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Optimal Coverage Control for Net-Drone Handover

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Optimal Coverage Control for Net-Drone Handover

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A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of Information and Communication Engineering. The study was conducted in accordance with Code of Research Ethics[1].

05. 15. 2015

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[1] Declaration of Ethical Conduct in Research: I, as a graduate student of DGIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, and distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Optimal Coverage Control for Net-Drone Handover

Kyung-Nam Park

Accepted in partial fulfillment of the requirements for the degree of Master of Science

05. 15. 2015

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ABSTRACT

The need for aerial network ensuring the stability of network at the specific area in which it is difficult to use network such as disaster area and rush hour is growing increasingly. However, the traditional aerial networks by UAV have problems such as limited battery for UAV, frequent handover by aerial environment and so on. These problems induce not only the fail of seamless handover but also a long handover time by frequent handover attempts.

This paper presents an effective solution for resolving problems which are mentioned above. The main idea is to control the drone's height and the distance between a drone and another drone. We also propose the seamless handover success probability and the false handover initiation probability to evaluate the optimal coverage decision algorithm. The simulation results using MATLAB show that the proposed algorithm operate to make the efficient handover compare with compare with conventional approach. The simulation also is conducted to compare the performance of the Optimal Coverage Decision algorithm by several elements. As a result, the proposed Optimal Coverage Decision algorithm guarantee the seamless handover and establish the one huge network by integrating the small networks.

Keywords: Seamless handover, Wireless LAN, Aerial network, Drone, Topology management

Ⅰ. INTRODUCTION

Along with the development of the mobile communication technology, humanity has been got high mobility and the wide scope of activity. As a result, it made us that we can construct the universal network it is not small network within the narrow area. However, the need about high communication rate and signal stability it is guaranteed anytime anywhere is growing depending on the increase of activity area [1]. One solution about these problems is to construct the aerial network using Drone that play a role as an access point to guarantee the sufficient network capacity to users at the specific environment in which existing network cannot function at certain times [2]. The aerial network using Drone is specified as Net-Drone in this paper. Figure 1 illustrates the overview of Net-Drone.

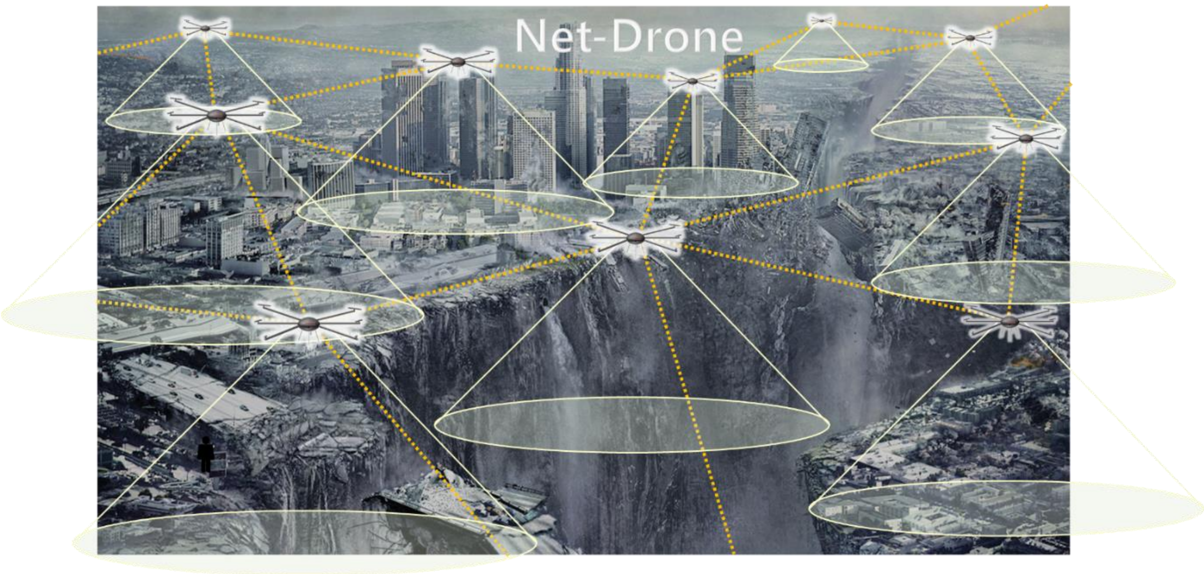


Fig. 1. Overview of Net-Drone.

However, Net-Drone has problems like this. First, Drone can only be used as Wi-Fi AP (access point) due to the limited weight of Drone (usually, the devices related Wi-Fi have lower weight than the devices related LTE. This low weight means that Drones are able to maintain the state Drone is flying). In case of Wi-Fi network comprised by Drone, it is difficult to do seamless handover because traditional Wi-Fi network not only has narrow communication coverage compared to cellular network but also a long handover time by frequent handover attempts [4]. Second, compared with that the traditional handover decision algorithms usually assume that the

AP's coverage same, Drones actually have various Drone's coverage by the surrounding obstacle and the height change by drastic aerial environment and so on [3]. Third, large scale deployment of Wi-Fi networks is highlighting certain technical challenges such as management, monitoring and control of large number of APs. It also induces the networks security issues which is always been a concern in large deployments and new architectures. In other words, distributing and maintaining a consistent configuration throughout the entire set of APs in the WLAN is a difficult task.

In this paper, the RSS based optimal coverage decision algorithm satisfying the seamless handover is proposed to search optimal Drone's coverage by controlling Drone's height and the distance between Drone and another Drone. Ultimately, we establish the one huge outdoor Wi-Fi network by integrating the small networks which is made by Drones in the air. It is similar to the enterprise Wi-Fi network using the AP controller to integrate the numerous small Wi-Fi networks. To establish the outdoor Wi-Fi network, the following matters should be guaranteed.

ⅰ. Seamless handover security should be guaranteed among small Wi-Fi networks.

ⅱ. Signal interference should be minimized among Drones.

ⅲ. Drones composing Wi-Fi network should be deployed to make optimal configuration.

The rest of this thesis is organized as follows. In section Ⅱ, we deploy the background information of Net-Drone and Wi-Fi handover procedure. In section Ⅲ, we study the optimal coverage decision algorithm in the 3D view point and show problems it is mentioned above through the simulation. In section Ⅳ, we proposes P_s as seamless handover initiation probability and P_f as false handover initiation probability they are element to evaluate the optimal coverage decision algorithm [5]. In section Ⅴ, we propose optimal coverage decision algorithm which adaptively controls the coverage of Drones. In section Ⅵ, we present the performance variation of the optimal coverage decision algorithm according to P_s and P_f through simulations [6] and finally conclusions are presented in the section Ⅶ.

Ⅱ. BACKGROUND

2.1. Net-Drone

Reconstructing the infrastructure in a disaster area is time consuming and very high cost. The survivors in such the disastrous area cannot connect to the network although it is much needed. Government and service providers attempt to deploy additional infrastructures to recover the hostile environment, but it require extensive time to recover. Moreover, in terms of safety, the survivors from disaster need to communicate with families and friends to notify their safety. A possible solution can be a mobile network infrastructure which can be deployed in the area instantly. To empower mobility to network infrastructure, the concept of mobile infrastructures was introduced in the shape of small cells in vehicles. However, such the vehicle may not enter the area if obstacles, such as pile of debris or rubble of collapsed buildings, prohibit the entrance, and this limits the vehicles' mobility. A new form of a mobile infrastructure that the ground obstacles cannot prohibit the deployment is much needed.

