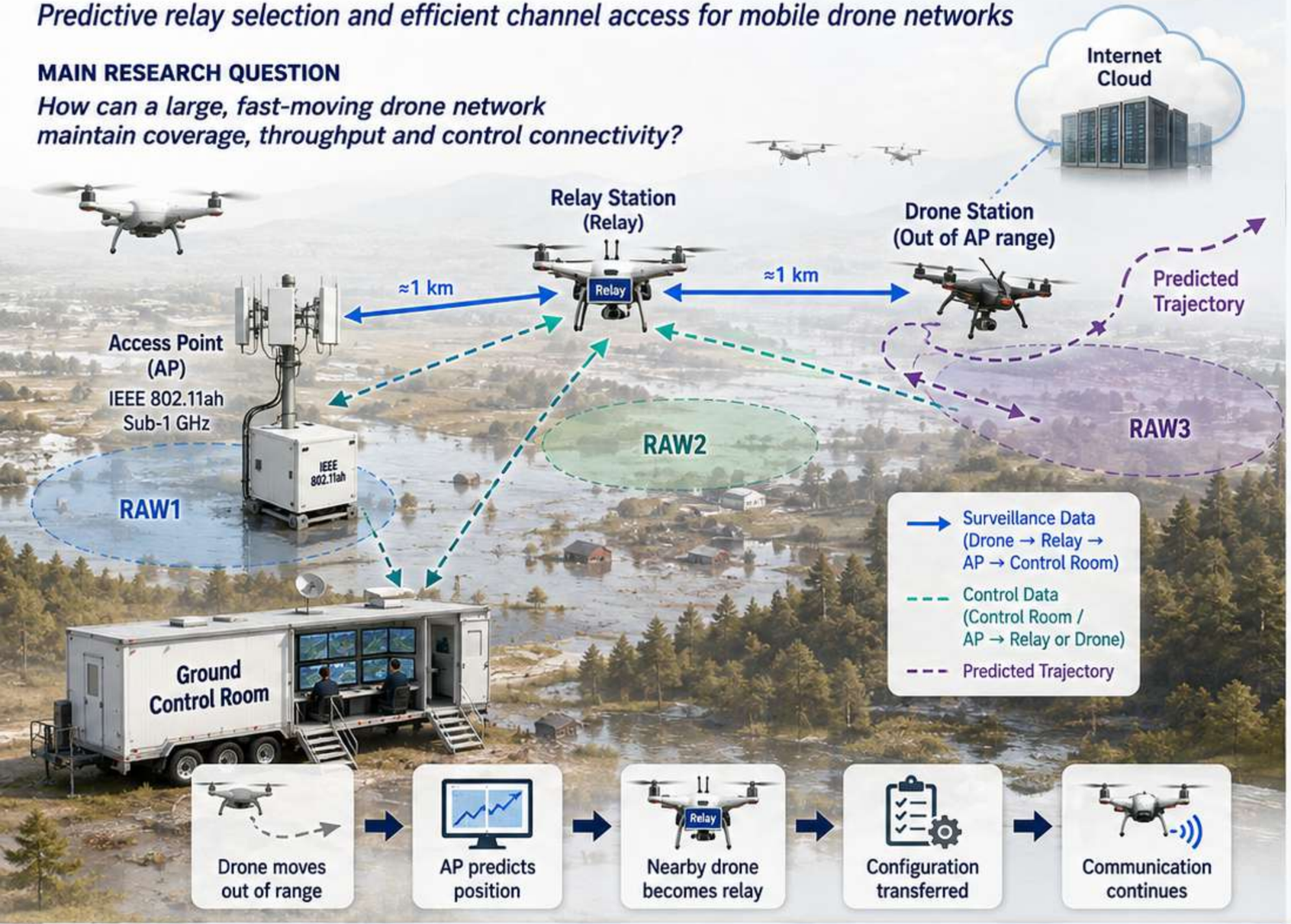
IEEE 802.11ah for the Internet of Drones

Predictive relay selection and efficient channel access for mobile drone networks

MAIN RESEARCH QUESTION

How can a large, fast-moving drone network maintain coverage, throughput and control connectivity?



