HSR Traffic Reduction Algorithms for Real-time Mission-critical Military Applications

Nguyen Xuan Tien and Jong Myung Rhee
Myongji University

Abstract

This paper investigates several existing techniques to reduce high-availability seamless redundancy (HSR) traffic. HSR is a redundancy protocol for Ethernet networks that provides duplicated frames for separate physical paths with zero recovery time. This feature makes it very useful for real-time and mission-critical applications, such as military applications and substation automation systems. However, the major drawback of HSR is that it generates too much unnecessary redundant traffic in HSR networks. This drawback degrades network performance and may cause congestion and delay. Several HSR traffic reduction techniques have been proposed to reduce the redundant traffic in HSR networks, resulting in the improvement of network performance. In this paper, we provide an overview of these HSR traffic reduction techniques in the literature. The operational principles, advantages, and disadvantages of these techniques are investigated and summarized. We also provide a traffic performance comparison of these HSR traffic reduction techniques.

I. Introduction

High-availability seamless redundancy (HSR) was standardized by the International Electrotechnical Commission (IEC) as IEC62439-3 Clause 5[1]. HSR is a redundancy protocol for Ethernet networks that provides duplicated frames on separate physical paths with zero switchover time in case of a network failure. Therefore, even in the case of a node or link failure, there is no communication interruption in the network. This feature of the HSR protocol makes it very useful for time-critical and mission-critical applications, such as military applications and automation networks.

The HSR protocol defines three types of nodes: doubly attached nodes for HSR (DANH) that are HSR-capable switching end nodes with two HSR ports sharing the same media access control (MAC) address, redundancy box (RedBox) nodes that are used to connect legacy devices, such as servers and printers to HSR networks, and quadruple port devices (QuadBox) that are used to connect HSR rings. The HSR principles and operations are described in detail in [1]-[4].

The major drawback of HSR is that it generates too much redundant unicast traffic in HSR networks. This is due to the following issues:

- forwarding frames into unused DANH rings;
- forwarding frames into unused QuadBox rings;
- doubling and circulating frames in all the rings.

This drawback results in the degradation of network performance and may cause congestion and delay. Several techniques have been proposed to reduce the unnecessary traffic in HSR networks. These techniques can be classified into the following two categories: traffic filtering-based techniques and predefined path-based techniques. Traffic filtering-based techniques, including quick removing (QR) [5], port locking (PL) [6], enhanced port locking (EPL) [7], and filtering HSR traffic (FHT) [8], mainly focus on filtering unicast traffic for rings in HSR networks and preventing the traffic from doubling and circulating in the rings. Predefined path-based techniques, including optimal dual path (ODP) [9] and dual virtual paths (DVP) [10], establish two separate paths for each connection pair of DANH nodes before transmitting unicast traffic in HSR networks. The dual paths are then used to forward unicast frames between each connection pair of nodes instead of duplicating and forwarding frames to all parts of the networks, as in the standard HSR protocol.

In this paper, we provide an overview of the HSR traffic reduction techniques in the literature. Operational principles, performance, advantages, and disadvantages of these techniques are investigated and summarized.

The rest of this paper is organized as follows. In Section II, we describe the traffic filtering-based techniques. In Section III, we describe the predefined path-based techniques. In Section IV, we present our conclusions.

II. Traffic Filtering-based Techniques

Traffic filtering-based techniques reduce redundant traffic by solving some or all of the issues related to HSR mentioned in Section I. There are several traffic filtering-based techniques, as follows:

- **Quick removing (QR)** [5]: QR removes duplicated and circulated traffic from the network.
- **Port locking (PL)** [6]: PL prunes unicast traffic for DANH rings.
- **Enhanced port locking (EPL)** [7]: EPL is an enhanced version of the PL approach. The EPL approach prunes unicast traffic for both DANH and QuadBox rings.
- **Filtering HSR traffic (FHT)** [8]: FHT filters unicast traffic for both DANH and QuadBox rings and removes duplicated and circulated traffic in the rings.

1. Quick Removing (QR)

a. Description

The purpose of QR [5] is to remove duplicated and circulated frames from a ring when all the nodes have received one copy of the frame and begin to receive the second copy.

