Effective Exchage of Real-Time Location Information Packets in an Integrated Voice/Data Ad-hoc Network Based on the MIL-STD-188-220C Standard

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***Abstract*— The MIL-STD-188-220C protocol, which is a standard of American Department of Defense, is designed for mobile ad-hoc networks that provide unicast and multicast routing capabilities in a military ad-hoc network environment. In this paper, we model an ad-hoc network consisting of 31 nodes hierarchically, each of which models a radio transceiver based on the MIL-STD-188-220C standard on a battle maneuver vehicle. We propose four possible scenarios to exchange the real-time location information of maneuver vehicles and evaluate the performance in the network, and determine the optimal strategy among them by OPNET simulations. Furthermore, we investigate the required values of system parameters, such as packet generation time interval and data rate to optimize the performance.**

I. Introduction

Recently, demands for digital information have been rapidly increasing with development of information and communication technologies. Digital information such as document, photograph, map, voice and animation produced or processed by computers is becoming more diverse day by day. Furthermore, as demands for more detailed and accurate information increase, a larger system capacity and higher data rates are also needed.

Especially, real-time location information has been increasing rapidly. Using global positioning system (GPS) information, it is possible to monitor the location of mobile terminals in real-time. Although the GPS applications are being expanded to various social public fields, it was used primarily for military purposes to obtain precise location information, or GPS information. In battle fields, military operations will be executed rapidly and effectively if it is possible to keep track of the location, arrangement state and mobility information of enemy troops and our forces. Of course, this information should be updated in real-time.

Data messages like location information can be exchanged in packet mode, while voice message are usually exchanged in circuit mode. Although voice communications over packet switching networks, or VoIP, gradually increse, it will take very long time to transfer from circuit switching networks to packet switching networks. Still, FM transceivers have been widely used to accomplish real-time voice communications in many military fields. If we transfer data packets such as location information of enemy troops, tactics and commands of our forces during the idle time including silent intervals in conventional voice communication systems, it is possible to enhance the efficiency of wireless communication resources.

In this paper, we model and simulate an integrated voice/data ad-hoc network which uses FM radio communications based on the MIL-STD-188-220C standard of American Department of Defense. The features of ad-hoc networks enable each intra-network to adapt various environments as shown in [1] and [2]. In other words, in ad-hoc network, even if a node (or a maneuver vehicle) is destroyed by attacks of enemy, another node can substitute for it. We need to give priority to voice traffic than data traffic. In this environment, we propose four possibile scenarios to deliver the location information packets of maneuver vehicles and compare the performance of the proposed scenarios by using OPNET simulations. We also determine the appropriate values of system parameters, such as packet generation time interval and data rate to optimize the performance. The rest of this paper is organized as follows: In Section II, we introduce the MIL-STD-188-220C standard of American Department of Defense and an ad-hoc network model based on the standard, and propose four location information delivery scenarios. In Section III, we list the system parameter values used in the simulation. In Section IV, we show the results obtained from OPNET simulations and determine the best location information delivery scenario. Finally, we present conclusion in Section V.

II. Network Model

A. MIL-STD-188-220C standard

The MIL-STD-188-220C standard [3] is a military data communication protocol. This protocol was developed for data communications in conventional wireless voice communication networks. It prevents radio transceivers from conflicts among them and provides specifications to exchange data traffic and voice traffic. It was published by the American Department of Defense in March 2002. This protocol has been upgraded to version C following versions A and B [4]. This standard has been used in data communications among DMTDs (digital message transfer devices) among DMTDs and C4I (command, control, communications, computer and intelligence) systems, and among C4I systems. Specially, it has been also used in the communication systems of the M1A1 maneuver vehicles which comprise a main force in American military units.

