Chapter 19

Techniques for Reducing Redundant Unicast Traffic in HSR Networks

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Additional information is available at the end of the chapter

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Abstract

High-availability seamless redundancy (HSR) is a seamless redundancy protocol for Ethernet networks. HSR provides seamless communication with fault tolerance based on the duplication of every unicast frame sent in a ring topology. HSR is very useful for mission- and time-critical systems such as substation automation systems (SASs). However, the main drawback of HSR is to generate excessively redundant network traffic in HSR networks. This drawback would unnecessarily waste network bandwidth and hence could degrade network performance in HSR networks. Several traffic reduction techniques for HSR networks have been proposed to improve the network performance in the networks. These techniques can be classified into two main groups: traffic filtering-based and dual paths-based techniques. In this chapter, we provide a description and comparison of these HSR traffic reduction techniques. This chapter describes these traffic reduction techniques and compares their network performance. The operations, advantages, and disadvantages of these techniques are investigated and summarized.

Keywords: high-availability seamless redundancy (HSR) protocol, traffic reduction techniques, fault-tolerant Ethernet networks, seamless communications, smart grids

1. Introduction

Seamless communication with fault tolerance is one of the key requirements for Ethernet-based, mission critical, and real-time applications such as substation automation systems (SASs), automation control networks, and other industrial Ethernet networks. The Ethernet standardized by the IEEE in IEEE 802.3 [1] does not support fault-tolerant capability. Various protocols have been developed and standardized to provide high availability and fault tolerance for Ethernet networks, such as rapid spanning tree protocol (RSTP) [2], media redundancy protocol (MRP) [3], shortest path bridging (SPB) [4], redundancy protocol for Ethernet (RPE) [5], time-sensitive network (TSN) [6, 7], parallel redundancy protocol (PRP) [8], and high-availability seamless redundancy (HSR) [8]. RSTP can be applied in arbitrary mesh topologies, whereas MRP is restricted to ring topology. Both these protocols provide redundancy in networks and suffer a switchover time delay [9, 10]. SPB, specified in the IEEE 802.1aq standard [4], is a computer networking technology intended to simplify the creation and configuration of networks while enabling multipath routing. It is the replacement for the RSTP. RPE is a redundancy protocol for Ethernet networks that not only provides seamless communications with zero switchover time in case of failure but also supports any topologies [5]. TSN is a set of IEEE 802 Ethernet substandards that are defined by the IEEE TSN task group (IEEE 802.1) [6]. These standards enable deterministic real-time communication over Ethernet. TSN is the second generation of audio and video bridging (AVB) standards [11]. It achieves determinism over Ethernet by using time synchronization and a schedule, which is shared between network components. It offers a way to send time-critical traffic over a standard Ethernet infrastructure. PRP and HSR provide seamless redundancy with zero recovery time. Both the HSR and the PRP are based on the principle of providing duplicated frames for separate physical paths with zero recovery time [8, 12]. PRP and HSR are seamless redundancy protocols that provide seamless communication with fault tolerance for Ethernet-based applications. However, unlike the PRP that requires dual redundant independent networks, the HSR can be applied to a single network and still retain its property of zero recovery time. HSR is one of the redundancy protocols selected for substation automation in the IEC 61850 standard [13].

1.1. HSR overview

HSR, a redundancy protocol for Ethernet-based networks, was standardized in IEC 62439-3 [8]. It provides seamless redundancy with fault tolerance for Ethernet networks by duplicating all frames sent in a ring topology. 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 or link failure, there is no stoppage of network operations. If both sent copies reach the destination, it takes the faster copy and discards the duplicate. This feature of the HSR protocol makes it very useful for time-critical and mission-critical systems, such as SAS.

The HSR protocol defines several types of nodes [8]: the doubly attached node with HSR protocol (DANH), the redundancy box (RedBox), and the quadruple port device (QuadBox). DANHs are HSR terminal nodes that have two ports operated in parallel. RedBoxes are used to connect legacy devices, such as maintenance laptops and printers, to HSR rings. QuadBoxes are used to connect HSR rings. The standard HSR protocol is mainly applied for ring topologies, including single-ring and connected ring topologies.

1.1.1. Single-ring topology

A single-ring HSR network consists of DANHs, each having two ring ports, interconnected by full-duplex links, as shown in the example of **Figure 1**. A source DANH receives a frame

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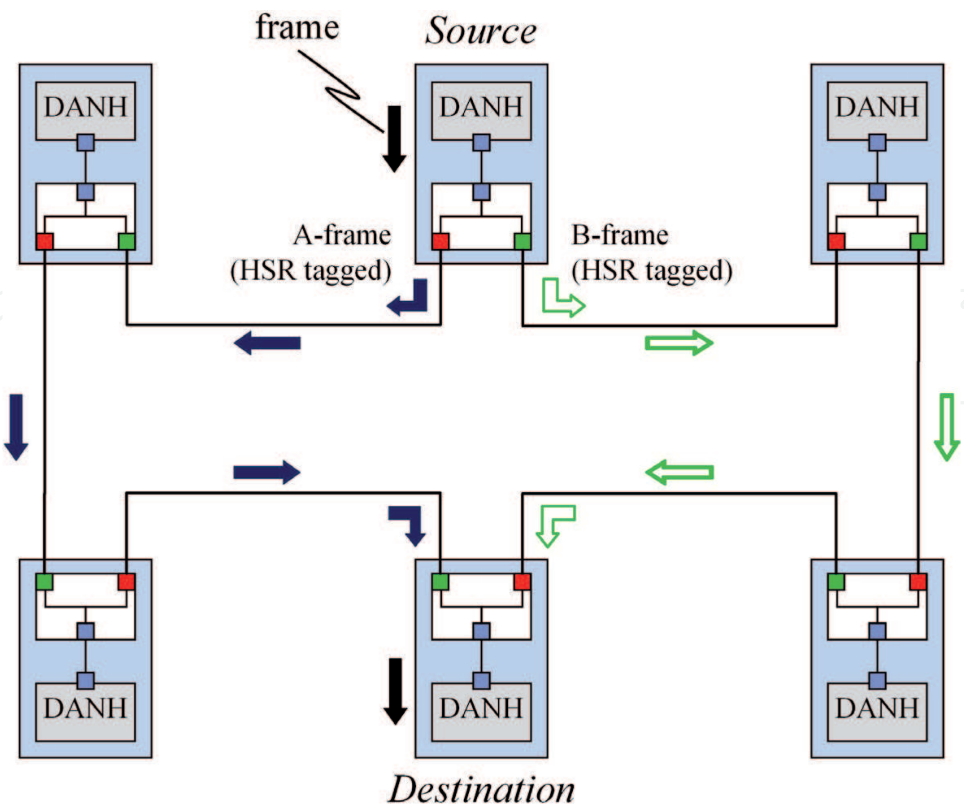

Figure 1. An example of HSR single-ring network.

passed from its upper layers, prefixes the frame by an HSR tag to identify frame duplicates, and sends the frame over each port. When a DANH receives the frame, the DANH forwards the frame to its other port, except if it already sent the same frame in that same direction. A destination node of a unicast frame does not forward the frame for which it is the only destination. In the fault-free case, the destination node receives two identical frames from each port, removes the HSR tag of the first frame before passing it to upper layers, and discards the duplicate.

1.1.2. Connected ring topology

To allow more complex network topologies, HSR rings can be connected through the use of QuadBoxes. A pair of QuadBoxes is used to connect two rings to prevent a single point of failure. A QuadBox forwards frames over each ring and passes the frames to the other ring without changes. **Figure 2** shows an example of a connected ring network that consists of eight DANH rings, each DANH ring includes four DANHs.

