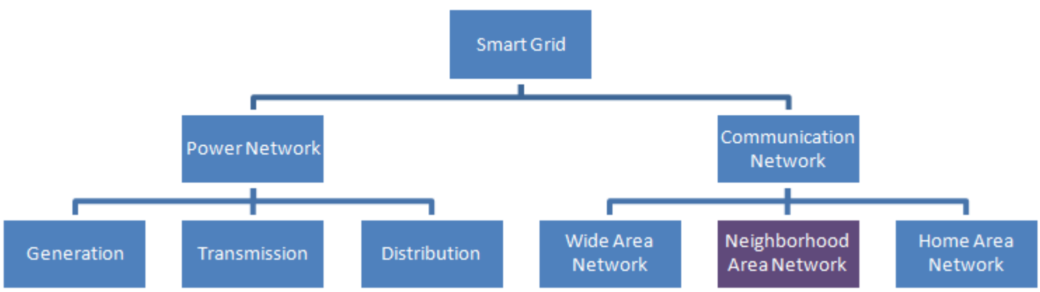


Fig. 1. Smart Grid Overview

## 2. Communications in the Power Grid

Some of the motivations behind having a communication network alongside a power grid are to give customers control over the price of their energy usage, which will lead to better management of demand. Also to reduce the personnel required to operate the Grid, and to integrate new Distributed Generation (DG) sources of energy that emit less $CO_2$ (Carbon Dioxide). In addition, since the electrical networks are one hundred and fifty years old, they face frequent disruptions (Farhangi, 2009). Smart Grid proposes to accomplish the above-mentioned goals by incorporating control technology in communication network. It is believed (Ericsson, 2010) that communication systems will be a critical tool for the operation and administrative purposes of the future power grid.

Our motivation for this research is also based on our understanding from other networked systems such as water distribution grids (Stoianov et al., 2007, Machell et al., 2010). Based on these studies, we believe that integration of computation and communication network could help power engineers to perform better control over the grid. Moreover, according to recent studies (Yang et al., 2011, Chuang and Mcgranaghan, 2008), it is believed that the controls that are being applied centrally could be done better by distributed control. Thus we have to design a system where some controls could be done locally in homes or at street level, while others could be done at higher levels. Furthermore, by reviewing the literature (Abbasi and Younis, 2007, Raghunathan et al., 2004, Youssef et al., 2003), we design an architecture to provide a better information flow in the grid, compared with the previously proposed systems.

From the literature mentioned above, and also from a wider literature review phase, we have identified that there is less research on street level communications, called a Local Area Network in this research, and most of the research considers the whole Distributed Generation (DG) network as well as the local area. Considering the case where all information is collected at a DG level database, where controls are applied, we encounter the problem of information flooding. Moreover, by conducting a survey of available communication technology (Parikh et al., 2010, Nordell, 2008), we identified that it is not feasible to use one single technology for the whole grid but that heterogeneous communication technologies should be provided. Observing that one of these technologies should be wireless, and since wireless sensor networks are energy constrained we believe the communication network in the Smart Grid should use energy efficiently in order to prevent poor communications.

## 3. Related Work

Recently several attempts have been made to upgrade the existing grid to the “smarter” grid, such as GridStat (Bakken et al. 2002), GridWise (Cherian & Ambrosio, 2004), and numerous others. However, this research mainly focuses on the Wide Area Network or Home Area Network and there is less research on Local Area Networks (LAN).. Therefore, in this paper, we concentrate on this level.

Currently the available intelligent monitoring system in place for the sub-Grid is SCADA (Supervisory Control and Data Acquisition) (Daneels and Salter, 1999). It is used for collecting data from the grid. One of the limitations of this system is that it fails to monitor the whole sub-Grid, and only monitors the critical areas of the network. Thus, our architecture should go beyond that and monitor the entire network. It has also been observed that SCADA has slow data update rate (Qiu et al., 2011), and lacks the ability to control the distribution network in real-time (Kayastha et al., 2012). These issues make SCADA inappropriate for the Smart Grid applications.

There has also been use of sensor data to monitor water networks, for example the Neptune project[1]. Building on this, it is possible to create dynamic visualization interfaces for monitoring and controlling the system (Haines et al. 2009). Our work extends this latter approach to the electrical Grid where the monitoring systems take account of much more rapid changes in the state of the network (seconds rather than hours).

