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Toward Terminal-to-Terminal Communication Networks: A Hybrid MANET and DTN Approach

Yuichi Kawamoto, Hiroki Nishiyama, and Nei Kato
Graduate School of Information Sciences, Tohoku University, Sendai, Japan
E-mails: {youpsan, bigtree, kato}@it.ecei.tohoku.ac.jp

***Abstract*—To realize ubiquitous wireless network environment, we focus on terminal-to-terminal communication networks in this research. Especially, Mobile Ad-hoc Network (MANET) and Delay-and Disruption-Tolerant Network (DTN) which are considered good candidates for next generation network model. In these networks, the users can transmit their data via other users' terminals (e.g., smart phones, notebooks, etc.) without special network equipment. However, the performance of these networks may decrease depending on the surrounding environment such as user density and mobility. Therefore, we propose a novel method to utilize both these network-technologies efficiently. In our proposed method, each node selects the network mode (i.e., MANET or DTN) according to its own condition and the surrounding environment. Additionally, we propose an efficient technique to combine MANET and DTN in order to avoid wasting the network resources. Moreover, we demonstrate the results of our experiments which are carried out with real smart phones where the proposed method is implemented. Furthermore, some future works to this research are introduced.**

***Index Terms*—Terminal-to-terminal communications, Mobile Ad-hoc Network (MANET), Delay-and Disruption-Tolerant Network (DTN), Unmanned Aircraft Systems (UAS).**

I. Introduction

In recent years, terminal-to-terminal communication networks have attracted attention with the wide spread of wireless devices such as mobile phones, smart phones, and mobile PCs. Since these networks are basically consisted of only mobile nodes, the network users can construct and access the network anytime and anywhere without base stations. Thus, it is expected to serve as a new network model for those areas where network infrastructure is inadequate. For example, the cost to prepare adequate network infrastructure is too high for developing countries. In addition, in disaster areas, it is difficult to provide network access to the people in those areas due to the damage of their local network equipment. Actually, in East-Japan Catastrophic Disaster which happened in March 2011, the earthquake and tsunami dramatically affected communication infrastructures. Although a few equipment remained in limited areas, many people experienced inconvenience with insufficient information due to the disruption of the network. In such areas, it is strongly required to revive network environment easily and quickly. Thus, we focus on terminal-to-terminal communication networks, especially Mobile Ad-hoc Network (MANET) [1], [2] and Delay-and Disruption-Tolerant Network (DTN) [3], [4].

In these networks, users consider each other as the network nodes and construct the network without base stations. As a result, they can deliver their data through the network to the area where network infrastructure is deployed. However, MANET and DTN have different features regarding the network environment. In areas where the user density is high, MANET provides high network reliability. On the other hand, in areas where the user density is low and/or the moving speed of the users is high, DTN achieves a certain level of network connectivity while the performance of MANET drastically decreases in such situation.

Therefore, we propose a novel method to utilize both MANET and DTN technologies efficiently. In our proposed method, each network user automatically selects which network mode to be used according to remaining amount of battery, mobility, and surrounding environment. By choosing adequate network mode, our proposal achieves high network performance. In addition, by combining MANET and DTN in our proposal, an efficient technique to avoid wasting network resources is described. Moreover, by conducting real-time experiment using smart phones, and demonstrating the experimental result, we verify the effectiveness of our proposal.

The remainder of this paper is organized as follows. Section II introduces the network model of MANET and DTN. In addition, the shortcomings of these network models are described. Section III demonstrates our proposed method to utilize MANET and DTN technologies efficiently. The experimental result is presented in Section IV. In section V, future work of this research is introduced. Finally, concluding remarks are provided in Section VI.

II. Existing network model

A. Mobile Ad-hoc Network (MANET)

In MANET, each node exchanges routing control message with other nodes and constructs a routing table based on the messages received from the other nodes. Each node sends data to destination node via some other nodes, which are utilized as routers. By using the routing table, the nodes are able to decide an adequate route to deliver the data depending on the adapting routing method. Thus, MANET ensures end-to-end communication. Additionally, since there are many routing protocols in MANET, the network resources such as bandwidth and nodes-buffer are utilized efficiently by selecting adequate routing method [5]–[8]. For example, Optimized Link State Routing (OLSR) [9] and Ad hoc On Demand Distance Vector (AODV) [10] are famous routing schemes. By adapting such routing methods, data is delivered through an efficient route in MANET. However, reliability of the network decreases when the node density is low and/or the moving speed is high. This is because the low density and/or the high moving speed of the nodes make(s) it difficult to construct an appropriate routing table. If the number of neighboring nodes is low, the number of links connected to the node decreases. On the other hand, if the moving speed of the nodes is high, it becomes difficult to keep the links with the neighboring nodes for a long time and the accuracy of the routing table decreases in a very short period of time. Thus, network connectivity and its reliability drastically decrease in such situations. Moreover, in MANET, since each node has to send routing control message in repeated fashion to update the routing table, the amount of energy consumption is high.