To understand the QR operation, we consider a single-ring network, as shown in 〈Fig. 1〉. Node 2 has sent copies A and B to all the ring nodes as the duplicated

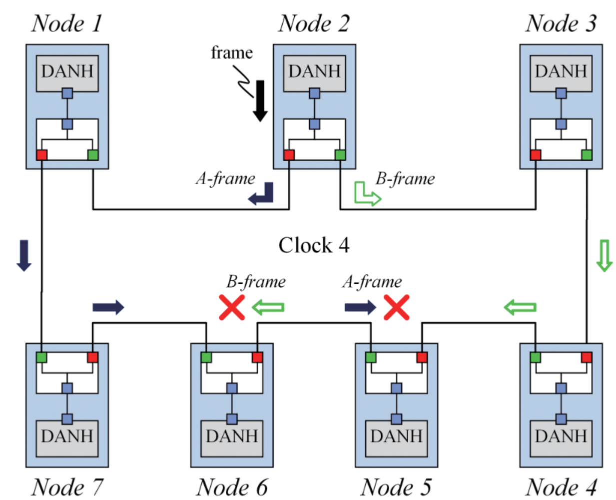

Figure 1. Removing duplicated copies under the QR approach.

copies for a frame generated in the upper layer. Within four clocks, each of the frame copies, A and B, will pass each other at the link between node 5 and node 6 and then travel towards node 5 and node 6, respectively. At this time, HSR nodes will take the following actions:

- If both frame copies are error-free: Nodes 5 and 6 have already received a copy of the frame. Node 5 has received copy B from the right side and then re-ceived copy A from the left side. The same is true for node 6; it has received copy A from the left side and then received copy B from the right side. In that case, nodes 1, 7, and 6 have received copy A, and there is no need for copy B. The same is true for nodes 3, 4, and 5; they have received copy B and do not need to receive copy A. Therefore, node 6 will remove copy B from the ring, and node 5 will remove copy A from the ring.
- If a frame copy is corrupted as soon as it leaves the source node: We assume that copy A was corrupted when it left the source node 2, moving towards node 1. In this case, node 1 will remove copy A from the ring as soon as it receives copy A, and all the nodes in the rings, except the source node, will wait for copy B. Therefore, each node will receive a copy and forward it to the next node until it reaches the source node.
- If a frame copy is corrupted during transmission: We assume that copy A was corrupted during

transmission between nodes 1 and 7. In that case, node 7 will remove copy A from the ring, and node 6 will not receive copy A. Therefore, node 6 will forward copy B as soon as it receives copy B from the right side. Node 7 will also forward copy B to node 1, but node 1 has already received copy A, so it will remove copy B from the ring.

b. Advantages and Disadvantages

QR is the simplest approach to reduce redundant traffic in HSR networks. The QR approach is easy to implement. The QR approach can be applied for any traffic, such as unicast, multicast, and broadcast traffic, in any network topology.

However, the main disadvantage of QR is that it does not prune traffic for unused rings. QR allows network traffic to be forwarded into all rings of the networks, even DANH rings that do not contain the destination and QuadBox rings not used to deliver the traffic from the source to the destination.

2. Port Locking (PL)

a. Description

PL [6] reduces redundant unicast traffic in HSR connected-ring networks by filtering traffic for DANH rings. PL divides the QuadBox into two sides, the DANH side and the QuadBox side. The DANH side is connected to a DANH ring, and the QuadBox side is connected to a QuadBox ring. The DANH side of the QuadBox uses the PL approach, while the QuadBox side continues working as a standard QuadBox. PL makes the network learn the location of the destination node without the network control messages. It then prunes all the DANH rings that do not contain the destination node by locking the ports of the corresponding DANH side.

When a source node sends frames to a destination node under the standard HSR protocol, each frame is tagged with an HSR tag, duplicated, and circulated inside the HSR ring network. If the destination node exists in a ring, it will take the frame without forwarding. If not, nodes in the network will forward the frame. When a QuadBox forwards a frame inside a DANH ring using one port and the frame is returned back to the QuadBox through the other port, it means that the destination node does not exist in that ring. The PL will lock these ports to prevent them from sending the frames to the DANH ring.

