# A Novel Routing Method for Improving Message Delivery Delay in Hybrid DTN-MANET Networks

# A Novel Routing Method for Improving Message Delivery Delay in Hybrid DTN-MANET Networks

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***Abstract*—Mobile Ad-hoc Network (MANET) has drawn attention of many researchers due to its ability to construct a network without any infrastructure. In MANET, mobile nodes can transmit packets by using multi-hop paradigm. However, with the high probability of link disruption, the performance of this network decreases with the increase of hop count between the source and destination. On the other hand, Delay- and Disruption-Tolerant Network (DTN) is more tolerant to the link disruption. These two types of networks can have different advantages depending on communication environments. Therefore, we focus on a system which is able to switch the routing method, i.e., DTN or MANET, in conformity with the change of communication environment. In this paper, we provide an adequate comparison between the performances of two transmission methods of MANET and DTN. With the aim of reducing the number of transmissions, we propose a routing method which combines both transmission methods. Simulation results show that our proposed method can significantly reduce the number of transmissions and it leads to lowering message delivery delay.**

## I. Introduction

The wide spread of wireless devices such as smart-phones and tablets has made wireless environments more important. However, in the areas without base stations, users cannot communicate with others. Disaster areas are typical examples. In disaster areas, the demand for communications becomes very high, but many users cannot use the wireless service because many base stations may be damaged by the effect of the disaster. In fact, after the Great East Japan Earthquake in March 2011, many people could not confirm the safety of their families and friends, and were unable to exchange information with others. Due to the need of communications in such situations, networks that can provide terminal-to-terminal communications have attracted much attention. Mobile Ad-hoc Network (MANET) is one of example of such a network. In MANET, once the network topology is decided, end-to-end transmissions can be carried out by using various routing protocols. Therefore, MANET has high reliability in high density and low mobility areas. On the other hand, in low density or high mobility areas, the reliability of this network decreases because of the unstable paths due to frequent disruption. In such environment, Delay- and Disruption-Tolerant Network (DTN) [1] performs more effectively. DTN does not use route information like MANET, and it has the ability to store the message whose destination is another node. Additionally, each node distributes a message's replica to its neighbor nodes, which store the message in their storage and forward it whenever new nodes come within their radio range until the message reaches the destination. Then DTN transmits messages in hop-by-hop method. Although this network has high adaptability, it uses the network resources inefficiently due to many replicas of messages. To cope with this problem, various routing protocols, which distribute message replicas efficiently have been proposed [2]-[4]. In these protocols, the nodes limit the number of replicas or predict the location of their destination. Nevertheless, in a high density area, DTN cannot utilize network resources efficiently because each node has many neighboring nodes.

In order to utilize the advantages of both DTN and MANET, some works, which combined both types of networks have been proposed in [5], [6]. These works use the route information obtained from the MANET routing protocol to enhance the performance of DTN. As a result, the nodes use the network resources efficiently even in high density areas. Most of these works use the MANET-based routing protocol in a limited manner, such as a way that only gets the route information. On the other hand, since MANET and DTN employ different transmission methods, i.e., end-to-end in MANET and hop-by-hop in DTN, the delivery delay might be different depending on their respective communication environments. In this paper, we focus on a network, which makes it possible to switch the type of the network, such as MANET and DTN based on different situations. In addition, we consider the difference between the transmission methods of MANET and DTN, and propose a routing method to decrease the delivery delay between the source and destination nodes.

The remainder of this paper is organized as follows. In Section II, we briefly introduce the related works on DTN and MANET. Section III describes a comparison of the transmission methods of DTN and MANET and the network assumption in this research. Our proposed routing algorithm, which focuses on the difference between the two transmission methods, is introduced in Section IV. In Section V, the simulation results are presented. Finally, the paper is concluded in Section VI.

