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Performance Analysis of a Directional MAC Protocol for Location Information Staleness in MANETs

Masanori Takata,† Masaki Bandai†† and Takashi Watanabe††

In recent years, several MAC (Medium Access Control) protocols using directional antennas have been proposed for mobile ad hoc networks (MANETs) including our proposed MAC protocol called SWAMP (Smart antennas based Wider-range Access MAC Protocol). These are typically referred to as directional MAC protocols. This paper first summarizes the proposed directional MAC protocols and outlines these common issues, which reduce the probability of successful transmissions, such as location information staleness, deafness and directional hidden- and exposed-terminal problems arisen due to directional transmissions. This paper formulates and analyzes the issues of directional MAC protocols, and proposes solutions of these issues, especially for location information staleness. The experimental results show that the mobility prediction and the optimization of parameters associated with location information staleness, such as the beamwidth and lifetime of the table information, may mitigate location information staleness and improve the overall network performance.

1. Introduction

Mobile ad hoc networks [1] are the autonomous system of mobile nodes which share a single wireless channel to communicate with each other. The previous works on ad hoc networks assume the use of omni-directional antennas that transmit or receive signals equally well in all directions. Traditional MAC protocols, such as IEEE 802.11 DCF (Distributed Coordination Function) [2], are designed for omni-directional antennas and cannot achieve high throughput in ad hoc networks because that waste a large portion of the network capacity as discussed in Ref. 3).

On the other hand, smart antenna technology may have various potentials [4]. In particular, it can improve spatial reuse of the wireless channel, which allows nodes to communicate simultaneously without interference. Furthermore, the directional transmission concentrates signal power to the receiver, which enlarges the transmission range. Thus, it can potentially establish links between nodes far away from each other, and it prevents network partitions and the number of routing hops can be fewer than that of omni-directional antennas.

However these potentials smart antennas may have, a sophisticated MAC protocol is required to take advantage of these benefits in ad hoc networks. Recently, several directional MAC protocols, typically modifications of IEEE 802.11 DCF, have been proposed for ad hoc networks including our proposed MAC protocol called SWAMP (Smart antennas based Wider-range Access MAC Protocol) [5]. SWAMP provides both spatial reuse of the wireless channel and communication range extension by two types of access modes that utilize the directional beam effectively, and it contains a method of obtaining the location information of its neighbors.

Directional MAC protocols, however, introduce new kinds of issues related to directional transmissions, such as location information staleness, deafness and directional hidden- and exposed-terminal problems. When the transmitter uses the directional beam based on the table information recorded in advance to point the beam towards the specific node, a gap between the table information and the actual location is arisen due to the lapse of time and the mobility of nodes. We refer to this phenomenon as location information staleness.

This paper first summarizes the proposed directional MAC protocols and outlines these common issues. This paper formulates and analyzes the issues of directional MAC protocols and confirms its negative impact on network performance through computer simulations. In addition, this paper proposes solutions of these issues, especially for location information staleness, and evaluates the effects of the solution of location information staleness. The experi-

† Graduate School of Science and Engineering, Shizuoka University
†† Faculty of Informatics, Shizuoka University

mental results show that the mobility prediction and the optimization of parameters associated with location information staleness, such as the beamwidth and lifetime of the table information, may mitigate location information staleness and improve the overall network performance.

2. Directional MAC Protocols

Several MAC protocols using smart antennas or directional antennas, typically referred to as directional MAC protocols, have been proposed for ad hoc networks.

Ko, et al.[6] propose DMAC (Directional MAC) in which all frames are transmitted directionally except for the CTS (Clear To Send). Choudhury, et al.[7] propose MMAC (Multi-hop RTS MAC), which involves the multi-hop RTS (Request To Send) to take advantage of the higher antenna gain obtained by directional antennas. These protocols, however, need various additional mechanisms to provide the location information and to forward the RTS.

In Refs. 8)∼11), RTS is transmitted omni-directionally in order to find the receiver in case location information is not available. Each node estimates the direction of neighboring nodes for pointing the beam with AOA (Angle of Arrival) when it hears any signal. Because these protocols employ at least one omni-directional transmission, it limits the coverage area provided by directional transmissions and do not exploit one of the main benefits of directional antennas, i.e., the increase of the transmission range, either.

