

Additional Bump Slot Allocation Scheme for QoS guarantee of Urgent Messages in TDMA-based Tactical Wireless Networks

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Abstract— In this paper, we propose an additional bump slot allocation scheme for QoS (Quality-of-Service) guarantee of urgent messages in TDMA-based Tactical Wireless networks. MIL-STD-188-220 is the most typical ad-hoc protocol based on military networks. The key focus of this paper is the performance enhancement of DAP-NAD for QoS guarantee of urgent messages which means the highest MP (Message Precedence). In the battlefield, QoS of urgent messages should be guaranteed because these require real-time and reliable transmissions, and QoS guarantee for these messages affects achievement of military operation, significantly. This scheme can prevent the case where the priority messages are transmitted in advance in compared to urgent messages over DAP-NAD. We define this case as “QoS violation”. To solve this problem, we analyze the case in which QoS violation occurs, and modify the mechanism of the conventional DAP-NAD by inserting an additional bump slot. The proposed scheme is thoroughly examined by simulation method. The results show that the variation of QoS violation according to the number of stations and interval of generation ratio of urgent messages. Consequently, the average delay of urgent messages derived from QoS violation in the proposed scheme becomes shorter than that in conventional scheme.

Keywords— MIL-STD-188-220, DAP-NAD, bump slot, QoS

I. INTRODUCTION

The changes of the future battlefield paradigm can be outlined as NCW (Network Centric Warfare). Thus, it is very important to communicate seamlessly with all the other combat units. MIL-STD-188-220 is a tactical wireless protocol based on CNR (Combat Net Radio) to support data communication in tactical edge. This standard is the interoperability Standard for Digital Message Transfer Device Subsystems (DMTDs) of U.S DoD (Department of Defense). This standard has been widely used in data communication among Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) systems [1-2]. The physical, data-link and network layers of OSI-7-layers are handled in the standard. The commercial protocols are used for the higher layers. Among the layers handled in the standard, the data-link layer is the largest part of the protocol. The data-link layer has MAC (Medium Access Control) protocol which is implemented by 6 different NAD (Network Access Delay) mechanisms. Among the six

NADs, P (Prioritized)-NAD, DAP (Deterministic Adaptable Priority)-NAD, and DAV (Data and Voice)-NAD support QoS (Quality-of-Service) by using three Message Precedences (MPs) according to the traffic types, and 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 [2].

The key focus of this paper is the performance enhancement of DAP-NAD for QoS guarantee of urgent messages which means the highest MP. In DAP-NAD, the message and network precedences are both divided into three precedences. They are urgent, priority and routine. To support QoS of urgent messages, only these messages can be transmitted when network precedence is an urgent precedence, and the bump slot, which is inserted after every transmission, can be access the channel and transmit its message by any station with an urgent message. However, there is the case in which QoS of urgent messages is not guaranteed over DAP-NAD. In other words, this means the case where priority messages are transmitted in advance in compared to urgent messages over DAP-NAD. We define this case as “QoS violation”.

So far, several papers have conducted study on NAD scheme based on this standard to improve the performance of DAP-NAD. In [3] and [4], a way to send voice packet as an urgent precedence using DAV-NAD is proposed. In [3], DAV-NAD was suggested through increasing the hit rate of FSN over DAP-NAD. [4] presented enhanced DAV-NAD scheme through cyclic jump scheme. It was called as DAP-NAD-CJ. In [5] and [6], authors proposed the scheme for enhancement of multicast transmission over DAP-NAD-CJ. In this scheme, the network access opportunity is given to the stations with multicast messages by inserting additional slots. These schemes reduced unused slots as the hit rate of FSN (First Station Number) was increased. However, these schemes do not suggest any technical solution to prevent QoS violation of urgent messages. Therefore, we analyze the case in which QoS violation occurs, and suggest an additional bump slot allocation scheme for QoS guarantee. In the proposed scheme, we modify the mechanism of the conventional DAP-NAD by inserting an additional bump slot.