Predict movement, activate the relay early and keep the drone network connected.

HIGHLIGHTS OF THE PAPER

01 — LONG-RANGE 802.11AH DRONE NETWORK

Sub-1 GHz communication, large station association and relay support extend IoD coverage.

02 — PREDICTIVE RELAY SELECTION

The AP predicts a drone's future location using a Gauss-Markov mobility model and activates a suitable relay.

03 — DYNAMIC CHANNEL ACCESS

AID, RAW and TIM configurations are transferred according to the drone's predicted position and relay association.

04 — EXPERIMENTAL FINDINGS

The proposed prediction-based architecture reports up to 58% higher throughput, more stable communication and improved association behaviour compared with traditional IEEE 802.11ah.

1,000 stations become completely associated in approximately 19 seconds in the reported proposed-network experiment.

The authors also report significant average-delay improvement.

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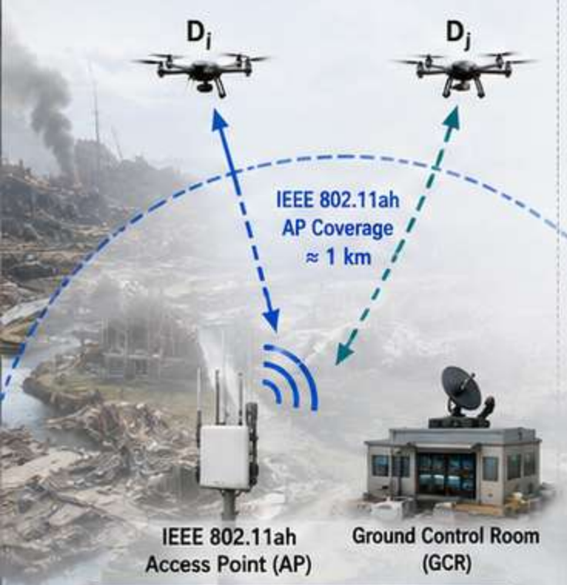
What Happens When a Drone Leaves AP Coverage?

Fast three-dimensional movement creates association, range and topology challenges

1 STAGE 1
Direct connection



Surveillance data:
Drone → AP → Control Room

Control data:
Control Room / AP → Drone

2 STAGE 2
Drone D_j moves out of coverage laterally and upward

D_j moves laterally and upward toward the edge of the ≈ 1 km AP coverage boundary.

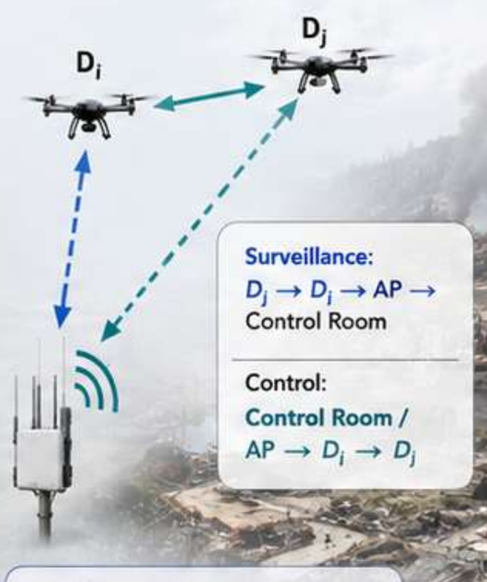
3 STAGE 3
Conventional failure: late reaction

- D_j leaves usable AP range.
- Late **Association/Handoff** occurs.
- **RAW** video stream interrupted.
- **TIM**-based data delivery delayed.
- Control latency increases.

