A Comparison Study of the Quick Removing (QR) Approach (HSR Mode X) under Cut-Through and Store and Forward Switching Modes

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***Abstract*—We previously introduced a quick removing (QR) approach (currently part of the IEC 62439-3 standard under the terminology of "HSR Mode X") to improve the high-availability seamless redundancy (HSR) protocol's traffic performance. The idea of the QR approach is to remove the duplicated frame copies from the network when all nodes have received one copy of the sent frame and begin to receive the second copy. Therefore, forwarding the frame copies until they reach the source node, as occurs in a standard HSR, is not needed in a QR. In our previous paper, we applied the store and forward switching mode, whereas in this paper, we present the performance of the QR approach using a cut-through switching mode. The performance analysis showed a reduction percentage in frame latency that reaches about 49% compared to the store and forward switching mode. Consequently, this will improve network performance, free more bandwidth, and quickly deliver sent frames to their required destinations, which is a firm condition in many industrial and automation applications.**

***Keyword*— HSR protocol, QR approach, HSR Mode X, HSR traffic performance, cut-through, seamless redundancy, IEC 62439-3.**

I. INTRODUCTION

MODERN control and time-critical systems typically require seamless communication networks. This means that some form of fault tolerance in the communications network is required to achieve satisfactory system availability. High availability, which can be achieved through redundancy and fault tolerance, can prevent a system from momentary interruptions that may be considered inconvenient and may cause critical stoppage in some industrial applications.

Generally, seamless communication with fault tolerance is one of the key requirements for Ethernet-based mission-critical systems, such as substation automation system (SAS) networks. A fault-tolerant Ethernet (FTE) eliminates the single point of failure and therefore improves the overall system availability [1]. Since the standard Ethernet does not provide a fault-tolerance capability, various FTE protocols for power applications have been developed [2]. Among these, only two protocols, the parallel redundancy protocol (PRP) and the high-availability seamless redundancy (HSR) protocol, which is standardized as IEC 62439-3, are suitable for seamless communication [2-4]. Both HSR and PRP are based on the same principle of active redundancy by duplicating the information frames, therefore resulting in a zero-delay reconfiguration in the event of a switch or link failure; however, only the HSR protocol is addressed in this paper because it is generally accepted as the developed version of PRP. The HSR protocol is a redundancy protocol for Ethernet-based networks, and it provides duplicated frame copies for each frame sent. In other words, the HSR protocol provides two frame copies for the destination node, one from each side, enabling zero-fault recovery time in case one of the frame copies is lost. This means that even in the case of a node failure or a link failure, there is no stoppage of network operations. If both sent copies reach the destination node, the node will take the fastest copy and discard the other copy. This feature of the HSR protocol makes it very useful for time-critical and mission-critical systems.

Generally, the HSR-based network has four types of nodes [5]:

- A doubly-attached node for HSR (DANH), which has two HSR ports sharing the same medium access control (MAC) and Internet protocol (IP) set addresses. This allows the address management protocols, such as the address resolution protocol (ARP), to operate as usual without modification, which simplifies network engineering. Each DANH node will duplicate a non-HSR frame that is generated at the upper layer into two frame copies. It will then append an

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HSR tag to each copy and send two copies out through DANH ports, one in a clockwise direction and the other in a counter-clockwise direction;

- A single-attached node (SAN), which is a non-HSR device, such as a commercial printer, server, or laptop. It cannot be directly inserted into the HSR networks because it lacks the forwarding capability of an HSR node and does not support the HSR tag. They must be attached through a redundancy box (RedBox) node type;
- A RedBox node, which has three ports. Two ports are HSR ports, and the third one is an Ethernet port that any SAN device, such as a PC, can be plugged into to be engaged with the HSR network. The RedBox node forwards the frames over the HSR network like any other HSR node and acts as a proxy for all SANs that access it. Thus, it must keep track of all traffic on behalf of the SANs. The RedBox can also act as a switch for the SANs. Therefore, it is somewhat more complex than HSR nodes;
- A quadruple port device (QuadBox node), which has four HSR ports. Each pair shares the same MAC and IP addresses. This type of node is used to connect two rings or networks. The QuadBox node removes duplication and performs additional tasks, such as multicast and virtual local area network (VLAN) filtering.

