Analysis and Design of a Guaranteed Real Time Performance Enhanced Industrial Ethernet

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Abstract: *Industrial Ethernet is a new trend in technology designed to replace the traditional industrial solutions such as point to point and field bus systems. The paper aims studying Industrial Ethernet performance under hard real time system conditions. Substation automation system is chosen to be the environment in which Industrial Ethernet was assumed to be installed. OPNET package is used to simulate the behavior of such a system. From running the simulation model, the different parameters affecting the system performance were determined. Three solutions are presented to enhance real time performance of Industrial Ethernet. First of all, the negative effect of FTP transfer to an industrial node is solved using a new method called FTP traffic shaping which is presented to enhance the performance of the system while keeping the same nodes performance. The second direction is to enhance nodes operation using multicasting/VLAN techniques. The third motivation is studying the effect on non real time traffic flowing between non industrial nodes on the system behaviour; different techniques were suggested to enhance the network performance and a modified Etherchannel switch architecture is proposed.*

Keywords: *Industrial Ethernet, Latency, Field Bus, FTP, Multicasting, VLAN, Etherchannel.*

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1. Introduction

Many field bus vendors are moving forward to unify their efforts to establish a common network for their industrial solutions. Industrial Ethernet was chosen to be that solution. Industrial Ethernet uses all types of the protocols of traditional Ethernet including the Transport Control Protocol (TCP), the Internet Protocol (IP) and the media access and signaling technologies found in all Ethernet networks [14],[9].

The present paper focuses on Internet Protocol (IP) communication and the use of standard Ethernet for automation networking. This direction agrees with the motivation of the Industrial Ethernet initiative EtherNet/IP [9], Interface for Distributed Automation (IDA) [12], and Foundation Fieldbus High Speed Ethernet (FF HSE) [12]. By contrast, another body of real-time Ethernet based systems use special proprietary protocols, optimized stacks or both. This is the case for Ethernet Powerlink [17], Ethernet for Control Automation Technology (EtherCAT) [13], and PROFINET Isochronous Real-Time (IRT) [30].

Recently, many studies have been published to study the suitability of using Ethernet as a control network and to test its performance in the industrial environments. The main goal of these researches is to modify the latency , determinism , protocols, availability and intelligence of Ethernet. Many of the papers present a software based solutions to enhance operating system, application layer or network stack of the end nodes. Another direction is to modify the design of network hardware (Network Interface Card(NIC) and switches)[33, 34, 35, 22, 27, 25, 18, 24, 7, 6, 32, 36, 20, 16, 26].

There are three basic techniques for evaluating the performance of such networks: analytical modeling, simulations, and real-life measurements. Evaluation by simulation is probably the most compelling generic technique for predicting network performance and has been used for decades by various research communities, including those engaged in automation research [34–25].

In this paper, OPNET package was chosen to be the research tool. OPNET (**Op**timized **Net**works) is an advanced package that allows the user to design and study communication networks, devices, protocols, and application [14, 9]. OPNET was used to simulate different types of computer networks working in different environments. Another use of OPNET is to simulate industrial networks [14, 11, 12]. This is done by using the general blocks of OPNET and feeding them with the important parameters of industrial protocols to simulate the behaviour of such networks.

This paper aims studying Industrial Ethernet performance under hard real time system conditions. Substation automation system was chosen to be the environment in which Industrial Ethernet was assumed to be installed. The current work makes use of the results obtained by T. Sekie et. al. [11, 12] and build up on them to start a new approach to enhance the real time performance of Industrial Ethernet.

The rest of the paper is arranged as follows : section II gives an introduction to substation automation concepts. Section III explains the simulation procedure with the results of the reference case. Section IV introduces the FTP traffic shaping method with its advantages, while sections V and VI introduce Multicasting/VLAN and Modified Etherchannel techniques. At last, In section VII, all the above methods were combined to obtain the optimum performance case.

2. Substation Automation System

A substation is a large number of switchgears controlled, supervised and protected by a Substation Automation System (SA). The Substation Automation System (SA) is a network of functions realized inside devices strongly interacting as a system. The Substation Automation System (SA) comprises full station and bay protection as well as control, monitoring and communication functions and provides all functions required for the safe and reliable operation of the substations. A typical high voltage substation connects 3-10 transmission lines (feeder bay); two or more power transformers (transformer bay) and has a physical dimension of hundreds of meters [11].

For protection purposes, reaction times of the complete system must be in the order of 4-10 ms (1 ms for extra high performance systems) between fault occurrence and circuit breaker deenergising. Other monitoring includes the state of the electrical process, currents and voltages, status information from circuit breakers, gas insulation units and more [14].

Communication requirements for the substation were implemented using different techniques, such as point-to-point and field bus systems (especially Modbus type [10]). Industrial Ethernet was entered strongly into this field and unified efforts of different organizations result the development of the International Standard – IEC 61850 – Communication Networks and Systems in Substations [14].

