차세대 차량 네트워크를 위한 HSR (High-availability seamless Redundancy) 프로토콜 적용 연구

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High-availability Seamless Redundancy(HSR) Protocol for Automobile Networks

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요 약

Ethernet 기반 차량 네트워크 구성 시 신뢰성은 요구조건 중 하나이다. 이를 위해 차량 네트워크 구조에 High-availability Seamless Redundancy (HSR) protocol (IEC 62439-3 clause 5)를 사용할 수 있다. HSR 프로토콜은 프레임을 전송할 때 서로 다른 경로에 각각의 복제된 프레임들을 제공한다. 이는 전송 오류로 인해 하나의 경로에서 프레임을 전송받지 못하더라도 목적지 노드는 다른 경로를 통해 적어도 하나의 프레임을 받을 수 있어 네트워크의 고장 발생 시에도 네트워크의 중단이 없음을 의미한다. 고장 발생 시에도 목적지 노드는 Zero-recovery time으로 하나의 프레임을 받을 수 있기 때문에 표준 Ethernet 과는 달리 보낸 프레임의 손실 시 네트워크를 재구성하는 시간이 필요 없다. 하지만 HSR 프로토콜은 복제 전송하는 프레임으로 인해 불필요한 트래픽을 발생시키는 단점이 있다. 이에 HSR 프로토콜의 성능을 향상시키기 위해 QR, VRing, RURT, DVP 와 같은 방법들이 이미 제안되었다. 본 논문에서는 차량 네트워크에 HSR 프로토콜을 적용한 3가지 구조를 제안하였고 여기에 트래픽 향상을 위해 QR, VRing을 적용하였으며 이 구조들의 트래픽 성능을 측정 및 비교하였다. QR과 VRing을 적용할 때 표준 HSR 프로토콜에 비해 48-75%의 트래픽 감소를 보여주었다. 이는 차량에서 신뢰성 향상을 위해 HSR 프로토콜은 Ethernet을 대신하여 사용할 수 있음을 의미한다.

Key Words : Automobile Ethernet Network; Fault Tolerant; High-availability Seamless Redundancy(HSR); QR Approach, VRing Approach

ABSTRACT

One of the most important requirements for the Ethernet-based automobile is the reliability. In order to achieve this goal, we propose using the High-availability Seamless Redundancy (HSR) protocol (IEC 62439-3 clause 5) in these networks. The HSR protocol provides duplicated frame copies for each sent frame, which means that the destination node will receive at least one copy in case the second copy is lost due to a failure. In other words, there will be no network stoppage even if failure occurs. Moreover, the destination node will receive at least one frame copy with zero-recovery time (seamless) and it will not need to wait to receive the other copy if the first one is lost, which occurs it in the Ethernet standard, as a result of reconfiguration of the network paths. However, the main drawback of the HSR protocol is the unnecessary redundant traffic that is caused by the duplicated frames. Several solutions, including QR, VRing, RURT, and DVP, have already been proposed to improve the traffic performance of the HSR protocol. In this paper, we propose three automobile network topologies. each of which has pros and cons depending on the automobile requirements. Then we applied the HSR protocol with and without the QR and VRing approaches to each scenario. The comparison among these topologies depend on the traffic performance result for each of them. The QR and VRing approaches give a better traffic reduction percentage, ranging from 48% to 75% compared to the standard HSR protocol. Therefore they could limit the redundant traffic in automobile networks when the HSR protocol is used instead of the Ethernet network, which does not provide any seamless recovery if a failure occurs.

