# Smart Grid Communications: A Renewed Challenge to Multiservice Networking

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## Abstract

This paper focuses on the multiservice aspects of the Smart Grid communications system with particular emphasis on the real time requirements of its control system. A general outline of the Smart Grid is presented and its general communications requirements are identified. The stringent real-time requirements of substation and transmission line control are discussed in greater detail. An overview of previous and current research into multiservice networking is given with the aim of identifying areas that need to be revisited, and extended, in order to meet the real time needs of the Smart Grid. The paper then presents proposals for future research into number of specific areas relevant to meeting these requirements.

## Keywords

Smart Grid communications; Multiservice Networking; Network Control Systems.

## 1. Introduction

The Smart Grid concept is motivated by the desire to make greater use of renewable energy sources and the need for a more efficient utilisation of existing energy supplies. The realization of the Smart Grid involves the amalgamation of a power distribution network and a communications system so that together they become a single more powerful system

Communication systems have played an important role in the management of power grids for many years, supporting both data acquisition for systems monitoring, and control functions. Existing power grids are mainly concerned with bulk generation of power, and its transmission and distribution to the consumers, who generally play a passive role in the process. However, in the Smart Grid, not only will there be a greater variety of power generation sources to manage, including many based on renewable energy, there will also be the need for more efficient control over existing resources. Furthermore the consumer’s role will no longer be passive. The introduction of smart metering, demand response, real time pricing and other interactive services will enable consumers to have greater control over their energy consumption. Consumers will also have the opportunity to implement the monitoring and control of smart devices within their own domain through the deployment of home area networks (HANs) that will be connected to, and thereby becoming part of, the Smart Grid communications system. Furthermore, the most significant paradigm shift is that consumers can also become suppliers, generally via renewable energy sources, e.g. solar, wind or water power. In addition to providing services for the monitoring, control and management of the technological infrastructure of the Smart Grid its communication system will be expected to provide services for a wide range of commercial and organizational activities, example of which include smart meter reading, automatic billing, real-time pricing, marketing etc. Many of these applications will have requirements very similar to those of applications being served by the current Internet, including the need for wide area, and possibly global, interconnectivity. Therefore, it is generally agreed that IP networks will form the basic transport mechanism for Smart Grid communications. However, many Smart Grid control functions have real-time requirements, some of which are both time critical and stringent. Therefore, the Smart Grid communication system will need to be a fully multiservice network. This paper presents an outline of the Smart Grid to identify its general characteristics and discusses its communications requirements with particular focus on its real-time needs. It then reviews the current state of research into multiservice networking, identifying what requirements can be met by existing facilities and those that will need additional support to be developed. The paper then presents some proposals for future research aimed at meeting the real-time requirements of the Smart Grid.

The remainder of this paper is structured as follows: section 2 introduces the Smart Grid and indentifies its communication requirements; section 3 discusses previous works into multiservice networking, indentifies the current state of the Internet's multiservice capabilities, and reviews more recent developments that could contribute to Smart Grid communications; section 4 presents some proposals for further research aimed at meeting the real-time requirements of Smart Grid communication; and finally section 5 concludes.

## 2. The Smart Grid

Over the past few year researchers have been addressing the problems of evolving and extending grid communications into a greater and more heterogeneous system that can support, and will help bring into being, the Smart Grid. This body of work has focused largely on the overall physical systems architecture of the smart grid, considering general infrastructure, the interoperation and integration of heterogeneous technologies and the relationship between different participants in the Smart Grid (Bouhafs 2012, Budka 2010, Fan 2010). It has resulted in the generalization of a Smart Grid system, a simplified topology of which is shown in Fig. 1. It has also addressed the challenge of Smart Grid communications and the Quality of Service (QoS) requirements of Smart Grid applications and services, including management, control and security (Budka 2010, Fan 2010). Collectively, this body of work presents a general picture of the Smart Grid system and its basic requirements that generally can be summarized by the following points.

- The Smart Grid will have a hierarchical structure
- It will comprise multiple domains of ownership that do not necessarily have a one-to-one correspondence with the hierarchical structure.
- It will involve bi-directional flow of both power and information.
- The Smart Grid will be built using heterogeneous technology.

