Multi-UAV Network Restoration Scheme using Recovery UAV

Min-Hui Jang, Hyeong-Jin Kim, Jae-Min Lee, *Member, IEEE* and Dong-Seong Kim, *Senior Member, IEEE*

***Abstract*— UAV(Unmanned Aerial Vehicle), which has advantage of flexibility, cost-effectiveness, easy to deploy and risk avoidance, is emerging as a communication relays for building network infrastructure not only in military but also in the civilian sector. However, these networks lack countermeasures for situations in which network disconnection occurs after construction due to UAV's own defects, such as variables that occur in nature, shooting down from enemy force in battlefield environments, operation shutdown and malfunction. Therefore, in this paper, recovery UAV is additionally deployed in a multi-UAV based FANET(Flying Ad-Hoc Network) environment composed of UAV-BS(UAV-Base Station). As a result, when a defect in the UAV-BS occurs, the recovery UAV moves to the corresponding coordinate. And Restores communications on behalf of the UAV-BS mission.**

I. Introduction

UAV(Unmanned Aerial Vehicle) is emerging as a communication relay to build network infrastructure. This environment is called FANET(Flying Ad Hoc Network) and has a multi-UAV system with a structure in which UAVs operate as a group[1]. However, When the UAV-BS(UAV- Base Station) has a defect, the multi-UAV network environment has a problem of disconnecting the entire network. It means that there is a lack of countermeasures for situations in which the network is disconnected due to UAV's own defects after the network deployment, such as variables that occur in nature, shooting down from enemy forces in battlefield environment, operation shutdown and malfunction. This can cause enormous losses due to defects in UAV-BS in environments that require real-time information sharing. Therefore, the transmission power of Hello messages was adjusted to solve the problem of network disconnection between dynamically moving UAVs in the FANET environment[2]. As a result, a scheme for acquiring location information of a UAV with disconnected communication and recovering the network was proposed. However, these measures cause delays for synchronization during recovery or lack immediate recovery.

This paper proposes a recovery scheme that minimize communication gaps in a specific area, considering that defects in UAV-BS may occur due to internal and external factors in a multi-UAV-based FANET environment. This makes it possible to provide an easy environment to understand and manage the status of each UAV-BS through Recovery UAV. In addition, in the event of a defect in the UAV-BS, Recovery UAV moves to the coordinates of the UAV-BS to enable rapid situation judgment and network recovery response on behalf of the mission. Finally, the performance evaluation of the network recovery function of the proposed scheme is conducted.

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II. Related Works

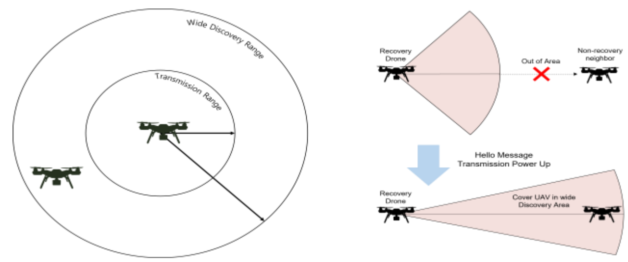

Figure 1. Hello-Message based recovery scheme

Reference [2] and Figure 1 shows how to maintain an uninterrupted communication link in the UAV-BS-based network environment. In this UAV-based network environment, the communication link is maintained by periodically exchanging Hello messages with neighboring UAVs. However, these environments can cause disconnection of communication link due to deviating from the designated location due to a natural variable or a hovering error in the UAV. Therefore, the transmission power of the hello message was increased to identify so that the communication link could be restored. However, this scheme is simply a communication recovery process due to the departing UAV. Therefore, there is a lack of countermeasures for situations where network disconnection occurs due to variables from nature, shooting down from enemy forces, and UAV's own defects. In addition, the process of periodically exchanging Hello messages between adjacent UAVs has a high possibility of collision in FANET environment composed of Multi-UAV. Therefore, by detecting and avoiding the collision of Hello messages, it is necessary to stably exchange status information in the network to check the survival of the network and take appropriate measures.

III. Proposed Scheme

A. System Architecture

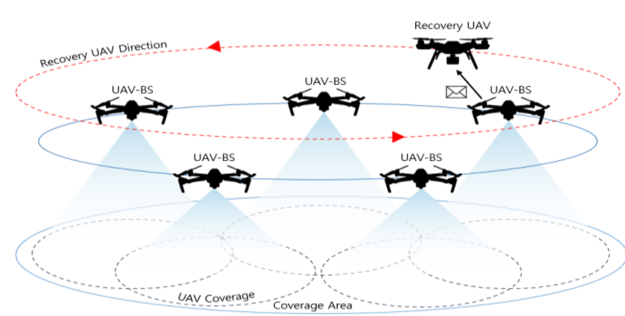

Figure 2. Multi-UAV network restoration architecture using recovery UAV

Figure 2 shows the architecture of Multi-UAV network and recovery UAV proposed in this paper. The proposed network is constructed using two types of UAVs. Each UAV-BS deployed in a Multi-UAV-based FANET environment can send and receive messages with each other and communicate with nodes on the ground. The Recovery UAV moves in a circle in the area where the UAV-BS is designated. The status of UAV-BS confirms survival through message with Recovery UAV.

