Resilient Network with Autonomous Flight Wireless Nodes based on Delay Tolerant Networks

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Abstract

Although the communication networks have been more important for one's life with the development of the technology, the resiliency of networks has been focused as the subjects of new network technology. When there are disasters, many residential areas might be isolated because of the disconnection of communication networks. Therefore, this paper proposes the resilient network with Autonomous Flight Wireless Nodes based on the Delay Tolerant Networks with the Data Triage Method, and then the implementation and the results of field experiments of the prototype is discussed for the future studies. In the proposed system, the AFW automatically flies for seeking possible wireless nodes, send and receive disaster information by the proposed DTN routings, and return to the possible stations that wireless charge units are equipped when the battery needs to charge. Then, the implementations the prototype is introduced, and the field experiments of the wireless networks are discussed for the future studies of the proposed methods.

Keywords: Delay Tolerant Networks, Drone, Disaster Information System, Wireless Networks, QoS

1 Introduction

The current developments of the information networks expect us to feel various applications of the technology for the future, and the networks are getting more important for our lives. Many people used smartphone with broadband wireless networks for various multimedia or social network services in today. On the other hands, with increasing the importance of the communication services, the resiliency of networks has been focused as the subjects of new network technology. Especially, today's network technology is based on the best-effort service, and such a network tend to weak for the congestion or malfunction of networks. For example, when there was the East Japan Great Earthquake in 2011, many of northern coastal cities in Japan were isolated from others because of the disconnection of communication networks and transportation [19]. The isolation of communication networks was supposed to cause the delay of rescues or evacuations at that time, and it is necessary to consider the function to deliver the important messages even under the severe network conditions.

Therefore, this paper proposes the resilient network with Autonomous Flight Wireless Nodes (AFW) based on the Delay Tolerant Networks (DTN), and then the implementation and the results of field

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experiments of the prototype are discussed for the future studies. Most of the previous DTN researches are based on the passive movements such as a random pedestrian's movement or the certain patterns of the public transportation until now. However, this paper newly introduces the Autonomous Flight Wireless Nodes (AFW) that consists of the drone with wireless interfaces and cameras. It provides the autonomous flights for seeking possible wireless nodes, send-and-receive disaster information by the DTN routing, and return to the possible stations that wireless charge units are equipped when the battery needs to charge.

In the followings, the related previous studies are explained in section 2. Next, the supposed resilient network with the AFW based on the DTN is shown in section 3, and the functions of the AFW are in section 4. Then, the implementation and prototype of the proposed methods are discussed in section 5. Section 6 deals with the reports of the field experiments of the prototype system, and the conclusion and future study is discussed in section 7.

2 Related Works

DTN is widely known as one of the resilient network protocols for the purpose of the Interplanetary Internet or Disaster Information Network System (DIS) [10]. It defined as "$achallengedcomputernetwork$" approach that based upon "$store-carry-forward$" protocol for the sake of carrying data packets under the disconnected networks. That is, if a node does not have a transmittable node, a node stores data until a possible node appears.

However, many previous researches [15] [9] [11] [7] have pointed out the subjects of DTN such as the poor data transmission rate, the large delays, or the resources of nodes such as HDD storages or memory. Thus, they proposed different DTN routing approaches such as Spray and Wait, MaxProp, Prophet, and RAPID. Also, the authors [16] [17] also mentioned the significant effects from the circumstances in local areas and the current rapid developments of mobile devices such as smartphones. That is, the use of DTN in local areas is considered to be worse than that of urban areas because of fewer roads or nodes, and the current enough resources of mobile devices cause the different experimental results from the previous studies. Therefore, they proposed DTN routing with the Enhanced Media Coordinate System (EMCS) [18] in order to realize the ordered-queue typed routing by the emergent user policy, the node priority by area of interests, and the dynamic forward error correction with total population method.

However, these previous DTN routing have been based on the random movements of pedestrians or certain movements of public buses or trains. That is, most of the previous DTN researches were considered as the passive approaches of DTN, and it is necessary to consider the active usages of DTN in order to support or improve the efficiency of DTN routing. Therefore, this paper proposed the AFW that support the wireless node's movement for the effectiveness of DTN.

