

An Enhanced DAP-NAD Scheme for Multi-hop Broadcast based on MIL-STD-188-220 Networks

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Abstract— In this paper, we propose an enhanced DAP-NAD scheme for multi-hop broadcast based on MIL-STD-188-220 networks. MIL-STD-188-220 is a key factor for real-time communication in the battlefield. We define it as “Multi-hop Broadcast” that a source station transmits a message to all stations in multi-hop wireless networks. The multi-hop broadcast schemes as defined in the standard cause a lot of unnecessary delays. This is because they do not suggest the algorithms about an optimal selection of relay stations for multi-hop broadcast. Furthermore, no priority of network access opportunity is given to these relay stations over DAP (Deterministic Adaptable Priority)– NAD (Network Access Delay). To solve this problem, we adopt the concept of MPR (Multi-Point Relay) and modify the mechanism of DAP-NAD based on the topology information. The proposed scheme is thoroughly examined by simulation method. The results show that complete time of multi-hop broadcast becomes significantly shorter than the time in conventional scheme. This improves the performance of MIL-STD-188-220 based on military systems.

Keywords—MIL-STD-188-220; multi-hop; DAP-NAD; broadcast; Multi-Point Relay; tactical; military

I. INTRODUCTION

In current battlefield, the most important combat power is communication because it can interconnect all the other combat units which are scattered over the theater. Especially, it is very important to communicate seamlessly with all combat units. Actually, combat units in the battlefield communicate with Combat Net Radio (CNR) to be synchronized with operation. MIL-STD-188-220 is a protocol based on CNR to support data communication in the battlefield. In other words, MIL-STD-188-220 is a key factor for communication in the battlefield. This standard has been widely used in data communication among Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems. The physical, data-link and network layers of OSI-7-layers are described in MIL-STD-188-220. The commercial protocols are used for the higher layers. The main parts described in the standard are data-link and network layers [1]. The data-link layer has MAC protocol which is related to single-hop communication. This is implemented by 6 different NAD (Network Access Delay) mechanisms. Among the 6 NAD schemes, R (random)-NAD and DAP- (Deterministic Adaptable Priority) NAD are mandatory. DAP-NAD has been known as the most effective and popular NAD scheme [2]. The network layer introduces

Limited flooding and Source Directed Route (SDR) schemes for multi-hop communication [1].

The key focus of this paper is the performance enhancement of DAP-NAD in multi-hop networks. Among many types of tactical messages, the urgent SA (Situational Awareness) messages should be diffused up effectively to all combat units because these include critical information such as the warning of nuclear attack. We define it as “Multi-hop Broadcast” that a source station transmits a message to all stations in multi-hop wireless networks. The multi-hop broadcast schemes as defined in the standard cause a lot of unnecessary delays. This is because they do not suggest the algorithms about an optimal selection of relay stations for multi-hop broadcast. Furthermore, no priority of network access opportunity is given to these relay stations over DAP-NAD.

So far, many papers have conducted study on NAD scheme to improve the performance of DAP-NAD. Most papers which are related with DAP-NAD have dealt with single-hop networks [3-6]. Regardless DAP-NAD, several papers have dealt with multi-hop networks [7-10]. In [7], authors suggested an effective traffic control scheme to reduce duplicate transmission of end-to-end ACK between data link and intranet layers in multi-hop networks. However, this scheme did not use DAP-NAD but R-NAD. [8] presented the limitation of multi-hop communication based on MIL-STD-188-220 networks. The author in [8] mentioned the importance of specific definition about routing and forwarding. In [9], authors discussed about an effective SDR scheme which is defined in MIL-STD-188-220D. However, they just suggested simple algorithms and did not evaluate the performance. [10] presented the design and modeling by using OPNET tool, and measured the performance in terms of adequate number of stations and hop counts over R-NAD and DAP-NAD. However, the authors did not consider limitation of multi-hop broadcast and just focused on OPNET modeling. Thus, previous papers did not analyze the limitation of multi-hop broadcast and suggest any technical solutions over DAP-NAD.