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

II. BACKGROUNDS

A. Network Access Control in MIL-STD-188-220

MIL-STD-188-220 standard specifies protocols in multiple layers for wireless tactical communication devices. The medium access method in MIL-STD-188-220 is named as Network Access Control (NAC). NAC is a carrier sense-based channel access method and includes six Network Access Delays (NADs), which defines the details how long each station has to wait to access channel. 6 NADs are R (Random)-NAD, P (Prioritized)-NAD, H (Hybrid)-NAD, RE (Radio Embedded)-NAD, DAP (Deterministic Adaptable Priority)-NAD, and DAV (Data and Voice)-NAD [1]. Among the six NADs, P-NAD, DAP-NAD, and DAV-NAD support QoS by using three MPs according to the traffic types. The MPs are Urgent, Priority, and Routine. The highest precedence is Urgent while the lowest precedence is Routine. As the precedence is higher, the transmission opportunities of the precedence packet increase so that it reduces the transmission delays [7].

B. DAP-NAD

Among the 6 NAD schemes, R-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 [2]. DAP-NAD is based on the transmissions in a time-slot, like Time Division Multiple Access (TDMA). However, there is not a central scheduler unlike TDMA so that each station has to maintain the transmission sequence and know when its own slot is. In this NAD, all participating stations are assigned with different channel access opportunities according to their MP [7].

In DAP-NAD, stations access the network in a predefined order, and the order is redefined after each transmission. Each station has the FSN that gives the order to access the channel. A station with FSN 1 accesses the channel first, followed by stations with FSN 2, 3, etc. During this first cycle, network precedence is set to Urgent, which means only urgent messages can be transmitted. If no urgent message is transmitted during the first cycle, the cycle restarts with a station with FSN 1, but the network precedence for this cycle becomes down to priority precedence. During this cycle, urgent and priority messages can be transmitted. If no transmission is made, the cycle restarts again with routine as network precedence. If any transmission is made, the cycle restarts, beginning with the station with the next FSN number, which is FSN 2. The network precedence of this cycle is set to the last message transmitted. Every station has TP (Timeout Period), consecutively after every transmission to be synchronized NAD of all stations. A bump slot is inserted after every transmission and TP. During the bump slot, any station with an urgent message can access the channel and transmit its message. Therefore, there may be a collision in a bump slot. However, if the network precedence of the current cycle is urgent, no stations can access the channel to send a message [1][8].

C. Problem Statement

We consider the case in which QoS of urgent messages is not guaranteed over DAP-NAD. In other words, this means the case where priority messages are transmitted in advance in compared to urgent messages over DAP-NAD. We define this case as “QoS violation”. One station generates an urgent message after own NAST (Network Access Slot Time) go pass, and another station generates a priority message before own NAST go pass, simultaneously over DAP-NAD. In this case, the station with an urgent message transmits it, after the station with a priority message transmits it. For example, there is the network which consists of 10 stations over DAP-NAD as shown in Figure 1. This figure shows an example of QoS violation. The initial NP is an urgent and FSN is 8, and other

Initial states; Total number of stations = 10; Network Precedence = U; FSN = 8

Event 1: An urgent message ready at station 1 & A priority message ready at station 8