We consider a scenario in which DANH 1 in DANH ring 1 sends unicast frames to DANH 10 in DANH ring 3. When the source sends a unicast frame to the destination under the standard HSR protocol, the frame is duplicated and circulated in all rings except the destination DANH ring. **Figure 3** shows the process of forwarding an HSR frame from the source DANH to the destination DANH in the sample HSR network under standard HSR protocol.

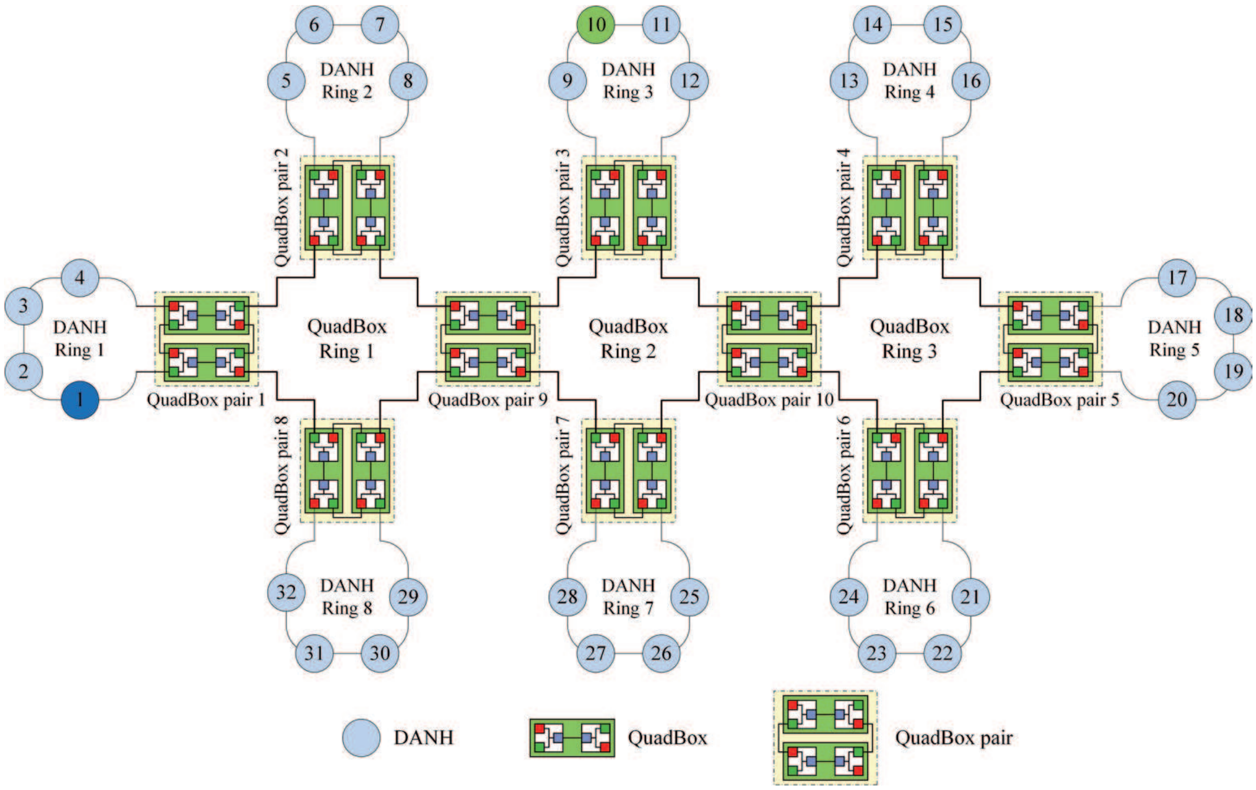

Figure 2. An example of HSR connected ring network with eight DANH rings.

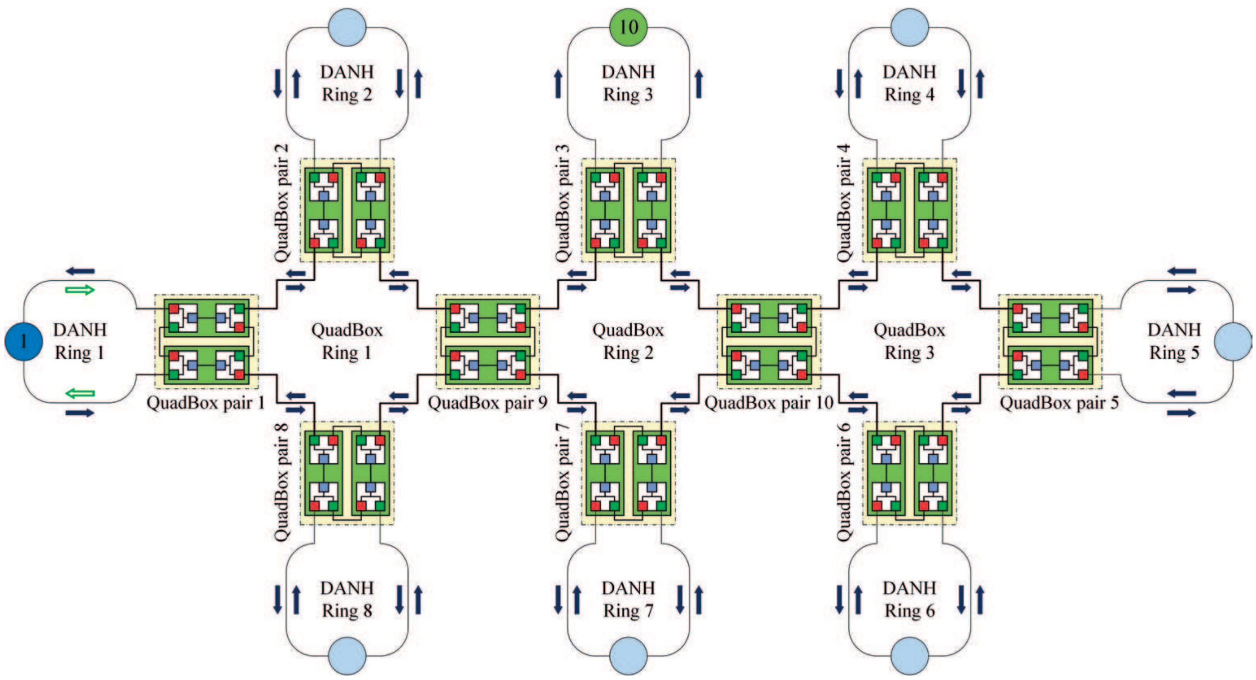

Figure 3. The process of forwarding a unicast frame under standard HSR protocol.

1.2. HSR drawbacks

HSR protocol has no issues with unicast frames inside single-ring networks. However, in connected ring networks, unicast frames are duplicated and circulated in all rings, except

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the destination DANH ring, as shown in **Figure 3**. The standard HSR protocol thus generates excessively redundant unicast traffic in the networks. This is the main drawback of the standard HSR protocol. The drawback is caused by the following issues:

1. Duplicating and circulating unicast frames in all the rings, except the destination ring;
2. Forwarding unicast frames into all DANH rings;
3. Forwarding unicast frames into all QuadBox rings.

This drawback of HSR degrades the network performance and may cause network congestion and delay in HSR networks. Several techniques have been proposed to reduce the redundant unicast traffic in HSR networks.

