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Performance analysis of substation communication network architectures in OPNET

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Abstract

Substation communication network (SCN) is critical for the transmission of mission critical messages in IEC 61850 based digital substation automation applications. This paper presents the performance analysis of various substation communication network architectures, considering the IEEE/PSRC (Power System Relaying Committee) suggested traditional Ethernet switched networks such as star, ring, and star-ring. Further, the feasibility of the Substation Automation System (SAS) architectures in implementing crucial substation protection applications is analyzed by calculating ETE delay performance of time-critical Sampled Values (SVs) and Generic Object Oriented Substation Event (GOOSE) messages over SCN. OPNET (Optimized Network Engineering Tool) modeler is used to design, simulate, configure and study the dynamic performance characteristics of different SCN architectures drawn for a typical substation layout under normal as well as worst network traffic conditions.

Keywords: substation automation system**,** substation communication network architectures, switched ethernet, OPNET

1. Introduction

Modern substations are implementing switched Ethernet technology based IEC 61850 based Substation Communication Networks (SCN) [1]. Substation Communication Network is critical for reliable and efficient operation of substation automation system (SAS) and the benefits will not be realized if the performance of these networks is in-adequate. Hence, much of the focus in IEC 61850 SASs is on the real time implementation and performance investigation of substation communication networks in different configurations [2-4].

The reliability and ETE delay performance of this IEC 61850 time critical Generic Object Oriented Substation Event (GOOSE) and Sampled Values (SVs) messages depend primarily on SCN topology and on communication mechanism as per IEC 61850 communication stacks [5-6]. Further, network traffic management features offered by switched Ethernet allows optimizing the SCN architecture as per IEC 61850-5 performance requirements taking into consideration the constraints of the system [7-9]. However, unlike conventional hardwired schemes, the performance of communication based substation applications is also influenced by the variation in communication network parameters such as network configuration, data rate, sampling frequency, packet size, network load condition, network background traffic etc., other than the processing capabilities of devices used. Hence it is crucial to analyze the network traffic characteristics of SVs and GOOSE for a protection and control application running on the process bus based SCN for different network traffic load conditions, with high data rates and strict performance requirements, before these can be realized in real time applications [10].

OPNET (OPtimized Network Engineering Tool) modeler is a networking simulator with various advance features that can be utilized to study the performance of substation communication network (SCN) architectures under varying network configuration parameters [11]. This paper presents the performance analysis of various substation communication network (SCN) architectures, considering the IEEE/PSRC (Power System Relaying Committee) suggested traditional Ethernet switched networks such as star, ring, and star-ring. Further, the feasibility of the networks in designing SCN architectures is analyzed by calculating ETE delay performance of messages over SCN. OPNET modeler is used to design, simulate, configure and study the dynamic performance characteristics of different SCN architectures drawn for a typical substation layout under normal as well as worst network traffic conditions.

Section 2 discussed the modeling of SAS components in OPNET. Section 3 discusses the dynamic simulation of standard practical Ethernet network architectures in OPNET. Section 4 discussed the performance testing results. Finally, Section 5 concludes this paper.

2. Modeling of SAS components in OPNET

OPNET provides a comprehensive development environment for the designing, specification, simulation and performance analysis of communication networks. OPNET uses the Object-Oriented Data Modeling (OODM) approach for the design of substation IED models. These models are used to simulate any IEC 61850 based substation communication network in OPNET simulation environment. The OPNET simulates the SAS network under different scenarios, allowing user to set the sample rate, fault time, no. of faults, background traffic and other configuration parameters.

The modeling of IEDs is based on the communication stack specified in IEC 61850 standard, in which the GOOSE (event triggered) and Sampled Values (SVs) (time triggered) message is directly mapped on the data link layer and client/server application messages are mapped using all seven OSI communication stack layers. Table 1 enlist the node models of SCN components in OPNET. The different types of messages configured in simulated SCN are listed in Table 2.