The PL consists of two stages, the learning stage and the working stage, as follows.

- **Learning stage**: In the learning stage, QuadBoxes check the destination's location and perform port locking if needed. When the source node sends the first frame to the destination node, copies of the first frame are flooded into the entire network. QuadBoxes will check the location of the destination of the frame and then lock the ports of their DANH side if the DANH rings connecting to the ports do not contain the destination of the frame.
- **Working stage**: After the learning stage, the DANH rings that do not have the destination node are pruned. The working stage starts from the second frame. In this stage, frames are sent and received on paths through unlocked ports.

b. Advantages and Disadvantages

The PL approach reduces redundant unicast traffic in HSR networks by filtering the unicast traffic for unused DANH rings. The PL approach does not use control messages for filtering traffic, thus avoiding additional control overhead in the networks.

However, the PL approach has some disadvantages. The PL approach does not prune unicast traffic for unused QuadBox rings. Additionally, unicast frames are still duplicated and circulated in all active QuadBox rings.

3. Enhanced Port Locking (EPL)

a. Description

EPL [7] is an enhanced version of the PL approach. The EPL approach was proposed to improve the PL approach for HSR unicast traffic performance in connected-ring networks. The EPL works with the same locking concept as the PL. Unlike the PL that prunes unicast traffic for only DANH rings, the EPL approach filters the unicast traffic not only for unused DANH rings but also for unused QuadBox rings.

The EPL approach uses a parameter ψ to trigger learning stages. Parameter ψ is an integer number that represents the number of returned frames required to activate the EPL effect. At the first frame, the network will work as the standard HSR. From the second frame to the ψ^{th} frame, the network will work under the PL effect to filter traffic for DANH rings. As from the (ψ^{th}+1) frame, the network will work under the EPL effect to prune traffic for both DANH and QuadBox rings.

The EPL approach works in three stages: the first and second learning stages, and the working stage.

- **The first learning stage**: In this stage, the network works as standard HSR during the sending of the first frame, and all DANH rings that do not contain the destination will be pruned. At this stage, QuadBoxes that connect to DANH rings will build their PL locking tables based on the concepts of the PL approach. The PL locking table inside a QuadBox stores the MAC addresses of DANH nodes that do not belong to the QuadBox's DANH ring.
- **The second learning stage**: In the stage, QuadBoxes that connect DANH rings will lock the ports of the DANH side that do not connect to the destination ring. QuadBoxes that connect to two QuadBox rings will build their EPL locking tables based on the same concepts used in the PL approach. The EPL locking table of a QuadBox contains the MAC addresses of DANH nodes that do not belong to DANH rings that connect to the QuadBox's QuadBox ring. The second learning stage is triggered according to the parameter ψ. After receiving ψ number of returned frames, the second learning stage will be triggered, and the EPL approach will decide to lock that interface by registering the destination MAC address in the EPL locking table. Putting a MAC address inside the EPL locking table means that the QuadBox will stop forwarding any frame tagged with that MAC address as a destination in that direction.
- **Working stage**: In this stage, QuadBoxes forward frames based on PL and EPL locking tables. Therefore, only rings used to forward traffic will remain active, while the rest of the unused rings will be pruned.

b. Advantages and Disadvantages

As an enhanced version of PL, EPL improves traffic performance in HSR networks compared with the PL approach. The EPL approach prunes unicast traffic not only for unused DANH rings but also for unused QuadBox rings. Therefore, it provides better unicast traffic reduction than the PL approach. Additionally, like PL, the EPL approach does not use control messages for filtering traffic; thus, there is no additional control overhead in the networks.

However, the EPL has some disadvantages. First, the EPL does not remove duplicated and circulated unicast frames from active QuadBox rings. Additionally, it is difficult to determine the optimized value of the parameter ψ that depends on the topology and size of HSR networks. Finally, because QuadBoxes learn the MAC addresses of destinations that do not belong to their corresponding rings, the size of the locking tables is large and directly proportional to the size of the network, resulting in high memory requirements.