A typical layout for a substation consists of several sub networks. Each sub network (bay) consists of the following components [11, 31, 28, 5]:

- (8) Intelligent Electronic Devices(IEDs) used as sensors (Sn) to measure different quantities at different sampling rates.
- (3) IEDs work as actuators (ACn) for different purposes (e.g., circuit breaker).
- One local controller which has the following functions:
  - Connection to remote centres (SCADA system purposes)
  - Automation and local control

Also, there is a global controller responsible for the whole substation's automation and protection functions. In addition, global controller can take the tripping actions of any local controller in the case of its malfunction.

In the control room, there is a computer used for:

- Operator interface for monitoring and control of the entire substation
- Maintenance interface
- System administration interface.

This is called Human Machine Interface (HMI).

3. Simulating Industrial Ethernet Performance in Substation Automation

An OPNET model (represents five sub networks substation automation system) is built to test the performance of Industrial Ethernet under hard real time conditions (with 1ms as the dead time). The different parts of the model have the performance listed in table (1) [12].

Table 1. Industrial Ethernet Performance

Ethernet Type	Fast Ethernet (Data Rate:100 Mbps)
Sensors packet processing rate	5000 Packet/s
Actuators packet processing rate	5000 Packet/s
Local controller's packet processing rate	10000 Packet/s
Global controller's packet processing rate	30000 Packet/s
Cables Types	UTP for short distances-Fiber optics for long distances

The traffic pattern (which represents the control activities of the different parts of the substation automation system) presented in references [10-12, 5] is adopted and it can be summarized as listed in table (2) (The detailed description of the protection algorithms for the substation is beyond the scope of this paper).

Table 2. Traffic Pattern of a typical substation Automation System

Source	Destination	Packet / s	Length
S1-S2-S3	Local Cont.- AC1-AC2-Global Cont.	1000	32 Byte
All Sensors	Local Cont.-AC1-AC2	10	32 Byte
Local Cont.	AC3	250	16 Byte
G. Cont.	AC3's in all subnet's	250	16 Byte
HMI	S1-S2-S3-Local Cont.-Global Cont.	1 file each	1Mbyte
Local Cont.-Global Cont.	HMI	2 file/min.	1Mbyte

As listed in the table, UDP protocol is used to transfer time critical data (measured samples) while TCP is used to transfer administrator's configuration information to some nodes. SCADA information is transferred periodically form global controller and from each local controller (summery of Bay data) to HMI in the control room for monitoring and control purposes. The traffic in the table, represent the traffic in one bay (sub network) and it is repeated in the other bays.

The metrics used to evaluate the performance of Industrial Ethernet are [12]:

- Local Latency: {the latency measured from the application layer in the sensors to the application layer in the local controller} + {the latency measured from the application layer in the local controller to the application layer in the circuit breaker}.
- Global Latency: {the latency measured from the application layer in the sensors to the application layer in the global controller} + {the latency measured from the application layer in the global controller to the application layer in the circuit breaker}.

3.1. Comments on the Simulation Results

From running the simulation model, different statistics (which explain the behaviour of the system) were collected as follow:

3.1.1. Traffic map of the Substation Automation system

The complete traffic flow of the control data packets on the network is shown in figure (1). The values shown in the figure are calculated by the simulation program as follows:

By taking node (S1) as an example, the throughput (actual data rate on a network channel) can be calculated by multiplying the packet production rate (4030 Packet/S) by the packet size (32 Byte + headers at different network's stack layers), which results in (3.8 Mbps).

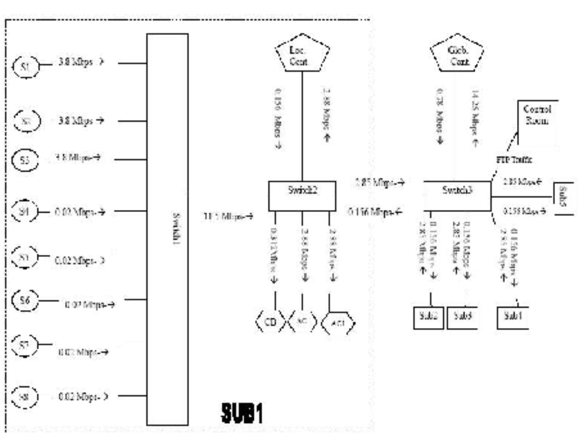

Figure 1. Traffic Map of the Reference Case.

The throughput on each segment represents low utilization of the whole channel capacity (100 Mbps).That means, congestion problem (nodes traffic exceed channel capacity) is avoided and hence, Ethernet delay has a minimal effect on the total latency. FTP traffic causes a transit increase in the throughput values shown in the traffic map.

