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Research Article

# Performance of Multi-hop Command and Telemetry Communication System in 169 MHz Band for Operation of Drones Beyond Line-of-Sight

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## Abstract

The cellular networks are becoming widely used for drone operations under the conditions including long range and beyond-line-of-sight. However, for the countries with many mountain areas and disasters like Japan, the cellular networks sometimes would not be available due to the service area limitation and damages or congestions in their network infrastructure. We developed a dual-band multi-hop command and telemetry communication system using 169 MHz and 920MHz bands to meet the requirement for the operation of drones in the areas with poor network infrastructure and BLOS environment. We call this system as "Command Hopper." Among the bands, the 169 MHz band particularly has a characteristic performance with the propagation range and diffraction. This paper presents the overview of the Command Hopper and the experiments, focusing on the use of the 169 MHz band. We assumed to apply the system to the drone operation in two practical use cases with difficult radio propagation: the volcano monitoring and the inspection of power transmission facilities in the mountains.

**Keywords:** Drone; command and telemetry communication; beyond line-of-sight (BLOS); 169 MHZ band; multi-hop

## Introduction

Small, unmanned aircraft system (UAS), or drone, is becoming popular for the applications such as aerial photography, delivery, facility inspection, agriculture and disaster monitoring. At the same time, the operational area for drone is extending from the visible vicinity of operator to the invisible remote area beyond line-of-sight (BLOS) [1]. For the remote and BLOS operation, it is significantly beneficial to use the cellular networks when the operation airspace is covered by the cellular service [2]. However, there would be a problem when a user wishes to fly over mountain or sea areas where the cellular coverage is not enough. Even over the urban areas, the cellular coverage would be damaged or congested under disaster situations, when the demands for drone operation would increase. On the other hand, the conventional direct wireless link between the ground station and the drone would be lost under BLOS conditions where the link is blocked by obstructions such as mountains or buildings. To establish the wireless link in the above situations without using an existing network infrastructure, the multi-hop or ad-hoc network technology is useful [3-6]. In the multi-hop network, the repeater stations, or nodes, relay the link between the ground station and the drone, where the repeater stations are located so as to make the link between the adjacent stations line-of-sight (LOS).

Based on the considerations above, we developed a multi-hop command and telemetry communication system, which is independent from the cellular networks. We call this system as "Command Hopper." The system relays the data between a ground station and a mission drone (terminal station) via one or two relay stations onboard drones or placed on the ground or buildings, providing a connection between the ground station and the mission drone even under BLOS conditions. The system works either in two bands, 920 MHz or 169 MHz, which are selectable according to the priority trade-off on data rate or communication range. The 920 MHz band is widely used for private IoT (Internet of Things) networks in many countries with good device availability at low cost. This band has the feature of longer propagation range than the 2.4 GHz band, which is mostly used to control drones. The range can be further increased to more than several km by using LPWA (Low Power and Wide Area) schemes such as LoRa modulation [7]. However, although even better than the 2.4GHz band, the propagation is still susceptible to the attenuation by trees, buildings, or terrains, when it is used without significant reduction of data rate. This band may be suitable for drone operation with the distance longer than that in the 2.4 GHz band and under the good LOS conditions.

The 169 MHz is one of the licensed bands granted to unmanned vehicles and robots in 2016 in Japan [a]. This band allows the transmission power of 1 W to meet the requirement of drone and robot users who wish to operate over the long range, noting that the transmission power is limited to 10 mW for airborne transmitter [8]. This band is expected to give a better penetration and diffraction characteristics particularly in forests and hilly terrains, although the available bandwidth and data rate are limited. The Command Hopper assumes the use of the 920 MHz band for initial two-way data connection procedure between the ground station and the flight controller onboard the drone, which needs relatively high throughput, whereas the use of the 169 MHz band for command and telemetry communication during the flight. In the following chapters, we present the overview of the Command Hopper and the experimental results focusing on the use of 169 MHz band, which assumed two kinds of practical use cases both in difficult radio propagation environment, namely, the volcano monitoring and the inspection of power transmission facilities, both in mountains. Finally, we summarize the performance and future study of the system. Our previously published paper [9] discussed the fundamental single-hop propagation of the Command Hopper in the 169 MHz band, whereas this paper mainly discusses 2-hop and 3-hop propagation in real mountain areas.

## The Command Hopper–Multi-hop Command and Telemetry Communication System

The Command Hopper consists of a ground station, two repeater stations, and a terminal station, as shown in Figure 1. The repeater stations are placed on drones, ground, buildings, or towers. The number of repeater stations is zero to two, each of which gives 1-hop link, or direct link, to 3-hop link. The number of hops is dynamically and automatically changeable according to the radio propagation condition. The terminal station is placed on a mission drone to be controlled and is connected to its flight controller. This system provides a continuous connection using the band, 920 MHz or 169 MHz, between the ground station and the terminal station onboard the mission drone via the repeater station(s) even under BLOS condition, such as in the areas with many buildings or mountains. The roundtrip latency from the command transmission to telemetry reception at the ground station is guaranteed within a certain period determined by the super frame length, which is given by TDMA (Time Division Multiple Access). Figure 2 shows a typical multi-hop command/telemetry data flow among the four stations. The frame timings of all the stations are synchronized to each other by a beacon signal transmitted by the ground station. The hopping route between 1 hop and 3 hops is dynamically and automatically changed within one frame length, when the radio condition changes due to the drone flight, by evaluating received signal strength at each of the stations.

