Performance Enhancements in TDMA-based Tactical Wireless Networks

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***Abstract*—Unlike analogue voice signal-oriented and narrowband-based conventional systems, the tactical wireless networks have been evolved to deal with multimedia traffics over wideband systems in a past decade. While new waveforms like Wideband Networking Waveform (WNW) have been developed for the physical layer of the future tactical networks, the enhancement in a network layer protocol is not well-reported. In this paper, an enhancement is proposed to improve the performances of the voice packet transmissions using the conventional TDMA-based protocol specified in MIL-STD-188-220 military standard over the wideband environments. By allowing stations to transmit voice packets in Bump-Slot, significant improvements are achieved. It is proved by the extensive simulations.**

Keywords; MIL-STD-188-220; DAP-NAD; Bump-slot; Tactical Network.

I. INTRODUCTION

The developments for the future wireless tactical networks are moving toward wideband and digital signal-based wireless networks. As a part of the developments, the future tactical networks are designed to support multiple waveforms including Amplitude Modulation (AM), Frequency Modulation (FM) and a new wave form, called Wideband Networking Waveform (WNW) [1]. WNW is developed to overcome the insufficient capacities of the conventional narrowband wireless channel, so that it provides higher data transmission rate and as a consequence multimedia and bulky data traffic are supported. WNW has been developed as a future communication waveform by the program of Joint Tactical Radio Systems (JTRS), named Ground Mobile Radio (GMR). It provides 1, 2, 3, 5, 10 MHz bandwidth using Orthogonal Frequency Division Multiplexing (OFDM) shown in [1]. In addition to WNW, the future tactical networks will utilize two emerging technologies such as Software Define Radio (SDR) and Cognitive Radio (CR). However, even though many researches and developments might have been done for the future tactical wireless networks, only few are reveled in the public.

Most of walkie-talkies used in the current tactical wireless networks over AM and FM waveforms are being operated using the protocol specified in MIL-STD-188-220 military standard. This specification defines protocols operating in physical, data-link, and network layers. Combat Net Radio (CNR) Working Group developed the first version of the standard in 1993, and its latest version is MIL-STD-188-220D with Change1 standardized in 2008 as shown in [2]. The latest standard defines 6 medium access protocols for data link layer. Among the 6 protocols, Random Net Access Delay (R-NAD) and Deterministic Adaptable Priority Net Access Delay (DAP-NAD) are defined as mandatorily protocols for the Digital Message Transfer Devices (DMTDs) and the rest 4 protocols, Prioritized Net Access Delay (P-NAD), Hybrid Net Access Delay (H-NAD), Radio Embedded Net Access Delay (RE-NAD), Data and Voice Net Access Delay (DAV-NAD), are optional. DMTDs are tactical communication devices used for communicating with automated Command, Control, Communications, Computers and Intelligence (C^4I) systems and to other DMTDs. A few researches on the protocols specified in MIL-STD-188-220D (that is the previous version of MIL-STD-188-220D w/Change1) have been done as shown in [3]-[10]. However, the researches are mainly focused the communication environments with the light traffics over the narrowband channels although the future networks evolves to operate with multimedia traffic over the broadband channel.

The key focus of this paper is the performance enhancement of DAP-NAD over WNW channel with voice traffic. As mentioned above, the future tactical wireless networks is going to operate over multi-waveforms including broadband as well as narrowband, and MIL-STD-188-220 standard has been used for narrowband-based communication devices. Therefore, instead of developing new protocol for WNW, we are focusing on using the data link protocols in MIL-STD-188-220D with Change1 standard for the backward compatibility with the conventional communication devices and for reduction of the development efforts. Therefore, in this paper, the latest version of MIL-STD-188-220 protocol, which is MIL-STD-188-220D w/Change1 (hereinafter "MIL-STD-188-220D w/Change1" is called as simply "MIL-STD-188-220"), is studied over wideband channel environment and the new method is proposed to enhance the performances of the protocol over broadband.

In Section II, prior researches on MIL-STD-188-220 standard are reviewed and DAP-NAD method is introduced in detail. In Section III, the motivation of this research is provided and the new method is introduced. In Section IV, the proposed method is evaluated through the extensive simulations and finally the collusions are made in the Section V.

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II. PRIOR ARTS

A. Network Access Control (NAC)

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 have to wait to access channel. Six NADs are R-NAD, P-NAD, H-NAD, RE-NAD, DAP-NAD, and DAV-NAD. Among the six NADs, P-NAD, DAP-NAD, and DAV-NAD support Quality of Service (QoS) by using three Message Precedences (MPs) according to the traffic types. The MPs are Urgent, Priority, and Routine, and 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.