This research supposes radio controlled drones with wireless IP network for implementation of the AFW. Recently, the remote controlled drones like Figure 1 [3] are rapidly spread over the whole world. Drones consist of multi-propeller, and so it is easy to control the body in the air. Also, with the recent development of the M2M (machine to machine) technology, some drones consist of the wireless IP network, GPS, and cameras. It is also called Unmanned Aerial Vehicle (UAV), and it can be controlled by mobile PC or smartphones in the purpose of not only hobbies but also surveillance system or ad-hoc network.

For example, the paper [12] proposed mobile ground control station for local surveillance by using drones with IP networks, and another paper [8] introduced the communication ad-hoc protocol for HD video transfer with drones and smartphones.

This paper especially considers the disaster usages of the drones with DTN routing, and the prototype system is introduced for the evaluation of the proposed method.

Figure 1: The Example of the Remote Controlled Drone

3 Proposed Methods

3.1 Resilient Network with the AFW

Figure 2 shows the supposed DIS in this paper. The fixed stations consist of a disaster headquarters, evacuation shelters, and residents. Also, mobile nodes are supposed as wireless drones, wireless cars, and mobile devices.

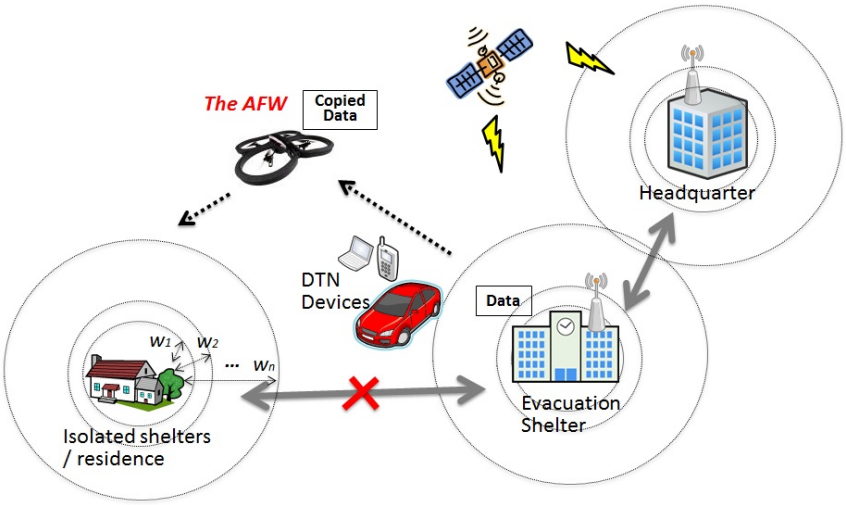

Figure 2: The Supposed Network

The stations and nodes are connected with wired and wireless networks, and every station and node have heterogeneous wireless links such as IEEE802.11a/b/g/n/ac. Also, fixed stations have robust interfaces such as satellite networks for the Never Die Network (NDN), and they are cognitively selected by the network conditions and the emergent user policy [14] . Moreover, they support the DTN routing with the mobile devices such as smartphones, mobile PCs, and wireless cars.

However, in case of the ordinal DTN devices such as smartphones, those mobile devices are moved by the pedestrians or cars. Besides, those movements are not based on the data delivery between shelters,

and so it is necessary to consider more effective movements for the delivery rate or latency for spreading the emergent messages. Therefore, the supposed resilient network includes the proposed AFW.

The AFW is autonomously operated to a stricken area just after the disaster in the supposed system, and supports the alternate data transmission of the broken connections by using DTN routing. Unlike the DTN over the random movements, the AFW seeks possible disconnected stations and nodes by itself, and also supports the DTN as more efficient as explained in the next chapter.

3.2 Autonomous Flight Wireless Nodes

This paper proposes the AFW to improve the DTN efficiency for the DIS. The AFW consists of IP based wireless interfaces (IEEE802.11b/g), GPS units, battery sensors, and cameras. Also, five functions are mainly considered for the AFW in Figure 3. They are autonomous flight, seeking transmittable wireless nodes, hovering during data transmissions, returning to the charging station, and wireless charge.

