Performance Improvement in Ad hoc Wireless Networks with Consideration to Packet Duplication

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Summary
Flexible Radio Network (FRN), one of the ad hoc wireless network systems, adopts an original protocol, which includes a packet retransmission mechanism against packet transmission errors. While this mechanism intends to improve packet reachability, it sometimes causes unnecessary packet duplications and degrades the network performance due to a lack of a capability that differentiates packet transmission errors and acknowledgement errors. In the latter case, packet retransmission causes packet duplication because only acknowledgement (ACK) packet is lost in actual. In this paper, we investigate the packet duplication process of FRN and suggest performance improvement techniques. Through simulation, it is shown that those techniques can actually decrease the number of duplicated packets and improve the network performance.

Key words: Ad hoc Wireless Network, Simulation, Routing Protocol, Packet Duplication

1. Introduction
An ad hoc wireless network is built with wireless terminals that communicate with each other. Those terminals have a capability that relay packets for other terminals. The ad hoc network needs neither a wired backbone network nor base stations, and therefore network installation, expansion and removal can be performed easily and quickly. Such a wireless infrastructure covers a wide range of applications, e.g., distributed computing, disaster recovery, and military operation. Accordingly, many studies have been dedicated to analyze its characteristics and/or propose new routing methods (see, e.g., [1, 2]).

Flexible Radio Network (FRN) is one of commercially available products based on ad hoc wireless networks [3]. A large-scale network with stationary terminals can be installed in existing facilities easily by FRN. In addition, the network can be extended only by adding the radio terminal if needed. It is now used for collecting usage information of ski lifts, and a sales account and monitoring information of vending machines [3]. FRN adopts a proprietary protocol that can efficiently adapt to terminal failures and/or a change of network configuration. In [4], we have investigated a basic property of the system and shown how system configuration parameters affect the network performance in terms of throughput and average packet delays.

In FRN, wireless terminals check packet transmission errors at every hop against a transmission error, and retransmit the packet if transmission error is detected. It can be detected when the terminal does not receive a corresponding ACK from the neighbor terminal within a pre-specified time. The problem is that the transmission terminal recognizes the packet transmission error in the case of the ACK transmission error even if a data packet transmission succeeds. In this case, the terminal retransmits the packet. Then, the duplicated packet is put in the network, because in FRN, no terminals manage the history of packet transmission to reduce the complexity of wireless terminals. The packet duplication leads to a higher traffic load than an actual one. To make the matter worse, higher the traffic load becomes, more duplicated packets are generated because the transmission error rate of ACK packets as well as data packets becomes large. Thus, the network performance degrades rapidly in such a condition.

In this paper, we first examine a packet duplication process in detail. We show that the network performance degrades rapidly as the number of duplicated packets increases. We next suggest performance improvement techniques with consideration to packet duplication. Through simulation, we show that those techniques can decrease the number of duplicated packets.

2. System Description of FRN

2.1. Network Configuration
In FRN, every wireless terminal is called a node. Nodes with which the node can communicate directly are called neighbor nodes. A host node generates and receives packets, and other nodes are called relay nodes. Every node maintains the network information in the configuration table that contains the routing information from the node itself to each destination node. The routing information consists of the list
of neighbor nodes to the destination node $i$, and hop counts to node $i$. Every node exchanges a configuration control packet at every pre-specified time, and updates its configuration table by the packets from neighbor nodes.

2.2. Data-link Protocol

A radio channel is divided into fixed-length time slots. All nodes synchronize their transmission with these slots. In a wireless network, each node existing in the area that radio wave is attainable can receive packets even when it is not the source/destination of the packet. In FRN, this property is utilized for the acknowledgement of the packet. See Fig. 1 as an example. Figure 1(a) shows a case where packet transmission and acknowledgement at node A is successful. Node B receives the packet from node A successfully and relays it to another node. At the same time, this relayed packet is received by node A. This acknowledgement is called relay echo (or simply echo). If the relay echo is successfully received by node A, it is recognized as a successful transmission from node A to node B. The case where node A fails in echo receipt is shown in Fig. 1(b). In this case, node A detects transmission failure because no echo from node B is received. Then, node A retransmits the packet.

The maximum lifetime of the packet is defined in every packet. For every time slot, it is decreased by one. When the value reaches zero, the packet is discarded due to the expiration of the lifetime. It is an important configuration parameter since it gives a chance to effectively remove the duplicated packets from the network as will be explained in the next section in more detail.

2.3. Routing Protocol

In the ad hoc wireless network, each node collects network information from neighbor nodes and decides the direction of relaying the packet. Since the radio environment changes frequently, a routing protocol must choose an appropriate route adaptively. Furthermore, if a node fails to transmit a packet on the first trial, another route should be chosen immediately. In FRN, every node maintains information on multiple routes for each destination node in the configuration table. The shorter hop route has a higher priority. If the shortest route is unavailable due to some reason, the node looks up the configuration table and chooses the next shortest route.

3. Performance Improvement with Consideration to Packet Duplication

3.1. Packet Duplication Process

As mentioned in Section 2, FRN has a packet retransmission mechanism against the transmission errors. While this mechanism is likely to contribute to packet reachability, it sometimes causes unnecessary packet duplications. Duplicated packets increase a possibility of more collisions, and occupy a node buffer. A packet duplication process is illustrated in Fig. 2. Node A transmits a packet to node B successfully at slot 0. Node B relays the packet to node C at slot 1. At the same time, it is expected that this relayed packet be received by node A as an echo. However, it sometimes happens that the echo is lost because of an obstacle (e.g., a person in the case of the skiing ground) or a collision with another packet. Then, node A cannot receive the echo successfully. In such a case, the copied packet in the buffer of node A should not be removed at the end of slot 1. In other words, the same two packets exist in node A and node C. Node A retransmits the packet later. It may be retransmitted through different routes to the destination with the multiple route information in the configuration table.

