A Novel Communication Mode Selection Technique for DTN over MANET Architecture

Citation:

Masaya Ito, Hiroki Nishiyama, and Nei Kato, "A Novel Communication Mode Selection Technique for DTN over MANET Architecture," International Conference on Computing, Networking and Communications(ICNC 2014), Honolulu, Hawaii, USA, Accepted.

A Novel Communication Mode Selection Technique for DTN over MANET Architecture

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***Abstract*—In this paper, we focus on the terminal-to-terminal communication technology, which enables communication without requiring any fixed infrastructure. The typical networks that fit this paradigm are Mobile Ad-hoc Network (MANET) and Delay and Disruption Tolerant Network (DTN). In these networks, the users can transmit messages by relaying the messages through other mobile terminals such as smartphone, laptop, or tablet PC. Since transmission methods of MANET and DTN are different, their performances depend on communication environment such as their mobility and overall terminal density. MANET is suitable for the environment where the terminals are static and are in dense area, but DTN is more suitable for the environment where user terminals have high mobility and are mostly isolated. Therefore, we propose a method, which switches the terminal's communication mode between MANET and DTN, to take advantage of different network characteristic and avoid wasting of network resource. Additionally, we implemented this algorithm in actual smartphones. Through the experiment using these smartphones, we have confirmed that the algorithm functions correctly.**

Fig. 1. The smartphones, which our algorithm is implemented.

I. Introduction

After the Great East Japan Earthquake in March 2011, many base stations were damaged, and many users could not use their communication devices such as smartphone. After disaster strikes, communication services become increasingly important as people will attempt to contact their families or friends to confirm their safety. Recently, the networks that can provide terminal-to-terminal communications have attracted much attention as one of the possible solutions to providing the needed communications services in the disaster area. These networks are able to construct a temporary network using only mobile terminals such as smartphone, laptop, or tablet PC that could eventually provide a mean of communication between users within or outside the disaster area even when the fixed infrastructure are unavailable. Currently, two types of networks for this purpose, which have been proposed are Mobile Ad-hoc Network (MANET) and Delay and Disruption Tolerant Network (DTN). MANET is flexible and can autonomously build a network. In addition, MANET can change its topology dynamically through cooperation of user terminals by exchanging the route control messages. Currently, various routing methods have been proposed for MANET [1][2]. In addition, it is possible to extend the communication range from each terminal to terminals that are further away by relaying messages in multi-hop fashion. However, if the users have high mobility and move out of transmission range, some messages will be dropped due to link disruptions. In such environment, DTN [3] is much more suitable. DTN does not require route information like MANET, and they transfer messages by using their mobility. In DTN, to increase the delivery ratio, several copies of the message are replicated and forwarded to the neighbor terminals. Each mobile terminal can store the replicated messages even though it is not the recipient, so the data transmissions between source and destination are realized by repeatedly replicating and forwarding the messages. Therefore, DTN can enable message transmissions in some area that MANET cannot support such as a low density area where users have high mobility. This is because MANET cannot establish end-to-end path from the source to the destination due to the mobility of the users. Additionally, the performance of DTN depends on its routing method, and various routing methods have been proposed [4][5].

These two networks achieve different performances under different situation [6]. In low mobility and high density area, MANET uses network resource more efficiently by sending the message directly to the destination on an end-to-end path, where DTN causes more overhead because it distributes many replicas of the messages. In high mobility and low density area, MANET suffers from frequent link disruptions and small number of neighbors. On the other hand, DTN has high possibility of delivering messages to the destination by using the store and forward method. In order to utilize the advantages and overcome the disadvantages of both MANET and DTN, some works that combine these networks were proposed [7]-

[9]. In order to enhance the performance of DTN, most of these works apply the route information, which are obtained from MANET-based routing protocol to the DTN routing method. On the other hand, they are intended to be used in particular environments such as high density or low mobility environments, and thus they have small adaptability as against the diversified environments. Therefore, we focus on a network where terminals can freely switch their communication mode between MANET and DTN according to their surrounding environments. In this paper, we propose algorithms, which allow each terminal to switch to a more appropriate communication mode to increase performance. We implemented our algorithm into some actual smartphones as shown in Fig. 1.