To solve this problem, we adopt the concept of Multi-Point Relay (MPR) [11] and modify the mechanism of DAP-NAD based on the topology information. A source station with an urgent SA message selects relay stations through the

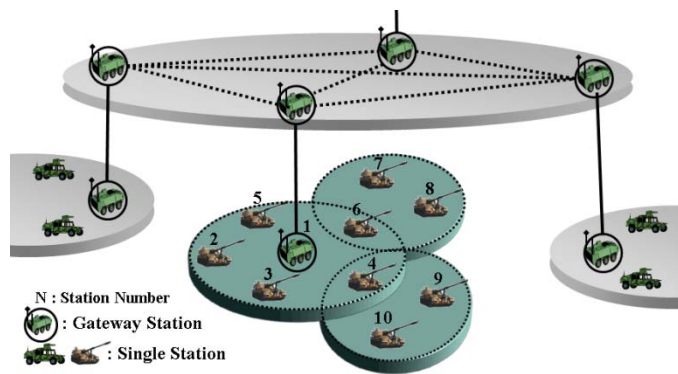


Fig. 1. An example of tactical communication structure

topology information and only these relay stations are assigned to address field. The network access opportunity is given to only relay stations over DAP-NAD. The proposed scheme is thoroughly examined by simulation, and the results show that complete time of multi-hop broadcast becomes significantly shorter than the time in conventional scheme.

The rest of this paper is organized as follows. In Section II we introduce the MIL-STD-188-220 and the problem statement. In section III, the proposed scheme is detailed. In section IV, we evaluate the proposed scheme with simulation models. Finally, a conclusion is presented in section V.

II. BACKGROUNDS

A. Overview of MIL-STD-188-220

The main parts described in the standard are data-link and network layers [1]. First, the data-link layer has MAC (Medium Access Control) protocol which is implemented by 6 different NAD mechanisms. Among the 6 NAD schemes, R (random)-NAD and DAP- NAD are mandatory. DAP-NAD has been known as the most effective and popular NAD scheme because there is the mechanism for QoS guarantee [6]. In DAP-NAD, both message and network precedence (NP) are divided into three priorities. They are urgent, priority and routine. First Station Number (FSN) signifies the station number which is to have the first network access opportunity at the next net access period. After a transmission, FSN increases by one. The standard utilizes four Types of operation modes for packet transmission. Among them, Type 1 (unacknowledged connectionless operation mode) and 3 (connectionless and coupled ACK operation mode) are mandatory. Second, the network layer has a function to keep the topology information and obtain the optimal data transmission path through the topology update by the conditions of topology update triggers. In other words, this layer is defined for multi-hop communication. For this, there are two mandatory schemes. One is Limited flooding scheme, which is used when the topology information is not known. The other one is Source Directed Route (SDR) scheme, which is used when the topology information is known.

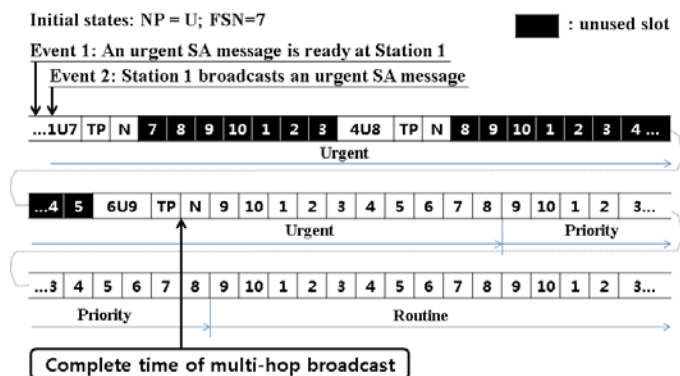


Fig. 2. An example of NAD procedure in conventional scheme

B. Problem Statement

Current tactical communication environment requires multi-hop communication rather than single-hop because combat units are deployed not in plain areas which have LOS environments, but in urban and mountainous areas which have NLOS environments in the battlefield. Thus, every combat unit should communicate effectively with each other in multi-hop environments. Every combat unit exchanges many tactical messages to be synchronized with operation. Among these, the urgent SA (Situational Awareness) messages should be diffused up effectively to all combat units because these include critical information such as the threat arising from the enemy attack of Chemical, Biological, Radiological and Nuclear (CBRN) weapons. If the critical information is not warned and diffused up to all combat units rapidly, the friendly forces are damaged seriously from the absence of no protection readiness. A station represents a combat unit equipped with combat net radio device. There are two kinds of stations as shown in Fig. 1. It shows a hierarchical structure in the tactical networks. The single station with single radio communicates with other stations in its own subnetwork. The gateway station with multi radio communicates with the upper echelon network and its own subnetwork at the same time. It receives urgent SA messages from the upper echelon network and then broadcast them to its own subnetwork.

