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Research Article

SDN-Based Management of Wide Area Measurement System (WAMS) and Traffic Optimization Mechanism for Smart Grid Communication

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Abstract:

Electricity has become one of the most fundamental resources of human life. The Supervisory control and data acquisition (SCADA) system was initially used in smart grid monitoring and is still present in traditional and semi-automated GRIDS. RTUs, meters and protective relays send the system measurements to the SCADA framework. The SCADA framework intermittently surveys estimating phasor data. SCADA takes 2-10 seconds to perform calculations of phase angle data. In addition to that, the SCADA system cannot assign timestamps to phase angle data. The Wide area measurement system is introduced in the Smart Grid monitoring System. The Wide Area Measurement system (WAMS) is more accurate and fast as compared to the SCADA framework. The WAMS architecture is specifically designed for monitoring purposes. The Phasor Measurement Unit (PMU) is attached to GPS (Global Positioning System), so the time and location of the PMU are fully accurate and synchronized. PMUs are efficient devices which can calculate the synchro phasor data accurately along with the timestamp. PMU can send 120 frames per second. When the Phasor Data Concentrator (PDC) receives PMU frames, it aligns them based on timestamps and sends them to the control center for processing. Our purposed SDN based communication model can be deployed within and among the substations and lead towards the regional and main control centers. In Smart Grid infrastructure, substations are the ending points of HAN and NAN and starting points of WAN. In Smart Grid, WAN is equipped with Wide Area Measurement devices such as PMUs, PDS and Communication Network. In our proposed SDN based model, SDN gateway switches are maintained at substations. However, these switches are controlled by SDN local controllers, local controllers placed to reduce the load from global controllers and network nodes. These local controllers are fully synchronized with the global controllers in order to maintain the updated network state. A Queuing priority mechanism is also proposed for important and delay-sensitive data. Simulation results show that the network load is optimized, and obtained jitter is less than 10ms by the proposed model.

Keywords: SDN, Smart Grid, PMU, PDC.

1. Introduction

Electricity has become one of the most fundamental resources of human life. In the past, the use of electricity was simple and low as compared to today's need. The use of electricity in human life has exponentially increased, not only due to population growth, but due to many new innovations in electrical appliances which are added to human life [1]. Existing electrical grids were built decades earlier. Despite the fact that it made a significant contribution to the satisfaction of human life prerequisites, this foundation can not support future energy needs. Conventional electricity grids cause problems in the transmission of electricity, such as voltage drops, power outages, excessive loads, and, at some point, misuse of energy, especially when interest in energy expands. Be that as it may, in an advanced period, individuals, including cars, join the existing electrical network, which leads to waste in the future [1]. In addition, in these conventional power systems, common assets are used as fuel, such as fossil fuels, coal, gas, etc., which is not only unsafe for these assets, but also effectively criticizes the state in which they are located [2]. The flow model of energy age and attribution is mainly based on unified power plants. The energy age at these power plants is regularly dependent on (coal, combustible gas, and oil) or atomic energy. Nevertheless, there are many problems associated with the integration of structures of power plants. This structure requires distribution from focus to distant customers, which means the transfer of control over the division. Despite transmission issues, these structures also contribute to the release of several harmful substances into the ozone layer, the generation of nuclear waste, wasteful aspects, and power problems on long transmission lines, as well as environmental and safety issues. In conventional networks, all life-changing methods are used to deliver energy and can harm the condition. Some of them have a dynamic effect, such as carbon dioxide, carbon monoxide, and air poisons [1-16]. Taking into account the natural effect, this age cycle of force should be taken into account. The fuel used for the transformation procedure requires creation and transportation. A huge amount of fuel used by fossil fuels and nuclear power plants is extracted from the ground. The basis of viability includes fuel recovery, fuel generation, transportation, energy transfer, and spent fuel. The whole system of the smart grid is equipped with strong network infrastructure and many other digital devices and sensors. The complete SG infrastructure from power generation to consumer end is categorized in three main areas Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN). However, these all areas are different in nature and each has different devices, network infrastructure, and communication requirement. Our proposed work is Wide Area measurement system (WAMS). This system is related to medium to high voltage area which is from NAN to WAN.

As discussed earlier Smart grid embraced many devices and sensors coordination with each other in the large distribute areas. Therefore, a strong communication model is required to support the smart grid's two-way communication and coordination among devices. In our purposed methodology we used Software Defined Networks paradigm for smart grid communications [17]. The current grid communication model is based on the traditional network paradigm, where rules for the network functionality are mostly made at the design phase [11][13]. It is difficult and even impossible to change them at run time. This nonelastic paradigm is not feasible to manage a network like smart grid. Because smart grid requires frequent changes in configurations [14], data transfer with low latency rate and quick response from the devices. Such a non-adaptive paradigm can become a performance and resilience bottleneck.