2. Traffic reduction techniques

2.1. Traffic filtering-based techniques

Traffic filtering-based techniques reduce redundant unicast traffic by solving some or all of the HSR issues mentioned in Section 1. There are several traffic filtering techniques, including quick removing (QR) [14], port locking (PL) [15], and filtering HSR traffic (FHT) [16].

2.1.1. Quick removing (QR)

QR is the simplest technique for reducing redundant traffic in HSR networks. It reduces the redundant traffic by preventing traffic frames from being duplicated and circulated in rings. It can be used in any topology and applied for any traffic, including unicast, multicast, and broadcast traffic.

2.1.1.1. Operations

The key idea of QR is that each HSR node forwards a unicast frame once, at most. When an HSR node receives an HSR frame, the node checks if the unicast frame has previously been received and forwarded. If not, the node sends the HSR frame over all its ports except the received port. If so, it discards the duplicated frame.

Figure 4 shows the process of forwarding a unicast frame between the source and the destination in the sample HSR network shown in **Figure 2** under the QR technique.

2.1.1.2. Advantages and disadvantages

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

However, QR forwards unicast traffic frames into all rings in HSR networks, even rings that are not used to deliver the frames from the source DANH to the destination DANH. In other words, QR does not filter unicast traffic for unused rings in the HSR networks.

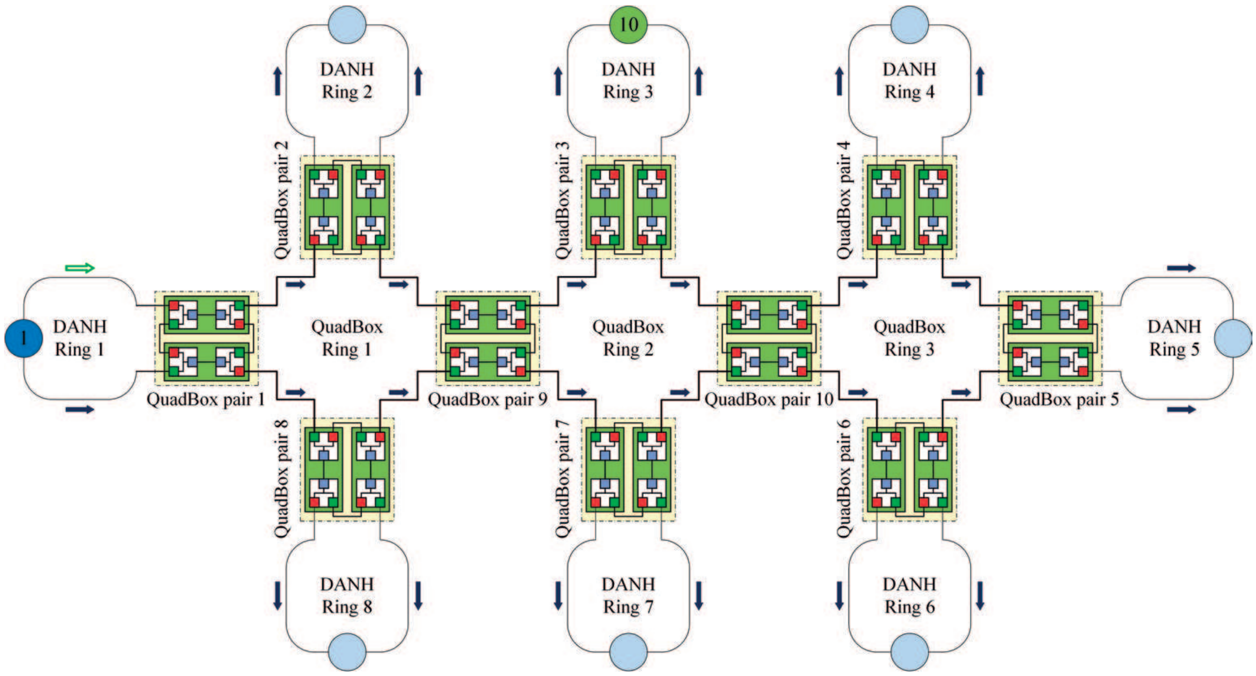

Figure 4. The process of forwarding a unicast frame under the QR technique.

2.1.2. Port locking (PL)

PL reduces redundant unicast traffic in HSR networks by filtering unicast traffic for unused DANH rings. The PL technique does not forward HSR unicast frames into DANH rings that do not contain the destination DANH.

2.1.2.1. Operations

PL is only applied to QuadBoxes that connect to DANH rings called access QuadBoxes. QuadBoxes that do not connect to any DANH ring work as standard QuadBoxes. PL divides an access QuadBox into two sides: DANH side and QuadBox side. The DANH side is connected to a DANH ring, whereas the QuadBox side is connected to a QuadBox ring.

When a source DANH sends a unicast frame to a destination DANH in an HSR network under the standard HSR protocol, the frame is forwarded into all DANH rings of the network. The frame is not circulated in the destination DANH ring that contains the destination DANH because the destination DANH does not forward the frame. Otherwise, the frame is circulated in all nondestination DANH rings that do not contain the destination DANH. The PL technique uses the concept to check and lock nondestination DANH rings. When an access QuadBox sends a unicast frame into its DANH ring over one port and receives the sent frame through the other port connected to the same DANH ring, it means that the destination DANH does not exist in that DANH ring. The access QuadBox then locks its DANH side to prevent it from sending unicast frames into its DANH ring.

The PL consists of two phases: the learning phase and the working phase.

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a. *Learning phase*: When the source DANH sends the first frame to the destination DANH, copies of the frame are flooded into the entire network, as under the standard HSR protocol. Each access QuadBox will check if its DANH rings contain the destination node. If not, the access QuadBox will lock its DANH site to prevent unicast frames from being forwarded to the DANH ring.

b. *Working phase*: After the learning phase, all DANH sites of access QuadBoxes of which DANH rings do not contain the destination DANH are locked. Unicast frames are not forwarded into DANH rings that do not contain the destination.

Figure 5 shows the process of forwarding a unicast frame between the source and the destination under the PL technique.

2.1.2.2. Advantages and disadvantages

The PL technique filters HSR unicast frames for nondestination DANH rings in HSR networks. In addition, PL does not generate additional control overhead in HSR networks because it does not use any control messages.

The main drawbacks of PL are that it still forwards HSR unicast frames into unused QuadBox rings and does not prevent the frames from being duplicated and circulated in all QuadBox rings.

