On treating asymmetric links in backoff-based opportunistic routing: problem and solution

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Abstract: In ad hoc networks, backoff-based opportunistic routing enables flexible forwarder selection based on a random backoff time. However, it assumes to require symmetry of each link due to the use of reverse path information. In this letter, we verify an asymmetric link problem based on their behavior and propose a solution to this problem. The proposed method checks and ensures the destination reachability of each terminal based on link symmetry using a flag and restricts the acknowledgment procedure to avoid the problem. Finally, we examine the impact of asymmetric link use and the effectiveness of the proposed method by simulations.

Keywords: ad hoc network, opportunistic routing, asymmetric link, destination reachability

Classification: Network

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1 Introduction

Ad hoc networks consisting of only mobile terminals require their routing protocols that dynamically adapt to the changes such as communication quality and terminal mobility.

As a solution to this, backoff-based opportunistic routing (OR), which can select an appropriate forwarding path based on a backoff time, has been proposed [2, 3, 4]. However, their performance may degrade when using them in an environment where impairs each link symmetry since they must be used with a bidirectional flow.

In this letter, we call the issues an asymmetric link problem in backoff-based OR. In addition, we examine the problem and propose a solution to select a forwarding path to avoid asymmetric link use.

2 Backoff-based opportunistic routing

We describe one of the backoff-based OR called PRIOR [4] as an example. Generally, they [2, 3, 4] selects a forwarder from among packet receivers called potential forwarders based on a backoff time. In addition, some of them [2, 4] use an explicit ACK (acknowledgement) to reduce unnecessary packet forwarding. Particularly in PRIOR, each forwarder selects a PF (prioritized forwarder) that immediately forwards packets to reduce the backoff delay.

In PRIOR, a source first floods a request packet for discovering a destination. Upon receiving this, each receiver records cost information, such as a hop count, PF to the source, and so forth. When the destination receives the request, it transmits the reply packet towards the source.

Reply and data packets are forwarded on the basis of a backoff time. First, when a terminal receives either of them, it checks whether the PF in the header coincides with itself. If the receiver is PF, it immediately forwards the packet without waiting for a backoff time. Otherwise, it calculates a backoff time and starts waiting as a potential forwarder. Note that a shorter backoff time is set for the terminal closer to the destination. If a potential forwarder receives the same packet from the others during the wait, it cancels its packet forwarding by regarding the received packet as an implicit ACK. Otherwise, it forwards the kept packet as a forwarder. If the forwarder re-receives the same packet after forwarding a packet, it sends an explicit ACK to cancel packet forwarding of its neighbors. Note that the destination transmits an explicit ACK instead of the data packet.

3 Asymmetric link problem and its solution

3.1 Asymmetric link problem in backoff-based opportunistic routing

In the backoff-based OR, a flow between a source and destination must be bidirectional since they select forwarders based on the information obtained from the reverse path flow. Namely, they require symmetry of all the links.

However, in actual environments, a wireless link faces unequal communication quality on up/down called an asymmetric link, which often occurs...
due to radio interference and differences in terminal performance. However, if the backoff-based OR is used in an environment with asymmetric links, their performance may degrade due to the above requirement. In particular, PRIOR may be unable to update PFs correctly due to asymmetric links since it strongly depends on the reverse path information. In this letter, we call the issues an asymmetric link problem in backoff-based OR.

Figure 1(a) shows an example of a packet transmission from S to D using PRIOR in an environment with asymmetric links (B-D and B-E). First, S transmits a data packet, and then A immediately forwards it as a PF. Next, assuming that C and B successfully receive the packet, C waiting for a random backoff time, and B forwards it immediately as a PF. Here, D and E cannot receive the data packet since links B-D and B-E are asymmetric. However, if A receives the packet from B as an implicit ACK, it transmits an explicit ACK to cancel the packet forwarding of neighbors including C. Hence, the packet consequently does not reach the destination.

3.2 Solution to the asymmetric link problem
To solve this asymmetric link problem, we propose a novel backoff-based OR which checks link symmetry and ensures the reachability to the destination. In the proposed method, each terminal stores a flag in addition to the cost information as used in PRIOR. The flag indicates its reachability to the destination based on the symmetry of each link on a forwarding path from it to the destination. By using this, the proposed method enables the explicit ACK function based on flag information to avoid the above problem.

In the proposed method, a source first initiates request packet flooding for discovering a destination in the same way as PRIOR. Note that flags of each terminal are set to false except for the destination.