Our purposed SDN based communication model can be deployed within and among the substations and lead towards the regional and main control centers. In Smart Grid infrastructure, substations are the ending points of HAN and NAN and starting points of WAN. In Smart Grid, WAN is equipped with Wide Area Measurement devices such as PMUs, PDS and Communication Network. In our proposed SDN based model, SDN gateway switches are maintained at substations. However, these switches are controlled by SDN local controllers, local controllers placed to reduce the load from global controllers and network nodes. These local controllers are fully synchronized with the global controllers in order to maintain the updated network state. A Queueing priority mechanism is also proposed for important and delay-sensitive data. Simulation results show that the network load is optimized, and obtained jitter is less than 10ms by the proposed model.

2. Literature Review

In this section, the framework, working module of SDN is discussed in detail. Advantages and disadvantages are being catered in this chapter. The layers which are the most fundamental part of SDN are also defined briefly in this chapter. The working of all the layers namely Application Layer, Control Layer, Infrastructure Layer are being discussed briefly in this chapter. How his layers work with the combination of SDN controllers are also discussed. SDN controllers can be categorized into two parts namely NFV (Network Function Virtualization) Datacenter and Ancient SDN Controllers. Software-Defined Networking (SDN) has turned out to be the most well-known technique for firms to set up applications. This advancement has been actively allowing firms to set up applications at a faster rate and lower the expense of setting out [33]. SDN has enabled admins to oversee and arrange system administrations from a concentrated area. The advantages of this arrangement are with the end goal that more firms than any other time in recent memory are beginning to ask, 'what is SDN' and making the change [39].

It’s a well-known fact that the equipment's/hardware which was manually configured are now outpaced by the growth of current innovation[19-30]. Conventional systems essentially can't stay aware of the requests that advanced undertaking clients have. SDN offers associations an appreciated elective where they can upscale their system framework with negligible interruption. Today we're beginning to see organizations setting up SDN like Cisco Open SDN Controller, Beacon, Brocade SDN Controller, and Juniper Contrail [71][72].

Smart grid embraced many devices distributed on the large geographical area with strong communication model and data management system. Therefore, communication is afundamental part of the smart grid to facilitate massive grid devices spread over a large geographical area. Furthermore, renewable distributed sources are also importantlarge number of Distributed renewable energy sources (DERs) are also part of the Smart Grid to reduce the usage of fossil fuel and other natural resources in electricity generation [45]. These DERs are also called green energy sources because they are environment-friendly and economical as well. Addition of these DERs to SG made Smart grid infrastructure more complex because these DERs are dependent on nature so their productivity varies with respect to time of the day and environment. This variable generation of DERs required several on and offs of main grid to fulfill the electricity requirements. Strong communication and computation in SG infrastructures are needed to achieve high reliability in system.

The current grid communication model is based on the traditional network paradigm, where rules for the network functionality are mostly made at the design phase [27],[29]. It is difficult and even impossible to change them at run time. This nonelastic paradigm is not feasible to manage a network like smart grid. Because the smart grid requires frequent changes in configurations, data transfer with low latency rate and quick response from the devices. such a non-adaptive paradigm can become a performance and resilience bottleneck. Moreover, in the current paradigm it is also impossible to change network configuration according to the change in policy. For example, if virtualization is required in IP standard network paradigms such as VLANs or VPNs, the configurations are required on each switch and must be done physically [30]. Furthermore, network limitations need to be considered in the

software designing phase which restricts the software developer to compromise some functionalities due to these network limitations.
The deployed infrastructure of the smart grid in several cities around the world is still in experimental phases. Many countries are planning to spread these infrastructures for the whole cities in near future. However, with the expansion of these systems, many new requirements and problem will be rise. In the result of these upcoming changes Current non-adaptive paradigm will lead to more inefficiency in system [34][36].
A good outcome of unified provisioning is that SDN gives the client greater versatility. By being able to arrange assets freely, you can change your system foundation immediately. The difference in versatility is prominent when compared with a conventional system, where assets are bought and designed manually [37]. Despite the fact that the development towards virtualization has made it progressively hard for admins to secure their systems against outer dangers, it has carried with it an enormous, preferred position. An SDN controller gives a brought together area to the admin to control the whole security of the system. While this comes at the expense of making the SDN controller an objective, it gives clients an unmistakable point of view of their framework through which they can deal with the security of their whole system [68-745].
NFV and SDN speak of an advanced method to design, transport and maintain systems that allow specialized organizations to change the way the client works in general by providing administration, capacity, and capabilities of the company's comparison system. SDN decouples the information plan from the management plan and allows the organization of the system, the controller and the administrator in an unimaginable way with traditional system management devices and programming arrangements. Meanwhile, NFV promises to virtualize system administration and decouple exclusive device programming. In this way, administrators can quickly design and transfer new system administrators. The world view of management merges depending on the product configuration. The two innovations support extremely flexible system administration, flexible implementation, shorter response times for new benefits and more fluid customers[76-90].