Ramanathan, et al.[12,13] propose circular directional transmission of periodic hello packets to obtain node information that is located farther away than the omni-directional transmission range, called directional neighbor discovery. Korakis, et al.[14] propose circular RTS, which scans all the area around the transmitter to find the addressed receiver and to tackle the deafness and the hidden-terminal problem arisen from directional transmissions. Bandyopadhyay, et al.[15] develop additional frames in order to determine the neighbor topology by recording the angle and signal strength. Although these schemes attempt communication range extension, circular transmission increases the delay and incurs large control overhead.

Ueda, et al.[16] propose a receiver-oriented rotational-sector based directional MAC protocol. If each node senses some signal, it rotates its directional antenna sequentially and senses the received signal at each direction. Then, it sets its beam to the direction with maximum received signal strength and receives the signal. To track the best possible direction of receiving signal, each control frame is transmitted with a preceding tone.

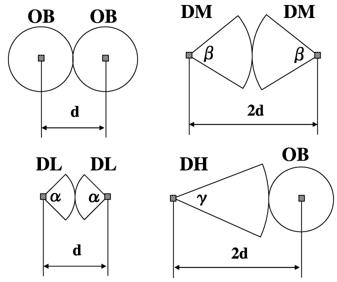

Fig. 1 Smart antenna beamforming (Left side is the transmitting beamforming and right side is the receiving beamforming).

3. SWAMP

In this section, we illustrate our proposed directional MAC protocol called SWAMP[5]. SWAMP is based on IEEE 802.11 DCF and utilizes the directional beam effectively to increase the spatial reuse and extend the transmission range. SWAMP consists of two access modes, OC-mode (Omni-directional transmission range Communication mode) and EC-mode (Extended transmission range Communication mode).

3.1 Antennas Models

SWAMP provides four antenna beam forms. **Figure 1** illustrates four beam forms and each transmission range. Note that in the figure nodes can communicate when the transmitting beam and the receiving beam are at least tangential to each other. OB (omni-directional beam form) and DL (directional low gain beam form) are for the regular link communication in OC-mode, while DM (directional middle gain beam form) and DH (directional high gain beam form) for the extended link communication in EC-mode.

3.2 OC-mode

Figure 2 illustrates the OC-mode frame sequence with the corresponding beams. OC-mode is selected when the receiver is located within the area of omni-directional transmission range or when the transmitter has no knowledge about the receiver. The RTS/CTS handshaking tries to reserve the wireless channel and to exchange the location information between the transmitter and the receiver.

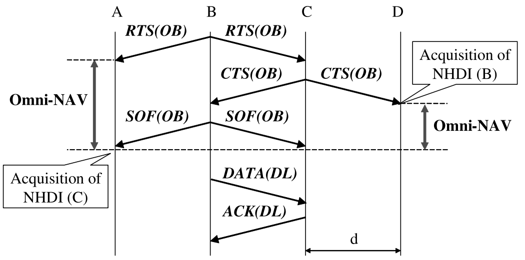

Fig. 2 OC-mode frame sequence (B to C).

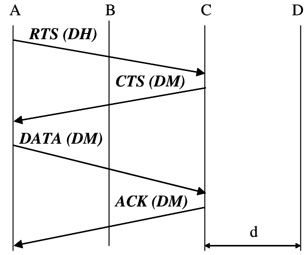

Fig. 3 EC-mode frame sequence (A to C).

Then, these nodes forward the location information that is obtained by the reception of the RTS or CTS to neighbors as the NHDI (Next Hop Direction Information) using omni-directional CTS or SOF (Start of Frame). NHDI is registered to the NHDI table of each node and this information is used in EC-mode. DATA and ACK are sent by DLs that point beams towards each other. Omni-NAV (Network Allocation Vector) shorter than ordinal NAV is used to increase simultaneous communications and the spatial reuse of the wireless channel.

3.3 EC-mode

Figure 3 illustrates the EC-mode frame sequence with the corresponding beam. EC-mode is selected when the receiver has been already registered in the transmitter's NHDI table. Because the transmitter has the prior knowledge of the direction of the intended receiver, the transmitter can determine the direction to point the beam towards the receiver. To perform communications between nodes at a distance of $2d$ (d in Fig. 1), RTS is required to use the high gain beam form (DH) because the receiver waits for signals with the omni-directional beam form (OB) in an idle state. After the transmitter sends RTS, it switches the beam form from DH to DM. After the receiver receives RTS, it also switches the beam form from OB to DM and points the beam towards the transmitter. When the transmitter fails EC-mode access over the EC-retry limit, the transmitter deletes the receiver information from its own NHDI table. In EC-mode, DNAV (Directional NAV)[10] is used instead of NAV for virtual carrier sensing.