The primary drawback of the HSR protocol is the unnecessary traffic due to the duplicated frames that are generated and circulated inside the network. If a typical HSR is applied, traffic will be doubled at each QuadBox node type. The situation becomes worse when the HSR is used for a generic object-oriented substation event (GOOSE) and sampled values (SV) messages' transmissions, which generate large amounts of traffic. This downside will degrade network performance and may cause network congestion or even stoppage. Therefore, data traffic control is essential for maximizing network operational performance [6]; however, due to the potential advantages of HSR, several works have also focused on implementing the HSR [7-9] and improving its performance by reducing its unnecessary redundant traffic [10-15]. To address this issue, we have proposed an HSR approach called quick removing (QR) [10] to remove the unnecessary redundant traffic from the network instead of allowing it to circulate inside the network and consume its bandwidth. The idea of the QR approach was to remove the duplicated frame copies from the network when all nodes have received one copy of the sent frame and began to receive the second copy. Due to the high efficiency of our QR approach, other papers and research studies have referred and reported on the QR approach, such as [16,17]. Consequently, the International Electrotechnical Commission (IEC) has included the QR approach in the newest edition of the IEC 62439-3 standard, Ed. 03- 2016, under the terminology of HSR mode X.

Nevertheless, in [10], we only considered the store and forward switching mode in which the entire frame needs to be stored in the ingress of the node before the node can forward it. Obviously, the node will require more time to forward the frame because the CRC code must be calculated and compared with the code appended to the frame to ensure that the received frame is error-free before sending it to the upper layers or forwarding it to the next nodes. In this case, as soon as the receiving node realized that it is the destination node of the received frame, the receiving node will wait to receive and read the source MAC address of the received frame. Then, the node will check its received frames table to see whether it has already received a copy from that frame. If the node does not find the source MAC address in its table, then it will buffer all received bytes until the reception of all is complete, and then, calculate the CRC code and compare it to the frame's CRC. If they are equal, the node will send that frame to the upper layers and update its received frames table; otherwise, it will delete it.

If the node does find the received source MAC address in its received frames table, then it will clearly, under this type of switching node, the node will require less time to forward the frame compared to the time used for the store and forward type. In other words, the cut-through mode will be much faster than the store and forward mode [18].

In this paper, we discuss the HSR node's behavior under the QR approach using the cut-through switching mode. Previously, we introduced this in [19], but in this paper, we add more details to the performance analysis of the QR approach under this type of switching mode.

The remainder of the paper is organized as follows. In Section II, we introduce our QR approach behavior under the cut-through switching mode. In Section III, we describe the analytical performance analysis of the QR approach under the cut-through switching mode. Section IV shows the results of the simulation analysis. Finally, in Section V, we summarize our work and present our conclusions.

II. QR Approach under The Cut-through Switching Mode

QR is an approach used to improve the traffic performance of the standard HSR protocol. It can be applied to any closed-loop network topology for all traffic types, especially the multi/broadcast type. The QR approach aims to remove the redundant frame copies from the network when all nodes have received one copy of the sent frame and begin to receive the second copy; however, the QR approach will only be applied to the data HSR frame types. Exempt from that the HSR supervisory frame type to allow the network nodes to check the network status of redundancy. The HSR node will recognize whether the received frame is a supervisory or a data frame through the bit pattern of the 4-bit path field of the received frame. The bit pattern of the supervisory frame type is 1111, whereas the data HSR frames have a bit pattern in the range of 0001-1001.

The QR approach does not need to use any special control frames; however, in [10], we discussed our QR approach using the store and forward switching mode only, which showed that the QR approach can reduce the unnecessary redundant network traffic in HSR networks up to 50%, as illustrated in Fig. 1.