3. Research Methodology

In this proposed SDN based model, SDN gateway switches are maintained at substations. However, these switches are controlled by SDN local controllers. In this purposed model, local controllers are placed to reduce the load from global controllers and network nodes. These local controllers are fully synchronized with the global controllers to maintain the updated network state. Different techniques are used to obtain updated information about the network state. Too many packets of this information may affect the quality of service (QoS). To minimize these effects and ensure correctness, our proposed model periodically quarries all switches and routers. In response, the Network Monitoring System obtained a global network state, built on the basis of this infrastructure. At the control centers, this global state is used by various applications. The global controllers are responsible for managing the network traffic according to applications requirements across the WAMS. Global controllers fill the tables with network traffic flow rules. These rules are communicated to local controllers and followed by network devices such as routers and switches. However, SDN infrastructure provides the flexibility to set separate rules for local controllers if required. For example, if a Smart Grid application aims to set different policies for adjacent areas, the SDN model is flexible enough to provide this elasticity at the same time.

Toward the design and implementation of a Software-Defined Network solution capable of resiliently routing smart grid traffic and reducing traffic load by optimizing the number of packets at the Wide

Area Network level. The SDN based communication model will be deployed within and among the substations and lead towards the regional and main control centers. We will consider different scenarios, and simulation will be performed for these scenarios. In the first scenario, the average load per PDC was measured and compared with a typical model of PDC placement. In the second scenario, the failure of a single PDC is considered and change in packet ratio analyzed. The third scenario will be carried out for a massive failure of a PDC in a zone and packets sent by the other PDC zone, with the increase in average packet rate analyzed. Simulations in the fourth scenario will be done by separating billing data packets from priority queues and the average packet reduction of priority queues analyzed. In the fifth scenario, latency rate for three models, simple networking model, MPLS based and proposed SDN based will be analyzed.

PMU is attached to GPS (Global Positioning System) so time and location of PMU are fully accurate and synchronized. PMUs are the efficient device which can calculate the synchrophasor data accurately along with the timestamp, PMU can send 120 frames per second When PDC received PMU frames and align them according to timestamps and send to control center for further processing. Several research articles proposed WAMS based Smart Grid Monitoring System in [11], [12], and [13] proposed WMAS model with centralized PDC, as number of PMUs is increased centralized PDC is overloaded by burst of frames send by PMUs or some time communication link is congested. In [14][15][16], and [18] they proposed the master and micro PDCs in WAMS model but not the regions of that PDCs assigned with the PMUs so, it difficult to manage area wise planning and policymaking also it is not feasible to implement high pricing policy for whole city just because of few areas. However, in the demand and response policy when peak hours are considered to be critical to Smart Grid when demand increase pricing model increases price of electricity so that, users postponed their less important task scheduled them for the normal hours. Furthermore, consumers can schedule their tasks at ideal pricing hours in this way they can manage their bill inefficient manner [17][19][20].

We proposed an efficient WAMS model which can overcome above mention issues with additionally provide fault tolerance in the WAMS system which is missing the existing models. We used the SDN network paradigm for in our proposed model to increase the adaptiveness and salability of the system. In the proposed model we divided the large geographical areas into the regions, these regions are further divided into the zones. PDCs are dedicated to these Zones and SDN controller sends information about these PDCs to all PMUs, PMUs must be registered with their Dedicated PDCs. Each zone has master PDC who manage PMUs in case of any failure occur in the PDC. Zone and regions have unique IDs hence system can differentiate between zones without performing huge calculations. When zones are separated and Identical, we can implementation of different policies for the different region or zone and also optimize the load per PDC. We proposed a hierarchical model of WAMS contain Local, centralized and Main PDCs, local PDCs place in the substation while centralized PDCs in regional office and Main PDCs are placed in the country-wise control centers. Each PMU must register itself in with Local PDC, Additional information about other local PDC of its own zone and about PDCs of other zones are provided to PMUs so that, in case of failure of local PDC, PMU send frames to other local PDC a local master PDC manages the load balancing when failure occurs in the system.