4. Issues of Directional MAC

This section discusses some common issues of directional MAC protocols such as location information staleness, deafness and directional hidden- and exposed-terminal problems. We propose solutions to deal with location information staleness, and propose the mechanism of interference suppression to mitigate the directional exposed-terminal problem.

4.1 Definitions of Directional Communication

We define N as a set of nodes in the network area ($N = \{n_1, n_2, \ldots, n_K\}$). We define the omni-directional antenna pattern as a circle with radius r^o, and the directional antenna pattern as a circular sector with radius $r^d (\geq r^o)$, angle (boresight of the antenna pattern) α ($0 < \alpha \leq 2\pi$) and beamwidth θ ($0 < \theta \leq 2\pi$). r^o and r^d are fixed in our study. Omni-directional transmission area and omni-directional reception area of $n_i \in N$ are defined as $T^o_{n_i}$ and $R^o_{n_i}$, respectively. Also, directional transmission area and directional reception area of n_i are defined as $T^d_{n_i}(\alpha, \theta)$ and $R^d_{n_i}(\alpha, \theta)$, respectively.

We assume that node n_t transmits a message with angle α_t and beamwidth θ_t, and node n_r receives it with angle α_r and beamwidth θ_r (**Fig. 4**). When the transmission area T_{n_t} and the reception area R_{n_r} are overlapped, n_r will receive a message transmitted by n_t, which is defined as $\{T_{n_t} \cap R_{n_r} \neq \emptyset\}$. In directional case, in addition, n_r will receive a message transmitted by n_t iff (if and only if) (1), (2) and (3) hold, which is defined as $\{T^d_{n_t}(\alpha_t, \theta_t) \cap R^d_{n_r}(\alpha_r, \theta_r) \neq \emptyset\}$.

$$\frac{\theta_t}{2} \geq \begin{cases} \mid \alpha_t - \delta_t \mid & (\mid \alpha_t - \delta_t \mid \leq \pi) \\ 2\pi - \mid \alpha_t - \delta_t \mid & (\mid \alpha_t - \delta_t \mid > \pi) \end{cases} \quad (1)$$

$$\frac{\theta_r}{2} \geq \begin{cases} \mid \alpha_r - \delta_r \mid & (\mid \alpha_r - \delta_r \mid \leq \pi) \\ 2\pi - \mid \alpha_r - \delta_r \mid & (\mid \alpha_r - \delta_r \mid > \pi) \end{cases} \quad (2)$$

$$\mid n_t - n_r \mid \leq r^d + r^d \quad (3)$$

where δ_t is an angle from n_t to n_r, δ_r is an angle from n_r to n_t, and $\mid n_t - n_r \mid$ is the distance between nodes. Informally speaking, a transmitting beam of n_t should be towards n_r, and

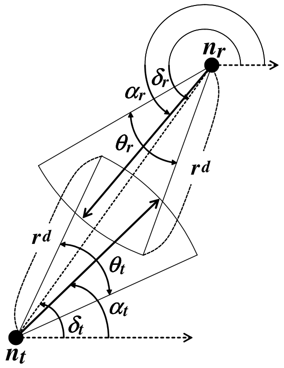

Fig. 4 Definition of directional communication.

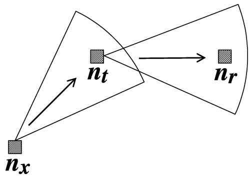

Fig. 5 Deafness.

vice versa.

4.2 Location Information Staleness

In directional MAC protocols, the transmitter must know and maintain the location of the intended receiver to point the beam in the appropriate direction. Therefore, most of directional MAC protocols use the table to maintain the direction of neighbor nodes. When the transmitter uses the table information recorded in advance to point the beam towards the specific node, a gap between the cached location information and the actual location of the neighbor node is arisen due to the lapse of time and the mobility of nodes. This gap deteriorates the reliability of the transmission because the direction of transmission becomes inaccurate due to the out-of-date location information.