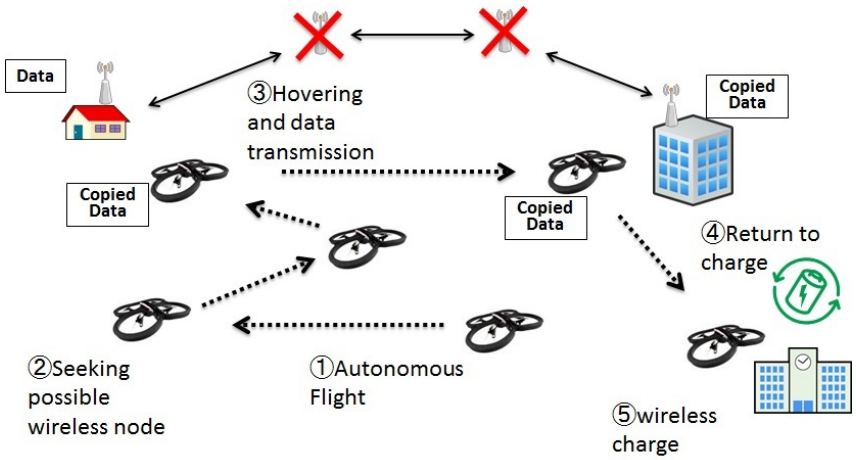

Figure 3: The Functions of the AFW

When a disaster disconnects communication networks between stations, the AFW takes autonomous flight with a certain pattern in a disaster area firstly. During the autonomous flight mode, the AFW is also seeking possible isolated wireless stations by radio detections. If the AFW detects a radio frequency from the station, the AFW tries to find three GPS points of the wireless range as shown in Figure 4.

After finding three edge points (x_1, y_1), (x_2, y_2), (x_3, y_3) of the wireless range from the possible wireless station, the location of the station is calculated by formula (1).

$$\begin{vmatrix} x^2+y^2 & x & y & 1 \\ x_1^2+y_1^2 & x_1 & y_1 & 1 \\ x_2^2+y_2^2 & x_2 & y_2 & 1 \\ x_3^2+y_3^2 & x_3 & y_3 & 1 \end{vmatrix} = 0 \tag{1}$$

After moving to the isolated station by the radio detection, the AFW hovers in the air, and it sends/receive disaster data by the DTN. After the data transmission is finished, the AFW get back to the autonomous flight mode with seeking the next possible wireless node until the battery becomes out.

When the battery of the AFW needs to charge, it moves back to the nearest preinstalled GPS point of the wireless charge stations. Then, the AFW lands to the wireless charging station, and the AFW takes the autonomous flight in the same way after finishing the wireless charge.

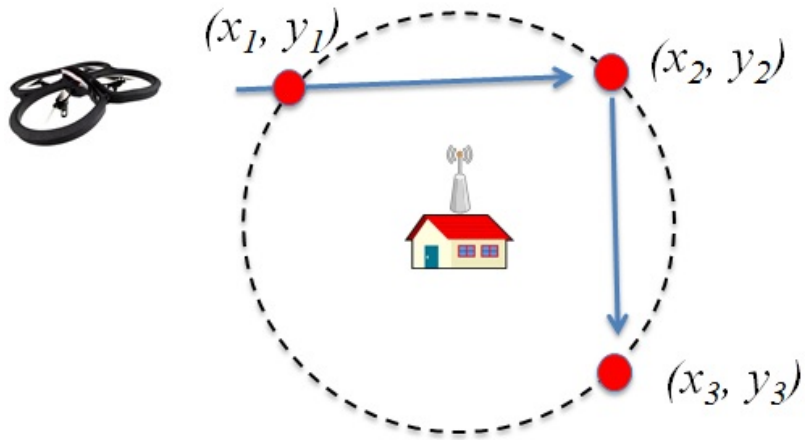

Figure 4: The Way to Search a Wireless Station

In addition, the proposed AFW has the Data Triage Method [18] for improving the efficiency of DTN. It reported that the data volume is greatly increased just after disasters according to the previous study [19], and so the DIS needs to deal with the increased data by the limited network resources under the emergent situation.

The Data Triage Method is the ordered-queue typed approach by considering the user policy under disaster, and it set the priority values for messages. According to the researches of the previous large natural disasters [13], the required information is changing through time. That is, text data such as rescues, evacuations, and safety status is significantly important just after disasters. Then, VoIP data is moderately important, and video content data is less important for the evacuator. Thus, in the proposed method, each message is marked by the user policies under the time transitional changes, and the order of the queued messages are rearranged by the priority as shown in Figure 5.