Synchro phasors are the main components used in wide area network monitoring system. We proposed modified WAMS structure to prevent overloading WAMS system. We optimize the Wide Area Measurement System's traffic by reducing the packets. Synchro phasors are highly used in Smart Grid Monitoring and Protection system. These systems required quick response time lower overshoot and undershoot values throughout the large disturbances [15]. A typical model of WAMS is shown in Figure 4.1.

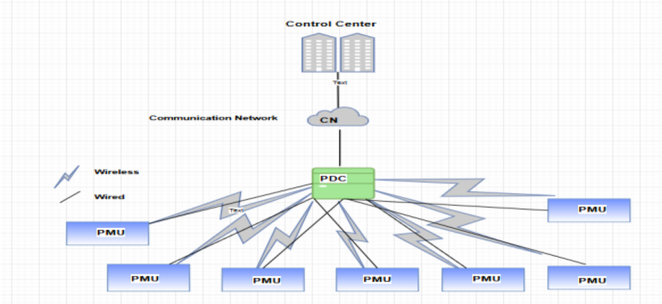
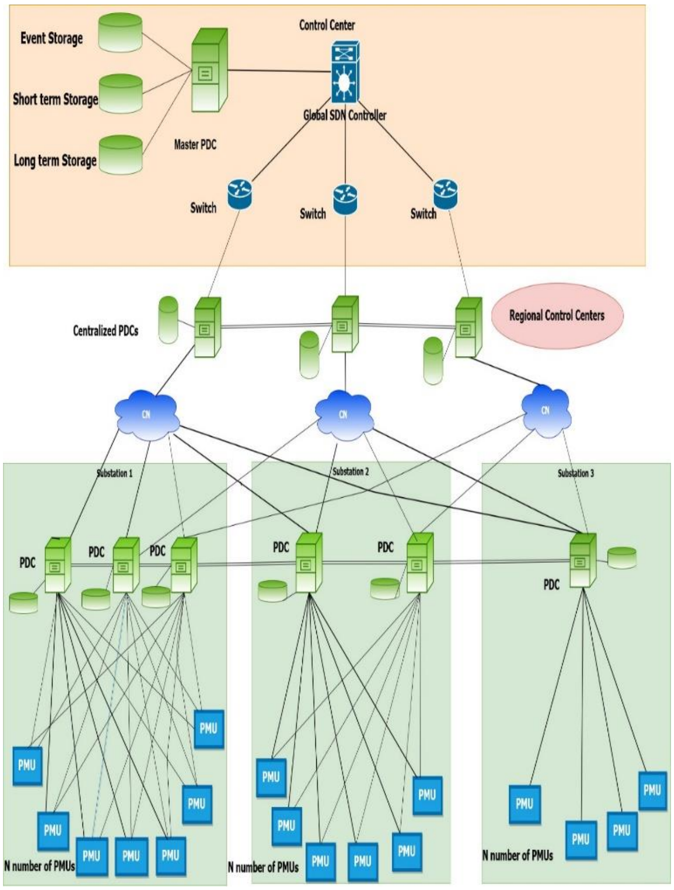


Figure 4.1: Typical WAMS Model

Our purposed WAMS architecture contains the concept of local, centralized and Master PDCs (MPDCs). This architecture optimized the PDC load and processing by dividing their tasks. The proposed architecture is shown in Figure 4.2.