We assume n_t attempts to communicate with n_r with angle α_t and beamwidth θ_t based on the cached angle information about n_r. Actual angle from n_t to n_r is δ_t.

When the angle gap becomes larger than the beamwidth, n_t fails to communicate with n_r, which is defined as (4). We refer to this phenomenon as location information staleness.

$$\frac{\theta_t}{2} < \begin{cases} \mid \alpha_t - \delta_t \mid & (\mid \alpha_t - \delta_t \mid \leq \pi) \\ 2\pi - \mid \alpha_t - \delta_t \mid & (\mid \alpha_t - \delta_t \mid > \pi) \end{cases} \tag{4}$$

In Refs. 9), 10), if a transmitter fails to get the CTS response back from the receiver after 4 consecutive directional transmissions of the RTS frame, it is assumed that the corresponding AOA information is out-of-date and subsequent RTS frames are sent omni-directionally to deal with location information staleness. These schemes, however, are only available for communications within the omni-directional transmission range.

In Ref. 14), multiple directional RTS frames are transmitted consecutively in a circular way for each transmitted data frame to handle location information staleness but it has high control overhead. In Ref. 17), if a transmitter does not receive a reply from the receiver, the transmitter sends hello packets using adjacent beams to update the location information of the receiver. It also incurs large control overhead.

To handle the issue of location information staleness with low overhead and to improve the reliability of the table based directional transmission, we propose the following schemes and evaluate the effects of these schemes in Section 5.

- Optimization of parameters related to location information staleness such as the beamwidth and lifetime of the table information
- Mobility prediction based on the history of the location information or other prediction algorithms

4.3 Deafness

Directional transmission of RTS/CTS, which is usually used in directional MAC protocols, introduces new kinds of problems. One problem is deafness [7]. In **Fig. 5**, deafness is caused when n_x repeatedly attempts to communicate with n_t, but it fails to communicate because n_t has its beam pointed towards a direction away from n_x and cannot hear the signal from n_x.

A set of deafness nodes $D(n_t, n_r)$ is defined as follows.

$$\begin{aligned} D = \{n_x | n_x \in N, \{T^d_{n_x} \cap R^d_{n_t} = \emptyset\} \\ \vee \{T^d_{n_x} \cap R^d_{n_r} = \emptyset\}\} \end{aligned} \tag{5}$$

where n_t is a transmitting node, n_r is a receiving node and n_x is a deafness node, which wants to communicate with n_t or n_r.

4.4 Directional Hidden Terminal Problem

The other problem of directional RTS/CTS is hidden-terminal due to asymmetry in gain [7], referred to as the directional hidden-terminal problem [18] in this paper. Assume that n_t is communicating with n_r (**Fig. 6**). Directional hidden-terminal problem is caused by the

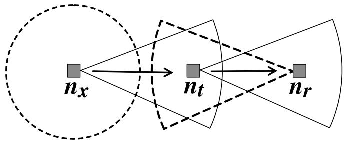

Fig. 6 Directional hidden-terminal problem.

neighboring node of the on-going communication, say n_x, which is far enough from n_r not to hear the CTS pointed towards n_t (and also n_x). If n_x transmits the RTS directionally towards the direction of n_r, it may interfere with the on-going communication because n_r is receiving DATA with a beam pointed towards n_t and n_x.

A set of directional hidden terminals $H(n_t, n_r)$ is defined as follows.

$$\begin{aligned} H = \{n_x | n_x \in N, &\{T^d_{n_t} \cap R^o_{n_x} = \emptyset\} \\ &\wedge\{T^d_{n_r} \cap R^o_{n_x} = \emptyset\} \\ &\wedge\{T^d_{n_x} \cap R^d_{n_r} \neq \emptyset\}\} \end{aligned} \quad (6)$$

where n_t is a transmitting node, n_r is a receiving node and n_x is a directional hidden terminal of n_r.

4.5 Directional Exposed Terminal Problem

In most of directional MAC protocols, each node waits for signals with the omni-directional mode in an idle state. Therefore, in **Fig. 7**, during the data transmission between n_t and n_r, n_x gets engaged in receiving signals between n_t and n_r. If n_y sends RTS to n_x, it will result in collision at n_x. We refer to this type of exposed-terminal problem as the directional exposed-terminal problem.