4. Filtering HSR Traffic (FHT)

a. Description

FHT [8] is an HSR traffic reduction technique that solves all HSR issues mentioned in Section I. The FHT approach prunes unicast traffic for both unused DANH and QuadBox rings and removes duplicated and circulated traffic in all active rings in HSR networks.

The FHT defines two types of QuadBoxes, access QuadBoxes and trunk QuadBoxes. Access QuadBoxes are QuadBoxes that connect to a DANH ring, and trunk QuadBoxes are QuadBoxes that connect two QuadBox rings. To filter unicast traffic for unused DANH rings, each access QuadBox learns the MAC addresses of DANH nodes that connect to its DANH ring and stores these MAC addresses in a MAC1 table. To prune unicast traffic for unused QuadBox rings, each trunk QuadBox builds a MAC2 table that is a collection of MAC1 tables of access QuadBoxes that connect to its QuadBox rings. In other words, the MAC 2 table of a trunk QuadBox contains the MAC addresses of DANH nodes that belong to DANH rings that connect to the trunk QuadBox's QuadBox rings.

To implement the functionality of filtering unicast traffic, the FHT defines two filtering rules, as follows.

- **Filtering rule 1**: Filtering inbound traffic for DANH rings. Access QuadBoxes are used to filter inbound unicast traffic for DANH rings based on their MAC1 table. An access QuadBox node forwards a unicast frame into a DANH ring if and only if its MAC1 table contains the destination node of the frame.
- **Filtering rule 2**: Filtering outbound traffic for QuadBox rings. Trunk QuadBox nodes are used to filter outbound traffic for QuadBox rings based on their MAC2 table. A trunk QuadBox node forwards a unicast frame from its first QuadBox ring to its second QuadBox ring if and only if the first QuadBox ring does not contain the destination node of the frame.

Additionally, the FHT approach removes duplicated and circulated traffic from active rings by defining a new forwarding rule. QuadBoxes forward a unicast frame once at most. When a QuadBox receives a unicast frame, it checks if the frame has previously been received and forwarded. If not, it forwards the frame. If so, it discards the frame. This new forwarding rule allows FHT to remove circulated traffic from all rings.

The FHT approach has two phases, the learning phase and the forwarding phase.

- **Learning phase**: In this phase, the FHT uses control messages to learn and build MAC tables. The MAC1 table is built at access QuadBoxes using Hello and ACK messages. QuadBoxes send Hello messages, and DANH nodes reply by sending ACK messages. Each access QuadBox builds its MAC1 table based on the ACK messages received from DANH nodes in its DANH ring. The MAC2 table is built at trunk QuadBoxes. Once access QuadBoxes have built their MAC1 table, they send MAC messages that contain the MAC addresses of their MAC1 table over ports that are connected to QuadBox rings. Trunk QuadBoxes build their MAC2 table based on received MAC messages.
- **Forwarding phase**: In this phase, QuadBoxes forward unicast frames based on MAC tables. The MAC1 table is used to prune the unicast frames for unused DANH rings, whereas the MAC2 table is used to filter the traffic for unused QuadBox rings. Additionally, based on the FHT's forwarding rule, the duplicated and circulated unicast traffic is removed from the active rings.

b. Advantages and Disadvantages

The FHT approach prunes unicast traffic not only for unused DANH rings but also for unused QuadBox rings. It also removes duplicated and circulated traffic from the active rings. These features make the FHT approach one of the most efficient HSR traffic reduction techniques.

The main drawback of the FHT approach is that FHT uses control messages to learn MAC addresses and build MAC tables. This results in additional control overhead in HSR networks.

5. Comparison

We described four traffic filtering-based techniques for reducing HSR unicast traffic. The QR removes duplicated and circulated unicast traffic in HSR networks. The PL prunes unicast traffic for unused DANH rings, while the EPL prunes the traffic for both unused DANH and QuadBox rings. However, the PL and EPL do not remove duplicated and circulated unicast traffic. The FHT filters unicast traffic for both unused DANH and QuadBox rings and also removes duplicated and circulated unicast traffic in HSR networks. Table I summarizes the traffic-filtering features of these techniques.

