Throughput Performances of UAV Multi-Hop Communications by Applying Link Adaptation

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***Abstract*—Although unmanned aerial vehicle (UAV) multi-hop network is effective to establish communications between a base station and remote harvesting robots with long distances, the studies of it have been limited to its information delivery time under delay tolerant networking (DTN) concept. In this paper, we focus on studying connection time between UAV and base station/harvesting robot, and link adaptation is used to increase the throughput performances. In this paper, the uplink throughput from the remote harvesting robot to the base station when applying link adaptation is numerically clarified through computer simulations.**

***Keywords*—throughput, UAV, multi-hop communications, remote harvesting robots, connection time, link adaptation**

I. Introduction

Currently, the study of Internet of Things (IoT) technologies in agriculture is in progress, which includes the using of remote harvesting robots [1]. The base station sends downlink signals to control the operation of the remote harvesting robots, meanwhile, the base station receives uplink signals from the remote harvesting robots, which include collected sensor information and other data. To make communication between the base station and the remote harvesting robots possible, a wireless multi-hop network utilizing unmanned aerial vehicles (UAVs) as relay stations should be used, especially when the farm is too large for the base station and the remote harvesting robots to communicate with each other directly. Fig. 1 shows an example of an UAV multi-hop communication system, for communicating between the base station and the remote harvesting robots. However, if the number of UAVs is limited, the concept of delay tolerant networking (DTN) [2] needs to be introduced. Although circular flight paths for UAVs have been proposed [3], the evaluation have been only limited to its delivery time based on the flight paths. Therefore, the throughput performances have not been investigated yet.

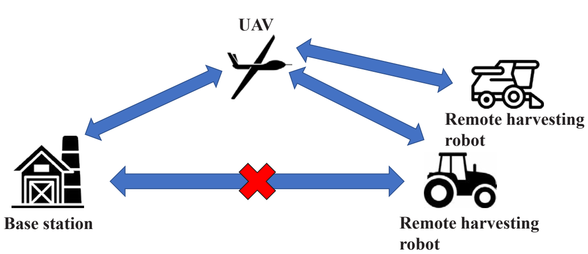

Fig. 1. An example of an UAV multi-hop communication system.

In this paper, we quantitatively evaluated the uplink throughput performances considering the connection time of UAV to the base station and remote harvesting robots. We calculate the connection time between the UAV and the remote harvesting robot refer to the UAV's flight path and determine the throughput by dividing the amount of received bit accumulation by the connection time. Furthermore, we applied link adaptation for an UAV communication system to increase throughput performances compared to a constant transmission rate.

II. Proposed Technologies

A. Connection Time

Fig. 2 shows the connection time between the UAV and remote harvesting robot. In this paper, a new concept of connection time is defined as the period in which the remote harvesting robot stays in the UAV communication range. The communication range is defined as the available range of UAV communication with the devices on the ground.

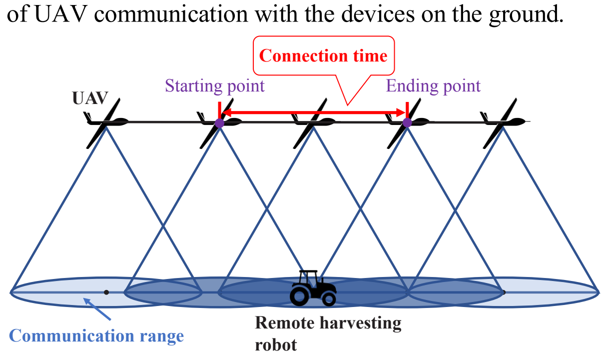

Fig. 2. Connection time between the UAV and remote harvesting robot.

B. Link Adaptation

About link adaptation, if the received power is high enough, higher-level modulation or higher forward error correction (FEC) coding rate will be used to achieve larger throughput, within a specified frequency bandwidth. However, if the received power is reduced to lower, the lower-level modulation or lower FEC coding rate will be used. This switching transmission rate technique according to the received power to change combinations of modulation and FEC coding rate is called "link adaptation" [4].

C. The Communication Range Based IEEE 802.11a

Table 1 shows the transmission rate for each modulation and FEC coding rate of “r” base on IEEE 802.11a specification [5]. In this paper, we assume that each communication channel between UAV and a remote harvesting robot should be separated because of the interference avoidance. Therefore, 5 GHz band standard of IEEE 802.11a specification with more communication channels compared to the 2.4 GHz is used according to an assumption of IEEE 802.11a specification outdoor usage in the future.

TABLE 1 TRANSMISSION RATES FOR EACH MODULATION SCHEME

Modulation schemes (FEC coding rate)	**Transmission rate (Mbps)**
BPSK (r=1/2)	6
QPSK (r=1/2)	12
16QAM (r=1/2)	24
16QAM (r=3/4)	36
64QAM (r=3/4)	54

Based on the bit error rate (BER) performance of each combination, we can introduce the relationship between signal-to-noise power ratio (SNR) and received bit rate. Fig. 3 shows the distance between the UAV and the remote harvesting robot versus received bit rate.