A set of directional exposed terminals $E(n_t, n_r)$ is defined as follows.

$$E = \{n_x | n_x \in N, \{T^d_{n_t} \cap R^o_{n_x} \neq \emptyset\}\} \quad (7)$$

where n_t is a transmitting node, n_r is a receiving node and n_x is a directional exposed-terminal of n_t.

We propose the interference suppression mechanism to reduce RTS collisions due to the directional exposed-terminal problem (Fig. 7). Because the data frame from n_t is unproductive for n_x, n_x needs not receive the signal from n_t. In our mechanism, n_x is beamformed in the direction away from the n_t's direction for duration of the on-going communication between n_t and n_r after the receipt of the RTS from n_t. Therefore, if n_y sends RTS to n_x, n_x can reply and communicate simultaneously. This mech-

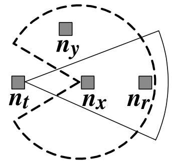

Fig. 7 Interference suppression (Solid line is the transmitting beamforming of n_t and Dotted line is the receiving beamforming of n_x).

anism may mitigate the directional exposed-terminal problem and improve the number of simultaneous communications. Evaluating the effects of our proposed interference suppression mechanism is our future work.

5. Performance Analysis

In this section, we analyze different factors which reduce the probability of successful transmissions, such as location information staleness, deafness and directional hidden- and exposed-terminal problems arisen due to directional transmissions, and confirm its negative impact on network performance through computer simulations. In addition, we investigate the effects of the different values of parameters related to location information staleness, such as the beamwidth and lifetime of the table information, and the mobility prediction to deal with the issue of location information staleness. Among directional MAC protocols, SWAMP is used to investigate the effects of issues mentioned in Section 4.

We make the following assumptions. A hundred nodes are arranged at random in a square area with dimensions of 1,500 m and move independently according to the random way point mobility model with a maximum speed of 40 km/h and a pause time of zero. Packets arrive at every node according to Poisson distribution with mean value of λ (packets/s). Destination node for each packet is chosen at random from two hop neighbors. A packet size is 512 bytes, location information is 4 bytes and an omni-directional transmission range (d in Fig. 1) is 250 m. The beamwidth of DL, DM and DH are 45 degrees. The data rate is 2 Mbps.

5.1 Performance of Protocols

The throughput versus the offered load is shown in **Fig. 8**. The throughput of SWAMP (OC), which is the case using OC-mode only for all communication, is roughly 2 times against IEEE 802.11 DCF. This is because OC-mode improves the spatial reuse of the wireless chan-

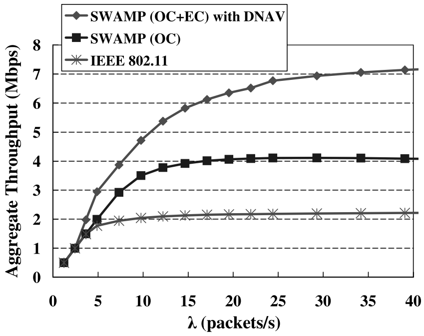

Fig. 8 End-to-End throughput.

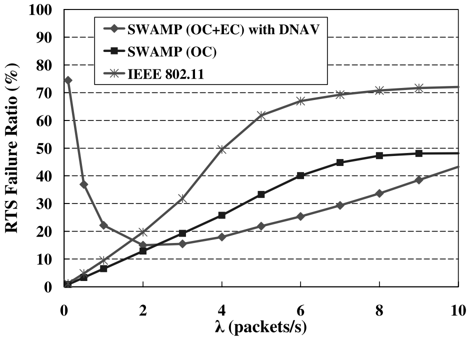

Fig. 9 RTS failure ratio.