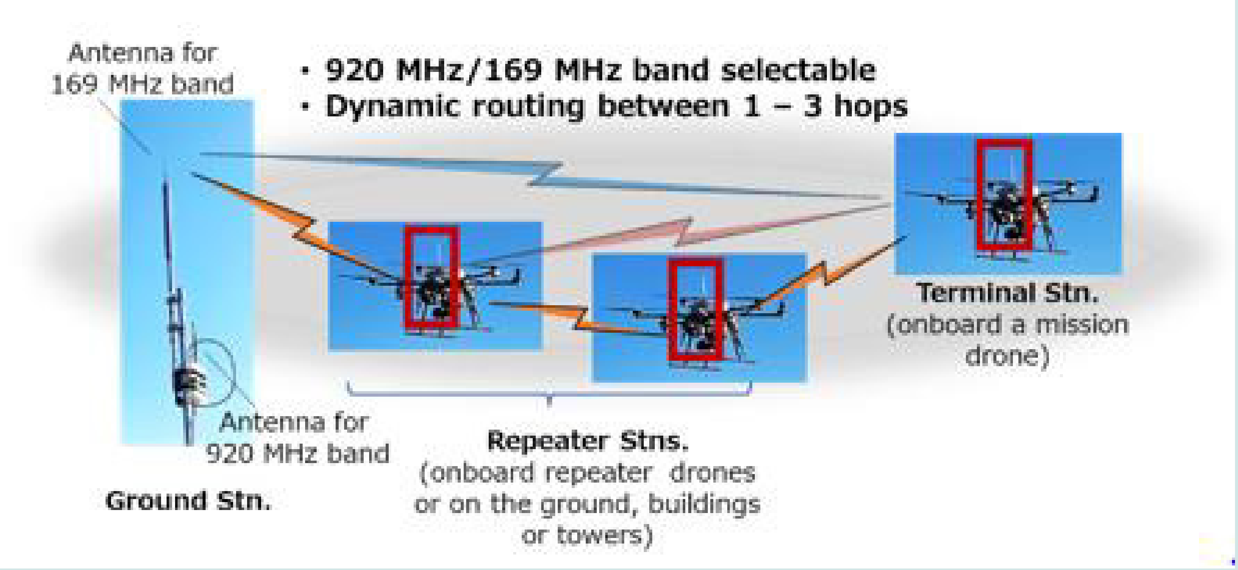

**Figure 1:** The command hopper–multi-hop command and telemetry communication system.

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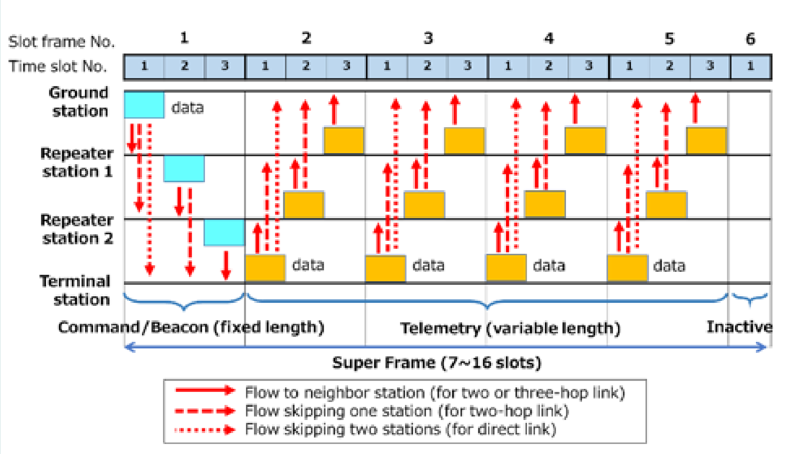

**Figure 2:** Multi-hop command/telemetry data flow among the stations.

The frequency band is selectable between 920 MHz and 169 MHz manually or automatically. Figures 3 & 4 show the dual-band hardware configuration of a Command Hopper unit and its view of the prototype version of 2021, respectively. The hardware is common for the four stations. The role of the stations, ground, repeater1 and 2, or terminal is determined by firmware. When the unit works as the ground station, the RJ-45 interface gives the connection to a PC to control and monitor the communication status and the UART interface gives the connection to another or the same PC working as a ground control station with a navigation software. When the unit works as the terminal station, the UART interface gives the connection to the flight controller of the mission drone. When the unit works as the repeater station, the interface connectors are open. Since the number of available channels in 169 MHz band is limited to 2 to 4 in the Radio Low in Japan, which is much less than that in 920MHz band, it is recommended to use the 169 MHz band as an emergency backup of 920 MHz band. The throughput and latency in the 920 MHz band is much better than those in 169 MHz. For example, when the link in 920 MHz band gets significantly attenuated by the degradation of radio condition, the operator would switch it to the 169 MHz band to keep connection. Then one would go back to the 920 MHz band, when the link quality gets recovered. Table 1 shows the specifications of the Command Hopper. It should be noted that, since the transmission power of the airborne station is lower than that of the other stations in the 169 MHz band as mentioned, the link transmitted by the airborne station determines the overall link performance.