## 4. Existing communication Systems

In order to transmit data in the communication network of the Smart Grid there exist several options such as using power line communication, fibre optic, radio wave and so on. Initially, Power Line Communication (PLC) seemed to be the best option, since the cables are already there and there will be no deployment cost. Also the energy constraint problem of a Wireless Sensor Network, WSN, could be prevented. However, due to two fundamental shortcomings, PLC was rejected. Firstly, advanced noise filtering and error correction mechanism is required in PLC (Galli et al., 2010). Noise filtering is a big problem, particularly when we want to collect fine-grained information at quite a high rate. Secondly, if we rely on the power line for communication, we cannot monitor the areas with cable breakage or some other faults in the field. On top of these, there exist other difficulties such as lack of standardization between different vendors. Moreover disturbances in the distribution line and switching off the distribution line will lead to changes in communication routing (Nordell, 2008).

Another option is a satellite system, but due to cost and signal delay it is not the best available option. Fibre optics offer high bandwidth, large communication distance and they are expected to be cost efficient in the long run, but due to the high cost of installing them in key areas of the electrical network, we consider they are not the best available option (Nordell, 2008). Our investigation for this project shows that what drives the cost up is the cost of actual installation. Radio systems use cheap components and they are easy to install, and they provide communication to any geographical area with poor access, thus they seem to be the best candidate.

It is considered that (Nordell, 2008) wireless can be used either for communications in the substation, or over longer paths such as between substations or between enterprises and the substation. Since the wireless communication is at a sufficiently high frequency as to be resistant to electromagnetic interference from the electrical and magnetic fields in each substation, this system is one of the best options for the communication system. Among various wireless communication technologies, each individual technology seems to be suitable for different applications in the Smart Grid. As an example, ZigBee (IEEE 802.15.4) operating on various unlicensed frequency bands with 20-250 Kbps data rate, covering 10-100m, is suitable for home area networks

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[1] http://www.shef.ac.uk/neptune/projectdetails

(Parikh et al., 2010). In addition, infrared transmissions are only suitable for home and indoor applications due to the drawback that can easily get absorbed by rain and dust, and they have a short coverage in distance (Tan et al., 2011).

Alternatively, Wireless LAN (IEEE 802.11a,b,g,n,i), WiMAX (802.16), cellular technology, and Mobile Broadband Wireless Access (IEEE 802.20) are appropriate for wide area network applications and in our proposed architecture they are suitable for providing the communication between the Wireless Sensor Network (WSN) and the local computation unit. Finally, Bluetooth (802.15.1) with its low power, short range coverage between 1 to 100m with extended antenna, and 721Kbps data rate, seems to be a good candidate for monitoring applications in home and neighbourhood area network. However, Bluetooth is less secure compared to other standards, and interferes with IEEE 802.11 (Parikh et al., 2010). Despite these drawbacks of Bluetooth its low power requirements fit the need for communication between street level sensors. Additionally, since Bluetooth is able to integrate well with mobile phones used by engineers in the field, this system is one of the best options, from current communication technologies, to meet our system requirements.

## 5. Research Methodology

In this project we apply principles of WSNs to the electrical network where monitoring and controlling is required. We test these principles in an actual NAN environment, where monitoring has not previously been deployed. Since there is no previous monitoring at this level we do not have previous experimental data to compare our results with. Thus, we use a combination of simulations and real experiments to evaluate our architectural proposals and communication technologies. The current monitoring and controlling system in place is a centralized system, which is no longer adequate for a new intelligent electrical grid. In this project we are migrating from centralized monitoring to distributed local monitoring. Since this new local monitoring is not a well-understood problem, first we have to design and build such a system to allow experiments. Observing that the information has to be sufficiently up-to date to permit effective control of the system, we are working to develop an ICT system that can meet their requirements in the most energy efficient manner (Pourmirza and Brooke, 2012a).

