A distance-aware forwarding protocol for beaconless communication in mobile ad hoc networks and its performance

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***Abstract*—Recently, routing protocols for Mobile Ad hoc NETworks (MANETs) which use position information to improve their efficiency have been actively studied. In this paper, we focus on Beacon-Less Routing algorithm (BLR) and propose a new forwarding algorithm that improves BLR and analyze its performance.**

BLR is efficient to reduce redundancy in its transmissions for flooding. When a node receives a packet, a time variable referred to as deferring time is calculated using the positions of the sender, the receiver, and the final destination of the packet. Each node forwards the packet after this deferring time unless it notices that another node forwards the same packet during the deferring time. As a result, only the node that is assigned the shortest deferring time forwards the packet. It is necessary to make this deferring time as short as possible in order to reduce the total deferring time in a multi-hop transmission.

In order to evaluate our approach named Distance-Aware Forwarding (DAF), we carry out a performance analysis. Numerical results demonstrate that the proposed approach reduces the total deferring time in a multi-hop transmission, although the number of hops slightly increases.

I. Introduction

Recently, with the rapid development of wireless technologies and miniaturization of terminals, networks requiring no fixed infrastructure have been getting attractive. Applications deployed in disaster area and under water area are emerging. These networks are called ad hoc networks, where a node plays a role as both end-host and router. Specifically, an ad hoc network formed by mobile nodes is known as Mobile Ad hoc NETwork (MANET). Due to the mobility, frequent and unexpected topology changes occur in MANETs. In such environment, the realization of efficient routing is crucial research topic. Many protocols applied in MANETs have been proposed. These protocols are classified into two types: topology-based routing and position-based routing.

Topology-based routing protocols use the information of link states in the network to forward a packet. These protocols can be further classified into two types, proactive and reactive. Proactive routing protocols, including OLSR [1], maintain all the route information existing in a network even if the routes are not currently used. Thus, the unused information wastes available bandwidth, as sending data packets while the topology change, becomes frequent. On the other hand, reactive routing protocols, including AODV [2], only maintain the information of routes which are currently used. Therefore, they have better scalability than proactive types. However, this type of protocols introduces delay caused by route discovery procedures when a node sends the first packet. Packets delivering routing information occupy available bandwidth as well as proactive routing protocols in high-mobility networks even if the nodes do not maintain unused route information. Hybrid routing protocols combining both proactive and reactive routing protocols are proposed in the literature, one of which is ZRP [3]. Hybrid routing protocols achieve more efficiency and scalability. However, they still need to maintain information on routes currently in use. Therefore, they also do not work well in the environments with high frequency of topology changes.

In recent years, position-based routing protocols have been studied actively. Position-based routing protocols use position information to overcome some drawbacks of topology-based routing protocols. In position-based routing, a node needs three pieces of information: its own position, one-hop neighbor positions and a destination position. Generally speaking, its own position is recognized through GPS or other positioning devices. A node senses the positions of one-hop neighbors with beacons. A source node utilizes a location service [4], [5] to locate the destination of the packet. Position-based routing protocols do not need control packets to maintain link states and update routing tables. Geocasting [6] is a further extension in position-based routings, and it enables sending a packet to a given geographic region. GPSR [7] selects a forwarding node which is the closest to the destination of a packet. If a node has no neighbor lying closer than itself, a node sends a packet according to the right-hand rule. GPSR achieves higher packet delivery ratio, lower overhead and less hops than DSR. LAR [8] is classified as a proactive routing protocol,

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and it uses position information. LAR calculates the expected area of the destination in terms of its latest available position information with time-stamp taken into account current time. In the context of LAR, the authors present two protocols, which we call LAR1 and LAR2 in the following. LAR1 suppresses redundant control packets by limiting the responders to route discover requests depending on their positions. The corresponding zone is called requested area. LAR2 lets nodes calculate a predetermined equation including its own position and the destination position. Those nodes with evaluated value larger than a threshold are selected for further forwarding a packet. Both LAR1 and LAR2 achieve lower overhead than a traditional flooding which is shown through some simulations. Although DREAM [9] is very similar to LAR1 and uses the idea of expected area describe in the above, it incorporates its own algorithm to get necessary position information. DREAM achieves higher packet delivery ratio than DSR in a high mobility network. These position-based protocols cause lower overhead or high packet delivery ratio; however, they still need periodical communication with beacons in order to sense the positions of one-hop neighbors.

Beacon-Less Routing algorithm (BLR) [10] is one of the position-based routing protocols and it is an efficient routing protocol requiring no periodical communication with beacons. Generally speaking, while position-based routing protocols need position information of neighbors, BLR never does. In this protocol, the node closest to the final destination forwards a packet by assigning a deferring time according to relative position. However, performance degradation occurs in a multi-hop transmission because this protocol adds the deferring time intentionally in order to select an appropriate node to forward a packet for the next hop.

