Next Generation Networks for Telecommunications Operators Providing Services to Transnational Smart Grid Operators

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Abstract: Due to the networking expertise, services and technical support of telecommunications operators, Smart Grid (SG) operators prefer telecommunications operators for their communications needs instead of creating private networks. In this paper, the use of Next Generation Networks (NGNs) by telecommunications operators to provide services to transnational SG operators for SG applications is evaluated. NGNs are all IP networks which are packet based and use IP to transport the various types of traffic such as data, voice, video, and signalling over converged fixed and mobile networks. The main idea of transnational SG operators is simple. By creating a huge single infrastructure for energy, more than one countries and nations can be powered at once. For this, it is not needed to install very huge power plants. Simply creating a complex network of power grid connections to each participating country is enough. The results of a set of simulation studies are given to show the efficiency of the NGN-based communication infrastructure for SG applications in terms of important network performance metrics. The results show that NGN-based communication infrastructures can carry packets based on their priority levels and bandwidth allocations in order to meet the specific requirements of SG applications.

1 INTRODUCTION

Considering environmental concerns, limited infrastructure is seen as one of the biggest constraints in green energy since it is not easy to shift to a totally different energy source and adapt of new energy technologies. On the other hand, if renewable energy systems are designed to provide power to many countries and nations, it is possible to connect each of their national energy systems together. However, if transnational Smart Grids (SGs) are designed, more economical issues and complexities than national SGs if purely fuel-based energy systems are involved. With renewable energy, the problems may not be completely resolved, but at least it will be possible to concentrate more on the distribution of the SG's energy output to the entire grid. For national power grids, load balancing may be a serious issue if individual or single location-based renewable energy systems are involved, but with a transnational power grid, the problem of intermittency may be solved by involving solar or wind farms connected to the grid that would always supply energy. In this way, the transnational power grid will basically just shift energy loads to the connected countries.

To fully exploit the benefits of Smart Grid (SG), many applications with varying levels of QoS, reliability, robustness and security for different purposes have been developed. The applications deal with different issues including demand and response management, asset management, and outage management. Since, in the SG with an advanced communication infrastructure, various types of data are required to communicate efficiently with different degrees of QoS, reliability, robustness, and security (Gungor et al, 2010; Livgard, 2010; Moghe et al, 2009; Sood et al, 2009). Therefore, the communication infrastructure requires end-to-end reliable two-way communications, and interoperability between applications with sufficient bandwidth and low-latencies (Erol-Kantarci and Mouftah, 2011).

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To the best of our knowledge, in the literature there are no prior studies evaluating the effectiveness of Next Generation Networks (NGNs) by telecommunications operators for utility applications in large scale SG deployments of transnational SG operators. Therefore, in this paper, we focus on the use of NGNs for smart grid and evaluate its effectiveness. The contribution of this paper is twofold. First, the use and advantages of using an NGN-based communications infrastructure are presented. Second, with the result of a set of performance evaluations, the effectiveness of NGNs for SG applications is shown. The rest of the paper is organized as follows. A description of the SG infrastructure is given in Section 2, focusing on the data communication properties, followed by an introduction to SG applications and their communication requirements. Section 3 presents the use of NGNs for SG applications and discusses implementation aspects. Section 4 presents performance evaluation. Finally, Section 5 concludes the paper.

2 SMART GRID COMMUNICATION INFRASTRUCTURE

As shown in Figure 1, the *communication infrastructure* can also be considered to consist of three different transmission categories: 1) Wide Area Network (WAN), 2) Neighborhood Area Network (NAN) and 3) Home Area Network (HAN) (Gungor et al, 2013). Between these three networks the core backbone, backhaul distribution and the access points are located. These transmission categories are briefly described below.