B. Ad-hoc network model

In battle fields, communication systems should be set up not in a fixed network model but in an ad-hoc network model. In the fixed network model like a base station oriented network model, if a base station is destroyed, the communication is completely unavailable. Meanwhile, in the ad-hoc network model, even if any node is destroyed, communications are still available. Fig.1 shows an ad-hoc network model of maneuver vehicles used in this paper. In this model, 31 nodes (maneuver battle vehicles) and 13 intra-networks are built hierarchically. Battalion intra-network F12 consists of one battalion commander node and three company commander nodes. In addition, there are three company intra-networks: F4, F8 and F12. Each company intra-network consists of a company commander node and three platoon commander nodes. The remaining nine intra-networks comprise the platoon intra-networks. Each platoon intra-network consists of one platoon commander node and two soldier nodes. A company commander node acts as a gateway between one battalion intra-network and one company intra-network. In addition, a platoon commander node acts as a gateway between one company intra-network and one platoon intra-network. Since each intra-network uses a distinct carrier frequency or code, the communication between two intra-networks should be relayed by these gateway nodes (company commander node or platoon commander node). Even if a gateway node is destroyed, then a neighboring node can substitute for it. In each intra-network, voice and data messages are exchanged through the same wireless channel, but we give priority to voice traffic than data traffic.

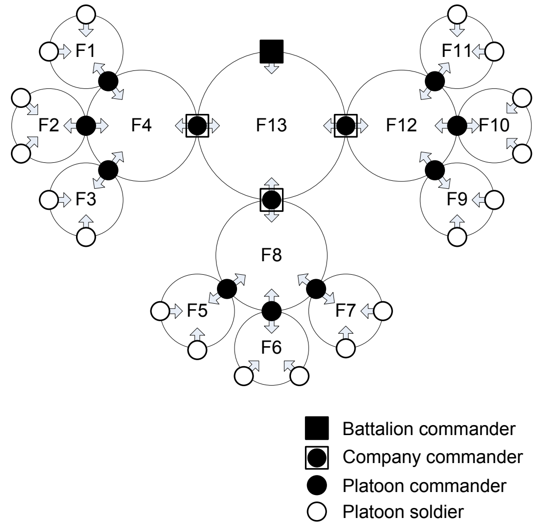

Fig. 1. Ad-hoc network model

C. Location information delivery scenarios

In this paper, we propose four location information delivery scenarios and determine the best one through OPNET simulation.

1) Scenario 1 (Flooding without merging)

In this scenario, each node broadcasts its own location information packet to all nodes in its intra-network. A gateway node relays location information delivered from a lower-level intra-network to all the nodes in the upper-level intra-network, and vice versa. For example, a platoon commander node broadcasts its own location information to its own company intra-network and its own platoon intra-network. It relays the location information delivered from its two soldier nodes to the other two platoon commander nodes and the company commander node in its own company intra-network. The number of hops required to propagate location information packets in the whole network is 1 to 5, depending on the location of source node. In this way, any node knows the location information of all the other ones in the whole network. Since all nodes relay location information without any packet manipulation like data merging, this scenario yields low packet delay. However, as each node generates more packets, congestion may occur. in the network.

2) Scenario 2 (Flooding with Uplink(UL) merging)

In this scenario, a gateway node keeps the location information delivered from a lower-level intra-network until its own location information is generated. When its own location is generated, it merges both of the location information, and broadcasts it to its upper-level intra-network. On the other hand, it relays the location information delivered from an upper-level intra-network to lower-level intra-networks without any packet manipulation. Since uplink packets should be queued until the location information of a gateway node is generated [5], packet delay becomes longer than the case of scenario 1. However, a merging operation in the uplink reduces the possibility of network congestion more or less, and, thus, enhances the quality of service (QoS).

3) Scenario 3 (Flooding with Uplink(UL)/Downlink(DL) merging)

In this scenario, a gateway node keeps both location information delivered from a lower-level intra-network and an upper-level intra-network until its own location information is generated. When its own location is generated, it merges the location information from the lower-level intra-network and the upper-level intra-network with its own location information, and broadcasts it to the upper-level intra-network and the lower-level intra-network, respectively. Since uplink and downlink packets should be queued until the location information of a gateway node is generated, packet delay becomes longer than the cases of scenarios 1 and 2. However, merging both uplink traffic and downlink traffic reduces the possibility of network congestion remarkably.