Reply and data packets are forwarded based on a backoff time are also in the same way as PRIOR as described in Sec. 2. Then, each forwarder updates the flag in the packet header with its flag stored in the cost information. Moreover, the forwarder keeps the previous-hop forwarder information to be used in the latter procedure for confirming the link symmetry between previous- and current-hop forwarders when forwarding a packet.
After forwarding a reply or data packet, if the forwarder re-receives the same packet, it checks a flag stored in the received packet header and its flag. If the both flags are true, it transmits an explicit ACK, which includes the previous-hop forwarder information, since these forwarders are destination reachable. Upon receiving an explicit ACK, if the receiver coincides with the previous-hop forwarder information in the packet header, it updates its own flag to true since the link is symmetric. By repeating the above operation, terminals on a path composed of symmetric links set the flag to true.

Fig. 1(b) shows an example of packet forwarding using the proposed method in an environment with asymmetric links. Note that A, C, and E have already set their flag to true. First, S sends a data packet and A immediately forwards it as a PF. Assuming that C and B receives the data packet, B forwards this immediately as the PF and C starts waiting as a potential forwarder. However, D and E cannot receive it from B due to asymmetric links. Then, although A also receives the data packet as an implicit ACK from B, it ignores this and forwards kept one based on the backoff time since the flag in the packet header is false. After that, E forwards the packet, and consequently the packet successfully reaches the destination.

4 Performance evaluation

4.1 Simulation setup
We evaluated the performance of conventional methods (SSR [2], LFBL [3], and PRIOR [4]) and the proposed method using QualNet. Each terminal employed IEEE 802.11b, and their data rate was set to 11 Mbps. We adopted almost the same parameters used in [4] except for a base backoff time parameter $T$ and disabled the retransmission control. In this simulations, $T$ in SSR and LFBL was set to 30 ms, and that in PRIOR and the proposed method was set to 60 ms.

Simulation 1: To observe the fundamental impact of asymmetric links and the effectiveness of the proposed method, this simulation adopted three scenarios as shown in Fig. 2(a): (scenario 1-1) all links are symmetry, (scenario 1-2) B is deleted from scenario 1-1, and (scenario 1-3) links B-C and B-F are asymmetry. In these scenarios, S and D alternately transmitted one thousand 1 kbyte UDP packets.

Simulation 2: This simulation evaluated the impact of changing the terminal density using random topology. Terminals were randomly placed in a $1000 \times 1000$ m area, and the number of terminals was varied from 20 to 200. This simulation consists of two scenarios to observe the effect of asymmetric links in random environments: (scenario 2-1) we set the transmission range to 150 m to simulate an environment without asymmetric links, and (scenario 2-2) we set the transmission range of 10% of all terminals to 300 m and the rest were set to 150 m to simulate an environment with asymmetric links. We randomly chose a pair from the terminals with the transmission range of 150 m, and the pair alternately transmitted one thousand 1 kbyte UDP packets.
### 4.2 Simulation results

**Simulation 1:** Fig. 2 shows the simulation results of three scenarios. First, every method in scenario 1-1 achieves the highest performance among all the scenarios since all links are symmetric, whereas the methods in scenario 1-2 degrade their performance due to only a detour path. In scenario 1-3, SSR and PRIOR have more number of transmitted packets than scenario 1-2 due to asymmetric links. LFBL achieves both the highest packet transmission success rate and the smallest total number of transmitted packets among them. However, the number of data packets in LFBL is increased since LFBL does not use an explicit ACK, and therefore the performance degradation occurs in random dense environments as described in simulation 2. The proposed method achieves a high packet transmission success rate and small number of transmitted packets compared to SSR and PRIOR, in order to forward data packets correctly based on the destination reachability. In addition, the proposed method also achieves the smallest delay among them regardless of the flow direction.

**Simulation 2:** Fig. 3 shows the simulation results of two scenarios. Figures 3(a) and (d) indicate PRIOR degrades the packet transmission success rate in scenario 2-2 due to asymmetric links. On the other hand, LFBL and the proposed method achieve a high transmission success rate in both the scenarios. However, Figs. 3(b) and (e) indicate that LFBL also causes the excess packet transmissions in both the scenarios. This is because LFBL does not use explicit ACK, and hence it cannot sufficiently cancel the unnecessary...
packet forwarding. In contrast to this, the proposed method achieves a small number of transmitted packets in both scenarios. The proposed method adaptively uses an explicit ACK based on the destination reachability, and therefore it enables to avoid the asymmetric link problem and to cancel the unnecessary packet forwarding. Figures 3(c) and (f) indicate their transmission delay becomes stable as the number of terminals increases regardless of scenarios. In particular, PRIOR and the proposed method achieves the smallest transmission delay since they can use PFs to reduce the backoff delay. Finally, the proposed method achieves both a high packet transmission success rate and a small total number of transmitted packets while suppressing the transmission delay.

5 Conclusion

In this paper, we addressed an asymmetric link problem in backoff-based OR, and proposed its solution. In the performance evaluation, we confirmed that the effectiveness of the proposed method in a random environment with asymmetric links. As a future work, we plan to conduct further performance evaluations using dynamic topologies for more realistic environments.

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