The rest of this paper is outlined as follows. In Section Ⅱ, we introduce the overview of our proposed algorithm, which can freely change its communication mode. The details of our implementation are shown in Sections Ⅲ, Ⅳ, and V. Section Ⅲ introduces the transmission method and address management. The algorithm for switching the communication mode is explained in Section Ⅳ. Section V shows the class signal algorithm, which achieves the effective network resource utilization. The experiment to verify functionality is presented in Section Ⅵ. Finally, this paper is concluded in Section Ⅶ.

II. System Overview

In the disaster area, the users need to send messages to the gateway, which provides connections from disaster area to the outside network such as Internet. Additionally, it is expected that each user has its own mobility and different number of neighbors. Thus, we divided the terminal status into two different communication modes, MANET mode and DTN mode. The terminals operating in MANET mode will try to build the end-to-end path with the terminals, which are operating in the same mode by using Optimized Link State Routing (OLSR) [10]. In OLSR, the terminals exchange topology control messages at regular interval and build the topology in network. The terminals operating in DTN mode store the messages in its buffer, and it distributes the replicated messages according to Epidemic Routing [11]. In Epidemic routing, the terminal transfers replicated messages to all terminals that are within its communication range. With Epidemic routing, terminals can achieve high delivery ratio even if they are far away from the destination terminal.

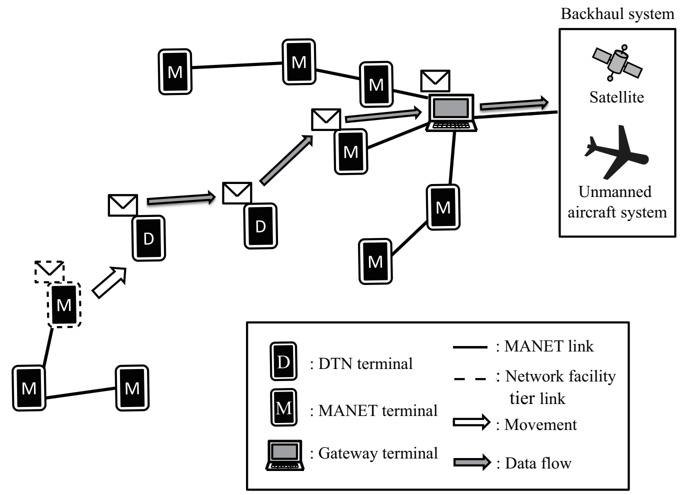


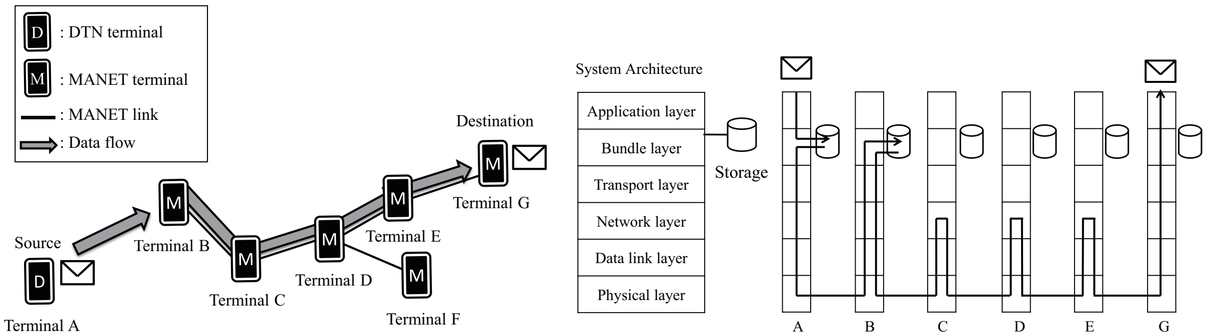
Fig. 2. The overview of our implementation.

