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Agenda Item 7: 5 GHz Band Planning

Handover system of plural ground stations in plural ua operation

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SUMMARY

This information paper is intended to inform ICAO FSMP-WG of a summary of handover system experimental measurement in 5GHz-band Control and Non-Payload Communications (CNPC) channels for unmanned aircraft systems (UAS).

1. INTRODUCTION

1.1 This information paper introduces some experimental results of handover system tracking multiple unamanned aircrafts (UAs) from plural ground stations at 5 GHz band allocated for UA CNPC links. NEC has conducted experimental measurements for this handover system. The purposes of the experimental measurements are to demonstrate functions of the handover system trackingsmall UAs, which can be one of core technologies for many applications; logistics, environment observation, infrastructure monitoring, and information collection at disaster, etc. The following sections show a overview and measurement results of handover system at 5GHz-band with using fixed-wing small UAs

1.2 This measurement was being conducted as a part of R&D on cooperative technologies and frequency sharing between UA systems based wireless relay systems and terrestrial networks supported by Ministry of Internal affairs and Communications (MIC), Japan.

2. Overview of Handover System Operation

2.1 Recently, Unmanned Aircraft Systems (UAS) applications are expected to expand to civilian use with the progress of UAS technologies. In particular, It is expected to expand the use of small and medium-sized UAs and operate them in a wide areafor various applications; pesticide spraying, aerial survey, logistics, environment observation, survey of animal and plant life, infrastructure monitoring, and post-disaster data collection. Identifing each UA's flight situation and shring them each other are key eleiments of flight safety among plural aircrafts in wide area for those applications. In particular, a simple system and lightweight devices should be necessary for flight control of small sized multiple UAs due to the limitation of payload.

2.2 Figure 1 shows the overview of handover system tracking multiple UAs from plural ground stations, which is assuming UA's operation in long-range flight routes for physical distribution and observation in mountain area. The terrain of the mountain are avoids establishing communication at some geographical postions where the ground stations are distributed along valley pathways. This system consists of a communication system mounted on an UA, access points (AP) on the ground, ground network system, and UA flight control system. The flight monitoring and control system achieves a stable and continuous flight control of the UA in a wide area by sequential handover of plural APs placed along the UA's flight path.