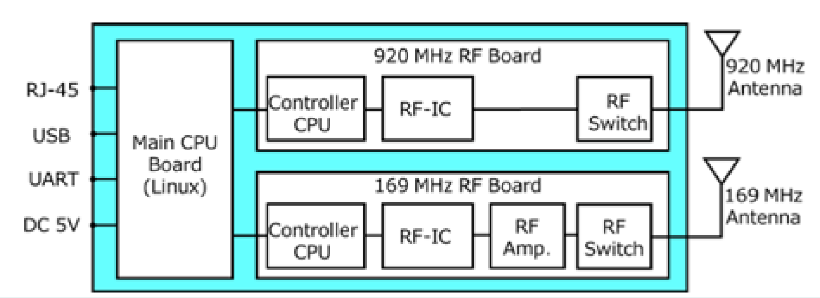

**Figure 3:** Dual band configuration.

**Figure 4:** View of a command hopper unit (prototype ver. 2021).

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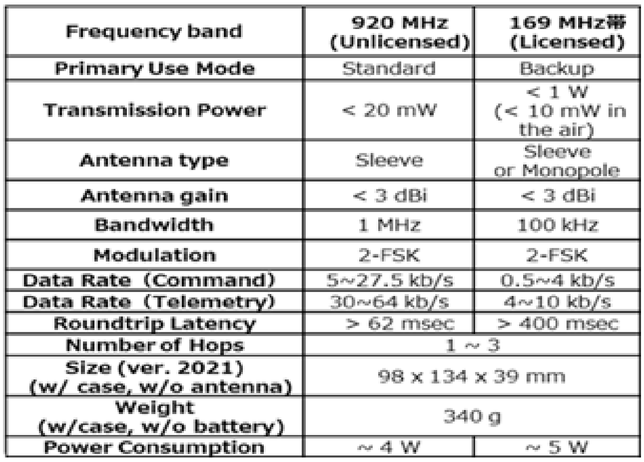
**Table 1:** Specifications of the command hopper prototype.



| Frequency band | 920 MHz (Unlicensed) | 169 MHz帯 (Licensed) |
|---|---|---|
| Primary Use Mode | Standard | Backup |
| Transmission Power | < 20 mW | < 1 W (< 10 mW in the air) |
| Antenna type | Sleeve | Sleeve or Monopole |
| Antenna gain | < 3 dBi | < 3 dBi |
| Bandwidth | 1 MHz | 100 kHz |
| Modulation | 2-FSK | 2-FSK |
| Data Rate (Command) | 5~27.5 kb/s | 0.5~4 kb/s |
| Data Rate (Telemetry) | 30~64 kb/s | 4~10 kb/s |
| Roundtrip Latency | > 62 msec | > 400 msec |
| Number of Hops | 1 ~ 3 | |
| Size (ver. 2021) (w/ case, w/o antenna) | 98 x 134 x 39 mm | |
| Weight (w/case, w/o battery) | 340 g | |
| Power Consumption | ~ 4 W | ~ 5 W |

The Command Hopper has a graphical user interface (GUI) to monitor the link quality in real time on a PC connected to the ground station. Figure 5 shows the example of the GUI, which displays the roundtrip latency, data rate in telemetry link and RSSI (received signal strength index) in the command link in each of the hops.

**Figure 5:** GUI example showing the status of the Command Hopper.

## Performance in Field Experiments Assuming Practical Use Cases

This section discusses the BLOS propagation data of the Command Hopper in the 169 MHz band obtained in field experiments, assuming two practical BLOS use cases: volcano monitoring and the inspections of power transmission facilities. The drones we used in the experiments are the multi-rotor type specified in Table 2.

**Table 2:** Specifications of the drone used in the experiment.

| | |
|---|---|
| Product name | E6106MP |
| Company | Eams Robotics |
| Diagonal wheel-base | 1060 mm |
| Maximum take-off weight | 8.32 kg |
| Payload | 6.2 kg |
| Flight time | 20 min. |
| Flight controller | Pixhawk family |

## Aerial Drone Relay for Volcano Monitoring

For volcano monitoring using drones, we often need to deliver the mission drone with sensors or cameras to the areas, where the cellular networks are not available. Figure 6 shows a scenario in the experiment. The mission drone delivers a volcano ash sensor to a desired placement point in restricted area close to the active volcano. For many cases in this kind of scenario, the mission drone needs to be delivered to BLOS area from the ground station. Particularly, if the mission drone needs to land at the desired point, the communication link between the ground station and the mission drone is likely to be disconnected. To maintain the communication link in this situation, we applied the Command Hopper in 169 MHz band and deployed a repeater drone in the airspace of line-of-sight from both the ground station and the mission drone. Figure 7 shows the antenna installations at the ground station and onboard the repeater and mission drones. The experiment took place at the east side of Mt. Shin-Moe dake in the Kirishima Mountains in Kyushu, Japan, in April 2022. Mt. Shin-Moe dake is an active volcano with the restricted area of 2 km in radius during the period of the experiment. In the experiment, the CTI Engineering Co., Ltd. (CTI) managed the total of the volcano monitoring test mission and operated the ash sensor to be carried by the mission drone. We provided the Command Hopper for the communication link between the ground station and the mission drone. Figure 8 shows the terrain profile and the flight path. The mission drone took off at the point near the ground station and carried the ash sensor to the placement point. The distance between the points is about 1.2 km, and their altitude difference is 190 m. The line-of-sight is blocked by the terrain between the points of placement and ground station. Thus, we deployed a repeater drone at 140 m above the ground station.