With the recent surge of UAV technology, there is just the solution to the problem. By deploying the network infrastructure from the sky, the utilization of unused wireless medium and the high mobility free from ground obstacles can both be achieved. Nowadays, the applications of UAVs are not only limited to military purposes, but expanding to distribution/delivery services such as Amazon and DHL. Furthermore, industry giants such as Google and Facebook is developing a balloon or a solar panel airplane to provide networking infrastructure to the area where the networking infrastructure is not deployed as a nation-wide infrastructure. Nonetheless, the usages of drones are very limited despite its potentials in vast areas. So, Net-Drone which aims at expanding drone's applicability to provisioning network infrastructure was proposed. By providing a better network infrastructure in disaster areas, Net-Drone is used to construct the network infrastructure on demand.

Figure 2 illustrates the core objective of Net-Drone. The core objective of Net-Drone is to enhance the network capacity of the specific area where the original network infrastructure is disabled or malfunctioning, specially the area where disaster occurs. In other words, Net-Drone is to deploy Drones to the area where network is needed and it is difficult to access from the ground level. The fleet of Net-Drone will provide a network to the users from the sky.

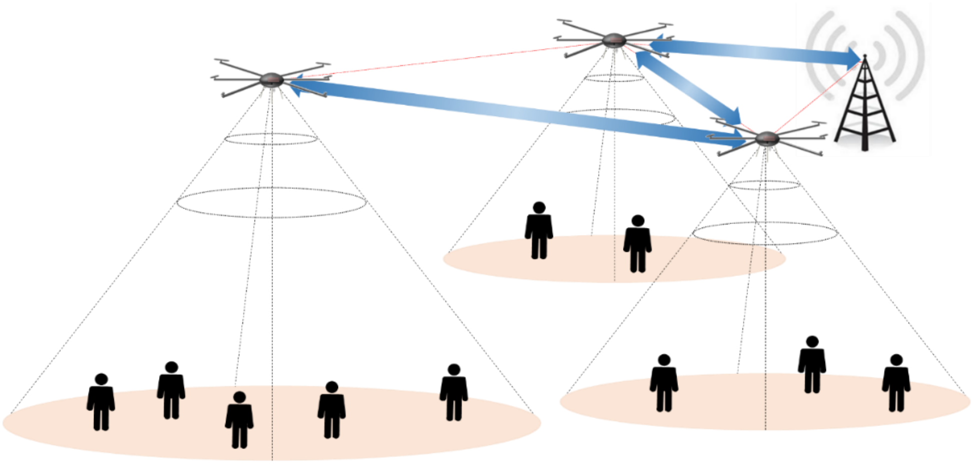


Fig. 2. Core objective of Net-Drone.

Figure 3 depicts the conceptual design of Net-Drone. Net-Drone is designed to frame an aerial infrastructure network, which increases the overall network capacity of the region. For example, for the area where the network connectivity is degraded due to congestion or hostile radio condition, Net-Drone is deployed to act as an aerial infrastructure node to enhance user's network connectivity.

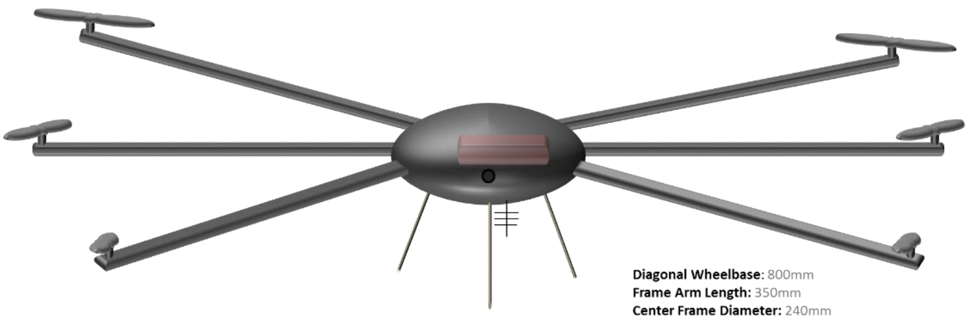


Fig. 3. Conceptual design of Net-Drone.

The deployment can improvise a network infrastructure in a disaster area without installing a new ground infrastructure node. With Net-Drone's ability to control the direction of communications and have multiple radio interfaces, the drones are expected to be effective better than traditional infrastructure nodes in terms of spatial reusability. Furthermore, Net-Drone is primarily designed as an aerial infrastructure node, and the service provider can utilize it for enhancing the network quality of experience (QoE) for the service users. When the service provider wants to deploy Net-Drone, it will be deployed in a federation of multiple drones which will continuously collect the information about link, traffic and neighboring drones. Based on the collected data, the fleet of Net-Drones will be adjusted to current link, congestion and drone status, and provide the enhance network access to users nearby.

2.2. Wi-Fi Handover Procedure

Wi-Fi handover is divided into layer 2 handover procedure and layer 3 handover procedure. Layer 2 handover procedure includes the process sharing the channel information among base-stations, AP search process, and AP selection as well as authentication process. Layer 3 handover procedure is actually to do handover and includes the Care of Address (COA) creation as well as binding table production process. Wi-Fi handover starts with AP selection process followed by AP search process then authentication process and finally association process. Figure 1 shows Wi-Fi handover procedure.

