Modeling of Smart Grid Traffics Using Non-Preemptive Priority Queues

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Abstract— **The Smart Grid which is a digitally-enhanced version of the traditional electric grid will provide the infrastructure to support financial, informational, and electrical transactions among consumers, assets, and those users who have authorized access. Smart grid has different capabilities. It can be used to monitor and control the national electrical network. By efficient control of electrical network it is possible to maximize the throughput of the system and reduce network energy consumption. n the smart grid networks, different traffics with different requirements are flow in the network. There are multiple smart grid applications which are running in the network simultaneously. As there are different traffic types with different quality of service requirements in the smart grid, in this paper we propose a service differentiation unit which can support different services in smart grid networks. The proposed model can support the already mentioned traffic classes. The Class1 is assigned to high priority real time traffic such as teleprotection. Alarm data or remote real-time monitoring and control with SCADA systems and DCS systems are assigned to Class 2. Surveillances camera and emergency connectivity through mobile base stations are some sample applications of Class 3. Metering data and event notification are assigned to Class 4. Finally, Class 5 is for VoIP traffics. Using Non-Preemptive Priority Queues, the smart grid traffics are simulated. Simulation results confirm that this type of queuing discipline is proper for smart grid traffics.**

Keywords- Smart Grid; Traffic classification; Non-Preemptive Priority Queues

I. INTRODUCTION

The Smart Grid is a digitally-enhanced version of the traditional electric grid, which employs an intelligent overlay of advanced communications, electronics and computing technologies. The Smart Grid will provide

the infrastructure to support financial, informational, and electrical transactions among consumers, assets, and those users who have authorized access [1-4] .

Using the smart grid capabilities, it is possible not only to monitor and control the national electrical delivery system but also to maximize the throughput of the system and reduce the network energy consumption.

Smart grid can be applied at different levels of electrical network including transmission and distribution. It allows utility companies to distribute the generated energy in an efficient and economic manner. Smart grid has also many benefits for customers. Using the communication capabilities of smart grid network, customer will be able to be informed about the current price of electric energy. Whenever the energy is too expensive, they can turn off some electrical appliances to reduce their total energy consumption. So, using smart grid customers are able to manage their electrical use to minimize their costs.

By adding the communication and control capabilities to the existing traditional electrical network, the smart grid can be realized.

Different new technologies are used in smart grid. These new technologies are: hybrid electric vehicles, Distributed Generation (DG), solar energy, smart metering, lighting management systems, distribution automation, and many more. Based on the **National Institute of Standards and Technology** (NIST) conceptual reference model, the smart grid consists of the following domains [5]:

- **Customer**: At customer domain, the electricity is consumed. This domain is usually partitioned into sub-domains for home, commercial/building, and industrial.

- **Market**: This domain includes the operators and participants in electricity markets. In this domain the grid assets are bought and sold.

- **Service providers**: Service providers are organizations which provide services to electrical customers and utilities.

In this domain some new and innovative services are provided by service providers. By developing these services it would be possible to meet the new requirements and opportunities presented by the smart grid.

- **Operations**: In this domain the movement of electricity is managed. Typical applications in the operations domain are: monitoring, control, fault management, analysis, reporting and statistics, calculations, training, records and assets, operation planning, maintenance and construction, extension planning and customer support.

- **Bulk generation:** In this domain by using other forms of energy the electricity is generated. There are two different sources for energy generation: renewable energy and nonrenewable energy. The energy which comes from natural resources is called renewable energy. There are three different sources of energy generation including: 1) renewable and variable such as: wind and solar, 2) renewable and non-variable such as: hydro and biomass, 3) non-renewable and non-variable such as: nuclear, coal and gas.

- **Transmission**: Transmission is the process of carrying the bulk electricity over long distances. Using electrical transmission lines and multiple substations, the generated electrical power is transmitted from generation sources to distribution through multiple substations.

- **Distribution**: This domain is responsible to distribute the electricity to and from customers. The customer domain and their smart meters, distributed storage and distributed generation are connected to the transmission domain using distribution domain. Figure 1 shows the position of these domains in a smart grid system Smart grid integrates information communication technologies into the electrical power grid. The Smart grid is expected to affect all fields of the current electrical grid system, from generation, to transmission, and to distribution [6].

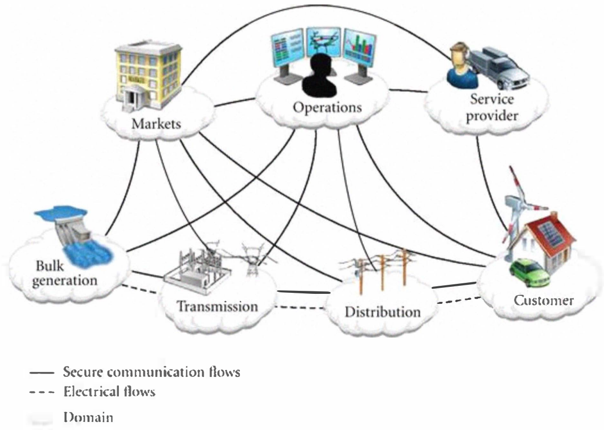

FIGURE 1. SMART GRID DOMAINS

The authors of paper [7], have proposed a mechanism to add the QoS into low cost protocols by providing differentiated service for traffic of different priority at the MAC layer of smart grid communication infrastructure. It has been shown that the delay and goodput performance of the network have been improved. In [8] a dynamic bandwidth allocation algorithm which allocates traffic with different Quality of Service requirements in terms of throughput, delay and failure probability to information networks with different performance characteristics has been proposed. The authors have defined a detailed queuing model for the system. In [9], a survey of QoS requirements for smart grid applications has been performed. Furthermore an analysis of using the strict priority queue to support multiple mission critical and other high priority applications has been performed.