The paper in [3] evaluates the performances of R-NAD and P-NAD with various packet lengths in terms of NAD and collision statistics. In the paper, R-NAD has better performances than P-NAD does.

Papers in [4]-[6] study DAP-NAD and RE-NAD. In particular, the paper in [4] concludes that the increase of the number of stations seriously deteriorates the performances of DAP-NAD and scheduling the transmission opportunities affects much on the performance of DAP-NAD. On the other hand, the paper also concludes that DAP-NAD has better performances than RE-NAD in terms of end-to-end delay and Network utilization. In [7], DAP-NAD is compared with Voice priority Net Access Delay (V-NAD) proposed in [8]. In that comparative study, DAP-NAD has better performances in terms of the latency and network utilization. In [9] and [10], a way to send voice packet as an urgent precedence using DAV-NAD is proposed. In the papers, the performances in the transmissions of voice packets over DAP-NAD shows better than that over V-NAD shown in [7] and DAP-NAD. However, the paper does not evaluate the effect of the voice packet transmission on the other precedence packets such as Urgent, Priority and Routine. Through the researches from [4]-[10], Network Busy Detect Time (NBDT), which decides the use of the channel before transmitting a packet, plays an important role on DAP-NAD-based and its alternative-based networks. The shorter NBDT is, the better the performances are. As a part of continuous researches on improving the performances of DAP-NAD method, studies in [11] and [12] proposes DAP-NAD-Cyclic Jump (DAP-NAD-CJ). Because the conventional transmission sequence is based on simply round-robin method, it is not efficient in the case with the variance in the traffic loads at stations. To solve this, the DAP-NAD-CJ proposes a algorithm to change the transmission sequence and shows that it improves the end-to-end delay and the packet lost ratio of DAP-NAD method..

B. DAP-NAD

Like Time Division Multiple Access (TDMA), DAP-NAD is based on the transmissions in a time-slot. However, there is not central scheduler unlike TDMA, so that each station has to maintain the transmission sequence and to know when its own slot is. In the NAD, all participating stations are assigned with different channel access opportunities according to their packet's precedence.

Each participating station (afterward, participating station is shortened to station) is pre-assigned with Station Rank (RS) number which is from 1 to Number of Station (NS). NS is the total number of stations. The transmission sequence of the stations is based on the RS number. That is, station with 1 RS number can firstly send its packet if it has a pending packet in its queue. If it does not have any pending packet, the next slot is for the station with 2 RS number. All stations have transmission opportunities in the sequence based on the RS number. The current sequence is repeated until any one station actually sends its data in a time slot. If any station sends its own data in a slot, the new sequence begin from a station whose RS is same as First Station Number (FSN). That is, FSN indicates the station that has the first opportunity of the new transmission sequence. For the first time, FSN is set to 1 so that the transmission sequence is started from a station with 1 as RS number. Then, whenever a station sends its data in a slot, FSN is updated as follows:

$$FSN_{i+1} = FSN_i + FINN,$$

where FSN_i indicates FSN for the current transmission sequence, FSN_{i+1} is FSN for the next sequence, and FSN Increment Number (FSNIN) is a increment constant. When FSN is greater than NS, then, FSN is updated as follows:

$$FSN_{i+1} = FSN_i \bmod NS.$$

For DAP-NAD, FINN is set to 1. On the other hands, for DAV-NAD which is another slot-based NAD, FINN is predefined in MIL-STD-188-220 standard [2]. DAP-NAD and DAV-NAD defined MIL-STD-188-220 standard are same methods except a way to set FINN.

Network Precedence (NP) represents the precedence of a packet that is allowed to be transmitted in the transmission sequence. Instead, MP represents the precedence of the packet of a station. The transmission sequence begins with Urgent as the NP. Then, if there is no transmission during the sequence, the NP of the next sequence is set to one step lower precedence, which is Priority, and then a new sequence begins. In this way, when the NP is Routine, which is the lowest precedence, the NP is unchanged until a station transmits a packet in a slot. A station can send its packet in its own time slot if the MP of its pending packet is equal to or higher than the current NP. If a station sends its packet in a slot, then, the NP is set to the MP of the transmitted packet and the next sequence begins.

