

UAV Speed Control for Data Harvesting in IoT Networks

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Abstract—In Unmanned Aerial Vehicle (UAV) assisted Internet of Things (IoT) wireless sensor networks, the flight speed of a rotary-wing UAV serves as a critical control parameter that simultaneously governs data collection throughput, channel quality, and energy consumption. Existing studies have largely focused on hover-based data harvesting strategies, without addressing the potential of continuous-mobility operation or providing a systematic performance comparison between the two approaches. This paper proposes Continuous-Mobility Communication Protocol (CMCP), a region-wise adaptive speed control scheme that regulates sensor-area and access point area speeds based on real-time channel state and buffer occupancy. The proposed CMCP is evaluated against the previously developed Hover-Assisted Communication Protocol (HACP), which employs multi-stage deceleration control with queue-state-driven mode switching. Simulation results demonstrate that CMCP achieves substantially higher throughput and energy efficiency across all buffer size configurations, while HACP retains advantages in environments where channel stability is the primary requirement. A comparative analysis provides practical guidelines for protocol selection according to operational conditions.

Keywords—Unmanned Aerial Vehicle (UAV), Wireless Sensor Network (WSN), Energy Efficiency, Data Harvesting

I. INTRODUCTION

The rapid proliferation of Internet of Things (IoT) technologies has driven the widespread deployment of large scale wireless sensor networks across a broad range of applications, including agriculture, environmental monitoring, and disaster response. In such scenarios, efficient data collection from sensor nodes distributed over wide geographical areas is a fundamental challenge. However, in environments where the deployment of fixed terrestrial infrastructure is impractical such as rural areas, marine environments, and disaster-affected regions—conventional ground-based communication systems are insufficient to ensure reliable data collection [1].

To address this challenge, unmanned aerial vehicles (UAVs) have attracted considerable attention as a promising alternative. Owing to their mobility and flexible deployment, UAVs can serve as aerial base stations and establish line-of-sight (LoS) communication links more readily than ground-based systems, thereby providing superior channel conditions for data collection. Despite these advantages, UAV operation is subject to two

fundamental constraints. First, the limited on-board battery capacity necessitates careful energy management throughout flight and communication. Second, the finite data queue capacity requires a careful balance between data collection and transmission. In particular, when the queue becomes full, the UAV can neither collect nor forward data, leading to a significant degradation in overall system performance [2].

To mitigate these issues, several studies have investigated UAV flight speed control as a means of improving communication performance proposed a method in which a UAV flying along a circular trajectory reduces its speed in the vicinity of the Access Point (AP), thereby extending the connection time and improving throughput [3]. demonstrated that adapting the UAV flight speed to varying operational conditions can maximize data collection efficiency [4].

Nevertheless, these existing studies share several critical limitations. First, UAV energy consumption is not adequately taken into account. Existing speed control schemes focus primarily on throughput improvement without incorporating a propulsion energy model. In practice, the propulsion energy consumption of a rotary-wing UAV varies nonlinearly with flight speed, and neglecting this factor may result in premature mission termination due to battery depletion. Second, the impact of finite queue constraints is not systematically addressed. Prior works either assume an infinite data queue or do not analyze the effect of varying queue capacities on system performance. In realistic deployments, the queue capacity is limited, and the optimal speed parameters are highly dependent on the queue configuration. Third, region-wise speed differentiation is not considered. Existing approaches apply a uniform speed control policy without distinguishing between the sensor area and the AP area, despite the fact that these two areas have fundamentally different communication requirements and channel characteristics.

To overcome these limitations, this paper proposes the Continuous-Mobility Communication Protocol (CMCP), a region-wise adaptive speed control scheme in which a single rotary-wing UAV sequentially traverses sensor and AP areas to collect and forward data. CMCP incorporates a rotary-wing UAV propulsion energy model and operates under a finite energy budget constraint, thereby enabling performance evaluation under realistic operational conditions. In addition, CMCP

is compared against the Hover-Assisted Communication Protocol (HACP), which employs multi-stage deceleration control with queue-state-driven mode switching. This comparative analysis provides practical guidelines for protocol selection under varying operational conditions.