In this paper, focusing on the deferring time, we propose an approach named Distance-Aware Forwarding (DAF). Our approach is expected to assign shorter deferring time per hop, but the number of hops in a multi-hop transmission may increase. We evaluate the performance of proposed routing algorithms through numerical experiments.

The remainder of this paper is organized as follows. In section II, we overview BLR and propose our packet forwarding algorithm. We describe its performance modeling and analysis in section III, which is followed by numerical examples in section IV. Finally, we conclude our paper and give some words for future work in section V.

II. Beacon-Less Routing Algorithm

Beacon-Less Routing algorithm (BLR) is an effective routing protocol which reduces redundant control packets. It selects the most eligible node to forward a packet by a forwarding timer. A deferring time is the time intentionally assigned by the forwarding timer. All nodes in a network have two important parameters r and d_{M} which denote the transmission range and the maximum deferring time, respectively. We assume that nodes recognize their own position through the positioning system such as GPS and that there are mechanisms that enable a source node to aware a position of a destination node. When the source node has a packet to send, it broadcasts the packet including information on its own and destination's positions to one-hop neighbor nodes. When neighbor nodes of the source node receive a packet, the deferring time is set according to its own, predecessor's and destination's positions. Each node forwards the packet after this deferring time unless it notices that another node forwards the same packet during the deferring time. Thus, only one node that is assigned the shortest deferring time forwards a packet. Nodes repeat this procedure until the packet reaches the destination node.

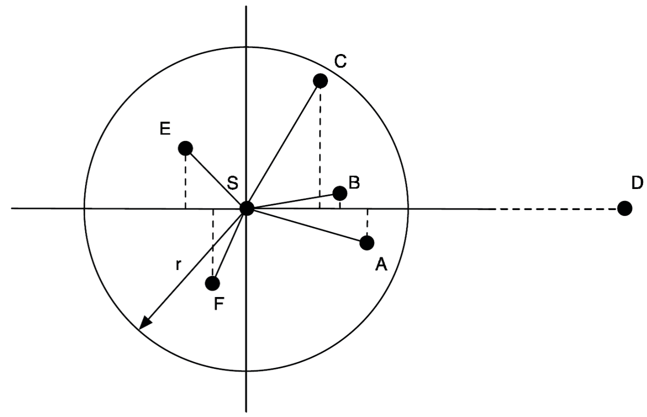

Fig. 1. Forwarding strategies.

A. Forwarding strategies

BLR can adapt to various forwarding strategies by adjusting their functions to calculate the deferring time. In this subsection, we describe the literature related to forwarding strategies. Most Forwarding within Radius (MFR) [11] tries to minimize the number of hops in a multi-hop transmission. It selects the node that has the most progress toward the destination node. Progress is defined as a projection of a distance that a packet travels over the last hop from its sender node to its receiver node onto the line from its sender node to its final destination node. Figure 1 illustrates forwarding strategies in more detail. MFR selects node A in Fig. 1. Nearest with Forwarding Progress (NFP) [12] is proposed in order to reduce interference among multiple transmissions. When a node adjusts the signal strength of transmission to the distance between sender node and its neighbor nodes, NFP achieves higher throughput than MFR. NFP selects node B in Fig. 1 which lies in the nearest position and gets closer to the destination node. Compass Routing [13] selects the node with smaller drift from the line connecting the sender node and the destination node. It tries to minimize the distance which a packet travels. Compass Routing selects node B in Fig. 1. Random Progress Method [14] selects a node randomly from among its neighbor nodes with positive progress. The original BLR adopts MFR as its forwarding strategy.

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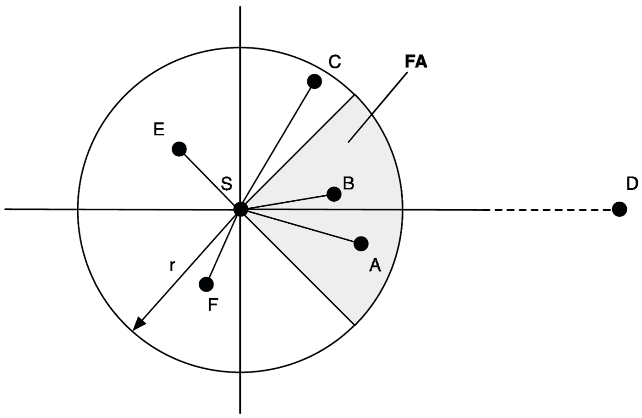

Fig. 2. Forwarding area.