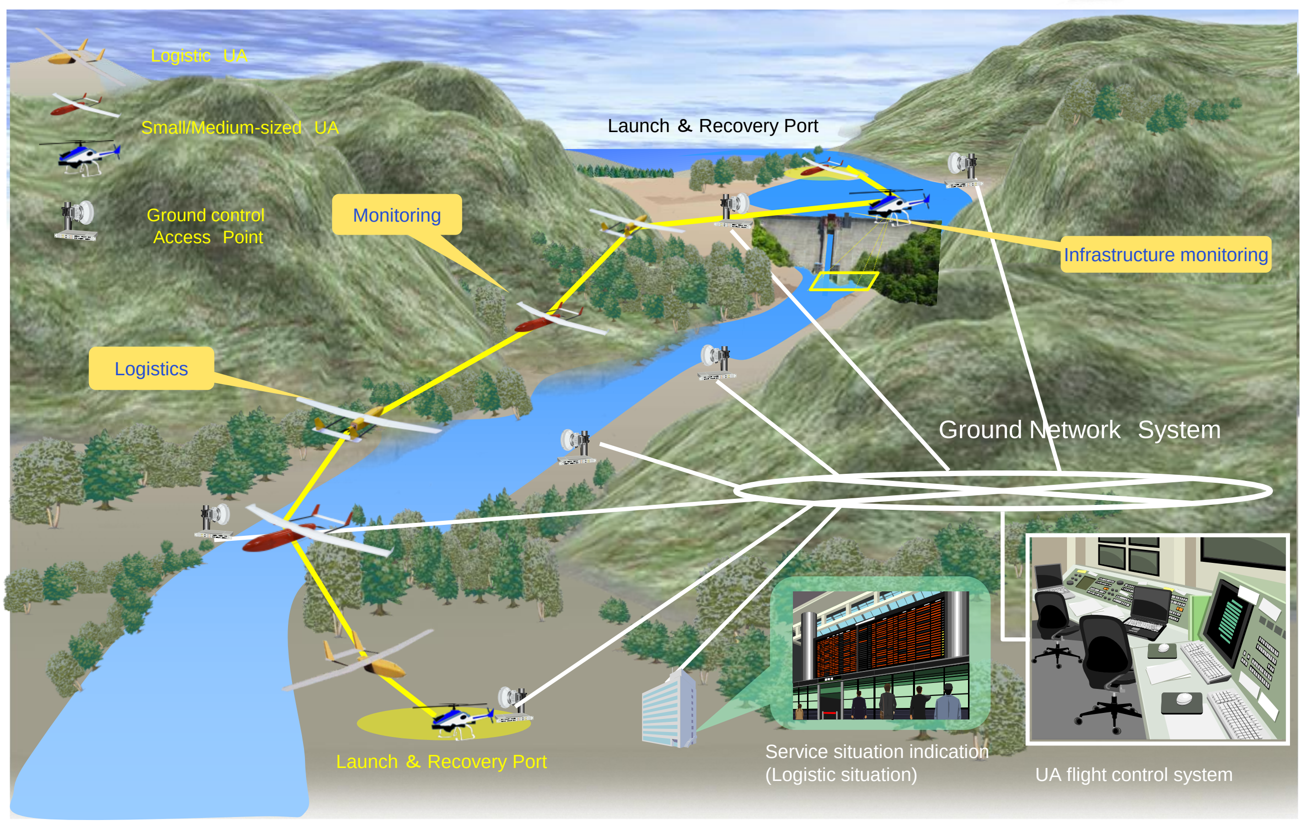


Figure 1 Overview of handover system tracking multiple UAs from plural ground stations

2.3 Our onboard devices of a flight control system for this handover technology are enough small and light to be mouted on a small and medium-sized UA. In general, those UAs are unable to be equipped with a large flight control system such as a satellite communication system, an ATC transponder, etc. Furthermore, a collision avoidance system between aircrafts will be required for potential future applications in sharing airspace between manned aircrafts and UAs. Currently, the collision avoidance system can be classified in Ground Base Sense and Avoid (GBSAA) and above-mentioned Ground Base Sense and Avoid (GBSAA). GBSAA is defined as groud based eqipments detecting aircrafts, such as ground radar, positions acquisition through satellite communication or ground communication. ABSAA is on-board based communication systems which exchange information between aircrafts, such as airborne radar, ATC transponder, etc. Our handover technology may contribute to the technical examination of UA information collection in the GBSAA.

3. OPERATIONS AND FEATURES IN A TYPICAL CASE

3.1 Operations

3.1.1 Figure 2 illustrates an operation of the UA handover system in a typical case. This system consists of Control and Non-Payload Communication (CNPC) devices mounted on an UA and APs located on the ground for simple control of an UA. These APs are placed along the flight path of an UA and keeps appropriate distance which enables to overlap radio coverage with an adjacent AP. When an UA approaches the coverage of an AP, the UA requests the AP to control the UA and the AP keeps to receive the flight information of the UA. The AP can control multiple UAs within its coverage. When the UA moves to an adjacent AP, the AP seamlessly handovers the UA’s information to the adjacent AP. This procedure enables to monitor the UA’s situation continuously.

3.1.2 An AP follows the current position, velocity, direction, altitude, and identification number of plural UAs. At the same time, the AP transmits those information to an UA flight control system through a ground network system. Based on those information, the UA flight system enables safe and efficient UA operations by directing not only distance between UAs but also altitude, velocity, direction, and route of each UA.

3.1.3 This system is intended for a small and medium-sized UA which is unable to be equipped with a large flight control system such as a satellite communication system, an ATC transponder, etc. Therefore, on-board equipment for handover needs to be small, lightweight, and power-saving. For wider service coverage of UAS, APs should be portable, inexpensive, and power-saving. Achieving these specifications allow the construction of flight control system enabling dynamic flight path and simultaneous operation of many UAs.