There are two multi-hop broadcast schemes mentioned before [1]. Firstly, Limited flooding scheme shall be implemented by Global group multicast address in the intranet header. This causes a lot of unnecessary traffic because all neighbors rebroadcast the messages. Secondly, SDR scheme provides a simple non-dynamic procedure based on the topology information, and shall be implemented by all destination & relay address based on the topology information for multi-hop broadcast. These addresses are specified as the destination/relay address field in the intranet header. This scheme is more effective than Limited flooding because it uses the topology information. Only relay stations rebroadcast messages. However, SDR scheme does not suggest the algorithms for an optimal selection of relay stations for multi-hop broadcast. Furthermore, no priority of network

Table I - List of symbols

Symbol	Description
N_k^h	Set of h -hop neighbor stations of station k
M_k	Set of MPR stations for station k
DR_{IH}	Set of Destination/Relay Address field value in Intranet Header
$X(m)$	m^{th} element of set X
S_{DL}	Source address in Data Link frame address
MPR_{IH}	MPR field value in Intranet Header
A_l	Address of station l

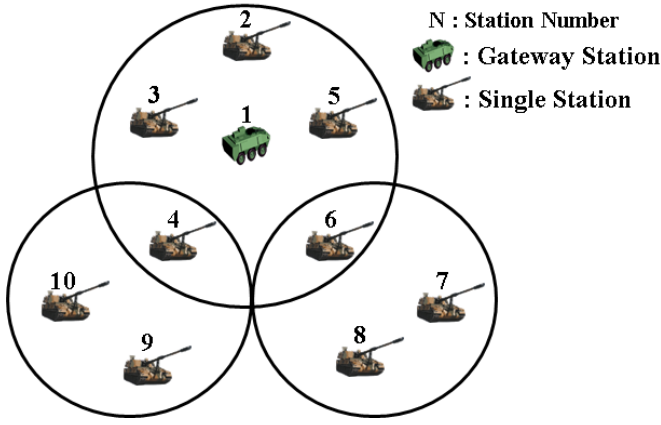


Fig. 3. System model

access opportunity is given to these relay stations over DAP-NAD. In other words, FSN just increases by 1 over DAP-NAD in SDR scheme regardless of relay stations. For example, there is the subnetwork depicted in Fig. 1. We assume the case in which an urgent SA message is ready at station 1 by using SDR scheme, and other traffic does not occur. The initial NP is an urgent and FSN is 7. Fig. 2 shows the multi-hop broadcast procedure over DAP-NAD. The unused slots are, which are depicted in block boxes, cause unnecessary delays. If data traffic is generated in unused slots and the number of stations is increased, complete time of multi-hop broadcast will be delayed seriously. Therefore, we suggest the algorithm about an optimal selection of relay stations in order to prevent duplicate rebroadcast, and the scheme where priority of network access opportunity is given to the relay stations over DAP-NAD.

III. PROPOSED SCHEME

We propose a mechanism that ensures effective multi-hop broadcast of SA messages by lessening the aforementioned problem. For this, we adopt the concept of MPR [11] and modify the mechanism of DAP-NAD based on the topology information. Here we provide some definitions that will be used later in this paper. The list of symbols used is presented in Table I.

A. System Model

We regard Fig. 3 as a system model. This model consists of 3 subsets in the subnetwork. The total number of stations is 10. Station 1 represents the gateway station. It broadcasts urgent SA messages periodically. All stations except for station 1 represent the single stations. MPR stations represent the relay stations selected at the minimum for multi-hop broadcast. Urgent SA message represents the time-critical message which requires rapid multi-hop broadcast. We assume that all stations maintain correct topology information through exchange of topology update messages. The size of the urgent SA message is exactly the same. All routing path has same cost and quality. We define it as MPR_{IH} that the 4 bits field was spare in the middle of intranet header therefore there is

no additional overhead. It is depicted in Fig. 4. . For the dissemination of FSN, every urgent SA message uses type 3 because two-hop neighbors from the source station can recognize who MPR stations are and when their network access opportunity is through the ACK of type 3. It is a kind of response from one-hop neighbors.