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Ⅰ. Introduction

In the current automobile network structure, it is difficult to accommodate communication performance requirements to keep pace with technological developments. An Ethernet-based network structure is required to apply enhanced network techniques in automobiles[1]. Ethernet AVB (Audio Video Bridging) technology is used to guarantee time-synchronized low-latency in a real-time network[2]. Currently AVB Gen 2 is being researched in the IEEE standard working group in order to meet requirements of automobile networks and industrial networks[2]. While a configuring network in Ethernet AVB Gen 2, one of the requirements is that it has to provide a quick recovery[2-3]. This is very important because when the automobile network fails without a quick recovery, a dangerous accident may result because a critical signal, e. g., a control signal, isn't delivered at the right time. Therefore, a redundancy scheme, such as the Fault Tolerant Ethernet(FTE) network, which provides quick or seamless recovery in an automobile network, could be a solution to this problem. This approach has a backup component that is automatically activated when the main component fails [4]. In the Ethernet AVB network, a system that can recover within micro seconds, is being investigated. Generally, manufacturing an FTE device is easy and less expensive than manufacturing other types of technology due to the low costs of the components, but the effectiveness of the device depend on the reliability of the switching chip that is used for the switching backup components. If the switching chip has a problem, it can't provide quick recovery. Moreover, if a failure occurs, the network's performance is affected by the fail-over time, the fault detection time and the fault recovery time [3].

For the reason presented above, the High-availability Seamless Redundancy (HSR) protocol can be a suitable solution for this issue. The HSR protocol has been standardized by the International Electrotechnical Commission (IEC) as IEC 62439-3 Clause 5. Basically, the HSR protocol provides a redundancy mechanism with zero-recovery time[5]. It provides duplicated frame copies for each sent frame, each on a separate physical path [5-6]. This means that even if one of the two paths fails, the destination node will receive two frame copies, one from each path with zero-recovery time. The destination node will use the first arrived frame and discard the second copy as soon as it reaches the destination node [5-6]. Other details of the HSR protocol are described in [5-8]. However, the drawback of the HSR protocol is the unnecessary traffic issue that caused by the duplicated frames. Several solutions, including QR, RURT, VRing, and DVP, have already been proposed to improve the traffic performance of the HSR protocol [6][11-13].

In this paper, we propose using the HSR protocol for automobile networks instead of the Ethernet standard that is currently used because HSR provides seamless redundancy. Toward that end, we proposed three different automobile topologies based on the automobile network functions, and then we applied the HSR protocol to each of them. Because the duplication process for the HSR protocol consumes more network bandwidth, we also applied QR and VRing approaches to solve this problem. We then derived expressions to represent the traffic under each of these cases and simulated their network traffic using OMNeT++v4.2.2 [13]. In the final section of this paper, we compare the results of our study.

The remaining section of this paper is organized as follows. In Section Ⅱ, we present the traffic issues for the HSR protocol. In Section Ⅲ, we propose three possible types of network topologies for the automobile networks. In Section Ⅳ, we present the analytical analyses for the network traffic under the HSR protocol, QR, and VRing approaches. In Section Ⅴ, the traffic network performance is calculated using OMNeT++ simulator. Finally, our conclusions and suggestions for future work are described in Section Ⅵ.

Ⅱ. HSR Protocol Traffic Issues

In general, the HSR protocol has four types of nodes [11], as descried below.

1) A doubly-attached node for HSR (DANH), 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 the 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 HSR tag to each copy and send two copies out through the DANH ports, one in a

clockwise direction and the other in a counter-clockwise direction;

2) A single-attached node (SAN), which is a non-HSR device, such as a commercial printer, server, or laptop, cannot be directly inserted into the HSR networks since these devices lack the forwarding capability of an HSR node and they do not support the HSR tag. They must be attached through a redundancy box (RedBox) node type;
3) A RedBox node has three ports; two of the ports are HSR ports, and the third port is an Ethernet port that any SAN device, such as a PC, can be plugged into to engaged with the HSR network. The RedBox node forwards the frames over the HSR network like any other HSR node and it acts as a proxy for all the SANs that access them. To this effect, they 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 the HSR nodes.
4) A quadruple port device (QuadBox node) has four HSR ports, and 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; it also does additional tasks, such as multicast filtering and virtual local area network (VLAN) filtering.

The HSR protocol has some issues with some the types of traffic and some network topologies as follows noted below [6].

A. Unicast Traffic Issues

The HSR protocol has no issues with unicast traffic inside a ring topology. In other closed-loop networks, the duplicated frame copies of the sent frames will be spread out across most of the links and nodes of the network due to the duplication of the HSR process at each QuadBox node [11]. This might cause traffic congestion or a delay if several data streams are transmitting simultaneously. However, eventually, the duplicated copies will be removed from the network and only one copy will be used by the destination node.

B. Multi/Broadcast Traffic Issues

1) Ring Topology

In ring topology, the duplicated frame copies are circulated inside the ring until the frames reach the source node, which then removes them from the ring.