Table 1: Network nodes available in simulated SCN architecture

SCN component Type	OPNET Node Model	Description
MU IED	ethernet_station_adv	Standard (Support SVs Stack)
P&C IED	ethernet_wkstn_adv	Customized to support Both client-server & GOOSE stack
CB_IED	ethernet_wkstn_adv	Customized to support both client-server & GOOSE stack
Ethernet switch	ethernet16_switch_adv	Standard
Fiber optics links	100BaseFX_adv	Standard
Station PC	ethernet_wkstn_adv	Standard
Server	ethernet_server_adv	Standard

Table 2: Message type and size among IEDs in the SCN [12]

Source Node	Traffic Type	Destination Node	Sam. Freq (Hz)	IEC 61850 Message Type	Message Size
MU IED	SV data	P&C IED	4800 Hz	Type 4	102 B
P&C IED	Background traffic	Station PC	1 Hz	Type 5	100-300 KBps
	GOOSE Trip signal	CB_IED	-	Type1	98 B
CB_IED	Status signals	Server	20 Hz	Type 2	150

3. Designing SCN & performance evaluation

Fig.1 shows the single line diagram of D2-1 type substation that consists of six feeder bays (F1-F6 bays), two transformer bays (TI&T2), and one bus section (S Bay) [17]. Fig. 2 shows the four conventional architectures, drawn for 220/132 kV substation shown in Fig.1, where each feeder bay is composed of one MU IED, two P&C IEDs, and one. Each transformer bay and bus section bay consists of two MU IEDs, one, and two P&C IEDs.

Fig.2 shows the substation communication network in star topology. Here, each transformer bay contains one Merging unit, two protections and control IEDs and two circuit breaker IEDs as shown in Fig. 3. The feeder bay as shown in Fig. 4 contains one merging unit IED, two protections and control IEDs and one circuit breaker IED.

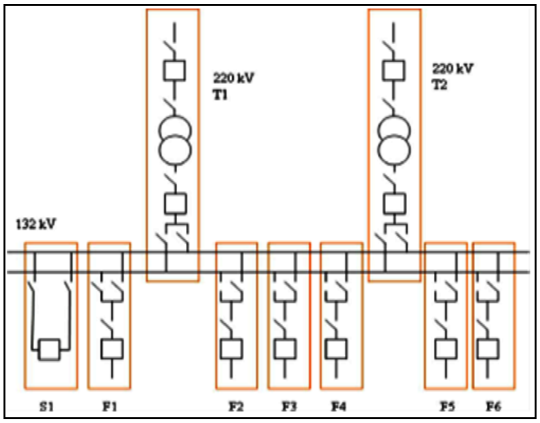

Fig 1: Substation single line diagram [2].

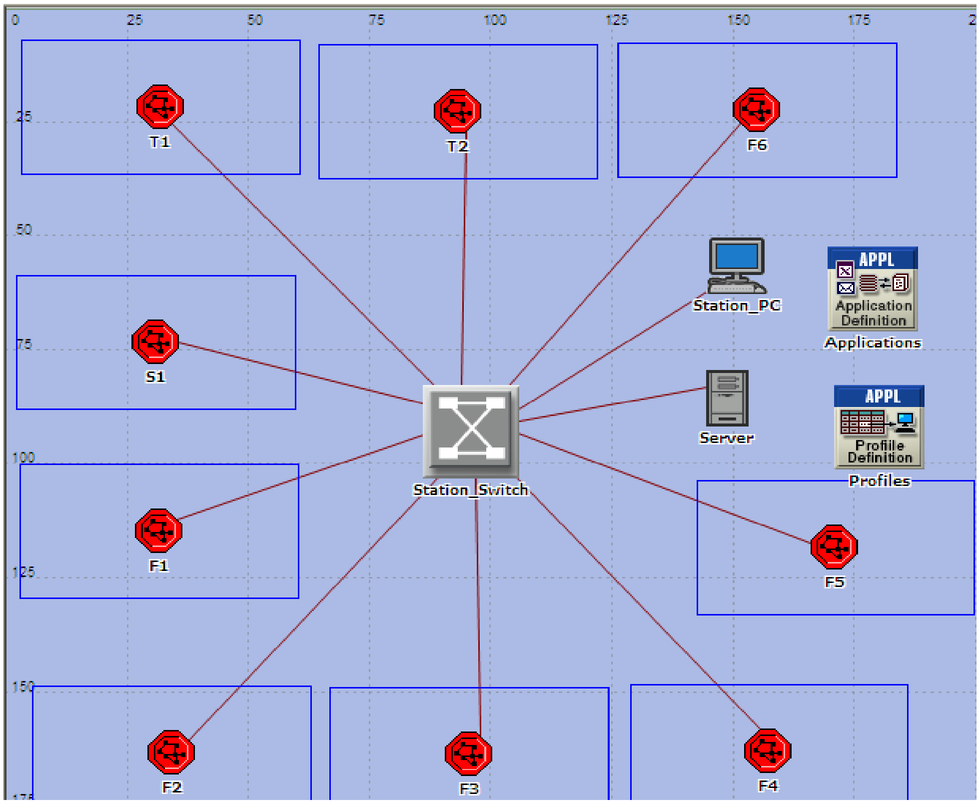

Fig 2: SCN in Star topology.

