Autonomous Networking

Gaia Maselli
Dept. of Computer Science

Today's plan

- Unmanned Aerial Vehicles (Drones)
- Networks of drones

Unmanned Aerial Vehicle (UAV)

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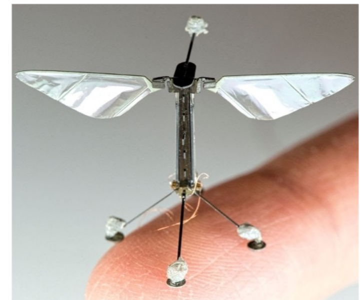
- UAV, commonly known as a **Drone**, is an **aircraft without a human pilot aboard** (*unmanned* or *uncrewed*).
- May operate with various degrees of autonomy:
  - **under remote control by a human operator**
  - **autonomously by on board computers**.

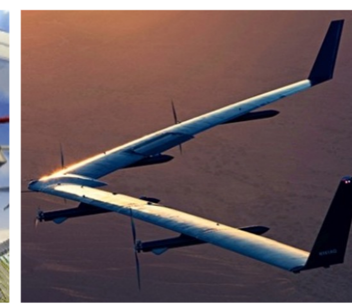
UAV or drone Characteristics

Weight: from 0.5 g (RoboBee) up to 15000 kg (Northrop Grumman RQ-4 Global Hawk).

Maximum speed: up to 11265 Kph (X-43A an unmanned hypersonic aircraft), commercial drones from 50 to 150 kph.

Propellant:
- Fossil Fuel: gasoline, methane, and hydrogen.
- Battery: Ni-Cd, Ni-Mh, Li-PO and Li-S.
- Solar cells.



UAV or drone Characteristics

Autonomy: commercial drones approximately 30 minutes.

Various shapes and flight modes:

Single-rotor helicopter

Multi-rotor helicopter

Aeroplane

Airship

Why UAVs?

- Can provide timely disaster warnings and assist in speeding up rescue and recovery operations.
- Can carry medical supplies to areas rendered inaccessible.
- Can be used in dangerous situations.
- Can be used in common applications as traffic monitoring, wind estimation and remote sensing.
- And so on…




