Determining the Relay Node Encode Packet in Multipath Routing Environment

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Abstract - Wireless networks, such as mobile ad hoc ones have low reliability for reasons such as phasing, noise, and packet collisions. FEC-based methods in ad hoc networks have been improved because of their increased reliability when used with multipath routing. However, the number of transmission packets from the source node has been increased. Therefore, we propose using an efficient and reliable packet transmission method: using multipath routing constructs from multiple node disjoint routes and applying network coding, which allows packet encoding at a relay node. Because the encoding packet is generated by a relay node, the source node does not need to encode the packets, and it sends only unencoded packets to each route. Thus, the number of packets transmitted by the source node does not increased. In addition, we also evaluated which node was most suitable to encode a packet, the location of the path that should be used to encode it and the delivery ratio by the number of packets used for encoding.

Keywords: Wireless network, MANET, Network Coding, Multipath Routing

1 INTRODUCTION

Recently, progress in wireless communication technology has meant that wireless modules have been mounted on various devices. These ad hoc networks are instantly deployable wireless networks, which rely on radio waves instead of base stations or communication infrastructure support. Because radio waves have a short propagation range, the route becomes “multihop” when a communication peer is not within range. In general, the reliability is low in ad hoc networks because of network topology, unstable radio environment, and packet collisions. By “reliability” we mean the probability that data generated at a source node in the network can be routed to the intended destination.

Packet-level forward error control (FEC) and automatic repeat request (ARQ) are two methods widely used to recover the lost packets in networks with unreliable links.

Automatic repeat request is an error recovery method that uses acknowledgment packets (ACKs) and a timer to transmit data reliably. The acknowledgment packet is a message sent by the receiver to the sender to indicate that it has correctly received a packet. If the sender does not receive an acknowledgment before a specified period of time (timeout), the sender usually retransmits the packet until it receives an acknowledgment or exceeds a predefined number of retransmissions. However, the ARQ method is not considered applicable in networks that have low reliability and that are highly mobile, such as ad hoc ones. This is because the transmission delay increases as a result of retransmissions by the sender for missing ACKs. In addition, because of its use of unidirectional links, ARQ is unfit for wireless networks [5].

Forward Error Control is an error correction method that is used in data transmission in which the sender generates an error correction code, adds it to the original packet, and then sends both the error correction code and the original packet. Using this method allows the receiver to detect and correct errors without the need to ask the sender for retransmission of the packet.

The use of FEC-based methods in ad hoc networks has been studied [6] [7] [8] and found to improve the reliability when used with multipath routing. However, the number of transmission packets of the source node is increased. For example, as shown in Figure 1, the source node S generates a code from Data 1 and Data 2 by encoding them. The source node then sends the code. In this case, the number of packets transmitted by the source node is three (Data 1, Data 2, and Code). Thus, the transmission frequency at the source node is increased.

We proposed using a method that involves Network Coding [2] that allows packet encoding at a relay node to decrease the number of packet transmitted by a source node and the number of packets that flow into the network accompanying it. In addition, we carried out a computing simulation to evaluate it [1].

The results from the simulation show that our proposed method transmits data more efficiently and more reliably than the current method does. However, when multiple paths are constructed from multiple relay nodes, how to decide on which node should be encoded has yet not been discussed. Thus, we theoretically evaluated which relay nodes should encoded and also on which paths packet from the delivery ratio and packet overhead, and the delay. In addition, to validate our theoretical evaluation, we conducted simulations.

Our method is discussed in Section 2. A prototype implementation of our proposal is described in Section 3. We evaluated our proposal by comparing related protocols in Section 4, and we summarize our work in Section 5.

2 PROPOSED METHOD

In this section, we describe our proposed method using Network Coding with Multipath Routing.

2.1 Basic Operation Model

The construction of the multiple route method is Split Multipath Routing [4], which is also known as extended Dynamic Source Routing [3].

Multiple paths are constructed, and then the source node sends data packets to neighbor nodes on all routes simultaneously. For example, as shown in Figure 1, when two paths are constructed a data packet is forwarded on one path, and a certain relay node on another path encodes a packet and forwards it.