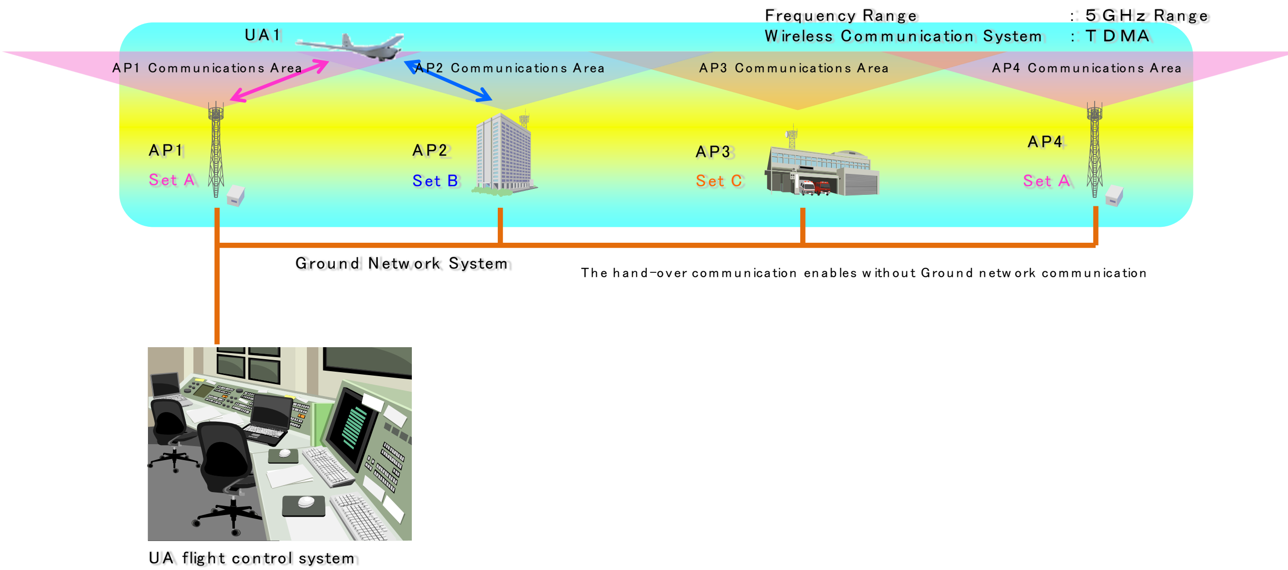


Figure 2 Example of Operations

3.2 Features of UA handover system

3.2.1 The UA handover system is intended for safe flight and efficient operation of small and medium-sized UAs by contiuous controlling in wide-area coverage including beyond line-of-sight (BLOS). Therefore, this system needs to have:

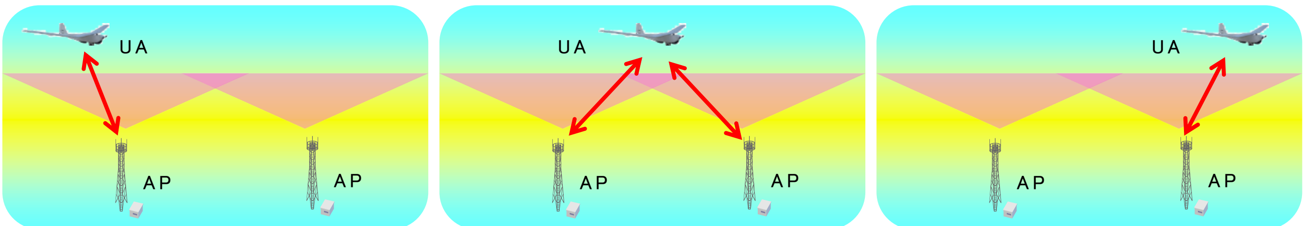
- — high efficiency of frequency usage and power-saving ground equipment
- — one channel at 5GHz band allocated after WRC-12
- — no cutoff during handover for safety flight control
- — small-sized ground equipments with easy installation, like base stations of cell phones
- — a small, lightweight, and power-saving on-board device mounted on a small and medium-sized UA
- — transmiting rate control of information volume about UA's condition, acquired images and data by sensor for flight control, depending on situations such as UA's takeing-off, collision avoidance in flight, etc.