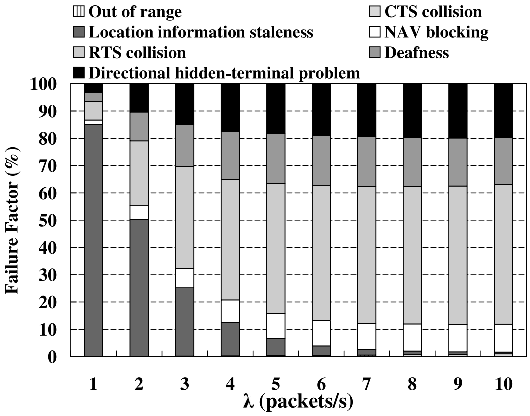

Fig. 10 Communication failure factors.

nel due to omni-NAV, and consequently more node pairs can communicate simultaneously. SWAMP (OC+EC) with DNAV outperforms others because packets are delivered to the destination in fewer hops in EC-mode, and the consumption of the wireless channel and store-and-forward overhead are reduced. In addition, since DNAV is used for virtual carrier sensing in EC-mode, nodes can initiate an EC-mode access if DNAVs are not set in the desired direction and it improves performance by allowing simultaneous transmissions.

5.2 Analysis of Communication Failure

Figure 9 shows the RTS failure ratio of three protocols. RTS failure ratio (RFR) is calculated as follows.

$$RFR = \frac{NR_{CTS}}{T_{RTS}} \times 100 \qquad (8)$$

where NR_{CTS} is the number of not received CTS and T_{RTS} is the number of transmitted RTS.

Figure 10 shows the communication failure factors of SWAMP (OC+EC) with DNAV. Communication failure factors in directional MAC protocols are classified as follows.

- Out of range: The addressed receiver node moves out of range of the transmitter's communication range.
- CTS collision: The receiver node sends CTS, however the transmitter cannot receive it because of collision.
- Location information staleness: The gap between the cached location information and actual location of the addressed node becomes larger than the beamwidth.
- NAV blocking: The receiver node receives RTS correctly, but cannot send CTS because DNAVs are set in the direction of the transmitter.
- RTS collision: RTS is not received correctly by the receiver since other nodes are transmitting (i.e., the receiver node is an exposed-terminal, or two or more nodes transmit control frames concurrently).
- Deafness: The receiver node cannot receive RTS because the receiver is beamformed towards the direction away from the transmitter.
- Directional hidden-terminal problem: Hidden terminal due to asymmetry in gain or hidden terminal due to unheard RTS/CTS [7].

As shown in Figs. 9 and 10, SWAMP increases the communication failure due to location information staleness especially when the offered load is low (out of range and CTS collisions are almost 0 % in Fig. 10). This is because the gap between the NHDI and actual location of the neighbor node is large when the frequency of update of the NHDI is low, and nodes try to communicate frequently and attempt multiple retransmissions under such situations. Therefore, handling issue of location information staleness is significant in directional

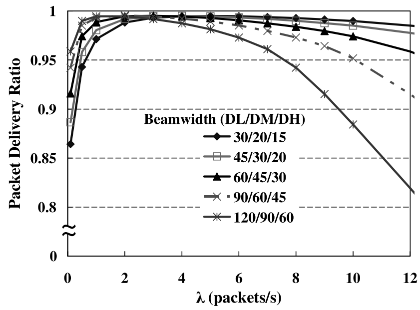

Fig. 11 Effects of the beamwidth (degrees).

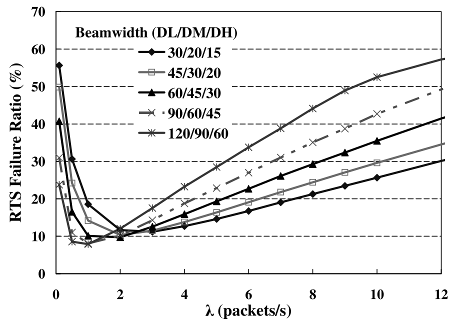

Fig. 12 Effects of the beamwidth on RTS failure ratio.

MAC protocols in low load.

Another main factor of communication failure is RTS collision. Since RTS collisions mainly occur due to congestion, it may not be possible to completely get rid of. However, our proposed interference suppression mechanism can mitigate RTS collisions due to the directional exposed-terminal problem. Evaluating the effects of interference suppression mechanism is our future work.

Deafness and directional hidden-terminal problems are also reduce the probability of successful transmissions, which may not arise in the case of omni-directional transmissions. Therefore, there is a tradeoff between spatial reuse of the wireless channel using directional transmissions and collision avoidance using omni-directional transmissions.

There are communication failure factors of SWAMP, but that may arise with other directional MAC protocols as well.

5.3 Analysis of Parameters

To handle the issue of location information staleness and to improve the reliability of the table based directional transmission, dynamic adaptation of parameters related to the reliability of the transmission such as the beamwidth and lifetime of the table information can be available.