DAP-NAD uses a unique time slot, called Bump-Slot, which has been shown from MIL-STA-188-220C version. The slot is automatically inserted right after the slot where a packet, whose MP is same as NP, is transmitted. In the slot, any station with pending urgent packets sends a short urgent control packet or queued actual urgent data packet in a manner of slotted aloha channel access method, and as a result, the NP of the next transmission sequence is set to Urgent. That is, the Bump-Slot is used to intentionally increase the current NP to Urgent. If any transmission or collision is detected in the Bump-Slot, all station set to the next transmission sequence to Urgent. In general, because DAP-NAD uses TDMA-based channel access and the transmissions of stations are pre-scheduled based on SR, MP, and NP, all transmissions are contention-free. However, in the Bump-Slot, there may be collision due to the slotted aloha based channel access. There are a few cases that the use of the Bump-Slot is prohibited. The first case is when the NP is already Urgent. The reason of this is that because the current NP is already Urgent, it is not necessary to upgrade the NP to Urgent. Even though the current NP is Urgent, a Bump-Slot is inserted because some station may not agree that the current NP is Urgent. This takes into account on the case that some station may not receive the packet from other stations, so that they may have different NP. In addition, sending an urgent data packet or a control packet in the slot when the NP is Urgent causes unnecessary collisions in the slot. If the RS of a station with the pending urgent packet is same as the current FSN, the station is prohibited from using the Bump-Slot. Because the station can send its data packet right after the Bump-Slot, it is not necessary for it to send the packet in the Bump-Slot which may cause a collision. If a packet is transmitted in a Bump-Slot (called the first Bump-Slot), a second Bump-Slot is followed by the first Bump-Slot. This is for the stations which may not successfully receive the transmitted packet in the first slot, but detects the transmission. The station expects the next slot will be a Bump-Slot and send its urgent packet. To protect this case, the second Bump-Slot is followed by the first Bump-Slot experiencing a packet transmission.

For the better understand, Fig. 2 provides an example of DAP-NAD.

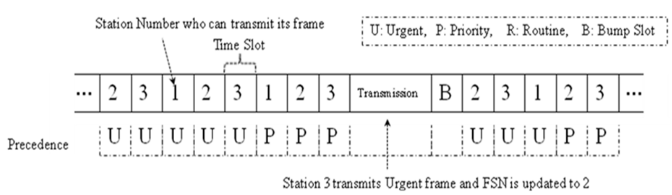

Figure 1. An example of channel accesses using DAP-NAD method.

III. PROPOSED METHOD

A. Motivation

MIL-STD-188-220 standard-based DTMDs have been operated over the narrowband channel. As shown [1], the future tactical wireless networks use WNW and using the WNW enables tactical networks to support tens of Mbps transmission rate and multimedia traffics by using OFDM-based physical layer and operating over maximum 10MHz bandwidth. During the transition from the conventional system to the future system, the inter-operability between the old and new devices is required. In this point, because MIL-STD-188-220 standard has already been used in the old devices, it is desirable to make the standard operable in the new devices over the broadband system. If the standard operates in the new devices, then the issue on inter-operability may be resolved, and the time and cost spent to develop a new protocol can be reduced. For this, we studied the feasibility of DAP-NAD and R-NAD-based communications over IEEE802.11-based broadband environment and showed using DAP-NAD over the broadband channel is feasible in [13]. As a next step of the study, this paper focuses on voice packet transmission using DAP-NAD over the broadband system. In the broadband tactical networks, various types of traffics including multimedia and bulky data traffics are supported for the better situation awareness and providing efficient military operations in the battlefield. However, the most important traffic in the tactical communications is voice traffic which will be transferred over Internet Protocol (IP) packet. Therefore, there is a way to provide the better performance on the Voice traffic than other traffics. However, researches on such issue have not extensively been made so far. In [9] and [10], the performances of the voice packet transmissions over DAP-NAD have been studied by setting the precedence of the voice packet to Urgent. However, the evaluations have been performed with the low traffic loads in the narrowband environments. Therefore, in this paper, we propose a method to enhance the voice transmissions over the broadband- and DAP-NAD-based communication system.

B. Proposed Method

The Bump-Slot mentioned in Section III has some serious problem when the loads of Urgent traffic increase. By the specification in MIL-STD-188-220 standard, when NP is set to Urgent, the Bump Slot is not used at all. If the traffic loads of the urgent precedence increases at many stations, NP will stay on urgent precedence during the most of times because the NP is updated to the MP transmitted in a slot. This can be imagined in the beginning of military operations or war, where urgent traffic storm might occur. An example of the case is shown in Fig. 2. In Fig. 2, the arrows indicate Bump-Slots which are not utilized by any station.