3.3 Features of installed algorithm

3.3.1 In accordance with the features of UA handover system described in 3.2, the handover control algorithm and transmission rate control algorithm have the following features:

- — Protocol that hand-over is available in one channel at 5 GHz band
- — Wireless Communication system is Time Division Multiple Access (TDMA) where one-to-many communication is available for UAs and APs
- — Reliable and seamless soft-handover to a new AP, by allowing the UA to communicate adjacent APs simultaneously located in an overlapped communication area
- — Contiuous communication by smooth handover between APs in order to improve the robustness of communication (See Figure 3)

— Well-established handover system only by communication between each AP and UA without any ground station network equipment such as a radio network control equipment which controls AP to control handover
— Power-saving design that An AP stops sending to reduce power consumption in case that there is no nearby UA requesting handover



(a) (b) (c)
Figure 3 Basic scheme of hand-over

3.3.1.1 In this handover system, an AP gives a transmitted packet to an UA after the UA sends a call to the AP. An transmitted packet given to one AP is limited and divided into three parts which are allocated in each communication area, as shown in Figure 4. This division avoids congestion by neighbour APs (See Figure 5).

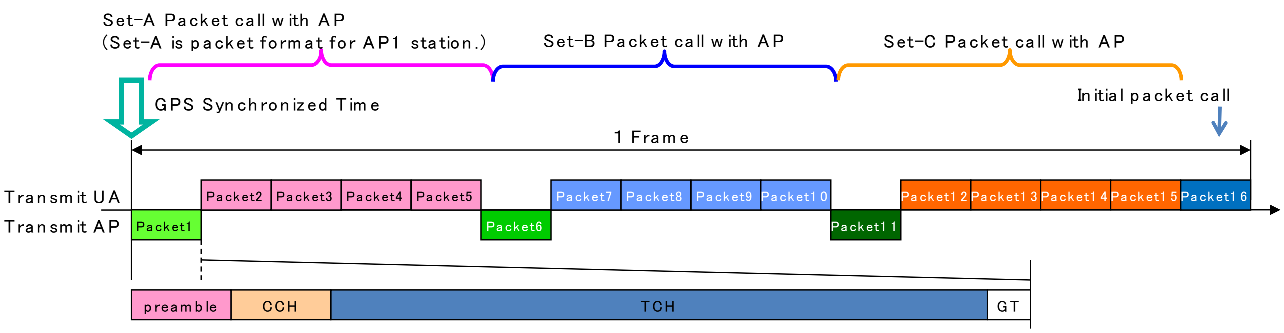


Figure 4 TDMA Format of Hand-Over Algorithm

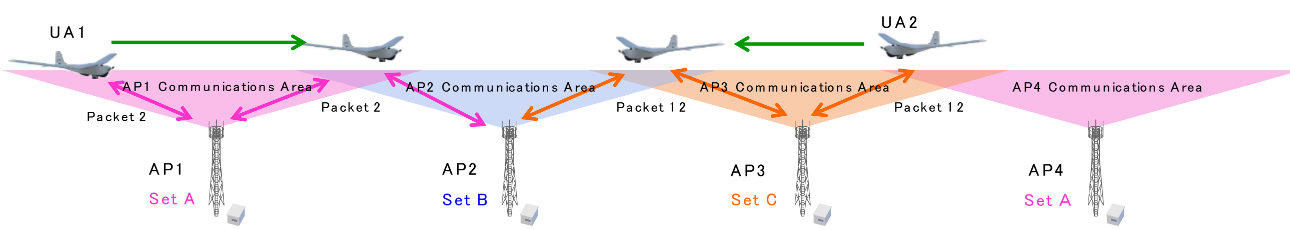


Figure 5 Picture of Hand-Over

3.3.2 the transmission rate control algorithms have the following features;

— Transmission rate control established by altering the time slot assignment
— Employed sequential transmission resource allocation that enables a gradual assignment to perform safe and secure transmission rate control.
— Defined and distributed resource request, whose values are decided with an application program instead of setting a fixed assignment to allow APs to perform fair and optimum transmission resource allocation to each UA

4. Verification test of the handover wireless system

4.1 Overview of the test system

4.1.1 A wireless system equipped with the above mentioned algorithms has been developed for verifng performance of the handover system. This system consists of a wireless communication unit on both a ground station and small UAs (Wingspan: 2.8m、Weight: 5.9kg), which have a common configuration of following units. Figure 6 shows photographs of the completed units.