In this paper, the application of the cut-through switching mode in the QR approach is described, which provides faster transmission and frees more bandwidth. Under the store and forward switching mode, the QR nodes wait to receive all of the frame's bytes and to calculate the CRC code to ensure that the received frame is error-free before deciding to send it to

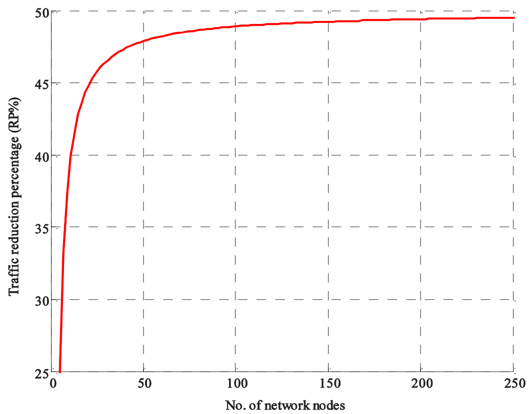

Fig. 1 Traffic reduction percentage (RP) of QR to the standard HSR protocol with respect to the number of nodes in a single ring.

the upper layers or forward it to the next nodes; however, under the cut-through switching mode, when a node receives a frame, it reads the first 6 bytes, or the destination MAC address. Thereafter, the node takes the following actions according to the type of destination MAC address.

A. Unicast MAC Type (The Receiving Node is the Destination Node for The Received Frame)

In this case, as soon as the receiving node realized that it is the destination node of the received frame, the receiving node will wait to receive and read the source MAC address of the received frame. Then, the node will check its received frames table to see whether it has already received a copy from that frame. If the node does not find the source MAC address in its table, then it will:

1) Buffer all received bytes until the reception of all is complete, and then,
2) Calculate the CRC code and compare it to the frame's CRC. If they are equal, the node will send that frame to the upper layers and update its received frames table; otherwise, it will delete it.

If the node does find the received source MAC address in its received frames table, then it will:

3) Wait to receive and read the HSR frame's header to check the sequence number if it is in the received frames table. If it is, then the node will delete the bytes that have been received thus far and all remaining bytes that will be received sequentially; otherwise, it will:
4) Buffer all received bytes until the reception of all is complete, and then,
5) Calculate the CRC code and compare it to the frame's CRC. If they are equal, the node will send that frame to the upper layers and update its received frames table; otherwise, it will delete it

B. Unicast MAC Type (The Received Frame is Heading to other Node)

If the received frame is a unicast type and is heading to a node other than the receiving node, or in other words, the frame is passing through the receiving node and going to another node, the receiving node will:

1) Look for that destination MAC address of the received frame in its forwarded frames table. If the address is not in the table, then the node will sequentially forward all received bytes into the other node's ports and then update its forwarded frames table.
2) If the destination MAC address is in the table, the node will wait to receive and read the source MAC address of the received frame and look up the table again for that pair of addresses. If the address pair does not exist, then the node will sequentially forward all received bytes into the other node's ports and then update its forwarded frames table; however, if that address pair is in the table, the node will wait to receive and read the HSR header of the frame to see whether it has already forwarded the same frame. If the node finds that it has forwarded a frame with the same destination, source MAC address, and HSR header, then the node will delete the received bytes and all remaining bytes of that frame as soon as they reach the node. Otherwise, the node will sequentially forward all received bytes into the other node's ports and then update its forwarded frames table.

C. Multi/broadcast MAC Type

The receiving node will wait to receive and read the source MAC address to determine whether the node has already received a copy of that frame. If the source node of that frame is not in the received frames table, then the node will:

1) Make a copy of each received byte, buffer it, and then forward the original bytes into the other ports.
2) When all bytes of that frame are received, the node will calculate the CRC code and compare it to the frame's CRC code. If they are equal, the node will send that frame to the upper layers and update its received frames table. Otherwise, it will delete it.

If the source MAC address is shown in the received frames table, the node will wait to receive and read the HSR frame's header. If the node shows that it has already received a copy of that frame, then the node will delete the received bytes and stop making a copy of each received byte of that frame; but it will only forward these bytes into the other ports if the node has not did that for that received frame.