Fig. 2 shows the overview of our implementation. In our algorithm, the terminals switch their communication mode between MANET and DTN modes according to their surrounding environments. In MANET mode, the terminals build the topology with neighbor terminals, which are operating in the same mode and efficiently send their messages by using multi-hop paths. An environment that has low mobility and high density is suitable for this mode. In DTN mode, the terminal utilizes its mobility to deliver the messages. An environment that has a lot of mobility and low density of mobile terminals is suitable for this mode. Additionally, by using the gateway terminal, the terminals can transmit the message to the outside network via the backhaul systems such as the satellite and Unmanned Aircraft System (UAS), which have drawn attention as the emergency communication systems. Our implementation is divided into four parts, transmission method, address management, network mode selection, and class signal algorithm. We will introduce the detail of these algorithms.

III. Transmisson method and Address management

To realize the system, which combined MANET with DTN, we need to solve a problem about the difference between data transmission methods of MANET and DTN. Generally, in MANET protocol, the end-to-end path is established between the source and the destination, and the source terminal sends a message through this path. In our implemented system, terminal in MANET mode uses IP protocol to establish end-to-end transmission. The IP protocol assumes that the end-to-end path has been established and the source knows the IP address of the destination. IP address is the terminal identifier used in IP protocol. If the path is disrupted before the outgoing packet reaches the destination then the packet is dropped. On the other hand, terminal operating in DTN mode needs to transfer messages in the environment where there are many link disruptions and large delay, so they cannot use the IP protocol. Thus, it utilizes DTN bundle protocol [12][13]. In this protocol, the message called a bundle, which is arbitrary size, is forwarded. In order to achieve this, the bundle layer operates above the transport layer. This layer is composed of storage for bundle, and has the role of storing the bundles and converting the message from application layer into bundle. The bundle is forwarded hop-by-hop from the source to the destination. Additionally, in DTN bundle protocol, terminals are identified by endpoint identifiers (EID), and each bundle has the EID of the source and the destination. EID enables the terminal which received a bundle to confirm whether the destination of the bundle is itself or not.

In our implementation, we use OLSRD [14] as MANET routing protocol, and IBR-DTN [15] as DTN routing protocol.



(a) An example of the message transmission.

(b) Detail of the message transmission flow.

Fig. 3. The architecture of our implementation.

However, each protocol uses different types of messages, and thus it is difficult to transmit message between MANET and DTN. To solve this problem, we implemented the bundle layer above the transport layer in all terminals, and we run OLSRD in the network layer for those terminals who are operating in MANET mode. In this system, the terminal in MANET mode also sends a bundle to the destination. The architecture of this system is shown in Fig. 3. Fig. 3(a) shows an example of the message transmission in this system. In this figure, terminal-A tries to send a message to terminal-G. Additionally, the detail of the message transmission flow is shown in Fig. 3(b). At first, terminal-A sends a replicated message to terminal-B, and terminal-B stores the message in its storage in bundle layer. Terminal-B can get routing information by running OLSRD in the network layer. After getting the routing information, terminal-B directly sends the bundle to terminal-G. In the transmission among the MANET terminals, the bundle is delivered through the network layer.

On the other hand, IP address is needed for the end transmission between the source and the destination in OLSRD. Because IBR-DTN uses EID as the terminal identifier, terminals require both the IP address and EID to transmit the bundle through end-to-end path. Hence, to enable this transmission, we assign the IP address and EID to each terminal beforehand. Furthermore, each terminal has a terminal number in addition to the two addresses mentioned previously, and they can refer to the IP address and EID of other users by using the terminal number of others. This makes it possible that the terminals use each address depending on their needs. The terminal in DTN mode, which runs only IBR-DTN, uses only the EID. The terminal in MANET mode, which runs IBR-DTN and OLSRD, uses both the EID and IP address.