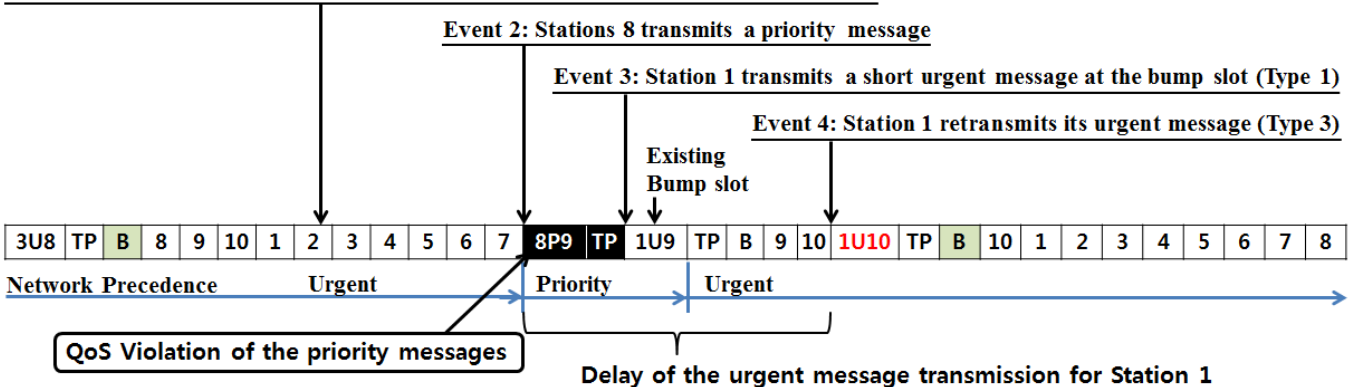


Figure 1. An example of the QoS violation over DAP-NAD

traffic does not occur. This procedure is as follows over the conventional DAP-NAD.

- Event 1 - An urgent message is generated by station 1, and a priority message is generated by station 8, at the same time. Station 1 cannot transmit an urgent message because own NAST go pass at slot 2.
- Event 2 - Station 8 transmits a priority messages at own NAST because NP is changed into the priority mode from the urgent one.
- Event 3 - Station 1 transmits a short urgent message for upping NP to the urgent precedence at existing bump slot.
- Event 4 - NP is changed into the urgent precedence then station 1 retransmits it at own NAST.

In this case, the transmission for station 1 with an urgent message is delayed as the sum of transmission period of a priority message and TP, which are depicted in black box. Furthermore, if data traffic and the number of stations increase, the number of QoS violation will be more increased. Consequently, QoS of the urgent message does not guarantee in this case. In the battlefield, the urgent messages should be transmitted rapidly to all combat units because these require real-time and reliable transmissions. If QoS for these messages does not be guaranteed, the military operation will fail. Thus, to solve this problem, we suggest the DAP-NAD scheme which modified by inserting an additional bump slot.

III. PROPOSED SCHEME

We propose an additional bump slot allocation scheme for QoS guarantee of urgent messages by lessening the aforementioned problem. To solve this, we modify the mechanism of the conventional DAP-NAD by inserting an additional bump slot.

A. Proposed Method

The total number of stations is 10. All stations are locates in one-hop distances as specified in [1], There is no blind

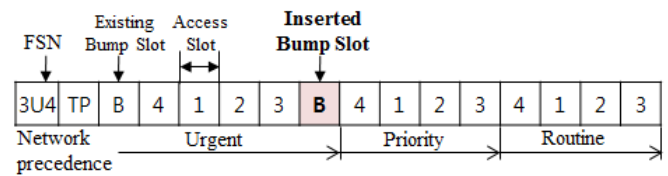


Figure 2. An example of inserting an additional bump slot

problem in wireless channel. DAP-NAD is used to MAC protocol. The proposed method is that an additional bump slot is inserted at next slot where the cycle of the urgent NP is ended. Figure 2 shows the procedure of the proposed method. The role of the additional bump slot aims for maintaining as urgent NP before NP is changed into Priority mode from urgent one. A station with an urgent message transmits it at an additional bump slot. This is because NP can be maintained as urgent precedence by using short message at an additional bump slot, before the urgent NP is changed into the priority one. A station with an urgent message at passed own NAST transmits a short message at the additional bump slot and then NP is maintained as the urgent precedence. The station retransmits an urgent message at own NAST. FSN does not increase at an additional bump slot.