- Its communication infrastructure will need to provide appropriate QoS for a number of different classes of communications traffic some of which will have stringent timing requirements
- Both power distribution and communications will need to be secure and robust.
- Because of the need for wide area connectivity, it is generally expected that IP networks will provide the basic transport mechanism for Smart Grid communications.

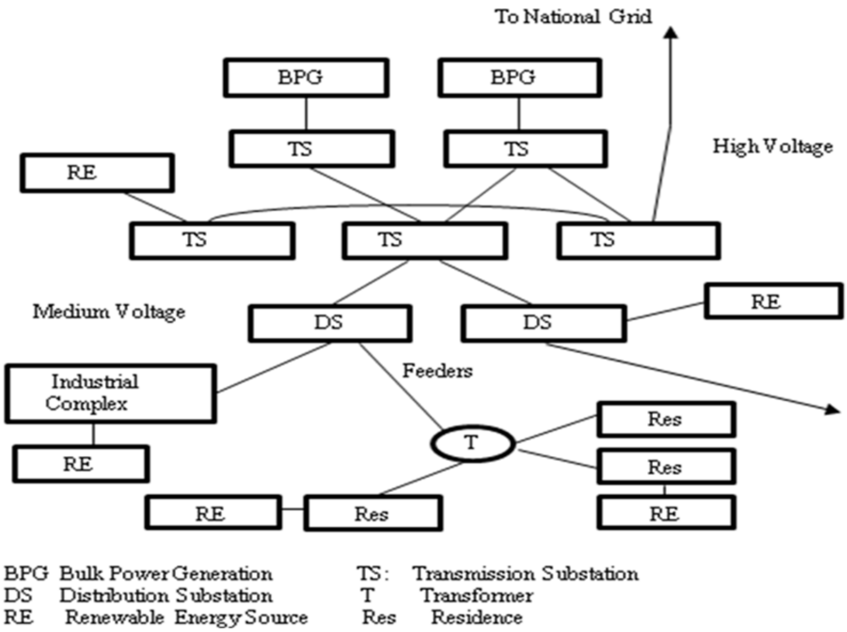


**Figure 1: A Simple Example of a Smart Grid Topology**

## 2.1. Heterogeneity and Diversity in the Smart Grid

The Smart Grid will comprise a wide range of heterogeneous equipment and technologies in both its power distribution network and it communications system. There will be a wide diversity of stakeholders and multiple domains of ownership. To compound this, these domains of ownership may not always correspond directly to the power distribution hierarchy. Furthermore, Smart Grid consumers can play a more active role in the control of their consumption (Bouhafs 2012, Budka 2010, Jeon 2011) and will also have the opportunity to become consumer-suppliers. In some cases the consumer-supplier could be a relative large scale industrial complex, in which case it could well have its own networked control system interconnect to the Smart Grid communications system. Although not as yet widely discussed, there is also the potential for communities of consumer-suppliers to form their own mini-grids of renewable energy resources and thereby sharing surplus generation between themselves before taking from, or putting into, the main grid. Because of this diversity the problem of building the Smart Grid will need to be addressed at multiple levels of abstraction, and to consider numerous different perspectives, e.g. scientific, technical, commercial, economic, political and social etc.

## 2.2. Smart Grid Communications Requirements

Wang and Khanna (Wang 2011) present a thorough and comprehensive discussion on the requirements for Smart Grid communications. In this section we highlight those elements which are most relevant to the objective of this paper. Firstly, the Smart Grid communication system will have many requirements in common with the global Internet and other networks, i.e. it will need to be reliable, secure and resilient (Sterbenz 2020). One difference being, that certain Smart Grid applications require a reliability of better than 99.999%, which translates to an average downtime of 5.3 minutes/year (Budka 2010). Also, many of the applications relating to its commercial activities such a marketing, customer relations, financial transaction etc. will have requirements identical to this type of application currently being served by the Internet.