The advantage of the duplicated frames is that they ensure that each node will receive at least one copy of the sent frame, especially if there is a fault in one of the ring components. However, if the ring is healthy, or fault-free, then each node will receive two copies of the sent frame, one from each direction. The node will accept the first frame that reaches it and discard the second frame. In this case, half the ring bandwidth will be wasted due to the duplicated frame copies, which will account for about 50% of the total frames. Note that these are unnecessary redundant frames, that will later be removed from the ring.

2) Other Closed-Loop Networks

The situation here is similar to that of unicast traffic within closed-loop networks, but it is more complicated because many duplicated frame copies will be generated, spread out, and then removed, which means that more network bandwidth will be consumed.

Ⅲ. Proposed Network Topologies

In this section, we propose three network topologies that provide redundancy capabilities for the automobile network.

1) Single Ring Topology

In the single ring topology, the basic idea of a switched Ethernet network is divided by each function field using different protocols and it is been translated into an Ethernet by application layer gateway[1][2]. To engage the Ethernet with the HSR protocol, the gateways is connected through a backbone single ring using the HSR protocol. In this case, the RedBox node is used in front of each Ethernet gateway in order to connect it to the HSR ring as shown in Figure 1, because the gateways are Ethernet-based. However, this topology will only provide redundancy for the HSR ring part; it will not provide redundancy for the entire network.

2) Double Ring Topology

The single HSR backbone topology can't provide full redundancy capability if a link at an end node has failed. Therefore, we propose using the full HSR protocol system for the automobile network, including all of its nodes. In that case, the automobile nodes behave like DANH nodes. The entire network, not just the backbone network, uses the HSR protocol. Therefore, the ECUs or end nodes in the network will work like a DAHN node. Figure 2 shows one of these cases , the double ring topology, in which two rings are divided and connected using the QuadBox node[5].

Each ring can be separated in different ways depending on the specific need or purpose. For instance, the critical and non-critical data ring can be divided to manage data traffic.

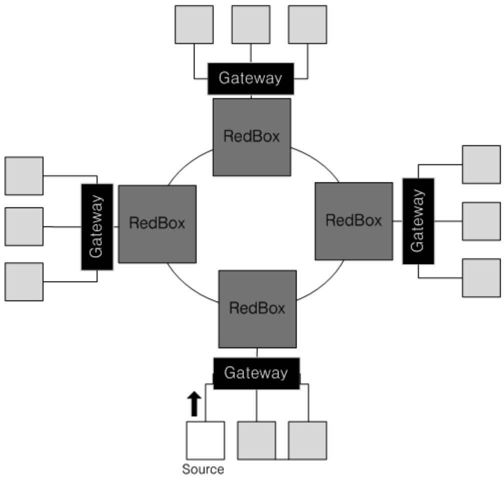


Figure 1. The HSR Backbone Ring

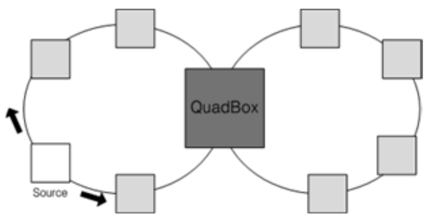


Figure 2. The HSR Double Ring

3) Backbone Ring with Sub-rings topology

The backbone ring with sub-rings is also a full HSR network topology system. In this type of system, we propose using four sub-rings connected to a backbone ring as shown in Figure 3. Each sub-ring will connect a certain type of automobile device based on its function. These rings are: Powertrain, Chassis, Body, and Infotainment/ Drive Assist. Redundancy will be available in each ring. The frames can move to another field through the QuadBox. In this case, we can provide redundancy capability with the sub-rings and the backbone ring.

Ⅳ. Analytical Traffic Analyses

The network traffic under the standard HSR protocol can be determined analytically as follows [6]:

$$T_{SH} = \sum_{i=1}^{N} 2(F \times L) \quad (1)$$

where N is the total number of network nodes that are sending simultaneously, L is the total number of network links, and F is the total number of the sent frames per for each sending node. The number 2 represents the number of frames that are passing by each network link, one in each direction.