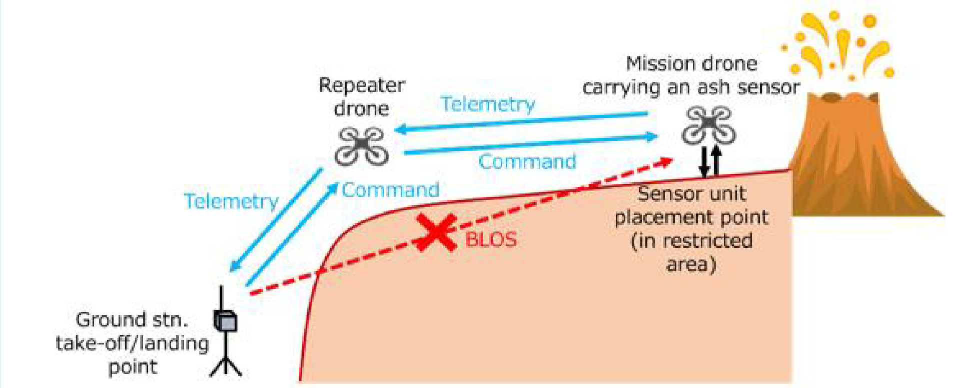
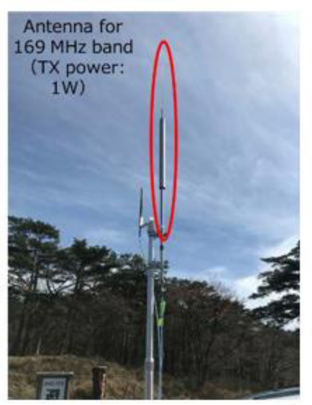


**Figure 6:** A Scenario for volcano monitoring using drones with an aerial multi-hop network.



**(a) Ground station**

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(b) Repeater and mission drone.
**Figure 7:** Antenna installation.

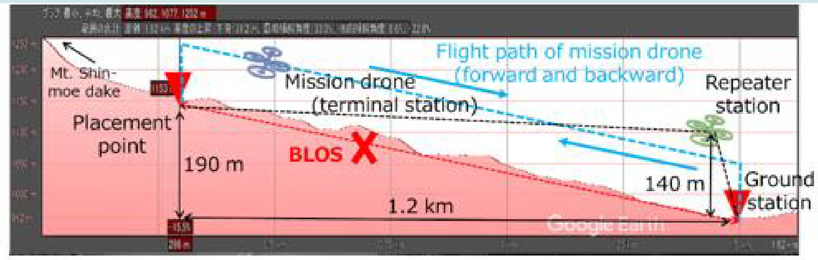

**Figure 8:** Terrain profile and flight path.

Firstly, we compared receiving signal power between the 1-hop and 2-hop links. For the 1-hop link, we observed the receiving signal power at the ground station, which is transmitted by the terminal station with the transmission power of 10 mW. For the 2-hop link, we observed the receiving signal power at the terminal station, which is transmitted by the repeater station with the same power. The reason of the difference of the observation station is that we did not have a measure to observe the receiving signal power at repeater station transmitted by the terminal station. Figure 9 shows the result along the timeline that the mission drone took off the home point with the ground station, flew to the sensor placement point, landed there and release the sensor, took off again, flew back to the home point, and landed there. As shown, the communication link is lost when the mission drone descends to land at the sensor placement point for the 1-hop link, whereas it is maintained for the 2-hop link. It is noted that the connection is maintained even with a small terrain blocking for the 1-hop link thanks to the strong diffraction performance in the 169 MHz band.

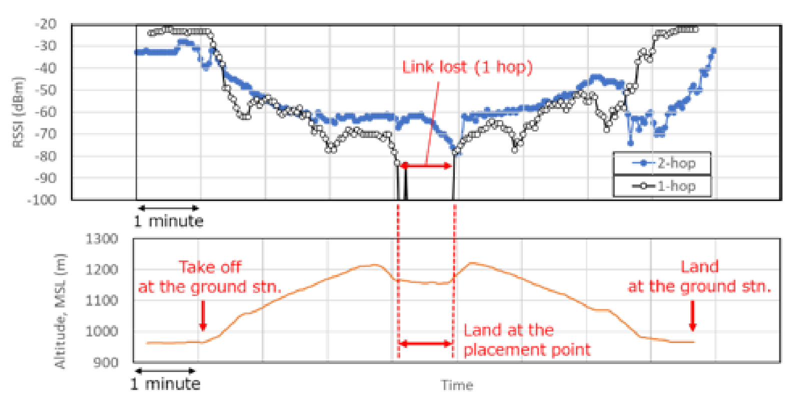

**Figure 9:** Comparison of the receiving signal power between 1-hop and 2-hop links. (The lower graph shows the altitude above the sea level of the mission drone).