The main contributions of this paper are as follows. First, a rotary-wing UAV propulsion energy model is integrated into the simulation framework, enabling performance evaluation under a finite energy budget constraint. Second, multiple queue size configurations are systematically evaluated to quantify the impact of buffer size on system performance and to derive optimal speed parameters for each scenario. Third, independent speed control for the sensor area and the AP area is introduced to simultaneously optimize throughput and energy efficiency. Finally, a systematic performance comparison between CMCP and HACP is conducted across various operational conditions, offering guidelines for protocol selection in practical UAV-assisted IoT deployments.

II. SYSTEM MODEL AND BACKGROUND

A. System Model

Fig. 1 shows the system model considered in this paper, where a single UAV repeatedly operates along a circular trajectory in a counterclockwise direction, sequentially passing through sensor areas and an AP area. Three sensor nodes are deployed in the sensor area (0° – 270°) and one AP is located in the AP area (270° – 360°). Each communication slot of duration $\tau = 1.0$ s is divided into a channel estimation phase (τ_1) and a data transmission phase (τ_2), with a ratio of $\tau_1:\tau_2 = 10\%:90\%$.

The channel model combines a line-of-sight (LOS) component and a non-line-of-sight (NLOS) component based on the Jakes model, where the NLOS component is correlated with the UAV flight speed. As the UAV speed increases, the Doppler spread increases and the channel quality degrades, which directly affects the achievable transmission rate r_{actual} . The transmission rate is determined based on the Shannon capacity, and a correction factor η is introduced to compensate for channel uncertainty. r_{send} is the transmission rate determined from the estimated SNR γ_{τ_1} during τ_1 , and r_{actual} is the actual transmission rate computed from N channel samples collected during τ_2 , as defined in (1) and (2), respectively.

$$r_{\text{send}} = \lfloor \tau_2 B \log_2(1 + \eta \gamma_{\tau_1}) \rfloor \quad (1)$$

$$r_{\text{actual}} = \lfloor B \tau_2 \frac{1}{N} \sum_{n=1}^N \log_2(1 + \gamma_{\tau_2,n}) \rfloor \quad (2)$$

If $r_{\text{send}} > r_{\text{actual}}$, the slot is declared as an outage; otherwise, the transmission is considered success.

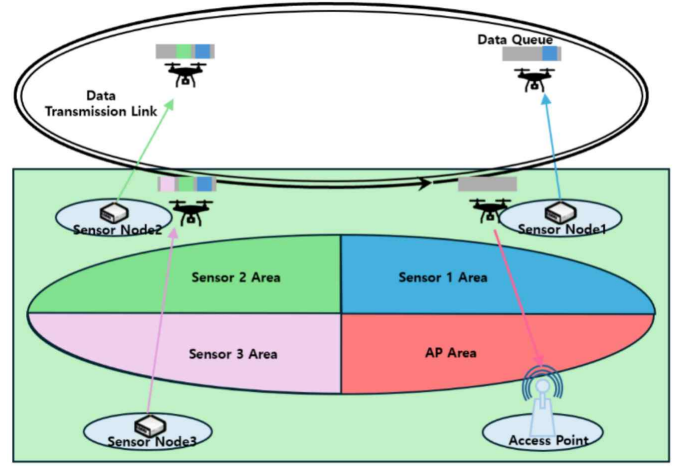


Fig. 1. System Model.

B. HACP

HACP consists of two operating modes based on the buffer state. In Mode 1 (Hover-Assisted Communication), the UAV alternates between odd slots, where it hovers to communicate with sensor nodes or the AP, and even slots, where it moves at speed v_{sen} or v_{AP} without communication. When the buffer occupancy reaches Q_{max} , the UAV switches to Mode 2 (Offloading Transit), in which it moves toward the AP without any communication. Once sufficient data has been offloaded at the AP, the UAV reverts to Mode 1. The AP area speed is defined as

$$v_{\text{AP}} = \alpha \cdot v_{\text{sen}} \quad (3)$$

where $\alpha \in (0, 1)$ is a deceleration factor that controls the UAV speed in the AP area relative to the sensor area. A smaller α increases the connection time with the AP, while a larger α reduces energy consumption but decreases communication opportunities. HACP has two main advantages. First, since the UAV communicates while hovering, it is not affected by Doppler fading, which allows the UAV to maintain stable channel quality. Second, since communication slots and movement slots are clearly separated, channel estimation accuracy is high, which improves the transmission success rate.