2.1.3. Filtering HSR traffic (FHT)

FHT is one of the techniques that solves all the issues caused the main drawback of the standard HSR protocol. The FHT filters HSR unicast frames for all unused rings, including

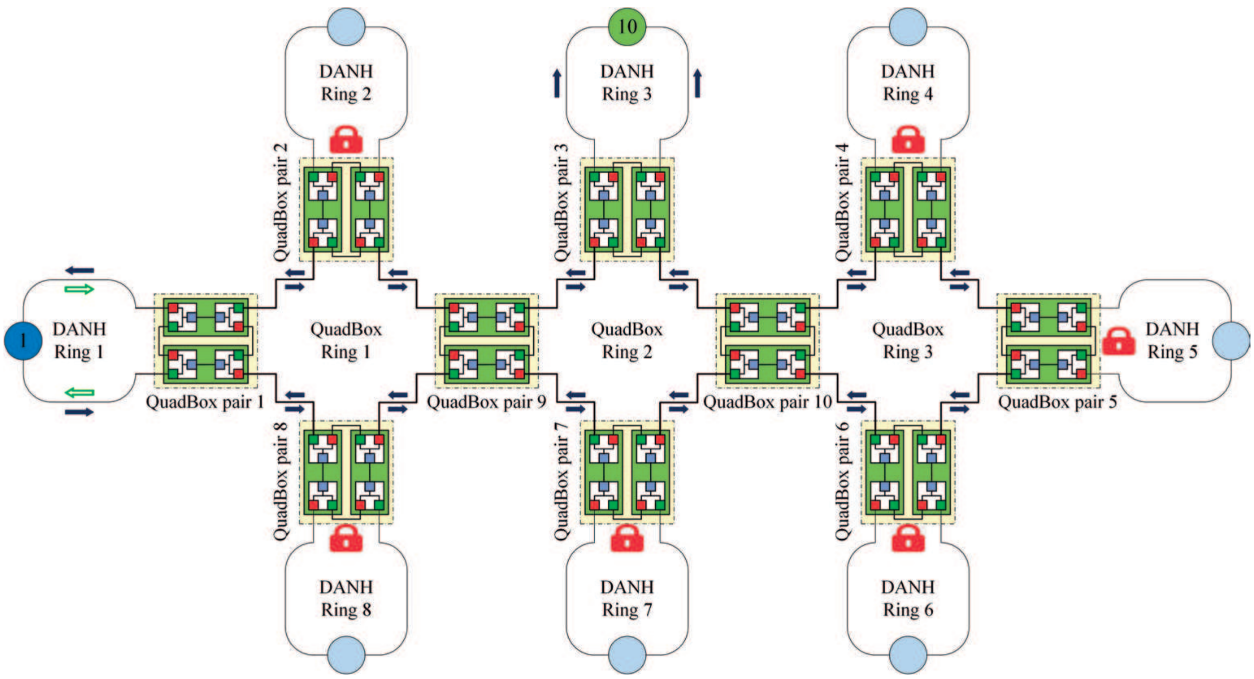

Figure 5. The process of forwarding a unicast frame under the PL technique.

nondestination DANH rings and unused QuadBox rings. In addition, the unicast frames are not circulated in HSR rings under the FHT technique.

2.1.3.1. Operations

FHT learns media access control (MAC) addresses of DANHs and builds MAC tables to filter unicast frames for unused rings in HSR networks. To prevent HSR unicast frames from being forwarded into nondestination DANH rings, each access QuadBox builds and maintains a MAC1 table that contains MAC addresses of DANHs that connect to its DANH ring. Each trunk QuadBox builds a MAC2 table that is a collection of MAC1 tables of access QuadBoxes that connect to its QuadBox rings. The MAC2 table is then used to filter unicast frames for unused QuadBox rings.

Two new traffic filtering rules are defined in order to filter unicast traffic for unused DANH and QuadBox rings:

- Filtering rule 1: An access QuadBox node forwards a unicast frame into its DANH ring, if and only if its MAC1 table contains the destination MAC address of the frame.
- Filtering rule 2: 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's MAC2 table does not contain the destination MAC address.

Additionally, a new traffic forwarding rule is also defined to prevent unicast traffic frames from being duplicated and circulated in rings:

- Forwarding rule: HSR nodes forward an HSR unicast frame once, at most. In other words, a node forwards an HSR unicast frame when the node receives the frame for the first time and discards duplicates.

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

a. Learning phase

In this phase, the FHT learns MAC addresses of DANHs and builds MAC tables. The learning phase consists of two steps: building MAC1 table and building MAC2 table.

Step 1. Building MAC1 table. The table is built at access QuadBoxes. To learn MAC addresses of DANHs, QuadBoxes periodically flood a Hello message. Upon receiving the Hello message, DANHs reply by sending an ACK message back to the sending QuadBox. Each access QuadBox learns MAC addresses of DANHs connecting to its DANH ring and builds its MAC1 table.

Step 2. Building MAC2 table. The table is built at trunk QuadBoxes. Each access QuadBox sends a MAC message that contains its MAC1 table into its QuadBox ring once it has completed building the MAC1 table. Upon receiving MAC messages, trunk QuadBoxes build MAC2 tables.

b. Forwarding phase

FHT uses MAC tables to forward HSR unicast frames in an HSR network. An access QuadBox forwards an HSR unicast frame into its DANH rings if its MAC1 table contains the destination

MAC address of the frame. In other words, the MAC1 table is used to filter unicast frames for nondestination DANH rings. FHT filters unicast frames for unused QuadBox rings based on MAC tables at trunk QuadBoxes. In addition, the new traffic forwarding rule of FHT prevents unicast frames from being duplicated and circulated in rings.

Figure 6 shows the process of forwarding a unicast frame from the source to the destination under the FHT approach.

2.1.3.2. Advantages and disadvantages

The FHT approach filters unicast traffic frames not only for the unused DANH rings but also for the unused QuadBox rings. Additionally, it prevents the unicast frames from being duplicated and circulated in active rings. In other words, the FHT approach solves all HSR issues abovementioned in Section 1. These features make the FHT approach become one of the most efficient HSR traffic reduction techniques.

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

2.1.4. Simulations and comparisons

As described above, different traffic filtering techniques have different advantages and disadvantages. The QR technique removes duplicated and circulated unicast frames from rings, but it still forwards the frames into all rings, even the nondestination DANH rings and the unused QuadBox rings. The PL technique filters unicast traffic for nondestination DANH rings, but unused QuadBox rings. In addition, it does not prevent unicast frames from being duplicated and circulated unicast traffic in QuadBox rings. The FHT technique filters unicast

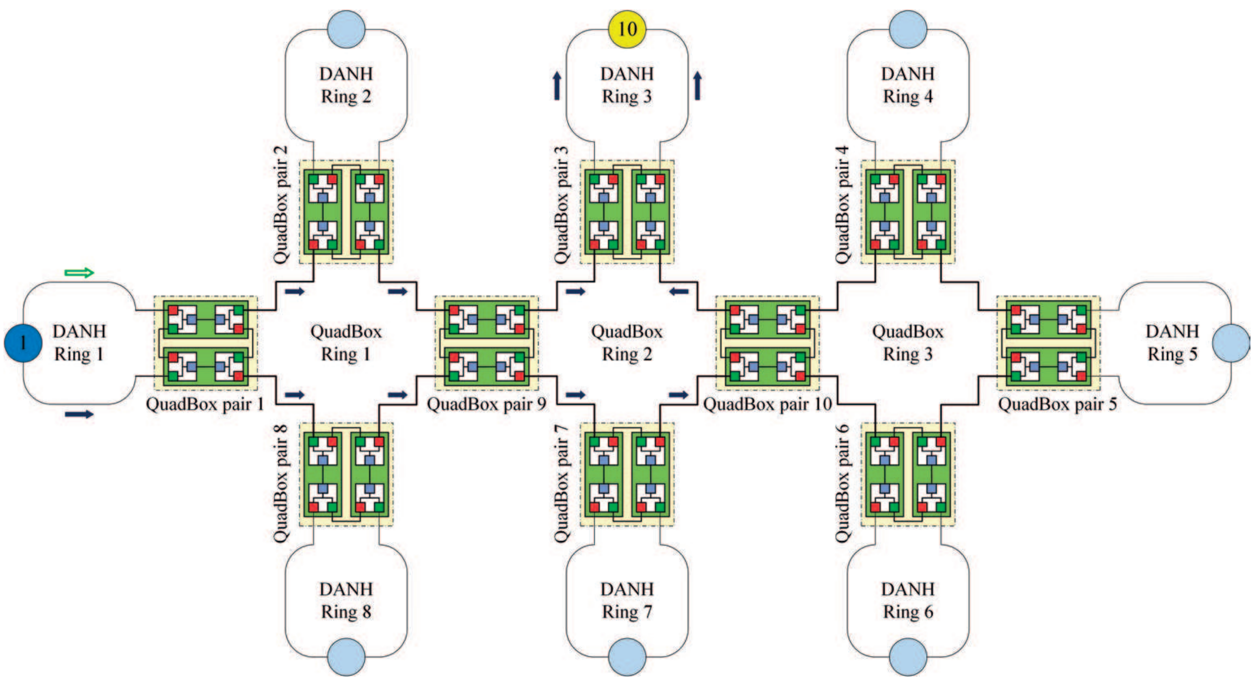

Figure 6. The process of forwarding a unicast frame from the source to the destination under the FHT technique.