Applications

- Search and rescue

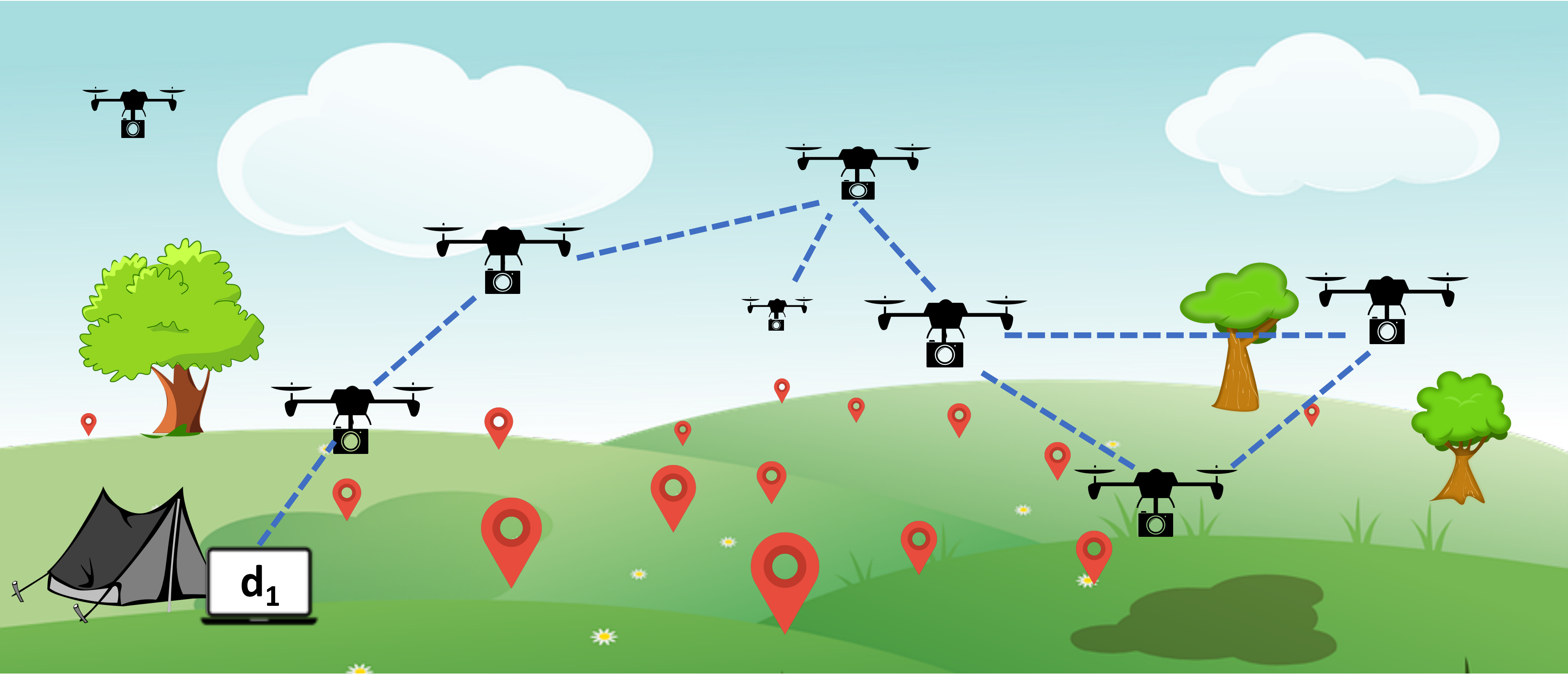
- Sensing, reconnaissance, search, detecting fires, tracking, …

- Attack , war and active defence

UAVNET or DRONET

- In general, drones are used to search, identify and monitor interesting events **over massive and/or inaccessible areas**.
- **Multiple UAVs** are deployed in a certain area and are expected to **coordinate actions in an autonomous fashion** or execute direct instructions from a control centre.
- **DRONET** – network of drones that fly over a zone and cooperate to accomplish a mission
- In many scenarios, the UAVs need to **exchange a relatively large amount of data** among themselves and/or with the control station (depot) to support a given service

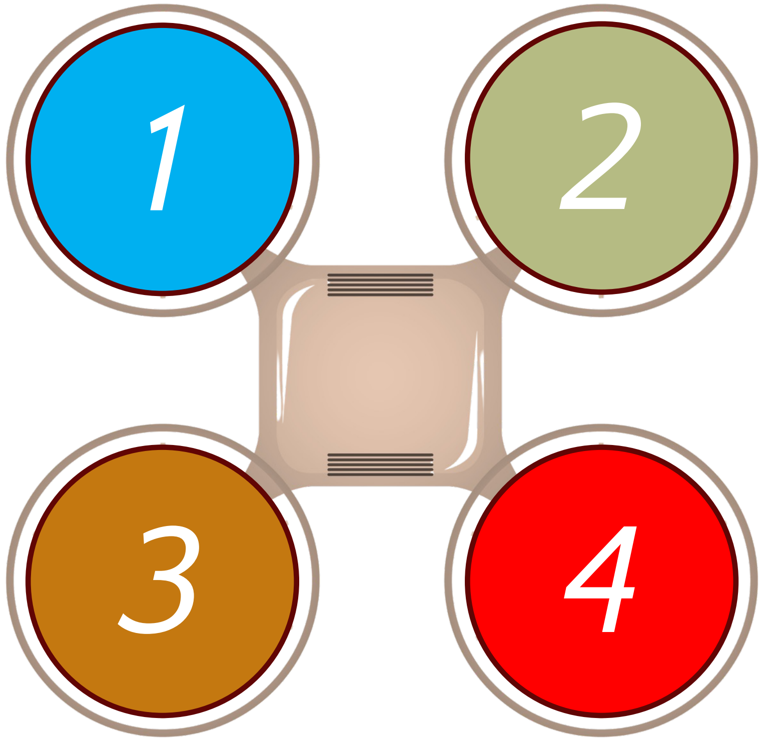
Dronet



Issues

How to provide communication in emergency scenarios where there is no network infrastructure available?