If the source MAC address is not shown in the received frames table, then the node will:

1) Make a copy of each received remaining byte of that received frame, buffer it, and then forward the original bytes into the other ports.
2) When all bytes of that frame are received, the node will calculate the CRC code and compare it to the frame's CRC code. If they are equal, the node will send that frame to the upper layers and update its received frames table. Otherwise, it will delete it.

Fig. 2 includes a flow chart that summarizes the QR steps under the cut-through switching mode.

III. Analytical Performance Analysis

In this section, we will demonstrate the performance of the QR approach under the cut-through switching mode compared to the store and forward mode from the point of view of the frame latency using the analytical approach. Let us consider the network shown in Fig. 3 as an example for our performance analysis; however, assume that node C has sent a unicast frame to node G. The following expression represents the latency of the frame from the time at which the sending

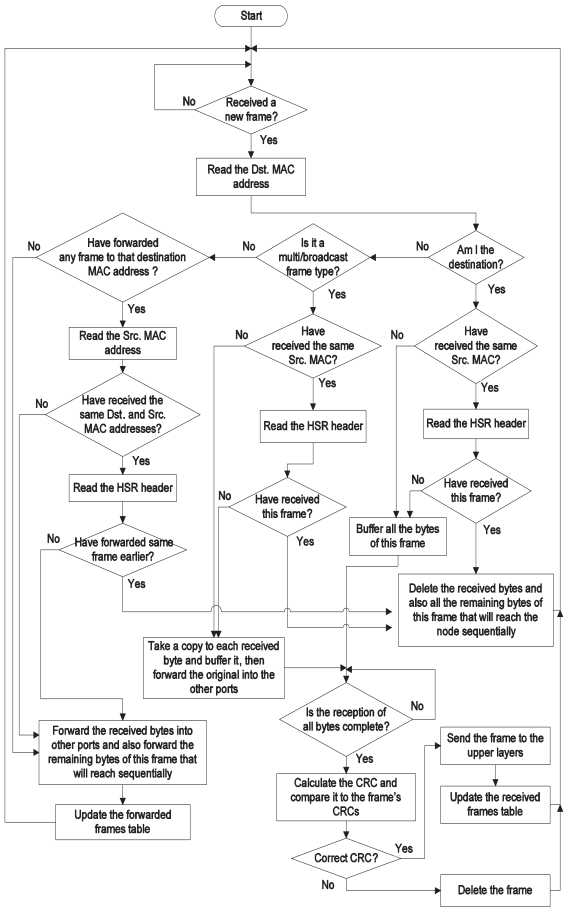

Fig. 2 Flow chart of the HSR node under the operation of the QR approach using the cut-through switching mode.

node sent its bits until the destination node has received all of the bits:

$$t_c = \tau_r + \tau_p + \tau_n$$

where t_c is the frame latency under the cut-through switching mode, τ_r is the transmission delay time, τ_p is the propagation delay time, which is assumed to be zero because the network example has short link lengths, and τ_n is the node processing rate. Assume the queuing delay time is zero.

The above expression can be written as:

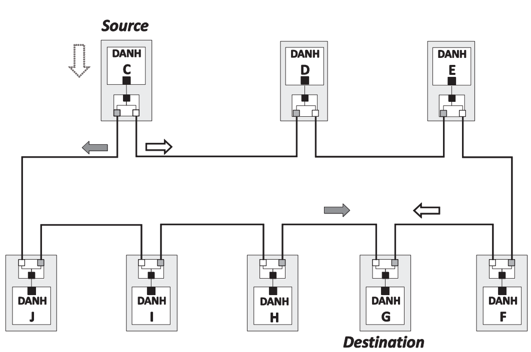

Fig. 3 An HSR example network for analytical analysis.

$$t_c = l\left(\frac{f}{\beta}\right) + \left[(n-2)\left(\frac{h}{\rho}\right) + \left(\frac{f}{\rho}\right)\right] \quad (1)$$

where l is the number of network links, f is the frame size in bits, β is link capacity in bits per second, n is the number of nodes in the path of the sent frame, h is the frame header size in bits, and ρ is the node processing rate. h might be 48 bits when the received node only reads the destination MAC address of the received frame, or it might be 96 bits or even 144 bits if the destination MAC, the source MAC, and the HSR frame header are read.