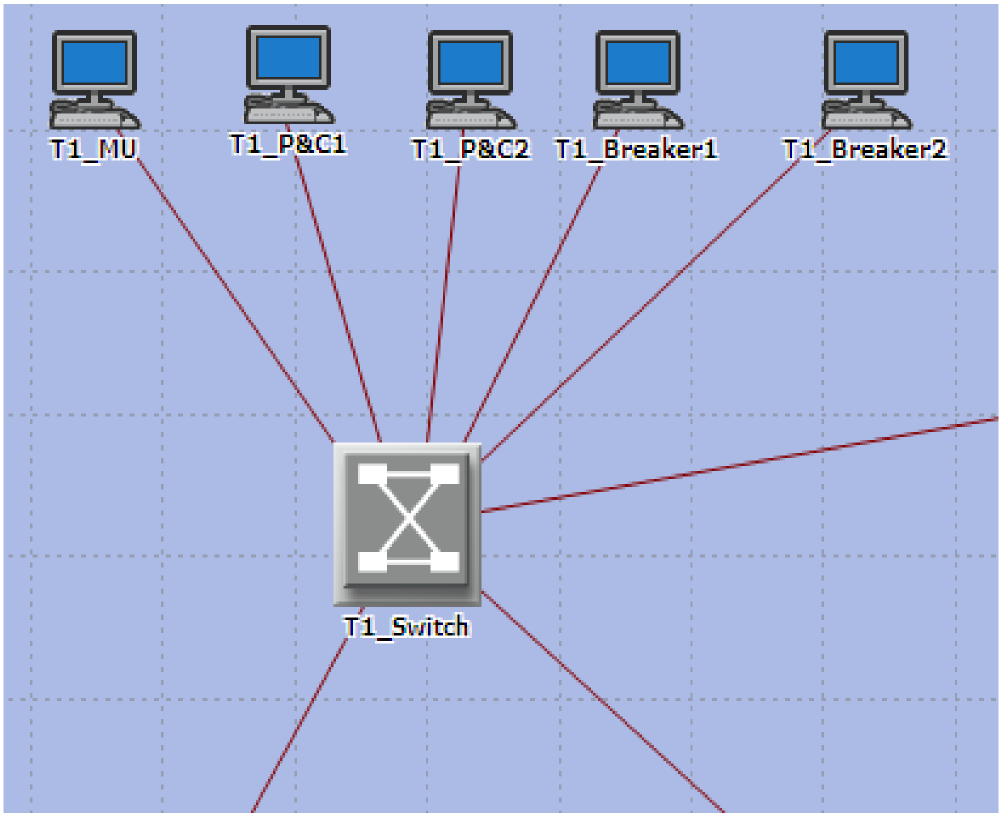

Fig 3: Subnet of transformer bay.

Similarly, it is possible to design SCNs using OPNET software in ring and star-ring configurations as shown in Fig. 5 and Fig. 6, respectively.