3.2. Control the Number of Duplication

Network performance degrades rapidly as the number of duplicated packets increases. This is caused by a wireless characteristic that the radio wave has the influence on all nodes within the reachable range. Moreover, the duplicated packet is unnecessary if its original packet reaches the destination properly. In this subsection, we suggest two techniques that can appropriately control the number of duplicated packets. As described in previous subsection, packet duplication is caused by a loss of relay echo, which can be reduced by the following two methods: (1) to intro-
duce the random delay before packet retransmissions, and (2) to remove the packets previously which cannot reach the destination host within rest of their lifetime.

The change (1) above is an improvement of the packet retransmission method described in Subsection 2.2. As shown in Fig. 1(b), when a node cannot receive an echo within a specified time, it chooses another route for retransmission. This time duration was a constant value in the original system, and therefore once the packets experience a collision, they tend to repeat it until transmission through another route succeeds. By introducing the random waiting time before retransmission, the possibility of collisions would be reduced. We explain why it can decrease the number of duplicated packets. See Fig. 2 again. Suppose that the waiting time before retransmission is fixed at three slots. Node A expects to receive an echo from node B at slot 1. Node X, however, sends a packet at the same slot and it collides with the echo. Therefore, node A cannot receive the echo and retransmits the packet at slot 3. At slot 4, the echo from node B collides again with the packet from node X because of the fixed waiting time. Collisions repeat until the transmission through another route succeeds. The change (1) can inhibit the repeated losses of relay echoes, and it can be expected to reduce the number of packet duplications.

The change (2) is a technique for decreasing unnecessary packets within the network. In FRN, the lifetime value of the packet is reduced by one for every time slot. That is, it should be ideally the maximum allowable hop counts of the packet. By using the configuration table, the hop counts to the destinations are maintained at each node. Thus, if the residual lifetime of the packet becomes less than the hop count of the shortest path to the destination, that packet should be discarded.

4. Simulation

4.1. Simulation Model

In this section, we first investigate an influence of duplicated packets. Then, the effect of the above two methods are demonstrated through simulation experiments. We use ns-2 [5] to utilize its packet propagation model. Then, the data-link and routing protocol of FRN are implemented on ns-2.

We use a network model shown in Fig. 3. A circle represents a node. A line connecting two nodes means that those are within the range that they can communicate directly. The numbered nodes (one through three) are host nodes that transmit and receive data packets. The packet generation rate per one slot at each host node is assumed to be identical. When a packet is generated at the host node, either of the other two host nodes is randomly chosen as destination. The traffic load is defined as the number of packets generated per one slot in the whole network (i.e., the sum of the packet generation rate at three host nodes). The network performance is largely affected by the maximum lifetime. When it is large, the packets can be relayed to the destination node even after some retransmission trials. As the traffic load becomes high, however, a smaller value is expected to keep the packet duplications low. In the experiments, we used two different values of packet lifetime, 8 and 128.

We use throughput and packet loss rate (PLR) to measure the performance. Throughput is an average number of successfully transmitted packets per one time slot. PLR is a ratio of the packet not reaching the destination.

4.2. Effects of Proposed Improvement Methods

In this subsection, we investigate the effect of two improvement methods that we suggested in Subsection 3.2. Figures 4 and 5 show the performance with two cases of maximum lifetime, 8 and 128, respectively. We compared four cases: the label “original” shows the result for the existing system without any changes. In “rnd”, only change (1), that decides the waiting time before retransmission randomly, is applied. The “drop” shows the case of applying only the change (2), dropping unnecessary packets previously. The line with the label “both” shows the case where two changes are applied. In each figure, the throughput, the packet loss rate and the number of dropped packets per second are shown.

The effects of changes (1) and (2) are much affected by the maximum lifetime. When the maximum lifetime is large as in Fig. 5, the effect of the change (1) is large. On the contrary, the change (2) provides a good effect when the lifetime is small as shown in Fig. 4. The decreasing number of duplicated packets gives evidence. Long-living packets sometimes repeat collisions when the maximum lifetime is large. The change (1) can decrease the possibility of repeated collisions and losses of relay echoes. When the maximum lifetime is small, however, the packets may be discarded due to an expiration of the lifetime. The change (1) is less efficient in such an environment. When the lifetime becomes small as shown in Fig. 4, the change (2) gives a better effect than the change (1). While packets do not repeat collisions with smaller lifetime values, the
number of packets discarded due to an expiration of the lifetime increases. The change (2) can discard the packets having no chance to reach the destination.

As the above results indicate, the lifetime of the packets should be determined according to the network traffic load. An appropriate determination method is left to be a future research topic.

5. Conclusion

In this paper, we have investigated a packet duplication process in the Flexible Radio Network. The packet duplication is caused by a packet retransmission mechanism against packet transmission failures. We have suggested two performance improvement techniques with consideration to packet duplication. Through simulation experiments, we have shown those techniques can decrease the number of duplicated packets and improve the network performance.

As a future topic, it is necessary to control appropriate lifetimes with the configuration table and network load. End-to-end performance by using, e.g., TCP as an upper layer protocol should also be investigated.

References