4 STAGE 4
Proposed response: predict and prepare

- AP predicts D_j future position.
- D_j lies between AP and predicted location of D_j.
  D_j pre-configured as **Relay Station**.
- **Association** and channel-access configuration sent in **advance.**

5 STAGE 5
Traffic continuity via relay



Traffic continuity maintained. Surveillance and control flows delivered without interruption via the Relay Station.

RESEARCH GAP

Existing approaches do not jointly handle large-scale drone **association**, high mobility, dynamic relaying and mixed **video/control traffic.**

- Large-scale drone association
- High mobility (3D movement)
- Dynamic relaying
- Mixed video/control traffic

A relay must be selected before the moving drone loses its usable connection.

Internet of Drones (IoD): Integrated network of drones, APs and control infrastructure. **Drone Station:** A drone with IEEE 802.11ah connectivity. **Access Point (AP):** IEEE 802.11ah AP providing IoD connectivity. **Relay Station:** A Drone Station operating in Relay Mode.

Station Mode: Standard IEEE 802.11ah STA operation. **Relay Mode:** Drone relays frames for another Drone Station. **Association:** Process of linking a Drone Station with an AP. **Handoff:** Transfer of Association to maintain connectivity. **TIW:** Traffic Indication Map used by AP to announce buffered data.

Inside the Predictive Relay Architecture

Ground AP control, three-dimensional mobility prediction and dynamic relay switching

IEEE

1 CONTROL ROOM

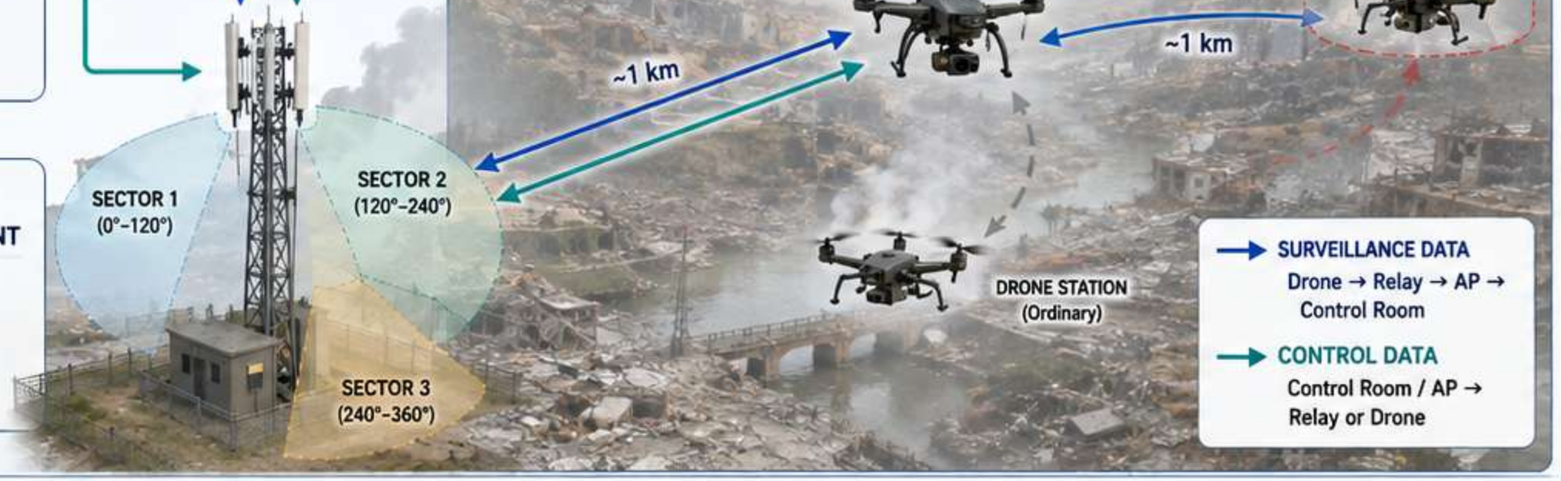
- Mission Monitoring
- Network Management
- Relay Selection
- Mobility Prediction