4) Scenario 4 (Top-merging and Down-flooding)

In this scenario, all nodes transmit location information only in uplink direction without data merging. The top (battalion

TABLE I

CRITICAL PARAMETERS OF MIL-STD-188-220C STANDARD

Parameter	Value	Parameter	Value
NS	4	TURN	395 [ms]
N4	2	TOL	50 [ms]
DATA_RATE	4,800 [bps]	B	32 [ms]
BUSY_PERIOD	120 [sec]	DTEACK	25 [ms]
EPRE	40 [ms]	DTEPROC	25 [ms]
PHASING	2 [ms]	DTETURN	10 [ms]
ELAG	950 [ms]	NAD	R-NAD

commander) node merges all the location information and floods the merged packet to lower-lower intra-networks. In contrast to flooding scenarios (scenarios 1, 2, and 3), in this scenario, the maximum number of hops to propagate the location information in the whole networks is 6 because all the uplink packets should be merged at the top node. Thus, packet delay becomes longer than scenarios 1 and 2. However, merging downlink traffic reduces the possibility of network congestion more or less, and, thus, enhances QoS.

III. SIMULATION ENVIRONMENT

In this paper, we evaluate the performance of an integrated voice/data ad-hoc network based on the MIL-STC-188-220C standard for the four scenarios described in Section II by OPNET simulation tool [6], [7].

A. Parameters of MIL-STD-188-220C standard

Table I lists the important system parameters of the MIL-STD-188-220C standard [8], [9]. 'NS' is the number of active nodes at a time instance. 'N4' is the maximum number of retransmission. 'DATA_RATE' is the transmission rate of radio transceivers. 'BUSY_PERIOD' is the time duration for which communication is stopped if an ACK message is not received yet from the receiver node. 'EPRE' is the time for transmission initialization. 'PHASING' is the time for transmitting synchronization signal. 'ELAG' is the time interval for transmitting data from the DCE of a node to the DCE of the other node. 'TURN' is the time for changing transmission/reception mode. 'TOL' is tolerance time. 'B' is the time for sensing data signal. 'DTEACK' is the time for generating an ACK message. 'DTEPROC' is the time interval between the reception of a data frame and the next transmission. 'DTETURN' is the time for changing a state from stand-by state to transmission state. 'NAD' is the network access delay which is used to distribute the time delay through a shared wireless channel to multiple nodes. There are three types of NAD: R-NAD, P-NAD, and H-NAD. In this paper, we use the R-NAD which allocates wireless resources to multiple nodes at random. Many other parameters of the MIL-STD-188-220C standard are not shown in this paper to save the space.

From the above parameters, we calculate the additional parameters as shown in Table II. 'S' is the time for transmitting an ACK message whose length is 312 bits. 'RHDO' is the time unit between arrivals of two ACK messages. 'NBDT' is the time for sensing data signals delivered from other node.

The MIL-STD-188-220C standard defines three QoS groups for transmitting data packets according to its importance level, as shown in Table III. Voice traffic has higher priority than any other QoS groups of data traffic. Location information packets may have 'Urgent', 'Priority', or 'Routine' QoS group.

TABLE II

ADDITIONALLY CALCULATED PARAMETERS FROM TABLE I

Calculated Parameter	Value
S	312bits / DATA_RATE
RHDO	EPRE+PHASING+S+ELAG+TURN+TOL
NBDT	EPRE+ELAG+B+TOL

TABLE III

QOS GROUPS IN MIL-STD-188-220C STANDARD

Importance level	QoS group
0	Voice
1	Urgent
2	Priority
3	Routine

B. Voice/Data traffic model

Voice traffic is modeled as an ON/OFF traffic model [10]. Here, 'ON' interval is subdivided into a 'Talk spurt' interval in which voice is generated and a 'Silence' interval in which one waits for responses. Each interval is exponentially distributed. The mean durations of 'ON', 'Talk spurt' and 'Silence' are 38 [sec], 6[sec] and 2[sec], respectively. As mentioned in Section III-A, we give higher priority to voice traffic than data traffic. Thus, location information packets are delivered using the 'OFF' interval of the voice traffic model. We assume that each node generates a location information packet for every 30 seconds.