B. Delay-and Disruption-Tolerant Network (DTN)

DTN uses a store and forward technique to deliver data to the destination. In a DTN, nodes choose to store or to forward their data according to the existence of neighboring nodes. If there is no neighboring nodes in its communication range, the node store the data and wait until a neighboring node appears. After finding a neighboring node, the node sends the stored data to it. On the other hand, if there are some neighboring nodes, the node sends the data to some of these neighboring nodes according to the applied routing method [11]. Two of the most commonly used routing methods in DTN are epidemic routing [12], [13] and Spray and Wait (SnW) [14]. In epidemic routing, every node distributes copy of the data with no limit. In other words, all nodes send their stored data to every neighboring node. In contrast, SnW adopts a limit to the number of data copies to be distributed. In this way, by making some copies of the data and send them to multiple neighboring nodes, the rate of data arrival at the destination increases in DTN. As a result, it achieves data delivery from the node which is isolated from other nodes by adapting the data storing technique. However, since each node does not use routing table in DTN, end-to-end communication cannot be ensured. Additionally, since each node sends data to multiple neighboring nodes by copying the data, more network resources are consumed in DTN than MANET. Moreover, delivery delay is not considered in this network.

III. Proposed hybrid utilization method of MANET and DTN

In this section, we propose a novel method to utilize both MANET and DTN technologies efficiently. We show how to select which network mode is suitable according to the surrounding environment. Additionally, an efficient technique to combine MANET and DTN in our proposal is described.

A. Effective network mode selection

In our proposed method, each node selects MANET or DTN as its network mode according to the surrounding environment and the condition of the node. Fig. 1 shows an example of the situation where the proposed method is applied [15]–[17]. As indicated in the figure, each node selects the network

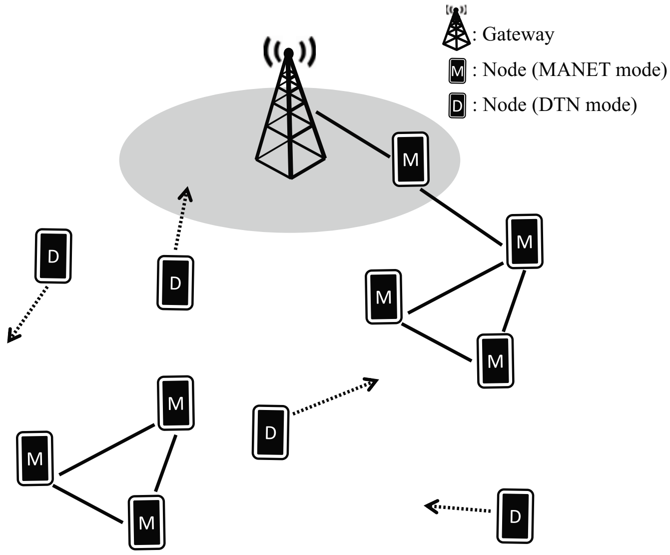


Fig. 1. An example of situation where MANET and DTN technologies are utilized in same area.

mode and delivers the data to the destination via other nodes. Additionally, we assume that the destination of every node is a gateway of the network (e.g., base station of cellular network). On the other hand, the algorithm of the proposed method is described in Algorithm 1. In this proposed method, each node selects the network mode according to three parameters related to the condition of the node in addition to the number of neighboring nodes. The three parameters related to the condition of the node are: (i) amount of remaining battery, (ii) moving speed, and (iii) acceleration.

At first, our algorithm checks the amount of remaining battery. If MANET mode is adopted, the node have to send routing control message at regular intervals to update the routing table, which results in more energy consumption than if DTN mode is selected. Thus, if the amount of remaining battery is less than a certain threshold, DTN mode is selected. Here, we define the threshold of the amount of remaining battery to decide the network mode as t_e and the amount of remaining battery as e. Hence, when the value of e is less than the value of t_e, the node selects DTN mode. Secondly, each node checks its own moving speed. If the moving speed of the node is high, it is difficult to keep accurate routing table in MANET mode because the positions of the node drastically change with time. Thus, DTN mode is selected if the moving speed, referred to as v, is higher than the value of t_v which is the threshold of the moving speed. Thirdly, the acceleration of the node is checked to decide the network mode. High acceleration of the node makes it hard to keep accurate routing table as in the case of high moving speed. Thus, the node selects DTN mode if the value of its acceleration, referred to as a, is higher than the threshold of the acceleration, referred to as t_a. At last, each node checks the number of neighboring nodes in its transmission range. Since a certain amount of

Algorithm 1 Proposed algorithm to select the network mode.