- — RF antenna (UA antenna/AP station antenna)
- — RF signal processing unit
- — Digital signal processing unit
- — GPS receiver
- — Power supply facilities for AC power (for ground stations)/Battery (on-board)

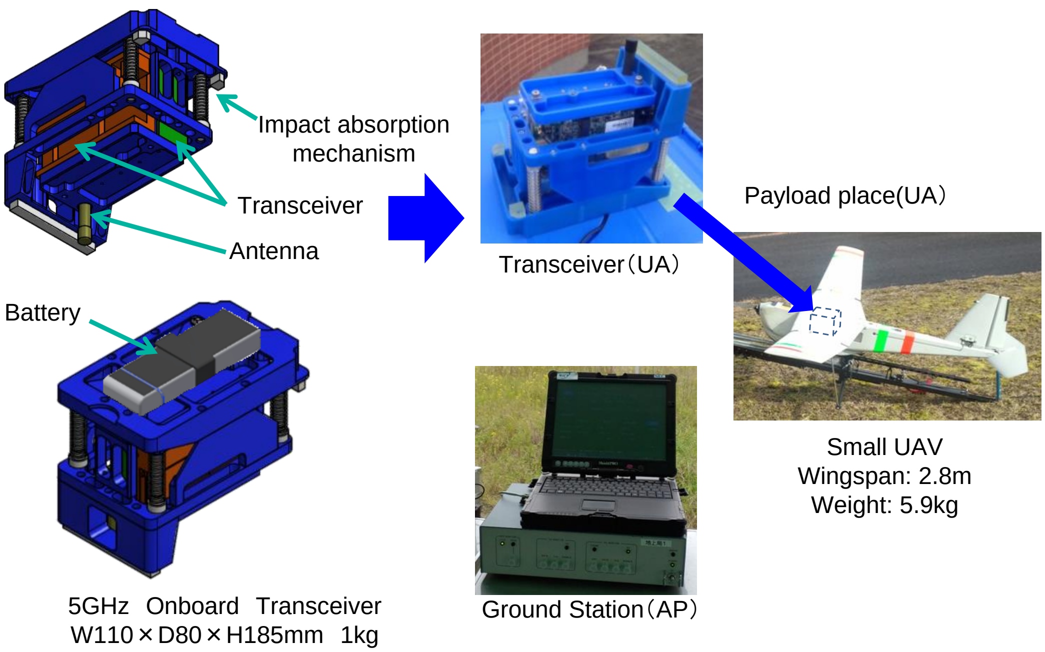


Figure 6 Handover wireless system

4.1.2 Also, specifications of the wireless equipment are shown as follows:

- — Service frequency: One channel at range between 5 030 and 5 090 MHz
- — Transmission output: 1 W
- — Multiple connection system: TDMA
- — Modulation system: MSK
- — Signal transmission rate: Approx. max. 5 Mbps
- — Occupied bandwidth: max. 20 MHz
- — Mass of on-board wireless unit: max. 1 kg

4.2 Overview of the verification test

4.2.1 The verification experiments of handover control and transmission rate control were conducted in December 2015 and March 2016. In these tests, two UA units equipped with the handover wireless unit flied at different altitude. Figure 7 shows a turning flight path of a UA named “UA1” at 300m and Figure 8 shows the other flight path of “UA2” at 200 m. Two APs named “AP1” and “AP2” were located in separated area as shown in Figure 7 and Figure 8.