B. Operation Scenario

For the understanding of the proposed scheme, a simple example is introduced. There is the network which consists of 10 stations. The initial NP is an urgent and FSN is 8, and other traffic does not occur. This example is the same one mentioned in Section II (Problem Statement). Figure 3 shows the DAP-NAD procedure comparison between the conventional and proposed schemes. The conventional scheme is depicted in the top of this figure, and the proposed scheme is depicted in the bottom of this figure. The procedure of the proposed scheme is as follows.

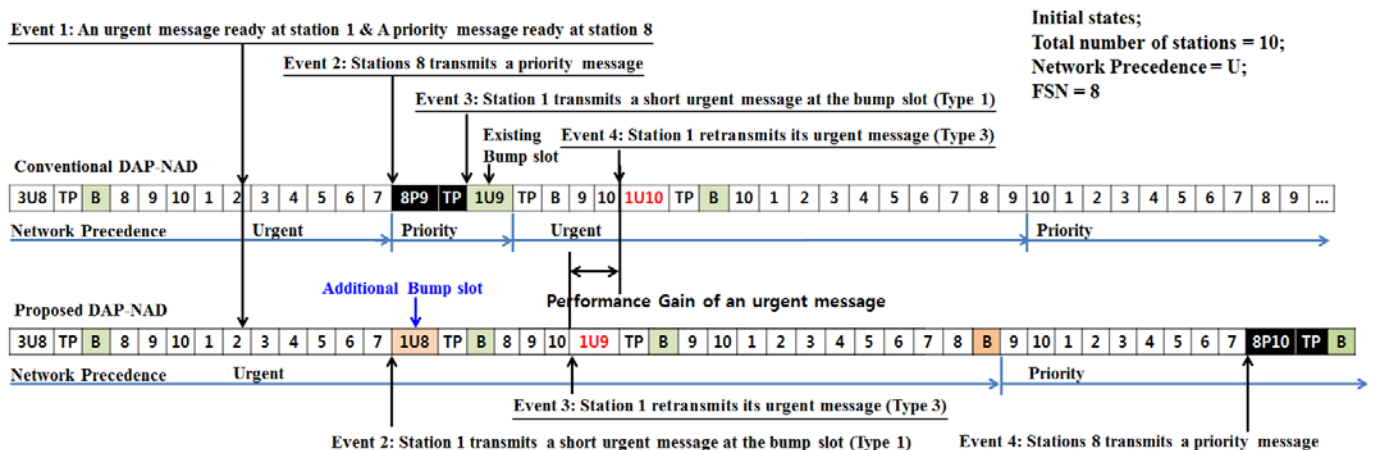


Figure 3. Comparison between the conventional and proposed scheme

- Event 1 - An urgent message is generated by station 1, and a priority message is generated by station 8, simultaneously.
- Event 2 - Station 1 transmits a short urgent message at the additional bump slot for maintaining as the urgent NP precedence.
- Event 3 - Station 1 retransmits an urgent message at own NAST.
- Event 4 - Station 8 transmits a priority messages at own NAST after the NP is changed into the priority precedence.

Consequently, the proposed scheme can prevent QoS violation of urgent messages. This causes the performance gain of urgent messages, which is the sum of transmission period of a priority message and TP for station 8, as shown in Figure 3.

IV. PERFORMANCE EVALUATION

A. Simulation Environments

The proposed scheme and the compared conventional scheme are implemented via the simulation to verify the performance. *Table I* 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 terms of PHY layer. These values are based on the previous papers [2-6].

Table II shows the traffic model used in this evaluation. Traffic interval and size are based on [2-3]. These are generated by Poisson distribution. The MPs consist of messages are urgent and priority MPs except for routine MP because routine messages do not affect QoS violation for urgent messages. XNP (eXchange Network Parameter) messages, which are periodically transmitted to be synchronized with network parameters, do not occur because XNP messages are the urgent NP.

The number of stations varied from 8 to 32 because the modeled network is a company size net considering of the feasibility. It is assumed that all stations are locates in one-hop distances as specified in [1].