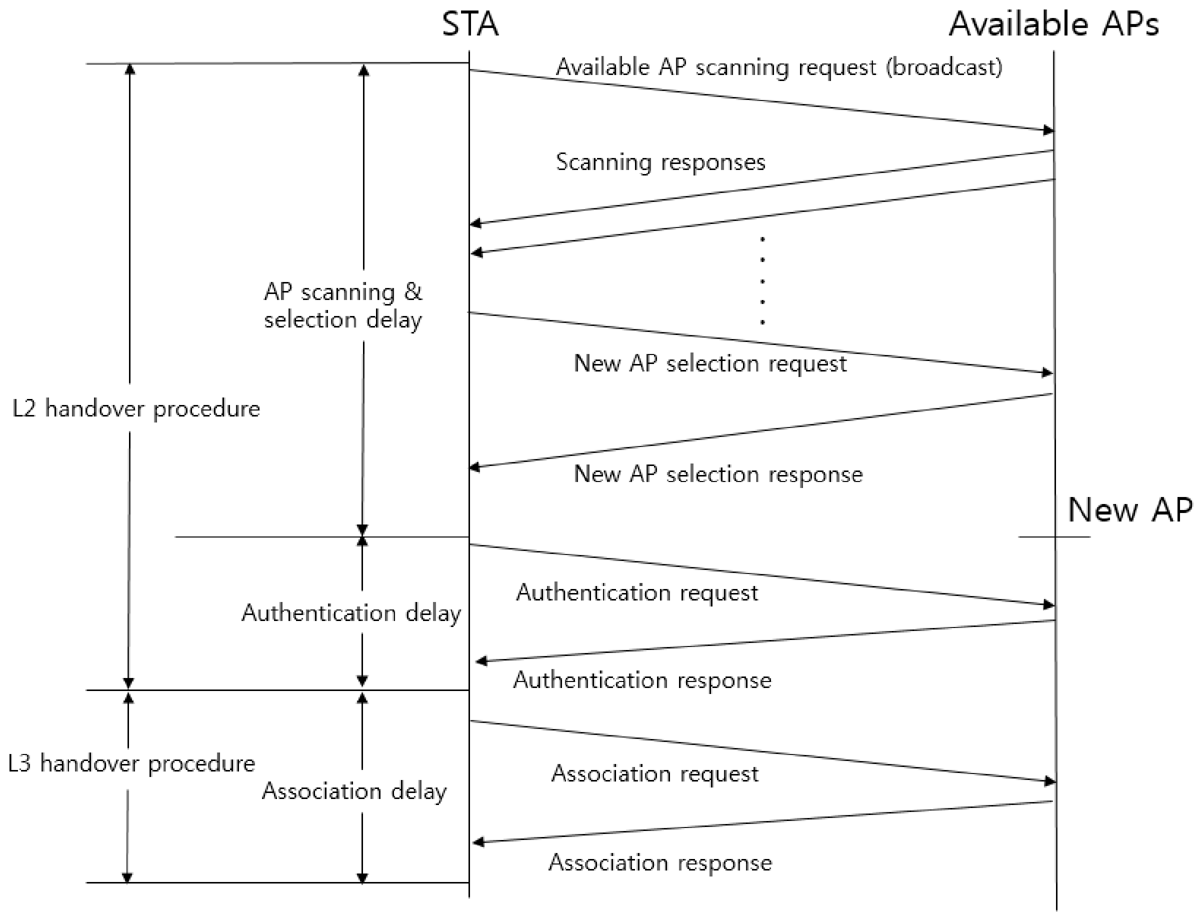


Fig. 4. Wi-Fi handover procedure [8].

Excremental research results indicate that the total handover time can exceed 2s and each phase contribute a different amount to the total handover time [7]. But the important factor is that it need sufficient layer 2 handover time and layer 3 handover time to satisfy seamless handover among small Wi-Fi networks. If sufficient L2 handover time and L3 handover time aren't guaranteed, user would be got out of the overlapped area while doing handover. As a result, seamless handover is ended in failure because it try to connect with new Drone after the communication is broken with earlier Drone.

To solve this problem, we use centralized architecture with the Access Controller (AC). It means that all the data traffic is handled at the AC and Wireless Terminal Points (WTP) serve only as media changing entities. In comparison with general Wi-Fi network, this network using AC store security information and AP context within the AC and do not distribute to WTPs to enhance security. As a result, L2 handover time is reduced and the efficiency of the whole network is enhanced.

2.3 Mobile IP

In this paper, L3 handover is performed based on Mobile IP [10]. Mobile IP is the representative solution among several global mobility solutions. Mobile IP supports mobility across both homogeneous and heterogeneous systems. It introduces three new functional entities: home agent (HA), foreign agent (FA), and mobile node (MN). Mobile IP supports mobility management using the following procedures; discovery, registration, routing and tunneling. The movement principle of Mobile IP is illustrated in Figure 6.

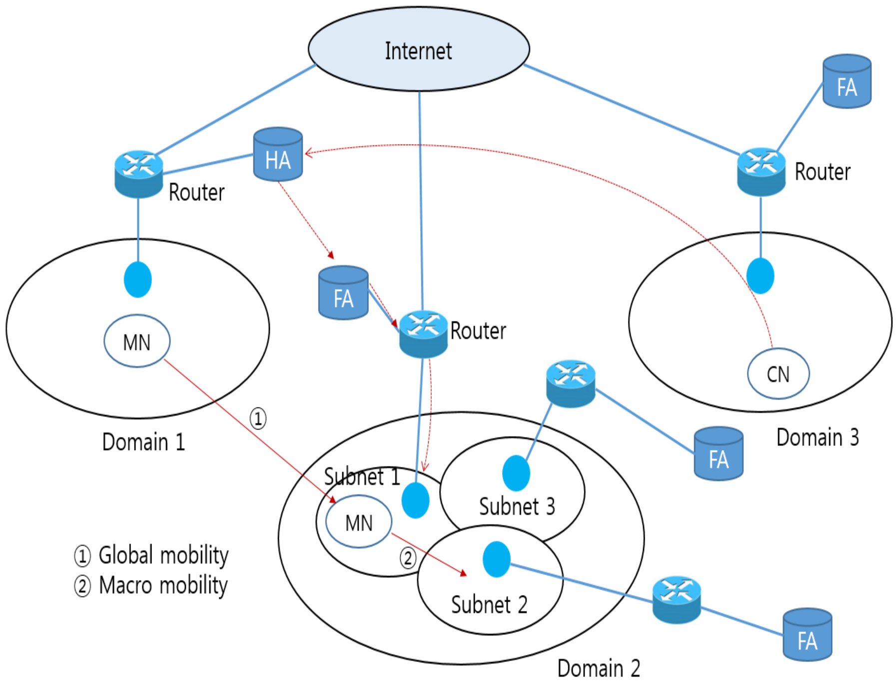


Fig. 6. Mobile IP architecture [11].

When MN move from one subnet to another, MN obtain a new CoA. Then, the MN registers the new CoA with its HA. The HA set up a new tunnel up to the end point of the new CoA and removes the tunnel to the old CoA. Once the new tunnel is set up, the HA is able to send the packet to MN using the MN's new CoA.

However, Mobile IP has the follow shortcomings; Triangular routing problem and old COA registration problem. Packets from the MN are sent directly to the CN. However, packets sent from a CN to an MN are first intercepted by the HA and then tunneled to the MN. This is the triangular routing problem. Triangular routing problem result in communication routes significantly longer than the optimal routes and introduces extra delay for packet delivery. On the other hand, when an MN moves from one subnet to another, the new FA cannot inform the old FA about the new movement of the MN. Hence, packets are already tunneled to the old CoA and in flight are lost. This is Old COA registration problem. Triangular routing problem and old CoA registration problem can be solved by route optimization as shown figure. 7.