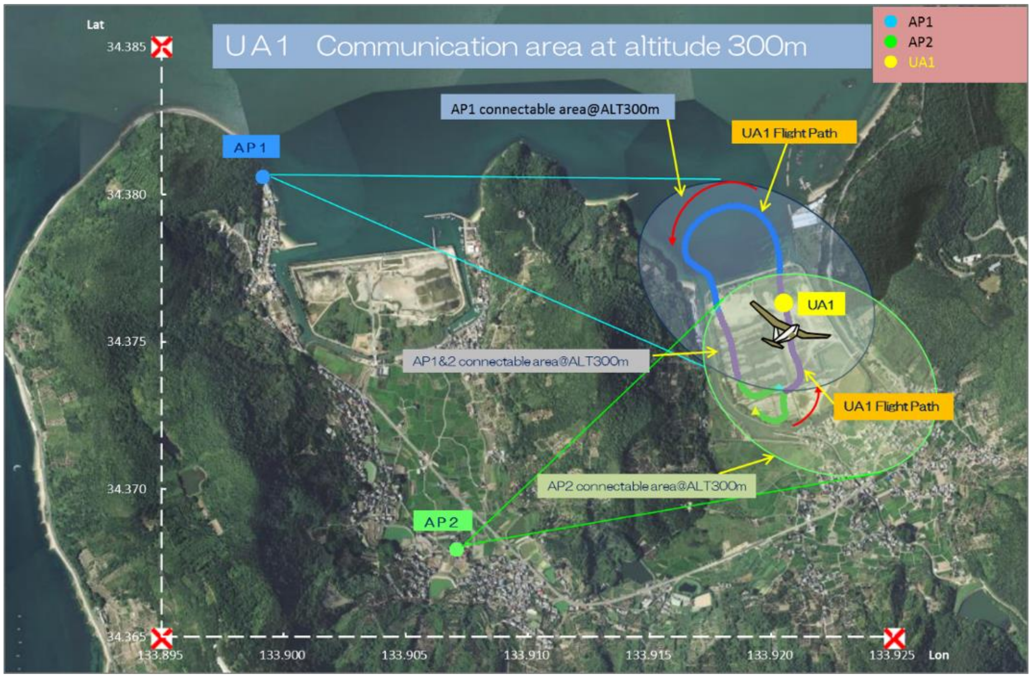


Figure 7 Flight path of UA1

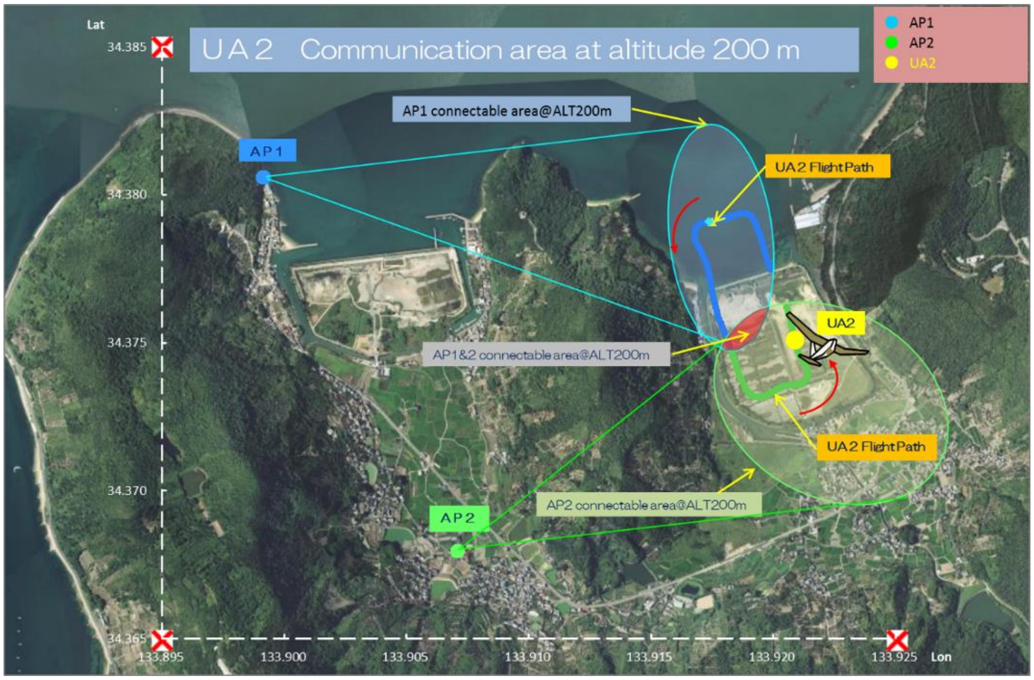


Figure 8 Flight path of UA2

4.2.2 These configuration of APs and UAs proves verification levels of handover actions, where communication link between an UA and an AP is affected by topographical form and difference altitude between UAs. This test field could be classified into three areas depending on characteristics of communication availablity; only AP1, only AP2, and both AP1 and AP2. The following two kinds of actions were checked for evaluating handover performance:

Handover actions

4.2.2.1 The handover actions of one or two UA's units during flying between AP1 connected area and AP2 connected area were checked.