Table I – Simulation Parameter Values

Parameter	Value	Parameter	Value
EPRE	40 msec	DTEACK	25 msec
ELAG	278 msec	DTEPROC	25 msec
PASHING	2 msec	DTETURN	10 msec
TURN	395 msec	B	32 msec
TOL	50 msec	NBDT	212 msec
DATA Rate	4,800 bps		

Table II – Traffic Interval and Size

Message Precedence	Interval	Size
Priority	200 (msg/hr)	200 byte
Urgent	2 (msg/hr)	1,024 byte

B. Experiment Results

We evaluate the performance in terms of the average number of QoS violation and average delay of urgent messages. The simulation time is 6 hours and these results are the mean values of 50 times experiments.

Figure 4 shows the average number of QoS violation. X axis represents the number of stations, Y axis represents the average number of QoS violation, and Z axis represents the generation ratio of urgent messages per 1 hour. In this figure, the number of QoS violation increases as the number of stations and the generation ratio of urgent messages per 1 hour increase. This result shows that the number of QoS violation increase drastically as the number of stations and generation ratio of urgent messages increase.

Figure 5 shows average delays of urgent messages derived from QoS violation according to the number of stations. Average Delay represents the time when an urgent message is transmitted from generation. It is similar to the queuing delay.

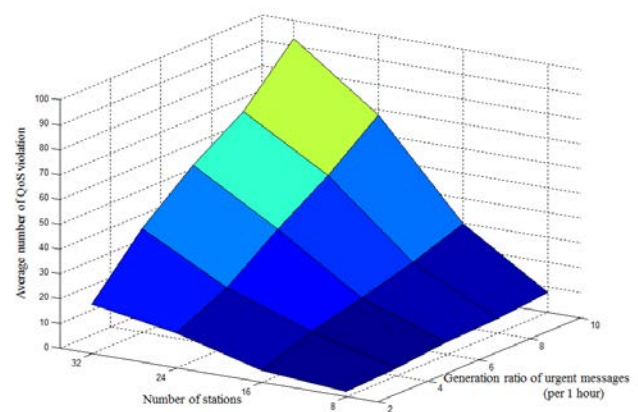


Figure 4. Average number of QoS violations

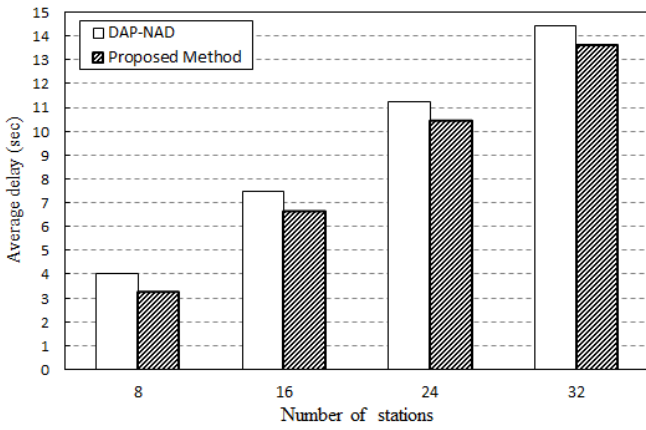


Figure 5. Average delay of urgent messages

The average delay of conventional scheme is longer than the proposed scheme. In other words, the performance of the proposed scheme is better than the conventional scheme in terms of the average delay. This is because the performance gain, which is depicted in Figure 3, derived from inserting the additional bump slot. If the number of urgent messages and the parameter values which make up TP increase, the number of QoS violation for urgent messages increase and the average delay will be increased, seriously.