II. CLASSIFICATION OF SMART GRID TRAFFICS

In the smart grid networks, different traffics with different requirements are flow in the network. There are multiple smart grid applications which are running in the network simultaneously. Each application generates traffic with different requirements. Different priority levels are assigned to different applications. If the utility companies be able to control and actively manage different smart grid traffics, they would be able to cope with the complex mix of requirements of multiple applications. We can classify the smart grid traffics based on the 3 different parameters including: delay, bandwidth and packet loss. In the proposed system we classify the smart grid traffics on to 5 different classes. Table 1 shows the traffic classes assigned to different smart grid applications. As it is shown in table 1, different smart grid applications have different delay requirements. The teleprotection needs less than 10ms delay while it is about 20 ms for some synchrophasor applications. The necessary delay for WACS, PMU and SCADA data is equal to 100ms, 16ms and 512ms, respectively.

TABLE I. TRAFFIC CLASSES ASSIGNED TO DIFFERENT SMART GRID APPLICATIONS

Traffic class	Latency(ms)	Bandwidth (kb/s)	Example applications
Class 1	8-10	64	Teleprotection
Class 2	100	1.2-64	WACS
Class 3	16	2048	PMU
Class 4	200	512	SCADA
Class 5	200	8-64	VoIP

As different traffic classes in smart grid application need different quality of service requirements, we propose a Differentiated Services (Diffserv) model.

In the proposed model, the input traffics are classified to five different classes based on their delay requirements. This can be done by using a unique small identifier such as DSCP (differentiated Service Code Point) in the incoming header. This traffic classification is performed at the edge network. At the intermediate nodes a specific forwarding treatments which is called Per-Hop Behavior (PHB) is applied to each incoming packet. This kind of treatment provides the appropriate delay-bound, jitter-bound and bandwidth for the packets of each traffic class.

We propose a service differentiation unit needed to support differentiated services in smart grid networks. The proposed model can support the already mentioned traffic classes. The Class1 is assigned to high priority real time traffic such as teleprotection. Alarm data or remote real-time monitoring and control with SCADA systems and DCS systems are assigned to Class 2. Surveillances camera and emergency connectivity through mobile base stations are some sample applications of

Class 3. Metering data and event notification are assigned to Class 4. Finally, Class 5 is for VoIP traffics. At each network nodes, a separate queue for each type of traffic class is used.

III. PROPOSED MODEL

The proposed model consists of two main parts: Bandwidth estimator and traffic classifier.

A. *Traffic Classification*

To provide low delay requirements of high priority classes flows, we use Non-Preemptive Priority Queuing (PQ) scheduler which prioritizes the packet transmission process at each concentrator. The queuing model of each node is shown in Fig. 2. To discriminate traffic classes from each other, the differentiated service concept is used. At the network node edges a traffic class identifier is added to the packets. At the intermediate nodes, each packet is put in the proper queue based on its traffic class. This identifier represents the traffic class of each packet. As shown in Fig. 2, in each intermediate node, arriving packets are sent to different queues according to their traffic class.

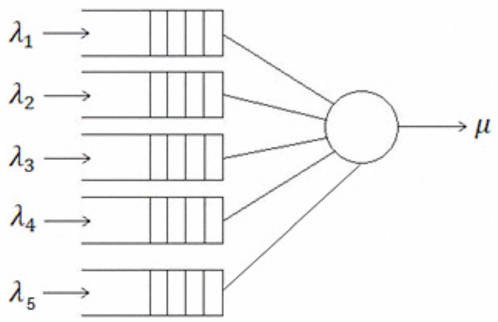

FIGURE 2. QUEUING MODEL OF EACH NETWORK NODE IN THE PROPOSED MODEL

Since there are five different classes for Smart Grid traffics, five M/M/1 queues with different specifications are needed. First Non-Preemptive Priority Queuing (PQ) method (method 1) is used and then a hybrid queuing method (method 2) is applied. In method 2 Non-Preemptive Priority Queuing for the first queue which needs very low delay is used while for other queues the Weighted Round Robin (WRR) is applied. The parameters of each queue can be calculated by following formulas using the specifications listed in Table. 1. First parameter is the mean arrival time which is calculated as below:

$$\lambda_i = \frac{B_i}{L_i}$$

Where B_i is the bandwidth in bit per second and L_i is the packet size that is assumed to be fixed and equal to 64 bytes (512 bits) for all the classes. Another parameter is the mean service time that is given by:

$$\mu_i = \frac{C}{L_i}$$

Where C is the output bandwidth and calculated as follows:

$$C = \alpha \sum_{i=1}^{K} B_i$$

Where α is a constant factor, $0<\alpha\leq 1$. To model the smart grid traffic, first we consider non-preemptive priority M/M/1 queues. In this kind of queuing, input packets of priority class i, i=1, 2 … K, arrive at the system according to a Poisson process with rate λ_i. Both service times and the arrival times are exponentially distributed. The service times and the arrival times are considered as independent i.i.d. Let ρ_i be the traffic intensity of class i, i=1, 2 … K. Our main objective is to compute the system time of class i input packets (T_i). Suppose W_i represents the mean waiting time of packets of class i waiting in queue. Using the queuing theory W_i and T_i can be calculated as below:

$$W_i = \frac{\sum_{j=1}^{K} \lambda_j h_j^{(2)}}{2\left(1-\sum_{j=1}^{i-1}\rho_j\right)\left(1-\sum_{j=1}^{i}\rho_j\right)}$$

$$T_i = \frac{1}{\mu_i} + \frac{\sum_{j=1}^{K} \lambda_j h_j^{(2)}}{2\left(1-\sum_{j=1}^{i-1}\rho_j\right)\left(1-\sum_{j=1}^{i}\rho_j\right)}$$

Where $h_j^{(2)}$ is the second moment of service time class j.

B. *Evaluation Results*

To evaluate the proposed model, a discrete event simulation software was developed in the Linux operating system environment. The analytical amounts of parameters and the results of the simulation for the first method are listed in Table 2.

TABLE II. SIMULATION AND ANALYTICAL RESULTS FOR METHOD 1

Traffic class	λ_i	**Analytical W_i**	**Simulation W_i**
Class 1	128	0	0
Class 2	64	1.85e-4	1.90e-4
Class 3	4096	2.30e-3	2.78e-3
Class 4	1024	8.56e-3	8.99e-3
Class 5	64	9.60e-3	9.84e-3

The results of the simulation for the second method are shown in Table 3.

TABLE III. SIMULATION RESULTS FOR METHOD 2

Traffic class	λ_i	Simulation W_i
Class 1	128	0
Class 2	64	1.64e-4
Class 3	4096	2.58e-3
Class 4	1024	8.75e-3
Class 5	64	9.54e-3

We compared the results of the presented analytical method and the results of the discrete event simulation. The difference between analysis and simulation is very small in the mean of waiting time and the Smart Grid traffics required latency is satisfied. The comparison is depicted on Fig. 3. In the second case using the hybrid method, even better results are achieved. The discrete event simulation results of mean waiting times for the hybrid method is shown in Fig. 4.

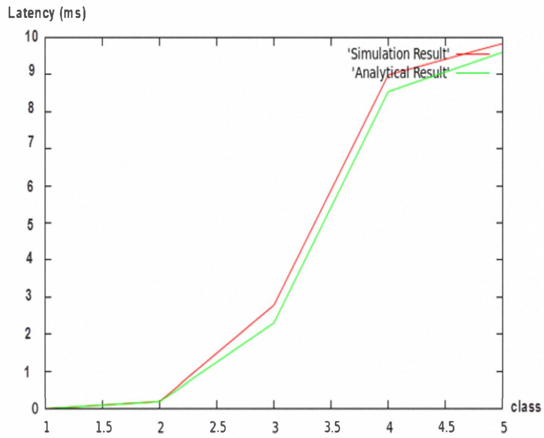

FIGURE 3. SIMULATION AND ANALYTICAL RESULTS OF METHOD 1

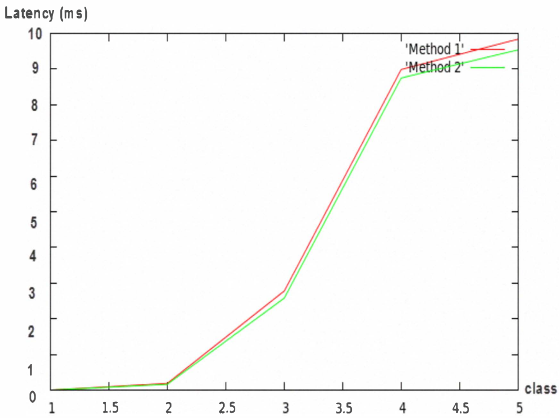

FIGURE 4. COMPARISON OF APPLYING METHOD 1 AND METHOD 2

IV. CONCLUSION

In this paper we proposed a model for serving smart grid traffics in an enhanced electric grid. In the proposed model the traffics is classified to 5 different classes. The first class is assigned to high priority real time traffic such as teleprotection. Based on delay requirements of smart grid applications the other traffics were classified to Class 2, 3, 4 and 5. We proposed two methods. In the first method, the Non-Preemptive Priority queues are used to serve all traffic classes while in the second method, for traffic class1, the Non-Preemptive Priority queue and for other traffic classes the weighted round robin queuing discipline is applied. The simulation and analytic results confirm that both proposed model can satisfy the delay requirement of Smart Grid traffics.

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