- **WAN:** Basically, it is a high bandwidth, two-way communication network which can handle long-distance data transmissions for automation and monitoring of SG applications. It provides all the communications between the substations and the electric utility. In order to be fully effective and scalable, it covers all the substations, the distributed power and the storage facilities along with any distribution assets such as transformers, capacitor banks and reclosers (Moghe et al, 2009).
- **NAN:** It is a broadband wireless resource and uses low bandwidth channels which meet the requirements for reliable and robust communications. It is developed between customer premises and substations with the deployment of intelligent nodes to collect and control the data from the surrounding data points and includes the communication between individual service connections, such as devices destined for distribution automation and control, and backhaul points to the electric utilities (Sood et al, 2009).
- **HAN:** It is a dedicated network which allows transfer of information between various electronic devices in the home, including home electrical appliances, smart meters, in-home display devices, energy management devices, distributed energy resources. It also contains software applications to monitor and control these networks. It enables consumers to get information about the consumption behaviors and the electricity usage costs via in-home display devices or through a web interface.

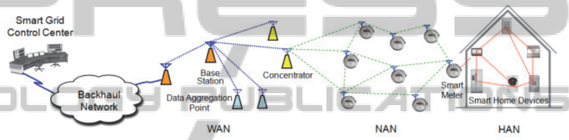

Figure 1: Smart Grid communication infrastructure.

2.1 Common Smart Grid Applications

In this subsection, major applications that can be found in a SG are briefly discussed along with their communication requirements.

- *Substation Automation:* All devices in a substation are controlled, monitored, and managed by Substation Automation Systems (SASs). They gather the data and perform routing and other operations, to make the system efficient, reliable, secure, and well responsive, with reference to real-time communication. The network technology is the key element in SASs to provide for full control over the devices, monitoring the operations, conditions of devices, and also the operations of substations. A successful deployment of a SG system always requires the effective and efficient communication infrastructure, which can be selected based on various network communication technologies. Wireless communication technologies that can be adopted in SASs are WiMAX or wireless mesh networks. Moreover, cellular network can be preferred for remote operations and maintenance at remote sites. Similarly, Wireless Local Area Network (WLAN) can be preferred to protect, monitor, and control the distributed energy resources where data rate requirements are less.

- *Overhead Transmission Line Monitoring (OTLM):* OTLM is one of the important operations of Transmission and Distribution (T&D) side SG applications, because overheating, icing, and lightning strikes always create vulnerability to the SG transmission lines. It monitors T&D systems to reduce the risk of failure. Wireless sensor nodes are deployed over the transmission lines and communicate via relays, to notify about the transmission lines and provide effective monitoring.
- *Home Energy Management (HEM):* It is generally considered at consumer side, where home equipment can be monitored and controlled. HEM can provide energy efficiency, data measurement, transmission, optimization, and balance to consumption and power supply. Advance control systems, in-home displays, smart appliances and smart meters are the main components of HEM. Mesh topology may be preferred in this type of system, which can provide higher reliability to various data paths.
- *Advanced Metering Infrastructure (AMI):* It provides a handshake communication between utility systems and smart meters and combines a variety of computer hardware, software, data management systems, monitoring systems, smart meters, and advanced sensors. In this way, it collects the distributed information from utilities and meters. AMI is a complex structure system, which requires efficient IT and communication infrastructure, such as, meter data management system which monitors and manages a large amount of data in efficient way to inform consumers and to maintain the billing information in a more intelligent way (Lu and Gungor, 2009).
- *Wide-Area Situational Awareness (WASA):* WASA is basically a set of technologies which provide an overall, dynamic picture of the operation of the grid. One of the key functions of SGs is monitoring and situational awareness to get reliability, protection, and interoperability among so many interconnected devices and systems. Any abnormalities can result in a widespread problem that endangers the system's dependability and protection.
- *Demand Response Management (DRM):* To reach a balance between demand and supply of electrical energy, DRM is responsible for controlling the energy demand and loads during critical peak situations (Quak et al, 2002).
- *Asset Management (AM):* The management of SG assets and the data they create requires the ability to capture, store and visualize data pertaining to asset status, performance and real-time risk. For this objective, asset management systems play a key role.
- *Future T&D Systems:* By the integration of a SG, the distribution and transmission infrastructures of existing power grids can be renewed for better reliability and flexibility to AC transmission systems. In urban areas, renewable energy sources, such as High-voltage DC (HVDC) technologies, may be used.
- *Renewable Resources:* In last few decades, there is a tremendous growth in the use of wind power generators and distributed solar plants.
- *Advanced Forecasting Algorithms:* In recent years, power demand has rapidly increased (Wagenaars et al, 2009) in the USA. Proper estimation of demand can provide better planning for the electricity generation. It can be promising to introduce SG technologies to existing systems to enhance the generation resources by robust two-way communications, active customer participation, dynamic pricing schemes, and other flexible technologies.