In this section, we confirm the effects of the different values of these parameters on the performance of our proposed MAC protocol.

Figure 11 shows the effects of the beamwidth. SWAMP uses three kinds of directional beam (i.e., DL, DM and DH). We set up five different sets of beamwidths while the transmission range of each beam is kept according to Fig. 1. When λ is low, the cases using wider beamwidths have better performance. This is because that the frequency of update of the NHDI table entry is low and the gap between the NHDI and actual location of the neighbor nodes is large. Under these situations, the wider beamwidth is suitable for struggling with location information staleness. When λ is high, to the contrary, narrower beamwidths have better performance. If the network traffic is high, each node can acquire the NHDI frequently by overhearing the communication between neighboring nodes and the NHDI is maintained fresh and accurate. Therefore, the narrower beam can reduce the interference and contention among nodes and improve the spatial reuse when the NHDI is sufficiently accurate and reliable. It implies that the optimization of the beamwidth based on the network traffic or the freshness of the table information mitigates location information staleness and improves the efficiency of spatial reuse.

Figure 12 shows the effects of the different values of the beamwidth on RTS failure ratio. It can be seen that wide beamwidth reduces the RTS failure compared with narrow beamwidth in low offered load. This is because the RTS transmission using wide beamwidth can cover the addressed node and fill the angle gap.

We have confirmed that the adaptation of the beamwidth requires not only the surrounding traffic information but also the mobility of nodes. **Figure 13** shows the relation among the elapsed time from NHDI receipt, average angle gap, and the mobility of nodes. It can be seen that the gap between the NHDI and actual location of the neighbor nodes becomes larger as the time elapses and the nodes move faster.

Figure 14 shows the effects of the lifetime of NHDI table information. Each node maintains an NHDI table with one record for every node that receives NHDI in SWAMP. In the NHDI table, the TTL (Time to Live) represents the lifetime of the entry and it is related to the re-

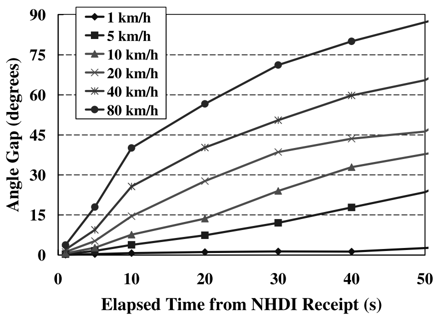

Fig. 13 Elapsed time from NHDI receipt and angle gap.

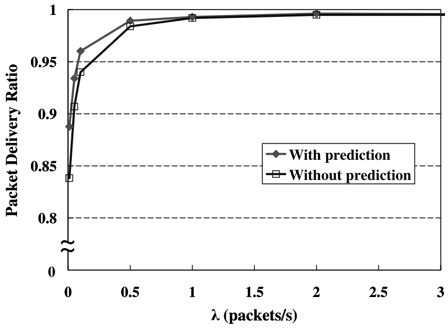

Fig. 15 Effects of the mobility prediction with arrival rate.

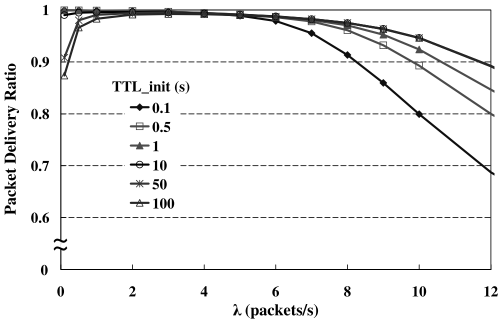

Fig. 14 Effects of the TTL.

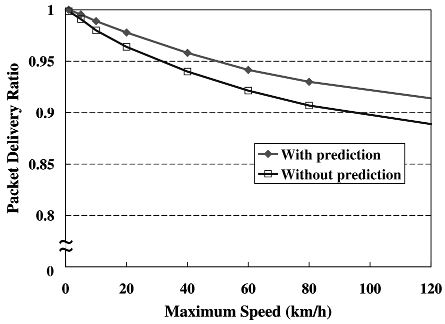

Fig. 16 Effects of the mobility prediction with mobility.

liability of the transmission. TTL is decreased during the progress of time. If the TTL expires, the corresponding record is deleted. When the NHDI is obtained that is already registered, it is updated and the TTL is initialized (TTL_init).