2 INTERNET

3 IEEE 802.11ah GROUND ACCESS POINT

- Long-Range Sub-1 GHz
- Sectorized Antennas
- Centralized Control
- Mobility Prediction
- Relay Management

4 DRONE NETWORK



5 AP NETWORK TABLE

Drone ID	AID	RSSI (dBm)	Antenna angle (°)	Current position (X, Y, Z)	Predicted position (X, Y, Z)	Mode: Station / Relay	RAW group
DR-1001	12	-63	42	(120, 85, 60)	(145, 98, 62)	Station	RAW-1
DR-1002	13	-58	78	(310, 210, 70)	(335, 228, 72)	Relay	RAW-1
DR-1003	14	-71	118	(480, 260, 55)	(515, 280, 50)	Station	RAW-1
DR-1004	15	-49	201	(650, 120, 65)	(690, 135, 68)	Station	RAW-2
DR-1005	16	--	--	(780, 300, 45)	(—, —, —)	Out of Range	RAW-2
...	...	...	...	...	...	...	...

6 GAUSS-MARKOV PREDICTION

Current X, Y, Z + Velocity Vx, Vy, Vz + Direction (Heading, Pitch, Yaw) + History (Past Positions) + Memory α

→ Predicted X, Y, Z (at $t + \Delta t$)

$\alpha \in [0,1]$

Higher memory preserves more of the previous movement pattern.

7 OPERATION FLOW (AP-CONTROLLED PREDICTIVE RELAY)

1. Drone associates with the ground AP.
2. AP monitors AID, RSSI and antenna direction.
3. AP estimates current position.
4. Gauss-Markov predicts future position.
5. AP identifies a suitable relay.
6. Association and access configuration are prepared.
7. Selected drone switches to Relay Mode.
8. Moving station connects through the relay.
9. Surveillance and control traffic continue.
10. Mode can return to Station Mode when relay service is no longer needed.

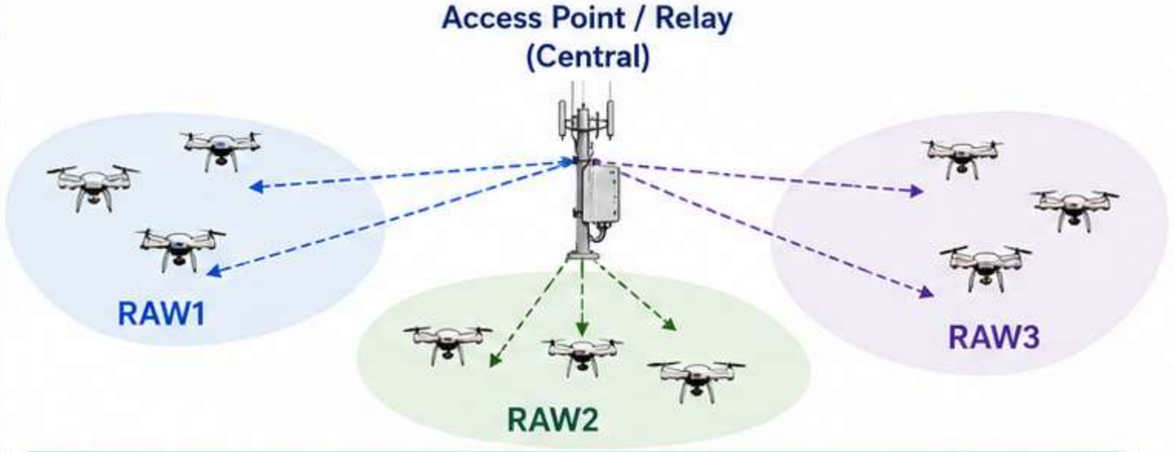
Mobility prediction lets the AP prepare the next communication path before the current path fails.