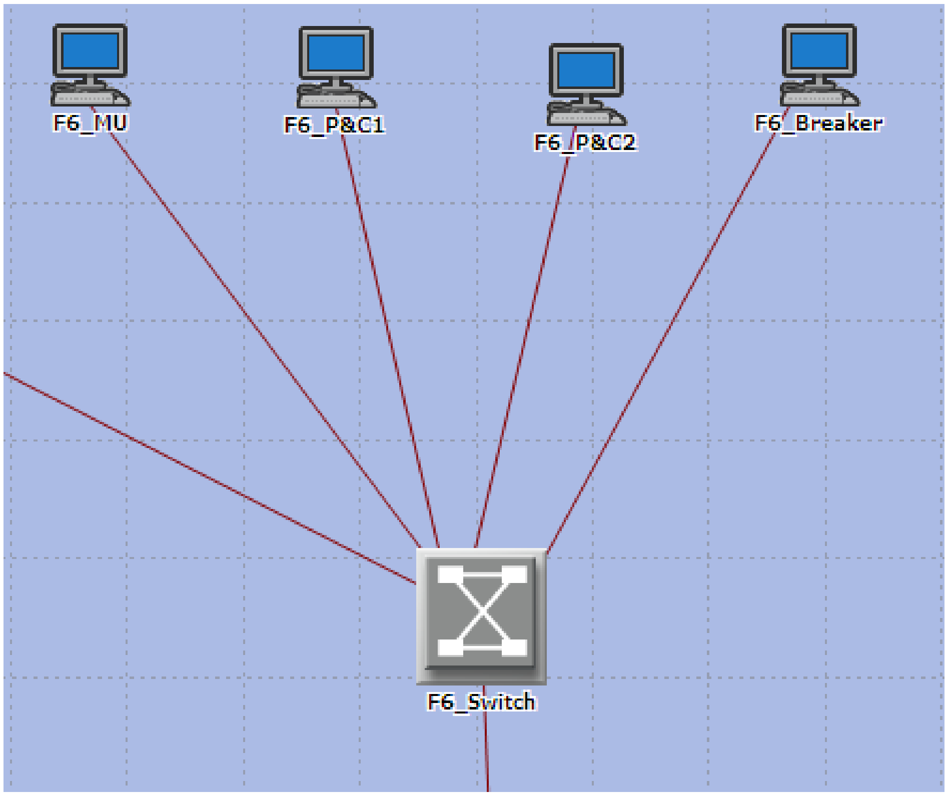

Fig 4: Subnet of feeder bay.

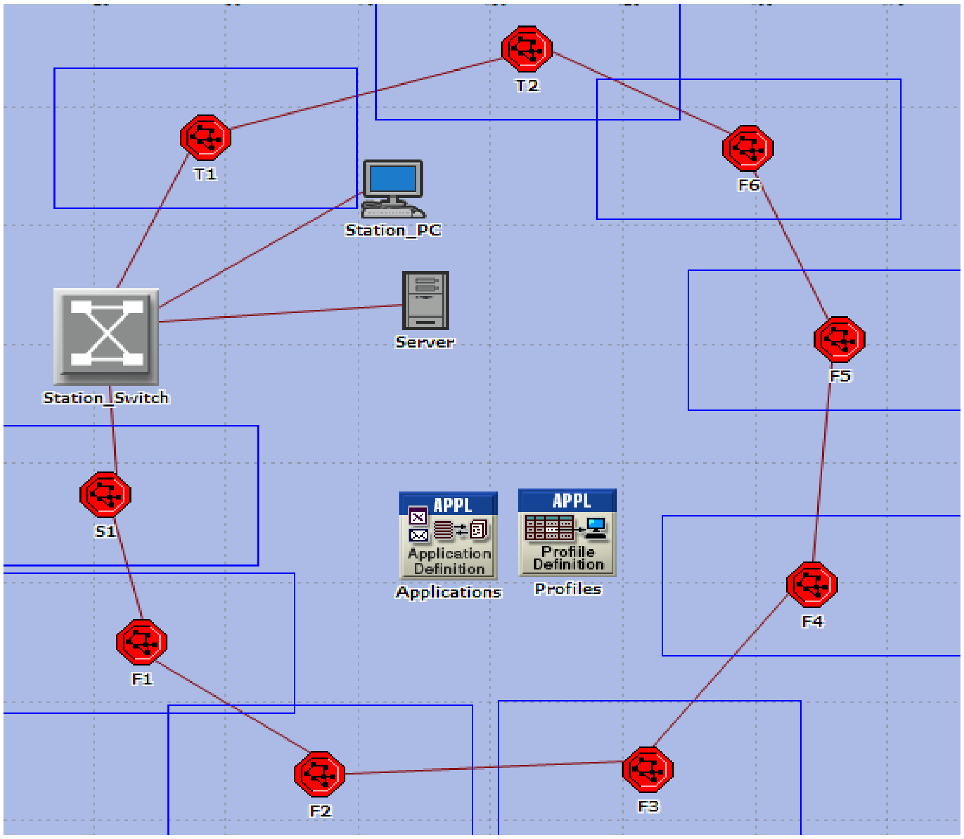

Fig 5: SCN in Ring topology.