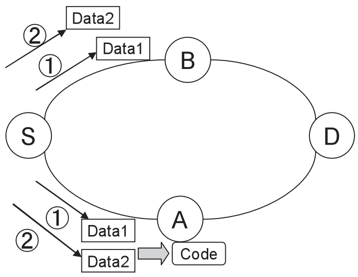

Figure 1 Proposed method

Therefore, the destination node is able to receive encoding packet even if there is no source node that encodes the packet and then transmits the encoding packet.

3 CHOICE OF NODE

Our proposal method is modeled by using a mathematical expression.

In addition, we evaluated whether a data packet should be forwarded and the position of the path where the encoding packet should be generated and forwarded. These conditions were on the basis of a theoretical formula.

Similarly, we evaluated which relay node should encode a packet, when the path is constructed by two or more relay nodes.

In order to estimate the efficiency of our proposal, we evaluated the packet delivery ratio, the packet overhead, and the transmission delay. We define these parameters as follows.

- Packet delivery ratio

The packet delivery ratio is defined as the number of correctly received data packets at the destination node divided by the number of original data packets sent by the source node.

- Packet overhead

The packet overhead is defined as the number of all node transmission packets, including data packets and encoded packets.

- Transmission delay

The transmission delay is defined as the period from which the source node generates a packet until the time when the destination node receives it. For encoding models, the transmission delay is defined as the period from when the source node generates a packet until the time the destination node decodes the encoded packets and retrieves the original ones.

3.1 Evaluation Model

The evaluation model is shown in Figure 2

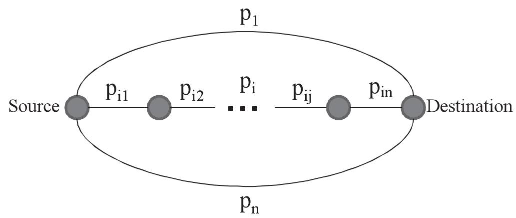

Figure 2 Evaluation model

Packet Loss Rate between nodes in the *i*th path is given by:

$$\left(p_{i1} \quad p_{i1} \quad K \quad p_{ij} \quad \Lambda \quad p_{in}\right) \qquad (1)$$

Packet Loss Rate between the source node and the destination node in each path is given by:

$$\left(p_1 \quad p_2 \quad K \quad p_i \quad \Lambda \quad p_m\right) \qquad (2)$$

The number of hops between the source node and the destination node in each path is given by:

$$\left(H_1 \quad H_2 \quad K \quad H_i \quad \Lambda \quad H_l\right) \qquad (3)$$

The packet loss rate in each path, which is computed from the packet loss rate between nodes, is given by:

$$p_i = 1 - \prod_{j=1}^{Hi} (1 - p_{ij}) \qquad (4)$$

3.2 Coding Scheme

When we constructed the redundancy packets, we assumed the that the encoding we used would have parameters (N, K, and t), where (i) N is the number of transmitted packets in a group; (ii) K is the number of the data packets in this group; and (iii) t is the erasure recovery capability, i.e., the maximum number of lost packets within the group that can be reconstructed on the basis of the received packets.

3.3 Precondition

In order to simplify the evaluation, the following items are defined as a precondition.

・Number of routes: 2
・Transmission path for data packets: path1
・Transmission path for encoding packets: path2
・Encoding parameters: (N, K, 1)

3.4 Packet Delivery Ratio

The relay node, which encodes is determined for the better packet delivery ratio. The following parameters are defined.

One of the following two requirements needs to be filled in order to send a packet to destination node correctly.

(Requirement 1) Destination is received data packet.

(Requirement 2) Destination node is received packet required decoding.

The probability of meeting requirement 1 is given by:

$$P_1 = 1 - p_1 \qquad (5)$$

We then calculated the probability of meeting requirement 2.

The encoding packet is generated and delivered to a destination node.

The probability that the source node can transmit one packet to the relay node that is an encoding packet is given by:

$$P_{e1} = \prod_{i=1}^{H_e} (1 - p_i) \quad (6)$$

The variable He is the number of hop to a relay node, which encodes the packet.

The probability that the destination node receives two, three, ..., K packets required for coding is approximated by:

$$P_{e2} = \sum_{n=0}^{X} \prod_{j=1}^{H_e} (1 - (1 - p_{2j}))^n (1 - p_{2j}) \approx 1$$

(7)

The probability that the source node can transmit a packet required for encoding to the relay node, which is encoding packet is given by:

$$P_e = P_{e1} P_{e2} = \prod_{i=1}^{H_e} (1 - p_i) \quad (8)$$

The relay node encodes packets if the packet required for encoding is received.