C. Radio channel model

Path loss is modeled using a Hata model [11]. We assume that thermal noise interferes voice and data traffic signal [12]. The effect of shadowing is assumed to have a thermal log-normal distribution with zero mean and a standard deviation of 8 dB [13]. The effect of fast fading is modeled using Jakes fading model [14].

IV. SIMULATION RESULTS

The performance of the integrated voice/data ad-hoc network is evaluated in terms of average delay and success probability. The average delay is the time from the generation of a location information packet to the complete transmission of the packet. It contains the framing time, queueing delay and transmission delay. Packets which fail to be successfully transmitted to destinations are not considered.

$$\text{Average delay} = \frac{\text{Total delay of received packets}}{\text{Number of received packets}} \quad (1)$$

The success probability is the ratio of the number of successfully transmitted packets to the total number of transmitted packets.

$$\text{Success probability} = \frac{\text{Number of successfully transmitted packets}}{\text{Number of transmitted packets}} \quad (2)$$

A. Data Traffic Only

First of all, we compare the performance of the four proposed scenarios for transmitting location information packets. We generate location information traffic of ‘Urgent’, ‘Priority’ and ‘Routine’ QoS groups, simultaneously, without voice traffic. Generation time intervals of ‘Urgent’ and ‘Priority’ location information packets have exponential distributions with mean 20 hours and 10 hours, respectively. The size of each packet is 200 bytes for both QoS groups. Meanwhile, we generate ‘Routine’ location information packets with a constant time interval of 30 sec and the size of 100 bytes. Among the three QoS groups, we used the performance of ‘Routine’ QoS group as a performance criterion for four scenarios.

Fig.2.(a) shows the average delay of ‘Routine’ QoS group packets for four different scenarios when all the network nodes generate location information packets without voice traffic. Scenario 3 yields the shortest average delay of 16sec. This is because merging the packets in both UL and DL directions reduces network congestion and transmission time remarkably. Thus, the average delay performance of scenario 3 is the best in spite of merging delay. Fig.2.(b) illustrates the success probabilities of four different scenarios when all the network nodes generate location information packets without voice traffic. Scenario 3 yields the highest success probability of 0.74. This is because merging the packets in both UL and DL directions reduces the conflicts of resource usage of each node. From these results, merging the packets in both UL and DL packets enhances the performance of the ad-hoc network based on the MIL-STD-188-220C standard.

B. Voice and Data Traffic

Now, it is very meaningful to find the optimum generation time interval of location information packets in scenario 3 when voice traffic, mentioned in Section III-B, exists. The generation time interval of packets affects the queueing delay at each node for data merging. Thus, it is a very important factor. Fig.3 shows the average delay and success probability of scenario 3 for varying GPS time intervals. When the GPS time interval, or generation time interval of location information packets, is set to 30 sec, the average delay decreases significantly. On the other hand, the success probability increases rapidly when the GPS time interval is shorter than 30 sec. However, the success probability is slowly saturated when the GPS time interval is longer than 30 sec. Thus, each node needs to generate location information packets with a time interval of 30sec. Here, we must keep in mind that although long GPS time interval guarantees the low average delay and high success probability, it reduces the real-time updating capability of the GPS information.