3.1.2. Local and Global Latency

Figure (2) shows the change in local and global latencies over simulation time. The following observations could be extracted from the graphs:

- Most of the latency is concentrated inside the node's network stack.
- Latency graphs have two regions: constant latency region and unstable region (since the system fails to respond within the dead line time of (1ms)).

Constant latency region represents the system behaviour when the traffic on the network is of the real time data only.

The value of this latency is less than (1ms) which responds successfully to the real time bounds of the system. However, this value is still relatively high, because for each measured sample , the sensors IEDs generate four packets addressed to four different destinations(refer to table (2)).This gives a rise to the node's CPU utilization (see Table(3)) and generates more queuing delay inside the nodes, and all that increase latency.

The unstable behaviour of the system shown in Figure(2), is coming up from the highly loaded nodes that are subjected to more traffic during the file transfer operation which adds more delay to the packet generation operation and hence, increased latency. File transfer protocol (FTP) is used to handle the operation of file transfer and it needs a maximum time of (3.5 s) to complete its task.

- Global latency has a lower value than local latency. This is caused by the higher processing capabilities of the global controller compared to local controller. On the other hand, the Ethernet delay to the global controller has an average value of (67 μS) while the average value of Ethernet delay on the local controller is equal to (46 μS) .This assures that Ethernet delay (in this model) has a minor effect on the total latency.
- The small peaks in the graphs were caused by the upload operation (SCADA information transfer) from the controllers to the control room.
- The Sensor nodes (especially S1-S3) suffer from a higher utilization of their associated CPU more than other nodes, See table (3)

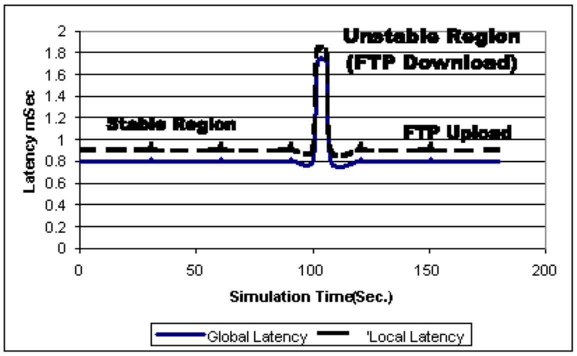

Figure 2. Global & Local Latency Change over Simulation Time

Table 3. CPU Utilization of the Substation Nodes

Node	Associated CPU Utilization %
Global Controller	60%
Local Controller	34%
S1-S3	83%
S4-S8	1%
AC1,AC2	31%
AC3	10%

4. Enhancing Industrial Ethernet Performance Using FTP Traffic Shaping Technique

As shown earlier in figure (2), the effect of transferring a file to a working industrial node is quite clear. The high arrival rate of the FTP byte streams to the node creates a new task which delays the packet production operation and hence, increases latency. The FTP effect on latency depends mainly on the transferred file size, see figure (3).

A possible method to solve this problem is to use a higher node's processor performance [29]. Another technique is to implement some TCP/IP software tasks in hardware [3].However, these methods suffer from high cost and compatibility problems [12].

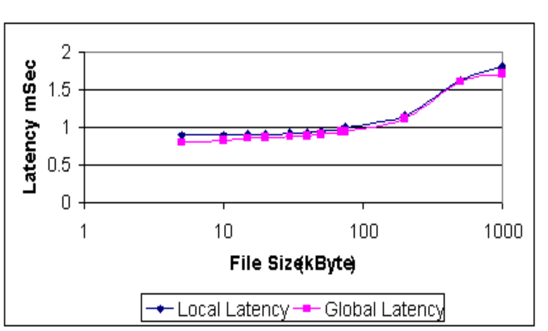

Figure 3. Effect of FTP File Size on Latency.

In this paper, a new method is presented to enhance the performance of the system while keeping the same nodes performance. The new method is based on inserting Quality of Service(QoS) concepts in the application layer FTP program. Our idea depends on the deceleration of the FTP traffic forwarded (from HMI) to certain nodes. Instead of sending FTP streams in the form of a sudden burst, it is divided into small segments with a certain time periods (gaps) between them .This arrangement gives the nodes (especially, sensors) enough time to generate their ordinary data packets within their real time bounds. This technique we call FTP traffic shaping because it enforce FTP traffic to take a certain manner. In order to achieve this, changes must be added to the operation of the file transfer protocol. Flowchart shown in figure (4) illustrates the operation of the proposed protocol. In this case, it is important to calculate both segment size and inter request time between segments.