## II. Related works

In the recent literature, various routing protocols, which combined MANET and DTN have been proposed. A routing protocol proposed by Otta *et al.* [7] realizes a higher range of communication in contrast with existing DTN-based routing protocol. This protocol uses AODV [8], which is a reactive routing protocol used in MANET as the method

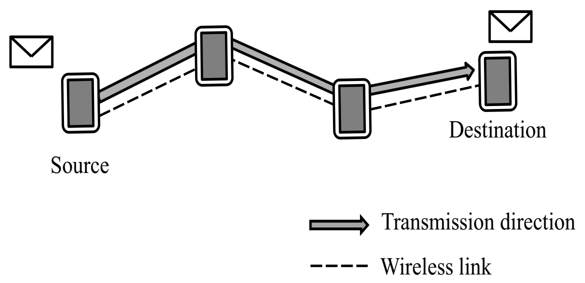


Fig. 1. Data transmission in MANET.

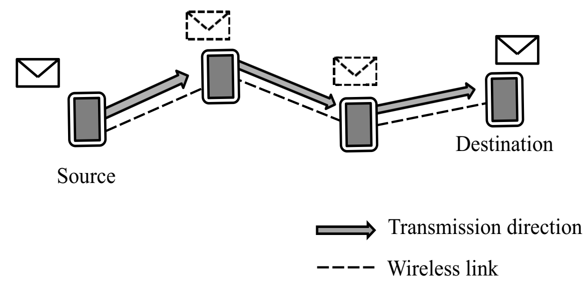


Fig. 2. Data transmission in DTN.

to search where the destination node is. In this protocol, the source node searches a route to the destination node, and if the route exists, the source node allows the transfer of the original message's replica along the route through hop-by-hop communication. Whitbeck *et al.* [9] proposed a hybrid routing protocol focusing on the high density and high mobility areas where DTN and MANET fail to show encouraging performances. This protocol splits all nodes into several groups, and uses different routing protocols for the intra-groups and inter-groups. These schemes achieve a higher performance than existing DTN-based routing protocols by using the route information obtained from the MANET-based routing protocol. In addition, several other studies were carried out in the works in [10]-[12]. The protocols presented in these studies show good performance in only limited communication environments. Therefore, a system which can be used in various environments has drawn attention [13]-[15]. This system enables to switch the type of network based on the communication environment. In this system, the nodes autonomously select their adaptive communication modes, such as DTN and MANET. These modes are selected based on the surrounding communication environment information such as mobility and density of nodes. If the nodes are in a low density area or high mobility area where DTN performs better, they select the DTN mode. On the other hand, if the nodes are in a high density and low mobility area where MANET efficiently performs, they select the MANET mode and build the network. However, in a situation that the number of hops between a source and a destination is large, if the source node transmits a message in MANET, it has a high possibility of a disruption in the end-to-end path. In the situation that the number of hops is small, MANET realizes the transmission with a relatively high possibility. Therefore, besides the mode switching method considering the surrounding environment, an appropriate routing protocol, which considers a situation between a source and a destination is required.

In this paper, we consider the routing protocol in this system, which makes an efficient use of the difference between MANET and DTN. In particular, we focus on the difference between the two transmission methods.

## III. Analysis

In this section, we describe both routing methods of MANET and DTN, and compare their performances.

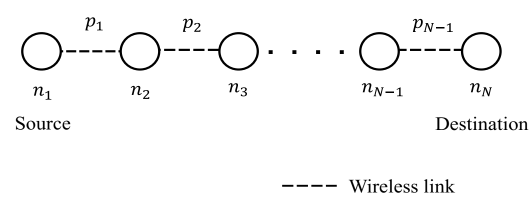


Fig. 3. Assumption model.

### A. Features of transmission methods

As shown in Fig. 1, MANET establishes end-to-end path between nodes, and transmits messages to the destination directly along this path. If the message does not reach the destination, the source attempts to perform retransmission. Thus, when the path is stable, the number of retransmission is small. However, with the increase of hop count between source and destination, the path tends to become unstable due to the frequent disruptions caused by the movements of intermediate nodes. In this situation, the source node has to retransmit the message many times.