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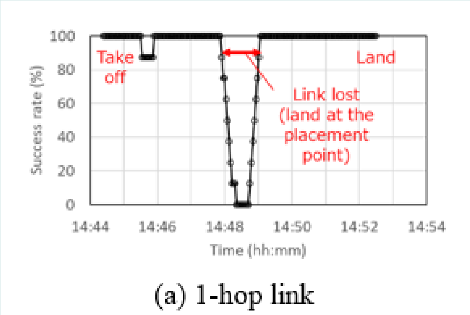
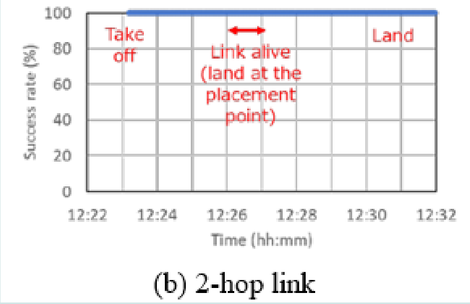
The advantage of the hop network is also confirmed in Figure 10, which compares the success rate of telemetry data packet between 1-hop and 2-hop links. Figure 11 shows the path loss characteristics by the distance for 1-hop and 2-hop links. The 1-hop link is affected by the attenuation by the terrain, whereas the 2-hop link almost agree with the free-space attenuation line. Since the receiver sensitivity is about -95 dBm, we can estimate the maximum communication distance as more than 20 km for the 2-hop link with no margin.



(a) 1-hop link



(b) 2-hop link

**Figure 10:** Success rate over 8 packets of telemetry data.

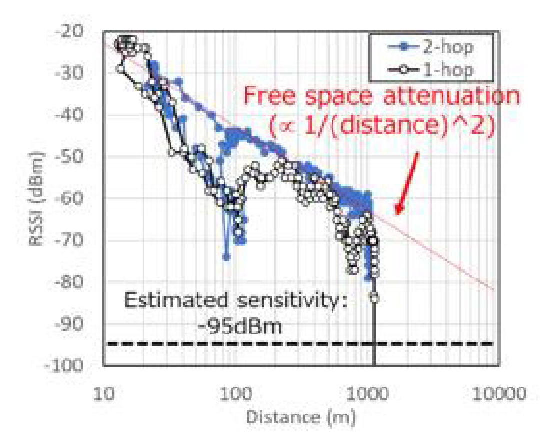


**Figure 11:** Path loss vs. distance for 1-hop and 2-hop links. (The data includes all the round-trip flight path).

## Tower Relay for the Inspection of Power Transmission Facilities in Mountains

The drone use for the inspection of the power transmission facilities in mountain areas would be also one of the use cases of the Command Hopper, where the cellular network coverage would be poor. In such a scenario, the repeater stations can be installed not only onboard the drone, but also on the power transmission tower with high elevation. Since the tower is regarded as an extension of the ground, the transmission power is allowed to be as much as 1 W according to the domestic regulation, thereby longer station-to-station link would be established than in the case with the repeater station onboard the drone. Figure 12 shows a scenario in the experiment applying the Command Hopper to the use case. A mission drone with an onboard camera and terminal station took off near the ground station, flew along the power transmission towers and lines beyond the mountain, and landed at the point of the other side of the mountain where the direct communication link with the ground station is completely lost. Figure 13 is a conceptual image for the dynamic change of the hopping route along with the flight over the repeater stations. The Command Hopper changes the hopping route automatically according to the availability of signal strength. In the experiment, the Chubu Electric Power Co., Inc. managed the total of the inspection mission and the use of the power transmission tower to install the repeater stations under the collaboration with Chubu Electric Power Grid Co., Inc. and Hitachi Ltd. Figure 14 shows the location of each station, the terrain profile and the flight path, in the experiment. The total distance between the ground station and the landing point is 2.4 km. It is noted that the drone gets into BLOS from the ground station when the distance from the ground station is more than about 1.2 km. Figure 15 shows the photographs of antenna installation for ground station and repeater stations 1 and 2. For the repeaters, the antennas and the RF units are fixed at the middle of the tower, whereas the batteries for them were place on the ground by using the Power-over-Ether (PoE) cables to supply power to the RF units.