How to optimize task assignment and trajectory planning for UAVs operating in real-world scenarios?



How to perform continuous data offloading when deployed in large and harsh areas?

How to perform periodic data offloading when deployed in large and harsh areas

1

- *How to provide communication in emergency scenarios where there is no network infrastructure available?*

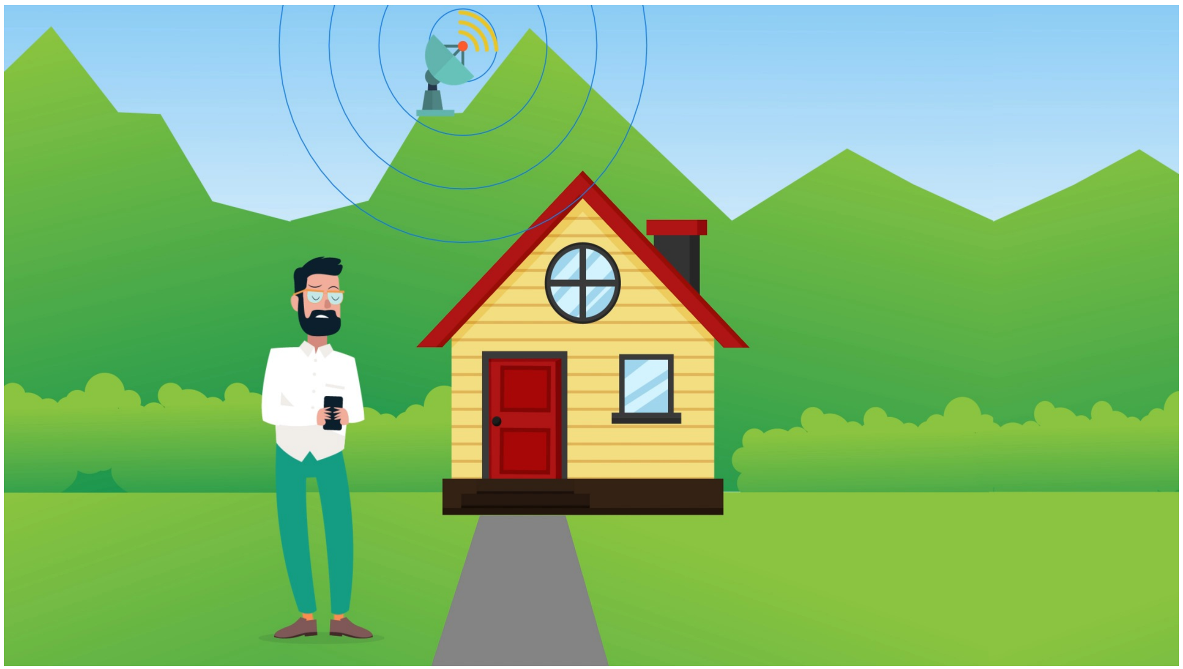
DANGER: a Drone-Aided Network for Guiding Emergency and Rescue operations

Andrea Coletta, Gaia Maselli, Mauro Piva, Domenicomichele Silvestri
Twenty-First ACM Mobihoc '20

Applications: Providing network connectivity

- Drones can act as **flying Base Stations** or **relay nodes** and support the connectivity of existing terrestrial communication networks

DANGER - Problem & Goal



Goal:
- easy to use communication service
- Wi-Fi
- no pre-installed app
- low cost