The most significant difference arises due to the requirements of Smart Grid control applications, in particular substation control and transmission line monitoring. Both require real-time bidirectional communications and for certain of their activities, e.g. teleprotection, the real-time requirements are quite stringent. These are also the applications that have the highest reliability requirements. Furthermore, it is almost certain that meeting these requirements will be enforced by regulation. Failure of teleprotection applications may result in outages, destruction of grid infrastructure, and in the worst case, potential loss of life (Budka 2010). Exchange of protection information has the shortest delay requirements: 10ms for messages conveying control and monitoring information; and 3ms for urgent fault reporting messages (Wang 2011). Delay is defined as the end-to-end delay, including both processing latency and network delays. Response messages have identical delay requirements. This class of traffic will require high transmission rates, but will produce a relatively low volume of traffic. Teleprotection devices produce continuous data streams with typical rates of between 60 and 100 messages per second for control and monitoring, and individual asynchronous messages for fault reporting. Also, in the case of substation control the domain of operation is within a relatively small geographical area as shown below in Figure 2.

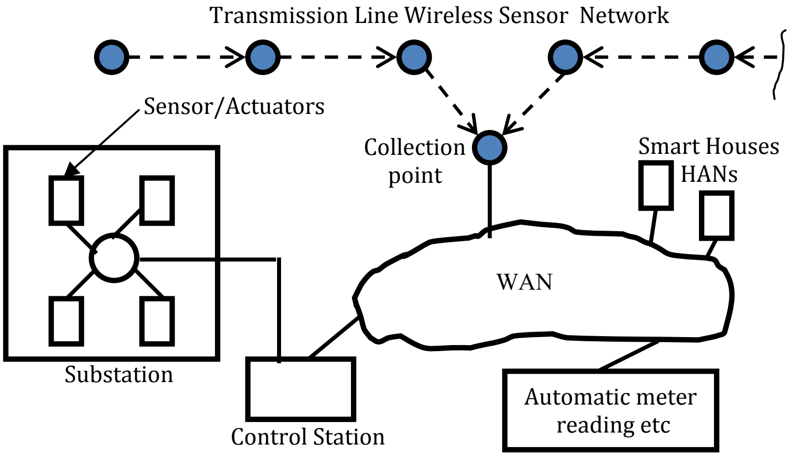


**Figure 2: Substation and Transmission Control Domain**

However, as shown in figure 2, protection information for transmission line monitoring may need to pass through a wide area network. Furthermore, for reasons of economy it is generally expected that wireless sensor networks will be used to collect real-time status information. Therefore, meeting the real time requirements of transmission line monitoring may be more problematic than meeting those of substation control. Substation control and transmission line monitoring are both examples of a Networked Control System (NCS) (Gupta 2010), i.e. a control system that operates over an open network that is shared with other classes of traffic. Designers of NCSs face two challenges: maintaining the appropriate QoS in the networks; and ensuring that the required Quality of Control (QoC) is provided. Therefore research into NCSs focuses on two objectives: Control of the network, to ensure a suitable QoS; and control over the network, that seeks to minimise adverse conditions in the network. The possibility that NCSs methodologies could achieve some relaxation of the more strident timing requirements is worthy of further investigation. Other Smart Grid applications that have less stringent real-time requirements are: voice communication, whose requirements are identical to those of VoIP; and video streaming for surveillance, the requirement of which are not as yet defined.

Finally, due to the complexity of the Smart Grid and diversity of its requirement a significant number of researchers support the need for a new reference model for Smart Grid communications (Bouhafs 2012, Budka 2010, Fan 2010, Jeon 201, Maqousi 2013).

## 3. Multiservice for Smart Grid Communications

Research into multiservice networking began more than two decades ago and early work clearly demonstrated that in order to meet QoS requirements of different classes of data traffic, continuous media traffic (real-time audio and video) and other real-time traffic within the same network three basic functions must be provided within that network (Campbell 1997): Bandwidth Partitioning or Class isolation; Admission Control; and Access Control. Also, the general philosophy at this time was that meeting QoS was the primary objective, and efficient utilization of bandwidth was a secondary goal. This early research activity focused on bandwidth partitioning mechanisms leading to the development of WQF, CBQ and their many variants. Hybrid CBQ-WFQ approach based on non-preemptive priority queuing were shown to fully meet the QoS requirements of both date and real-time traffic in IP networks (Ball 1999) and it also shown they could operate in conjunction measurement based admission control mechanisms (Maqousi 2002) to further improve the efficiency of bandwidth allocation.