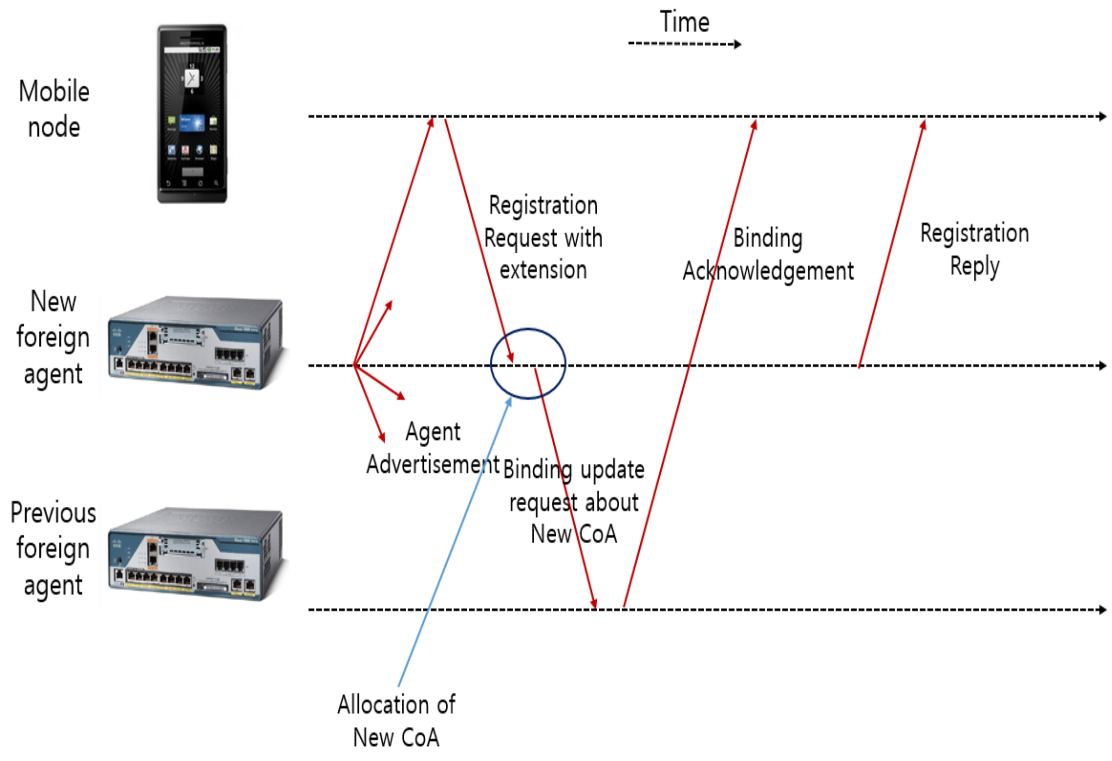


Fig. 7. Handover procedure by route optimization [12].

When MN move to the new FA coverage, new FA assign new CoA to MN. Then, new FA inform previous FA of new FA. Previous FA receiving new CoA information update the binding table and send binding acknowledgement message to MN. Through this process, this ensures not only that packets in flight to the old

CoA are successfully forwarded but also packets from the CN with out of date binding table for MN are successfully delivered to the MN’s new CoA. Besides, triangular routing problem is solved by sending mapping information including that old IP is replaced to the new CoA.

Ⅲ. NET-DRONE SEEN FROM 3D VIEW POINT

When we looked into 3 dimension, the biggest difference of Drone network compared with the existing Wi-Fi network is that Wi-Fi APs are located in the air shown in figure 8. Because of 3D view point, Drone's coverage (which is depicted as A) is described by

$$A = \pi d^2 = \pi(R^2 - h^2), \tag{1}$$

Where h is the Drone's height, R presents the radius of Drone's Wi-Fi coverage and d represents the radius of Drone's coverage. This Drones have various Drone's coverages by the surrounding obstacle, drastic height change by aerial environment and so on.

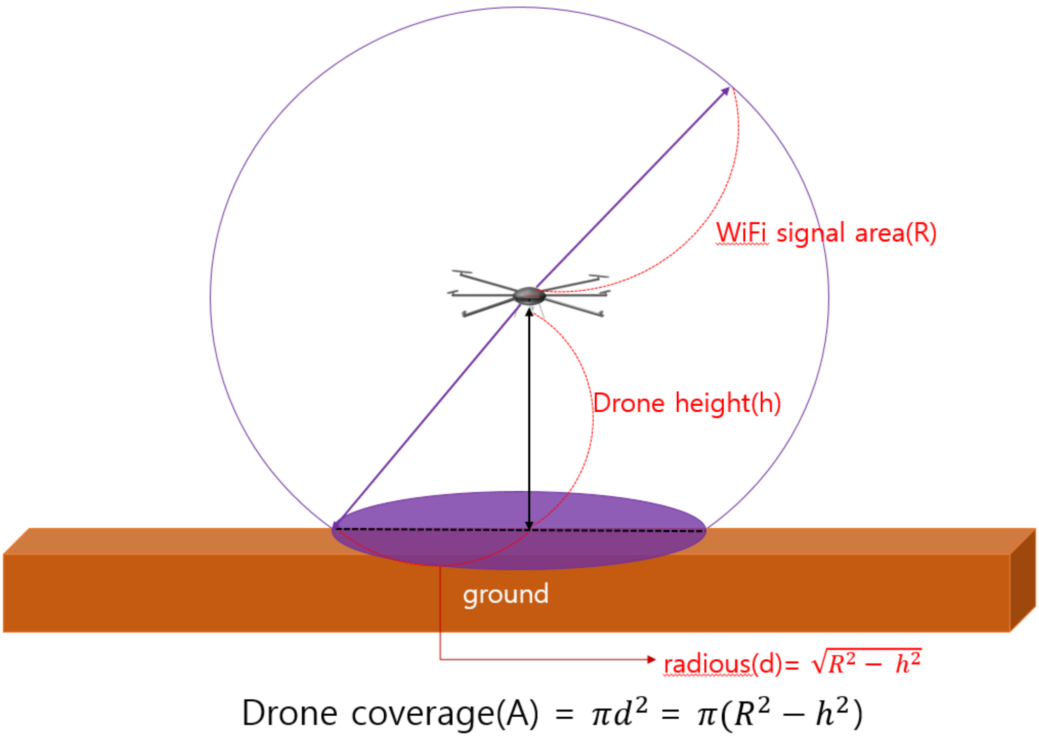


Fig. 8. Drone coverage seen from 3D view point.

A number of studies published earlier have surveyed various types of handover decision algorithms [3]. Among that, optimal coverage decision algorithm is based on received signal strength (RSS). RSS (in dB) is calculated as

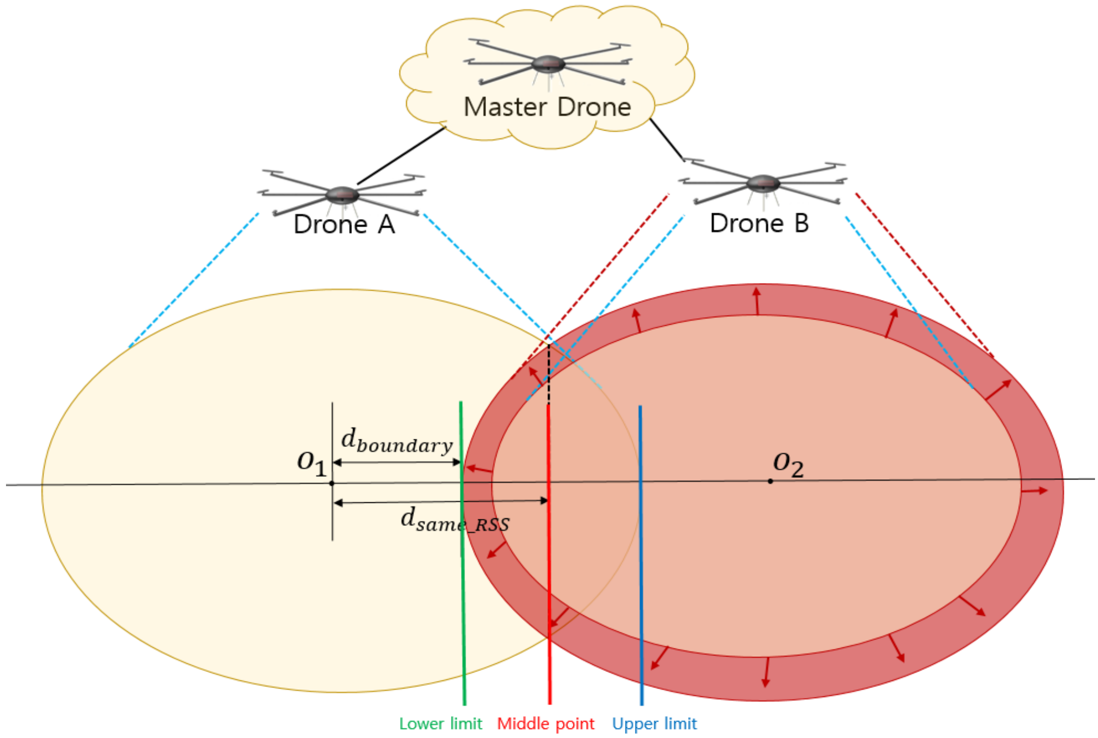
$$RSS_{cur} = RSS_{min} - 10\beta log(d) + \epsilon. \tag{2}$$