Actions of transmission rate control against plural UA units

4.2.2.2 The actions of the transmission rate control units mounted on the two UA after changing their resource request values were checked.

4.2.2.3 Typical data obtained in these experiments are shown as below:

— GPS coordinates and time of each UA and AP
— ID of each UA and AP
— Call up and connection receive status
— Signal reception intensity at each UA and AP
— Resource request value from each UA
— Transmission time slots of each UA and AP

4.3 **Verification test results**

4.3.1 These verification tests gave the following results:

Checking the handover actions

4.3.1.1 Handover connection transition in this verification process is shown in Figure 9. In the flight process of UA1, it was verified that soft handover was performed during changing the counterpart of communication in the sequence of (a) UA1 to AP2 connection, (b) UA1 to each of AP1 and AP2 stations, and (c) UA1 to AP1 connection. Likewise, it was confirmed that UA2 similarly performed the handover between AP1 and AP2 during connecting with both APs. Furethermore, re-connection with a link after interruption was recognized in the flight process of UA2. These results verified multiple simultaneous handover actions executed by two UA units at different altitudes during flying between two APs.

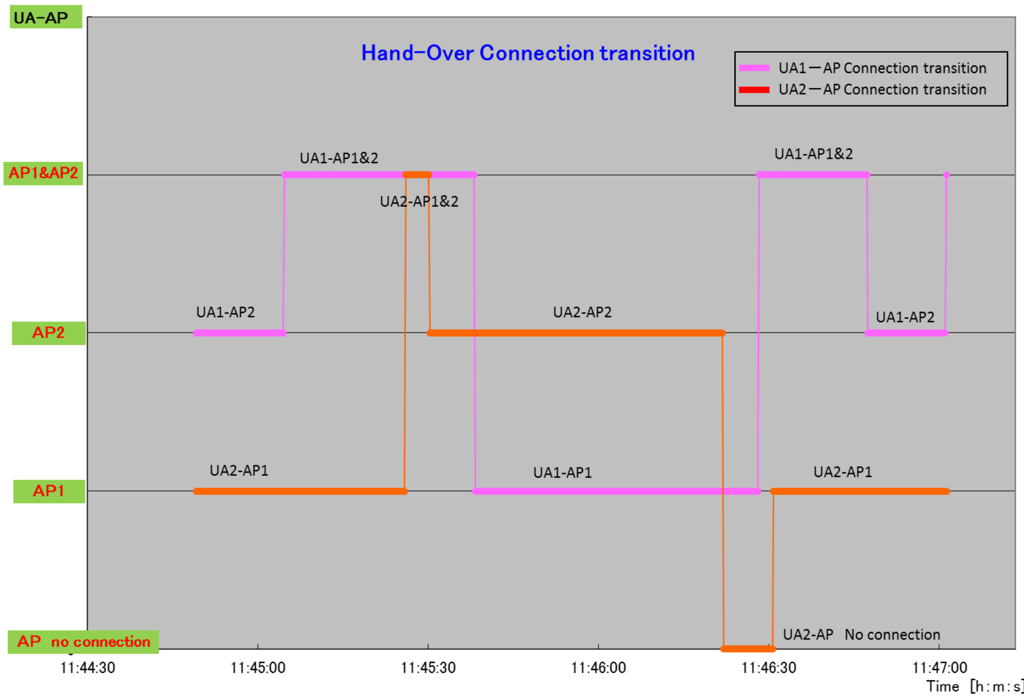


Figure 9 Handover connection transition

Checking actions of transmission rate control against plural UA units

4.3.1.2 In this verification, resource request values of both UA1 and UA2 were changed in order to understand relationship between the request values and actual rate change transition. Acquired rate change transition is shown in Figure 10. As shown in Figure 10, transmission rate varies depeing on resource request value change in both cases of UA1 and UA2. Also, the rate control was executed in a step-wise manner. Conducting controlling action via an intermediate state during such a rate control process suppresses the loss probability of communications by reducing the congestion probability, thereby enabling the allocation of communication resources with further enhanced reliability.