On the other hand, in DTN, the nodes forward a message in a hop-by-hop manner from the source to the destination as shown in Fig. 2. Each node stores the messages in its storage during each transmission. As a result, the effect of the hop count in DTN is less than that in MANET because transmissions are independent of each other.

Depending on the hop count and the stability of the paths, the two transmission methods show different performances. In order to make a comparison, we consider a simple network model as shown in Fig. 3. In this model, the nodes line up and each node is in the radio range of its left and right neighbors. Additionally, we define the transmission success probability between the node $i$ and node $(i+1)$ as $p_i$, where $p_i$ can be any value in the range from 0 to 1. In practice, this parameter is a function of node density, mobility and so on.

At first, we consider a one-hop transmission. In the situation that the node $n_i$ tries to send a message to the node $n_{i+1}$, node $n_i$ continues to retransmit until the transmission becomes successful. As the decreasing of the value of $p_i$, the number of retransmissions becomes bigger. The expected number of

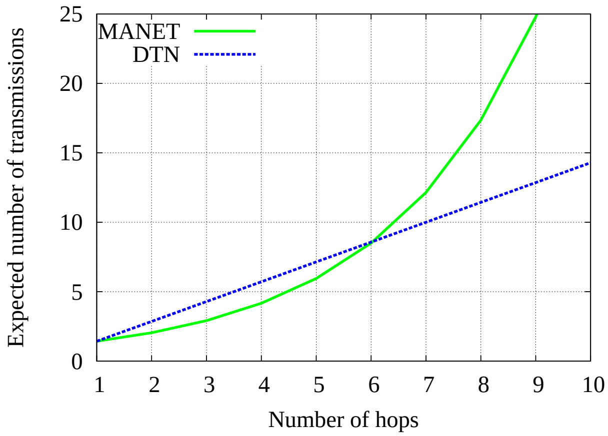


Fig. 4. Relationship between the number of hops and expected number of transmissions.

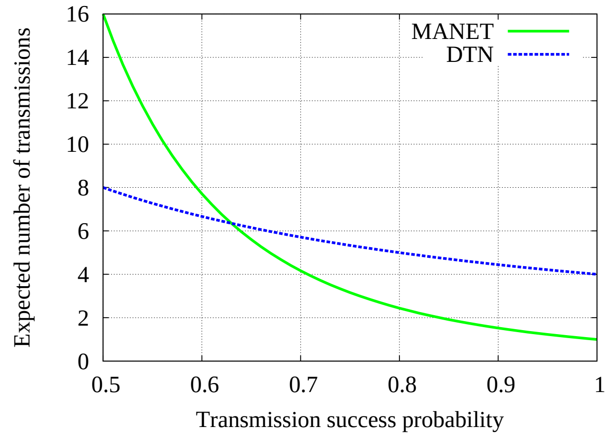


Fig. 5. Relationship between the transmission success probability and expected number of transmissions.

transmissions required to have the success of transmission, namely $E$, is formulated as the following equation.

$$E = \sum_{k=1}^{\infty} k(1-p_i)^{k-1} = \frac{1}{p_i}. \tag{1}$$

In a one-hop transmission, there is no difference between MANET and DTN in terms of the value of $E$.

Secondly, we consider a multi-hop transmission in Fig. 3. In this situation, node $n_1$ tries to send a message to node $n_N$. In MANET, the source node sends a message by using end-to-end paths, and thus, the transmission success probability on this path, namely $P$, is calculated as follows.

$$P = \prod_{i=1}^{N-1} p_i, \tag{2}$$

where $N$ is the number of nodes. Therefore, in MANET, the number of transmissions, namely $E_{\mathrm{MANET}}$, is expressed as follows.

$$E_{\mathrm{MANET}} = \frac{1}{P}. \tag{3}$$

In DTN, the source node sends a message by using hop-by-hop transmissions as shown in Fig. 2. The expected number of transmissions in DTN, namely $E_{\mathrm{DTN}}$, is expressed as follows.