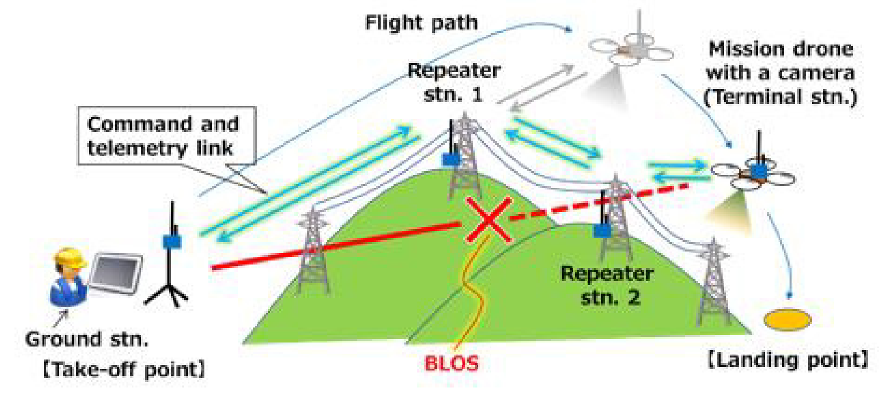


**Figure 12:** The inspection of power transmission facilities in the mountains using drones with tower-based multi-hop network.

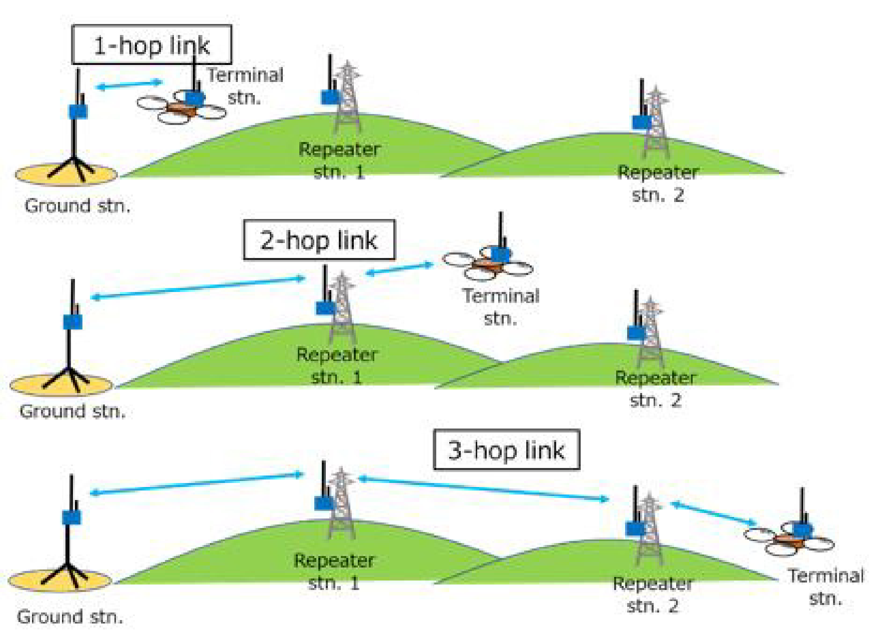


**Figure 13:** The dynamic change of the hopping route.

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**Figure 14:** The location of each station, the terrain profile and the flight path.

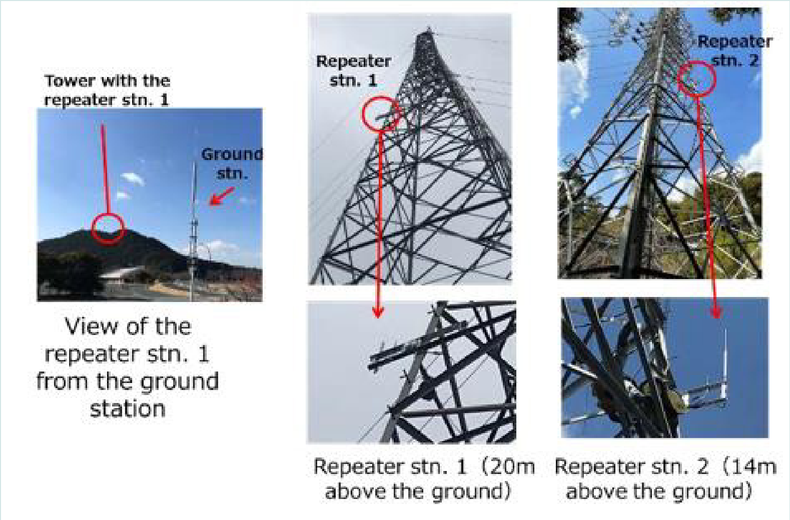

**Figure 15:** The installation of antennas for ground station and repeater stations 1 and 2.

Figure 16 shows the change of the number of hops with the flight location. It is found that the 2-hop link and the 3-hop link frequently switched over to each other during the flight between the take-off point and the repeater station 1, whereas the link settled into 3 hops after approaching to the repeater station 1. Figure 17 shows the change of the receiving signal power at the terminal station onboard the mission drone. The transmitting station to the terminal station is the repeater station 1 for 2-hop link and the repeater station 2 for 3-hop link, respectively. Thus, the receiving power gets to be the maximum when the drone flies near the repeater station 2.