To compare the traffic performance of these techniques, we conducted several simulations using the OMNeT++ simulation tool [11]. We consider a sample network, as shown in 〈Fig. 2〉. In these simulations, a source node in DANH ring 1 sends unicast frames to a destination node in DANH ring 5. 〈Fig. 3〉 shows the comparison of the traffic performance of these techniques. The simulation results show that in the sample network, the

QR approach reduces network unicast traffic by 37% compared to the standard HSR protocol. The PL approach has better traffic performance than the QR approach; it reduces network unicast traffic by 59% compared to the standard HSR protocol and by about 34% compared to the QR approach. The EPL improves traffic performance for the PL approach; it reduces network unicast traffic by 66% compared to the standard HSR protocol and by about 18% compared to the PL approach. FHT provides the best traffic performance. For our sample network, the FHT approach reduces network traffic by 80% compared to the standard HSR protocol and by about 40% compared to the EPL approach.

III. Predefined Path-based Techniques

Predefined path-based techniques reduce redundant traffic in HSR networks by forwarding unicast traffic through two separate predefined paths instead of duplicating and flooding the traffic, as in the standard HSR protocol. There are several predefined path-based techniques, as follows.

- **Optimal Dual Paths (ODPs) [9]:** ODPs establish dual paths that have optimal link metrics and no common nodes based on network link information.
- **Dual Virtual Paths (DVPs) [10]:** DVPs establish dual paths by sending and receiving control messages.

1. Optimal Dual Paths (ODP)

a. Description

The purpose of ODPs [9] is to establish dual paths for each connection pair of terminal nodes, including DANH nodes and RedBox nodes, in HSR networks. The dual paths have optimal link metrics and no common nodes.

Table 1. Traffic-Filtering Features of Techniques

Traffic-Filtering Features	QR	PL	EPL	FHT
Filtering traffic for DANH rings	No	Yes	Yes	Yes
Filtering traffic for QuadBox rings	No	No	Yes	Yes
Removing traffic circulation	Yes	No	No	Yes

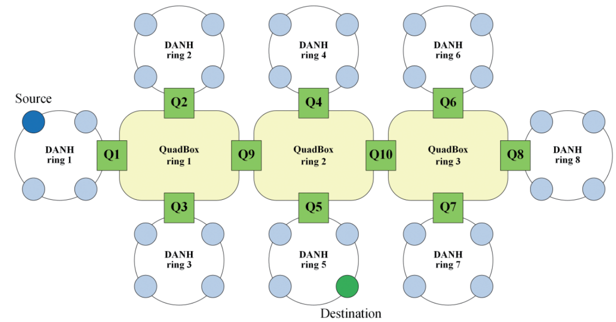

Figure 2. The simulation network for traffic filtering-based techniques

The dual paths are determined based on network link information. Each terminal node automatically establishes dual paths with the other terminal nodes in the network. To determine the dual paths with optimal metrics, each terminal node has to know the metric values for all the network links. Therefore, the ODP approach builds a link metric table that contains all network links' metrics. Based on that table, the ODP approach searches all the available paths for each connection pair, sorts them in ascending order of path metrics, and identifies the dual paths that satisfy the above conditions. After selecting the optimal dual paths, each terminal node that has completed the selection process informs the intermediate QuadBox nodes located in the dual paths about the selected dual paths passing through the QuadBox nodes. The QuadBox nodes save the path information, and the next time, they forward the received frame of that connection pair to a proper output port according to the previously learned information. In this case, the Quad-

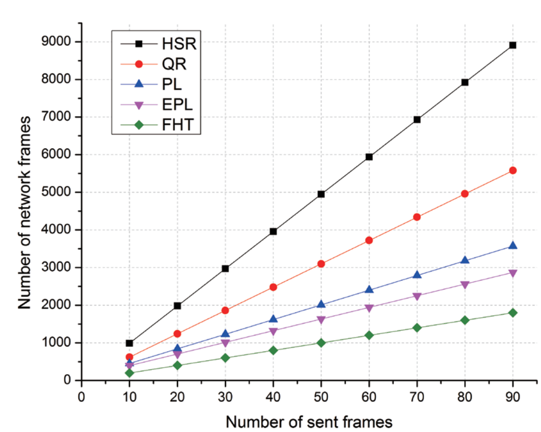

Figure 3. Comparison of the traffic performance of traffic filtering-based techniques.