IV. Network mode selecting

In our implementation, each terminal autonomously switches its mode between MANET and DTN modes by considering both its surrounding environment and the terminal's condition. Our algorithm for selecting network mode is divided into three parts: checking for acceleration, checking for the remaining battery, and checking for the number of neighboring terminals.

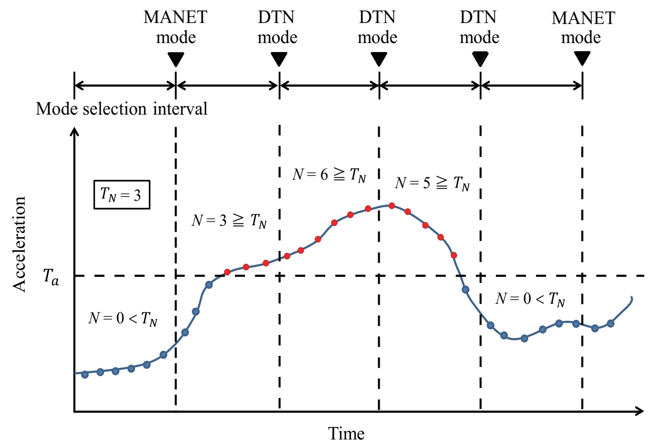


Fig. 4. An example of communication mode selection based on acceleration.

At first, we introduce the algorithm that checks for acceleration. Since terminals that have high mobility can cause link disruptions, DTN mode is more suitable for those terminals with a lot of mobility. In our implemented system, we define the threshold of the acceleration, namely T_a, and then each terminal measures its acceleration at regular intervals. In addition, since the acceleration tends to so fluctuate, we define another threshold of the number of time intervals, namely T_N, which the acceleration exceeds the threshold of the acceleration. During the mode selection interval, each terminal counts the number of time intervals N, which the acceleration exceeds the threshold. If N is bigger than T_N, the terminal selects the DTN mode, because it continually has high acceleration. Otherwise, it selects the MANET mode. Fig. 4 shows the example of this mode selecting process. In this case, T_N is set to three, and the terminal switches to the MANET mode if N is lower than T_N. However, if N is equal to or higher than T_N, it switches to the DTN mode. By repeating these processes, the terminals which have low mobility are selected as the MANET mode, and they are able to construct the stable path among the other MANET terminals.

Secondly, we show the algorithm for checking the amount of remaining battery. In MANET mode, the terminals exchange

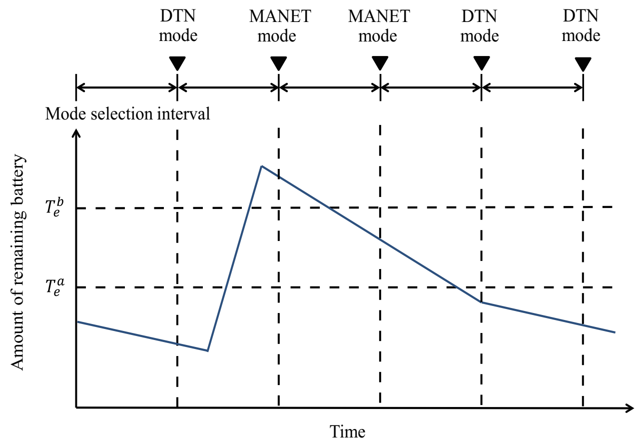


Fig. 5. An example of communication mode selection based on amount of remaining battery.