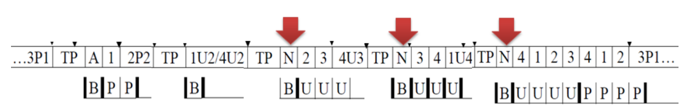

Figure 2. The example of Bump slot

As proposed in [9] and [10], voice packets need to be set to Urgent MP among three MPs. However, the other multimedia traffics may set to Urgent MP as well. In this case, voice packets have same transmission opportunity as the other Urgent packets do even though the voice packets have the higher priority than the other packets due to strict delay-constraints and packet loss rate. In fact, in the warfare, the voice communications is the most important comparing to any other data communications.

To have a better transmission opportunity on the voice packets, this paper utilizes the unused Bump-Slots. When the traffic loads in the networks is light, it is fine that the voice packet is transmitted same way as general urgent packet does. However, when the traffic loads is heavy, then the transmission delay of the voice packet increases because stations with voice packet have to waits for their own slot. Furthermore, it causes packet-drop of the voice packet. To provide more transmission opportunities to the voice packets comparing to the general urgent packets, the proposed method allows voice packets to be transmitted in a Bump-Slot while the MP of voice packet is still set to Urgent. That is, the voice packet can be transmitted in a station's assigned slot as well as a Bump-Slot. Because of allowing voice packet transmissions in the Bump-Slots, the proposed method is absolutely backward-compatible.

IV. PERFORMANCE EVALUATIONS

A. Simualtion Environment

In this section, the proposed enhancement for voice transmission over DAP-NAD is evaluated. Because the proposed method in this paper is for the future tactical networks using DAP-NAD over WNW, the evaluation is also performed in a wideband networks. However, most of studies on MIL-STD-188-220 standard in [3]-[12] has been done in narrowband channel environment, and the actual specification for WNW is not revealed due to the confidentiality. Therefore, we refer the specification of commercially available Off-The-Shelf (COTS) supporting WNW described in [1] to obtain physical parameters for the simulation environments. According to the specification described in [1], the WNW system adopts OFDM technology as a physical layer over 10MHz bandwidth channel. That is, the system is very similar to IEEE802.11a-based system except the bandwidth. The IEEE-802.11a specification in [14] is well-known and broadly used specification for OFDM-based system. Therefore, the proposed method is evaluated with the IEEE 802.11a-based parameters as shown in Table I. All IEEE802.11a-based time durations used in the simulation is adjusted for 10MHz bandwidth channel because the channel bandwidth is 10MHz while IEEE 802.11a specification operates over 20MHz bandwidth channel. Because NBDT is a time to sense the channel to detect any transmission and "Slot Time" in IEEE 802.11a standard is also used to sense the channel, NBDT is set to the "Slot Time" shown in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Data rate	3 Mbps
Preamble Length	32 us
PLCP Header Length	8 us
MAC Header Length	272 bit
Default Slot Time	13 us
SIFS Time	32 us
Voice Packet Lifetime	150ms
Other Packet Lifetime	500ms

In MIL-STD-188-220 standard in [2], the total number of bits assigned for FSN is 6-bit, that implies the maximum number of stations in a sequence. According to this, the maximum number of stations is set to 63. In the simulation, it is assumed that all stations are locates in one-hop distances as specified in [2], so that all station can hear the other's transmission. A station generates only one MP traffic of three MPs, and the ratio of the number of stations with three different MPs are 1:1:1. At the beginning of the simulations, all stations are randomly assigned with a MP and RS. Only two stations among 64 stations generate voice packets. The reason to set only 2 stations for the voice traffic is that voice communications in tactical networks are group communications by using multicast or broadcast transmissions and push-to-talk method. Therefore, setting 2 voice traffics means two group calls which may be reasonable in the tactical situations. Regardless of MP, the packet length is generated following exponential distribution with mean 1024 bytes and inter-arrival times of packet are following Poisson distribution with mean 1/λ. The life times for all three precedence packets in the MAC layer is set to 500 ms as specified in IEEE 802.11 standard and the packet dropping occurs when the life time expires.