B. Multi-hop Broadcast Algorithms

The proposed scheme consists of 2 algorithms. In the algorithm 1, when station k has an urgent SA message, it selects MPR stations and modifies DAP-NAD. The algorithm 2 is a procedure where station l receives an urgent SA message.

Firstly, the procedure of algorithm 1 is as follows.

- Step 1 - Source station k selects one-hop neighbors from station k as MPR stations which are the also one-hop neighbors of two-hops neighbors from station k simultaneously.
- Step 2 - It minimizes the number of MPR stations to prevent duplicate rebroadcast.
- Step 3 - These selected MPR stations are assigned to the Destination/Relay Address field in the intranet header.
- Step 4 - One is assigned to MPR_{IH} . This means that this message is Multi-hop broadcast. MPR_{IH} gives MPR stations the priority of networks access opportunity over DAP-NAD.

Secondly, the procedure of algorithm 2 is as follows.

- Step 1 - Station l checks MPR_{IH} when it receives a message. If MPR_{IH} has the value as one, this is an urgent SA message.

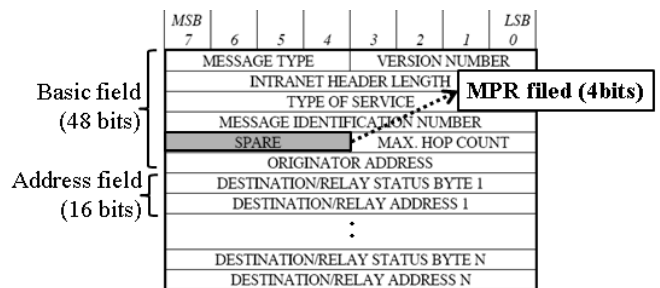


Fig. 4. Modified MPR field in the Intranet header

- Step 2 - If $DR_{IH}(c)$ is the same as S_{DL} , $DR_{IH}(c + 1)$ is considered as the FSN and the existing FSN does not increase but just it is saved.
- Step 3 - If $DR_{IH}(c + 1)$ does not have the same address of station l , it just receives a message.
- Step 4 - If $DR_{IH}(c + 1)$ has the same address as station l and is not the last Destination/Relay Address field value, station l rebroadcasts the message.
- Step 5 - If $DR_{IH}(c + 1)$ has the same address as station l and is the last Destination/Relay Address field value, zero is assigned to MPR_{IH} and then station l rebroadcasts the message. Finally, multi-hop broadcast is completed and DAP-NAD is operated with existing FSN.

Note that in case of broadcast beyond two-hop, MPR stations, which are one-hop neighbors of the original source station, select 2-hop neighbors which are the original source station, as its own MPR stations. Thus, the broadcast of urgent messages are progressed through this process over multi-hop networks beyond two-hop.

C. Operation Scenario

For the understanding of the proposed scheme, a simple example is introduced. There is the subnetwork which is the same as the system model in the Fig. 3. We assume the case in which an urgent SA message is ready at station 1, and other traffic does not occur. This case is the same one mentioned in section II. Fig. 5 shows the DAP-NAD procedure comparison between the conventional and proposed schemes. The procedure of the proposed scheme is as follows.

Firstly, there is a procedure for a source station. Station 1 should select MPR stations. M_1 , which represents a set of MPR stations for station 1, means $\{\omega \in N_m^1 | m \in N_1^1 \text{ and } \omega \in N_1^2\} = \{4, 6\}$. Station 1 minimizes $|M_k|$ without overlap. MPR field value is assigned to one and MPR stations are assigned to the Destination/Relay Address field in the intranet header, and then station 1 broadcasts an urgent SA message.