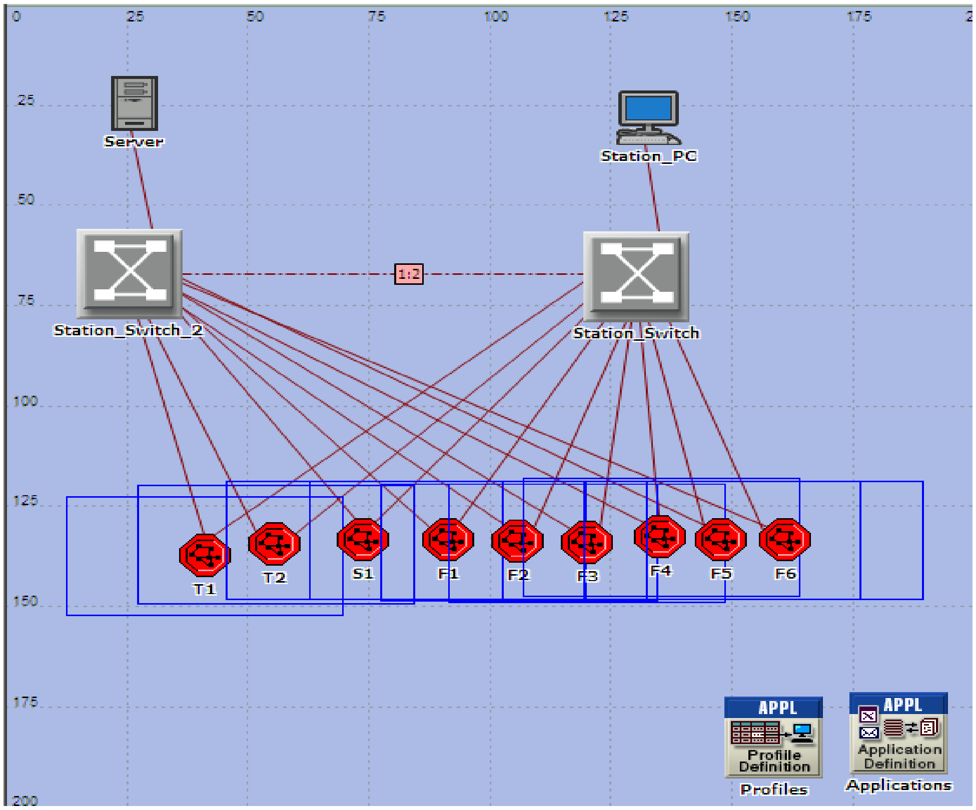

Fig 6: SCN in star-ring topology.

2. ETE delay Performance

Through the simulation, it is possible to observe the ETE delay in transmission inside the SCN so that the network performance, as specified in IEC 61850, could be checked or achieved by selecting proper topology and network configurations. Fig. 7 shows the comparison between message delay under 10mbps and 100mbps bandwidth of star topology.

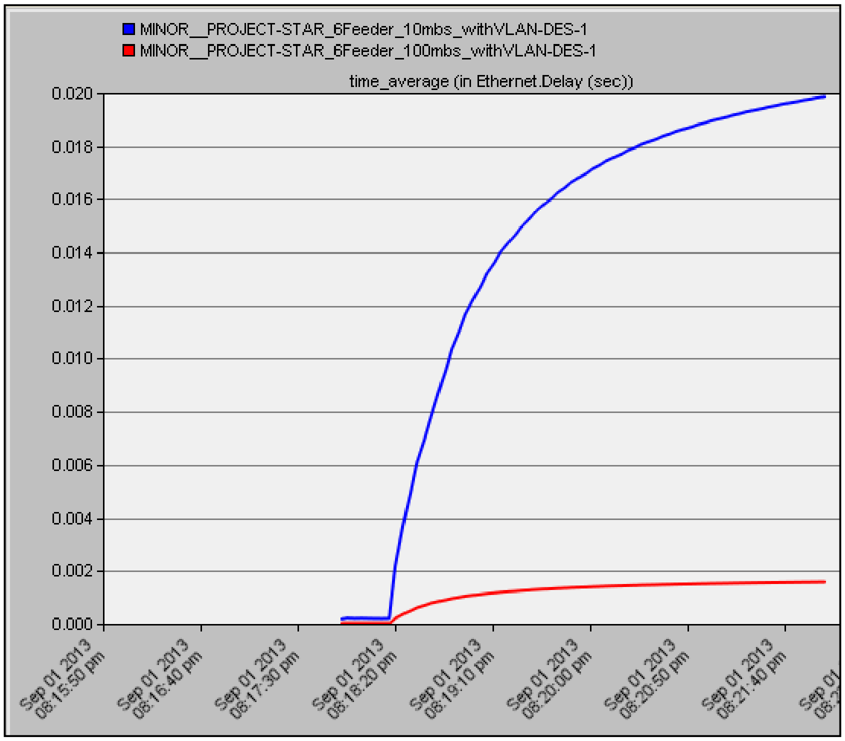

Fig 7: ETE delay in star under 10Mbps and 100 Mbps.