The term $(n-2)$ represents the exclusion of the source and destination nodes from the calculation of the delay time on the path of the sent frame, whereas $\left(\frac{f}{\rho}\right)$ represents the delay time of the destination node.

On the other hand, the latency under the store and forward switching mode can be determined as follows:

$$t_{sf} = l\left(\frac{f}{\beta}\right) + \left[(n-1)\left(\frac{f}{\rho}\right)\right] \quad (2)$$

$(n-2)$ represents the exclusion of the source node from the calculation of the delay time on the path of the sent frame.

Assume that the frame size that node C has sent is 1522 bytes, each of the network links' capacity is 100Mb/s, and the node processing rate is 100Mb/s. Thereafter, the latency under both the cut-through and store and forward switching modes will be determined using (1) and (2) as follows:

$$t_c = 4\left(\frac{1522\times 8}{100\times 10^6}\right) + \left[(5-2)\left(\frac{48}{100\times 10^6}\right) + \left(\frac{1522\times 8}{100\times 10^6}\right)\right]$$

$$= 0.610 \; ms$$

Note that $h = 48$ bits, which is the size of the destination MAC address of the sent frame, because each node can recognize that the frame is a unicast frame and is sent to a unique address. Therefore, the nodes do not need to read additional bits from the frame.

$$t_{sf} = 4\left(\frac{1522\times 8}{100\times 10^6}\right) + \left[(5-1)\left(\frac{1522\times 8}{100\times 10^6}\right)\right] = 0.974\, ms$$

Let us find the latency reduction percentage with respect to the network size, or in other words, with respect to the number of network nodes. This can be represented in the following expression:

$$\lim_{n\to\infty} \varepsilon = \lim_{n\to\infty}\left(1 - \frac{t_c}{t_{sf}}\right)\times 100\%$$

where ε is the latency reduction percentage of the cut-through mode compared to the store and forward mode.

$$\lim_{n\to\infty} \varepsilon = \lim_{n\to\infty}\left(1 - \frac{l\left(\frac{f}{\beta}\right) + \left[(n-2)\left(\frac{h}{\rho}\right) + \left(\frac{f}{\rho}\right)\right]}{l\left(\frac{f}{\beta}\right) + \left[(n-1)\left(\frac{f}{\rho}\right)\right]}\right)\times 100\%$$

Assume that $\beta = \rho$. In Fig. 3, the path from nodes C to G has a number of links equal to the number of nodes –1, or it can be said that $l = n-1$.

Thus, we can rewrite the above expression as follows:

$$\lim_{n\to\infty} \varepsilon = \lim_{n\to\infty} \left(1 - \frac{n\left(\frac{f}{\rho}\right) - \left(\frac{f}{\rho}\right) + \left[(n-2)\left(\frac{h}{\rho}\right) + \left(\frac{f}{\rho}\right) \right]}{n\left(\frac{f}{\rho}\right) - \left(\frac{f}{\rho}\right) + \left[(n-1)\left(\frac{f}{\rho}\right) \right]} \right) \times 100\%$$

$$\lim_{n\to\infty} \varepsilon = \lim_{n\to\infty} \left(1 - \frac{n\,f + nh - 2h}{2nf - 2f} \right) \times 100\%$$

$$\lim_{n\to\infty} \varepsilon = \left(\lim_{n\to\infty} 1 - \lim_{n\to\infty} \left(\frac{n\left(f + h - 2\frac{h}{n} \right)}{2n\left(f - \frac{f}{n} \right)} \right) \right) \times 100\%$$

$$\lim_{n\to\infty} \varepsilon = \lim_{n\to\infty} \left(1 - \frac{f+h}{2f} \right) \times 100\% \qquad (3)$$

It is obvious from (3) that ε is not affected by the number of nodes when this number becomes large; on the contrary, it varies inversely with respect to the frame size. Fig. 4 shows that ε increases when the frame size increases, and the maximum reduction percentage that can be achieved is 49.4% when $h=144$ and $f=1522$ bytes; however, the lowest ε value is about 35% when the frame size is 64 bytes. It is also shown in Fig. 5 that the cut-through mode offers less latency than the store and forward mode, which in turn improves network performance and delivers the sent frames quickly.