Check the amount of remaining battery, e.
Check the moving speed, v, and acceleration, a.
Check the number of neighboring nodes, N_{neighbor}.
if $t_e \geq e$ **then**
  Select the DTN mode.
else if $t_a \geq a$ **then**
  Select the DTN mode.
else if $t_v \geq v$ **then**
  Select the DTN mode.
else if $t_N \geq N_{\text{neighbor}}$ **then**
  Select the DTN mode.
else
  Select the MANET mode.
end if

nodes is required to construct topology in MANET, DTN mode is selected if the number of neighboring node, referred to as N_{neighbor}, is less than t_N which is the threshold of the number of neighboring nodes to construct topology in MANET.

B. Efficient technique to combine MANET and DTN

As discussed in the previous section, each node selects one network mode (i.e., either MANET or DTN) and sends their data in that network. When the nodes select the same network mode, they transfer their data in a conventional manner of the exiting protocol of MANET or DTN. Additionally, in the case where a node in MANET mode sends data to a node in DTN mode, the data delivery is done as DTN, which means that the node in MANET mode sends the copy of the data and also keeps the original data. On the other hand, when a node in DTN mode sends data to a node in MANET mode, we apply a new technique to combine MANET and DTN to improve the network performance.

We divide the situation where a node in DTN mode sends data to a node in MANET mode into two cases. First case is that the destination node or network gateway belongs to a local connected network constructed by nodes in MANET mode. Fig. 2 shows an simple example of this case. As shown in the Fig. 2, a node in DTN mode wants to send data, and the neighboring nodes are two nodes in MANET mode. If the node sends the data to both the nodes in MANET mode, same data will reach the destination node or gateway, which results in a waste of the network resources. Thus, we propose a new technique to avoid the useless data sending. In this proposal, the nodes in MANET mode which construct the local connected network are classified according to the number of hops from the destination node or gateway as shown in Fig. 2. We refer to the number of hops as *Class*. When the node in DTN mode finds the nodes in MANET mode, it chooses the node having lower number of the *Class*. As a result, the node can send data to the destination node or gateway via minimum hops and avoid wasting the network resources.

Second case is that the destination node or the network gateway does not belong to local connected network constructed

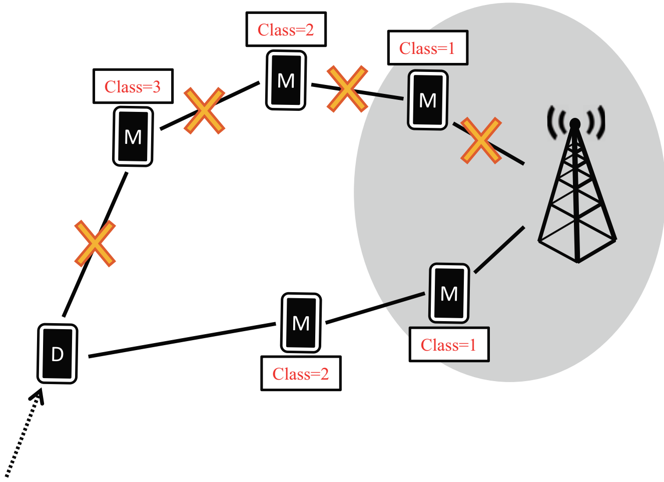


Fig. 2. An example of data delivery using *Class* of each node.