It has been observed that the delay at the server with 10mbps bandwidth Ethernet fibre optic cable is more as compared to 100mbps bandwidth capacity. Similar type of comparison is done for SCN in ring topology, as shown in Fig. 8. Results are same as expected i.e. delay is more for 10Mbps network as compared to 100 Mbps SCN.

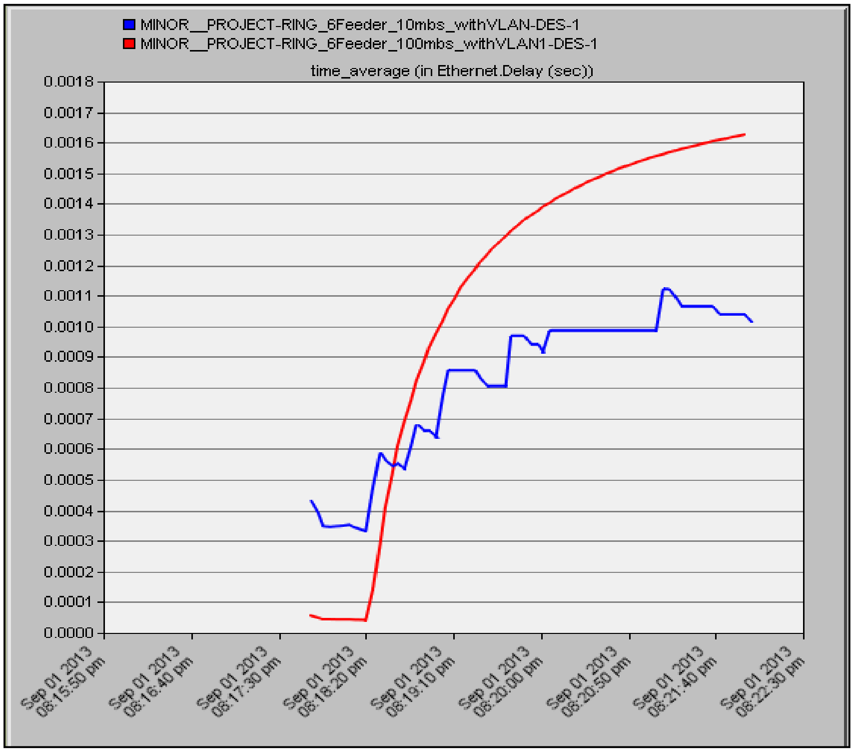

Fig 8: ETE delay in star under 10Mbps and 100 Mbps.

Now, a comparison is made among star, ring and star-ring topologies for the same 100 Mbps network, as shown in Fig. 9. Initially the delay in the star-ring topology is largest and then gradually becomes constant. Star topology provides the lowest delay but it is least reliable in case of fault as it has a single point of failure. Star-ring topology is having larger delay but it is reliable. So trade-off must be done between reliability and delay.