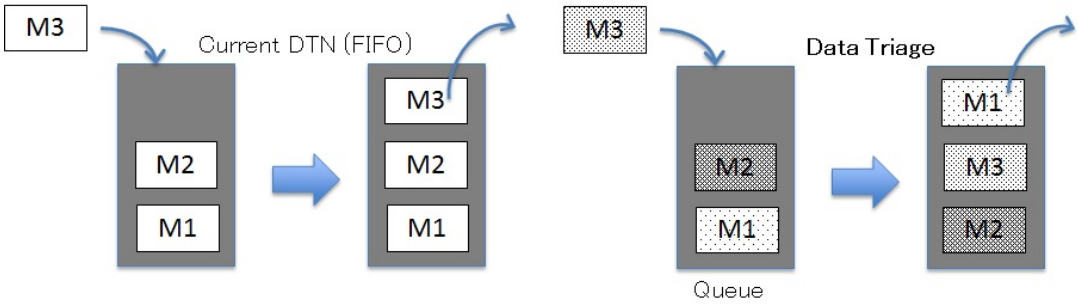

Figure 5: The Message Orders in Queue by Data Triage Method

Although the ordinal DTN routing stores the messages as the chronological order in the buffer, the messages are rearranged by the user policies in the proposed method. For instance, if the M1 is the most important message, the M2 is a moderate, and M3 is the less, these cached messages would be rearranged as M1, M3, M2. Then, M1 is firstly delivered to the others.

4 Prototype System

The prototype system is now preparing for the evaluation of the proposed methods as shown in Figure 6. In the prototype system, Parrot AR.Drone 2.0 [3] is used for the drone, and Galaxy SIII alpha [5] is used for the controller of the drone and the data transmission with the DTN. Also, Figure 7 shows the interface of life safety information system with the DTN by the Data Triage Method.

Figure 6: The Prototype System

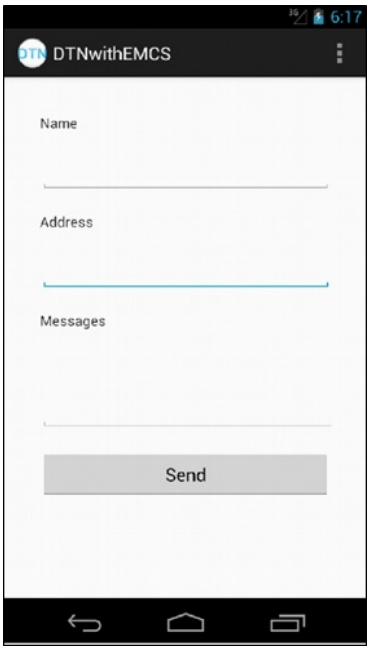

Figure 7: The Prototype System

The following Table 1 shows the hardware specifications, and Table 2 is about the software specifications [1] [2] [4] [6] of the prototype system.

Then, Figure 8. shows the data flow diagram of the main functions in the smartphone of the prototype system.

Table 1: The Hardware Specifications

Wireless Nodes	Samsung Galaxy S III alpha (SC-03E) (CPU: Samsung Exynos 4412 1.6GHz, MEM: RAM 2GB, ROM 32GB, Micro SDHC: 4GB, Wireless: IEEE802.11a/b/g/n, Bluetooth4.0, Size: 137x71x9mm, 139g, OS: Android 4.1.2)
Drone	Parrot AR.Drone2.0 (CPU: 32bit ARM Cortex A8 1GHz, MEM: RAM 1GB, GPS: Parrot Flight Recorder (with 4GB MEM), Wireless: IEEE802.11b/g/n, Size: 512x451mm, 380g (outdoor hull), Camera: HD 720p, QVGA, Battery: 1500mAh, 11.1V, OS: Linux 2.6.32 (Busybox))

Table 2: The Software Specifications

Implementation tools	Android Developer Tools (ADT) 22.3.0, JDK 1.7.0.45 64bit, PC: Win7/Ubuntu 13.04
Drone controls	Python 2.6.6, sl4a r6, python for android r4, python-ardrone , MAVLink

In the prototype system, after entering life safety information in the Figure 8's interface, the unique ID (UID) that consists of the priority value (9-1), date and time, and node's ID are added to the message data. Then, the message is stored in the DB, and the cached messages in the DB are rearranged by the decreased number of the message UID. Thus, the most significant and recent message is listed among the queued messages, and the message is firstly used for the data transmission.