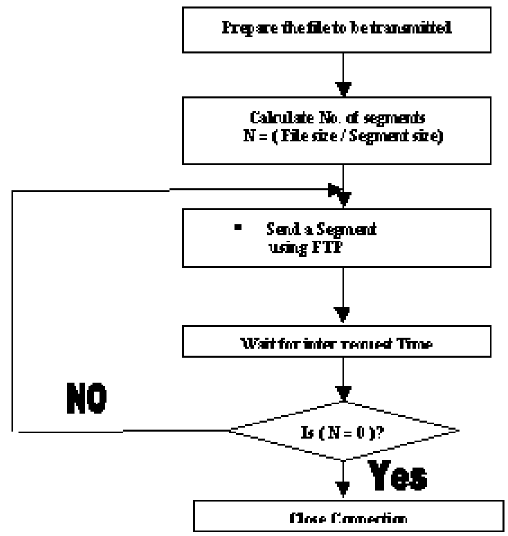

Figure (4): The Proposed FTP Operation

In order to find the optimal values for both segment size and inter request period, the following steps were followed :

- Finding the relation between maximum latency and file sizes, see Figure (5). From this relation, the segment size was chosen to be the maximum file size that makes no change in the latency. This choice decreases the number of segments, which minimizes both overhead processing and the total FTP response time.
- Finding the FTP response time to the different file sizes in step (1), as shown in Figure(6). The gap period is chosen to be slightly more than the FTP response time of the chosen segment size.

Using the above procedure, for 20kByte segment size, the value for the inter request time is (0.25 s). The choice of the gap time between segments takes into consideration a compromise between latency and FTP response time. From figures (7 & 8), choosing large values of inter-request time (in order to get low latency values) results in large value of FTP response time
Returning to the case of (1Mbyte) file size, it was divided into (50) segment, each sent separately using FTP which results the system behaviour shown in figure 9.

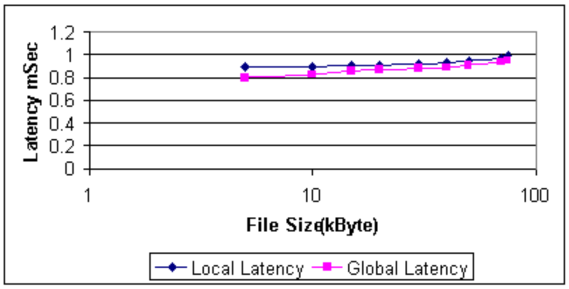

Figure 5. Maximum Latency Variation against Different Files Sizes.

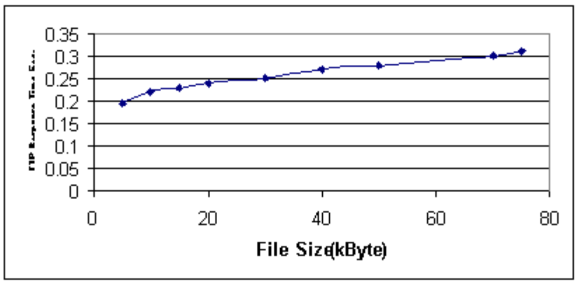

Figure 6. FTP Response Variation against Different Files Sizes.

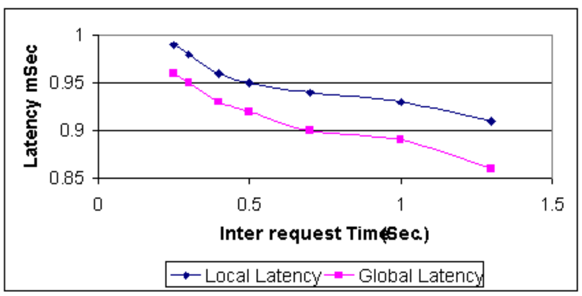

Figure 7. Effect of Inter Request Period on Latency

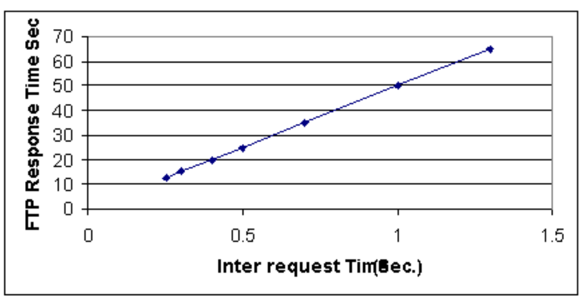

Figure 8. Effect of Inter Request Period on FTP Response Time

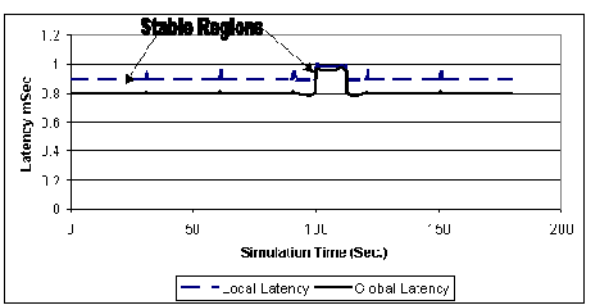

Figure 9. Modifying Latency Using FTP Traffic Shaping

The upload operations done by the controller nodes (SCADA system), have minor effects on latency (due to the relative high processing capabilities of these nodes), so that, FTP traffic shaping technique was not applied in these nodes.