Box node does not duplicate and flood the frame to all its other ports, as in the standard HSR protocol.

The establishment process for the dual paths consists of three phases. In the first phase, nodes exchange their links' information to build the link metric table. In the second phase, each terminal node builds its link metric table. In the third phase, each terminal node determines the dual paths with the other terminal nodes based on the link metric table and then informs the QuadBoxes in order to complete the establishment of the dual paths.

- **Exchanging link metrics**: In this phase, nodes exchange their links' metrics so that each node knows the links' metrics of the entire network. This is accomplished by broadcasting the links' metrics using a metric (Met) message. However, to reduce the size and total number of exchanged Met messages, the node with the lowest node identifier (ID) broadcasts its links' metrics to the other nodes. The adjacent nodes that connect directly to it and that have a higher ID do not broadcast the metrics of the shared links. However, these nodes will broadcast for other links they have.
- **Building the link metric table**: Based on received Met messages, each terminal node builds a link metric table that contains the metrics of the entire network's links. Ideally, all the terminal nodes will have the same link metric table.
- **Establishing dual paths**: Based on the link metric table, each terminal node establishes dual paths with each corresponding terminal node. To do this, the following procedure is performed.

1) **Searching all available paths**: The ODP approach searches the link metric table of a terminal node for all the available paths from that node to all the other terminal nodes in the network.

2) **Sorting the searched paths list**: The available paths are sorted in ascending order of the paths' metrics.

3) **Selecting dual optimal paths**: Based on the sorted paths list, the ODP approach determines dual paths for each connection pair of terminal nodes.

4) **Confirming the selection**: After selecting the dual paths for each connection pair, the terminal nodes send messages to inform the selected paths. QuadBoxes build their forwarding tables based on the messages.

b. Advantages and Disadvantages

ODP significantly reduces redundant unicast traffic compared to the standard HSR by forwarding the unicast traffic through two predefined paths instead of duplicating and flooding in the network. Additionally, the dual paths have optimal link metrics, resulting in improved network service.

The main drawback of ODP is that it has to build and maintain the link information table, resulting in high control overhead in the network.

2. Dual Virtual Paths (DVPs)

a. Description

Like ODP, DVPs [10] establish two predefined paths for each connection pair of terminal nodes. However, unlike ODP that discovers the dual paths based on the network link information, the DVP approach discovers and establishes the dual paths by sending and receiving control messages, such as path selection and path confirmation messages. These dual paths will be automatically established in a DVP setup process. Such a process simply makes all the QuadBox nodes "smart" after a learning task. The QuadBox nodes then understand how to forward a unicast frame to a proper destination through only one of their ports instead of duplicating and flooding the frame through all ports, except the port on which the frame was received, as in the standard HSR protocol.

The DVP approach is composed of three phases, the announcement phase, the path establishment phase, and the final phase.

- **Announcement phase**: In the first phase, each node builds a neighbor (Ne) table that contains the MAC addresses of all terminal nodes. To build the Ne table, each terminal node has to announce itself by broadcasting an announcement (Ann.) message. Based on received Ann. messages, all the network nodes build the Ne table. Once the building task of the Ne table at each node is completed, every node knows how many terminal nodes are available in the network and what their MAC addresses are.

- **Path establishment phase**: In this phase, all the terminal nodes establish dual virtual paths with each other and use them for point-to-point communication instead of spreading their data frames through the network, as in the standard HSR protocol. This task is achieved by teaching QuadBox nodes how to forward the received frames to their destinations without duplicating and forwarding them randomly. This mission is accomplished by sending a path selection (PaS) message from each terminal node to each node listed in its Ne table. In other words, the terminal nodes of each connection pair send a PaS message to each other.

When a QuadBox receives a PaS message, it saves the information, including the sequence number, the source MAC address, and the destination MAC address, into a pre-path (PrP) table and then appends its identification (ID) tag, duplicates the tagged PaS message, and sends them out.