The probability that the relay node can encode and forward the packet to the destination node is given by:

$$P_{ed} = \prod_{j=H_e+1}^{H_2} (1 - p_{2j}) \qquad (9)$$

From (8) and (9), the probability that the encoding packet is generated by a source node is forwarded to the destination node is given by:

$$P_{sd} = P_e P_{ed} = 1 - p_2 \qquad (10)$$

The probability data packet is decoded from an encoding packet and another data packet required for decoding without receiving a data packet is given by:

$$P_2 = p_1 (1 - p_1)^{K-1} P_{sd} = p_1 (1 - p_1)^{K-1} (1 - p_2)$$

(11)

On the basis of (5) and (11), the packet delivery ratio is obtained by:

$$P = 1 - p_1 + p_1 (1 - p_1)^{K-1} (1 - p_2) \qquad (12)$$

(1) Determination of relay node encode

We evaluated which relay node should be encoded.

Formula (12) does not contain the variable He. Thus, we were able to set up a packet delivery ratio regardless of the number of hops to a relay node that encodes the packet.

The packet delivery ratio is the same regardless of node encodes packet.

(2) Determination of the Path

Next, we evaluated whether a data packet should be transmitted on the path and in which conditions.

The formula which is transformed from (12) is given by:

$$P = 1 - p_1 \{1 - (1 - p_1)^{K-1} (1 - p_2)\} \qquad (13)$$

For both two possible relative values the path $p_1 < p_2$ or $p_1 > p_2$, we evaluated, the packet delivery ratio increases.

If the path in which p_1 become smaller is determined, $(1 - p_1)^{K-1}(1 - p_2)$ increases. Therefore, P increases as p_1 decreases. Thus, we determined the path such that $p_1 < p_2$. If the packet loss rate is defined as equal among all the nodes, the path which forwards data packet is determined such that $H_1 < H_2$. Thus, we determined which data packet is forwarded on the path with fewer hops.

3.5 Packet Overhead

Next, we evaluated the packet overhead.

Packet Overhead O is set by setting X as all data packet, which should be sent is given by:

$$O = \frac{X}{K} \left\{ K \left(\sum_{j=1}^{H_1} (1 - p_{1j})^{j-1} + \sum_{j=2}^{H_e} (1 - p_{2j})^{j-1} \right) + \sum_{j=H_e+1}^{H_2} (1 - p_{2j})^{j-1} \right\}$$

(14)

(1) Determination of relay node encode

We decided on the basis of our evaluation, which relay node should be encoded.

We see that the packet overhead O decreased as the amount of *He* decreased as a result of (14). Thus, the relay node adjacent to the source node should encode the packet.

(2) Determination of the path

We evaluated whether a data packet should be transmitted on the path and in which conditions from number of hops.

Packet overhead increases because the number of packets that are forwarded decreases as the packet loss rate increases.

However, packet delivery ratio decreases as the number of packets that is forwarded decreases. Therefore, we did not find the packet delivery ratio because it is factor.

We see that O decreases when the path is determined such that $H_1 < H_2$. Thus, the data packet should be forwarded on the path in which number of hops is fewer.

3.6 Delay

To simplify the evaluation, the following items are defined as assumptions.

We evaluated the delay on the basis of the following parameters.

t_s : transmission interval[s]

t_n : wireless delay[s]

(fixed among all nodes)

The average delay, T_s, which forwards a data packet to a destination node is given by:

$$T_s = H_1 t_n (1 - p_1) \quad (15)$$

The average delay, T_e, the period from when a data packet is decoded from an encoding packet to another data packet is given by:

$$T_e = p_1(1-p_2)(1-p_1)^{K-1}\prod_{j=1}^{H_e}(1-p_{2j})(K-1) \times \sum_{i=1}^{X}((\max(H_1,H_2)t_n + t_s i)(1-\prod_{j=1}^{H_e}(1-p_{2j}))^{i-1}) \quad (16)$$

On the basis of (15) and (16), average delay is obtained by:

$$T = \frac{T_s + T_e}{P} = \frac{p_1(1-p_2)(1-p_1)^{K-2}(K-1)\left(\max(H_1,H_2)t_n + t_s\prod_{j=1}^{H_e}(1-p_{2j})^{-1}\right) + H_1 t_n}{p_1(1-p_2)(1-p_1)^{K-2}+1} \quad (17)$$

(1) Determination of relay node encoding

We evaluate which relay node should code.