Figure 4.2: Proposed WAMS Model



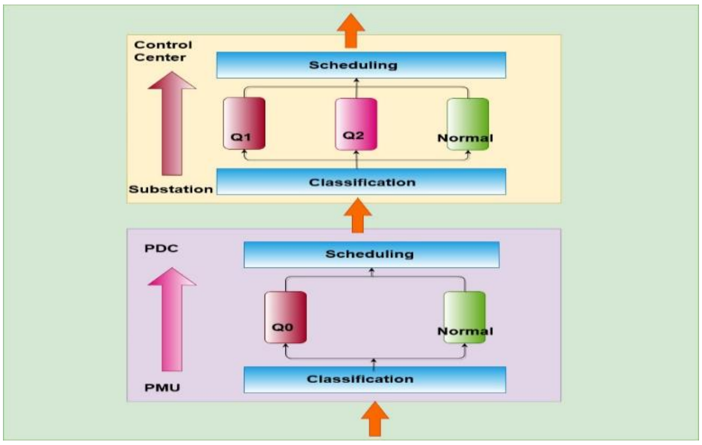


Figure 4.3: Proposed Queueing Model

PMUs are connected and there is synchronized with the Global Positioning System (GPS). PMUs measures the synchrophasor data and timestamps them, as per the standard of Synchrophasors. This time-synchronized data is utilized for the analysis and other processing to perform different policy implementations and other activities over large geographical area. As we discussed earlier, in WAMS architecture newer data has higher priority and it is more use full than the older data and should be sent immediately. Note that when high priority queue has packets other queues are not served or served with the minimum bandwidth. What if Q0 or Q1 who both have the higher priority in their defined domains are full and drops the packets in that case newer packets are more important than the packets placed in the last places of queues we use two threshold values Tn or Th when threshold value exceeds from the Th algorithm performed the packet drop operations at the end of the queue so the newer packets can be sent to control centers.A similar mechanism is performed on Q2 shown in algorithm 3 and 4.

Algorithm 3: Priority Queue management (PMU to PDC)
Function Enqueue (Pc):
1: #A new packet Pc of flow F is received;
2: Len=Queue_Length()
3: if Len < TRthen
4: put p at the end of the queue
5: else ifLen > TRandLen < THthen
6: sel_flow=Select_min_flow()
7: reroute(sel_flow)
8: put p at the end of the queue
9: else ifLen> THthen
10: f=Select_Flow()
11: packet=Select_first_packet(f)
12: drop(packet)
13: put p at the end of the queue
14: end
End of Function

Algorithm 4: Priority Queue management (PMU to PDC)
Algorithm active queue management.Function Enqueue (p): 1: #A new packet p of flow F is received; 2: Len=Queue_Length() 3: ifLen < TRthen 4: put pat the end of the queue 5: else ifLen > TRandLen < THthen 6: sel_flow=Select_rnd_flow() 7: reroute(sel_flow) 8: put p at the end of the queue 9: else ifLen > THthen 10: packet=Select_first_packet() 11: drop(packet) 12: put p at the end of the queue 13: end ifEnd of Function

4. Results & Discussion

Performance and evaluation are performed in this chapter. To simulate SDN network Minninet and Ryu controller, Wireshark and GNS3 software are integrated to track the packet and GUI mapping of the model. All Simulations are performed on Core i7 Desktop PC with 16GB RAM. Other components are listed in table 4.1.

Components	Values
CPU	Core i7
Computer Type	Desktop
Generation	3rd
System OS	Windows 10
RAM	16 GB
Oracle VM	
OS in VM	Ubuntu
OpenFlow	
Mininet	
Ryu controller	
PMUs	16
PDCs	9
Bandwidth	2 MB

Table 4.1: Specification of Simulation Components

Different scenarios are considered, and simulation is performed for these scenarios. In the first Scenario average load per PDC is measured and compared with typical model of PDC placement. In the second scenario, the failure of single PDC is considered and change in packet ration is analyzed. Third scenario is performed for massive failure of PDC in a zone and packets are now sending by the other PDC zone, increase in average packet rate is analyzed. Simulations in the fourth scenario are done by separating Billing data packets from priority queues and average packet reduction of priority queues is analyzed. In the fifth scenario latency rate for three models simple networking model, MPLS based and proposed SDN based is analyzed.

4.1 Average Load Per PDC

PDC is one of the main components of the WAMS system. In this section we analyzed the average load per PDC of proposed model and compared with the traditional model. Simulation results show that proposed model prevents the PDCs from overloading. As in traditional when the number of PMUs has increased, it overloads the PDC. Smart Grid infrastructure should be scalable and designed with consideration of future need. When smart Grid infrastructure will be deployed for large areas traditional WAMS model will become the bottleneck in performance of Smart Grid as it is unable to handle failures and increased load. Our proposed model solved both issues.