DANGER - System Components

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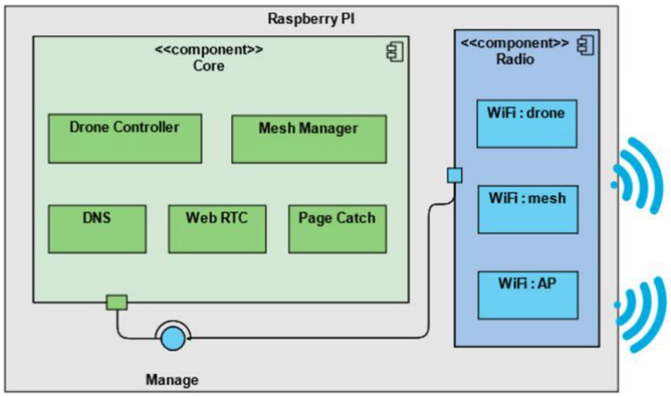
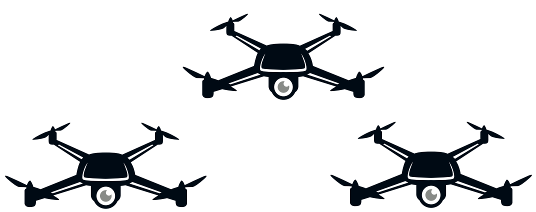