However, at some point in the late 1990s, the increasing popularity of the Internet and consequential increase in demand for the fast transfer of bulk data led to a change in priorities. Research into multiservice networking and QoS began to focus more on the higher layer and in meeting the requirements of adaptive applications. This change also reversed the earlier philosophy and placed a greater importance on maximizing throughput. Research that continued in the network layer focused mainly on active queue management e.g WRED etc, Diffserve, MPLS and QoS routing.

In general, today's Internet has become optimized for the rapid transfer of high volume data traffic. Service differentiation is offered but generally limited to a small number of classes with different levels of throughput assurance. Expedited Forwarding is available but is not guaranteed to be respected on a global basis. Real-time continuous media traffic is accommodated, but only with loose guarantees. In general, these services reflect the current commercial and economic demands of the Internet's users and providers.

Some Smart Grid applications such as automated meter reading, real time pricing, marketing etc., have very similar requirements to current Internet applications, and therefore could be served adequately by the current Internet. However, it is clear that, without significant changes, the current Internet is not capable of meeting all the requirements for Smart Grid communication. However, from the point of view of cost effectiveness, making as much use of existing infrastructure would be beneficial, although new infrastructure will need to be developed to meet the new requirements where necessary.

Fortunately, concepts such as virtualisation, and overlay networks provide the means to integrate exiting and new infrastructure into one generalised communication system. Fan et al (Fan 2010) consider the use of self-organizing overlay networks over the wide range of existing infrastructure to be the best way forward for developing Smart Grid communications. However, it is emphasised that in order to meet delivery guarantees the real-time requirements of certain Smart Grid applications, appropriate support mechanisms will also need to be deployed within the lower layers of the network. Without this support in the lower layers, overlay approaches would be unable to request guaranteed communication channels. Therefore the requirements of Smart Grid Communication are renewing the old challenge of fully supporting the QoS requirement for all classes of traffic within the lower levels of the network.

Recently, researchers have begun to revisit the problem of multiservice at the network level in line with the requirements of Smart Grid communications (Alishahi 2013, Sadeghi 2012). Proposing the combination of non-preemptive priority based scheduling, CBQ/WFQ and AQM mechanisms within the network layer to provide the necessary degree of class isolation. They indentify that the current Diffserve framework has an insufficient number of classes to meet the needs of Smart Grid traffic, and that more classes will need to added. Apart from the specific focus on Smart Grid requirements, this work mainly confirms the findings of much earlier research.

However, there have been many changes during interceding years that can influence performance within the substrate. In particular, robust security is an essential requirement, resulting in security measures being almost universally applied throughout all levels of the communications process. Davies et al (Davies 2011) demonstrated by measurement and experimentation that security measures, in particular the processing of Access Control Lists (ACLs), can add significantly to packet forwarding delay. Producing a general increase in the order of 100%, and even greater in certain cases. Furthermore, they discovered that the magnitude of these delays was such that packet forwarding, and not link speed, could becoming the limiting factor for throughput, thereby invalidating a general assumption used in many performance evaluation scenarios. This work clearly demonstrates the importance of understanding the performance characteristics of specific network equipment, and the effects of certain configurations, when carrying out performance evaluations. This is particularly important if these evaluations are to be used in the design of networks that are expected to meet real-time requirements.

Fortunately, there have also been potentially beneficial developments. Cross-layer Architectures (Kliazvich 2011) have been proposed as a solution to the problem of providing interaction and exchange of information between non-adjacent layers in the protocol stack. Software Defined Networking (SDN) paradigm, of which OpenFlow is a particular example (Egilmez 2012 ), separates packet forwarding from network control and allows complex functions e.g. route management, dynamic QoS routing, dynamic resource allocation etc, to be executed in the higher layers of the network. It also provides for the dynamic reconfiguration of network equipment itself, i.e. routers and switches. Egilmez et al (Egilmez 2012) have shown that QOS-routing implemented in a SDN framework can provide an improvement in QoS for video streams without the need for resource allocation, however, the improvements shown relate only to the image quality and the effects on temporal quality are not discussed. Meeting strict real-time requirements will most probably need class isolation to be provided in the routers. Both cross-layering and SDN will inevitably generate some form of control traffic, however, to some degree this may be predictable from the type of control functions being used. SDN is based on a central controller for the network or for large networks, a domain. Domain controllers can be connected together via a higher level controller to form hierarchies in the network. Network equipment and traffic control mechanisms can be configured to suit the individual requirements within the domain. The SDN paradigm supports the dynamic reconfiguration of network equipment, and the provisioning of resources on a domain by domain basis, therefore making it a suitable framework within which to develop a Smart Grid communications system. The potential reliability problem associated with central controllers may need to be addressed, however, substation control and transmission line monitoring are already based on a single control centre.