In addition to the abovementioned applications, Meter Data Management (MDM), Distribution Automation (DA), Distribution Management (DM) and Outage Management (OM) are also important applications.

3 NEXT GENERATION NETWORKS FOR SMART GRID APPLICATIONS

Since SG concept relies on the seamless integration of the traditional power grid infrastructure with a sophisticated advanced communication infrastructure (Gungor et al, 2013), the communication infrastructure plays a key role for the overall system and moves different types of data with different communication requirements and varying degrees of reliability, Quality of Service (QoS), and security. Therefore, it must be flexible, interoperable, scalable, and secure to meet the communication requirements of each SG component (Tuna et al, 2013; Amin and Wollenberg, 2005;

Yigit et al, 2014; Yang et al, 2007). A list of the common requirements of SG applications is given as follows.

- *Data rate:* Different SG applications require different data rates. For instance, the data rates for some SG applications such as SASs, OLTM, DA, AMI, DRM, HEM, OM, AM, MDM, DM, Distributed Energy Resources and Storage (DERS), Vehicle to Grid (V2G), and Electrical Vehicles Charging (EVC) are low, typically <100Kbps (ALCATEL, 2014). On the other hand, a few applications which transmit audio and video data require higher data dates, such as WASA, require data rates of 1-1.5Mbit/s (Gungor et al, 2013).
- *Throughput:* Throughput requirements are different for each specific SG application.
- *Latency:* Some SG applications such as AMI, HEM, OM, AM, MDM, V2G, and EVC can tolerate latencies up to 2 sec (Gungor et al, 2013). On the other hand, mission-critical SG applications such as WASA may not tolerate such high latencies.
- *Reliability:* Although most SG applications need highly reliable data communication, some specific SG applications can tolerate short outages during data transfers (Moslehi and Kumar, 2010).
- *Frequency Range:* To achieve reliable and high-quality data communication, and overcome environment-specific problems and line of sight issues such as penetration through walls, rain fade and foliage lower frequency ranges (<2 GHz) are preferred in the service area of electric utilities (Kilbourne and Bender, 2010; Sahin et al, 2014).
- *Security:* The critical data gathered from various SG components must be protected against both physical and cyber attacks (Leon et al, 2007).

Considering the application specific requirements of different SG applications along with the integration with different access networks and complexity introduced by heterogeneous network infrastructures, meeting the QoS requirements of SG applications becomes a significant performance issue. Moreover, fixed and wireless access networks converge towards IP based transport in SG networks. Therefore, addressing the requirement for scalable and effective control and management becomes critical. To address this challenge, policy-based management tools can be employed. To meet QoS requirements of SG applications, network designers should take into consideration several parameters including bandwidth, delay, jitter, and packet loss rate, and employ various mechanisms such as rerouting in the core of the network control access at the corners of the network, and filters. Moreover, for some SG applications, meeting the QoS requirements is not enough. In addition to this, Quality of Experience (QoE), users' perception of a provided service, should be enhanced. Finally, some SG networks should facilitate a single party to establish QoS-enabled path between the two IP providers mutually interconnected by one or more transit providers (Stojanovic et al, 2013). Therefore, negotiating and maintaining an end-to-end service level agreement is needed.