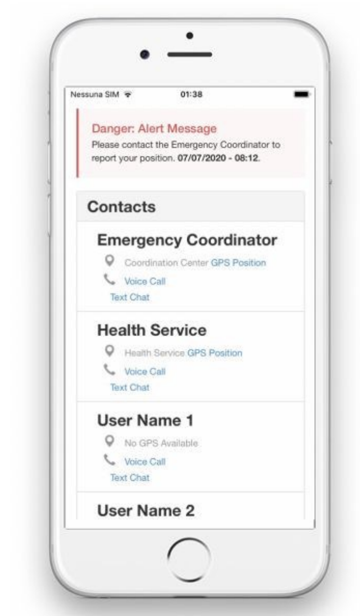
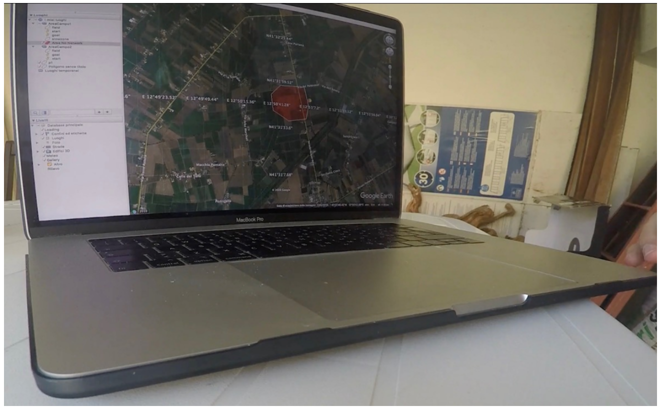
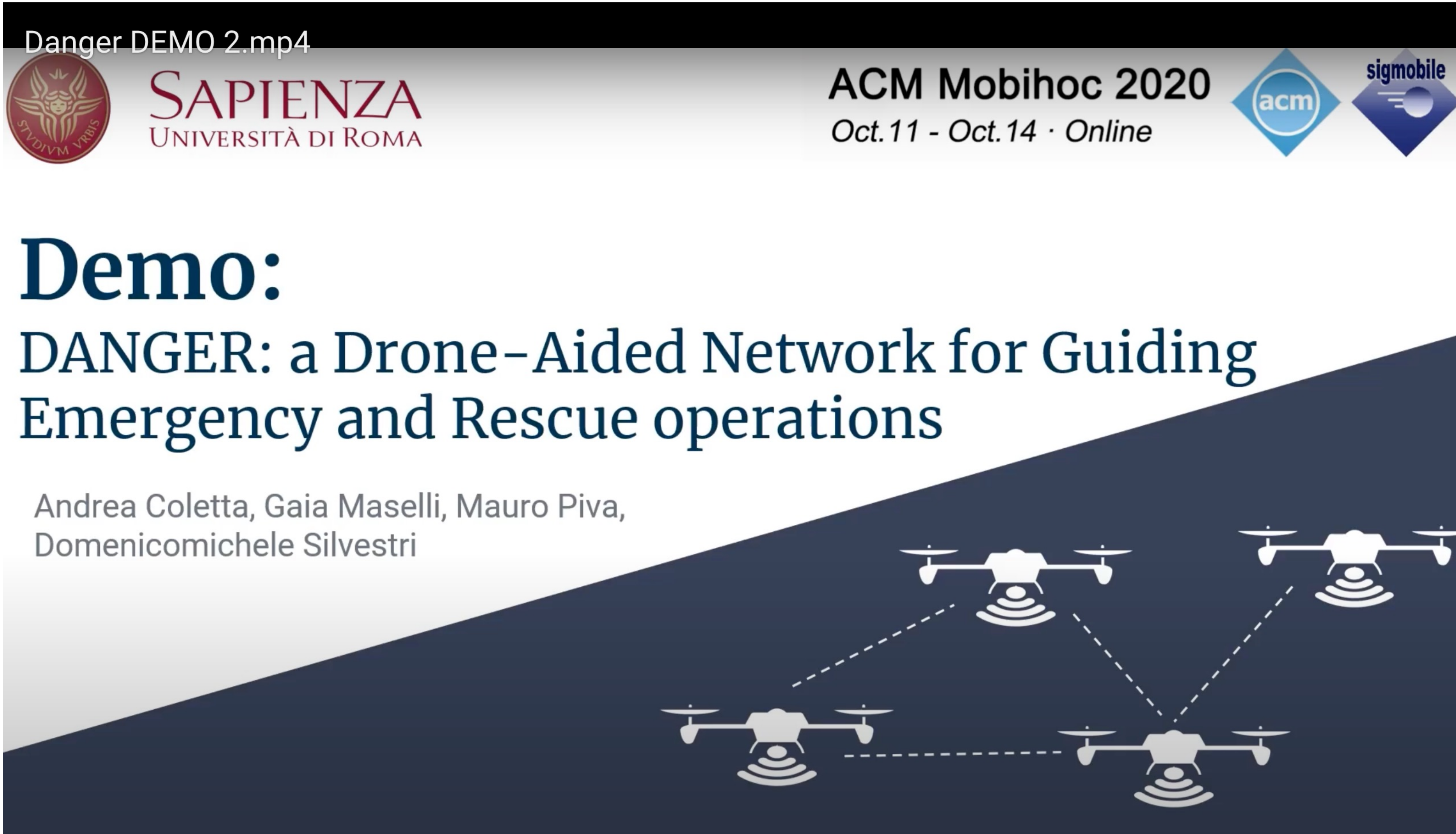