When a terminal node receives a PaS message that does not belong to its connection pairs, the terminal node forwards the message or deletes it if it has been forwarded before in the same direction.

Each terminal node receives two copies of each PaS message sent to it, one from each direction, and then builds or updates its PrP table and finally replies with a path confirmed (PaC) message. Each copy of the PaC message will travel through one of the established dual virtual paths, and during this journey, each QuadBox will learn which port leads to the destination terminal node of that connection pair. Thus, all the QuadBox nodes that the PaC message has passed through become ready to forward any frame in both directions of that connection pair. The PrP tables will also be updated after this step. Eventually, after the building process of the PrP tables of all the nodes is complete, each QuadBox node will deduce another table from its PrP table to use to forward the received frames in both directions. This table is called the final path (FP) table. This FP table shows the input and output ports for each path.

- **Final phase**: After completing the building process of the FP tables, the DVP approach becomes ready to use, and any data frame that needs to be sent to a destination node in a connection pair will be duplicated at its source node. Each copy will then be sent in a virtual path that was established earlier with that destination terminal node. Each QuadBox will be able to forward the received unicast frames to their destination terminal nodes using its FP table instead of using the standard HSR transmission process.

b. Advantages and Disadvantages

Like ODP, DVP significantly reduces redundant unicast traffic compared to the standard HSR protocol by forwarding the unicast traffic through two predefined paths instead of duplicating and flooding in the overall network. Instead of building and maintaining the link metric table for building dual paths as in the ODP approach, the DVP approach establishes dual virtual paths for each connection pair by sending and receiving control messages, such as PaS and PaC messages.

However, because the DVP approach establishes dual paths for each connection pair of terminal nodes, the number of connection pairs is very large. This results in high control overhead for building dual paths in the network.

3. Comparison

We described two predefined path-based techniques for reducing HSR unicast traffic. The ODP approach establishes dual paths based on the network's link information, whereas the DVP approach builds dual paths by sending and receiving control messages.

To compare the traffic performance of these techniques, we conducted several simulations using the OMNeT++ simulation tool. We consider the sample network, as shown in 〈Fig. 4〉. In these simulations, a source node in DANH ring 1 sends unicast frames to a destination node in DANH ring 5. 〈Fig. 5〉 shows the comparison of the traffic performance of these techniques. The simulation results show that in the sample network, the ODP and

DVP approaches have the same network unicast traffic performance. These techniques significantly reduce network unicast traffic by about 80% compared to the standard HSR protocol.

IV. Conclusion

The standard HSR protocol generates too much unnecessary redundant unicast traffic in HSR networks, resulting in the degradation of network performance. Several techniques have been proposed to solve this problem. In this paper, we presented a review of typical HSR traffic reduction techniques. We showed that these HSR traffic reduction techniques significantly reduce redundant unicast traffic compared to the standard HSR protocol and improve network performance in HSR networks. These techniques are classified into two categories based on their traffic reduction manner, traffic filtering-based techniques and predefined path-based techniques. Each technique has advantages and disadvantages. The selection of which HSR traffic reduction technique to implement depends on the particular application and trade-offs. Some of the objectives are traffic performance, network topology, control traffic volume, and storage requirements. With this review paper, researchers can acquire what has been investigated, and network designers can identify which technique to use and what the trade-offs are.

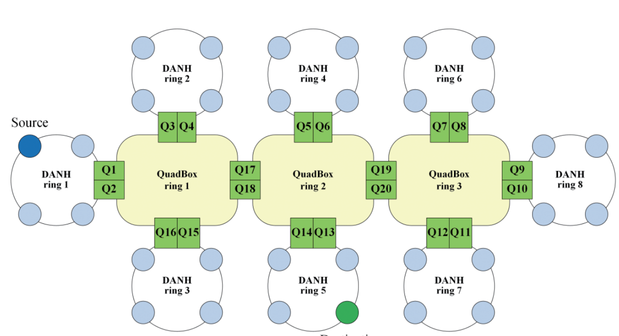

Figure 4. The simulation network for predefined path techniques.

