

Performance Evaluations of Next Generation Networks for Smart Grid Applications

Gurkan Tuna

Dept. of Comp. Prog.

Trakya University

Edirne, Turkey

gurkantuna@trakya.edu.tr

Esra Kaya, Kayhan Gülez

Dept. of Control & Automation Eng.

Yıldız Technical University

İstanbul, Turkey

{esrakaya, gulez}@yildiz.edu.tr

George Kiokes

Dept. of Elec., Electr. Pwr., Tele.

Hellenic Air-Force Academy

Dekeleia, Greece

gkiokes@iccs.gr

V. Çağrı Güngör

Dept. of Comp. Eng.

Abdullah Gül University

Kayseri, Turkey

cagri.gungor@agu.edu.tr

Abstract—Smart Grid (SG) can be described as the concept of modernizing the traditional electrical grid. Through the addition of SG technologies traditional electrical grids become more flexible, robust and interactive, and are able to provide real time feedback by employing innovative services and products together with communication, control, intelligent monitoring, and self-healing technologies. For being fully functional, utility operators deploy various SG applications to handle the key requirements including delivery optimization, demand optimization and asset optimization needs. The SG applications can be categorized into two main classes: grid-focused applications and customer-focused applications. Although these applications differ in terms of security, Quality of Service (QoS) and reliability, their common requirement is a communication infrastructure. In this paper, we focus on the use of Next Generation Networks (NGNs) for SG applications. We also present a detailed analysis of a NGN-based communication infrastructure for SG applications in terms of global network statistics and node-level statistics.

Index Terms—Smart Grid; Smart Grid Applications; Next Generation Networks; Performance Evaluations

I. INTRODUCTION

The main concept of Smart Grid (SG) is to add communication, control, monitoring and analysis capabilities to the traditional electrical delivery system to maximize the throughput of the existing system [1]. In addition, the SG provides many economic and environmental benefits. The SG is basically the integration of two networks, namely the electrical transmission and distribution network, and the IP communications network. As electric utilities move towards the SG, they look toward a communications architecture which can be shared among many applications with different speed, reliability and security requirements [2]. Although communication was not the fundamental activity of electric utilities in the past, it plays a key role in the SG by supporting traditional electric utility functions and adapting to new requirements such as distributed generation, demand response, advanced metering [3], [4].

To enable the functions of the SG, an integrated overall communications infrastructure is a foundational need. Since traditional electric utilities privately own and operate geographically dispersed large-scale communication networks supporting both fixed and mobile data and voice communications for their operational and corporate functions,

there is no “one size fits all” communications solution for their SG transformation. To flexibly accommodate their different communication technologies and physical requirements, layered communications architectures can be used due to their performance, management, security, and cost advantages.

Next Generation Network (NGN)-based communications infrastructures offer maximum flexibility, maximum scalability, and maximum security at maximum cost efficiency to electric utilities. In addition, they provide collaboration tools, video conferencing solutions and cloud-based services. Therefore, NGN-based networks are especially suitable for country-wide big electric utilities. To the best of our knowledge, there have been no prior studies on the use of NGNs for SG applications. In this respect, in this paper, we focus on the use of NGNs for SG applications and present the effectiveness of this approach. 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 as follows. Section 2 presents the details of using NGNs for SG applications and discusses implementation aspects. Section 3 presents performance evaluation. Section 4 concludes the paper.

II. NEXT GENERATION NETWORKS FOR SMART GRID APPLICATIONS

SG can be described as the seamless integration of the traditional electrical grid infrastructure with an advanced communication infrastructure [1]. Since its communication infrastructure needs to move different types of data with different communication requirements and varying degrees of Quality of Service (QoS), reliability and security, it must be integrated, interoperable, secure, flexible and scalable to meet the communication requirements of each SG component [2]. A list of the common requirements of SG applications is given as follows.