III. PROPOSED CONTINUOUS-MOBILITY COMMUNICATION PROTOCOL SCHEME

CMCP is a protocol in which the UAV flies continuously without hovering and applies independent speeds to the sensor area and the AP area. Unlike HACP, the UAV performs movement and communication simultaneously in every slot, so there is no loss of communication opportunity.

In the sensor area, the UAV adjusts its speed based on the change in the moving average SNR. If the SNR increases, the UAV reduces its speed to extend the dwell time. If the SNR decreases or remains the same, the UAV increases its speed to

quickly pass through the low-SNR area. The speed update in the sensor area is defined as

$$\begin{aligned} v_{S,k+1} &= \max(v_{S,k} - \delta_S, v_{S,\min}^S), \text{ if } \bar{Y}_{S,k} > \bar{Y}_{S,k-1} \\ v_{S,k+1} &= \min(v_{S,k} + \delta_S, v_{S,\max}^S), \text{ if } \bar{Y}_{S,k} \leq \bar{Y}_{S,k-1} \end{aligned} \quad (4)$$

where $v_{S,k}$ is the UAV speed at the current slot, $v_{S,k+1}$ is the speed at the next slot, δ_S is the speed control step size, and $v_{S,\min}^S$ and $v_{S,\max}^S$ are the minimum and maximum speeds in the sensor area, respectively.

In the AP area, the UAV adjusts its speed based on the amount of data remaining in the buffer. The normalized queue ratio q_k is defined as

$$q_k = \frac{Q_k}{Q_{\max}} \quad (5)$$

where Q_k is the amount of data currently stored in the UAV buffer and $Q_{\max}$ is the maximum buffer size. A larger q_k means more data remains to be forwarded to the AP, so the target speed decreases to allow the UAV to stay longer in the AP area. The final speed in the AP area is determined as

$$\begin{aligned} v_{\text{cmd},k} &= \min(v_{\text{target},k}, v_{\text{AP},k}), \text{ if } \bar{Y}_{\text{AP},k} > \bar{Y}_{\text{AP},k-1}, Q_k > 0 \\ v_{\text{cmd},k} &= v_{\text{target},k}, \text{ if } \bar{Y}_{\text{AP},k} \leq \bar{Y}_{\text{AP},k-1}, Q_k > 0 \\ v_{\text{cmd},k} &= v_{\text{max}}^{\text{AP}}, \text{ if } Q_k = 0 \end{aligned} \quad (6)$$

When $Q_k > 0$, the target speed is applied to secure sufficient data forwarding time. When $Q_k = 0$, the UAV moves at maximum speed since there is no data to forward.

CMCP has two main advantages. First, since the UAV flies continuously without hovering, unnecessary energy consumption is reduced. Second, since the speeds of the sensor area and the AP area are controlled independently, both throughput and energy efficiency can be improved at the same time.

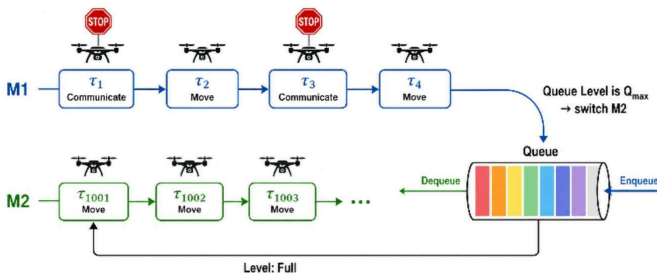


Fig. 2. UAV operation modes in the HACP scheme.

Fig. 2 illustrates the two operating modes of HACP. In Mode 1, the UAV alternates between communication slots, in which it hovers to collect data from sensor nodes or forward data to the AP, and movement slots, in which it advances along the trajectory without communication. When the buffer occupancy

reaches $Q_{\max}$, the UAV transitions to Mode 2, in which it moves continuously toward the AP without collecting data until sufficient data has been offloaded.

Fig. 3 illustrates the continuous flight operation of CMCP, in which the UAV communicates during every slot while adjusting its speed independently in the sensor area and the AP area.