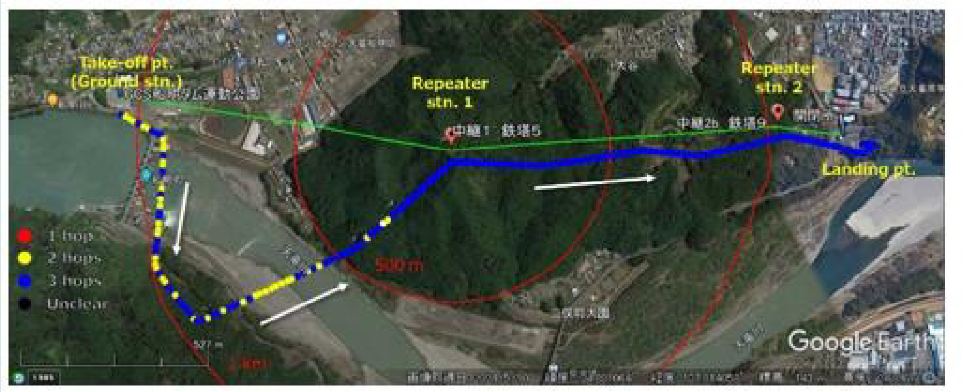

**Figure 16:** The change of the number of hops along with the flight location.

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**Figure 17:** The change of the receiving signal power at the terminal station along with the flight path.

Figure 18 shows the detail of the data in the timeframe. Before the take-off, the 3-hop link was unstably connected, which means that the drone captured the link to/from the repeater station 2, which is completely in BLOS from the ground station. As a reason of this, we think that the drone occasionally received reflected signals by the surface of surrounding mountains. While the drone was ascending, the number of hops alternately switched over between 2 and 3, which means that the direct link between the drone and the repeater station 2 was still often connected. Since the 3-hop link including the reflected path is unstable due to very small receiving power, the success rate is a little degraded. After the drone approached to the repeater station 1, which is placed near the peak of the mountain, the link was settled down into 3 hops without the reflected path, thereby resulting in a constant success rate of 100 % all the way until the drone landed at the landing point behind the mountain. It would be a further study to improve the selection algorithm of the optimum multi-hop route to stabilize the link performance. (The upper graph shows the distance from the ground station and the altitude of the mission drone.) Figure 19 shows the path loss characteristics to the distance for the link from the repeater station 2 to the terminal station in 3-hop link. When the distance is between 100 m and 1000 m, the path loss almost agrees with the theoretical line of free-space attenuation. When the distance is less than 100 m, where the drone flies above around the repeater station 2, the received power is attenuated. This may be due to the antenna gain degradation caused by the antenna pattern with vertical polarization for both antennas on the tower and the drone. The signal attenuation with the distance more than 1000 m may be due to the link including reflected path by the surrounding mountain surface right after the take-off near the ground station. Since the sensitivity of the receiver is estimated with about -95 dBm, the maximum 1-hop link distance from the terminal station, with the transmission power of 10 mW, to the repeater station is expected to be more than 10 km in free space and line-of-sight environment. Although we did not evaluate the possibility of distance extension between the repeater towers, it is expected that it would be more than several 10 kilometers, since the repeater station on the tower can transmit with the power up to 1 W, which is higher than the terminal station by 20 dB, for both directions as estimated from Figure 19. By comparing Figures 11 & 19, it is found that the receiving power for free-space propagation in Figure 19 is less than that in Figure 11 by about 5 to 6 dB. Although the reason of this difference is still not clear, a certain level of coupling between the tower itself and the antenna on it could be a possible factor to degrade the antenna gain, where the gap between the steel frame of the tower and the antenna element was 50 cm.

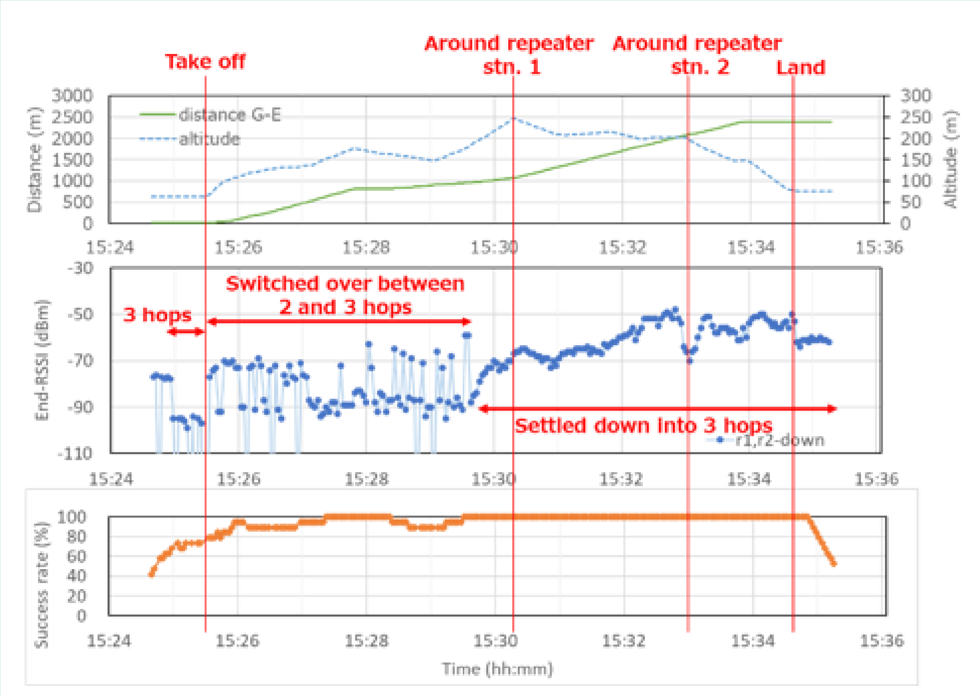

**Figure 18:** The receiving signal power at the terminal station and packet data success rate received at the ground station.