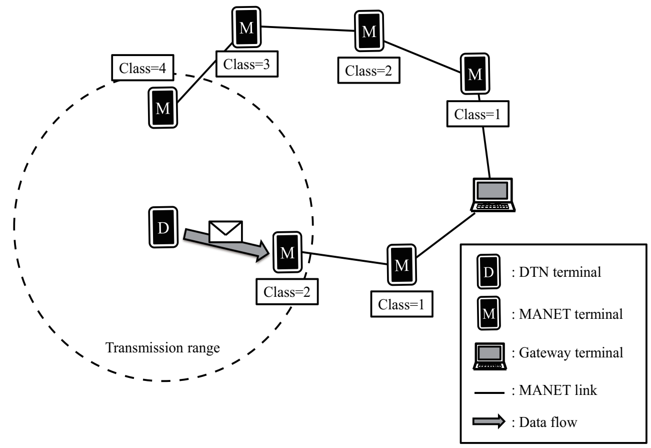


Fig. 6. An example of class signal algorithm.

a lot more routing control messages than DTN routing at regular interval to keep their end-to-end paths updated, which drains much more energy than the DTN mode. Therefore, the terminals that have low battery power are more suitable to be assigned to DTN mode, because they can extend their battery life. In our system, we define the two threshold for the amount of remaining battery power, namely T_e^a and T_e^b. T_e^a is the mode selection threshold when the terminal switches from DTN mode to MANET mode. On the other hand, T_e^b is the threshold when the terminal switches from MANET mode to DTN mode. Fig. 5 shows the mode transition with amount of remaining battery. The mode selection procedure is conducted at a regular interval, and if the amount of remaining battery power is less than the value of T_e^a, the terminal switches from MANET mode to DTN mode. Additionally, the amount of the battery can increase when the terminal is charged, and when the value goes over T_e^b, the terminal shifts its mode to MANET mode.

Thirdly, we introduce the process of checking for number of neighboring terminals. MANET protocol requires a certain number of neighboring terminals to build the topology. Moreover, since MANET terminals always send a routing control messages, there are unnecessary energy consumption if they has only a few or no neighboring terminals. Therefore, we define the threshold of the number of neighboring terminals, namely T_n, and the terminal selects the DTN mode if the number of neighboring terminals is less than T_n.

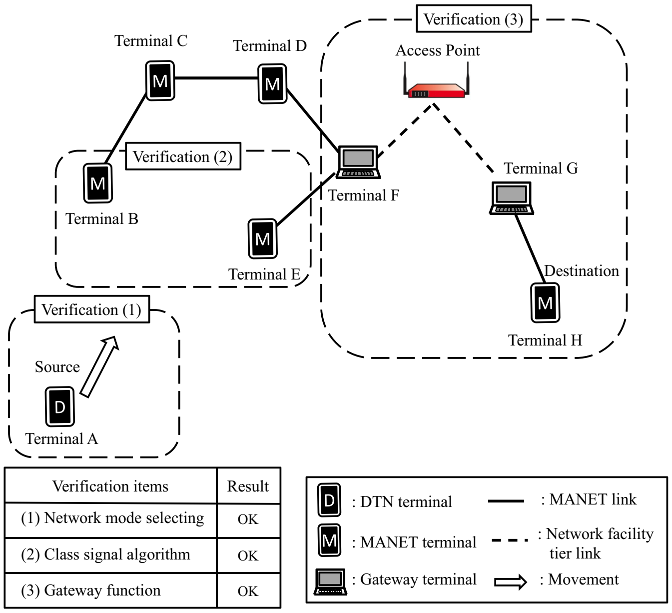
V. Class signal algorithm

Our implemented system can connect to other systems by using the gateway terminal. In this system, the smartphone uses Wi-Fi interface operated in the ad-hoc mode. However, by using the interface, the smartphone cannot transmit the message through other systems. Therefore, we use a general laptop computer, which is equipped with multiple interfaces, as the gateway terminal. It takes a role in the interconnection between our implemented system and other systems.