traffic for nondestination DANH rings and unused QuadBox rings. FHT also prevents unicast frames from being duplicated and circulated in rings. However, the FHT generates an additional control overhead in HSR networks. The characteristics of these filtering techniques are summarized in **Table 1**.

To compare traffic performance of these techniques, several simulations were conducted using the OMNeT++ simulation tool [17]. We consider the sample HSR network consisting of eight DANH rings; each DANH ring has four DANHs, as shown in **Figure 2**. In these simulations, source DANH 1 in DANH ring 1 sends N (N = 10, 20, …, 100) unicast frames to destination DANH 10 in DANH ring 3. **Figure 7** shows the comparison of traffic performance of these traffic filtering-based techniques. The simulation results show that, in the sample network, the QR technique reduces network unicast traffic by 40% compared to the standard

Features	QR	PL	FHT
Preventing unicast traffic from being duplicated and circulated in rings	Yes	No	Yes
Filtering unicast traffic for unused DANH rings	No	Yes	Yes
Filtering unicast traffic for unused QuadBox rings	No	No	Yes
Generating additional control overhead	No	No	Yes

Table 1. Characteristics of traffic filtering-based techniques.

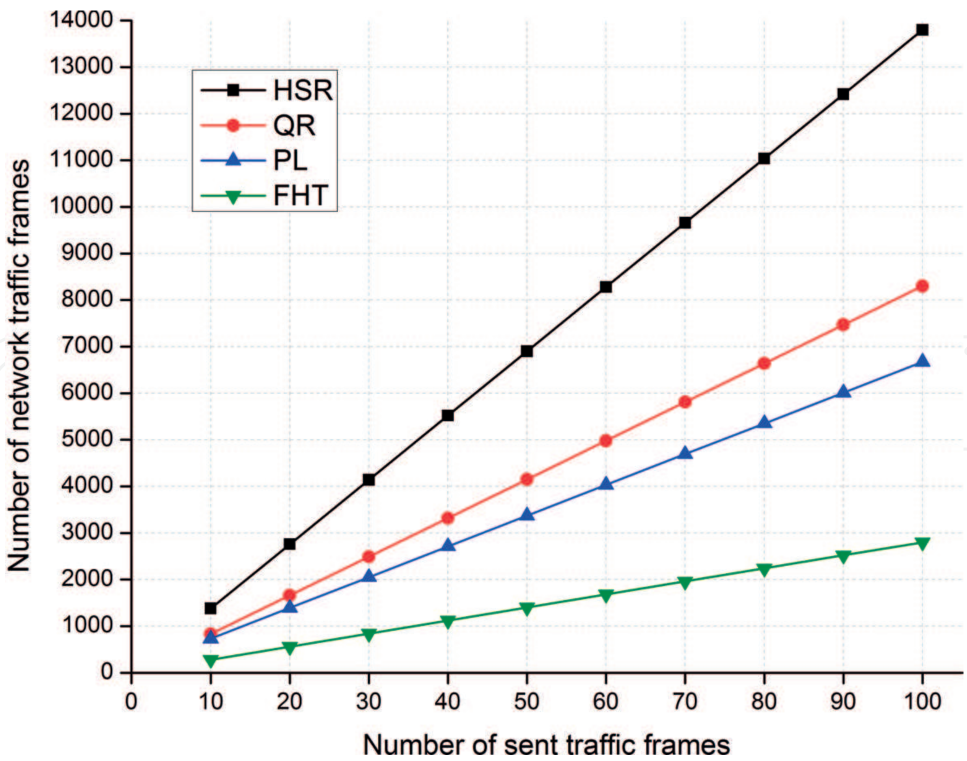

Figure 7. A comparison of the traffic performance of traffic filtering-based techniques.

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HSR protocol. The PL technique has better traffic performance than the QR technique; PL reduces network unicast traffic by 51% compared to standard HSR protocol. The FHT technique provides the best traffic performance and reduces network traffic by 80% compared to standard HSR protocol.

2.2. Dual paths-based techniques

Dual paths-based techniques reduce the redundant unicast traffic in an HSR network by forwarding unicast frames from a source to a destination in the network through two predefined separate paths instead of duplicating and flooding the frames into all rings as in the standard HSR protocol. There are several dual paths-based techniques, including dual virtual paths (DVP) [18], ring-based dual paths (RDP) [19], and dual separate paths (DSP) [20].

2.2.1. Dual virtual paths (DVP)

DVP discovers and establishes two separate paths for each connection pair of DANHs in HSR networks. These two paths are DANH-based dual paths. The DVP technique discovers the DANH-based dual paths by sending and receiving control messages, including path selection (PaS) and path confirmation (PaC) messages.

2.2.1.1. Operations

The operation of DVP includes the following phases:

a. Announcement phase

In the announcement phase, each HSR node learns MAC addresses of DANHs by broadcasting an announcement (Ann) message. The MAC addresses are then stored in a table called neighbor (Ne) table.

b. Path establishment phase

In this phase, all the DANHs establish DANH-based dual paths with each other DANHs. To discover and establish DANH-based dual paths, each DANH sends PaS messages to other DANHs listed in its Ne table. When a node, such as QuadBox or DANH that is not the destination DANH, receives a PaS message, it forwards the message to other nodes. The destination DANH receives two identical copies of the PaS message. Once the destination DANH receives a PaS message, it replies by sending a PaC message back to the source DANH. There are two PaC messages sent back to the source DANH from the destination DANH; each travels through one of the established dual paths. Upon receiving PaS and PaC messages, QuadBoxes in between the dual paths build a final path (FP) table. The FP table is then used to forward HSR frames from the source to the destination.

c. Final phase

When the source DANH sends unicast frames to the destination DANH, the frames are delivered through the pre-established dual paths between the source and the destination.

2.2.1.2. Advantages and disadvantages

As a dual paths-based technique, DVP significantly reduces redundant unicast traffic compared with the standard HSR protocol by forwarding unicast traffic frames through pre-established dual paths instead of duplicating and flooding in the overall network.

However, since the DVP technique establishes dual paths for each connection pair of DANH nodes, the number of connection pairs is very large. This results in high control overhead for discovering and establishing dual paths in HSR networks.

2.2.2. Ring-based dual paths (RDP)

RDP discovers and establishes two separate paths for each connection pair of DANH rings in HSR networks. These dual paths are ring-based dual paths. Like DVP, the RDP uses control messages to discover and establish the ring-based dual paths.