Fig.4 shows the performance of scenario 3 in terms of average delay and success probability for varying data rates. The result shows that high data rates result in low average delay and high success probability. More specifically, as the data rates increase, the transmission time and queueing delay, which are main factors of the average delay, decrease. Since the number of packets in the queue at each node decreases as the data rate increases, packet discard rate also decreases. Thus, the success probability is high when data rates are high. From the result, the minimally required data rate is 4800 bps

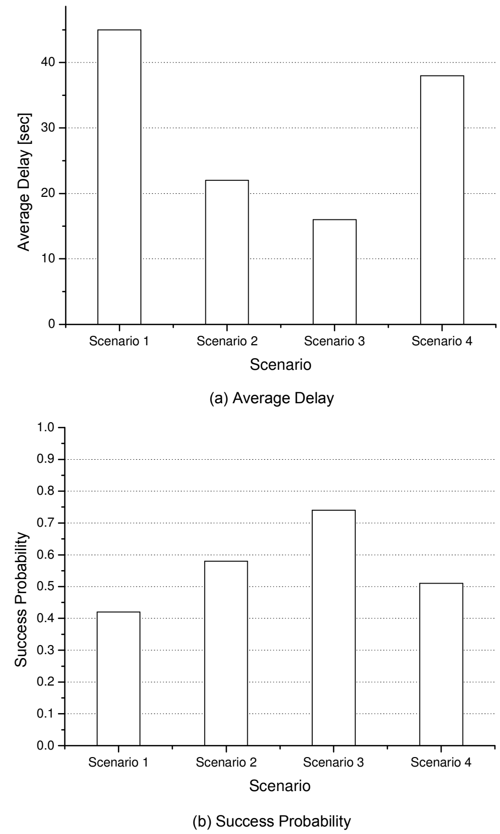

Fig. 2. Performance comparion of all scenarios

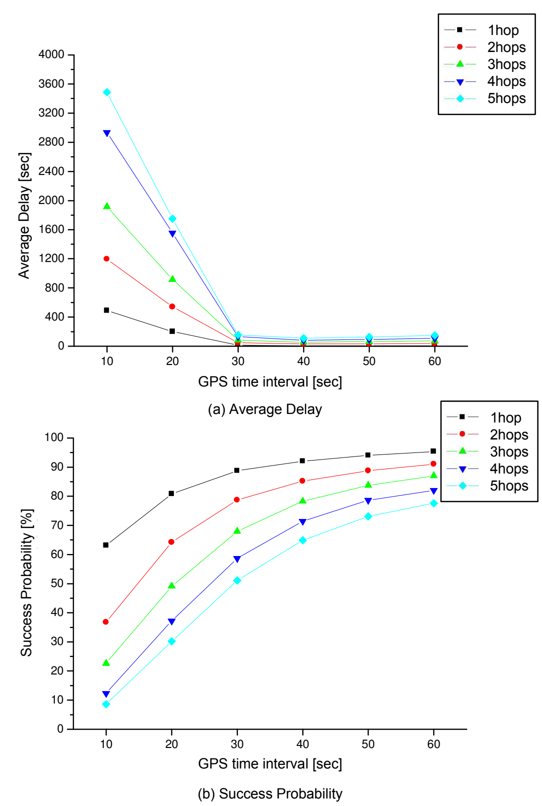

Fig. 3. Performance of Scenario 3 for varying GPS time intervals

to have reasonable performance. However, we should note that the performance enhancement becomes small when the data rate is higher than 4800bps, while it is large when the data rate is lower than 4800bps. This is because the relationship between the average delay and date rate is reciprocal as shown in Eq. 3.

$$D = \frac{U}{R} + Q + P \propto \frac{1}{R}, \quad (3)$$

where D is the average delay, U is the packet size, R is the data rate, Q is the queueing delay, and P is the propagation delay. Thus, the average delay or the success probability also increases more slowly as the data rate increases.

V. Conclusion

In this paper, we modeled an integrated voice and data ad-hoc network based on the MIL-STD-188-220C standard of American Department of Defense. We proposed four scenarios for the effective delivery of GPS location information packets and compared the performance of all scenarios by OPNET simulation. The result shows that merging the packets in UL/DL directions yields the best performance in the terms of average delay and success probability. Furthermore, we note that the optimum value of GPS time interval is 30 sec and the minimally required data rate is 4800 bps. These results can be utilized in tactical communication network systems based on the MIL-STD-188-220C standard of American Department of Defense for better performance.