IV. Simulation Analysis

To illustrate the performance of the QR approach in a wider network, the network shown in Fig. 6 was selected as a network example for simulating the QR operation under both the cut-through switching and the store and forward modes. Then, the results were compared. For this purpose, the OMNeT++ Simulator version 4.6 [20] was used in two scenarios. In these scenarios, the frame latency of all travelling frames in the network was accumulated and then compared under both switching modes. Assume that the frame size is 1522 bytes, all channels have a capacity of 100Mb/s, and all nodes have a processing rate of 100 Mb/s.

A. First scenario

In this scenario, each source node of the connection pairs listed in Table I sent 10 frames to each corresponding node in its pair (source-destination). In other words, this scenario was used for testing the QR approach with the cut-through switching mode under a unicast traffic type.

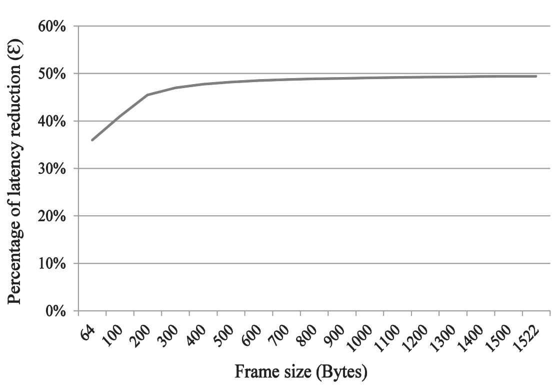

Fig. 4 Percentage of latency reduction versus frame size.

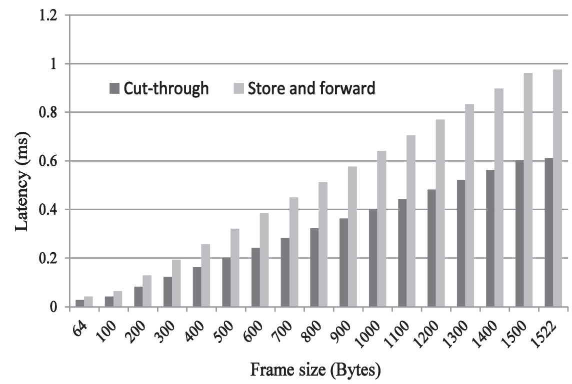

Fig. 5 Frame latency under the cut-through and store and forward switching modes using the QR approach.

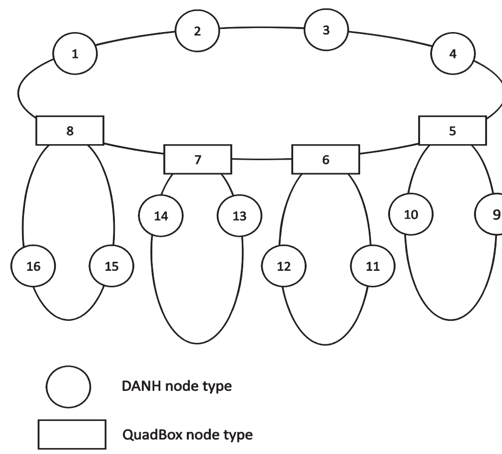

Fig. 6 An example network for simulation analysis.

B. Second scenario

Table II shows the details of the connection pairs for this scenario in which each source node sent 10 multi/broadcast frame types.