$$E_{\mathrm{DTN}} = \sum_{i=1}^{N-1} \frac{1}{p_i}. \tag{4}$$

### *B. Comparison*

We compare both transmission methods, end-to-end and hop-by-hop, in the situation as shown in Fig. 3. We assume that every $p_i$ ($i$ = 1,2,3,$\cdots$,$N$-1) has the same value of $p$ in order to make a clear explanation for the difference between their performances. At first, we set the parameter $p$ to 0.7, and change the number of hops between the source and the destination from 1 to 10. As shown in Fig. 4, as the number of hops increases, $E_{\mathrm{MANET}}$ increases exponentially while $E_{\mathrm{DTN}}$ increases proportionally. With the low hop count transmission situation, $E_{\mathrm{MANET}}$ obtains lower values than $E_{\mathrm{DTN}}$ due to the high stability of the end-to-end paths. However, when the hop count becomes bigger, the value of $E_{\mathrm{DTN}}$ is bigger than $E_{\mathrm{MANET}}$ because the reliability $P$ decreases rapidly with the increase of the hop count. Therefore, in the area where the number of hops is small, it is more effective to use end-to-end transmission method. In contrast, if the number of hops is large, the hop-by-hop transmission method is more effective. Secondly, we change the value of $p$ from 0.5 to 1.0 and set the total number of hop count to 5. Fig. 5 depicts the result. In this situation, $E_{\mathrm{MANET}}$ decreases sharply with the increase of the value of $p$. In contrast, $E_{\mathrm{DTN}}$ decreases gradually in contrast with MANET. Therefore, when the hop count is set to 5, if the value of $p$ is smaller than nearly 0.62, DTN performs more effectively than MANET. On the other hand, MANET shows better performance in the stable area in which the value of $p$ is relatively high. Thus, it becomes obvious that there are communication environments, which are suitable for

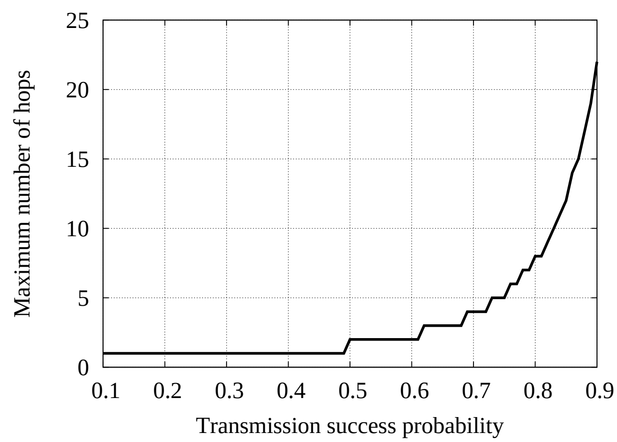


Fig. 6. Relationship between the transmission success probability and maximum hop number.

each transmission method. Moreover, the suitable method can be decided by using the hop-count and transmission success probability. In a scenario that every $p_i$ is set to the same value of $p$, we consider the threshold of hop count to decide which method is the most effective one. The difference between $E_{\text{MANET}}$ and $E_{\text{DTN}}$ in the $h$ hops transmission, denoted by $D(h)$, is expressed as the following equation.

$$D(h) = E_{\text{DTN}} - E_{\text{MANET}} = \frac{h}{p} - \left(\frac{1}{p}\right)^{h}, \tag{5}$$

where $h$ is the hop count between the source and the destination. If the value of $D(h)$ is positive, MANET performs more effectively than DTN in terms of the lower number of transmissions. Additionally, $D(h)$ has a maximum value with a certain hop count because $D(h)$ is the convex function. Therefore, we can calculate the maximum hop count, which end-to-end transmission performs more effectively than hop-by-hop transmission. This maximum hop count, namely $h_{max}$, is calculated by following expression.

$$h_{\max} = \left\lceil \frac{\ln\left(p \ln \frac{1}{p}\right)}{\ln p} \right\rceil. \tag{6}$$

The value of $\ln(p \ln \frac{1}{p})/\ln p$ is equal to the maximum value of $h$, and in the right side of this equation, the maximum value of $h$ is rounded off because the hop count has to be the integer value. We calculated $h_{max}$ with the increase of the value of $p$, from 0.1 to 0.9. This result is shown in Fig. 6. As shown in this figure, when $p$ is less than 0.5, the value of $h_{max}$ is equal to 1 and it means that the 1-hop transmission realizes the lowest number of transmission. Therefore, in this situation, it is better to use hop-by-hop transmission method in DTN. On the other hand, when $p$ is higher than 0.5, the value of $h_{max}$ is more than 1, and it means that the $h_{max}$ hops end-to-end transmission shows better performance than the hop-by-hop transmission.