Secondly, after the takeoff of the AFW, the AFW automatically moves by the previously programmed flight route or the GPS points. During this autonomous flight mode, the AFW always checks the radio frequency from other nodes. If the AFW detects the radio frequency, the AFW controls change to the seeking mode that the AFW tries to find the center location of the WiFi range. Then, the AFW moves to the calculated GPS point, and it confirms the WIFI-direct connection and the data merge in the DB with hovering over the point at the data transfer mode. The AFW gets back to the autonomous flight mode after finishing the DB comparison and merging.

The battery level of the AFW is always checked. If the battery level becomes lower, the AFW is forced to move back to the charging station. The main class and API of the functions used for the system are shown in Table 3.

5 Experiments

For the evaluation of the proposed method, the field experiments are held by using the prototype system. The experiments were carried out in the rugby ground of Saitama Institute of Technology, Japan, and the AFW was moved to the preinstall target GPS point as shown in Figure 9 [5].

As in the Figure, there is 50 meters between the starting point of the AFW and the target point. Then, the experiments were held for the measurements of the wireless network conditions between the AFW and Note PC. For the measurements, WiFi explorer is used for SNR levels, ping (56 bytes) is for RTT (Round Trip Time) and PER (Packet Error Rate), and iperf is for throughput. Also, as shown in Figure 10, the network conditions were measured when the drone is hovering and when it is flying.

The details of experiment conditions are shown in Table 4. When the drone is flying, it moves to the preinstalled GPS point with 1.0 meter per second. Also, IEEE802.11b is used for the wireless transmission, and the wind during the experiments was 2.4 meters per second. On the contrary, when

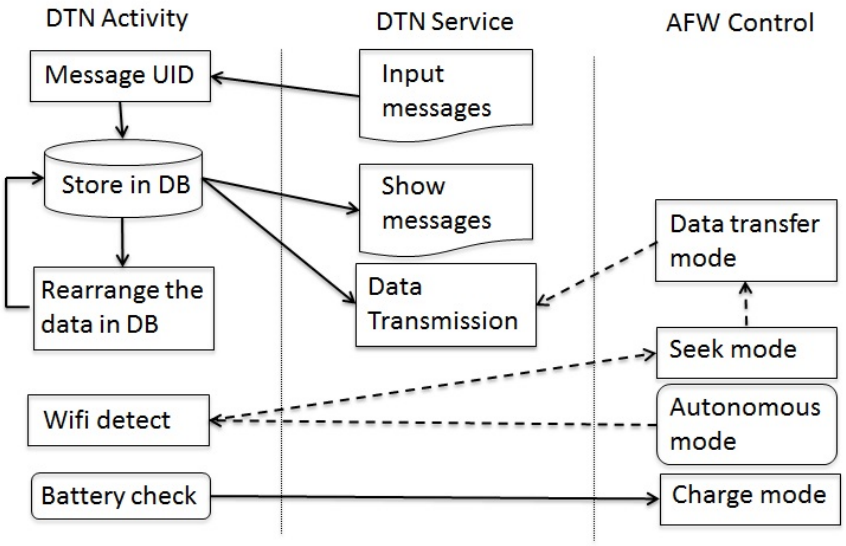

Figure 8: The Data Flow Diagram of the Prototype System

Figure 9: The Map of the Experiments

Table 3: The Software Specifications

WiFi detection LocationManager	ConnectivityManager
Data Triage (Data stores and rearrangement) execSQL	SQLiteDatabase
Data transfer ServerSocket	Wi-fiP2pManager
Battery check LocationManager	libardrone.py (python-ardrone)
AFW controls mavlinkgenerator.py (MAVLink)	libardrone.py (python-ardrone)

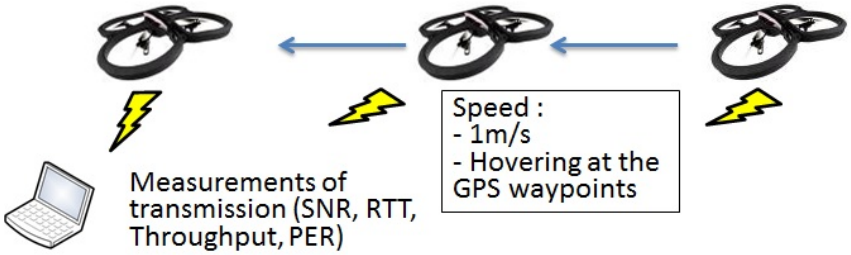

Figure 10: The Field Experiments by the Prototype System

it is hovering, the data transmissions were by one meter each from the target point. Also, the same IEEE802.11b was used for the wireless interface.