For both scenarios, the simulation tests were conducted

TABLE I
DETAILS OF THE CONNECTION PAIRS FOR THE FIRST SCENARIO

#	Source node	Destination node
1	Node 1	Node 14
2	Node 2	Node 10
3	Node 11	Node 3
4	Node 9	Node 13
5	Node 15	Node 12
6	Node 16	Node 4
7	Node 3	Node 15
8	Node 4	Node 9
9	Node 13	Node 10
10	Node 14	Node 2
11	Node 10	Node 1
12	Node 12	Node 16

TABLE II
DETAILS OF THE CONNECTION PAIRS FOR THE SECOND SCENARIO

Group number	Source node	Destination node
Group 1	Node 1	Nodes 3, 4 and 16
Group 2	Node 10	Nodes 11, 13 and 12
Group 3	Node 13	Nodes 3, 9, and 14
Group 4	Node 2	Nodes 10, 15, 16 and 2
Group 5	Node 15	Broadcast

under the cut-through and store and forward switching modes. The results are shown in Figures 7 and 8. The results illustrate that the QR approach has a better performance under the cut-through switching mode with respect to the frame latency parameter.

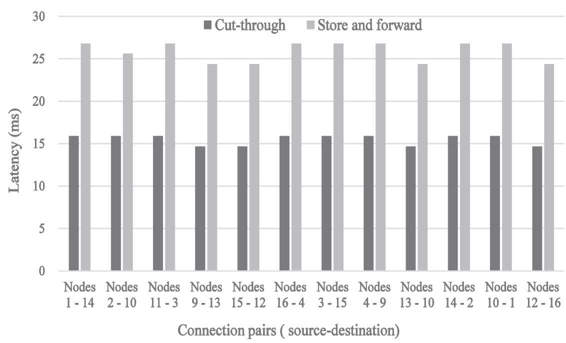

Fig. 7 Frame latency under the cut-through and store and forward switching modes for the first scenario.

Fig. 8 Frame latency under cut-through and store and forward switching modes for the second scenario.

V. CONCLUSIONS

In this paper, we describe HSR node behavior when it receives a frame under the QR approach (HSR mode X) using the cut-through switching mode as well as which actions it will take to receive or forward the received frame depending on the destination MAC, source MAC, and HSR header. We also simulated the QR performance from the point of view of the frame latency because the cut-through and the store and forward switching modes will not differ from the traffic reduction aspect. In a single ring network topology, the QR approach under the cut-through switching mode was shown to have reached a reduction percentage in the frame latency of more than 49% compared to the store and forward mode when $h = 144$ and $f = 1522$ bytes. In general, a reduction percentage ranges from 35% to 49% with respect to the frame size. The simulation analysis also showed a superior performance of the QR approach under the cut-through mode for both of the proposed scenarios, or in other words, under any traffic type.

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REFERENCES

[1] D. H. Lee, H. A. Pham, and J. M. Rhee, "SAFE: A Scalable Autonomous Fault-Tolerant Ethernet Sch eme for Large-Scale Star Networks," *Proc. IEICE Transactions on Communications*, vol. 95, no.10, pp.3158-3167, Oct. 2012.

[2] IEC 62439-1 Ed. 1.1, "IEC Industrial communication networks – High availability automation networks – Part 1: General concepts and calculation methods," *The International Electrotechnical Commission*: Geneva, Switzerland, 2013.

[3] IEC 62439-3 Ed.03, "IEC Standard. Industrial Communication Networks - High availability automation networks - Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR)," *The International Electrotechnical Commission*: Geneva, Switzerland, 2016.

[4] IEC 61850-90-4, "IEC Standard. Network Engineering Guideline for Communication Networks and Systems in Substations," *The International Electrotechnical Commission*: Geneva, Switzerland, 2013.

[5] S. A. Nsaif and J. M. Rhee, "DVP: A Novel High-Availability Seamless Redundancy (HSR) Protocol Traffic-Reduction Algorithm for a Substation Automation System Network," *Proc. Energies*, vol. 7, no. 3, pp.1792-1810, 2014

[6] J.C. Tan and W. Luan, "IEC 61850 based substation automation system architecture design," *Proc. IEEE Power Energy Soc. General Meeting*, pp.1-6, San Diego, CA, USA, July 2011.