For the seamless transformation from traditional power grids to SGs, especially in large-scale SG deployments, electric utilities can employ NGNs for their communications infrastructures. The NGNs are packet based networks and use IP to transport the various types of traffic, e.g. data, signalling, voice and video. They are fully managed services platforms which combine multiple services over a single access line (ETSI, 2014) and enable the deployment of access independent services over converged fixed and mobile networks to provide flexibility, scalability and security at maximum cost efficiency (Lovrek et al, 2011). IP Multimedia Subsystem (IMS) can be viewed as the core component of the NGNs and provides an access independent platform for a variety of access technologies (ITU, 2006). The NGNs offer many advantages to SG operators which install and manage their communication networks as well as the ones who use the services provided telecommunication operators.

For telecommunications operators, SG is an opportunity to expand their businesses into the energy market and become established players in the electricity value chain. There is an urgent need for this since in the SG each consumer location has a piece of equipment, collocated with the smart meter, that communicates information related to usage, demand-response triggers, and failures to another unit aggregating the information of multiple smart meters and ultimately communicating the aggregated data to the main SG operations center. Therefore, telecommunications operators can offer competitive services to SG operators in terms of investment cost, operational complexity, reliability, and flexibility.

4 PERFORMANCE EVALUATION

Different from the traditional power grids, for the SGs, the communication infrastructure plays a key role for the overall system performance. Therefore, there is a need to predict and analyze in time the behaviour of NGNs for SG applications in terms of major network parameters. The main objective of the performance evaluation study presented in this section is to analyze the effectiveness of NGNs for SG applications with different priorities in large scale SG deployments using the OPNET Modeler (Riverbed, 2014). The performance evaluation study is based on the Asynchronous Transfer Mode (ATM) (Kouvatsos, 2002) protocols and architecture modified to SG system requirements. Inside the network, the packets are sent with random priority from one to three, one being the highest weight factor and three being the lowest as it is defined for NGNs, in the control plane service layer with uniform distribution, and are stored in several buffers in the network with different priorities. The nodes are outspread in large cities in the geographical area of Turkey and Greece in order to create a specified wide area network (WAN) which occupies almost 500.000 Km^2 area and interconnected through the Getaway node. As shown in Figure 2, the topology study includes twenty one nodes-cities which function as end users (clients) and two gateways cities which communicate between each other, Istanbul for the Turkish region and Athens for the Greek region through they pass all the data.

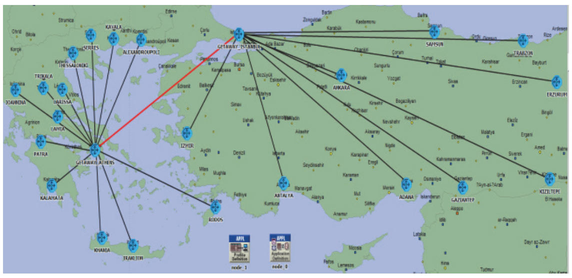

Figure 2: Next generation network nodes-cities location for the two countries.

The explanation of the priority levels is given below.

- *Priority level 1:* It has the higher acceptance indemnity in the network. This priority is addressed in emergency telecommunications over the NGN and data services are examined.
- *Priority level 2:* It has lower acceptance indemnity from level 1, but higher acceptance indemnity from the one that is granted in the level 3. As examples of level 2 priority are the real time services (VoIP, video), VPN and voice services. In this study voice applications are studied.
- *Priority level 3:* It has the smaller acceptance priority in the network. As examples are reported the "traditional" services of Internet Services Provider (e.g. e-mail). In this study email applications are studied.

The nodes are interconnected through the Getaway node. Each node transmits packets that the node itself generates and packets assumed are guaranteed to be successfully delivered to the Getaway node in NGN network. The application's operation mode is assigned as Simultaneous, and start time is set to Constant (100). Links between neighbouring nodes and Getaway are bi-directional with transmission data rate of up to 155.52 Mbit/s (payload: 148.608 Mbit/s; overhead: 6.912 Mbit/s, including path overhead) using fiber optics. Thus, all nodes can both send to and receive from the Getaway. The simulation duration is set to End of Simulation and lasts 6000 simulation sec. Finally all nodes have an equal transmission power and transmissions can reach up to the Getaway node according the region. The assumptions that are taken into account while developing the network are:

- 20% bandwidth is occupied for data emergency applications.
- 50% bandwidth is occupied for voice applications.
- 30% bandwidth is occupied for email applications.