Secondly, there is the procedure for MPR stations. For station 4, because MPR_{IH} value received from station 1 is one, this message is an urgent SA message. Next, since address of station 1, which is source address in the data link frame address, is same as $DR_{IH}(0)$ (Originator address in the Intranet header), $DR_{IH}(1)$ is considered as the FSN and the existing FSN(7) does not increase but just it is saved. Station 4 rebroadcasts the message because $DR_{IH}(1)$ has the same address as station 4 and is not the last Destination/Relay Address field value. For station 6, $DR_{IH}(2)$ is considered as the FSN because address of station 4, which is source address in the data link frame address, is the same as $DR_{IH}(1)$. Since $DR_{IH}(2)$ has the same address as station 6 and is the last Destination/Relay Address field value, zero is assigned to MPR_{IH} and then station 6 rebroadcasts the message. The multi-hop broadcast for station 1 is completed. The other stations which are not MPR stations only receive the message.

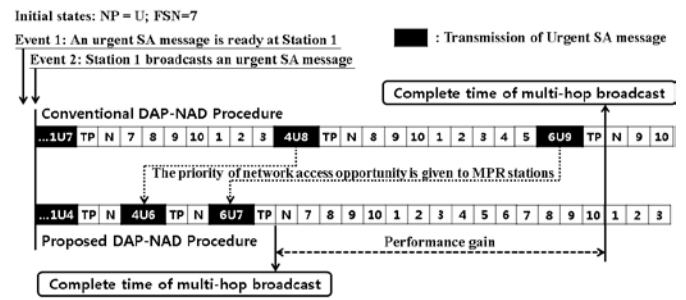


Fig. 5. An example of DAP-NAD procedure comparison between the conventional and proposed schemes

Consequently, the complete time of multi-hop broadcast becomes significantly shorter than the time in conventional scheme. The proposed scheme reduces unnecessary delays, which are depicted in black boxes in Fig. 2. In other word, the multi-hop broadcast in the proposed scheme becomes shorter to the performance gain in Fig. 5.

IV. PERFORMANCE EVALUATION

A. Simulation Environments

The proposed scheme and the compared conventional scheme are implemented via the simulation to verify the performance. We used the MATLAB simulator, and Table II summarizes the important MAC parameters of MIL-STD-188-220D used to obtain the simulation results. EPRE represents the time for transmission initialization. ELAG represents the time interval for transmitting data from the Data Circuit-terminating Equipment (DCE) of a node to the DCE of the other station. PHASING represents the time for transmitting synchronization signal. DTEACK represents the time for generating a DL (Data link) ACK. TURN represents the time for changing transmission/reception mode. DTEPROC represents the time interval between the reception of a data frame and the next transmission. DTETURN represents the time for changing a state from stand-by state to transmission state. TOL represents the tolerance time. NBDT represents the time for sensing data signals delivered from other node. S represents the time for transmitting a DL ACK whose length is applying FEC/TDC. DATA RATE represents the transmission rate of radio transceivers in term of PHY layer. These values are based on the previous papers [2-7]. We use the traffic model from [2-3]. MPs are urgent, priority and routine MPs. These are generated by the Poisson distribution.

Table II – Simulation Parameter Values

Parameter	Value	Parameter	Value
EPRE	40 msec	DTEACK	25 msec
ELAG	278 msec	DTEPROC	25 msec
PHASING	2 msec	DTETURN	10 msec
TURN	395 msec	B	32 msec
TOL	50 msec	NBDT	400 msec
DATA Rate	4,800 bps		