[7] J. A. Araujo, J. Lázaro, A. Astarloa, A. Zuloaga, and J. I. Garate, "PRP and HSR for High Availability Networks in Power Utility Automation: A Method for Redundant Frames Discarding," *Proc. IEEE Transaction on Smart Grid*, vol. 6, no. 5, pp.2325-2332, Jan. 2015

[8] A. Astarloa, J. Lazaro, U. Bidarte, J. A. Araujo, and N. Moreira, "FPGA implemented cut-through vs store-and-forward switches for reliable Ethernet networks," *Proc. IEEE conference on design of circuits and integrated circuits (DCIS)*, pp. 1-6, Madrid, Spain, Nov. 2014.

[9] J. A. Araujo, J. Lazaro, A. Astarloa, A. Zuloaga, and N. Moreira, "Duplicate and circulating frames discard methods for PRP and HSR (IEC62439-3)," *Proc. IECON 2013-39th Annual Conference of the IEEE in Industrial Electronics Society*, pp.4451-4456, Vienna, Austria, Nov. 2013.

[10] S. A. Nsaif and J. M. Rhee, "Improvement of high-availability seamless redundancy (HSR) traffic performance for smart grid communications," *Proc. Journal of Communications and Networks*, vol.14, no.6, pp.653-661, Dec. 2012.

[11] S. A. Nsaif and J. M. Rhee, "RURT: A novel approach for removing the unnecessary redundant traffic in any HSR closed-loop network type," *Proc. International Conference on ICT Convergence (ICTC)*, pp.1003-1008, Jeju, South Korea, Oct.2013.

[12] S. A. Nsaif and J. M. Rhee, "RMT: A novel algorithm for reducing multicast traffic in HSR protocol networks," *Proc. Journal of Communications and Networks,* vol.18, no.1, pp.123-131, Feb. 2016.

[13] N. X. Tien, S. A. Nsaif, and J. M. Rhee, "High-availability Seamless Redundancy (HSR) Traffic Reduction Using Optimal Dual Paths (ODP)," *Proc. International Conference on Green and Human Information Technology (ICGHIT)*, pp.37-40, Da Nang, Vietnam, Feb. 2015.

[14] N. X. Tien and J. M. Rhee, "FHT: A Novel Approach for Filtering High-Availability Seamless Redundancy (HSR) Traffic," *Proc. Energies 8*, no. 7, pp.6249-6274, 2015.

[15] I. R. Altaha, J. M. Rhee, and H. A. Pham, "Improvement of High-Availability Seamless Redundancy (HSR) Unicast Traffic Performance Using Enhanced Port Locking (EPL) Approach," *Proc. IEICE Transactions on Information and Systems*, vol. 98, no. 9, pp.1646-1656, 2015.

[16] H. D. Ngo and H.S. Yang. "Latency and Traffic Reduction for Process-Level Network in Smart Substation based on High-availability Seamless Redundancy", *Proc. IEEE Transaction on Industrial Electronics Society*, pp. 2181 - 2189, 2015.

[17] J. A. Araujo, J. Lazaro, A. Astarloa, A. Zuloaga, and A. Garcia. "PRP and HSR version 1 (IEC 62439-2), improvements and a prototype implementation", In *Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE*, pp. 4410-4415. IEEE, 2013.

[18] Cisco white paper, "Understanding Switch Latency," June 2012. Available: http://www.cisco.com/c/en/us/products/collateral/switches/nexus-3000-series-switches/white_paper_c11-661939.html

[19] S.A. Nsaif, S. Kim, and J. M. Rhee. "Quick removing (QR) approach using cut-through switching mode." In *2016 18th International Conference on Advanced Communication Technology (ICACT)*, pp. 170-174. IEEE, South Korea, 2016.

[20] http://omnetsimulator.com/

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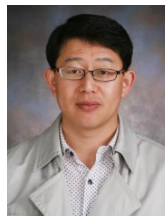

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