Our proposed architecture (Pourmirza and Brooke, 2012a) uses a sensor network communicating via radio technology to monitor the whole system. This architecture is a combination of peer-to-peer and hierarchical architectures, utilizing various communication technologies for transmitting data. It represents the integration of sensor networks and distributed computation. An advantage of the proposed architecture is that it will prevent a single point of failure. It is a modular architecture for controlling a particular local area in the sub-Grid. In previous work, we provided evidence that the proposed architecture will bring energy efficiency to the communication network (Pourmirza and Brooke, 2012b). Moreover, we demonstrated the optimal topology of the WSN in our test bed (Pourmirza and Brooke, 2013).Given that the energy for data transmission is higher than energy for data computation (Heinzelman et al., 2000), by reducing the transmission range and adding more computational units for local control, we could achieve an even more energy efficient architecture. Finally this architecture can avoid a bottleneck caused by huge amounts of information travelling in the system, by adding a number of local computational units and by sending a lesser but sufficient amount of data to enable higher level control.

## 6. A Monitoring Network for a Neighbourhood Area

As discussed earlier, we consider the implementation of a monitoring network over the power network in the neighbourhood area of the Smart Grid. A list of applications for such a monitoring system, has been identified through our research and that of other researchers (Veleva and Davcev, 2012). The list is as follows:

- Real-time data collecting applications,
- Home Area Network (HAN) applications,
- Substation monitoring applications,
- Energy management applications,
- Power quality analysis,
- Equipment monitoring,
- Equipment theft prevention,
- Traffic monitoring applications,
- Weather (temperature and humidity) monitoring applications,
- Outage warning,
- Fast fault identification and rectification,
- Planned outage scheduling,
- System maintenance scheduling,
- GIS applications,
- Motion applications,

Finally, monitoring at this level can also be used for car park monitoring in order to predict the future load from electrical vehicle charging.

## 7. Visualisation Tool for Neighbourhood Area Monitoring

Visualisation tools are employed in many engineering fields, such as water distribution grids, to display and manage large volume of data. However, there is far less research on this topic in the power network. In order to make the real data and network topology of the power grid comprehensible by network operators and engineers in the field, a software system representing a visualisation tool has been developed. It overlays information about the condition of the electrical network onto GIS systems, in our case Google maps. We use it to visualise real data extracted from a University Campus NAN test bed. We also overlay visualisations of the sensor data in the form of charts and graphs, and give users the option to choose specific data from a desired time interval, and finally to send active and passive alerts in case of emergency.  Figure 2 below illustrates our visualisation tool and demonstrates how data relating to the sensors is overlaid on the Google Maps GIS background.

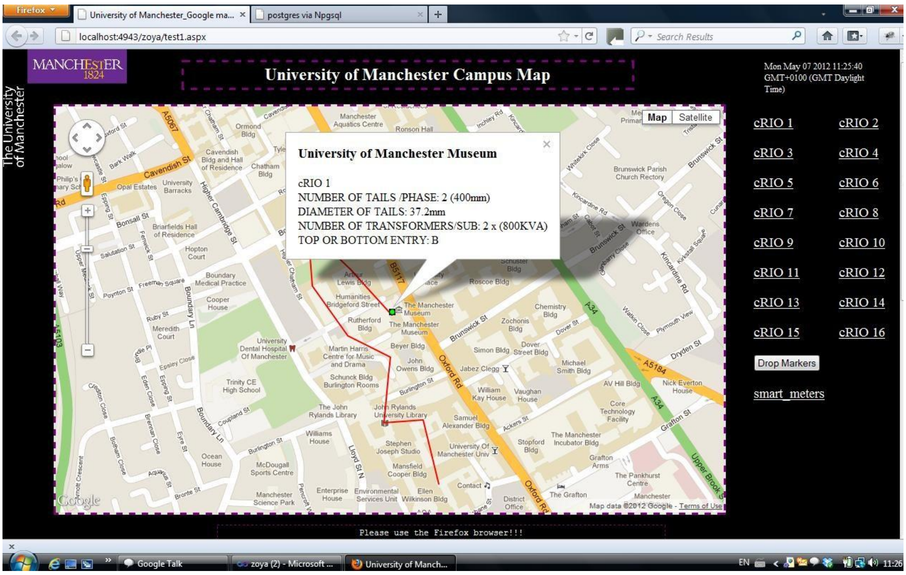


Fig. 2. Visualisation tool

The first step in designing a new software system is to identify its requirements. In software engineering, functional requirements are defined as the concrete functionalities of a software system. Most of the functional requirements are used to provide the use cases. However, non-functional requirements are described as the qualitative characteristics of a system. We now outline the functional and non-functional requirements of our visualisation system and present a use case diagram of our visualisation tool.