FTP traffic shaping method has a number of advantages:

- It is an easy solution, needs minor software changes in the FTP program installed on the different nodes.
- The new method effectively enhances the real time performance of the system.
- The adoption of this method gets rid of the instability. Any file size could be downloaded or uploaded to/from the nodes without any effect on its operation.

However, this technique adds more delay to the FTP response time (from 3.5s to 12.5s).This could be acceptable because file transfer operation is considered as a non real time task.

5. Modifying Industrial Ethernet Behaviour Using Multicasting / VLAN Techniques

It is noted in figure (2) that latency values are still relatively high. Most of the remaining latency comes from the originating nodes (sensors). The packet generation technique used by the sensors follows the unicast procedure.

Unicast procedure consumes CPU power and resources of the industrial node (return to Table 3). In addition, if the packet production rate is high, queuing delay is created at different network layers of the industrial node. All this adds extra delay to the total value of the latency. Unicast is usually used when the node intends to send to a specific destination .If the node intends to send the same packet to multiple receivers at the same time, multicasting technique is used. Today, this technique is used by various internet applications, such as: video conferencing, corporate communications, distance learning, and distribution of software, and news. The main contribution of multicasting in these fields is to minimize channel utilization, and hence, improves internet services characteristics [29].

Some researchers [11, 12, 23] suggested (as a future work) the use of multicasting to enhance the performance of the real time systems. However, none of them studied the effect of such a suggestion. In this paper, a comprehensive study to the effect of using multicasting was made.

5.1. Using Multicast in Industrial Ethernet

Multicast is based on the concept of grouping. A multicast group is an arbitrary group of receivers that expresses an interest in receiving a particular data stream. This group has no physical or geographical boundaries—the hosts can be located anywhere on the Internet or any private network [29]. IP multicast addresses specify a "set" of IP hosts that have joined a group and are interested in receiving multicast traffic designated for that particular group [29].

In this paper, IP multicast is used to enhance the real time performance of Industrial Ethernet by modifying packet generation process. Nodes were arranged into several multicast groups according to traffic pattern listed earlier in table (2). Table (4) detailed this arrangement. Accordingly when sensors generates a packet, its address is the value of IP multicast group and therefore this packet is forwarded to all members of the multicast group in the same time.

Table 4. Multicast Groups for Different Nodes

Multicast Group 1	S1 - Local Controller – AC1 – AC2 – Global Controller
Multicast Group 2	S2 - Local Controller – AC1 – AC2 – Global Controller
Multicast Group 3	S3-Local Controller – AC1 – AC2 – Global Controller
Multicast Group 4	S1 - Local Controller – AC1 – AC2
Multicast Group 5	S2 - Local Controller – AC1 – AC2
Multicast Group 6	S3- Local Controller – AC1 – AC2
Multicast Group 7	S4 - Local Controller – AC1 – AC2
Multicast Group 8	S5 - Local Controller – AC1 – AC2
Multicast Group 9	S6 - Local Controller – AC1 – AC2
Multicast Group 10	S7 - Local Controller – AC1 – AC2
Multicast Group 11	S8 - Local Controller – AC1 – AC2

The multicast groups were fed into OPNET simulation environment. The results obtained from running the simulation show that CPU utilization of the sensors falls (from 83% to 20%) which decrease the delay inside those nodes. The positive effect of multicasting technique on latency is shown in shown in figure (10).

However, Multicasting causes an increase in network traffic. The reason behind this increase belongs to the fact that Ethernet switch do not have the ability to forward multicast traffic to its intended destinations only. Ethernet switch keeps a list of the physical addresses of the nodes connected to it, if it receives any packet carried a different destination address (including a multicast group address), it will forward it to all other ports except the one which come from. This is called "flooding" [29]. In flooding, the traffic on the network is increased and the nodes receive more traffic, that most of it does not belong to those nodes .This causes additional load on the node's NIC, and hence, more delay. In addition, Ethernet delay increased (especially queuing delay in the switches) because more packets are competing on the same output port. In the internet, the problem of flooding was solved by using Internet Group Management Protocol Snooping (IGMPS) which is installed on the network's routers [8]. In the present system, routers were not used. The alternative solution is to use virtual LAN (VLAN) technique.

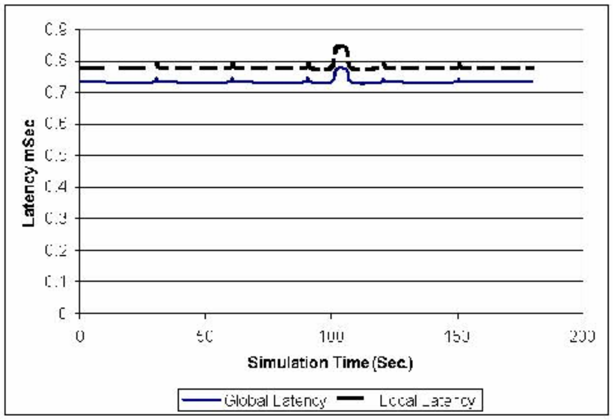

Figure 10. Latency Variation in Multicasting case.