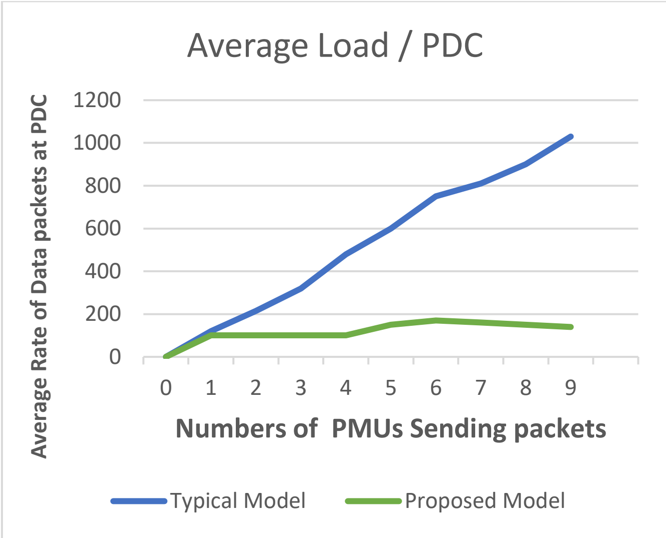


Figure 4.1: Average Load per PDC

4.2 Average Load After Single Failure

The proposed model can detect and avoid the failure of the PDCs. When the single PDC crashed this failure can be detected by either PMU or neighbor and Local master PDCs. However, load of fail PDC is assigned to nearest PDC by local master in case of single failure. Simulation statistics show the efficiency of proposed model. Data traffic is efficiently balanced and still less than the traditional WAMS model. The performance graph is shown in Figure 4.2.

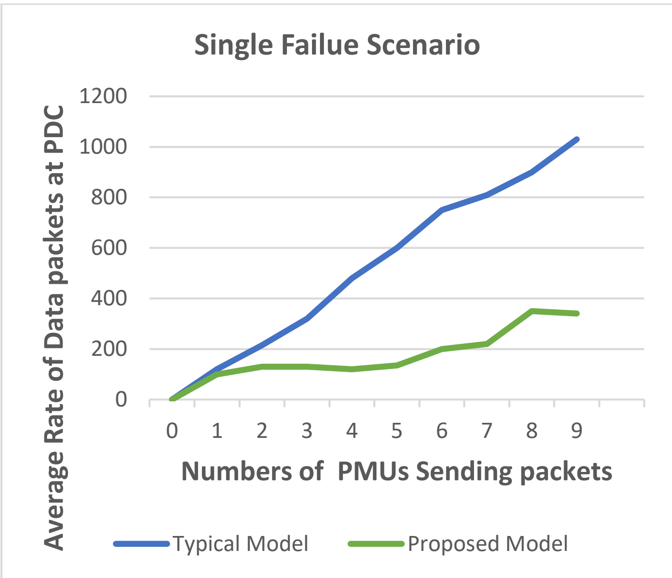


Figure 4.2: Average Load per PDC after Single Failure

4.3 Simultaneous Failure of Multiple PDCs

AS we discussed above that the proposed model could detect and avoid the failures, proposed model can handle not only single failure but Multiple failures as well. In case of simultaneous failures of multiple Local Master or Neighbor Master detects the failures by ping timeout and distributes the load among all its PDCs of its zone instead of assigning to single PDC so that, load is balanced equally, and system can run smoothly. Compression with traditional model, result shows that load balancing mechanism performed better than traditional model.

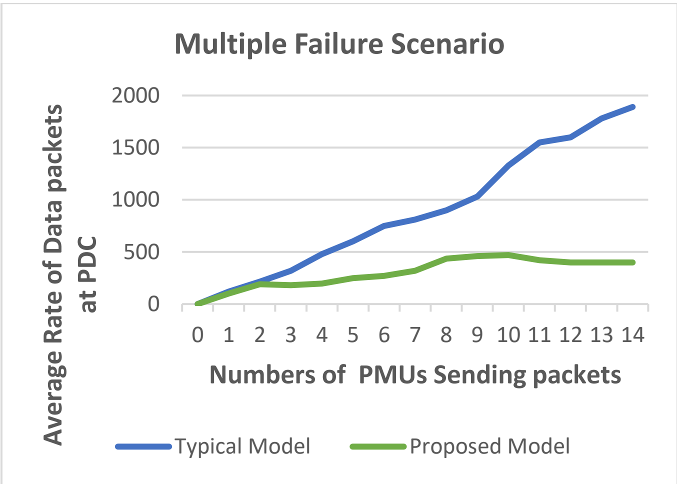


Figure 4.3: Average Load per PDC after Multiple Failure

4.4 Separating of Real-Time Billing Data from Priority Queues.

In our proposed solution for real-time billing calculation, we provide efficient billing mechanism for real-time calculations. After proposed transmission of billing data packets in priority queues are no longer needed. We separation of billing packets from these priority queues reduced the load from these queues. These resources can be allocated to important data transmissions to fulfill QoS requirements. Simulation results in figure 5.6 show the reduced load from priority queues.