2.2.2.1. Operations

The functions of discovering and establishing dual paths between rings are implemented at QuadBox nodes in HSR networks. The dual paths establishment of RDP consists of three phases, namely building the MAC table, establishing ring-based dual paths, and building the forwarding table.

a. Building the MAC table

Each DANH periodically sends an HSR_Supervision frame over both its ports. Each access QuadBox learns MAC addresses of DANH nodes connected to its DANH ring based on the HSR_Supervision frames sent by the DANH nodes. By learning the MAC addresses of DANH nodes, each access QuadBox builds its MAC table that contains MAC addresses of DANHs that connect to its DANH ring. By looking up the MAC table, access QuadBoxes do not forward unicast frames into nondestination DANH rings.

b. Establishing ring-based dual paths

In the phase of establishing dual paths, the following two-step process is performed:

Step 1. Path request. In this step, each access QuadBox sends a path request (PREQ) message to discover ring-based dual paths. Upon receiving the PREQ message, QuadBoxes process information fields of the message, add their node ID into the received message, and then forward the updated message to other QuadBoxes. Based on information of the received PREQ message, trunk QuadBoxes update their ring table that contains MAC addresses of DANHs and ring IDs of DANH rings, whereas access QuadBoxes reply by sending a path reply (PREP) message back to the sending access QuadBox.

Step 2. Path reply. When an access QuadBox has received a PREQ message sent by another access QuadBox for the first time, the access QuadBox builds a path between the sending and receiving access QuadBoxes. The path is the first ring-based path between the source DANH ring and the destination DANH ring. The QuadBox then sends a PREP message back to the sending access QuadBox.

c. Building the forwarding table

Based on received PREQ and PREP messages, trunk QuadBoxes in between ring-based paths build their forwarding table. Each entry of the forwarding table consists of a source ring, a destination ring, and an output port.

2.2.2.2. Advantages and disadvantages

Like other dual paths-based techniques, the RDP technique significantly reduces redundant unicast traffic in HSR networks compared with the standard HSR protocol by forwarding the unicast traffic through two predefined paths. Like DVP, the RDP technique uses control messages to discover and establish dual paths. However, unlike the DVP technique that establishes DANH-based dual paths, the RDP technique establishes ring-based dual paths; therefore, the RDP dramatically reduces the number of established dual paths, which in turn decreases additional control overhead compared with the DVP technique.

However, because of using control messages to discover and establish dual paths, the RDP technique still generates additional control overhead to setup dual paths in HSR networks.

2.2.3. Dual separate paths (DSP)

DSP establishes two separate paths for each connection pair of QuadBoxes in HSR networks. These dual paths are QuadBox-based dual paths. Unlike DVP and RDP that use control messages to discover and establish dual paths, the DSP technique finds the QuadBox-based dual paths based on network topology information.

2.2.3.1. Operations

The establishment of dual paths is implemented at QuadBoxes. The DSP technique first builds MAC and link tables for each QuadBox, then discovers and establishes dual paths for each connection pair of access QuadBox, and finally, sets up the dual paths and builds a forwarding table for each trunk QuadBox.

a. Building the MAC table

Both access and trunk QuadBoxes learn and build their MAC table; however, the MAC table of access QuadBoxes is different from that of trunk QuadBoxes. Access QuadBoxes learn MAC addresses of DANH nodes connected to its DANH ring, whereas trunk QuadBoxes learn MAC addresses of all DANH nodes in the HSR network. Like in the RDP technique, each access QuadBox learns the MAC addresses of DANH nodes connected to its DANH ring based on HSR_Supervision frames sent by the DANH nodes. The process of learning MAC addresses for trunk QuadBoxes is similar to that of Ethernet switches. Trunk QuadBoxes learn MAC addresses of all DANH nodes in the network.

b. Building the link table

RDP establishes ring-based dual paths in an HSR network based on the network's link information. Each QuadBox builds and maintains a link table that contains information of all links in the network. QuadBoxes first build a neighbor list by exchanging Hello messages. Two access QuadBoxes of a QuadBox pair have the same node ID and the same neighbor list. QuadBoxes then send a Link message that contains their neighbor list. Upon receiving Link messages, QuadBoxes build their link table.

c. Finding dual paths

Each access QuadBox pair finds QuadBox-based dual paths to all other access QuadBox pairs. To find the dual paths for each connection pair of QuadBox pairs, each access QuadBox pair applies the DSP algorithm to the network link table. The DSP algorithm consists of the following steps: searching step, sorting step, and selecting step.

Step 1. Searching step: In this step, the DSP algorithm searches all available paths between the source and destination QuadBox pairs in the network. The searched paths associated with their path distance are then added to a path list.

Step 2. Sorting step: The path list found in the searching step is sorted in ascending order of path distance.

Step 3. Selecting step: In this final step, based on the sorted path list, the DSP algorithm selects two node-disjoint paths that have the best path distances.

d. Establishing dual paths

After finding dual paths for each connection pair of access QuadBox pairs, the QuadBox pair with a lower node ID sends a path setup (PSET) message through each path of the dual path to the corresponding QuadBox pair. The corresponding QuadBox pair replies by sending a path acknowledgment (PACK) message once it receives the PSET message. Based on the received PSET and PACK messages for each connection pair of QuadBox pairs, trunk QuadBoxes in between the dual paths build their forwarding table. Each entry of the forwarding table consists of the source QuadBox pair ID, the destination QuadBox pair ID, and the corresponding output port.

2.2.3.2. Advantages and disadvantages

Like DVP and RDP, the DSP technique significantly reduces redundant unicast traffic in HSR networks compared with the standard HSR protocol. In addition, unlike the DVP technique that discovers and establishes DANH-based dual paths for each connection pair of DANH nodes, the DSP technique finds QuadBox-based dual paths for each connection pair of QuadBox nodes; therefore, the DSP technique significantly reduces the number of connection pairs, which in turn reduces additional control overhead for discovering and establishing dual paths compared with the DVP technique.

However, because of using control messages to build the link tables and establish the dual paths, the DSP technique still generates additional control overhead in HSR networks.

2.2.4. Simulations and comparisons

These dual paths-based techniques discover and establish dual paths for each connection pair of nodes in HSR networks. These dual paths are then used to forward unicast frames from

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the source to the destination. **Figure 8** shows the process of forwarding a unicast frame from source DANH 1 to destination DANH 10 through dual paths under the dual paths-based technique.

As described above, these dual paths-based techniques have advantages and disadvantages. While the DVP and RDP techniques discover and establish dual paths by sending and receiving control messages, the DSP technique establishes dual paths based on the network topology information. The DVP technique setups DANH-based dual paths for each connection pair of DANHs, while the RDP and DSP techniques establish ring-based and QuadBox-based dual paths for each connection pair of DANH rings and for each connection pair of QuadBox nodes, respectively. Therefore, the RDP and DSP techniques significantly reduce the number of connection pairs required to discover and establish dual paths. The characteristics of these dual paths-based techniques are summarized in **Table 2**.

Several simulations were conducted using the OMNeT++ simulator to compare the traffic performance of these dual paths-based techniques. We consider the sample HSR network as shown in **Figure 2**. In these simulations, source DANH 1 in DANH ring 1 sends unicast frames to destination DANH 10 in DANH ring 3. The line graph in **Figure 9** shows the comparison of traffic performance of these dual paths-based techniques. Overall, it can be seen from the graph that these traffic reduction techniques have the same network traffic performance and significantly reduce network unicast traffic compared with standard HSR protocol.