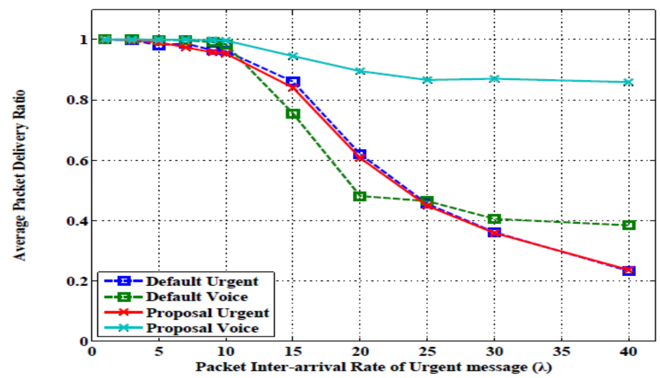

Figure 3. Average Packet Delivery Ratio as a function of λ of Urgent Traffic

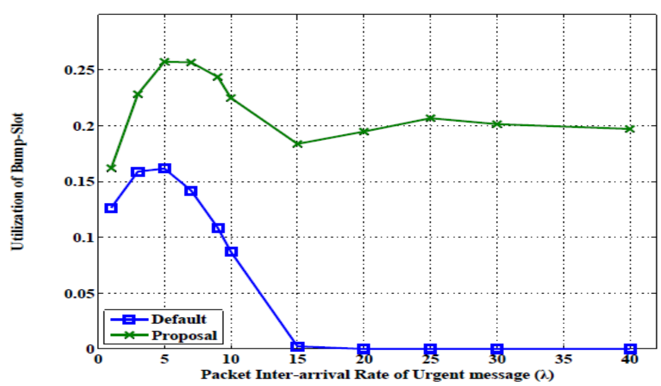

Figure 4. Average Bump slot utilization as a function of λ of Urgent Traffic

The model for the voice traffic is well-known On-Off model used in [15]-[17]. The mean time durations of On and Off states are 0.352 and 0.650 seconds, respectively. In the on state in the model, the voice packet is generated with a fixed 20ms inter-arrival time and packet length 234bytes. As recommended in International Telecommunication Union (ITU) in [18] and [19], and ITU-T G.114 in [20], unlike other types of packets, the voice packet's life time is set to 150ms.

The performances of voice packet transmissions using the proposed method and the conventional DAP-NAD are compared as the loads of the voice traffic increases by increasing λ. It is assumed that the conventional DAP-NAD transmits voice packet as an urgent precedence shown in [9] and [10].

B. Simulation Results

Fig. 3 shows the average packet delivery ratio of voice and urgent packets as the packet arrival rate, λ, increases from 1 to 40. The packet delivery ratio is defined as the ratio of the number of successfully transmitted packets to the number of generated packets in the network. In the figure, "Default" indicates the conventional DAP-NAD while "Proposal" indicates the proposed method. As the λ increases, the performances of both methods decrease. However, the performances of voice packet using the proposed method are much better than that of the conventional DAP-NAD are. As shown in Fig. 3, the proposed method achieves around 90 % packet delivery ratio while the conventional method achieves only 40%, respectively, at λ=30. That is, the proposed method increase more than two times in the packet delivery comparing to the conventional method. For the urgent packets, both of methods have similar performances. That is, the proposed method increases the performances of voice packet transmissions without decreasing the performances of Urgent packet transmissions. Fig. 4 illustrates the reason of the enhancements on the performances. Fig. 4 shows the utilizations of Bump-Slots as the traffic loads increase. As shown in the figure, the conventional method uses no Bump-Slot after λ becomes 15. As the urgent traffic increases, most of time slot is occupied by the urgent packets and it causes to maintain the NP with urgent precedence. In addition, as λ increases, the more Bump-Slots are inserted because of the more transmission. Even though there are the more Bump-Slots, stations with voice traffic cannot transmit the voice packet in Bump-Slots because the NP is already urgent precedence. On the other hand, the proposed method keeps using the Bump-Slots as shown in Fig. 4 because the proposed method enables voice packet to be transmitted in the slot.

V. CONCLUSIONS

The future tactical networks are moving towards the networks supporting multimedia traffics over wideband channels, so that a new data link protocol is required. However, because DAP-NAD in MIL-STD-188-220 military standard has been used for a long time, enhancing the protocol to fit in the wideband networks is to reduce the time and costs for developing a data link protocol and to provide backward compatibility with the old devices. This paper proposes an enhancement to support voice traffic over wideband networks. The enhancement is to allow stations to send their voice packets during Bump-Slots while a general urgent packet is not allowed to be transmitted in the slot. Through the simulations, it is shown that the enhancement achieves significant performance improvements on the voice transmissions. As future works, the other enhancement for video traffics will be studied.

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