We see that the delay T decreases because $\prod_{j=1}^{H_e}(1-p_{2j})^{-1}$ decreases as He decreases since (17).

Thus, the relay node adjacent to the source node should encode the packet.

(2) Determination of Path

Next, we evaluated whether the data packet should be forwarded on the path and in which conditions.

(16) with H_e=1 is given by:

$$T = \frac{p_1(1-p_2)(1-p_1)^{K-2}(K-1)(\max(H_1,H_2)t_n + t_s) + H_1 t_n}{p_1(1-p_2)(1-p_1)^{K-2}+1} \quad (18)$$

We evaluated the delay only when the number of hops was changed.

We assumed that p1 and p2 do not change even if the number of hops changes.

For either values of H, i.e., when $H_1 > H_2$ or when $H_1 < H_2$, we found that the delay decreases. In either case, T remains unchanged because max(H_1, H_2) does not change. Therefore, the delay T decreases as H1 decreases. Thus, the data packet should be forwarded on the path that has fewer hops .

The path on which the data packet is forwarded does not determine the change of the packet loss rate because of the dependence on the number of hops and on each delay time.

4 EXPERIMENT

We verified the validity of the result of the theoretical evaluation by carrying out a computor simulation. We used ns2, a discrete event simulator, [9]. The simulation topology is shown in Figure 3.

The simulation environment is shown in Table 1.

We only considered packet loss from data packets when we evaluated the data transmission rate

Packet Loss Rate is defined as being an equal value among all the nodes.

Table 1 Simulation parameters

Field [m]	1000 × 1000
Number of Nodes	7
Radio range [m]	250
Speed [km/h]	0
Simulation time [sec]	500
Data size [bytes]	512
Transport Protocol	UDP
Time between generating packet [s]	0.25

Packet Loss Rate [%]	0 ~ 50
Encoding parameter	(3,2,1)

4.1 Simulation results

In three evaluation models shown in Table 2, the theoretical result obtained from the formula and the simulation result are shown in Figure 6 through Figure 4.

Table 2 Evaluation model

	Path data packet is forwarded	Path encoding packet is forwarded	He
Model 1	Path 1	Path 2	1
Model 2	Path 1	Path 2	3
Model 3	Path 2	Path 1	1

・Packet Delivery Ratios

The results obtained from Formula (12) (Theory) and the simulation result (Simulation) are shown in Figure 4.

To determine the relay node that encodes the packet, the packet delivery ratio remains unchanged regardless of the number of hops to a relay node which encodes the packet as well as the result proven by the formula.

To determine the path on which the data packet is forwarded, Model 1 has a higher packet delivery ratio than that of Model 3. Thus, this proves that the method to forward data packet should be forwarded on the path in which the packet loss rate is low (the path with few hops) has higher packet delivery ratio.

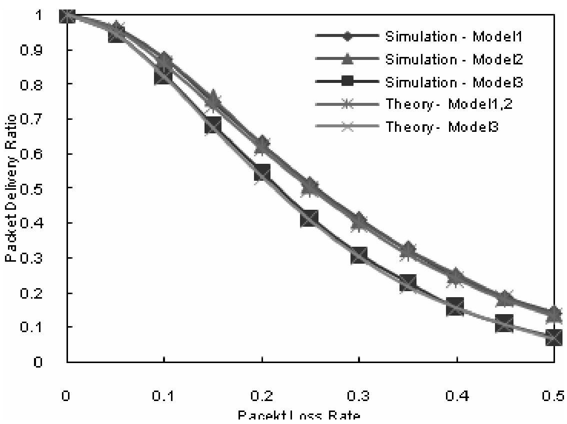

Figure 4 Packet Delivery Ratio

・Packet Overhead

Figure 5 shows the packet overhead.

The result obtained by (14) is the same as that obtained by using a simulation.

Model 1 has the smallest, and Model 3 has the largest packet overhead. Thus, we proved that the way to forward a data packet is to use the path in which the total number of hops is low and the number of hops to the relay node that encodes the packet is low has lower packet overhead.