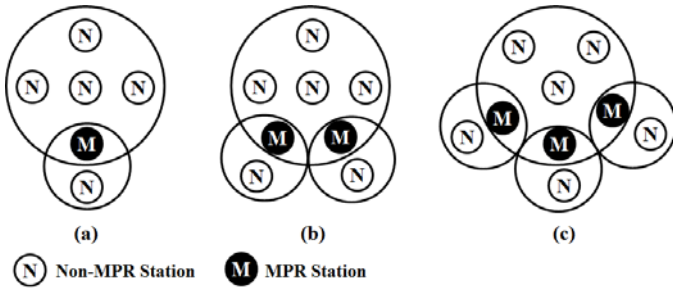


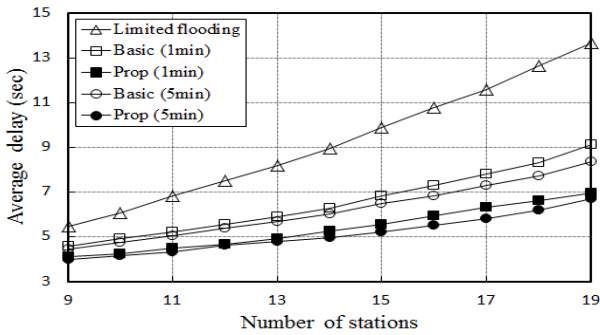
Fig. 6. Examples of simulation model

We regard Fig. 6 as a simulation model. N means a set of non-relay stations, and M means a set of MPR stations. The gateway station which broadcasts urgent SA messages belongs to N . For example, Fig. 6(a) shows the model which consists of 2 subsets. The number of non-relay stations, which is same as $|N|$, is 5. The number of MPR stations, which is same as $|M|$, is 1. Thus, the total number of stations, which is same as $|N \cup M|$, is 6. In Fig 6(c), the system model consists of 4 subsets. The number of non-relay stations is 6. The number of MPR stations is 3. The total number of stations is 9. For the performance evaluation of multi-hop environment, we consider various cases based on the simulation model. The number of stations varied from 9 to 19 because the modeled network is a company size net considering of the feasibility. We represent the conventional scheme (SDR) as the Basic, and the proposed one as the Prop.

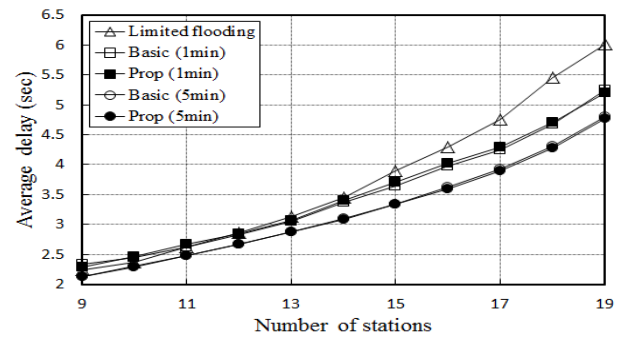
B. Average Delay

Exchange of topology update messages is essential to maintain correct topology information for multi-hop broadcast. However, this causes additional traffic as overhead. We consider that topology update messages have an urgent precedence, and they are generated by each station periodically. The case 1 implies that $|M|$ becomes fixed as 2, and $|N|$ whose initial value is 7 increases by one, and the interval time, when topology update messages are generated by each station, is changed into one and five minutes. Fig. 7(a) shows the variations of the average delay of Urgent SA messages which mean multi-hop broadcast delays, and Fig. 7(b),(c),(d) show the variations of the average delays of Urgent, Priority and Routine messages which mean single-hop delays.

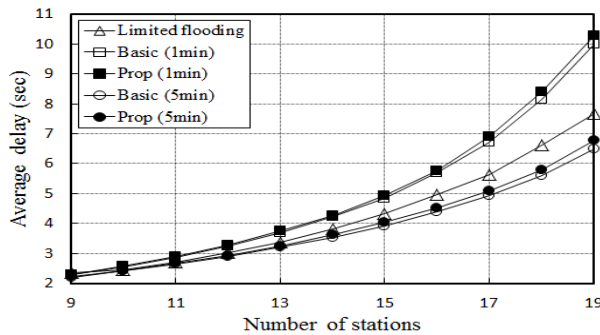
Firstly, we compare the average delays of 3 types of schemes which are Limited flooding, SDR and proposed scheme according to the interval time when topology update messages are generated by each station. Regarding the delays of Urgent SA and Urgent messages, the performance of SDR and proposed schemes are better than Limited flooding scheme regardless of the interval time. Regarding the delay of Priority and Routine messages, the average delay of Limited flooding scheme is longer than SDR and proposed schemes when the interval time is five minutes. However, it is shorter than SDR and proposed schemes when the interval time is one minute. These results show that short interval time improves the performance of high precedence messages but degrades the performance of low precedence messages. As a result, total system performance degrades as shown in Fig 8. Therefore, we adopt the interval time as five minutes.