In (2), RSS_{min} is the minimum level of the RSS required for the mobile terminal when the distance is 1 meter between the sender and the receiver, β is the path loss coefficient, d is the distance between the sender and the receiver (in meters), $\in$ (in dB) is zero-mean Gaussian random variable with a standard deviation that represents the statistical variation in RSS caused by shadowing. L3 handover is triggered at the point at which RSS is same (D_{Same_Rss}) [11]. Using (1) and (2) D_{Same_Rss} is described by

$$D_{Same\_Rss} = \sqrt{(\frac{A \times D_{01,o2}}{1-A})^2 + \frac{A}{1-A}\left(D_{o1,o2}{}^2 + h_2{}^2\right) - (\frac{1}{1-A} \times h_2{}^2)} + \frac{A \times D_{01,o2}}{1-A} \text{ where A is } 10^{\frac{P_1 - P_2}{5\beta}}. \quad (3)$$

The traditional RSS based handover decision algorithm usually assume that the AP's coverage is same. In this case, D_{Same_Rss} is the midpoint of the overlapped area. However, as mentioned above, Drone has various coverage. The issue is that D_{Same_Rss} gradually moves toward the outskirts of the overlapped area it is not a midpoint as the difference of Drone's coverage decreases.

Figure 9 illustrates the variation of the D_{Same_Rss} as the difference of Drone's coverage increases when Drone A's RSS is fixed at 68dB and we change the Drone B's RSS. The green line is the overlapped coverage's lower limit, while the red line is the overlapped coverage's midpoint and the blue line is the upper limit of overlapped coverage. Fig. 9 shows that D_{Same_Rss} gradually approaches the green line as Drone B's RSS increases. In order to guarantee the seamless handover, every Drone should adjust Drone's height and location to get the same RSS, which moves D_{Same_Rss} from the original location to the midpoint.



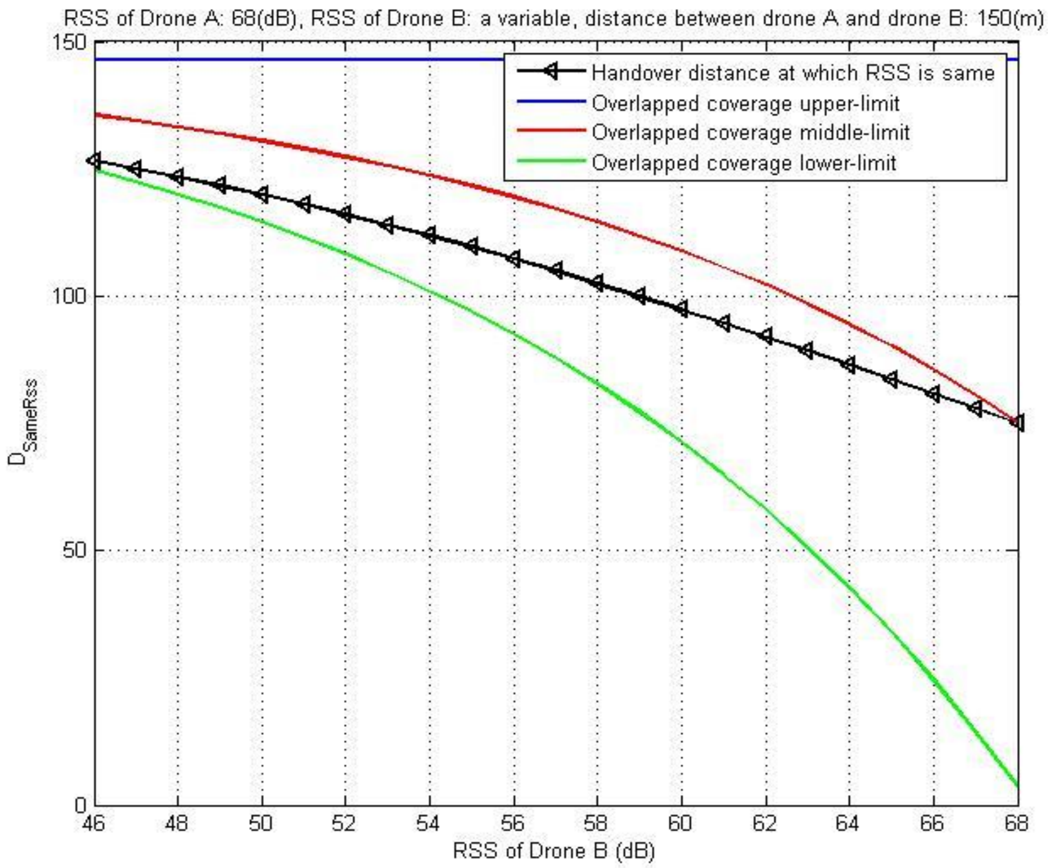


Fig. 9. Variation of the D_{Same_Rss} as the difference of Drone's coverage increases.

Ⅳ. SEAMLESS HADNDOVER SUCCESS PROBABILITY AND FALSE HANDOVER INITIATION PROBABILITY

4.1 Seamless handover success probability

The coverage decision algorithm uses P_s and P_f to search the optimal overlapped coverage which minimizes the interference among Drones and makes every RSS the same. Here, P_s is calculated as the taken time which mobile terminal (MT) initiates handover process and escapes from the current service area divided by the time taken to complete the whole handover process. If MT's moving direction is in the range $(-\pi, \pi]$, and the maximum distance which MT can move during T_h is described by $D_h = V_{mt} \times T_h$. Here, V_{mt} is the maximum velocity and T_h presents L3 handover completion time. Also, P_s is the coverage overlapped area between two Drones divided by the green area which can move during T_h in figure 10.