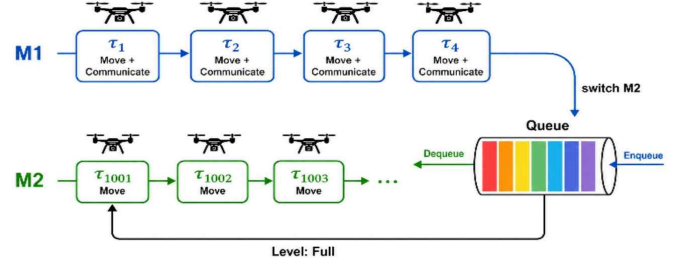


Fig. 3. UAV operation modes in the CMCP scheme.

IV. PERFORMANCE EVALUATION

This section presents the simulation setup and results used to evaluate the data-harvesting performance under both energy constraints and limited storage in a UAV-based sensor network.

A. Simulation Setup

This section presents the simulation setup used to evaluate the performance of HACP and CMCP. Based on the system model described in Section II, the UAV propulsion power is modeled using the rotary-wing UAV energy model proposed in [5], and is defined as (7).

The parameter P_0 is the blade profile power, P_i is the induced power, U_{tip} is the blade tip speed, v_0 is the mean rotor induced velocity, d_0 is the fuselage drag ratio, ρ is the air density, s is the rotor solidity, and A is the rotor disc area. The parameter values are summarized in Table I, and Fig. 4 illustrates the propulsion power consumption as a function of UAV flight speed. The queue size is varied as $Q_{\max} \in \{\text{Inf}, 10\text{G}, 15\text{G}, 20\text{G}, 25\text{G}\}$ to evaluate throughput and energy efficiency under different buffer configurations.

$$P_{\text{prop}}(v) = P_0 \left(1 + \frac{3v^2}{U_{\text{tip}}^2} \right) + P_i \left(\sqrt{1 + \frac{v^4}{4v_0^4}} - \frac{v^2}{2v_0^2} \right)^{\frac{1}{2}} + \frac{1}{2} d_0 \rho s A v^3 \quad (7)$$

TABLE I
UAV PROPULSION MODEL PARAMETERS

Parameter	Value
P_0	79.8563 W
P_i	88.6279 W
U_{tip}	120 m/s
v_0	4.03 m/s
d_0	0.6

ρ	1.225 kg/m ³
s	0.05
A	0.503 m ²

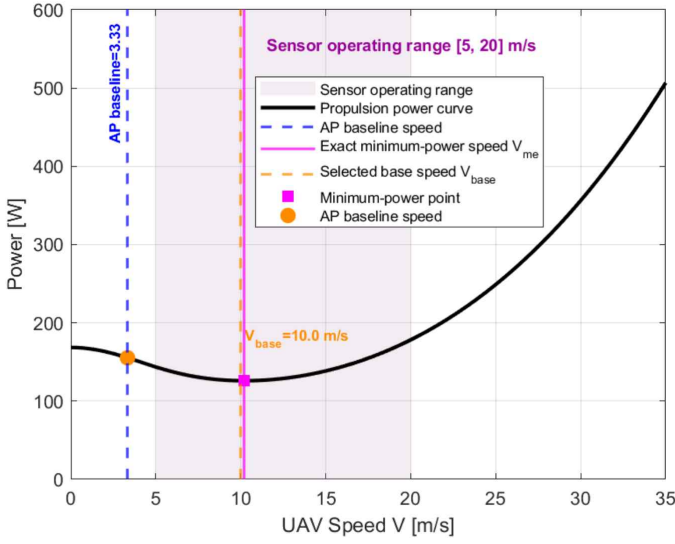


Fig. 4. UAV energy consumption according to flight speed.

B. Simulation Results

Fig. 5 presents the throughput performance according to δ_{AP} under different queue capacities. As δ_{AP} increases, the throughput generally increases because the UAV can secure more time for data forwarding in the AP area. However, the performance gain becomes saturated after a certain point. This indicates that AP-side speed control improves forwarding performance, but the improvement is limited by the queue capacity. In particular, a larger Q_{max} provides higher throughput, while a smaller Q_{max} limits the amount of data that can be stored and forwarded. Therefore, the finite queue becomes an important factor that determines the throughput performance in CMCP.