There are two main types of statistics in the performance evaluation. The first type is the collection of values from individual nodes in the network (node statistics) and the second type is from the entire network (global statistics). Global statistics can be used when we are interested in an overall picture of the network performance. Global Statistics are collected for all nodes/links in the network. Node statistics provide information about individual node. The Global Statistics of the network are evaluated based on the following factors.

- *Delay (sec):* It represents the end to end delay of data received in the network. End to end delay is measured from the time it is created to the time it is reassembled at the destination.
- *Delay Variation:* It measures the variance among samples of end-to-end delay experienced by packets traversing the network along all connections established network-wide.

- *Cell Delay (sec):* It represents the end to end delay of cells received by all layers in the network. It is measured from the time a cell is sent from the source layer to the time it is received by the layer in the destination node.
- *Cell Delay Variation:* It measures the variance among end to end delays for cells received at all layers in the network.
- *Traffic Sent (bits/sec):* It represents the application traffic sent by the layer in bits/sec through the network.
- *Traffic Received (bits/sec):* It represents the application traffic received by the layer across the network.

The Node Statistics of the network is evaluated based on the following factor.

- *Voice application traffic received (bytes/sec):* It represents average bytes per second forwarded to the voice application by the transport layer in this node.
- *Traffic received signaling queue (bits/sec):* It represents traffic received (in bits/sec) by each queue of a certain port.
- *Queue delay deviation:* It is standard deviation of queuing delay experienced by packets in each queue. This statistic is computed as: (q_delay - E[q_delay])^2 and expressed in seconds.

Figure 3 is the graph of delay variation and delay in the simulation scenario. Delay variations and delay across the network are crucial for providing acceptable services. The analysis indicates that the developed network offers minimum latency in order to avoid distortion situations. Similar observations can be also made for Cell delay and Cell variation as shown in Figure 4. Figure 5 is the graph of data traffic received for the sum of applications by the network. If the first high spike for email traffic is excluded, it can be seen that data emergency application achieves the lowest values in traffic which is in line with our priorities levels and a steady stream of data traffic is sent without disruption. The spikes at the beginning of the simulation are the indications of control traffic due to the presence of nodes. The results shown in Figures 6 and 7 are related to node statistics. Blue line represents Istanbul node statistics and red line represents Athens node statistics. In Figure 7, the results show that almost average equal performance is obtained for delay deviation for the two nodes.

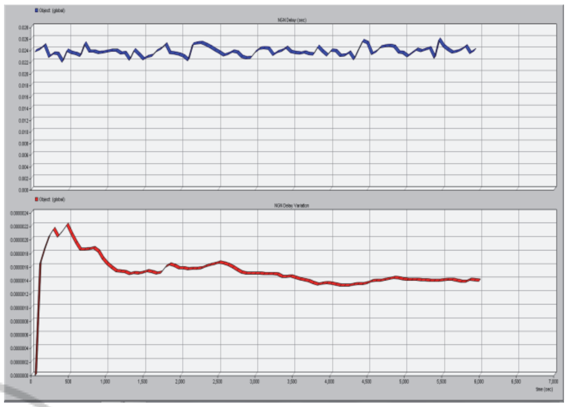

Figure 3: Delay and delay variation.