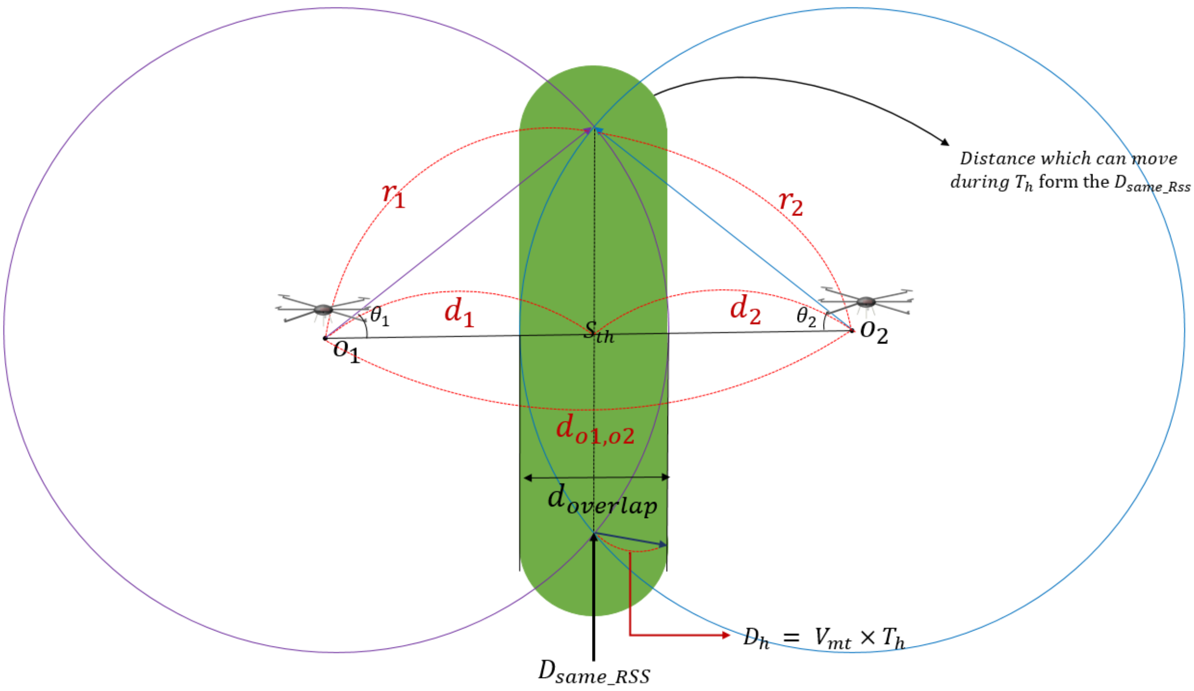


Fig. 10. Analysis of seamless handover success probability.

Here, P_s is given as

$$P_s = \frac{W_{overlap}}{\pi {D_h}^2 + 4D_h \times r_1 \times sin\theta_1}, \quad (4)$$

where $W_{overlap}$ means the width of the coverage overlapped area.

4.2 False handover Initiation probability

During the course of MT's movement, when the MT reaches the point P, the RSS from the old Drone (OD) drops below S_{th} and L2 handover initiation request is triggered. Also, L2 handover is initiated when the MT reaches P. If the MT does not move to the new Drone (ND) when L2 handover initiation request is triggered during a period of time, L2 handover initiation request is considered as an incorrect report. It is the false handover initiation probability. If the MT has the equal probability that can move to all directions when the MT is located at point P as shown figure 11. The pdf of MT's direction of motion is described by

$$f_\theta(\theta) = \frac{1}{2\pi} \quad -\pi < \theta < \pi. \tag{5}$$

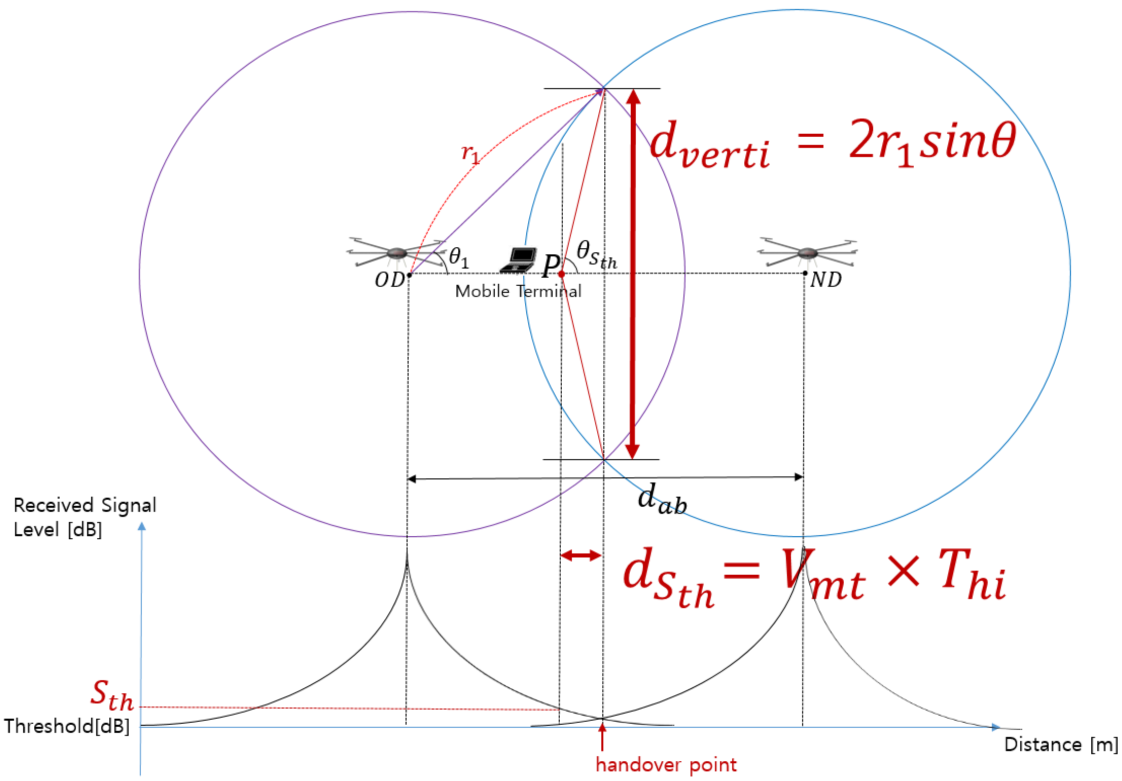


Fig. 11. Analysis of the false handover initiation probability.

In figure 11, if MT's direction of motion from P is in the range except $(-\theta_{S_{th}}, \theta_{S_{th}}]$, P_f is described by

$$P_f = 1 - \frac{1}{\pi} arctan(\frac{2r_1 sin\left(cos^{-1}\frac{d_{o1,o2}}{2r_1}\right)}{2d_{S_{th}}} \qquad \text{where } \theta_{S_{th}} = arctan\left(\frac{d_{verti}}{2d_{S_{th}}}\right).$$

Ⅴ. OPTIMAL COVERAGE DECISION ALGORITHM

In this chapter, we want to show optical coverage decision algorithm which controls the coverage of Drones deploying Net-Drone topology. First, in case of the P_s, if the overlapped area ($D_{overlap}$) is bigger than 2× D_h, the seamless handover probability will be increased, but the interference among Drones is increased and the distance among Drones is reduced as well. Moreover, the overall Net-Drone topology needs more Drones to cover the same service area. But, if you consider the interference, the number of Drone to cover the service area and P_s, the optimal seamless handover probability is attained when $\frac{D_{overlap}}{2}$ is the same as $D_{S_{th}}$ as shown in figure 10. In case of the P_f, $D_{S_{th}}$ is determined in accordance with V_{mn} and T_{hi}. If $D_{S_{th}}$ is bigger than $\frac{D_{overlap}}{2}$, the L2 handover initiation point is triggered on the outside of the overlapped area and the L2 handover process including the cell scanning and channel allocation is failed. Therefore, the $\frac{D_{overlap}}{2}$ has to be selected as the value bigger than $D_{S_{th}}$. When we consider all conditions, the algorithm is described by

$$
\begin{aligned}
&if\ (\frac{d_{overlap}}{2} \geq d_{S\_th})\\
&\quad if\ d_{S\_th} \geq D_h\\
&\qquad \frac{d_{overlap}}{2} = d_{S\_th}\\
&\quad else\\
&\qquad \frac{d_{overlap}}{2} = D_h.
\end{aligned}
$$