Fig. 6 shows the energy efficiency according to δ_{AP} under the same queue conditions. The energy efficiency has a similar trend to the throughput result. This is because CMCP operates with continuous mobility, so the energy variation caused by δ_{AP} is relatively small compared with the change in forwarded data. As a result, improving throughput also leads to improved energy efficiency in CMCP. However, when the queue capacity is small, the energy efficiency improvement is also limited. These results show that the optimal speed control in CMCP should consider both queue capacity and energy consumption. These results show a different trend from the simple 1/N-based AP area speed reduction used in the previous study. In

the previous method, the AP area speed is fixed as $\frac{V_{sen}}{N}$ according to the number of sensor nodes. This method focuses on increasing the stay time in the AP area so that the data collected in the sensor area can be sufficiently forwarded to the AP. Therefore, the speed reduction ratio is directly determined by the number of sensor nodes. In contrast, in the proposed

CMCP, δ_{AP} is used as a speedcontrol parameter for the AP area. It determines how actively the UAV adjusts its speed for data forwarding. In addition, the queue state and the finite queue capacity also affect the system performance. Therefore, the optimal performance is not determined only by the number of sensor nodes. Instead, it is determined by the combined effect of δ_{AP} , Q_{max} , and energy consumption.

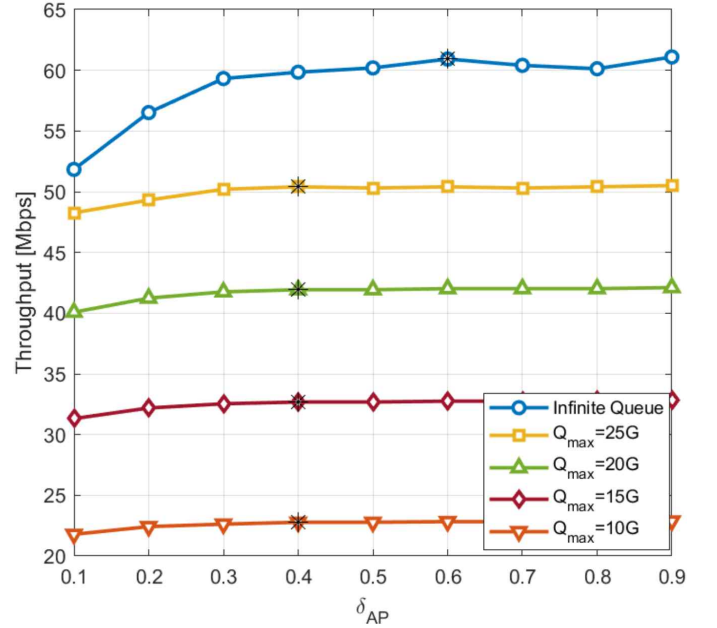


Fig. 5. Throughput versus δ_{AP} under different queue capacities.

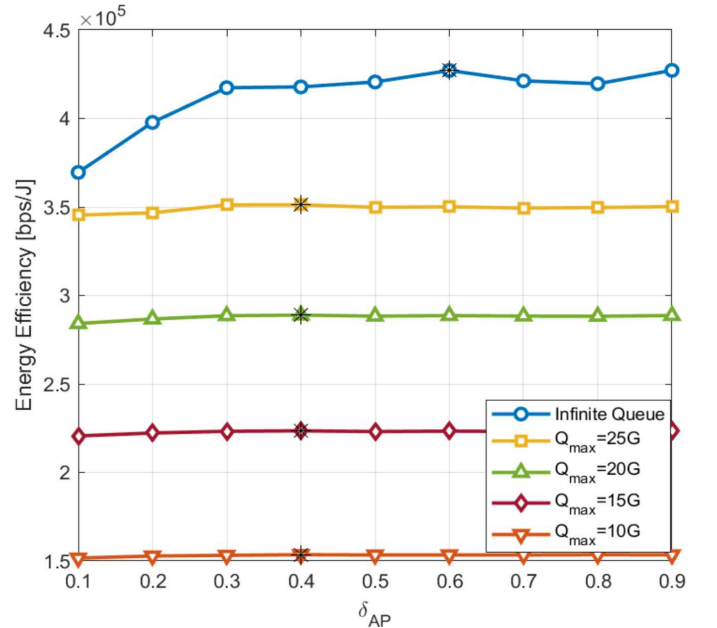


Fig. 6. Energy efficiency versus δ_{AP} under different queue capacities.