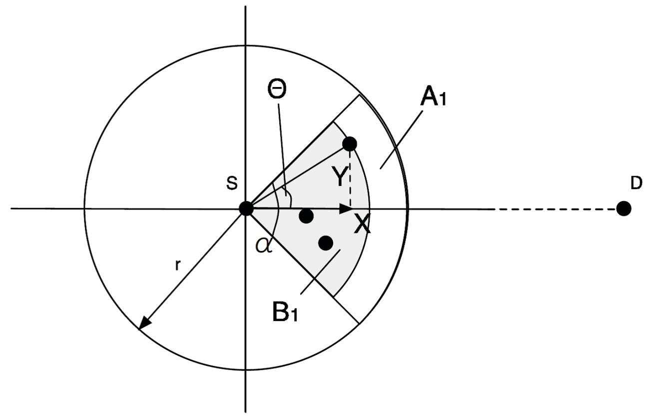

Fig. 3. Illustration of A_1 and B_1 in DAF.

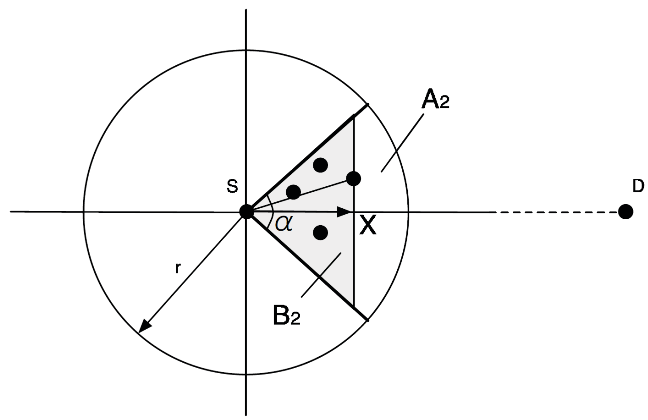

Fig. 4. Illustration of A_2 and B_2 in MFR.

B. Forwarding area

A packet is broadcasted and all neighbors of a sender receive it. However, if those nodes with negative progress forward the packet, they obviously waste the available bandwidth in a network. Then, BLR utilizes Forwarding Area (FA). Only nodes in FA are selected as candidates to forward a packet and calculate the deferring time. We should set FA so that any two nodes in FA can recognize their transmissions each other, which suppresses redundant packet forwarding conducted by those nodes in the same FA. By doing this, the number of forwarding packet is always one. Additionally, we can consider some shape of FA, however, we assume that the shape of FA is a sector form in this paper.

C. Proposed approach

In this paper, we propose a distance-aware forwarding algorithm. It selects a node that forwards a packet according to the distance which the packet travels. This idea is similar to NFP in the sense that both of the algorithms utilize information on one-hop distance. The difference is that our approach selects the farthest node. In our approach (DAF) and traditional approach of BLR (MFR), when a node receives a packet, the node is assigned a deferring time d_A given by

$$d_A = \begin{cases} \dfrac{r-y}{r} \times d_M & \text{(DAF)}, \\ \dfrac{r-x}{r} \times d_M & \text{(MFR)}, \end{cases} \tag{1}$$

where y and x denote the distance and the progress, respectively. When our approach is applied to BLR, it can reduce the deferring time per hop; however, it may need more hops in comparison with traditional approach. The performance of both the algorithms depends on the size and the shape of FA. As for the latter, we consider the case of a fan-shape as described in the previous subsection. Then the size of FA is determined by the transmission radius and angle. If FA gets smaller, the probability of finding no forwarding nodes becomes larger. On the other hand, if FA gets larger, the bandwidth utilization acquired by channel reuse becomes worse. As a result, in order for us to evaluate the performance of the two algorithms we need to develop a mathematical model incorporated with these two important parameters.

III. Performance Modeling and Analysis

In this paper, we carry out a performance analysis of both DAF and MFR, and show that our algorithm achieves significant performance improvement in terms of the total deferring time in a multi-hop transmission despite a slight increase in the number of hops. In our analysis, we assume that nodes are distributed according to two-dimensional Poisson distribution with a mean λ per unit area. All the nodes have the same transmission radius r and same fan-shape for FA with a central angle α.

A. Analysis of one-hop transmission

In this subsection, we start our performance analysis with one-hop transmission case. Firstly we calculate the progress on condition that transmission is successful, that is, at least one of nodes receives the packet in FA.

When nodes are assumed to be spatially distributed with Poisson distribution with a mean λ per unit area, the proba-

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bility that there are n nodes in zone A is given by

$$\Pr(N = n) = \exp(-\lambda\omega)\frac{(\lambda\omega)^n}{n!}, \tag{2}$$

where ω is the area of zone A. Thus, we can calculate the probability of $N \geq 1$:

$$\Pr(N \geq 1) = 1 - \exp(-\lambda\omega). \tag{3}$$

Secondly we analyze the progress, which is defined in section II-A. In DAF, we calculate the progress with Y and Θ, which represent the distance the packet travels and the angle from the direction to the destination, respectively. Let Z^+ and Z^- denote the event that at least one node exists and the event that no node exists in zone Z, respectively. Then the conditional probability distribution function of the distance Y is given by

$$\begin{aligned} G_1(y) &= \Pr(Y \leq y \mid N^+) \\ &= \frac{\Pr(A_1^- \text{ and } N^+)}{\Pr(N^+)} \\ &= \frac{\exp(-\lambda A_1(y)) - \exp(-\lambda\alpha r^2/2)}{1 - \exp(-\lambda\alpha r^2/2)}, \quad 0 \leq y \leq r, \end{aligned} \tag{4}$$

where $A_1(y)$ is the area of A_1 and is calculated as follows.