## IV. Multihop-by-multihop routing method in hybrid DTN-MANET networks

In this section, we propose a new routing method, which integrates the hop-by-hop and end-to-end transmission methods, to decrease the number of transmissions which are generated until the message gets to the destination. Additionally, since one of the factors which increases the delay is the retransmissions of message, it also realizes lower message delivery delay. As noted above, in some stable environments where the value of $p$ is high or the number of hops is small, MANET will perform more effectively. On the other hand, DTN shows high performance in some unstable environments. However, in fact, it is expected that the communication environment contains both of the high and low stability areas. Therefore, we propose a new routing method which shows the better performance than both MANET and DTN. In our routing method, we assume that all nodes have route information, and they construct an overlay network by themself. For minimizing the number of transmissions, by using this overlay network,

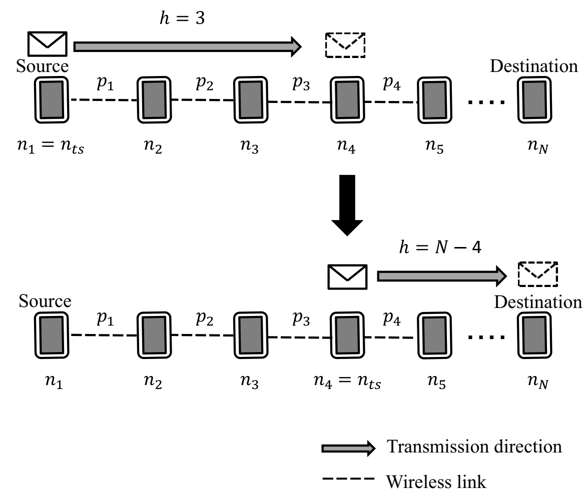


Fig. 7. The overview of our proposed routing method.

**Algorithm 1** Multihop-by-multihop routing algorithm

$ts \Leftarrow 1$;
**while** The destination node has not received the message **do**
  $h \Leftarrow 1$;
  **if** $n_{ts+1}$ is the destination node **then**
    **while** Transmission is not completed **do**
      $n_{ts}$ sends the message to $n_{ts+1}$;
    **end while**
  **else**
    **while** $n_{ts}$ does not send the message **do**
      **if** $1/\prod_{i=ts}^{h+1} p_i < 1/\prod_{i=ts}^{h} p_i + 1/p_{ts+h}$ **then**
        $h \Leftarrow h + 1$
        **if** $n_{ts+h}$ is destination **then**
          **while** Transmission is not completed **do**
            $n_{ts}$ sends the message to $n_{ts+h}$
          **end while**
        **end if**
      **else**
        **while** Transmission is not completed **do**
          $n_{ts}$ sends the message to $n_{ts+h}$;
        **end while**
        $ts \Leftarrow ts + h$;
      **end if**
    **end while**
  **end if**
**end while**

transmissions between the source and destination are conducted by multihop-by-multihop transmission which combines end-to-end and hop-by-hop transmission.

### A. Considered scenario

We consider the same scenario as shown in Fig. 3. In this scenario, node $n_1$ sends a message to node $n_N$, and all nodes have the route information and the transmission success probability of every path. The nodes get such information through exchanging some topology control messages among the nodes according to existing routing protocol of MAENT such as OLSR [16].