To improve the traffic performance of the HSR protocol, the QR and VRing approaches are applied to each of three topologies that were discussed in Section Ⅲ. Thereafter, the traffic under the QR approach and the VRing approach is estimated as described below:

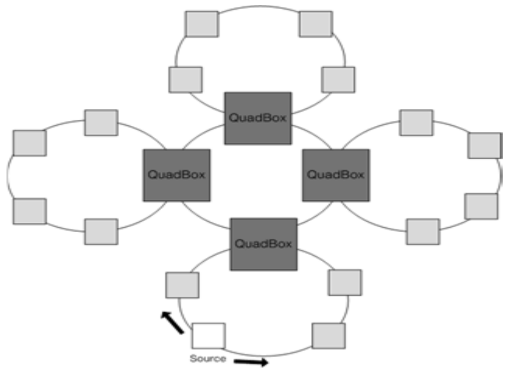
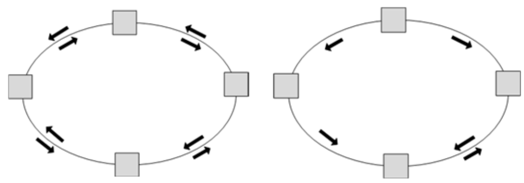


Figure 3. The HSR Backbone with The HSR Sub-ring



(a) Standard HSR (b) QR approach

Figure 4. QR approach

A. The Quick Removing(QR) Approach

The idea of the quick removing(QR) approach is to remove the duplicated frame copies from the network when all the nodes have received one copy of the sent frame and they begin to receive the second copy. In other words, if a frame copy has been passed earlier through a certain node, then it will be deleted and removed from the network if it has passed again through the same node-(Figure 4).

The network traffic under the QR approach (T_{QR}) can be determined analytically as follows [6]:

1) Multi/Broadcast Traffic

$$T_{QR} = \sum_{i=0}^{R} (2(Roundup(\frac{N}{2}) \times F) + A \quad (2)$$

where ***R*** is the number of rings and, A is a parameter that is equal to 1 if the number of the node rings is even; otherwise it is equal to zero.

2) Unicast Traffic

$$T_{QR} = \left\{ \sum_{i=0}^{R-1} (2(Roundup(\frac{N}{2}) \times F) + A \right\} + m \quad (3)$$

where m is the number of nodes in the destination ring.

B. The VRing Approach

Automobile nodes are fixed when they are installed in their structures and their tasks are predictable. Because of this characteristic, the VRing can be a suitable and easy approach to use in an automobile network. The idea is very simple and it depends on creating virtual ring among the nodes that usually communicating with each other. This will guide the sent frame inside that virtual ring instead of separating them through all the network links and nodes, as occurs in the standard HSR protocol. To implement the VRing, we propose two methods. The first method is to use a special flag inside each sent frame in order to enable each QuadBox node to read that flag and then make the proper decision for forwarding that frame to the proper output port that leads to the destination node. The details of this idea are described in [11]. The other approach is to establish a table inside the QuadBox node that depends on the source and the destination MAC addresses, in addition to the input and the output port for each established VRing [6].

In this second, the network traffic can be determined as follows:

$$T_{Qca} = m \quad (4)$$

if the destination and the source node are in the same ring (Figure 5).

$$T_{Qca} = \left[\sum_{i=0}^{R-1} (2N_i) \right] + m \quad (5)$$

if the destination and the source nodes are located in different rings (Figure 6).

V. Performance Evaluation

Traffic simulation for the HSR protocol, QR, and VRing is accomplished for each of the three topologies. For this purpose, OMNeT++v4.2.2 [13] is used. The following scenarios are adopted for the simulation:

A. Scenario 1

In this scenario, an HSR node that is connected to a RedBox through a gateway (Figure 1) has broadcasted a single frame. In addition, the number of the RedBox nodes gradually increases under this scenario until it reaches 32 nodes. Figures 7 and 8 show the network traffic and the reduction percentage for this scenario.

B. Scenario 2

An HSR node that connected to one of the two HSR rings in Figure 2 has broadcasted a single frame. However, the number of the DANH nodes is gradually increase until reach 32 nodes in each ring. Figure 9 and 10 shows the network traffic and the reduction percentage for this scenario.