Table 4: The Experiment Conditions

During Flying	Moving Speed: 1.0m/s, Setting Height: 2m from the ground Wireless: IEEE802.11b, Wind: 2.4m/s East (at Kumagaya by tenki.jp (Japan weather Association))
During Hovering	Setting Height: 2m from the ground, Wireless: IEEE802.11b
Measurement Tools	PC : MacBook Air, OSX10.7, WiFi explorer, ping(56bytes), iperf(TCP). Galaxy SIIIα: SC-03E, iperf, sl4a r6, python for android r4, pythonardrone, MAVLink generator

As the results, Figure 11 and Figure 12 show the results of the hovering drone. First of all, Figure 11 shows the SNR and RTT at each distance between the starting point and the target point. According to the results, the SNR was shown from 20 meters, and it is gradually becoming larger from 15 meters. Also, the RTT shows that the wireless connections began to stable from 15 meters although the RTT is extremely high at 20 meters from the target point. Thus, it is supposed that the distance of the AFW needs at least 15 meters for the stable wireless connection with IEEE802.11b. Moreover, since the RTT is average results with 20 packets x 3 times measurements, it looks like more stable than the following

moving drone.

Secondly, Figure 12 presents the results of throughput and PER at each distance when the drone is hovering. The throughput also began from 20 meters from the target points. Then, it is gradually becoming larger, and it became about 20Mbps at the 12 meter's distance. However, the PER showed high error rates at 20 meters, and it became the stable transmission at 16 meters. The results suggested the AFW needs at least 16 meters from the target point for the stable wireless data transmission as the same as the results from the Figure 11.