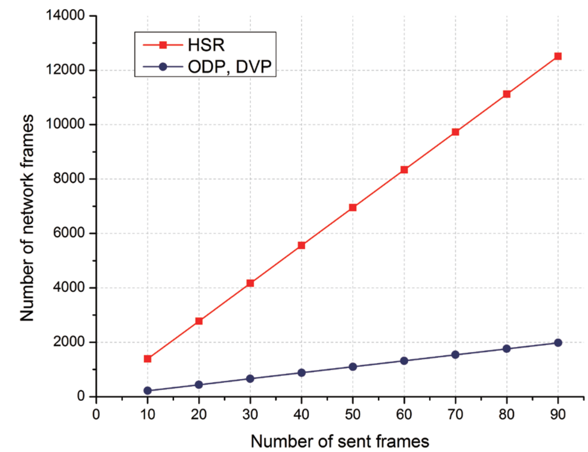

Figure 5. Comparison of traffic performance of predefined-paths

Acknowledgement

This work was supported by basic science research program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT, and Future planning (No. 2013 R1A1A2008406) and by the Human Resources Development Program of the KETEP grant funded by the Korea government Ministry of Trade, Industry, and Energy (No. 20134030200310).

References

[1] IEC 62439-3 Standard for Industrial Communication Networks - High Availability Automation Networks, Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR), 2012.

[2] IEC 61850-90-4 Standard for Network Engineering Guidelines for Communication Networks and Systems in Substations, 2013.

[3] Kirrmann H., Weber K., Kleineberg O. and Weibel H. "HSR: Zero recovery time and low-cost redundancy for Industrial Ethernet (High availability Seamless Redundancy, IEC 62439-3)," IEEE Conference on Emerging Technologies & Factory Automation (ETFA) 2009, Mallorca, Spain, pp. 1-4, September 2009.

[4] Kirrmann H., Weber K., Kleineberg O. and Weibel H. "Seamless and low-cost redundancy for Substation Automation Systems (High availability Seamless Redundancy, HSR)," Power and Energy Society General Meeting, Detroit, Michigan, USA, pp. 1-7, July 2011.

[5] Nsaif S.A. and Rhee J.M. "Improvement of High-availability Seamless Redundancy (HSR) Traffic Performance for Smart Grid Communications," Journal of Communications and Networks, vol. 14, pp. 653-661, December 2012.

[6] Abdulsalam I.R. and Rhee J.M. "Improvement of High-availability Seamless Redundancy (HSR) Unicast Performance Using Port Locking," The Fourth World Congress on Software Engineering (WCSE), Hong Kong, China, pp. 246-250, December 2013.

[7] Altaha I.R., Rhee J.M., and Pham H.A. "Improvement of High-availability Seamless Redundancy (HSR) Unicast Traffic Performance Using Enhanced Port Locking (EPL) Approach," to be appeared.

[8] Tien N.X. and Rhee J.M. "FHT: A Novel Approach for Filtering High-Availability Seamless Redundancy (HSR) Traffic," Energies, vol. 8, pp. 6249-6274, June 2015.

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

[10] Nsaif S. and Rhee J.M. "DVP: A Novel High-Availability Seamless Redundancy (HSR) Traffic-Reduction Algorithm for a Substation Automation System Network," Energies, vol. 7, pp. 1792-1810, March 2014.

[11] OMNeT++ Version 4.6 Simulator. Available online: http://www.omnetpp.org.

약 력

Nguyen Xuan Tien

1997 B.S. at Danang University of Technology.
2004 Master of Engineering at Danang University of Technology.
1997~2009 Deputy Head of Technical Department, VTI – VNPT.
2009~2014 Head of Operations Department, GTEL Mobile.
2014~present PhD candidate at Myongji University.
Research interests: fault-tolerant system, HSR, wireless networks, military communications.

Jong Myung Rhee

1976 B.S. at Seoul National University.
1978 Master of Engineering at Seoul National University, Korea.
1987 PhD at North Carolina State University, USA.
1978~1997 Senior Researcher of Agency for Defense Development.
1997~1999 Deputy Director of DACOM.
1999~2005 CTO & Executive Vice President of Hanaro Telecom.
2006~present Professor, Information and Communications Engineering, Myongji University.
Research interests: fault tolerant system, HSR, green IT, military communications.