2.3. HSR SwitchBox technique

Unlike the mentioned techniques, which propose algorithms implemented in existing HSR components to improve the network traffic performance in HSR networks, the HSR SwitchBox

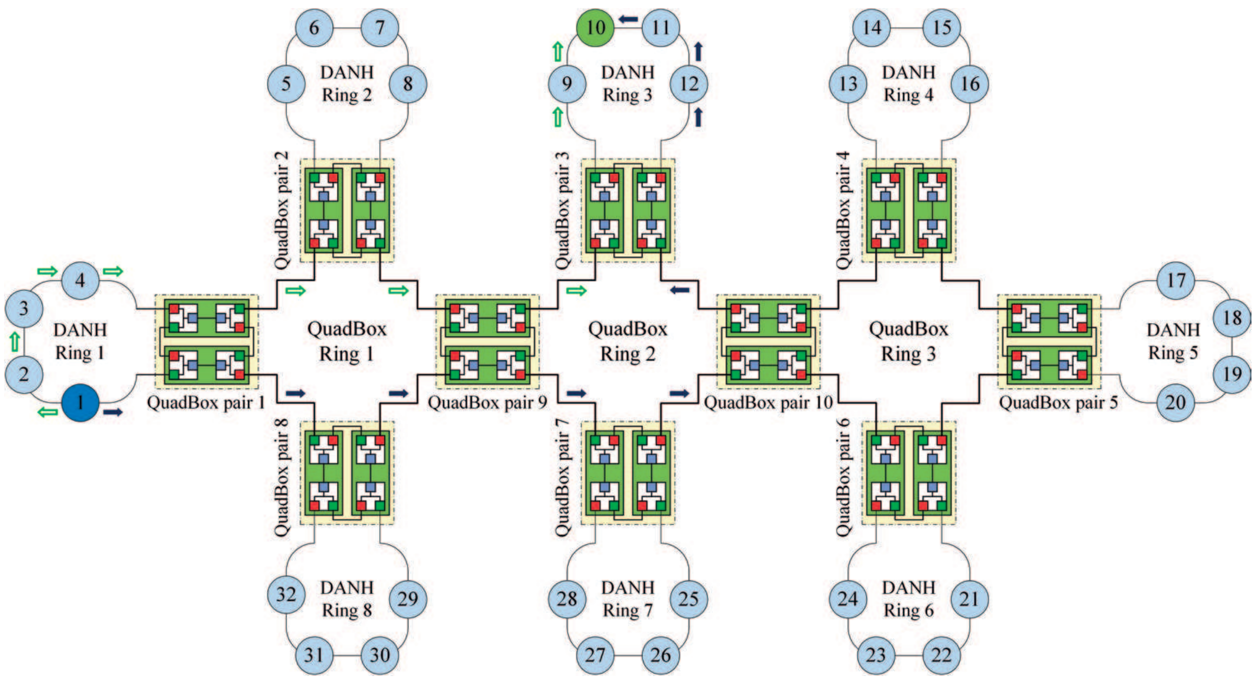

Figure 8. The process of forwarding a unicast frame under the dual paths-based techniques.

Features	DVP	RDP	DSP
Type of dual paths	DANH-based	Ring-based	QuadBox-based
Method of establishing dual paths	Control messages	Control messages	Topology information
Number of dual paths	Large	Small	Small
Generated control overhead	High	Medium	Medium

Table 2. Characteristics of dual paths-based techniques.

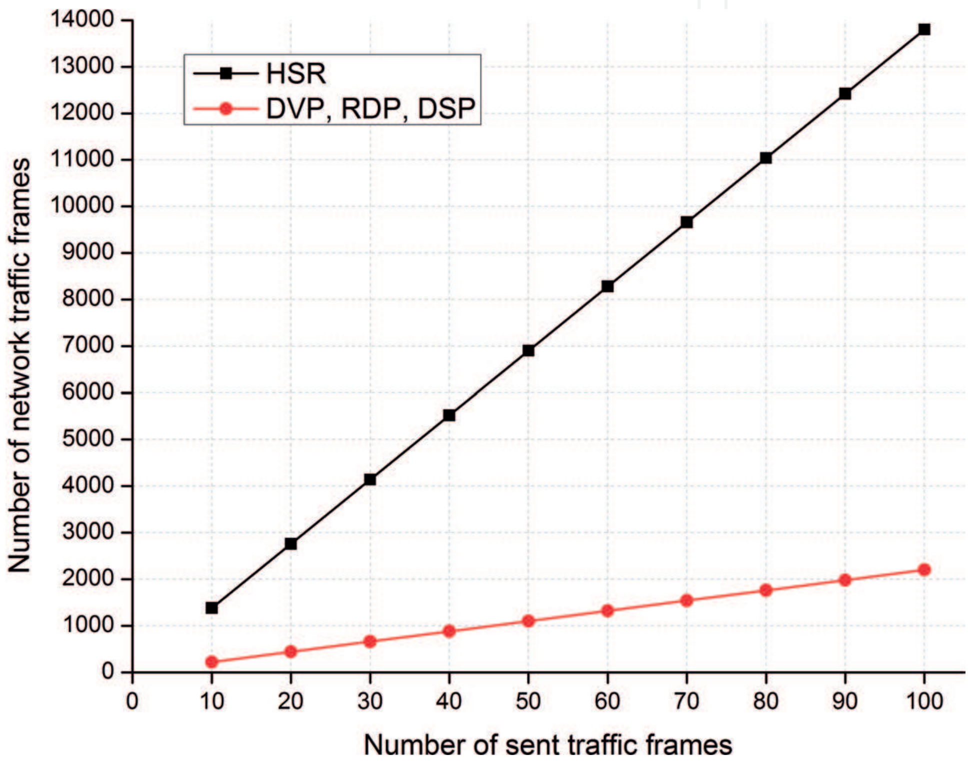

Figure 9. A comparison of the traffic performance of dual paths-based techniques.

technique [21] defines a new HSR switching node (SwitchBox) for HSR networks. By using the SwitchBoxes, HSR can be applied to any topology, such as a ring, mesh, or star topology. In addition, SwitchBox-based HSR significantly reduces redundant network traffic compared to the standard HSR.

2.3.1. Operations

An HSR SwitchBox is a switching node with many ports that performs the switching functionality in HSR networks. SwitchBoxes forward a received HSR frame by looking up the MAC table instead of flooding and circulating the HSR frame in the HSR network as current HSR nodes.

http://dx.doi.org/10.5772/intechopen.71783

The HSR SwitchBox technique defines the following new forwarding rules:

- Do not forward HSR unicast frames into nondestination DANH rings.
- Forward HSR unicast frames on network trunk links.
- Prevent HSR frames from being circulated in HSR networks.

The operation of HSR SwitchBox technique consists of three phases, including setting port type, building MAC table, and forwarding frame.

a. Setting port type

There are two types of port defined for HSR SwitchBoxes: access and trunk ports. An access port is connected to a DANH node, whereas a trunk port is connected to another SwitchBox. SwitchBox ports are set to the access type, by default. The type of SwitchBox ports can be configured automatically or manually. A Hello message is used to automatically configure the port type. Whenever a port of a SwitchBox changes its status to up, the SwitchBox sends a Hello message over the port. When a SwitchBox receives a Hello message on a port, it sets the type of the port to the trunk type.

b. Building MAC table

Each SwitchBox learns the MAC addresses of DANHs that connect to it based on receiving the HSR_Supervision frames sent by the DANH nodes. Each SwitchBox builds its MAC table, which contains MAC addresses of the DANH nodes that connect to the SwitchBox.