As shown in Fig. 14, the cases using the large TTL_init are unsuitable compared with the cases using small one when λ is small because the transmission based on the obsolete table information deteriorates the reliability. As λ becomes larger, however, the cases using the small TTL_init grow rapidly worse. This is because that the NHDI entry is deleted frequently although it is sufficiently accurate and reliable. In this case, each node cannot gain the benefits of directional communications. Therefore, the reliability of the transmission and the overall network performance has the relation of a trade-off. To adapt the TTL_init dynamically, we must consider the network load, mobility of node, and QoS (Quality of Service) requirement.

5.4 Mobility Prediction

SWAMP and most of the previous works on smart antennas based MAC protocols use the table to maintain the direction of neighbor nodes. Therefore, each node can predict the mobility of neighbor nodes based on the history of the location information and its receipt time. Because the mobility prediction algorithm is out of scope of this paper, we use the simplest linear prediction algorithm to predict the direction of the neighbor nodes. Other mobility prediction algorithms are proposed in Refs. 19), 20), these are used to predict the link expiration time. **Figures 15** and **16** show the packet delivery ratio with and without the mobility prediction versus the arrival rate (when maximum speed = 40 km/h) and the mobility speed (when $\lambda = 0.1$) respectively. As shown in Figs. 15 and 16, the mobility prediction improves packet delivery ratio due to the improvement of the reliability of the transmission, especially when the arrival ratio is low and the node mobility is high.

6. Conclusion

This paper has analyzed the issues of directional MAC protocols, such as location information staleness, deafness and hidden- and exposed-terminal problems arisen due to directional transmissions. We have summarized the proposed directional MAC protocols and have discussed the common issues of directional MAC protocols, which reduce the probability of successful transmissions, and have confirmed its negative impact on network performance through computer simulations. Results show that RTS collision and location information staleness are significant issues among the communication failure factors. In addition, we have proposed the mechanism of interference suppression in order to mitigate the directional exposed-terminal problem, and have investigated the optimization of parameters associated with location information staleness, such as the beamwidth and lifetime of the table information, and have evaluated the effects of mobility prediction to deal with location information staleness.

The experimental results show that the different values of the beamwidth and lifetime of the table information have an impact on the performance of protocol and these parameters should be optimized based on the network traffic, the freshness of the table information, the mobility of nodes and the QoS requirement to mitigate location information staleness and to improve the overall network performance.

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Masanori Takata received his B.S. and M.S. degrees in computer science from Shizuoka University in 2003 and 2004 respectively. Currently, he is working towards his Ph.D. degree at Shizuoka University. He has been a COE researcher at Shizuoka University since December 2004. He received the TELECOM System Technology Award for Student from the Telecommunications Advancement Foundation in 2004 and the IPSJ Yamashita SIG Research Award in 2005. His current research interests include wireless networks, ad hoc networks and sensor networks. He is a member of IEEE, IEEE Communications Society, IEICE and IPSJ.

Masaki Bandai received his B.E. and M.E. degrees in electrical engineering and Ph.D. degree in information and computer science from Keio University in 1996, 1998 and 2004 respectively. From 1998 to 2000, he joined Sony Corporation. From 2001 to 2003, he was a Research Fellow of the Japan Society for the Promotion of Science. He is currently an assistant professor of Faculty of Informatics at Shizuoka University. His current research interests include computer network systems. He is a member of IEEE, IEICE and IPSJ.

Takashi Watanabe received his B.E., M.E. and Ph.D. degrees in communications engineering from Osaka University in 1984 and 1987 respectively. In 1987, he joined Faculty of Engineering, Tokushima University as an assistant professor. In 1990, he moved to Faculty of Engineering, Shizuoka University. He was a visiting researcher at University of California, Irvine from 1995 through 1996. He is currently a professor of Faculty of Informatics, Shizuoka University. He is a translator of Japanese version of 802.11 Wireless Networks: The Definitive Guide (published by O'REILLY, 2003). His current research interests include computer networks, mobile networking, ubiquitous networks, ad hoc networks and sensor networks. He is a member of IEEE, IEEE Communications Society, IEEE Computer Society, ACM SIGMOBILE, IEICE and IPSJ.