If the gateway terminal is reachable by other terminals, it is better to transfer the messages to the gateway terminal, because it has higher possibility of delivering the messages to the destination. In order to collect the messages from other terminals to the gateway terminal effectively, we propose the class signal algorithm. Here, we consider the case where the gateway terminal is in the MANET topology and DTN terminal tries to send a replicated message to MANET terminal which is a member of the MANET topology. In this case, the DTN terminal sends a message to the gateway terminal except when the destination is in the MANET topology. However, when the DTN terminals come in contact with MANET terminals, DTN terminals will distribute the bundles to all neighboring MANET terminals. This leads to an inefficient resource usage because same messages will be sent to the gateway terminal by multiple MANET terminals. In this algorithm, the gateway terminal sends a class signal message to its neighbor MANET terminals. This message contains class number, which is the number of hop from the gateway terminal. The terminals, which received class signal message will retransmit it to their neighboring MANET terminals. Hence, the class number of each terminal is simply just the number of hop from the gateway terminal in the MANET topology. When the terminals operating in DTN mode transfer the messages to the MANET cluster, which contains gateway terminal, it sends the message to gateway terminal through the MANET terminal that has the smallest class number. In Fig. 6, the DTN terminal came in contact with two MANET terminals that have class number of two and four. In this situation, the DTN terminal will transfer the replicated message to the MANET terminal with class number of two, because it has a shorter path to the gateway terminal. In turn, the MANET terminal will transfer the message to the gateway terminal using two-hop path.

VI. Functional verification experiment

We conducted an experiment using the smartphones, in which our algorithm is implemented to validate the correctness



Verification items	Result
(1) Network mode selecting	OK
(2) Class signal algorithm	OK
(3) Gateway function	OK

Fig. 7. Delpoyment of terminals in the experimentation

of the algorithm. The scenario is shown in Fig. 7. In this scenario, the message is generated at terminal-A, and it tries to send the message to terminal-H. This experiment is divided into three parts. In each part, we confirmed whether our implemented algorithm performs correctly.

1) Verification of network mode selecting: In this experiment, terminal-A selected DTN mode, because it had high acceleration and no neighboring terminal. Additionally, MANET mode was selected in terminal-B, terminal-C, terminal-D, terminal-E, and terminal-H, because they had low acceleration, high amount of remaining energy, and some neighbor terminals.

2) Verification of class signal algorithm: After terminal-A moved, it could transfer the replicated messages to the both of terminal-B and terminal-E, because they were within its communication range. However, terminal-A sent the replicated message only to the terminal-E which has lower number of hops from terminal-F.

3) Verification of gateway function: In this experiment, terminal-F and terminal-G were gateway terminals, and they connected with each other via an access point. After the terminal-E received the message from terminal-A, terminal-E directly sent the message to terminal-H, which was the destination terminal. At this time, the message was transmitted by using end-to-end path through the gateway terminals and access point. From these results, we confirmed that our implemented system performed correctly.

VII. Conclusion

In this paper, we focus on the type of networks that can provide terminal-to-terminal communications, especially MANET and DTN. These networks enable communication between mobile terminals, such as smartphones and laptops, without using fixed infrastructure. On the other hand, MANET and DTN use different transmission methods and each network shows different performance depending on their surrounding environment. Hence, we consider that it is more efficient to select the appropriate communication mode for each terminal according to their surrounding environment. We developed the devices, which can freely change its communication modes between MANET and DTN. Additionally, we implemented the mode selection algorithm, which changes its communication mode autonomously based on the device's acceleration, amount of remaining battery, and the number of neighboring terminals. They also use network resource effectively. We conducted the experiment, and confirmed that the algorithm functions correctly.

This research was partially funded by the national project, ”Research and Development on Cooperative Technologies and Frequency Sharing Between Unmanned Aircraft Systems (UAS) Based Wireless Relay Systems and Terrestrial Networks”, supported by the Ministry of Internal Affairs and Communications (MIC), Japan.

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