### B. Proposed routing algorithm

The overview of our proposed routing method is shown in Fig. 7. In this method, we define two parameters: $ts$ and $h$. The parameter $ts$ means the temporary source node number, and $h$ means the hop number used for the end-to-end transmission. In order to realize the multihop-by-multihop transmission, the temporary source node $n_{ts}$ calculates the optimum value of $h$, and sends the message to the temporary destination which is $h$ hops away. Depending on $h$, the multihop-by-multihop transmission is conducted as shown in Fig. 7. The detail of our proposed routing algorithm is presented in Algorithm 1. Initially, the value of $ts$ and $h$ is set to 1. Firstly, the source node checks whether the node in the next hop is the destination node or not. If it is the destination node, the source node tries to send the message to the destination until the transmission is completed. On the other hand, if the node is not the destination, the source node decide the optimum value of $h$ based on the following inequality,

$$\frac{1}{\prod_{i=ts}^{h+1} p_{\mathrm{i}}} < \frac{1}{\prod_{i=ts}^{h} p_{\mathrm{i}}} + \frac{1}{p_{ts+h}}. \tag{7}$$

In the left side of this formula, $1/\prod_{i=ts}^{h+1} p_{\mathrm{i}}$ means that the expected number of transmissions when the temporary source node $n_{ts}$ sends the message to the node $n_{ts+h}$ directly using end-to-end transmission. In the right side of this formula, we assume that the node $n_{ts}$ sends the message to the node $n_{ts+h-1}$ in the end-to-end path and then the node $n_{ts+h-1}$ sends it to the node $n_{ts+h}$ in the one-hop path. If the value of $h$ satisfies the inequality (7), the temporary source node $n_{ts}$ increments the value of $h$. After repeating the above process, if the value of $(h+1)$ does not satisfy that inequality, the node $n_{ts}$ sends the message to the node $n_{ts+h}$. Additionally, the value of $ts$ is set to the value of $(ts+h)$ and the process of calculating $h$ is conducted again. By repeating these processes until the destination node receives the message, our proposed method realizes the minimum expected number of transmissions.

## V. Performance evaluation

In this section, we evaluate the performance of our proposed method. We compare the performances of the considered methods in terms of the number of date transmissions before the message get to the destination. Actually, the success of transmission relies on some uncertain elements such as mobility, density, and geographical dimension. In this simulation, whenever the node transmits a message to other node, we set a random value to $t$ which can be from 0.1 to 1. By using $t$, we define whether the transmission between nodes becomes successful or not. If the value of $t$ is smaller than $p_i$, we consider that the transmission of this path is successful. On the other hand, if the value of $t$ is bigger than $p_i$, we consider that the node fails to transmit, and needs to retransmit the message. Therefore, as the stability $p_i$ becomes higher, it is easy to complete the transmission between nodes. Based on these, we measured the average number of transmissions before the message reaches the destination through two thousands times of trials. This comparison is conducted in two scenarios. At first, we verify our proposed method in the situation that $p_i$ is constant in order to demonstrate the effectiveness of our proposal. In this scenario, we demonstrate the effectiveness of our proposal in comparison with the basic assumption as described in Section III. Secondly, we evaluate the effect of $p_i$ on the transmission performance. In this scenario, we suppose that the realistic environment where $p_i$ has various values depending on the location of each node.

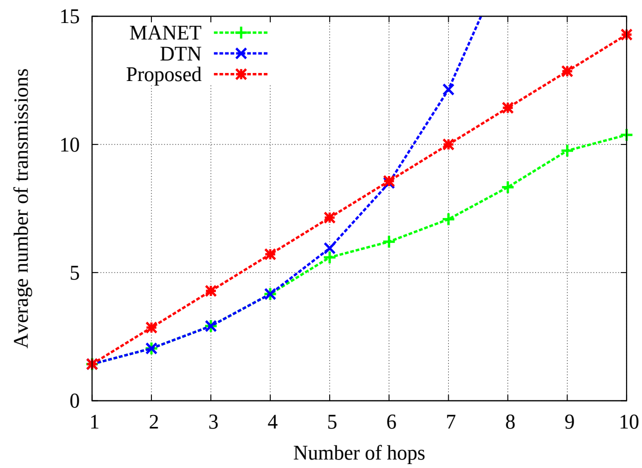


Fig. 8. Performances in the basic scenario ($p_i$ is constant).