5.2. Using Multicasting / VLAN in Industrial Ethernet

One of the benefits behind using VLAN technique is the isolation of the traffic of different multicast groups[2]. This may solve the flooding problem mentioned earlier. In order to investigate the effectiveness of this solution, multiple VLANs were created according to the multicast groups listed earlier, see table (5).

Table 5. Dividing the Nodes into Different VLANs

VLAN1	S1 - Local Controller – AC1 – AC2 – Global Controller-HMI
VLAN2	S2 - Local Controller – AC1 – AC2 – Global Controller-HMI
VLAN3	S3-Local Controller – AC1 – AC2 – Global Controller-HMI
VLAN4	S1 - Local Controller – AC1 – AC2
VLAN5	S2 - Local Controller – AC1 – AC2
VLAN6	S3- Local Controller – AC1 – AC2
VLAN7	S4 - Local Controller – AC1 – AC2-HMI
VLAN8	S5 - Local Controller – AC1 – AC2-HMI
VLAN9	S6 - Local Controller – AC1 – AC2-HMI
VLAN10	S7 - Local Controller – AC1 – AC2-HMI
VLAN11	S8 - Local Controller – AC1 – AC2-HMI
VLAN12	Local Controller- Global Controller-AC3

The VLANs shown in the table above were submitted to the OPNET environment. The available type of VLAN in OPNET environment is port based VLAN. The change in latency is shown in Figure (11) and the traffic map of the network is shown in Figure (12).

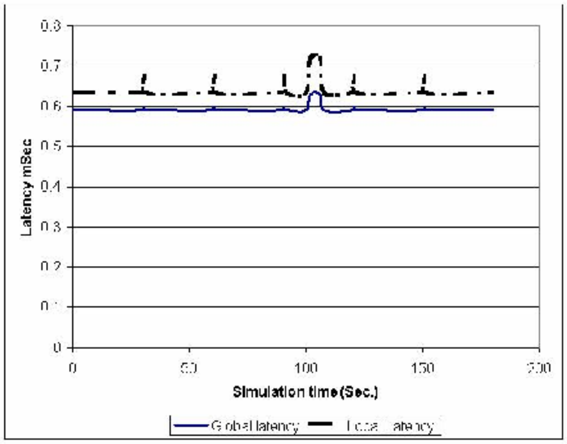

Figure 11. Latency Variation in Multicasting/VLAN Case

As compared to Figure (4), the traffic on the network is greatly reduced and the flooding problem was totally removed which affects positively on the latency .The other gain beyond using Multicasting / VLAN solution, is the optimized use of industrial node resources, especially the sensors CPU utilization, which was reduced to (20%). Multicasting frees the nodes from running the unnecessary tasks. At the same time, partitioning the network to multiple VLANs, guides the multicasting traffic to the intended destinations only. It is also noted that the FTP response becomes (3 s), which reflects the enhanced abilities of the nodes to receive and process more traffic, without threatening their primary tasks.

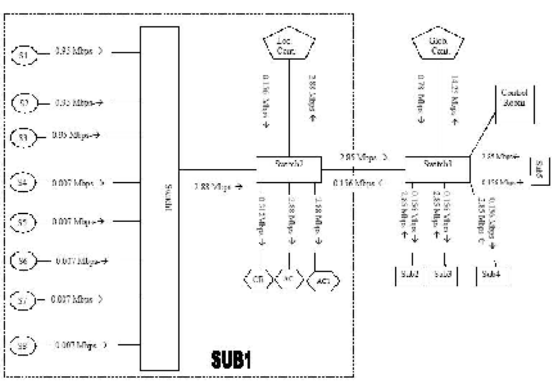

Figure 12. Traffic Map in Multicasting/VLAN Case

6. Effect of Network Delay on Latency

In the previous sections, it was shown that nodes performance and their response to different traffic types seriously affect on the system latency. This section deals with the effect of network delay on the system's real time performance. Network (Ethernet) delay depends mainly on the load offered to the network. In the previous sections, the network assumed to be lightly loaded compared to its 100 Mbps channel capacity, see figure (1). Therefore network delay is considered to have a minor contribution among all other factors. Ethernet delay consists of three parts [17]: packet transmission time, propagation delay (Propagation delay is relatively small and could be neglected) and switch delay.

In this section, network behaviour with the presence of non real time traffic (flowing between non industrial nodes) is to be studied. This traffic was added as background traffic, with a variable load conditions. The effect of such traffic was evaluated, and three different solutions were presented to minimize its effect on latency. These solutions are based on either limiting the amount of the added traffic or increasing channel bandwidth of the network.