Using this algorithm, we can make the flow chart of the optimal coverage decision algorithm in figure 12. The optimal coverage decision algorithm determines the r_{max} which is the smallest Wi-Fi coverage at the H_{min}(H_{min} is the smallest height which Drones can come down) among Drones and adjusts all Drone's heights to match the r_{max} in figure 12. And then, the distance between the Drones is adjusted to make the overlapped coverage satisfying the L3 handover time and the L2 handover time by using the P_f and the P_s.

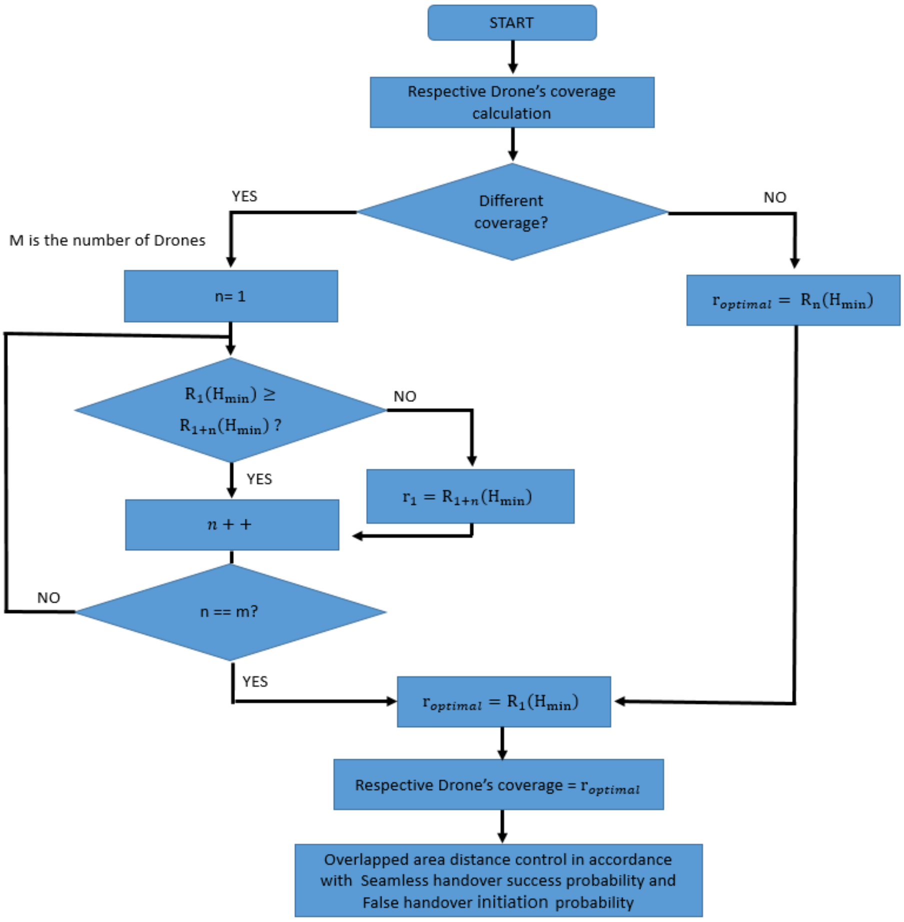


Fig. 12. The flow chart of the optimal coverage decision algorithm.

Ⅵ. SIMULATION

In this section, we several simulations was proceeded to show that how the P_f and the P_s is changed by various factors.

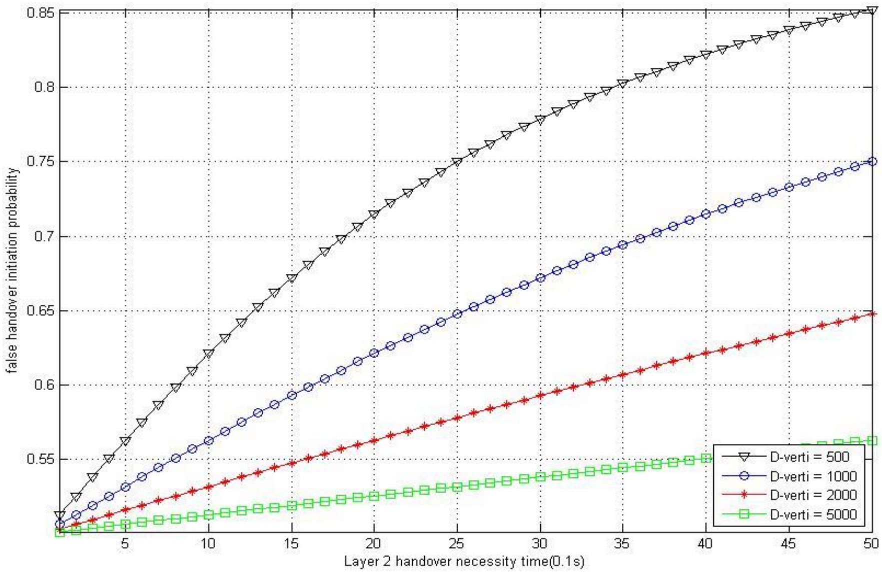


Fig. 13. Relationship between false handover initiation probability and vertical distance of the overlapped area.

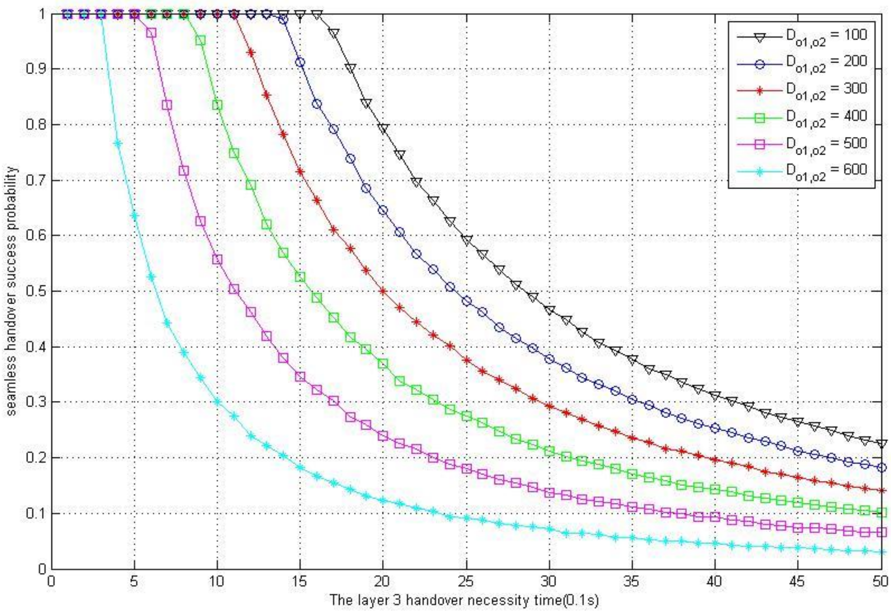


Fig. 14. Relationship between the seamless handover success probability and the L3 handover necessity time.