Note that there is the case in which the urgent messages are generated intensively. For example, many urgent messages, which include C2 (Command & Control), critical SA (Situational Awareness) and call for fire, are generated and transmitted in critical battlefield situations. Thus, we evaluate experiments for QoS violation when urgent messages are generated intensively. Figure 6 shows QoS violation rate according to the interval of urgent messages. QoS violation rate represents the percentage in the proportion of the total number of generated urgent messages to the number of delayed urgent messages. This is as follow equation (1).

$$\text{QoS Violation rate} = \frac{\text{Number of delayed urgent messages}}{\text{Total number of generated urgent messages}} \quad (1)$$

The interval of urgent messages means the urgent messages are generated per one hour. This is changed into 2, 10 and 20 per one hour. In this figure, QoS violation rate increases as the

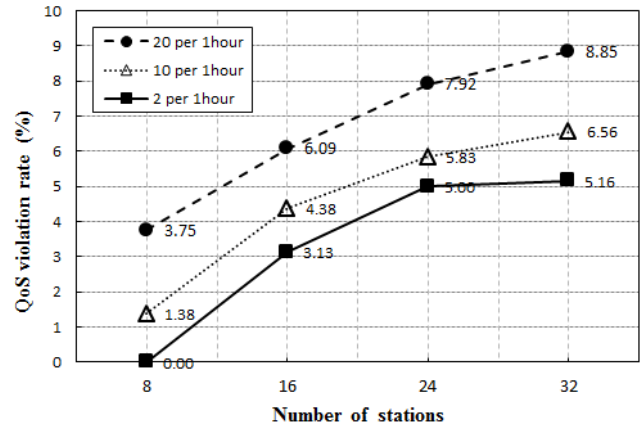


Figure 6. QoS Violation Rate

number of stations and interval of urgent messages increase. QoS violation rate is about 9 percentage of the total number of generated urgent messages when the number of stations is 32 and the interval of urgent messages is 20. Consequently, this result shows that a part of QoS for urgent messages cannot be guaranteed when urgent messages are generated intensively.

C. Numerical Analysis

In this section, we numerically evaluate the number of QoS violations. This numerical analysis means the probability of QoS violation for urgent messages. Figure 7 shows the time table of DAP-NAD procedure. In DAP-NAD, all stations have TP to be synchronized with time slot after TT (Transmission Time) for one station, and all stations have NAST to access channel after TP. Thus, the procedure of DAP-NAD has the cycle of TT, TP and NAST consecutively. N represents the cycle of TT, TP and NAST by time axis, and is equation (2).

$$N = TT + TP + NAST \times NBDT \quad (2)$$

U means the slot where an urgent message is generated in this cycle (N). The probability of QoS violation for urgent messages is the conditional probability of that a priority message is generated at the period ① and an urgent message is generated at the period ② given that urgent messages are transmitted before the period ①. These messages are generated by the poisson distribution.