- **Data rate:** It specifies how fast the data is transmitted between SG components. Data rate requirements for some SG applications differ from others. For instance, the data rates for some SG applications such as Substation Automation (SA), Overhead Transmission Line Monitoring (OTLM), Distribution Automation (DA), Advanced Metering Infrastructure (AMI),

Demand Response Management (DRM), Home Energy Management (HEM), Outage Management (OM), Asset Management (AM), Meter Data Management (MDM), Distribution Management (DM), Distributed Energy Resources and Storage (DERS), Vehicle to Grid (V2G), and Electrical Vehicles Charging (EVC) are low, typically <100Kbps [14]. On the other hand, a few applications including Wide Area Situational Awareness (WASA) System which transmit audio and video data require higher data rates, such as 1-1.5Mbit/s [1].

- **Latency:** It is the delay of the data transmitted between SG components. For some SG applications such as AMI, HEM, OM, AM, MDM, V2G and EVC, latency is not critical and up to 2 sec is tolerable [14]. On the other hand, mission-critical SG applications such as WASA may not tolerate such high latencies.
- **Reliability:** It is a measure of how reliably a SG communication system is able to transmit data between SG components while meeting the application-specific requirements. Although some SG applications are able to tolerate short outages during data transfers, reliable data communication is a requirement for most SG applications.
- **Frequency Range:** To overcome in the service area of electric utilities, lower frequency ranges (<2 GHz) are preferred. In this way, reliable and high-quality communication can be achieved, and environment-specific problems and Line of Sight (LOS) issues such as penetration through walls, rain fade and foliage can be overcome [15].
- **Security:** Protecting the critical data gathered from SG components is a key requirement since end-to-end security is a primary concern for all SG applications [16]. Vulnerabilities to the critical assets of SG must be prevented by combating with both physical and cyber security attacks [15].
- **Throughput:** It is the rate of successful data delivery over a communication channel. Throughput requirements are different for each specific SG application.

Due to the abovementioned specific requirements of their applications, inherently heterogeneous network infrastructures and integration with different access networks, meeting the QoS requirements of SG applications becomes a significant performance issue [10]. In addition, since fixed and wireless access networks converge towards IP based transport in SG network and due to the complexity introduced by their heterogeneity, addressing the requirement for scalable and effective control and management becomes critical. For addressing this challenge, policy-based management tools can be used.

Meeting QoS requirements for a network depends on different parameters such as bandwidth, packet delay, packet loss, latency, and jitter. It can be handled using various mechanisms such as rerouting in the core of the network

control access at the corners of the network, and filters. More importantly, the goal should be maximizing users' perception of a provided service, sometimes called Quality of Experience (QoE) [11]. Moreover, SG networks are generally interconnected by one or more transit providers [12]. This requires negotiating and maintaining end-to-end service level agreements (SLAs). Considering these issues, NGNs are promising solutions for electric utilities. NGNs are packet based networks and use IP to transport the various types of traffic, e.g. data, signaling, voice and video. The NGNs are fully managed services platforms, combining multiple services over a single access line [5], [6]. They enable the deployment of access independent services over converged mobile and fixed networks, and provide flexibility, scalability and security at maximum cost efficiency [7]. At the core of the NGNs the IP Multimedia Subsystem (IMS) lies. IMS provides an access independent platform for a variety of access technologies such as xDSL, fiber, Cable, Wi-Fi, GSM, 3G and 4G [8]. As shown in Fig. 1, it can be broken into three distinct functional layers: the service layer, the control layer and the transport layer.

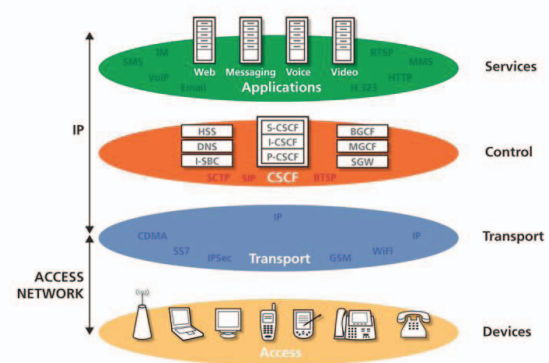


Figure 1. Layers of IMS [9]

The service layer is where the actual services lie and provides the final layer of abstraction giving IMS architecture the flexibility and power to quickly deploy new services [9]. The control layer is responsible for controlling the authentication, routing, and distribution of IMS traffic between the transport layer and the service layer. Its main component is the Call Session Control Function (CSCF) which is responsible for the signaling which controls the communication of IMS User Equipment (UE) with IMS enhanced services across different network accesses and domains [9]. The transport layer is responsible for the abstraction of the actual access networks from the IMS architecture and acts as the intersection point between the access layers and the IP network above it. It does initial IP provisioning and facilitates the registration of devices with the higher layers.