### A. Basic scenario in which $p_i$ is constant

In this scenario, we set the value of $p_i$ to 0.7. The result is shown in Fig. 8. In this figure, our proposed method shows smaller average number of transmissions than MANET and DTN. Additionally, as noted in section III, the maximum hop number $h_{max}$ is calculated, and the value is equal to 4. In fact, our proposed method shows the same performance as MANET when the number of hops is smaller than 5. When the number of hops is equal to or higher than 5, the performance of our proposed method is significantly better than that of MANET.

### B. Realistic scenario in which $p_i$ has a random value.

In this scenario, we set each $p_i$ to a random value. Firstly, we determine the range of the random value from 0.7 to 0.9. This situation supposes that the nodes communicate under a relatively stable environment. This result is shown in Fig. 9. When the number of hops is equal to or lower than 10, MANET performs more effective than DTN. However, with the increase of the total hop count, there is no difference of average number of transmissions between MANET and DTN. Our proposed method shows a smaller average number of transmissions than both MANET and DTN for any value of the hop number.

After that, we determine the range of the random number from 0.1 to 0.9. In this situation, we consider that the nodes

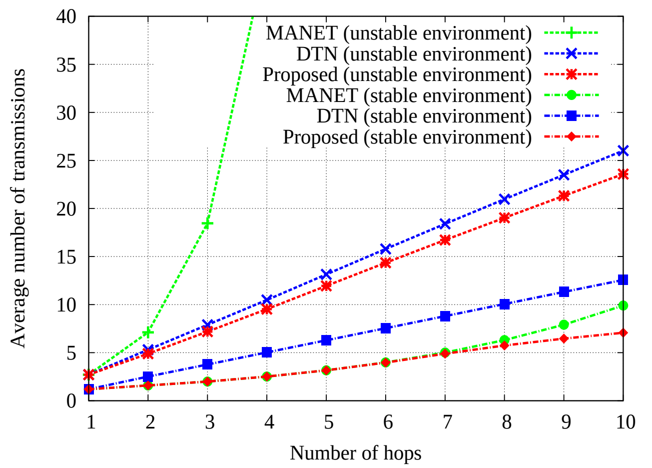


Fig. 9. Performances in the realistic scenario (each $p_i$ has a random value).

communicate in the unstable communication environment, where $p_i$ has widely different value. As shown in Fig. 9, the average number of transmissions in MANET increases greatly because the transmission success probability between the source and the destination decreases rapidly. On the other hand, DTN and our proposed method show a steady performance without being influenced by the unstable environment. Moreover, the proposed method performs more effectively than DTN. From these results, we confirmed that our proposed method shows significantly better performance than other routing methods in any communication environment.

## VI. Conclusion

In this paper, we focus on the system which can dynamically switch the communication mode between DTN and MANET by considering the surrounding communication environment. Due to the differences between the two transmission methods, which are DTN-based hop-by-hop and MANET-based end-to-end, each method shows a different performance depending on the communication environment. However, since the existing system only switches its communication mode, it does not take advantage of their differences. Therefore, we proposed a new routing method in this system with the aim of realizing the transmission in the minimum number of transmissions. In this method, the message is transmitted in multihop-by-multihop transmission method which combined hop-by-hop transmission method with end-to-end transmission method. Additionally, in response to the path condition, each node calculates the optimum number of hops in just one transmission. Through simulations, we have shown that the transmission conducted by the proposed method can achieve a significantly low number of transmissions. If the nodes are in an unstable area where the transmission success probability changes irregularly, the proposed method performs like DTN. On the other hand, if they are in the stable area where the probability is almost unchanged, the proposed method performs like MANET. Moreover, our proposed method realizes a significantly lower number of transmissions than DTN and MANET in any environments. Additionally, by reducing the number of transmissions, our proposed method realizes a low message delivery delay.

## VII. Acknowledgments

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