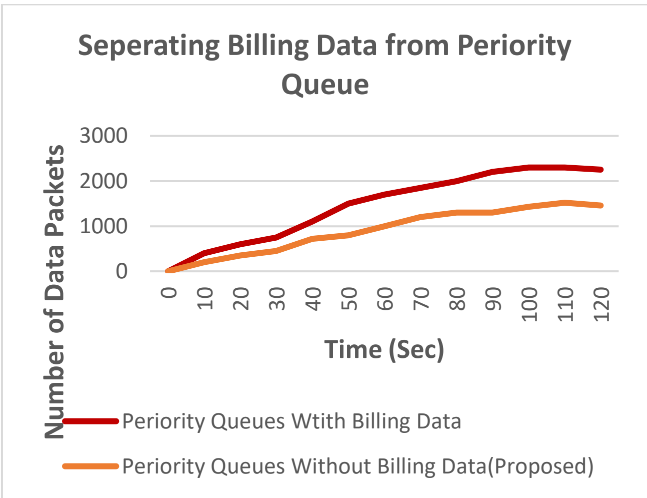


Figure 4.4: Separation of Real-Time Billing packets from Priority Queue

4.5 Jitter in Proposed Model Vs. MPLS Based Model

In Fig 4.3 jitter value is analyzed using MPLS based queueing values and in Figure 5.6 shows jitter in the proposed model, results clearly shows the jitter is reduced in propose model while in MPLS base when priority queues traffic is increased the jitter for other two queues increased more.

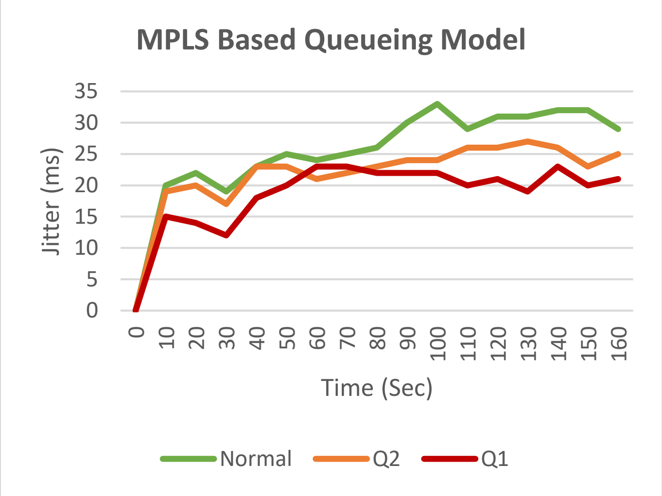


Figure 4.5: MPLS Based Model

In our proposed SDN based model jitter is reduced, QoS requirements demands to reduce the jitter in order to provide stability in Smart Grid Infrastructure by sending data related to Grid health in fast and efficient manners.

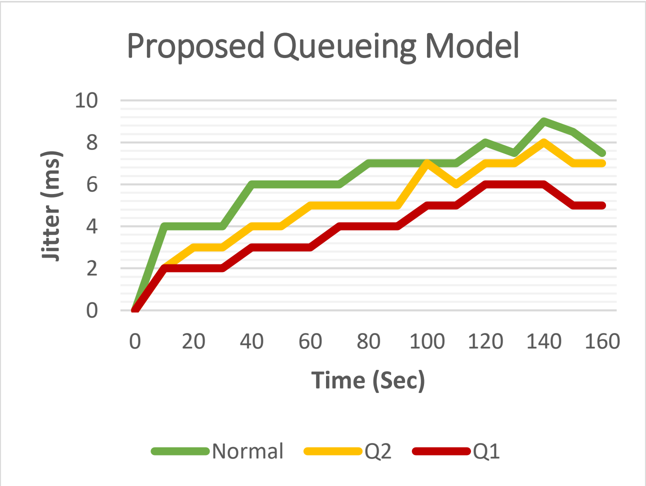


Figure 4.6: Proposed Model

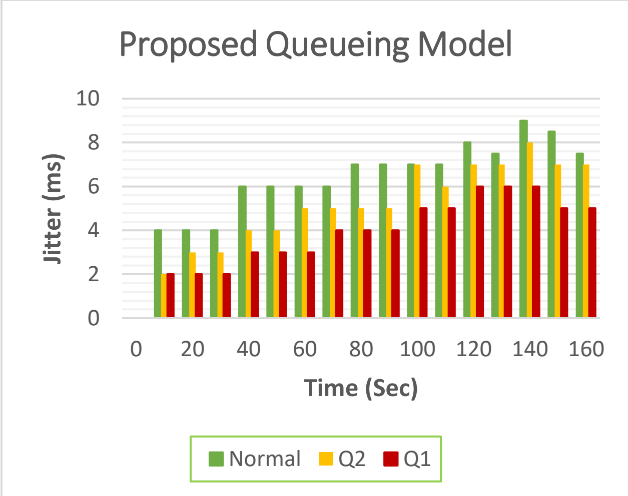


Figure 4.7: Proposed Model (Bar Graph)