NGNs offer several advantages to electric utilities which own their communication networks as well as the ones who use the services provided telecommunication operators. Their distinct advantages over traditional networks can be listed as follows.

- Offering broadband capabilities with transparency and end-to-end QoS,

- Interworking with existing legacy networks,
- Providing a variety of identification schemes for routing in IP networks,
- Converging services between mobile and fixed networks,
- Supporting both real time and non-real time services, and applications based on service building blocks [17],
- Separating control functions,
- Being compliant with all Regulatory requirements,
- Enabling access to different service providers and unified service characteristics for the same service,
- Decoupling service provision from network and defining open standards to support the interaction between underlying infrastructure and service provision. This enables operational license holders to accommodate different content/application providers and niche service providers for offering innovative multimedia services to their customers [18].

Traditionally, the design and planning of an electrical grid infrastructure composes of large-scale power distribution networks, autonomous generators, monitoring and control networks, and electricity consumers, industrial, commercial or residential. On the other hand, for a SG, the communication infrastructure plays a mission-critical role for the overall system performance. In this respect, there is a need to predict and analyze in time the behavior of NGNs for SG applications in terms of traffic rate, delay variation, buffer usage and service queue.

III. PERFORMANCE EVALUATIONS

The main purpose of the simulation analysis was the development and study of a NGN for SG implementation consisting of applications with different priorities. The OPNET Modeler [19] architecture was used to simulate the network. OPNET Modeler constitutes a specialized tool in the area of communications, having graphic environment for modelling and simulation, of various types of networks. Moreover simulating separate models for each network, it is possible to take measurements of global and object parameters, such as packet delay, packet loss, throughput, etc. and through them general conclusions of the systems performance can be exported.

In the simulation study, the packets were stored in several buffers in the network with different priorities and inside the network were sent with a priority from one to three – one the highest weight factor and three the lowest. As shown in Fig. 2, the studied topology includes ten nodes which function as end users (clients) and a gateway in Ankara through they pass all the data. Other nodes are Istanbul, Izmir, Antalya, Adana, Gaziantep, Kiziltepe, Erzurum, Trabzon and Samsun. The priorities levels used in the simulation analysis are given below.

- **Priority level 1:** This priority level has the higher acceptance indemnity in the network. This priority is

addressed in emergency telecommunications over NGN and data services will be examined.

- **Priority level 2:** This priority level has lower acceptance indemnity from level 1, but higher acceptance indemnity from the one that is granted in the level 3. The examples of level 2 priority are VPN, video and voice services.
- **Priority level 3:** This priority level has the smaller acceptance priority in the network. The examples of level 3 priority are the traditional services of Internet Services Providers and Transit Providers, e.g. e-mail.

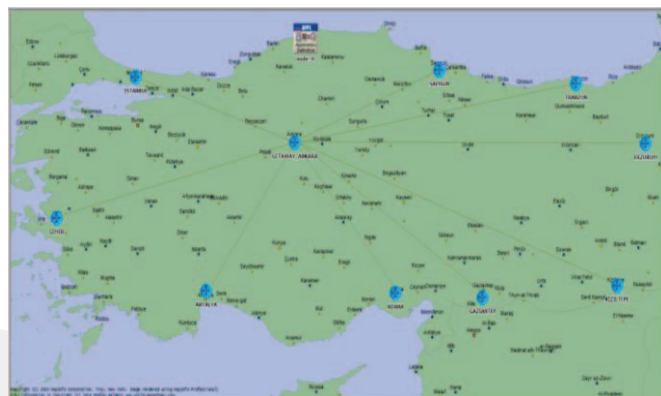


Figure 2. NGN nodes-cities locations

The NGN is a network which has convergence of all technologies that are widely used while the node model is a simple model since the major operation is executed in the service layer. The assumptions that were taken into account while developing the network were:

- 10% bandwidth was occupied by data and emergency applications.
- 50% bandwidth was occupied by voice applications.
- 40% bandwidth was occupied by email applications.