Slide 4

How IEEE 802.11ah Organizes Drone Traffic

Geographic RAW grouping and lower-overhead relay forwarding

1) Geographic RAW Grouping



Drones in nearby geographic regions share the same RAW group

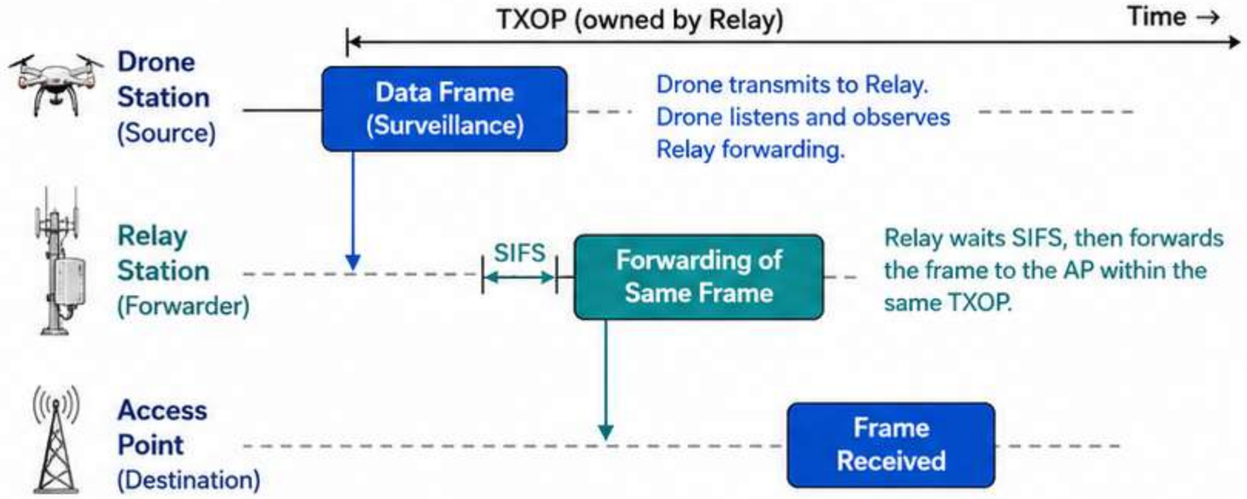
Benefits
- less contention
- organized channel access
- scalable station management

Configuration Flow

Predicted location → New relay or group → AID update → RAW mapping → TIM update

2) TXOP with Implicit ACK

PAID in the PHY header helps identify the destination



The forwarding transmission confirms that the relay received the frame.

Implicit acknowledgment reduces control-message overhead.

Traffic Direction

Surveillance traffic: Drone → Relay → AP

Control traffic: AP → Relay / Drone

MCS Adaptation

Dynamic MCS selection adapts the link to distance and data-rate requirements.

Important Note

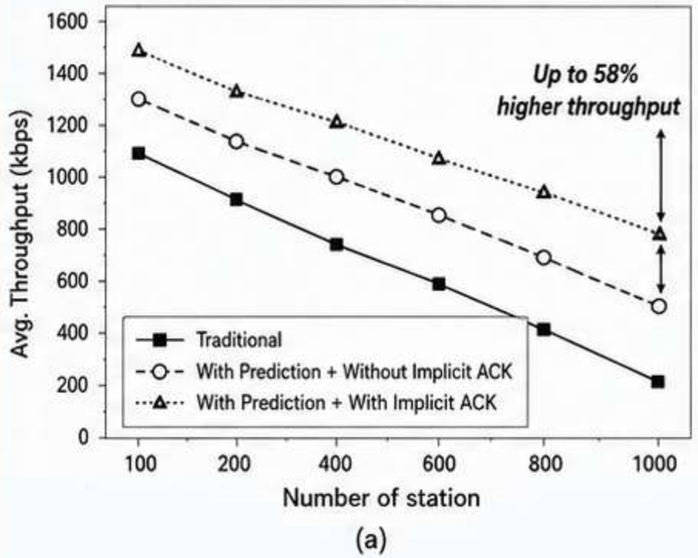
Implicit acknowledgment reduces control-message overhead. It does not claim that all acknowledgments disappear.