$$A_1(y) = \frac{\alpha}{2}(r^2 - y^2). \tag{5}$$

We assume that Θ is uniformly distributed, then the probability distribution function of progress X with DAF is given by

$$\begin{aligned} F_1(x) &= \int_{-\frac{\alpha}{2}}^{\frac{\alpha}{2}} \int_0^{\frac{x}{\cos\theta}} \Pr(y < Y \leq y + \mathrm{d}y, \theta < \Theta \leq \theta + \mathrm{d}\theta) \\ &= \frac{1}{\alpha}\int_{-\frac{\alpha}{2}}^{\frac{\alpha}{2}} G_1\left(\frac{x}{\cos\theta}\right)\mathrm{d}\theta, \qquad 0 \leq x \leq r. \end{aligned} \tag{6}$$

Thus, the expected progress with DAF is expressed as

$$E[X] = \int_0^r x\mathrm{d}F_1(x) = r - \int_0^r F_1(x)\mathrm{d}x. \tag{7}$$

Next, we analyze the progress per hop with MFR. The conditional probability distribution function of X is given by

$$\begin{aligned} F_2(x) &= \Pr(\text{progress} \leq x \mid N^+) \\ &= \frac{\Pr(A_2^- \text{ and } N^+)}{\Pr(N^+)} \\ &= \frac{\exp(-\lambda A_2(x)) - \exp(-\lambda\alpha r^2/2)}{1 - \exp(-\lambda\alpha r^2/2)}, \quad 0 \leq x \leq r, \end{aligned} \tag{8}$$

where $A_2(x)$ is the area of A_2 and is calculated as follows.

$$A_2(x) = \begin{cases} r^2\cos^{-1}\left(\frac{x}{r}\right) - \frac{x}{r}\sqrt{1 - \left(\frac{x}{r}\right)^2}, & \left(x \geq r\cos\left(\frac{\alpha}{2}\right)\right), \\ \frac{\alpha r}{2} - x^2\tan\left(\frac{\alpha}{2}\right), & \left(x < r\cos\left(\frac{\alpha}{2}\right)\right). \end{cases} \tag{9}$$

Thus, the expected progress in MFR is expressed as

$$E[X] = \int_0^r x\mathrm{d}F_2(x) = r - \int_0^r F_2(x)\mathrm{d}x. \tag{10}$$

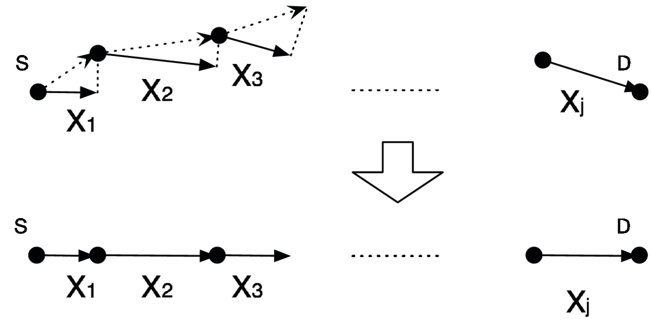

Fig. 5. Illustration of multi-hop analysis.

In the next step of our analysis, we analyze the deferring time. A node calculates the deferring time for each algorithm using equation (1). We use equations (4) and (8) in order to calculate the conditional probability distribution functions of the deferring time $D_1(t)$ of DAF and $D_2(t)$ of MFR. Thus, these are given by

$$\begin{aligned} D_1(t) &= \Pr(T \leq t \mid N^+) \\ &= 1 - G_1\left(r - r\frac{t}{d_{\mathrm{M}}}\right), \end{aligned} \tag{11}$$

$$\begin{aligned} D_2(t) &= \Pr(T \leq t \mid N^+) \\ &= 1 - F_2\left(r - r\frac{t}{d_{\mathrm{M}}}\right). \end{aligned} \tag{12}$$

The expected deferring time is expressed as

$$E[T] = \begin{cases} \int_0^{d_{\mathrm{M}}} G_1\left(r - r\frac{t}{d_{\mathrm{M}}}\right)\mathrm{d}t & \text{(DAF)}, \\ \int_0^{d_{\mathrm{M}}} F_2\left(r - r\frac{t}{d_{\mathrm{M}}}\right)\mathrm{d}t & \text{(MFR)}. \end{cases} \tag{13}$$

B. Analysis of multi-hop transmission

In this subsection, we consider multi-hop transmission. In order to apply the analytical result for one-hop transmission to multi-hop case, we need to evaluate the extent of divergence of routing path from the ideal straight-line path connecting the origin and destination nodes after one-hop transmission, which we call the drift in the following.