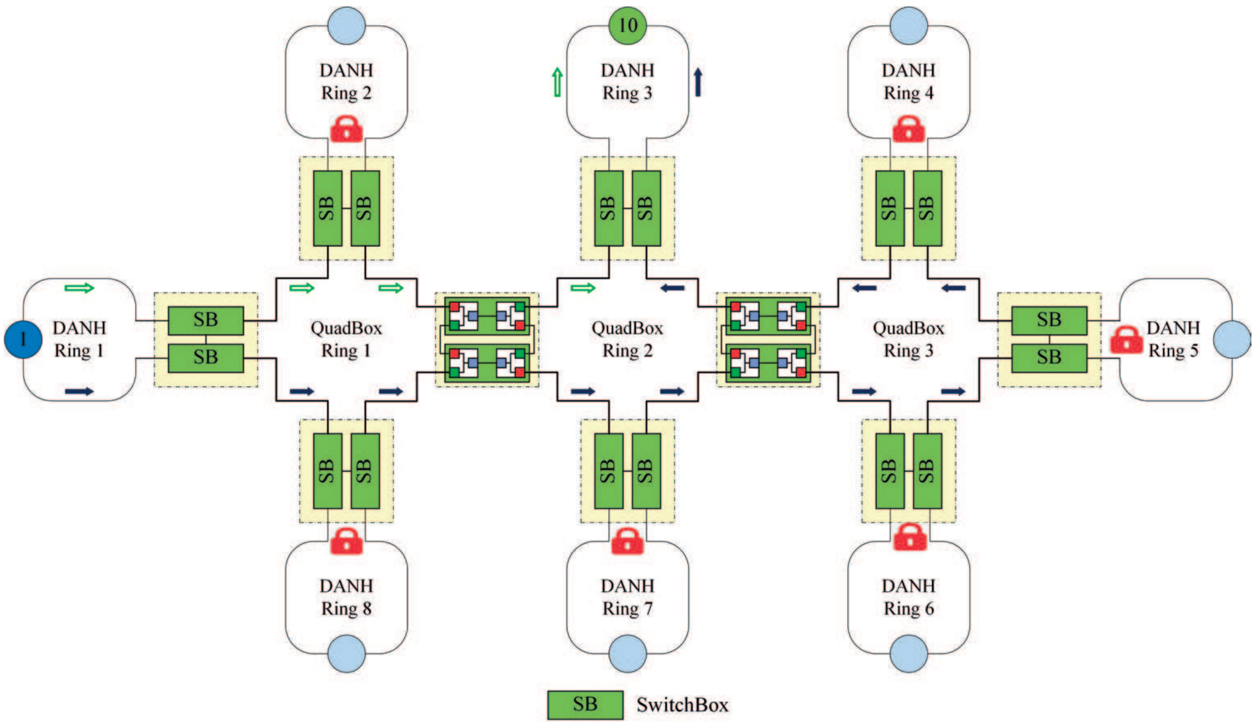

Figure 10. The process of forwarding a unicast frame under the SwitchBox-based HSR.

c. Forwarding frame

Instead of flooding and circulating HSR unicast frames, SwitchBoxes forward the frames based on looking up the MAC table. When a SwitchBox receives a unicast frame, it checks if its MAC table contains the destination MAC address of the frame. If not, it sends the received frame over its trunk ports, except the received port. If so, it forwards the frame to the port that connects to the destination node. The SwitchBox discards duplicated copies of the frame.

When source DANH 1 in DANH ring 1 sends unicast frames to destination DANH 10 in DANH ring 3, SwitchBox-based HSR filters the unicast traffic for DANH rings that do not contain the destination node, as shown in **Figure 10**.

2.3.2. Simulations and comparisons

Several simulations were carried out using the OMNeT++ simulator to evaluate and compare the traffic performance of the SwitchBox-based HSR with that of the standard HSR. In these simulations, we considered the sample HSR network as shown in **Figure 2**. **Figure 11** shows the comparison of the traffic performance between the SwitchBox-based HSR and the standard HSR. Unlike standard HSR, which floods unicast frames to all rings, SwitchBox-based HSR does not forward the unicast frames to nondestination DANH rings. In addition, SwitchBox-based HSR prevents the frames from being duplicated and circulated in rings. Therefore, SwitchBox-based HSR significantly reduces network traffic compared with

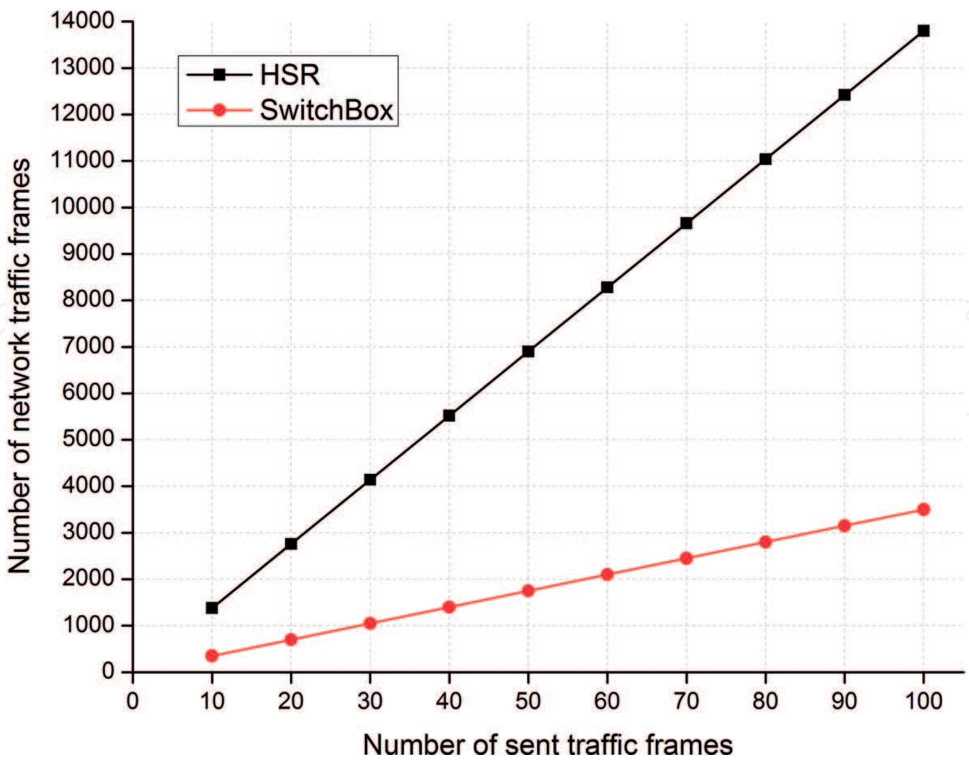

Figure 11. A comparison of the traffic performance between standard HSR and SwitchBox-based HSR.

the standard HSR. Numerically, the simulation results show that the SwitchBox-based HSR reduced network unicast traffic by 75% compared to the standard HSR.

3. Conclusions

The standard HSR protocol generates excessively unnecessary redundant unicast traffic in HSR networks, resulting in the degradation of network performance. Several traffic reduction techniques have been proposed to solve this problem. In this chapter, we present a review of HSR traffic reduction techniques. These traffic reduction techniques are divided into two categories: traffic filtering-based and dual paths-based techniques. Each HSR traffic reduction technique has its own advantages and disadvantages. The selection of which technique to implement depends on the particular application and trade-offs. With this chapter, researchers can acquire what has been investigated, and network designers can identify which technique to use and what are the trade-offs.

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