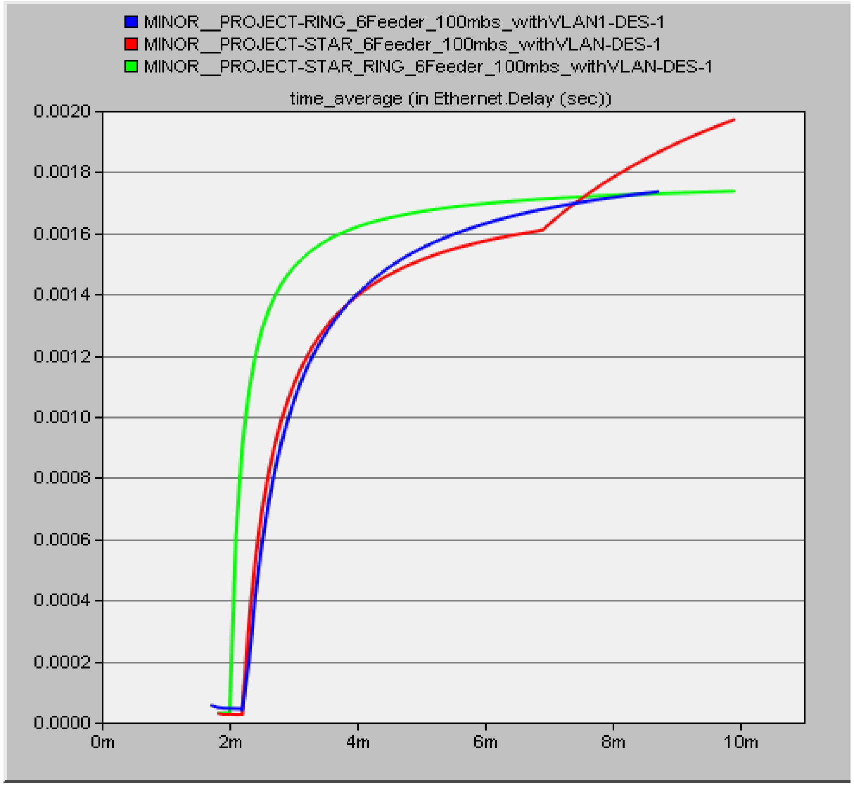

Fig 9: ETE delay in star, ring and star-ring topology.

Further, ETE delay is compared under VLAN feature of switched Ethernet technology for ring topology. It is found that the delay is more if the messages are sent without using VLAN, as shown in Fig. 9.

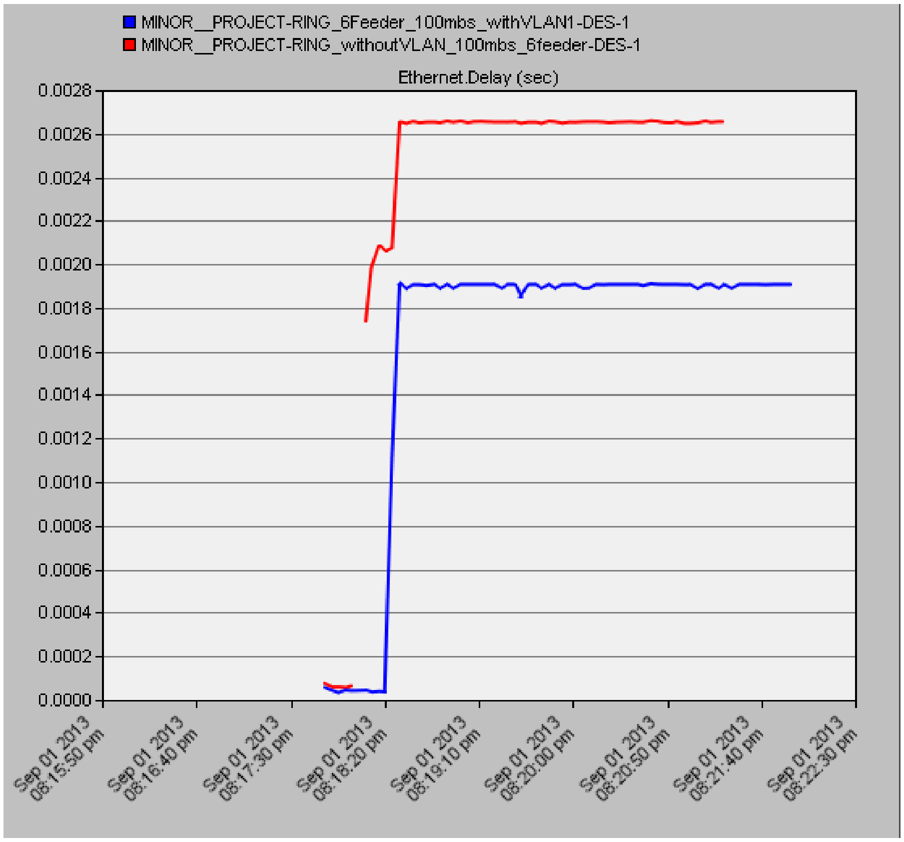

Fig 10: ETE delay under VLAN and Without VLAN in ring topology.

Finally, the delay performance is calculated under the load of feeders in substation i.e. on the amount of traffic on SCN. If the number of feeder is increased in the network, the ETE delay in the system increases as shown in Fig.10. The above result shows that the ETE delay in 15 feeder in greater than the 6 feeder substation i.e. on expansion of substation its effect will be render by delay in protection and control signals. Also, on increasing the number of feeders' packet loss started to occur in various VLANs. The above result shows the packet loss in VLAN ID 120.