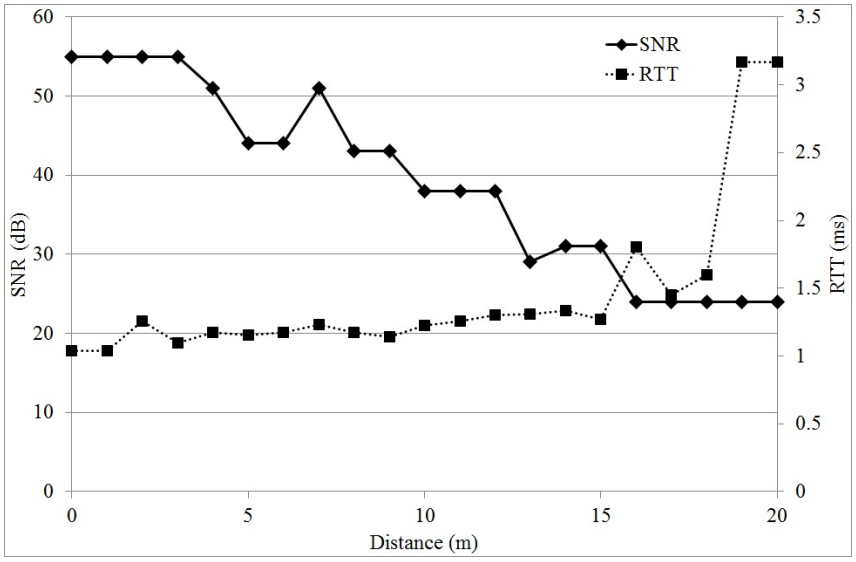

Figure 11: The SNR and RTT of the hovering AFW

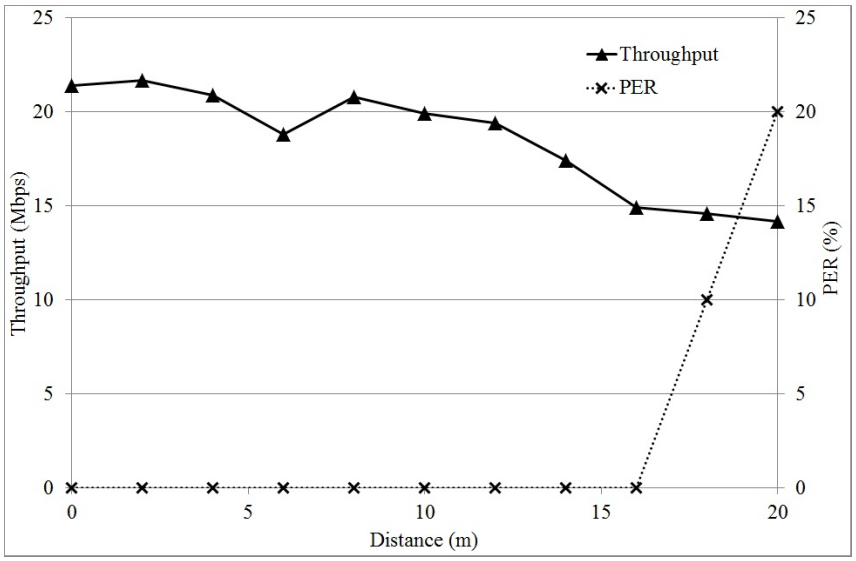

Figure 12: The Throughput and PER of the hovering AFW

In contrast, Figure 13 shows the results of the SNR and RTT when the AFW is flying. According to the results, the wireless network connected from about 20m as the same as the previous experiments, but the data transmission was not stable such as the hovering drone. Firstly, although the SNR levels

were gradually increasing by the distance, it showed that there were many noises through the results. There are some considerable reasons of the noises such as from the body shaking or the motors, but it is necessary to consider these noises for the future studies. Secondly, the RTT also showed the large noises. Although the data connection was started from 20 meters, the results showed high latency even at the 0 meter's point. That is, the data transmission might be unstable whenever the drone is moving, and it is necessary to consider additional functions to make the transmission stable.

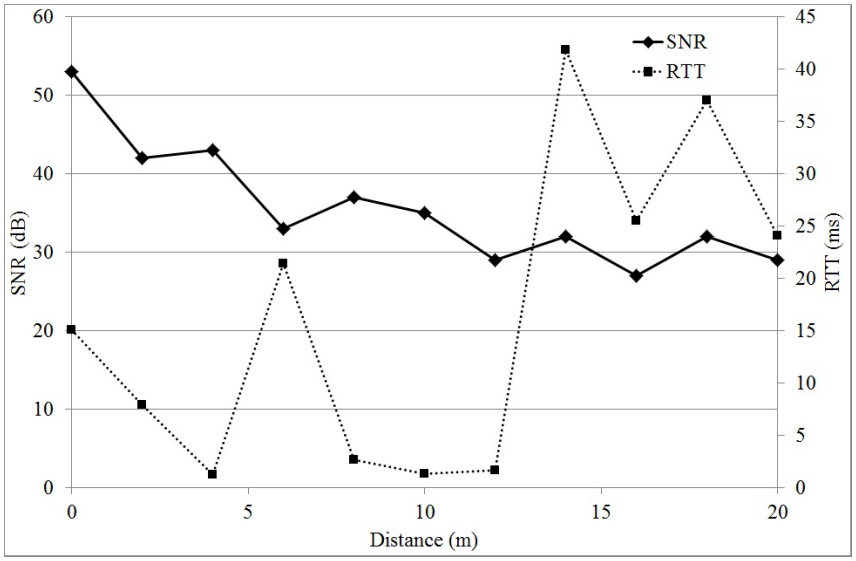

Figure 13: The SNR and RTT of the flying AFW

Finally, the results indicate that there are some noises such as motors or random shakes for the wireless network conditions when the drone is moving, and it is necessary to consider about these factors for the controls of the AFW. Therefore, the additional functions to stable to data transmission might be required for the proposed functions of the AFW in the future studies.

6 Conclusion and Future Study

Although communication networks are getting more important with the developments of the technology, there are also some considerable subjects for the networks. The resiliency of the networks is one of the considerable problems. There are many cities or towns that are surrounding by mountains or seas, and those areas are likely to isolate from others if a large scale would disaster occurs.

This paper proposes the Autonomous Flight Wireless Nodes (AFW) for the resilient networks consist of the autonomous drone and DTN, especially for DIS. In the proposed methods, the AFW takes the autonomous flight with seeking possible wireless stations, and sends the message data by the DTN with the Data Triage Method. Then, when the battery needs to charge, the AFW automatically moves to the preinstalled charging station in order to get wireless charge.

The implementations of the prototype system are introduced, and the field experiments of the wireless network conditions by the prototype system are reported for the discussion of the future studies. Then, the results show the unstable data transmission when the drone is flying, and it is supposed that additional functions might be required for the seeking mode and data transmission mode in the proposed method.

For the future studies, more additional implementations of the prototype system are planning to improve the efficiency of data delivery. Also, more field experiments of the proposed methods are planning in the future.

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