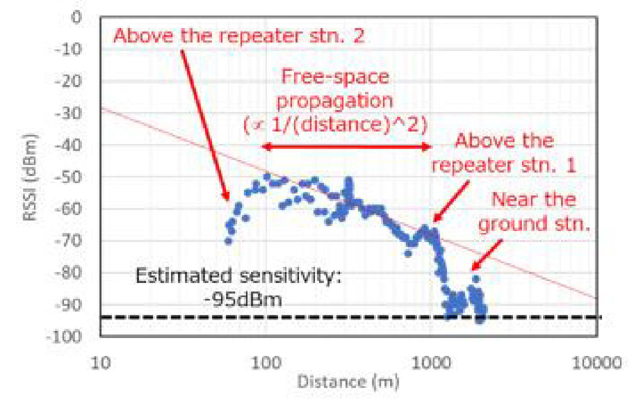

**Figure 19:** Path loss to the distance for the link from the terminal station to the repeater station 2 in the 3-hop link.

## Conclusion

This paper presents the performance evaluation of the multi-hop command and telemetry communication system, the Command Hopper, for drones in 169 MHz band. For the evaluation, we assumed two practical use cases: the volcano monitoring and the inspection of power transmission facilities, both in mountain areas under BLOS conditions. In the experiments, the system provided 2-hop or 3-hop link by using repeater stations onboard a repeater drone or on power transmission towers. The results show the significant advantage of the multi-hop link compared to the conventional direct link in the BLOS environment with terrain blocking and gives the end-to-end (ground station to terminal station onboard the mission drone) packet success rate more than 90 %. Also, based on the experimental results, the end-to-end propagation distance is estimated with more than several 10 km when the repeater stations are installed on high elevation towers or buildings. Such performance would give a significant benefit particularly for the operation of drones over the areas, where the BLOS condition is dominant and where the cellular coverages are not enough or are damaged in disaster scenarios. One of the further studies may be remained on the improvement of the stability of multi-hop link to choose the optimum routing in the critical situation with weak signals. The unique propagation performance in the 169 MHz also needs to be addressed furthermore, e.g., long-range drone operation with more than 10 km in 1 hop and the operation in the forest.

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## Acknowledgments

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## References

1. K Nonami (2018) Research and Development of Drone and Roadmap to Evolution. S.I. Cutting Edge of Drone Research and Development, and its application. J Robotics and Mechatronics 30(3).
2. M Mozaffari, ATZ Kasgari, W Saad, M Bennis, M Debbah (2019) Beyond 5G With UAVs: Foundations of a 3D Wireless Cellular Network. IEEE Transactions on Wireless Communications 18(1): 357-372.
3. JH Jung, S Park, and SL Kim (2010) Multi-robot path finding with wireless multihop communications. IEEE Commun Mag48(7): 126-132.
4. K Takizawa, M Suzuki, R Miura (2013) Telemetry system deployable into nuclear power plants by using 429-MHz radio communications. Proc. IEEE IROS2013 Tokyo.
5. P Necsulescu, K Schilling (2015) Automation of a multiple robot self-organizing multi-hop mobile ad-hoc network (MANET) using signal strength. Proc. 2015 IEEE I2MTC, Pisa, Italy.
6. Esrafilian, R Gangula, D Gesbert (2020) Autonomous UAV-aided mesh wireless networks. Proc. 2020 IEEE INFOCOM, Virtual.
7. Lavric (2017) Internet of Things and LoRa™ Low-Power Wide-Area Networks: A survey. Proc. 2017 ISSCS, Lasi, Romania.
8. T Kagawa, F Ono, L Shan, R Miura, K Nakadai, et al. (2020) Mulit-hop wireless command ante telemetry communication system for remote operation of robots with extending operation area beyond lin-of-sight using 920 MHz/169 MHz. Advanced Robotics 34(11): 756-766.
9. R Miura, T Kagawa, F Ono, L Shan, T Matsuda, et al. (2021) Propagation Measurements of Multi-Hop Command and Telemetry Communications System in the 169 MHz Band for Drones. Journal of Robotics and Mechatronics 33(2): 363-370

**Supporting Online Materials**

a) Ministry of Internal Affairs and Communication Official Website.

b) IMPACT Tough Robotics Challenge Official Website.

c) NEDO DRESS Project Official Website.

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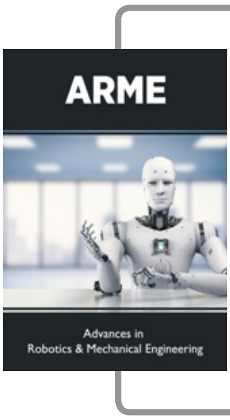

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