## 4. Addressing the Real Time Requirements of the Smart Grid

The real-time requirements for certain Smart Grid functions are quite stringent and must be met or these functions will fail to work correctly. Failure could have serious consequences; therefore, meeting these requirements must be the primary objective, with efficient utilization of resources as a secondary goal. Fortunately, the most stringent requirements will, in general, only need to be met within particular domains (e.g. within substations), and along certain paths through other domains. There is also a possibility that these requirements may be mandated by some regulatory body, or through standards. Therefore, whatever solution is deployed to meet these requirements, its ability to meet them must be known *a priori* to deployment. Therefore, some form of pre-deployment evaluation or compliance testing may be required. With these points in mind we offer the following proposals for future research into meeting Smart Grid real-time requirements.

We believe there is the need for a number of performance evaluation studies to be carried out within the context of a network domain and using relative detailed modeling of network equipment. One focus for study is the case of strong class isolation through multi-level priority queuing and resource allocation for the priority based classes being implemented within the lower layers. Results from such studies would be aimed at supporting the design, and deployment of future networking equipment. Another focus would be based on the deployment of existing networking equipment and the use of over provisioning in an attempt to meet these requirements. These two focuses represent the two extremes of the available options; therefore other studies could consider the evaluation of some examples of DiffServe implementations. Results obtained from the different focuses could be used for comparative evaluations of the various options, and the models developed during these investigations could serve as tools for network design. It is also possibly that these evaluations could identify a baseline, below which certain options could be eliminated as suitable candidates.

A significant problem faced when attempting a detailed performance evaluation of existing equipment is the lack of detailed information regarding its internal operations. Such information is not generally available from vendors for reasons of commercial confidentiality. However, if the required information could be provided in the form of some generic model, or abstraction that would meet the needs for performance evaluation without disclosing sensitive information, this could be a solution to the hidden-detail problem. The Queuing Network Model (QNM) is one potential abstraction that might serve this purpose. QNMs are generic to any system of flow involve discrete entities, of which a communication network is a prime example. Although very often difficult to solve analytically, with some experience forming the model itself is not too difficult, and once formed it can be evaluated via simulation. We have used QMN successfully in our previous work and would recommend them as a potential candidate for the proposed evaluation studies presented above. Their potential as a possible solution to the hidden-detail problem could be investigated as a related side issue.

There also the need for performance evaluation studies of the combined operation of the SDN control system and the substrate, since both will influence the overall performance within the domain. At this level evaluation will need to consider the influence and effectiveness of dynamic reconfiguration, QoS routing, dynamic resource allocation, security and reliability and the influence of different protocols. Models that have been developed for evaluation at substrate level could be incorporated into this high level study possibly leading to a layered evaluation model. Furthermore, given that functionally, control and communication are effectively one system, co-evaluation may also be required. Co-design and co-simulation is considered the way forward by the NCSs community for respectively developing and evaluating NCSs. Therefore, a structured evaluation methodology developed in conjunction with the initial evaluation studies, and based on the experience gained, could make a useful contribution to the design of future Smart Grid networks.

## 5. Conclusions and Future Work

This paper has outlined the Smart Grid concept and discussed the requirements of its communication system. It has reviewed the current state of multiservice networking research and practice, recognising that certain Smart Grid communication requirements that cannot be supported by existing networks in general. The paper then considered how results of earlier work could be revisited and extended to provide the appropriate level of support for these new multiservice requirements. Finally, the paper offered some proposals for further research that could contribute to the development of a fully multiservice Smart Grid communications system. In future work the authors will be pursing research in line with the proposals presented in this paper, and are interested in discussion and collaboration with others involved in related work.

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