In the simulation study, two types of statistics were gathered. The first type is the collection of values from individual nodes in the network called node statistics and the second type is from the entire network called global statistics. The global statistics provide an overall view of the network performance and are gathered for all nodes/links in the network. On the other hand, the node statistics provide information about individual nodes. In the simulation study, the global statistics of the network were calculated based on:

- **Delay:** 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.

- **Traffic Received (bits/sec):** It represents the application traffic received by the layer across the network.
- **Traffic Sent (bits/sec):** It represents the application traffic sent by the layer in bits/sec through the network.

The node statistics of the network were calculated based on:

- **Buffer usage (Bytes):** It represents buffer used in number of bytes for a specific queue. By default, a time-average of this statistic is plotted.

The simulation results consisting of results and graphs from OPNET are presented in the following. Delay variations and delay across the network are crucial for providing acceptable services. Fig. 3 shows that the network performed well in terms of delay and delay variations. As shown in Fig. 4, a steady stream of traffic for emergency applications was provided by the network. Small spikes at the beginning of the simulation are the indications of the control traffic. Fig. 5 is the graph of data traffic received for voice applications by the network. As shown in Fig. 6, voice applications performed higher buffer usage queue due to the fact that the channel was always busy with data transmission and voice applications had high priority level.

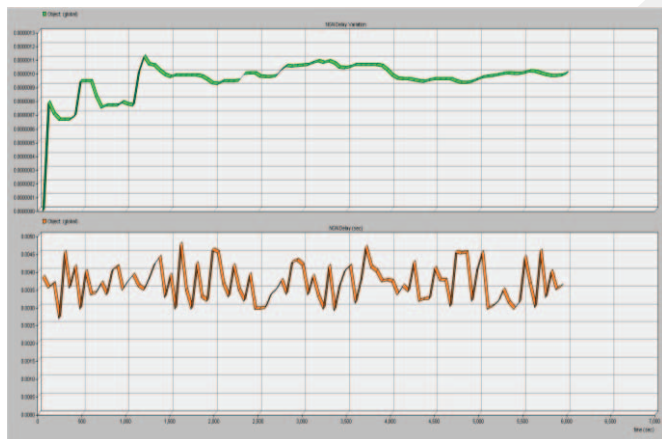


Figure 3. NGN delay variation and delay

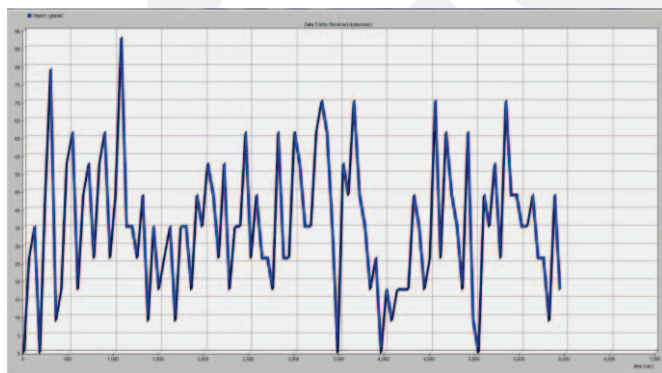


Figure 4. NGN data traffic received for emergency applications

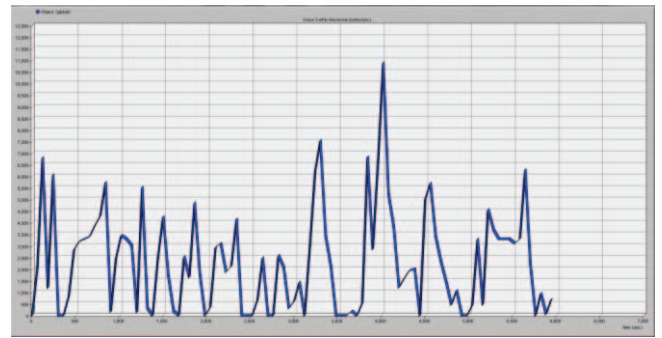