Although the drifts after hops are mutually dependent with each other, we assume that they are independent. This assumption makes the following analysis tractable in order for us to consider the number of hops necessary to reach the destination from the origin node. Because of the drift, the sum of progresses to reach the destination is slightly larger than the length of the straight path from the origin node to the destination node. We neglect the difference between the two when we calculate the number of hops necessary for a packet to traverse from the origin to the destination.

Let X_j ($j = 1, 2, \ldots$) and l denote a random variable of the progress at j-th hop and the distance to the destination, respectively. If $X_1 + X_2 + \cdots + X_j > l$, then a packet reaches the destination after j hops. If we use DAF of MFR, the

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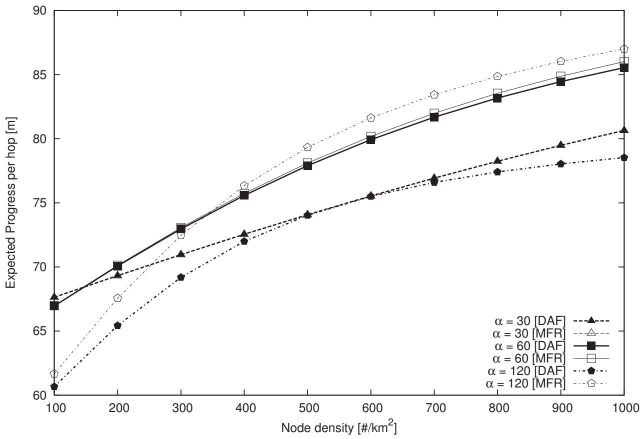

Fig. 6. Expected progress per hop vs. node density.

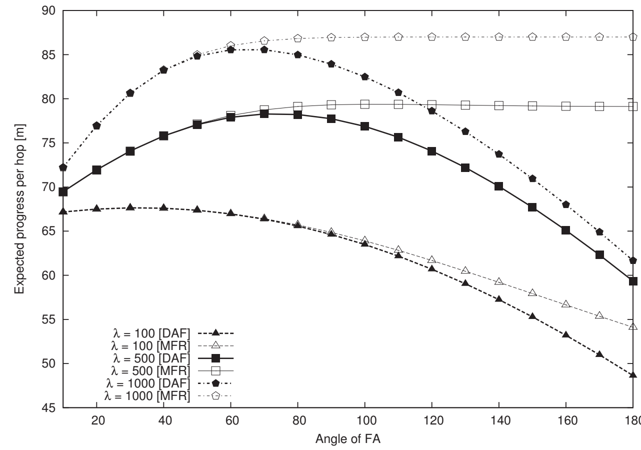

Fig. 7. Expected progress per hop vs. angle of FA.

probability that the total progress gets over l after j hops is given by

$$\begin{aligned}\Pr(X_1 + X_2 + \cdots + X_j > l) &= 1 - \Pr(X_1 + X_2 + \cdots + X_j \le l) \\ &= 1 - F_i^{(j)}(l). \qquad (14)\end{aligned}$$

We denote by $F_i^{(j)}(x)$ the j-convolution of $F_i(x)$ $(i = 1, 2, \dots)$. The probability that a packet reaches the destination after j hops is given by

$$\begin{aligned}\Pr(J = j) &= \left(1 - F_i^{(j)}(l)\right) - \left(1 - F_i^{(j-1)}(l)\right) \\ &= F_i^{(j-1)}(l) - F_i^{(j)}(l). \qquad (15)\end{aligned}$$

Let T_i denote the deferring time at i-th hop and W_j denote the total deferring time experienced by a j-hop transmission. When a packet reaches a destination after j hops, the number of the intermediate nodes is $j - 1$. Then we have

$$\begin{aligned}\Pr(W_j \le t) &= \Pr(T_1 + T_2 + T_3 + \cdots + T_{j-1} \le t) \\ &= D_i^{(j-1)}(t). \qquad (16)\end{aligned}$$

The expected total deferring time caused by a multi-hop transmission is given by

$$\begin{aligned}E[W] &= \sum_{j=2}^{\infty} \Pr(J = j) \times E[W_j] \\ &= \sum_{j=2}^{\infty} \left(F_i^{(j-1)}(l) - F_i^{(j)}(l)\right) \times \int_0^{d_M} t \mathrm{d} D_i^{(j-1)}(t). \qquad (17)\end{aligned}$$

We note that the above equation yields the approximation because the progress and the deferring time are not mutually independent.