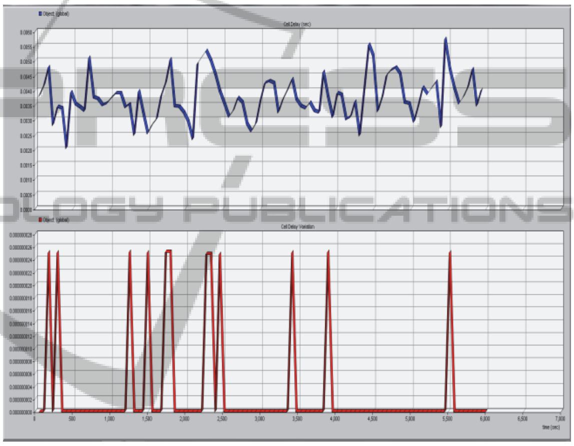

Figure 4: Cell delay and cell delay variation.

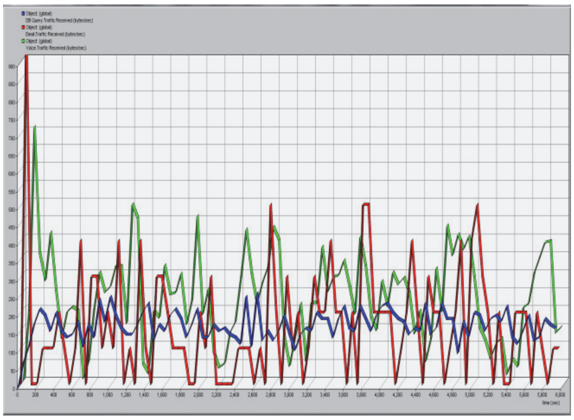

Figure 5: Traffic received comparison for applications.

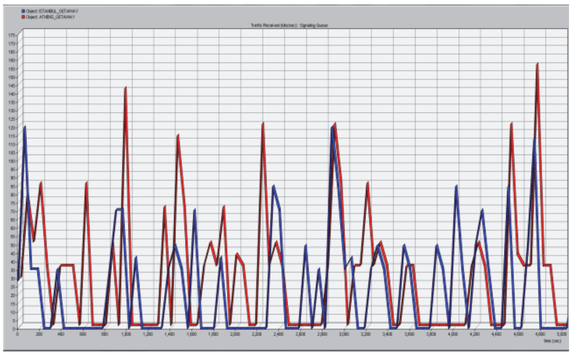

Figure 6: Traffic received – Signalling Queue two getaways-nodes comparison.

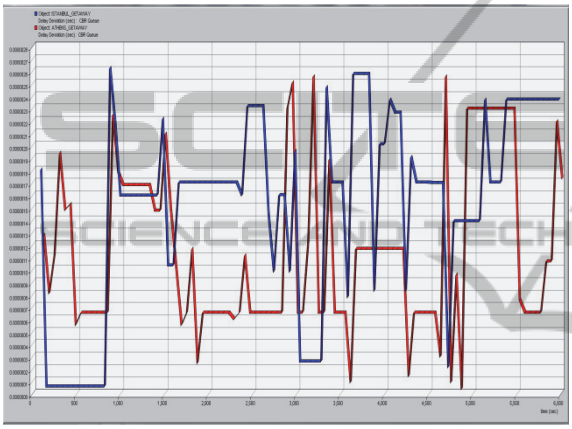

Figure 7: Delay Deviation-CBR queue two getaways-nodes comparison.

5 CONCLUSIONS

It is seen that all over Europe electric utilities and telecommunications operators have started collaborating to deliver information and communications technology and telecommunication services for smart grid. In addition, countries around Europe and Asia have started to create huge single power grid infrastructures for energy that can power many countries and nations at once. To do this, they have simply been creating a complex network of power grid connections to each participating country. But, several challenges have been identified and called for further discussions and investigations on how telecommunications operators can meet the special requirements of the electric utilities in building the proposed grid infrastructures. It is widely recognized that meeting the communications requirements is mission critical.

In this paper, the use of Next Generation Networks for Smart Grid applications used by transnational Smart Grid operators has been discussed and a detailed analysis has been presented. As depicted and shown with the results of the simulation studies presented in this paper, Next Generation Networks based backbones offer better delay handling and bandwidth allocation features to different Smart Grid applications, and in this way, QoS requirements of these applications can be handled efficiently.

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