Figure 5. NGN data traffic received for voice applications



Figure 6. NGN data traffic application services buffer usage queue

Fig. 7 shows the comparison for two client end user nodes, Istanbul and Erzurum, respectively, in terms of traffic received. Istanbul node gathered more data since it was closer to the gateway. Furthermore, the results of the simulation study showed that distance between nodes is an essential parameter regarding traffic priority. The simulation results prove that while NGNs can address the communication requirements of SG applications, transit providers must take necessary precautions to provide QoS in their generally heterogeneous, multi-domain and multi-services networks.

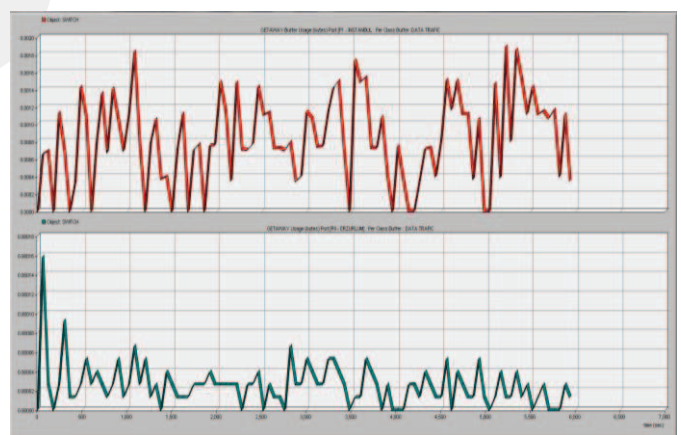


Figure 7. NGN application services buffer usage queue comparison for two cities

IV. CONCLUSION

In the past, electric utilities had limited control on their infrastructures and assets. Thanks to the transformation to Smart Grid, they have now more control and improved capabilities. However, different from the past, distributed architectures and various communications technologies found in the Smart Grid create different challenges for the electric utilities in terms of many parameters including reliability, redundancy, robustness, service quality and policy. Therefore, the electric utilities should base their network choice on factors such as topology, latency, bandwidth, redundancy, and management activities to be carried out. For all these goals, NGN is one of the best choices for SG backbones due to security, scalability and flexibility related reasons.

In this paper, the use of Next Generation Networks (NGNs) for SG applications has been discussed and a detailed analysis of an NGN-based communication infrastructure for SG applications has been presented. As depicted in the paper, NGN-based backbones offer better delay handling and bandwidth allocation features to different SG applications, and in this way, QoS requirements of these applications can be handled efficiently.