In this paper, the transmission power is set to 8 dBm according to a commercial product shown in Ref. [6].

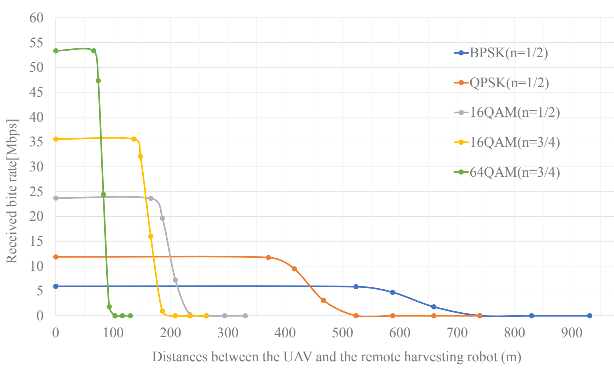

Fig. 3. Distances vs. Received bit rate.

III. SIMULATION

A. Simulation Parameters

We assume that the UAV cruising by a circular path with a radius of 200 meters in a 500×500 square meters area. The UAV flight speed is set to 28 m/s refer to the specifications of an actual vehicle [7].

TABLE 2 MAJOR SIMULATION PARAMETERS

Service area	500×500 (m^2)
Frequency	5 (GHz)
UAV's onboard antenna	60 (°)
UAV flight speed	28 (m/s)
UAV flight altitude	400.00 (m)
UAV Communication radius	200.00 (m)
UAV flight path	Circle [3]

Fig. 4 shows an example of the communication range of the UAV with an ordinary constant rate. The beam width of the UAV's onboard antenna is set to 60 degrees and the flight altitude is set to 400 meters, the maximum communication distance is calculated to be 461.88 meters. Therefore, communication range radius is calculated to 230.94 meters. In this case, the received bit rate is 6 Mbps within the communication rage, according to minimum mandatory transmission rate in specification of IEEE 802.11a.

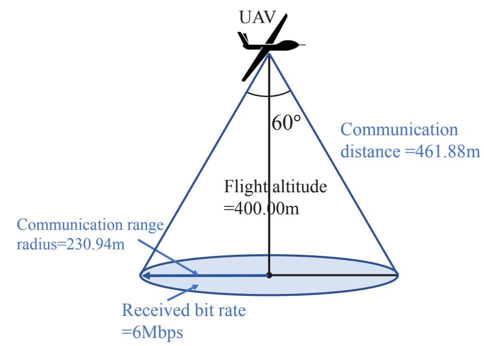

Fig. 4. An example of the communication range of the UAV with an ordinary constant bit rate.

Next, Fig. 5 shows an example of the communication range applying link adaptation of IEEE 802.11a specification as shown in Fig. 3. According to Fig. 3, we can determine each received bit rate with link adaptation applied. The received bit rate is 6 Mbps within the communication range radius from 230.94 meters to 222.5 meters, which is same to the ordinary constant rate. On the other hand, when the communication range radius is less than 222.5 meters, the received bit rate become 12 Mbps.

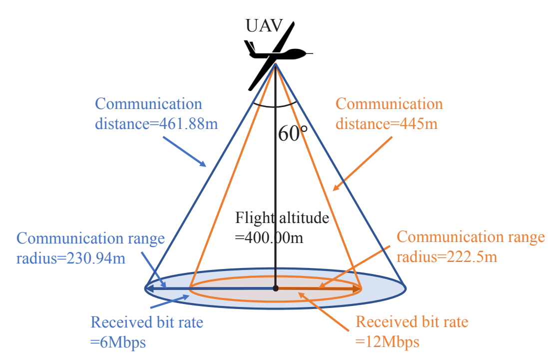

Fig. 5. An example of the communication range of the UAV applying link adaptation.

B. Connection Time

B-1. Ordinary Constant Rate

Fig. 6 shows the connection time between UAV and remote harvesting robot without applying link adaptation. In Fig. 6, we set the remote harvesting robot in the upper right corner of the area and the base station in the lower left of the area, so the UAV's flight path length within the communication range is 264.24 meters. Therefore, the connection time between the UAV and the remote harvesting robot is calculated to be 9.43 seconds according to the UAV flight speed of 28 m/s.

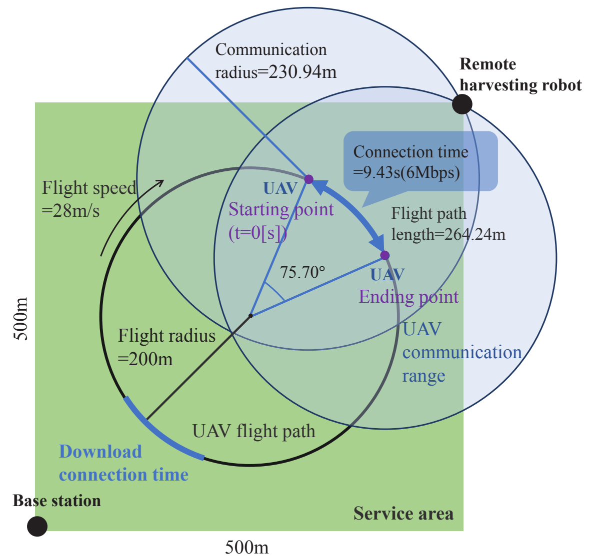

Fig. 6. Connection time between UAV and remote harvesting robot without applying link adaptation.