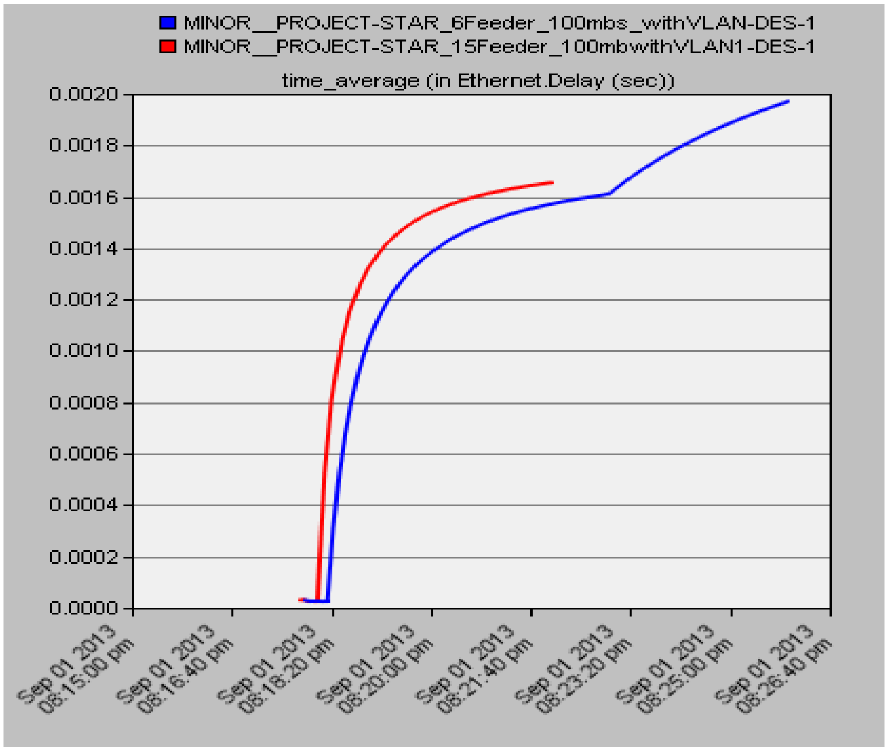

Fig 10: Effect of number of feeders on ETE delay.

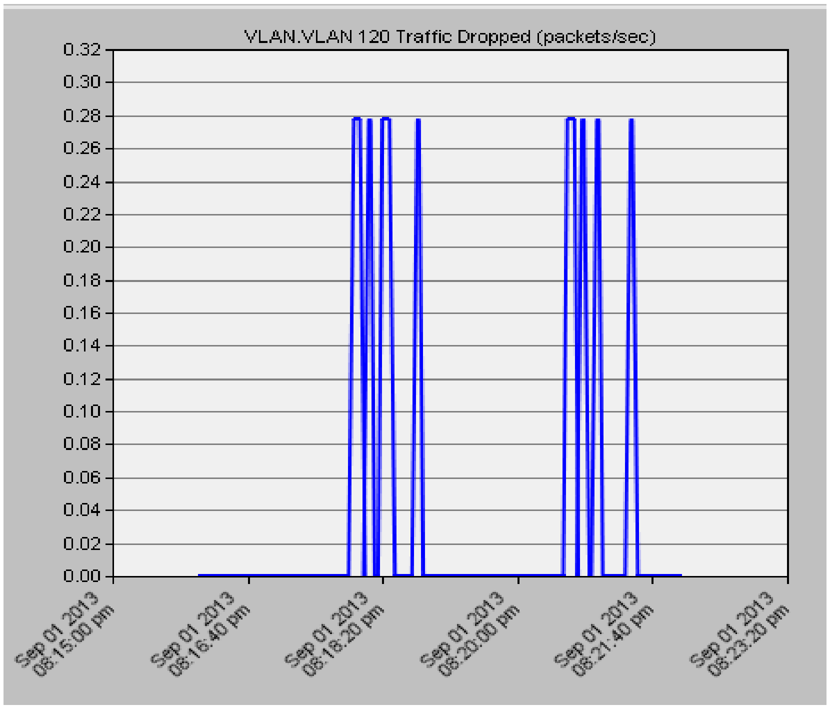

Fig 11: Packet loss in VLAN ID 120.

5. Conclusion

The performance of IEEE/PSRC (Power System Relaying Committee) suggested traditional Ethernet switched networks such as star, ring, and star-ring architectures are analysed under various network scenarios and observed their impact on End to End delay and Packet loss. It has been shown that the delay performance of IEC 61850 messages degraded and packet loss has been increased by the network traffic/feeder loads on a network. However, network management features such as priority tagging & VLAN has shown a significant improvement. The paper proposed to design an optimized substation communication network architecture that can fulfil the real time demands of modern substation automation system under worst case scenarios.

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