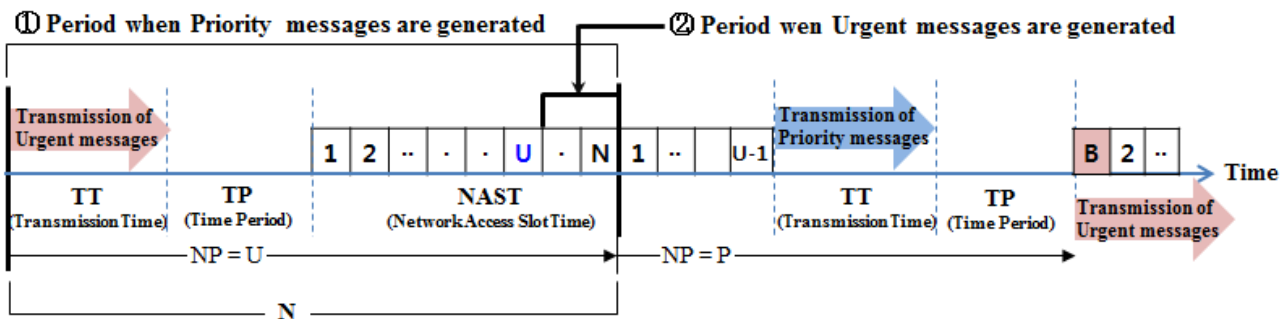


Figure 7. Time table of DAP-NAD

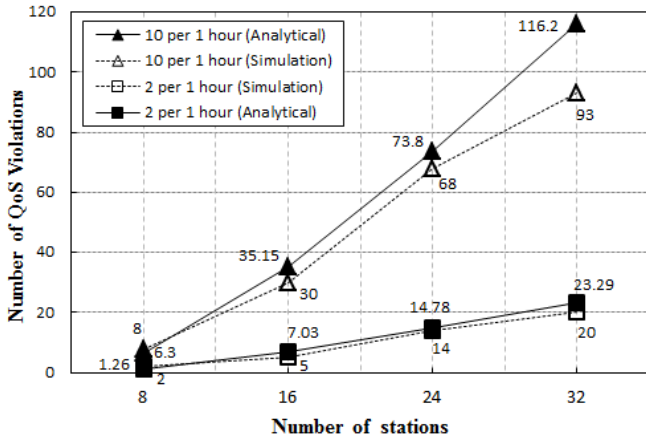


Figure. 8. Comparison of the number of QoS Violation between analytical and simulation results

Being transformed into generation frequency of these messages at NBDT in N , RU represents the generation frequency of urgent messages and RP represents the generation frequency of priority messages. The probability (Pp), where priority messages are generated at the period ①, is equation (3).

$$Pp = \sum_{U=1}^{N-2} U \times (RP \times N / NBDT) e^{-(RP \times N / NBDT)} \quad (3)$$

The probability (Pu), where urgent messages are generated at the period ②, is equation (4).

$$Pu = \sum_{U=2}^{N-1} (NS - U) NBDT \times N, \quad (1 < U \leq N - 1) \quad (4)$$

$P(U_f)$ is the probability of that urgent messages is transmitted at period N_i given that urgent messages are transmitted at period N_{i-1} . $P(U_f)$ is equation (5).

$$\begin{aligned} P(U_f) &= 1 - P(X \geq 1) = 1 - \{1 - P(X < 1)\} \\ &= 1 - \left(1 - \int_0^1 \lambda e^{-\lambda x} dx\right) \\ &= 1 - e^{-\lambda} \end{aligned} \quad (5)$$

The urgent messages are generated by the exponential distribution at the period N . In other words, $P(U_f)$ is calculated by subtracting 1 from the probability of that urgent messages is not transmitted at period N_i given that urgent messages are transmitted at period N_{i-1} . In equation (5), X means N and λ means the number of urgent messages in N . In conclusion, $P(Q)$ is the probability of QoS violation for urgent messages. This probability is equation (6).

$$P(Q) = P(U_f) \times P(p) \times P(u) \quad (6)$$

We numerically evaluate the number of QoS violations by using equation (6). Figure 8 shows the comparison of the number of QoS violation between analytical and simulation

results. These results is a little difference between analytical and simulation.

V. CONCLUSIONS

In this paper, we have proposed an additional bump slot scheme for QoS guarantee of urgent messages in TDMA-based tactical wireless networks. We considered the case in which QoS of urgent messages is not guaranteed over DAP-NAD. In other words, this means that the case where priority messages are transmitted in advance in compared to urgent messages over DAP-NAD. To solve the problem of QoS violation, we analyzes the case in which QoS violation occurs and suggest DAP-NAD modified by inserting an additional bump slot. The proposed method is that an additional bump slot is inserted at next slot where the cycle for the urgent NP is ended. The proposed scheme is thoroughly examined by simulation method. The results show that the variation of QoS violation according to the number of stations and interval of generation ratio of urgent messages. Consequently, the average delay of urgent messages derived from QoS violation in the proposed scheme becomes shorter than that in conventional scheme. This improves the performance of MIL-STD-188-220 based military systems.

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