One of the most important functionalities in our systems is to display the flow of data via tables and graphs. In addition, it is vital to demonstrate the position of each metering devices on the map since their data may vary according to their locations. Security requirements dictate that users need to be authorised to gain the required read permission of the database to access the data. Finally, monitoring needs to be combined with the ability to alert users about unusual events or conditions and also their locations in the sub-Grid.

The aforementioned functional requirements allow us to identify some use cases for the proposed tool. The title of each use case is selected as an action-verb, which refers to the primary goal of each functional requirement. The internal-actors of this system can be divided into two categories: unauthorised and authorised user. The system starts with the first use case, called 'Show Map'. This use case is based on the Google Map API and locates all the metering devices on the map. 'Select Device' is identified as a second use case. This case can be called by both authorised and unauthorised users, and it is employed to present the information regarding a specific metering device on the map as well as showing its position according to its longitude and latitude, and displaying its data. However, the data demonstration functionality requires two prerequisite use cases, including 'Login' which changes the status of the user from unauthorised to authorised user and 'Request for Data' which has some sub-functional requirements such as filtering the data according to the date and drawing an appropriate chart. The last use case describes how the system informs its users of data that exceeds a threshold. This action can be an active procedure that sends data over a threshold to both authorised and unauthorised users. It can also be a passive procedure that highlights these values in a table to be viewed by an operator. Figure 3 below illustrates the use case diagram for the proposed visualisation tool.

Furthermore, some non-functional requirements have been considered in the design of the proposed system such as:

- Accessibility: this system can be accessed via different devices such as PCs and portable devices such as PDAs and Mobile devices.
- Backup: the tool will save a mean value of data in another table, in order to have a backup system when required.
- Open Source: the system is under the GNU LGPL 2.1 license.

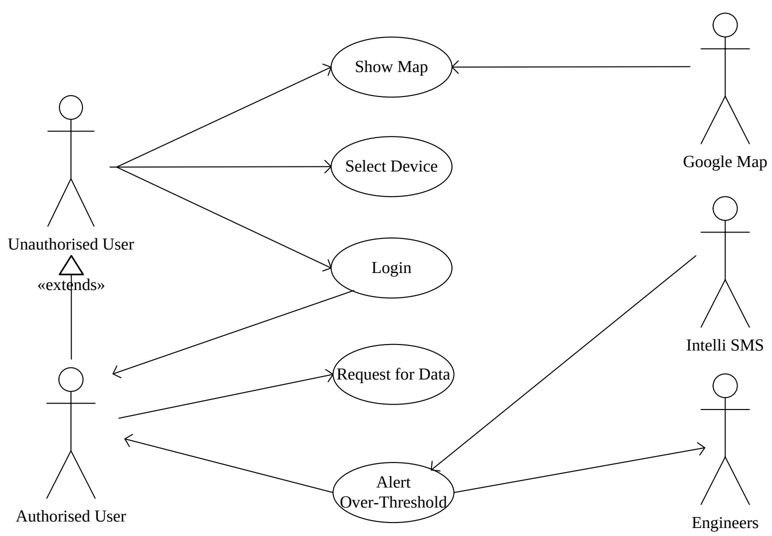


Fig. 3. System Use Case Diagram

## 8. Conclusion and Future research

In this paper we have focused on the communication system in the neighbourhood area network of the Smart Grid and we justify the need for having such a system alongside the current power grid. Bluetooth is selected as an appropriate communication technology due to its low power requirements and ability to integrate well with the mobile devices. Also the applications of the monitoring network in the neighbourhood is identified and discussed. Moreover, we have developed a visualisation tool for monitoring the neighbourhood area in the power grid. Finally, the functional and non-functional requirements of this system are discussed. Currently the visualization tool is receiving real data from smart meters on the University Campus. These are already connected by wired connections. We are simulating sensor data from a TinyOS sensor simulator to represent the real data that will come when the sensor network is installed.

In future work we will add more functionality to the visualisation tool, according to the needs of the electrical engineers. Also it is intended to implement a control algorithm via the visualisation tool for controlling the sub-grid. Thus this tool will not be only used to monitor and display the information of the grid, but also it can be used to actively control the grid locally and examine the what if scenarios. Additionally we will investigate data reduction algorithms to provide efficient flow of the information between the sensing field and the visualisation tool, which is located at the control unit.

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