Implementation



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2

- *How to optimize task assignment and trajectory planning for UAVs operating in real-world scenarios?*

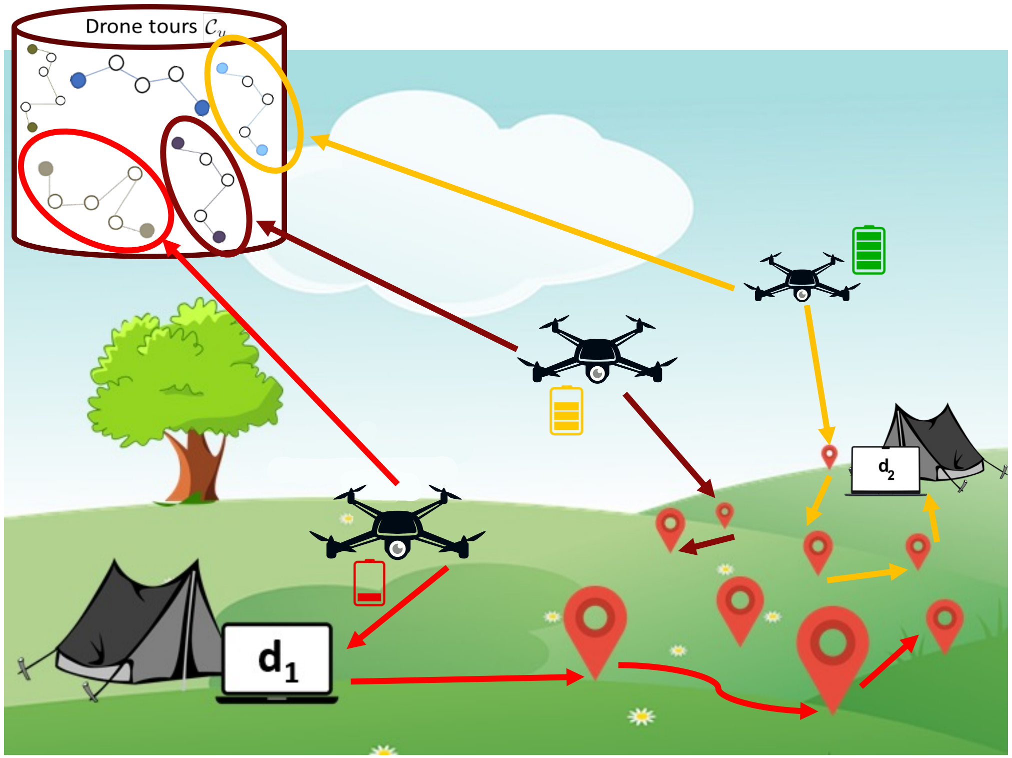
Trajectory Selection Problem

Problem formulation:

- Multi-depot
- A UAV squads
- Heterogeneous energy, capabilities and equipment
- **A set of trajectories (<u>input</u>)**
- A required target hovering time