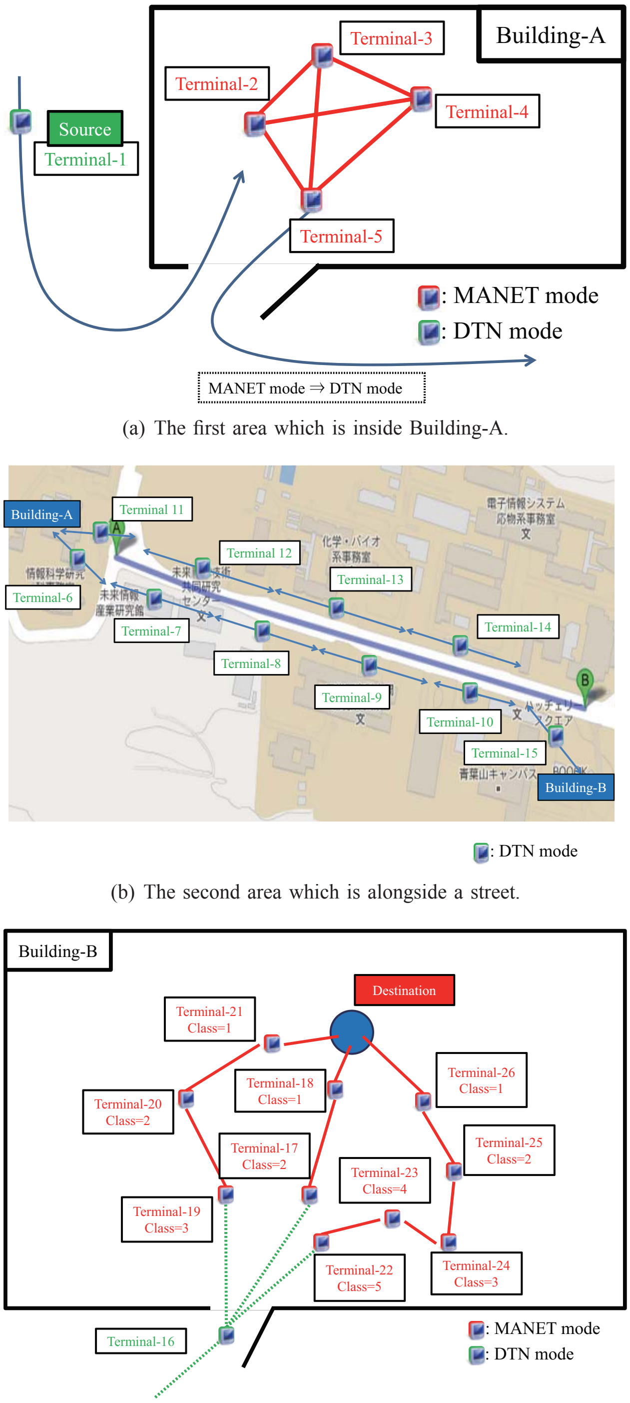
by nodes in MANET mode. In this case, the node in DTN mode sends the data to all the nodes in MANET mode in the transmission range. The nodes in MANET mode which receive the data from the node in DTN mode share the data with all nodes in the local connected network. By sharing the data with other nodes in MANET mode, it increases the probability that the data will be delivered to the destination.

IV. Experiment

In this section, we describe our experiment in which we used real smart phones. The proposed method has been implemented into the smart phones to give them the ability to select the network mode from either MANET or DTN automatically. Firstly, we show the experimental environment. Secondly, the result of the experiment is demonstrated.

A. Experimental environment

We deployed twenty-six users having the smart phones which the proposed method is implemented and a user having a notebook as the destination. The deployment of the users are shown in Fig. 3. Additionally, the terminal identification number of each smart phone that the users had is also described in the figure. As shown in Fig. 3, the deployment of the users is divided into three areas. The first area is inside Building-A as presented in Fig. 3(a). In this area, we deployed a source node in DTN mode and some nodes in MANET mode which construct the local connected network. Fig. 3(b) shows the second area which is outside Building-A. The users in this area are deployed alongside a street and move along the street. The third area is described in Fig. 3(c). In this area, some users are deployed to construct a local connected network with a user having the destination terminal inside Building-B. In these three areas, data is delivered from the source user to the destination user via other users in MANET mode or DTN mode.



(a) The first area which is inside Building-A.

(b) The second area which is alongside a street.

(c) The third area which is inside Building-B.

Fig. 3. Deployment of users in our experiment.