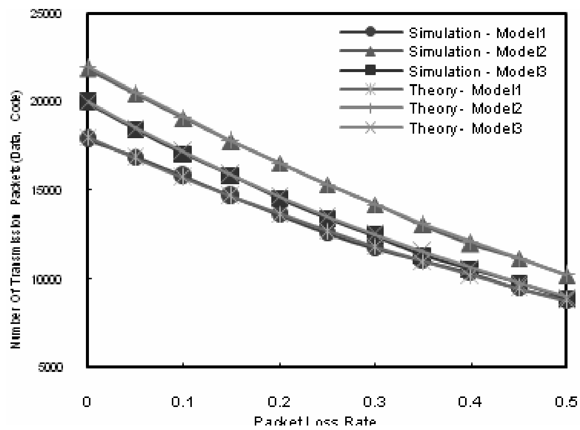

Figure 5 Packet Overhead

・Delay

The delay is shown in Fig. 6: the graph shown was obtained by using Formula (17) with $t_s = 0.25$ and $t_n = 0.01$ and the simulation result.

The graph obtained by using the formula (Theory) is not equivalent to the simulation result (Simulation) because we did not include the time needed to construct a path nor the validity of the set-up wireless communication delay between each node.

However, the result for the magnitude relation is same as that obtained by the simulation, i.e., by determining the path and the relay node encode.

Model 2 has a higher delay in comparison with that obtained by using Model 1. Thus, the delay increases with the number of hops to the relay node that encodes

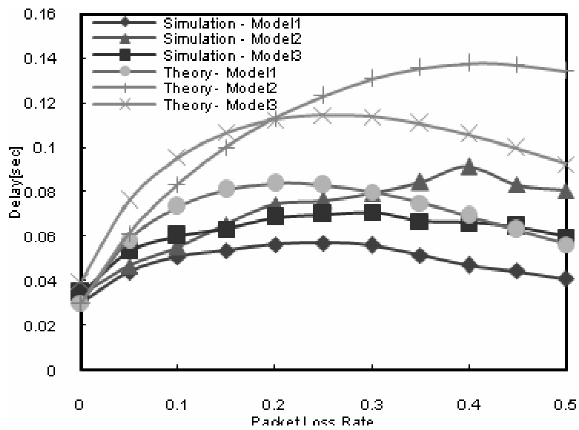

Figure 6 Delay

the packet. As a result, the relay node nearest the source node encodes the packet.

In addition, Model 3 has a higher delay than Model 1. Thus, this proved that the delay decreases when a data packet is forwarded on a path with fewer hops.

4.2 Summary

The data packet that should be forwarded on a particular path and in which conditions, and which relay node should encode a packet is shown in the results of the evaluation (Table 3).

Our method has a higher packet delivery ratio, a lower packet overhead.

The number of hop to a relay node that encodes packet has no relation to the packet delivery ratio. Furthermore, the relay node adjacent to the source node should encode the packet.

Table 3 Result

	Packet Delivery Ratio	Packet Overhead	Delay
Path data packet is forwarded (Packet Loss Rate)	Low	-	-
Path encoding packet is forwarded (Hop)	Few※	Few	Few
Number of hops to a relay node which encodes packet	independent	1	1

*When Packet Loss Rate between all nodes is equal.

5 CONCLUSION

We evaluated our proposed method by using network coding with a multipath routing environment.

We evaluated only two paths: the first path in which data packet is forwarded, and the second one in which the encoding packet is forwarded and limited by encoding parameters with (N, K, 1).

To determine the path on which the data packet is forwarded, we proved that the data packet should be forwarded on a path with few hops when the packet loss rate is equal among all nodes.

To determine which relay node should encodes the packet, we theoretically proved that the relay node adjacent to the source node encodes packet is better.

In addition, we proved the validity of the theoretical evaluation with a simulation.

6 FUTURE WORK

We evaluated a limited number of paths. In addition, all data packets and encoding ones are distributed and forwarded in each path.

However, to ensure that our work takes load balancing into consideration we should evaluate how a packet should be scheduled when more than three paths are constructed.

In addition, we proved that the packet delivery ratio is better when a data packet is forwarded on the path in which the packet loss rate is lower. However, the path is not determined if this rate is not measured. Thus, we need to investigate how to measure the Packet Loss Rate on each path.

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