IV. Numerical Result

In this section, showing some numerical examples, we demonstrate performance improvement brought by our approach. In the following examples, all nodes have the same transmission range r = 100m if not otherwise specified.

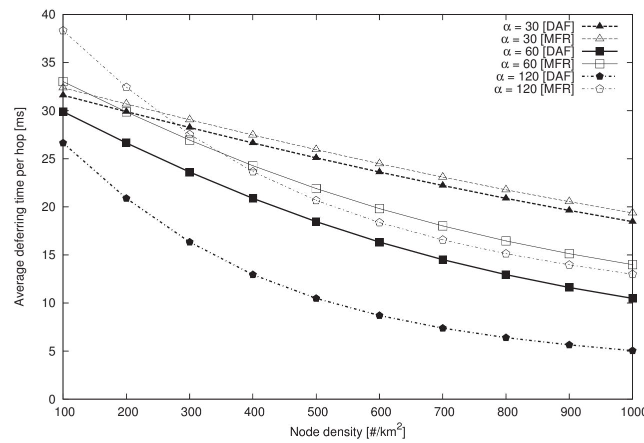

Fig. 8. Average deferring time per hop vs. node density.

A. One-hop transmission

In this subsection, we start with some numerical examples of one hop progress and deferring time. In the following, the density of nodes (λ) is set to 100–1000 and the angle of FA (α) is set to 30°, 60° and 120°.

In Fig. 6, we illustrate the expected progress per hop. From the figure it is found that when the node density of the network increases, the progress becomes larger in both the strategies. It is also found that MFR makes more progress than DAF in all the scenarios. Additionally, the difference in the progress between the two strategies increases as the node density gets higher and FA becomes larger. Next, we represent the relationship between the central angle of FA and the progress in Fig. 7 in order to investigate the performance of the two strategies in more detail. Figure 7 shows that as the node density becomes higher, MFR makes more progress. In contrast, DAF makes less progress when FA becomes too large. This is because DAF and MFR select nodes according to the achievable distance and progress, respectively. If we use the distance as a metric and if FA is set large, a packet may significantly deviate from the direction to the destination after

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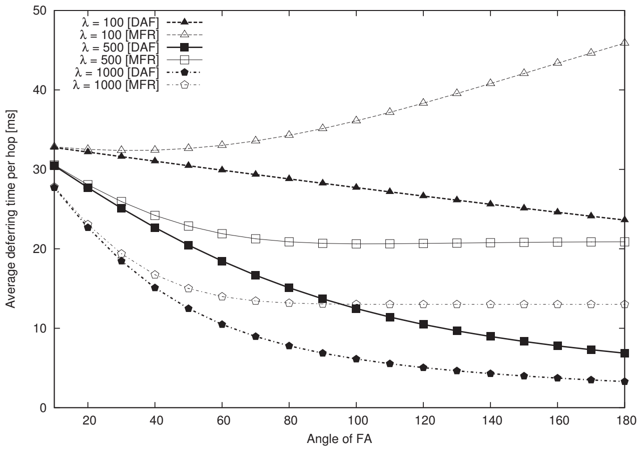

Fig. 9. Average deferring time per hop vs. angle of FA.

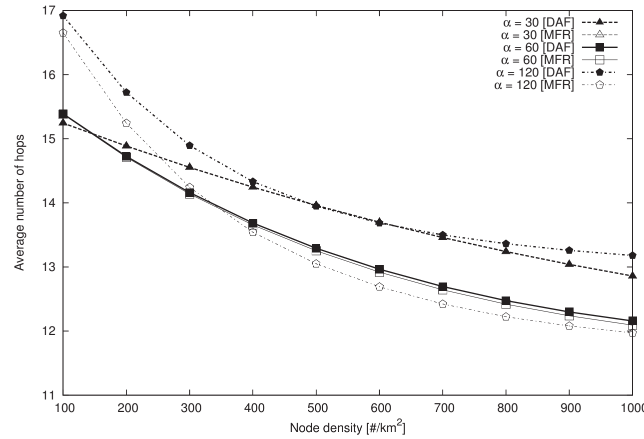

Fig. 10. Expected number of hops vs. node density.

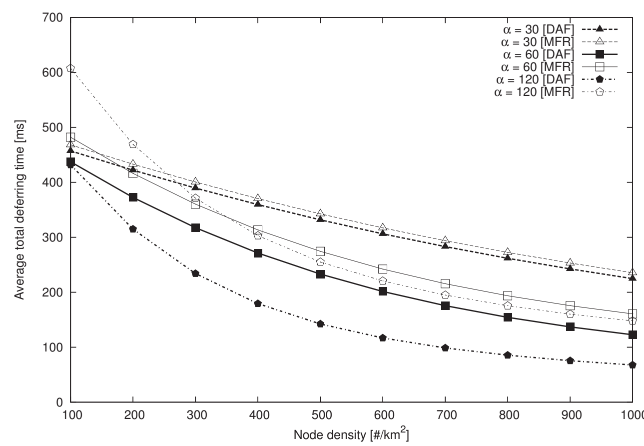

Fig. 11. Average total deferring time in a multi-hop transmission vs. node density.

each hop. As a result, in DAF, too large FA may cause an increase in the number of hops in a multi-hop transmission.