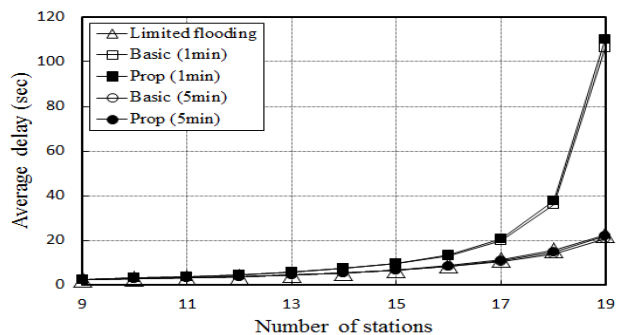
(a)



(b)



(c)



(d)

Fig. 7. Average delay of (a) Urgent SA messages, (b) Urgent messages, (c) Priority messages, (d) Routine messages

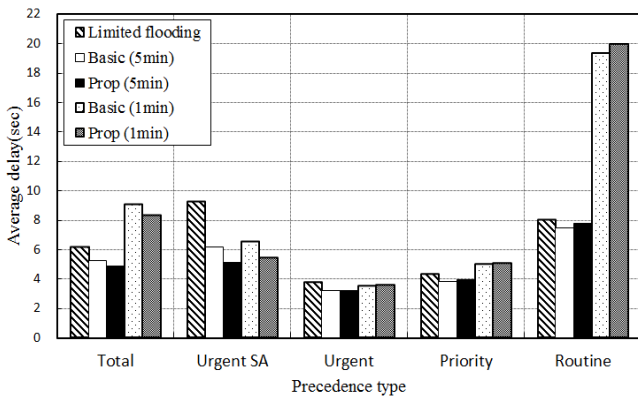


Fig. 8. Total average delay according to interval time

Secondly, we compare the average delay between SDR and proposed scheme fixed to the interval time as five minutes. Regarding the delay of Urgent SA message, the performance of the proposed scheme is better than the conventional scheme. This is because there is the performance gain, which means FSN jumps to MPR stations directly. The performance of Urgent message is little different between proposed and conventional scheme. However, the delays of Priority and Routine messages of the proposed scheme are slightly longer than the conventional scheme. This is because network access opportunity is given additionally to MPR stations over modified DAP-NAD. Nevertheless, this is a minor effect compared to the improvement of the total system performance of the proposed scheme as shown in Fig. 8. In this figure, total average delay of the proposed scheme (5min) is shortest among them.

The case 2 implies that $|N|$ whose initial value is 17 decreases by one, while $|M|$ whose initial value is 2 increases by one, simultaneously. Fig. 9 shows the average delay of Urgent SA message according to the number of MPR stations. The performance of the proposed scheme is better than the conventional scheme. However, as the number of MPR stations increases, the performance gap between the proposed and conventional schemes decreases. This is because as the number of MPR stations increases, the performance gain, which means FSN jumps to MPR stations directly, decreases.

V. CONCLUSIONS

In this paper, we have proposed the enhanced DAP-NAD scheme for multi-hop broadcast based on MIL-STD-188-220 Networks. In the proposed scheme, we adopt the concept of MPR and modify the mechanism of DAP-NAD based on the topology information. The proposed scheme is thoroughly examined by simulation method, and the results show that complete time of multi-hop broadcast becomes significantly shorter than the time in conventional scheme. This improves the performance of MIL-STD-188-220 based military systems. However, the proposed scheme should be applied adaptively by the condition of networks because the additional overhead

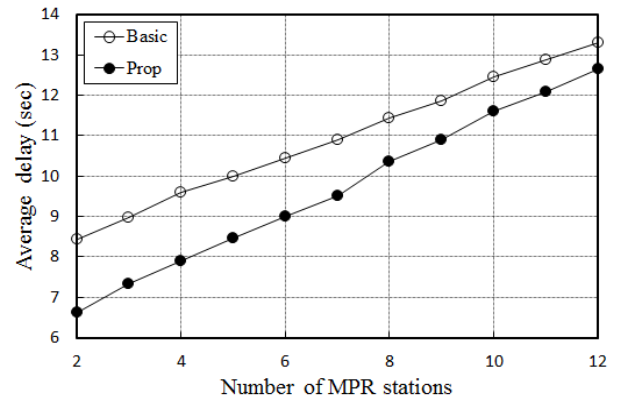


Fig. 9. Average delay for varying the number of MPR stations

derived from exchange of topology update messages affects the total system performance significantly.

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