References

[1] C. K. Toh, *Ad Hoc Mobile Wireless Networks: Protocols and Systems*, Prentice Hall PTR, 2002.

[2] Mohammad llyas, *The Handbook of Ad-hoc Wireless Networks*, crc press, 2003.

[3] *'Interoperability Standard for Digital Message Transfer Device Subsystems (MIL-STD-188-200C)'*, 2 March 2002.

[4] *http://www-cnrwg.itsi.disa.mil/*

[5] Jonathan M. Nicholas, Albert Futernik, "Queuing Structures in SINCGARS Radio Networks", *IEEE Military Communications Conference*, Vol. 1, pp. 211-217, Oct., 1998.

[6] *Formal Specification of MIL-STD-188-220C written in Estelle Formal Description Technique*

[7] *ISO Standard 9074*

[8] *MIL-STD-188-220C Protocol Parameters and Values*

[9] *MIL-STD-188-220C Media Access Configuration Parameters and Parameter Values*

[10] P. T. Brady, "A Technique for Investigating On-Off Patterns of Speech", *Bell System Technical Journal*, pp. 1-22, Jan., 1965.

[11] Arturas Medeisis, Algimantas Kajackas, "On the Use of the Universal Okumura-Hata Propagation Prediction Model in Rural Areas", *IEEE Vehicular Technology Conference 2000*, Vol. 3, pp. 1815-1818, May. 2000.

[12] Sklar, *Digital Communication*, Prentice Hall, 2004.

[13] Rapparport, *Wireless Communications*, Principle and Practice, second edition.

[14] Jakes, W.C., *Microwave Mobile Communications*, Wiley, New York, 1974.

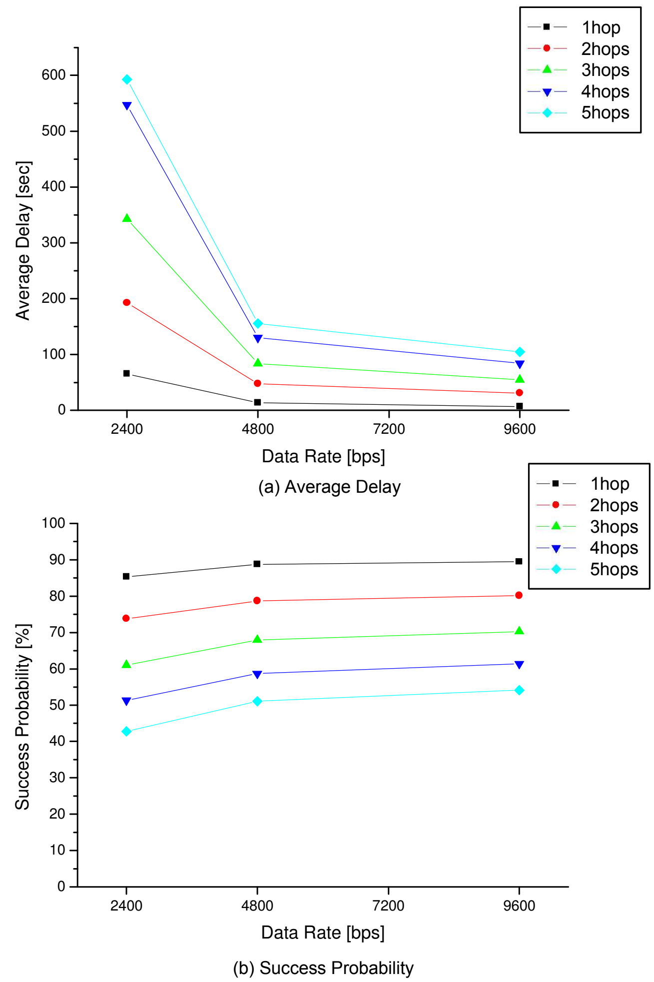

Fig. 4. Performance of Scenario 3 for varying data rates