Next, we show some numerical results of the deferring time per hop under the same parameter setting in the above. In addition, maximum deferring time per hop, d_{M}, is set to 100ms.

Figure 8 reveals that the deferring time gets shorter as the node density becomes higher. When FA is large, the difference between DAF and MFR becomes larger and DAF always assigns a shorter deferring time than MFR does. This is because the one-hop distance is closer to the radius than the one-hop progress.

Figure 9 shows the relationship between the deferring time per hop and the angle of FA. In a low-density network, transmission failures occur frequently. Then a simple solution of this problem is an extension of FA. However, Fig. 9 shows that it causes longer deferring time in a low-density network when MFR is applied. When $\lambda = 500$ or 1000, the average deferring time gets shorter, as FA becomes larger in both strategies. However, the deferring time with MFR gets stable when the angle of FA is greater than a certain value. This is because the progress with MFR becomes stable beyond a certain angle. Although the progress of DAF has similar tendency, an extension of FA is more efficient in DAF than in MFR.

From these results, the performance of DAF is better than that of MFR in terms of the deferring time per hop, while DAF performs worse than MFR in terms of the progress per hop. This agrees with our prediction.

B. Multi-hop transmission

In this subsection, we show some numerical examples of a multi-hop transmission. In the previous subsection, we found that DAF has shorter deferring time but less progress than MFR. Now we investigate how these two effects influence the total deferring time in a multi-hop transmission. In the following numerical examples, the distance between the source node and the destination node is set to 1000m.

Figure 10 shows the relationship between the number of hops and node density. The angle of FA is set to 30°, 60° or 120°. The number of hops decreases as the node density becomes higher, and MFR has smaller hops than DAF in all the scenarios. Additionally, we can see that the difference between DAF and MFR gets bigger as the angle of FA becomes larger. Figure 6 agrees with this result.

In Fig. 11, we show the total deferring time in a multi-hop transmission. The total deferring time that caused by DAF is shorter than that of MFR. Additionally, the difference between DAF and MFR gets bigger as the angle of FA becomes larger as well as the progress.

In summary, our strategy shortens the total deferring time in a multi-hop transmission compared to the original strategy adopted in BLR, although the number of hops slightly increases.

C. Simulation

In our analysis of the number of hops, we assume that the drifts after hops are independent and that a packet always travels to the direction to its destination node. We run a simulation

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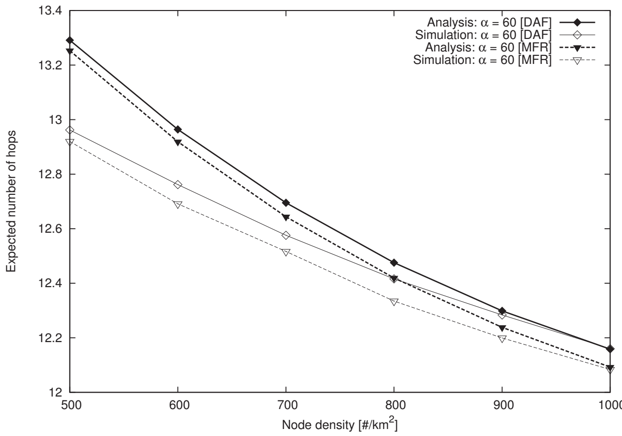

Fig. 12. Comparison of expected numbers of hops obtained by analysis and simulation.

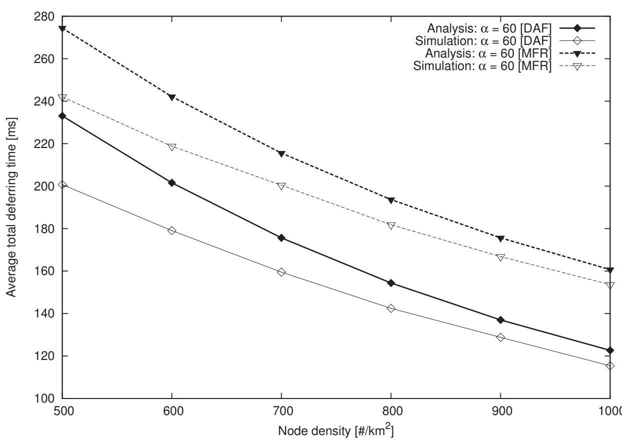

Fig. 13. Comparison of average total deferring times obtained by analysis and simulation.