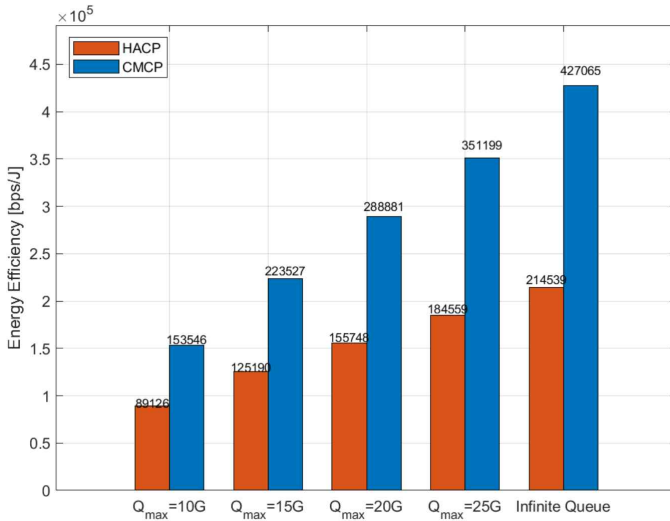


Fig. 7. Throughput comparison between HACP and CMCP for different $Q_{\max}$ values.

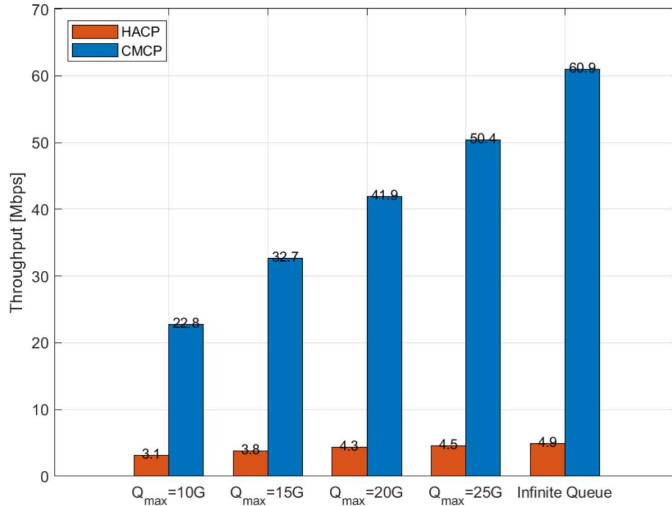


Fig. 8. Energy Efficiency comparison between HACP and CMCP for different $Q_{\max}$ values.

Fig. 7 and Fig. 8 compare the throughput and energy efficiency of HACP and CMCP across five queue size configurations $Q_{\max} \in \{\infty, 10G, 15G, 20G, 25G\}$. In all cases, CMCP achieves significantly higher throughput and energy efficiency than HACP. This performance gap arises from the fundamental difference in protocol design: HACP alternates between communication and movement slots, inherently limiting communication opportunities, whereas CMCP communicates continuously during flight, maximizing data collection and forwarding time. As the queue capacity decreases, the advantage of CMCP narrows because the finite buffer constrains the amount of data that can be stored and forwarded regardless of protocol. Nevertheless, CMCP consistently outperforms HACP under all evaluated conditions, demonstrating the effective-

ness of continuous-mobility operation combined with region-wise adaptive speed control.

V. CONCLUSION

This paper presented a comparative study of two UAV-assisted IoT data collection protocols, HACP and CMCP, under a shared circular-trajectory scenario with a fixed energy budget. HACP achieves channel stability through periodic hovering, whereas CMCP eliminates hovering entirely and compensates for channel estimation error during continuous flight through a correction margin factor and decoupled speed control.

Simulation results across five queue configurations consistently demonstrate that CMCP outperforms HACP in both throughput and energy efficiency. It should be noted that the two protocols differ fundamentally in design objective and operational assumption. HACP prioritizes channel reliability by maintaining a stationary link during each communication slot, making it suitable for environments where precise hovering is feasible and channel stability is paramount. CMCP, by contrast, targets real time high volume data acquisition during continuous flight. Accordingly, a direct performance comparison should be interpreted in the context of deployment requirements rather than as a measure of absolute superiority. In practical deployments, factors such as multipath interference, physical obstruction, and airframe vibration caused by wind may alter the relative performance gap between the two protocols. Future work will validate both protocols under realistic conditions through ROS/PX4/Gazebo based simulation.

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