6.1. Network Delay Investigation

In order to investigate network delay causes and effects, two nodes (computer1 & computer2) were added to the substation network.

In the beginning, these two nodes were connected to the same switch (SW3). The two nodes exchange a TCP data with a total rate of 100 Mbps on the line. The latency was measured and global latency only was increased by a ratio of (1%). This little increase assures the affectivity of the *non blocking* property of the switch. This property allows any two ports to exchange data without disturbing or blocking other ports on the switch [15].

Now, computer1 & computer2 are connected to switch1 and switch3 respectively and the load between them is changed from (0 to 100 Mbps) while measuring the maximum latency value. Figure (13) indicates that the network delay becomes more effective when the offered load exceeds (40Mbps), and the network becomes more congested when the load exceeds a value of (80Mbps).

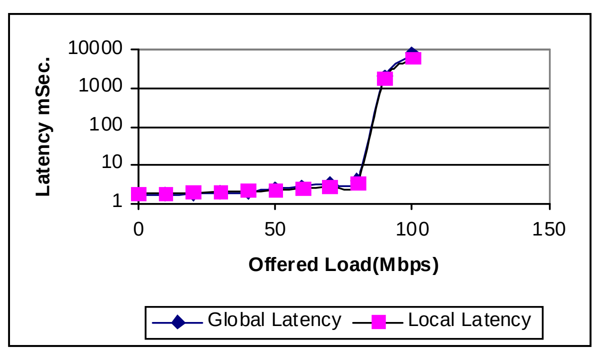

Figure 13. Effect of Non Real Time Traffic on Latency

The main reason beyond the increase in network delay, and hence latency, is the competition between different traffic types. When the packets moved from a switch to another, they pass through the ports that connect the two switches. When the load increases, more packets try to pass these ports which create more queuing delay inside the switch (bottle neck point).

When the offered load becomes very high, the queued packets inside the switches occupy most of its memory, which force the switch's controller to take one (or both) of the following two actions[13,19]:

- Removing the packets that spent a certain time inside the switch's memory (aged packets).
- Suspend accepting any further packets.

These network conditions; caused a very high delay to packets (some packets do not reach their destinations at all). Figure (14) shows the latency change when (100 Mbps) load is offered to the network. The latency increment is unlimited, which disable the whole network operation. It is noted that global latency has a higher value than the local latency, because the packets forwarded to global controller suffer from higher Ethernet delay.

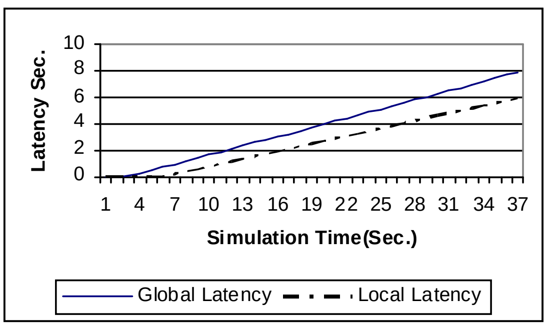

Figure 14. Latency Performance with (100 Mbps) Background Traffic

6.1.1. Solving Network Delay problem

Network delay problem could be solved by limiting the non real time traffic offered to the network, increasing the channel bandwidth between the switches or using Quality of Service techniques. The first solution was achieved by limiting the network connection to the non industrial nodes via (10 Mbps). This is the easiest and cheapest option. The ports, to which non industrial nodes are connected, could be reconfigured to work at 10 Mbps speed. This puts an upper limit to the non real time traffic contribution, which minimizes its effect on the network delay. The simulation results (refer to Figure (13)) show very stable network behaviour in the presence of the (10 Mbps) traffic and the latencies keep their values without any change.

The other solutions use either EtherChannel technology or 10 Gigabit Ethernet to increase the bandwidth between the switches. . In this paper, 10 Gigabit Ethernet is used to connect the industrial network switches together, which increases the bandwidth between them to 10 Gbps. This arrangement allows both real time data and non real time data to be existed on the same network without disturbing each other. The simulation gives a maximum local latency value of (1.6 ms) and (1.5 ms) for global latency. However, 10 Gigabit Ethernet represents the highest cost option. The above solutions were tested in OPNET environment, assuming the presence of a (100 Mbps) non real time load to the network (worst possible case in our model).

6.1.2. Using a Modified EtherChannel Technology to Increase Channel Bandwidth:

EtherChannel technology builds upon standards-based 802.3 full-duplex Fast Ethernet to provide network managers a reliable, high-speed solution for the campus network backbone. EtherChannel technology offers bandwidth scalability within the campus by providing full-duplex increments of 200 Mbps to 8 Gbps [19, 12].

Fast EtherChannel and Gigabit EtherChannel port bundles allow grouping multiple Fast or Gigabit Ethernet ports into a single logical transmission path between a switch and a router, server, or another switch. Depending on the hardware, EtherChannel can be formed with up to four compatibly configured Fast or Gigabit Ethernet ports on the switch. All ports in an EtherChannel must have the same speed.