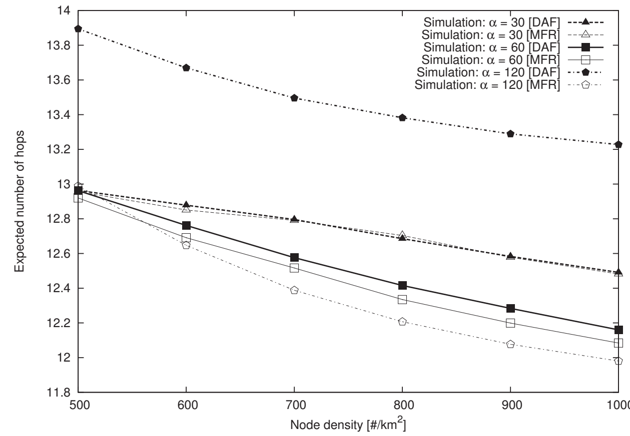

Fig. 14. Expected number of hops obtained by simulation.

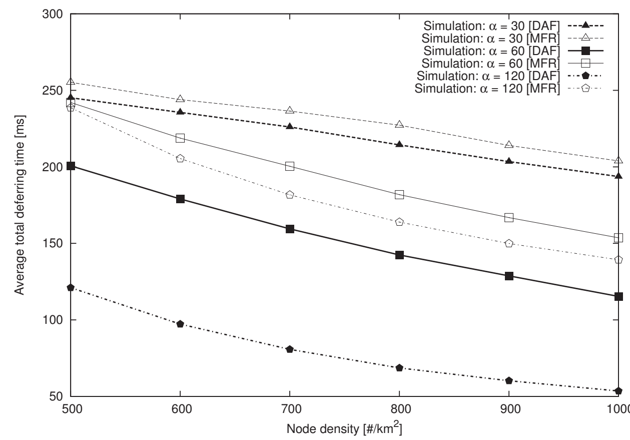

Fig. 15. Average total deferring time obtained by simulation.

and compare the experimental result of the simulation with the numerical result of our analysis in order to discuss the effect of these assumptions.

Figures 12 and 13 show the expected number of hops and total deferring time for $\alpha = 60°$, respectively. Although the above-mentioned assumptions cause a certain amount of difference between those values obtained by our analysis and the simulation, they show similar variations with respect to the node density. In addition, the simulation results lead to the same conclusion as what is stated in the previous subsection: DAF makes the total deferring time shorter compared to MFR at the expense of a slight increase in the number of hops. This holds true for the cases of $\alpha = 30°$ and $\alpha = 120°$, which are illustrated in Figs. 14 and 15.

We cannot conclude that making the FA large is better just because it shortens the total deferring time according to the analytical results (Fig. 11) and the simulation results (Fig. 15). If the angle of FA is larger than 60°, there is a possibility that some nodes in the FA cannot receive a packet forwarded by another node in the FA. Since those nodes cannot notice that the packet has already been forwarded, they redundantly forward the packet. Thus, multiple packets with the same content travel in multiple routes, which wastes the bandwidth. Figure 16 shows that the traffic drastically increases due to the redundant forwarding as the angle of FA gets larger. The tradeoff between the deferring time and the traffic should be carefully considered when determining the angle of FA.

V. Conclusion

In this paper, we focused on BLR, and we proposed a new approach named Distance-Aware Forwarding (DAF). We used mathematical model to evaluate the performance of our approach. The numerical results show that the performance of DAF is better than that of MFR (the original strategy adopted in BLR) in terms of the deferring time per hop, while DAF performs worse than MFR in terms of the progress per hop. The numerical results also show that DAF shortens the total deferring time in a multi-hop transmission compared to MFR, although the number of hops slightly increases.

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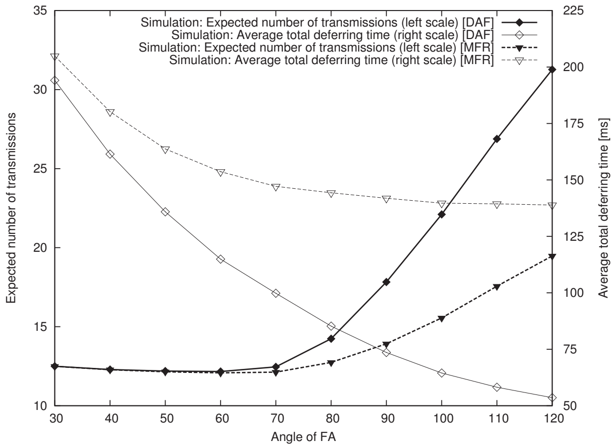

Fig. 16. Expected number of transmissions and average total deferring time obtained by simulation for $\lambda = 1000$.

In the future, we plan to carry out a performance analysis considering packet collisions in order to discuss the relationship between network usage parameters and the optimal transmission range.

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