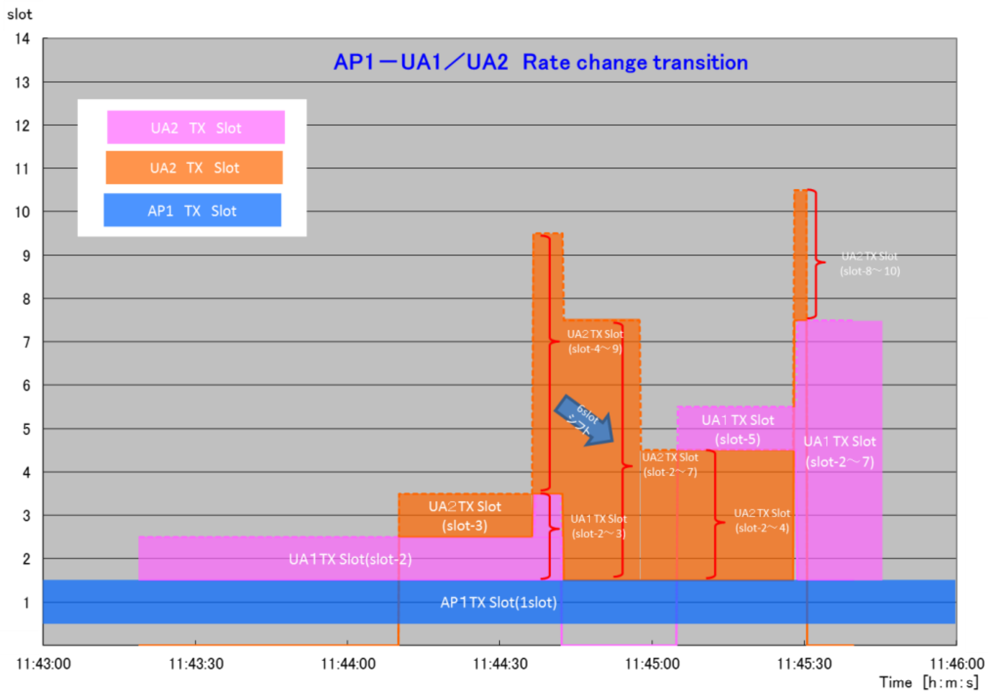


Figure 10 AP1-UA1/UA2 Rate change transition

4.3.1.3 The verification test proved that UAs can autonomously switch ground stations and plural UA units can execute the assignment of time slots for sharing resources in accordance with resource request values. Consequently, it was verified that the handover algorithm and the transmission rate control algorithm can be installed in compact and light-weight wireless units to be in service in an actual flight environment. Furthremore, these algorithms are installed mainly by using software so that maintaining both down-sizing and scalability can be achieved.

5. **Conclutions**

5.1 This information paper presented the outline of the handover system between multiple UAs and multiple ground stations at the 5 GHz band allocated to UA CNPC and the results and analysis of the demonstration experiments. These results could confirm the operation of the basic handover algorithm and the operation of the transmission rate control algorithm. This confirmation included multiple handoveres in the case that two UAs flew simultaneously between two APs. Moreover, the rate control provided enough performance in step-wise manner depending on request values from two UAs, and communication resource allocation with suppressed congestion probability could be performed.These results confirme that the handover system in the 5 GHz band can be operated with maintaining the radio link in long distance fly paths for logistics, observation survey, etc. This system provide strength to the difficulty of radio communication between UAs and APs due to terrain such as mountains.

5.2 In addition, the practical application of the handover control technology developed in this study involves challenges, such as methods for applying to specific CNPC links, coexistence with on-going communication protocols, and stable operation in larger communication environment. There are also challenges for further sophistication, such as collaboration with flight control system, ground station deployment method, application of optimum algorithms, control parameters extension (threshold value, action timing, modulation and coding for example), setting automation, etc.

— END —