RAW controls who transmits; TXOP and implicit ACK control how efficiently the data move.

What the Experiments Show

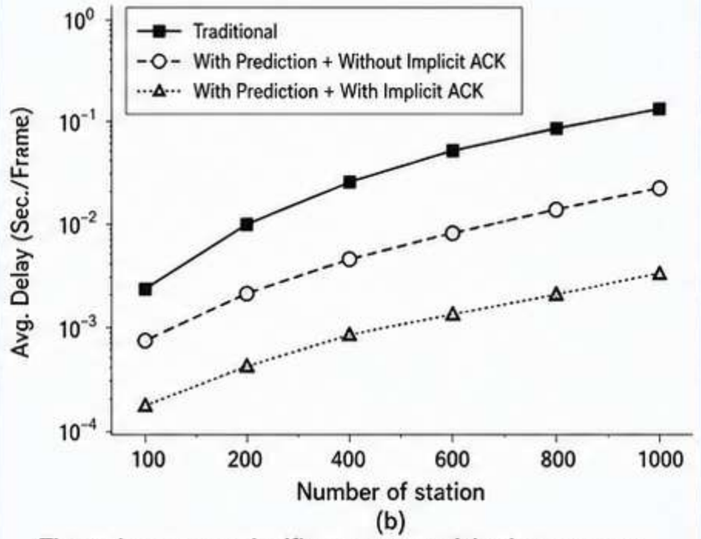
Prediction and implicit acknowledgment improve large drone-network communication

RESULT MODULE 1 Average Throughput



(a)

RESULT MODULE 2 Average Delay

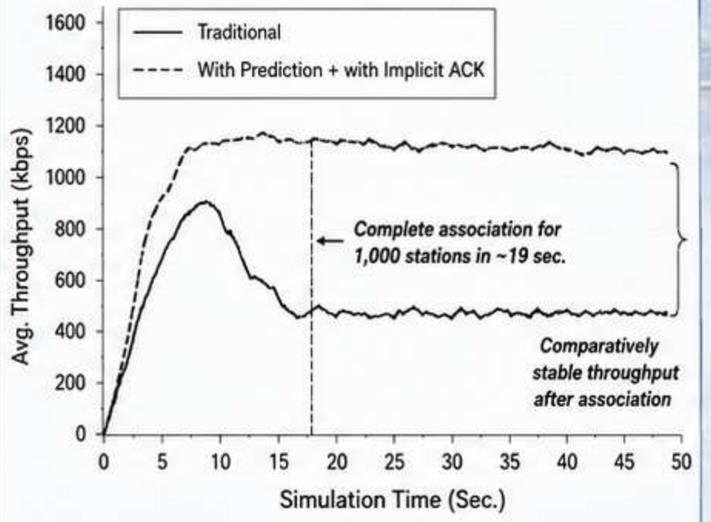


(b)

The authors report significant average-delay improvement

Original paper graph preserved without reinterpretation

RESULT MODULE 3 Association and Throughput Stability



EXPERIMENTAL SETUP

- NS-3
- IEEE 802.11ah
- up to 1,000 drone stations
- dynamic MCS
- MPEG transport-stream traffic
- mobility and relay drones
- prediction with and without implicit ACK

CONCLUSION (PROCESS CHAIN)

Predict drone movement → Prepare relay association → Update AID / RAW / TIM → Forward through relay → Reduce repeated association → Improve throughput stability

CURRENT SCOPE AND COST

- association and re-association: $O(n^2)$
- simulation-based
- optimal TIM / DTIM size remains open
- application-specific QoS needs more analysis

FUTURE WORK

- multiple MCS configurations
- optimize TXOP size
- application-specific QoS
- handoff between multiple APs
- improved prediction accuracy
- optimize TIM and DTIM beacon size

Predict the path. Prepare the relay. Keep the drone swarm connected.