REFERENCES

- [1] V.C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, and G.P. Hancke, "A survey on smart grid potential applications and communication requirements," *IEEE Trans. Ind. Inform.*, vol. 9, no. 1, pp. 28-42, 2013. doi: 10.1109/TII.2012.2218253
- [2] G. Tuna, V. C. Gungor, and K. Gulez, "Wireless Sensor Networks for Smart Grid Applications: A Case Study on Link Reliability and Node Lifetime Evaluations in Power Distribution Systems," *International Journal of Distributed Sensor Networks*, Vol. 2013 (2013), Article ID 796248, 2013. doi:10.1155/2013/796248
- [3] M. Yigit, V. C. Gungor, G. Tuna, M. Rangoussi, and E. Fadel, "Power Line Communication Technologies for Smart Grid Applications: a review of advances and challenges," *Computer Networks*, vol. 70, pp. 366-383, 2014. doi: 10.1016/j.comnet.2014.06.005
- [4] D. Sahin, V. C. Gungor, T. Kocak, and G. Tuna, "Quality-of-Service Differentiation in Single-Path and Multi-Path Routing for Wireless Sensor Network-Based Smart Grid Applications," *Ad Hoc Networks*, 2014. doi: 10.1016/j.adhoc.2014.05.005
- [5] Next Generation Networks, Available at: <http://www.etsi.org/technologies-clusters/technologies/next-generation-networks> [Accessed November 15th, 2014]
- [6] J. J. Ganuza and M. F. Viegans, "Exclusive contents and next generation networks," *Information Economics and Policy*, vol. 25, pp. 154-170, 2013. doi:10.1016/j.infoecopol.2012.10.001
- [7] I. Lovrek, D. Lucic, and G. Gacina, "Next Generation Network and Regulatory Challenges," Proceedings of 2011 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), pp. 1-9, 2011.
- [8] Y.2021: IMS for Next Generation Networks, Available at: <http://www.itu.int/rec/T-REC-Y.2021-200609-I/en> [Accessed November 15th, 2014]
- [9] K.J. Salchow, Introduction to the IP Multimedia Subsystem (IMS): IMS Basic Concepts and Terminology, Available at: <https://www.f5.com/pdf/white-papers/ims-introduction-wp.pdf> [Accessed November 17th, 2014]
- [10] O. Markaki, D. Charilas, and D. Nikitopoulos, "ENHANCING QUALITY OF EXPERIENCE IN NEXT GENERATION NETWORKS THROUGH NETWORK SELECTION MECHANISMS," Proceedings of the 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07), 2007. doi: 10.1109/PIMRC.2007.4394198
- [11] J. Zhang and N. Ansari, "On Assuring End-to-End QoE in Next Generation Networks: Challenges and a Possible Solution," *IEEE Communications Magazine*, vol. 49, no. 7, pp. 185-191, 2011. doi: 10.1109/MCOM.2011.5936172
- [12] M. D. Stojanovic, A. M. Kostic-Ljubisavljevic, and V. M. Radonjic-Djogatovic, "SLA-controlled interconnection charging in next generation networks," *Computer Networks*, vol. 57, pp. 2374-2394, 2013. doi: 10.1016/j.comnet.2013.04.013
- [13] S. Y. Yerima, G.P. Parr, S. McClean, and P. J. Morrow, "Modelling and Evaluation of a Policy-Based Resource Management Framework for Converged Next Generation Networks," 12th IFIP/IEEE IM 2011: Mini Conference, pp. 563-570, 2011.
- [14] "Smart Choices for the Smart Grid Using Wireless Broadband for Power Grid Network Transformation," TECHNOLOGY WHITEPAPER. Available at: http://enterprise.alcatel-lucent.com/private/images/public/si/pdf_smartChoice.pdf [Accessed November 17th, 2014]
- [15] B. Kilbourne and K. Bender, "Spectrum for smart grid: Policy recommendations enabling current and future applications," Proceedings of the 1st IEEE Int. Conf. Smart Grid Commun., Oct. 4-6, 2010, pp. 578-582.
- [16] H. Li, L. Lai, and W. Zhang, "Communication requirement for reliable and secure state estimation and control in smart grid," *IEEE Transactions on Smart Grid*, vol. 2, no. 3, pp. 476-486, Sep. 2011.
- [17] T. Plevyak and V. Sahin, Next Generation Telecommunications Networks, Services, and Management. NJ: Wiley-IEEE Press, 2010.
- [18] T. Cohen, "NEXT GENERATION NETWORKS (NGN) REGULATION OVERVIEW," GSR 2007 Discussion Paper. Available at: http://www.itu.int/ITU-D/treg/Events/Seminars/GSR/GSR07/discussion_papers/Cohen_NGN_Overview_Final.pdf [Accessed November 18th, 2014]
- [19] <http://www.riverbed.com/products-solutions/products/opnet.html?redirect=opnet> [Accessed November 25th, 2014]
- [20] D. Kouvatso, Performance Evaluation and Application of ATM networks. New York: Kluwer Academic Publishers, 2002.