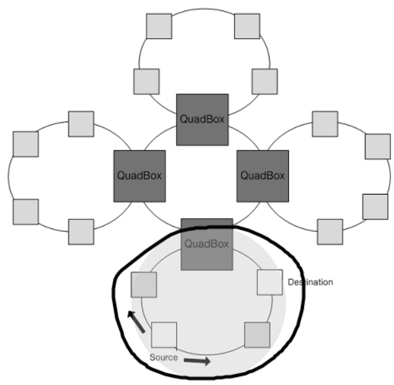


Figure 5. The VRing Approach–Source and Destination Nodes in the Same Ring

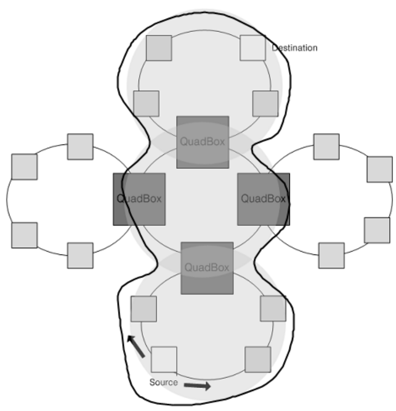


Figure 6. The VRing Approach–Source and Destination Nodes in Different Rings

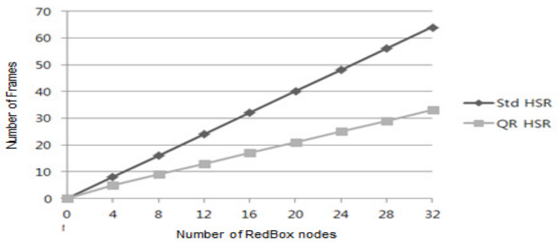


Figure 7. Network traffic in Topology 1 (Multi/Broadcast)

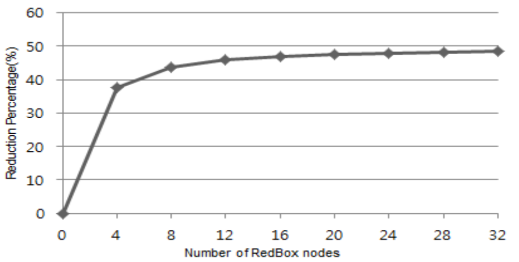


Figure 8. Reduction Percentage in the Topology 1 (Multi/Broadcast)-Only QR Approach

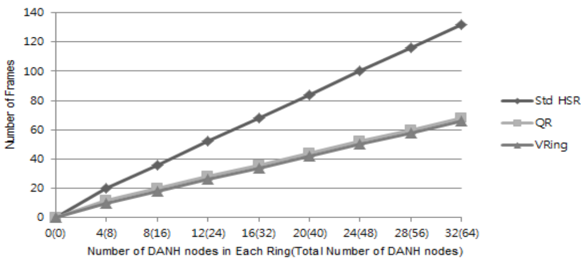


Figure 9. Network Traffic in Topology 2 (Multi/Broadcast)

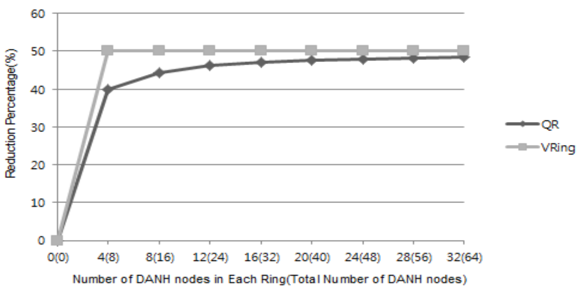


Figure 10. Reduction Percentage in Topology 2 (Multi/Broadcast)

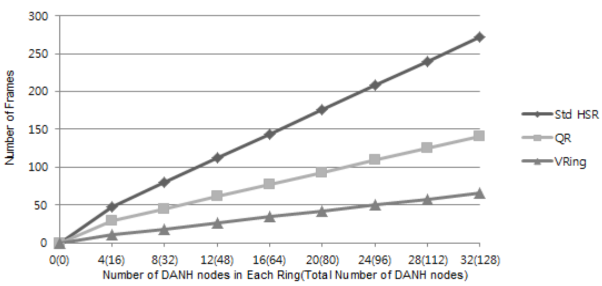


Figure 11. Network of Traffic in Topology 3 (Multi/Broadcast): Source and Destination Nodes in the Same Ring