Fig. 13 is the relationship between false handover initiation probability and vertical distance of the overlapped area. As you know, fig. 13 shows that the P_f increases as the L2 handover necessity time increases, and the overlapped area's vertical distance decreases. Fig. 14 is the relationship between the seamless handover success probability and the L3 handover necessity time. Fig. 14 shows that the P_s decreases ad the L3 handover necessity time increases and the overlapped area decreases in accordance with the distance between the Drones increases. Through fig. 13 and 14, we can know that how to control the Drone's height, distance between one Drone and another.

Generally, the RSS is the fluctuated by the measurement error of the receiver, the attenuation by the various noises in the wireless environment and so on. Consequently, the mean value of RSS during the RSS's measurement time is used instead of the RSS's instantaneous value.

$$\lambda = V_{mt} \times T_m$$

$$RSS_{1,\ avg}(d,\lambda) = \frac{1}{\lambda}\int_{d_{mn}}^{d_{mn}+\lambda} RSS_1(x)dx$$

However, though stable RSS value can be obtained as RSS's measurement time increases, P_s and P_f are changed as seen below because the MT's movement direction and the MT's rate can be changed during the T_m.

$$p_s = \frac{W_{overlap}}{\pi(D_h+\lambda)^2+4(D_h+\lambda)\times r_1 \times sin\theta_1}$$

$$p_f = 1 - \frac{1}{\pi}arctan(\frac{2r_1 sin(cos^{-1}\frac{d_{o1,o2}}{2r_1})}{2(d_{S\_th}-\lambda)})$$

In the Fig. 15, the seamless handover success probability is decreased as average RSS measurement increases. On the other hand, the Fig. 16 shows that the false handover initiation probability is decreased as the average RSS measurement time increases because the MT is closed with the point at which L3 handover is initiated.

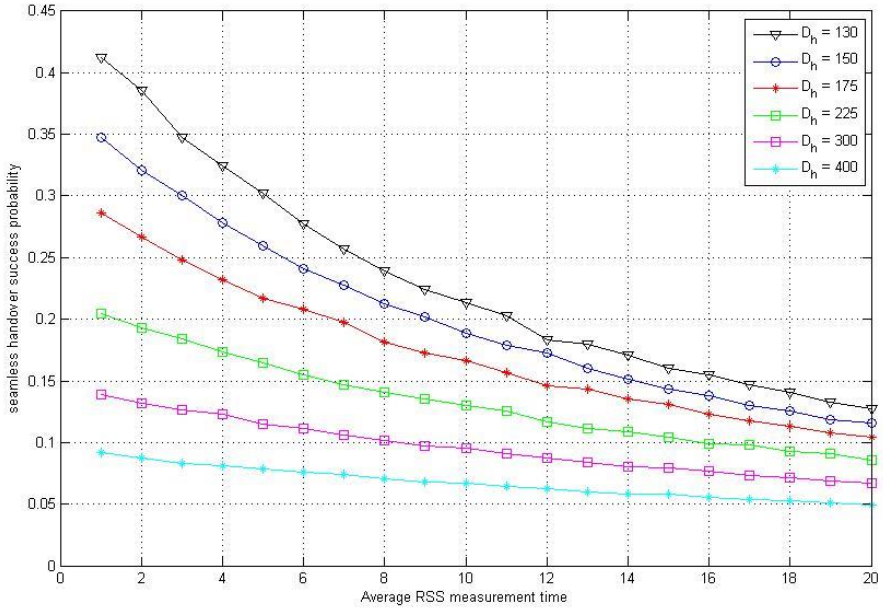


Fig. 15. Relationship between average RSS measurement time and the seamless handover success probability.

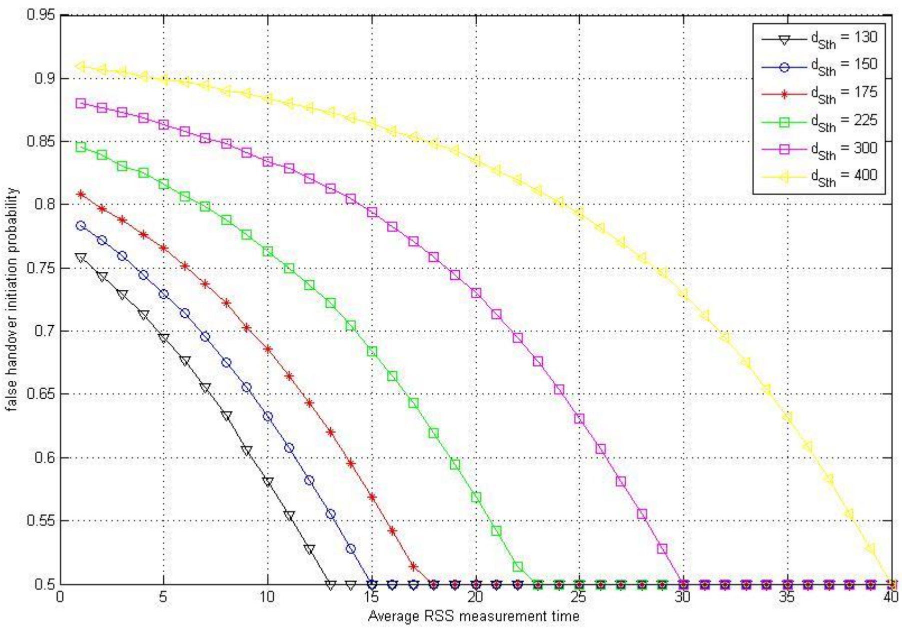


Fig. 16. Relationship between average RSS measurement time and false handover initiation probability.

Ⅶ. CONCLUSION

In this thesis, we deal with one promising solution to construct an aerial Wi-Fi network by using Drones, which is so called Net-Drone to resolve several issues of the traditional aerial networks by UAV (Unmanned Aerial Vehicle) such as limited battery capacity and frequent handover caused by time-varying aerial environment. In Net-Drone, it is a crucial issue how to provide reliable handover for ground users. In particular, it is hard to resolve because Wi-Fi has narrow communication coverage compared to cellular networks. In addition, Drones have different coverage according to their different environment as well as their height. Consequently, traditional handover decision algorithms are not very effective because they assume the same coverage of the AP's.

In this paper, an RSS based efficient coverage decision algorithm was proposed that can determine the coverage of each Drone by controlling the height of each Drone and the distance between Drones. Ultimately, we aimed at constructing a fully connected aerial Wi-Fi network by connecting all the Net-Drones. To this end, we calculated the seamless handover success probability and the false handover initiation probability to search the proper overlapped coverage that minimizes the interference between Net-Drones and makes RSS of every Net-Drone the same. Then, by using these criteria, we evaluated the proposed coverage decision algorithm. Consequently, our simulation results confirmed that the proposed algorithm can effectively provide improved handover performance.

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