B. *Communication between Recovery UAV and UAV-BS*

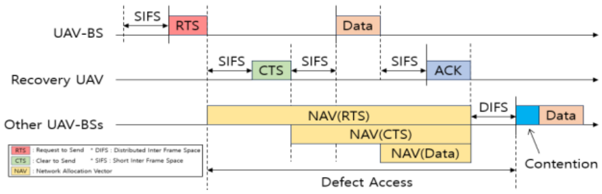

Figure 3. Timing diagram of IEEE 802.11 CSMA/CA between UAVs

The Multi-UAV system based FANET environment proposed in this paper, several nodes, that is, UAVs, are distributed and deployed. In addition, since each node contains aerial deployment and mobility, there are cases different from the predicted deployment. Therefore, when a defect in the UAV-BS occurs, each neighboring UAV-BS may attempt to simultaneously transit the status message and data of the defective UAV-BS to the Recovery UAV. This can lead to data collisions and lead to network performance degradation and data loss and errors. Therefore, in this paper, IEEE 802.11 DCF based MAC protocol using CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism was used[3]. Figure 3 shows the timing diagram of RTS/CTS (Request to Send/Clear to Send) for protection mechanisms in CSMA/CA. This minimizes data collisions problem and the hidden terminal problem, which occurs when some UAVs are unaware of the presence of the other UAVs due to constraints in communication range or obstacles.

C. *Restoration of defect UAV-BS using Recovery UAV*

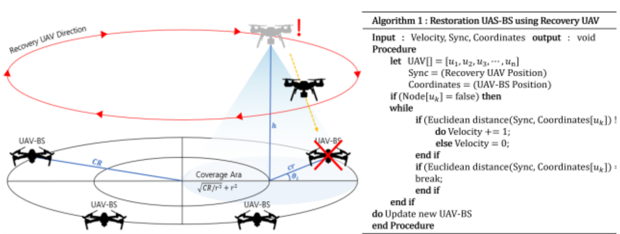

Figure 4. Configuration diagram and algorithm of recovering process

Figure 4 is a configuration diagram of the process of recovering a defect in the UAV-BS. UAV-BS and Recovery UAV periodically have a recovery data transmission process. When a defect in the UAV-BS occurs, the nearest Recovery UAV recognizes the state of the UAV-BS. The Recovery UAV which recognizing the occurrence of defective UAV-BS predicts the corresponding coordinates and moves to the fastest path. And then Recovery UAV replaces the role of UAV-BS. The UAV-BS is distributed in the CR(Coverage Radius) area. And cr stands for the radius of the Coverage Area of the Recovery UAV. And location of UAV-BS is (1).

$$\theta_i \in (0, \pi/2). \tag{1}$$

Algorithm 1 is a method in which the Recovery UAV moves to the coordinates of a defective UAV-BS and performs the task instead when a specific UAV-BS is defective.

IV. PERFORMANCE EVALUATION

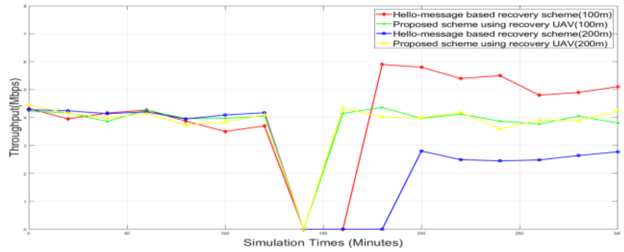

Figure 5. Performance comparision of recovery scheme

Figure 5 shows a comparison of the throughput of UAV-BS over time when out of the specified position. Reference [2] can improve network performance because UAV increases transmission power when it is out of coverage. It may increase the throughput. However, blindly increasing transmission power is not always effective. Increasing transmission power may increase power consumption and increase interference. In this case, signal quality may decrease due to interference, and network performance may decrease. Therefore, the result of [2] confirmed that the throughput decreases as the transmission power increases. Also, as the distance outside of coverage increased, the time it took to recover increased. On the other hand, the proposed scheme confirmed that not only did the recovery time of UAV-BS decrease compared to [2], but also that the network performance before and after recovery and the time it takes to recover are almost the same even if the distance out of coverage increases.

V. CONCLUSION

In this paper, we proposed the deployment and utilization of Recovery UAV how to cope with situations in which variables occurring in nature, shooting down, and UAV's own defects can cause network disconnection. The interaction between Recovery UAV and UAV-BS can help identify problems with UAV-BS and ensure the reliability of UAV networks through the process of recovering them. In the process of analyzing the performance of the proposed scheme, it was confirmed through comparison with existing scheme that the scheme proposed in this paper could be recovered quickly.

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