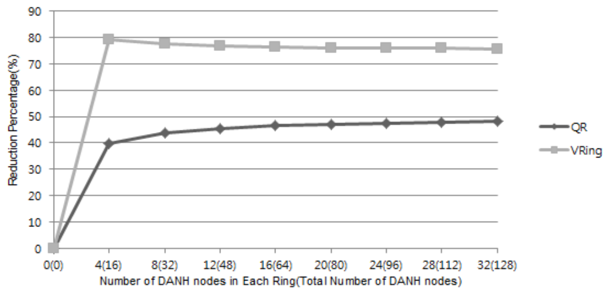


Figure 12. Reduction Percentage in Topology 3 (Multi/Broadcast): Source and Destination Nodes in the Same Ring

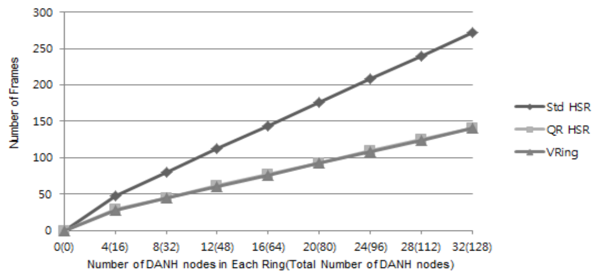


Figure 13. Network of Traffic in Topology 3 (Multi/Broadcast): Source and Destination Nodes in Different Rings

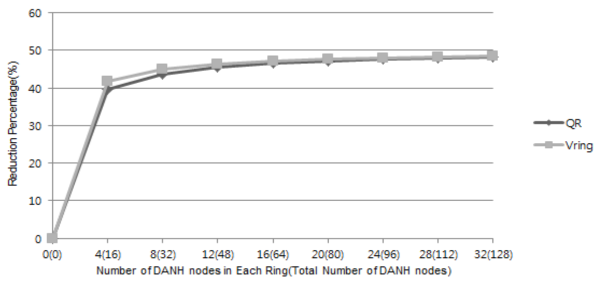


Figure 14. Reduction Percentage in Topology 3 (Multi/Broadcast): Source and Destination Nodes in Different Rings

C. Scenario 3

An HSR node that is connected to one of the two HSR rings (Figure 3) has broadcasted a single frame. The number of DANH nodes gradually increases until it reaches 32 nodes in each ring. Figures 11, 12, 13, and 14 show the network traffic and the reduction percentage for this scenario.

As seen in the information in the figures presented above, the network traffic and the reduction percentage under the VRing approach always perform better than the standard HSR protocol and the the QR approach. By the way, QR approach is only applied to topology 1 because it only has one ring and it will be useless to apply the VRing approach on to a single ring.

The reduction percentage for the network traffic under the simulation process is ranged from 48% to 75% in comparison to the HSR protocol. For the topology 3 case, the results show that the network traffic was close to 25% when compared to the standard Ethernet scheme that is currently used in automobile networks.

Ⅵ. Conclusion

In this paper, we have proposed three automobile network topologies using the HSR protocol in order to achieve seamless recovery. QR and VRing approaches were also applied to these proposed topologies to improve the HSR traffic performance. The OMNeT++ simulation was used to simulate these approaches under the three proposed topologies.

Based on the result obtained from scenarios, the network traffic reduction ranged from 48% to 75% compared to the standard HSR protocol. This means that the redundant traffic can be limited when the HSR protocol is used in an automobile instead of the Ethernet network. If the HSR protocol is used in automobile networks, the network will experience about a 25% over load as compared to the standard Ethernet, but it will provide seamless recovery that the Ethernet can not offer. However, during the simulation experiments, we only selected multi/broadcast traffic because it is more important than unicast traffic and it has more of an effect on the network.

In future work, more practical topologies should be simulated under various situations and other parameters besides network traffic should be taken into consideration in order to obtain an optimal solution for an automobile network that provides high reliability and availability.

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<관심분야> : Military Communication, Fault Tolerant System, Ubiquitous Network

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