In this paper, EtherChannel is used to enhance real time performance of Industrial Ethernet and to solve network delay problem caused by the network congestion.

In OPNET environment, the number of EtherChannels and their speed were varied, i.e., the channel bandwidth. The goal is to find the necessary amount of channel bandwidth to handle the load offered to the network without affecting its latency values. Table (6) lists the various possibilities of EtherChannels and their corresponding latency values. It is obvious that (4 Channels, 1 Gbps) option gives the best latency results, and therefore network delay problem could be completely vanished (the system gives the same behaviour shown earlier in Figure (2)). This choice allows the stacked packets in the switch buffers to have multiple high speed (1 Gbps) paths to pass through, which decreases the queuing delay inside the switch to its minimum value.

Table 6. Effect of EtherChannel Performance on Latency

Number of Channels	Channel speed	Maximum Local Latency	Maximum Global Latency
2	100 Mbps	0.7 s	1.3s
4	100 Mbps	0.007s	0.15 s
2	1000 Mbps	2.1 ms	2.2 ms
4	1000 Mbps	1.8 ms	1.7 ms

In spite of the clear advantage behind using Etherchannel technique, simulation results show that average utilization of each EtherChannel in the case of (4 Channels , 1 Gbps), does not exceed (3%). It is obvious that offered load consumes only a small portion of the channels bandwidth, which can be considered as waste of bandwidth with unnecessary additional cost.

In order to fix this short come, i.e., using resources optimistically, a special type of Quality of Service (QoS) technique is adopted. New architecture for a switch is presented in this paper to implement this simplified (QoS) version. The main idea behind introducing this design is to separate real time data from non real time data. The operation of the new switch can be described as follows:

- A new unit called "packets classification and forwarding unit" is added to the Etherchannel unit. Its duty is to classify and forward the packets to one of the switch. Packet classification is crucial for real time applications because it enables the switch or router to differentiate the traffic streams and treat them differently depending on their individual requirements. Classification can be divided into two parts; data extraction, where the relevant fields are extracted from the packet header, and data comparison, where the extracted fields are compared to predefined data. The MAC addresses of the industrial nodes are stored (by the network administrator) in a lookup table inside this unit.
- When a packet arrives the switch, its "source & destination MAC address" fields are checked by the nodes classification unit (by comparing them with the table mentioned above), and then forward the packet to one of the Etherchanel ports. This arrangement guarantees full isolation between the two traffic types.
- Each one of the EtherChannels is reserved to one of the traffic types, i.e., the packets coming out are directly forwarded (by the EtherChannel controller) to one of these channels.

The effect of the proposed architecture is added in the OPNET environment, and the speed of the two EtherChannels was chosen to be (100 Mbps). The results obtained from running the simulation shows that the proposed switch architecture is able to fully isolate the two traffic types and gives a system behaviour analogue to that shown earlier in figure(2) (the reference case) which removes the negative effect of Ethernet delay on latency. In addition, the use of two (100 Mbps) EtherChannels keep the cost to its minimum value.

7. Combining All the Solutions Together

In this section, all the mentioned enhancements: FTP traffic shaping, Multicasting/VLAN and network delay solutions, have combined together. The simulation model assumes the presence of non industrial nodes in the network which exchange TCP packets at a rate of (100 Mbps) on the line. The network was divided into several Multicast/VLAN groups (as detailed earlier) to enhance node operation. Also, FTP traffic shaping method used the same values of segment size and Inter request period. Modified EtherChannel technology was used to protect the network performance against high load conditions. The results obtained from running the simulation is shown in Figure (15).

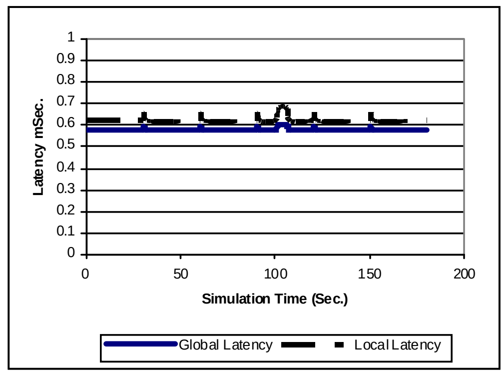

Figure 15. Modifying Latency Using All Proposed Solutions

8. Conclusions

In this paper, different techniques is introduced to modify Industrial Ethernet performance and to enhance its stability under different load conditions. These methods have a number of advantages:

- The latency values are minimized to the lower possible limits.
- The system performance is absolutely stable. The various techniques give immunity against sudden changes in network conditions.
- The network can be used to carry control data as well as ordinary data (multi purpose network) in an efficient manner.
- No change is made to the Ethernet standardization

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