B. Experimental result

In this experiment, at first, data was generated at Terminal-1 in Fig. 3(a). Since Terminal-1 was far from other terminals at first, DTN mode was selected. After generation of the data, terminal-1 moved to the area where some terminals in MANET mode construct the local connected network. Since the destination terminal is not in that local connected network constructed by the terminals in MANET mode, Terminal-1 sent the data and the terminals in MANET mode shared the data. After that, Terminal-5 stepped out of Building-A and got close to Terminal-6 and Terminal-11. At this time, Terminal-5 changed the network mode to DTN mode because of its movement. Additionally, Terminal-6 and Terminal-11 were in DTN mode because they were moving faster than a certain level of speed. Moreover, other terminals in the second area were also in DTN mode for same reason. After Terminal-6 and Terminal-11 received the data from Terminal-5, the data is delivered to Terminal-15 via some terminals in DTN mode. After that, Terminal-15 moved to Building-B and sent the data to Terminal-16 which was also in DTN mode because it was far from other terminals inside Building-B. After receiving data, Terminal-16 moved inside Building-B and sent the data according to *Class* of the terminals in Building-B. Since there were some terminals in MANET mode and the destination terminal, the terminals in MANET mode were classified according to the number of hops from the destination terminal. As shown in Fig. 3(c), Terminal-16 found Terminal-17, Terminal-19, and Terminal-22 but only Terminal-17 had the smallest *Class*. Therefore, Terminal-16 sent the data to only Terminal-17. As a result, the data was delivered from Termianl-17 to the destination terminal via Terminal-18. In this way, we confirmed that the data was delivered from the source terminal to the destination terminal via some nodes in MANET mode or DTN mode in this experiment.

V. Future Work

As a future work of this research, we consider expanding the scenario of the experiment and optimizing the proposed method. In this paper, we introduced that data is delivered from a source node to a destination node via other nodes in MANET mode or DTN mode using our proposed method. The next step is to evaluate the performance of the proposal in an environment where multiple source nodes and multiple destination nodes exist in the network. In such situation, one of the important issues is how to avoid frequency interference between the nodes if the density of the nodes is high. Since the nodes in MANET mode transmit routing control message at certain intervals, it causes an increase of the frequency interference. On the other hand, in DTN, since each node makes a copy of the data in order to increase the arrival rate of the data, the frequency interference caused by data transmission increases. Moreover, since all nodes in DTN mode and MANET mode store the copy of the received data when they cannot find the destination node in their transmission range or routing table, the number of copies of the same data may increase too much. Thus, an efficient way to control the number of data copies is also required. Furthermore, the threshold to select the network mode in the proposed method needs to be optimized. Evaluating the proposed method in the expanded scenarios by using some numerical results is also one of our next target.

Fig. 4. An example of UAS which is utilized in our research.

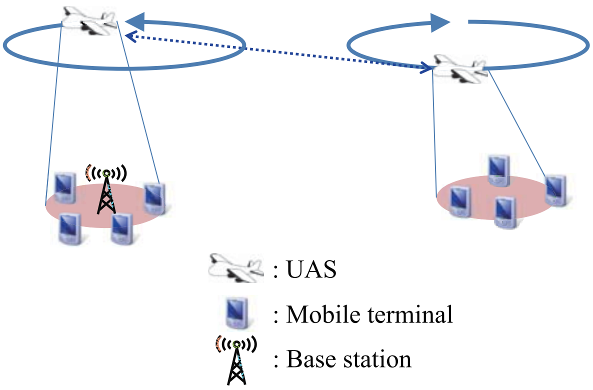


Fig. 5. An example of a network model where UAS network and ground networks are combined.

On the other hand, combining the proposal with Unmanned Aircraft Systems (UAS) is also considered as a future work of this research. UAS is an aircraft without a human pilot on board. Its flight is controlled autonomously by computers in the aircraft or a pilot on the ground. Fig. 4 shows an example of UAS which is utilized in our research. By implementing our proposal to UAS, it can expand the network area and improve its flexibility. Fig. 5 shows an example of network model that UAS network and ground networks such as MANET and DTN are combined. Since UAS fly in the sky, it can cover larger area than a terminal on the ground. Thus, for example, it can deliver the data from isolated user on the ground more easily. Additionally, UAS is supposed to be able to have bigger buffer size than a terminal on the ground. Hence, it can carry data from multiple terminals on the ground at once.

VI. Conclusion

In this paper, we proposed a novel method to utilize MANET and DTN technologies efficiently. MANET and DTN are considered as good candidates for the next generation network model. However, each of these networks provides good network performance only in limited environment. Thus, in our proposal, each node selects the network mode from either MANET or DTN according to the surrounding environment and its condition. By selecting adequate network mode, it improves the network performance in diversified environment. Additionally, an efficient technique to combine MANET and DTN was developed in this research. Moreover, we introduced an experiment which we carried out to show the effectiveness of our proposal. In this experiment, we used real smart phones in which our proposed method is implemented. From the experimental result, it is confirmed that data is delivered from a source node to a destination node via other nodes in MANET mode or DTN mode with the proposed method. At last, we introduced some future works of this research.

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