5. Conclusion & Summary

This section explained the importance of Smart Grid infrastructure in current and future fulfillment of electricity needs. We explained the drawbacks of the traditional power grid as they are unable to meet the future electricity requirements. In addition to that, the whole process of traditional power depends on fossil fuel, natural gas and natural resources. The impact of using these resources on the economy is very high. In addition to that, these resources emit carbon gases during the electricity generation process. The emission of carbon gases is very harmful to the environment and it is one of the main reasons for climate change. It has a bad effect on human life. Smart grids (SG) are the necessary enablers in the transition of new infrastructure to fulfil the current electricity demands. Unlike traditional grids, the Smart grid introduced a two-way communication system where electricity and information can be exchanged. The smart grid is an intelligent and digitalized energy network to deliver electricity in an optimal way from generating sources to consumption ends. This can be achieved by the integration of information, communication and power technology into existing infrastructure. The whole system of the smart grid is equipped with strong network infrastructure and many other digital devices and sensors. The complete SG infrastructure from power generation to consumer end is categorized into three main areas: Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN). However, these areas are different in nature and each has different devices, network infrastructure, and communication requirements. Our proposed work is the Wide Area measurement system (WAMS). This system is related to medium to high voltage area which is from NAN to WAN. A large number of Distributed renewable energy sources (DERs) are also part of the Smart Grid to reduce the usage of fossil fuel and other natural resources in electricity generation. These DERs are also called green energy sources because they are environment-friendly and economical as well. The addition of these DERs to SG made Smart grid infrastructure more complex because these DERs are dependent on nature, so their productivity varies with respect to time of the day and environment. This variable generation of DERs requires several on and offs of the main grid to fulfill the electricity requirements. Strong communication and computation in SG infrastructures are needed to achieve high reliability in the system. In order to achieve this, we provided the design and implementation of a Software-Defined Network solution which can resiliently route the smart grid traffic and reduce the traffic load by optimizing the number of packets at Wide Area Network Level. Our purposed SDN based communication model can be deployed within and among the substations and lead towards the regional and main control centers. In Smart Grid infrastructure, substations are the ending points of HAN and NAN and starting points of WAN. In Smart Grid, WAN is equipped with Wide Area Measurement devices such as PMUs, PDS and Communication Network.

In our proposed SDN based model, SDN gateway switches are maintained at substations. However, these switches are controlled by SDN local controllers. In our purposed model, local controllers are placed to reduce the load from global controllers and network nodes. These local controllers are fully synchronized with the global controllers in order to maintain the updated network state. Overcome WMAS latencies by optimizing the load PMUs frames received at PDCs. In a large geographical area, we made zones. Each zone has a different number of PMUs. All PMUs are connected to all of their local PDCs. Local PDCs are placed according to the number of devices. All local PDCs are connected to all PMUs placed in their zone by mesh topology, but each PDC is responsible for a few PMUs. We assigned a unique ID to each PDC. SDN controllers are responsible for communicating these IDs to all PMUs. These PMUs have IDs of all PDCs placed in their zone but send their frames only to their assigned PDC. Demand and response (DR) are also an important and fundamental component of the Smart Grid which plays an important role in policy making and also in changing these policies. However, the addition of DERs to the Smart Grid infrastructure threatens stability because of their variable nature. To overcome stability issues, several researchers proposed method to control demand side instead of increasing and spinning power generation side. The Demand and response mechanism proposed the stability of the Smart Grid by offering consumers to participate by reducing their load at peak hours and providing benefits during the normal hours by reducing electricity prices. Peak hours are defined as when electricity requirement exceeds the generation, which may lead to blackouts. To avoid blackouts during peak hours, motivate users to reduce their load by rescheduling pending tasks. As mentioned earlier, billing data and billing calculations data can not be considered an affecting factor in the Smart Grid's health and stability. Using priority queues for this data is not a good practice to follow as these queues should be fully utilized for Smart Grid monitoring and other important issues related data. Approximately all of the above mentioned research articles are using priorities for these calculations. We proposed an efficient billing calculation mechanism without occupying any priority queues for this purpose. Our model can perform calculations accurately even if the data packets are dropped or lost. Quality of service in Wide Area Measurement System networks is an important factor. We proposed a traffic optimization mechanism to meet the QoS requirements of Smart. We provide a WMAS architecture model that has never been presented before. The proposed model balanced the complete load of Wide Area Network. The proposed model can handle the various types of failures and provide sustainable communication to the Smart Grid. We also proposed a queueing model to provide the priority to grid health-related data. However, the overall communication of WAN is optimized by proposed work simulation results show the performance of proposed work.

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