B-2. Link Adaptation

Fig. 7 shows the connection time between UAV and remote harvesting robot applying link adaptation. If we consider the physical layer specifications of 5 GHz IEEE 802.11a, the received bit rate of the UAV changes based on the performances as shown in Fig. 3. In this case, the connection time is also 9.43 seconds as same as the ordinary constant rate, but it is divided to 3 periods according to the link adaptation as shown in Fig. 7. In the 1st and 3rd periods for a sum of 1.46×2=2.92 seconds, 6 Mbps received bit rate is used as same as the ordinary constant rate. On the other

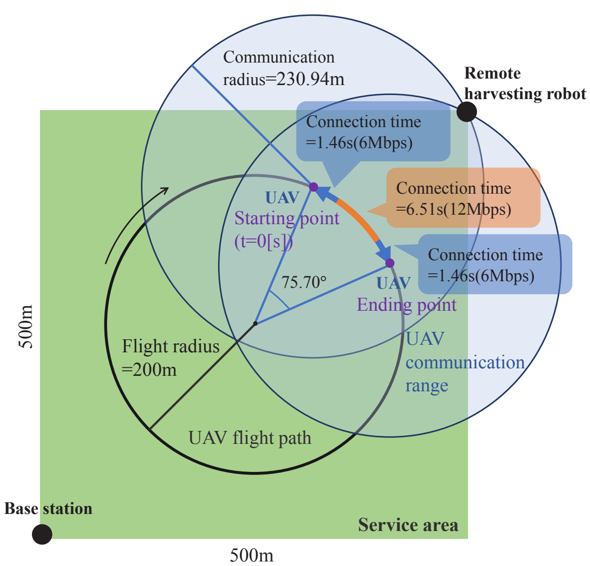

Fig. 7. Connection time between UAV and remote harvesting robot applying link adaptation.

hand, during the 2nd period, 6.51 seconds of the connection time corresponds to 12 Mbps received bite rate.

C. The Comparison of Throughputs

Fig. 8 shows connection time versus UAV received bit accumulation. As mentioned above, in the connection time of 9.43 seconds, the ordinary constant rate uses 6 Mbps of received bit rate always, and link adaptation uses 6 and 12 Mbps, respectively. Therefore, as shown in Fig. 8, the ordinary constant rate achieves 56.58 Mbits of UAV received bit accumulation. On the other hand, by using link adaptation, UAV can receive 95.64 Mbits during the connection time.

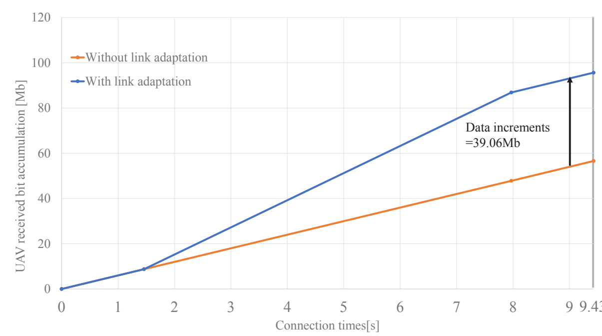

Fig. 8. Connection time vs. UAV received bit accumulation.

Due to the symmetry of this model, the UAV's connection time to the base station would be the same 9.43 seconds. The base station received bit accumulation is equivalent to the UAV received bit accumulation from the remote harvesting robot. In this simulation, the time of one cycle of the UAV's circular flight path is 44.88 seconds. The UAV received bit accumulation from the remote harvesting robot during the connection time is defined as B_{uav}. On the other hand, the base station received bit accumulation from the UAV during the connection time is also defined as B_{base}. In this symmetrical simulation model, $B_{uav} = B_{base}$. Moreover, the time taken for one circle flight is defined as T_c. Eventually, throughput can be calculated by B_{base} / T_c. As just obtained before, $B_{uav} = B_{base} = 56.58$ Mbits and $T_c = 44.88$ seconds. Therefore, with the ordinary constant rate, the uplink throughput from the remote harvesting robot to the base station can be calculated by 56.58/44.88=1.26 Mbps. Identically, the throughput with link adaptation can be calculated by 95.64/44.88=2.13 Mbps.

IV. Conclusion

In this paper, we have quantitatively evaluated the uplink throughput between the remote harvesting robot and the base station in a DTN-based UAV multi-hop communication system considering the connection time with UAVs. The evaluations have conducted under the condition of one remote harvesting robot and one UAV cruise in circular orbit, based on the physical layer specifications of 5 GHz IEEE 802.11a. Also, we have compared the throughput between the remote harvesting robot and the base station with and without applying link adaptation. According to the results of the simulation, we have found that 5 GHz IEEE 802.11a link adaptation can increase the throughput from the remote harvesting robot compared to that without link adaptation.

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