Existing works:
Perform multi-trip mission one trip at time

Goal:
Perform a multi-trip mission with recharging and off-loading operations

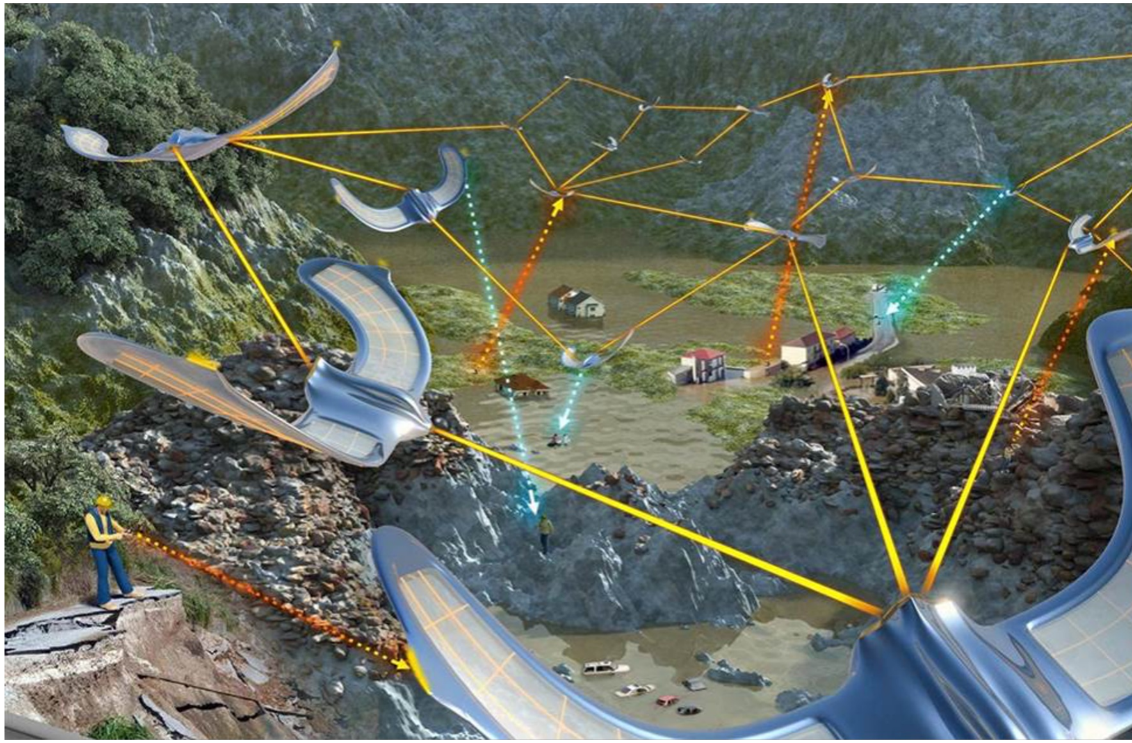


3

- *How to perform continuous data offloading when deployed in large and harsh areas?*
- *No cellular network is available*

UAVNET Issues and Challenges

- Medium to high mobility
- Fluid Topology
- Node Failure
- Energy constraints
  - Movement is much more expensive than transmission



MAC in UAVNET

- Drones can be equipped with several **standard radio modules**
- Wi-Fi
- Cellular (often not available)
- LPWAN - Low Power Wide Area Network (e.g. LoRa - Long Range)

Routing

- Distributed area monitoring/patrolling applications often **require the drones to stream high definition video or thermal camera recordings to the depot, which demands wideband communication technologies** (limited coverage range)
- Providing video monitoring over wide areas may require **multi-hop** data connections, where the drones themselves can act as relays for other nodes in the network
- Which routing protocol?

Comparison

	WSN	Dronet
Mobility	None or partial	**High (even 3D)**
Topology	Random, star, ad-hoc Node failure	Mesh **Jeopardized**
Infrastructure	Absent (sink)	Absent (depot)
Energy source	battery	**Battery (very limited)**
Typical use	Environmental monitoring	Rescue, monitoring, Surveillance

Routing in UAVNET (3)

Goals of Routing protocol:

Routing Protocols: recap

- DRONETS are similar to Mobile Ad-Hoc Networks (MANETs) and WSN, but typically have much **higher mobility**
- **Proactive protocols**: use tables in their nodes to store all the routing information, they are updated when topology changes.
- **Reactive protocols**: a route is found when there is need of communication between nodes (on-demand).
- **Hybrid protocols**: try to reduce overhead of protocol mixing proactive and reactive approaches.
- **Geographic protocols**: a routing scheme based on the geographical position of the nodes.

Proactive Protocols

- Characteristics:
  - routing tables saved on nodes to store all the routing information of other nodes
  - tables need to be updated when topology changes
- **Suitable for UAV network?**
  - bandwidth constraints
  - slow reaction to topology changes causing delays
- Protocols:

OLSR - Optimized Link State Routing

DSDV - Destination-Sequenced Distance Vector

B.A.T.M.A.N. – Better Approach to Mobile Ad Hoc Network

Reactive Protocols

- Characteristics:
  - On demand
  - No periodic messages
  - Source or hop by hop routing
  - Route acquisition latency

- **Suitable for UAV network?**
  - **Scalability?**
  - **Latency ?**

- Protocols:
  - **DSR** – Dynamic Source Routing
  - **AODV** – Ad hoc On Demand Distance Vector

Hybrid Protocols

Characteristics/Goals:

- Mix reactive and proactive approach
- Reduce reactive delay of discovery process
- Reduce proactive overhead of control messages
- Scale well on large network
- Hard to implement

Protocols:

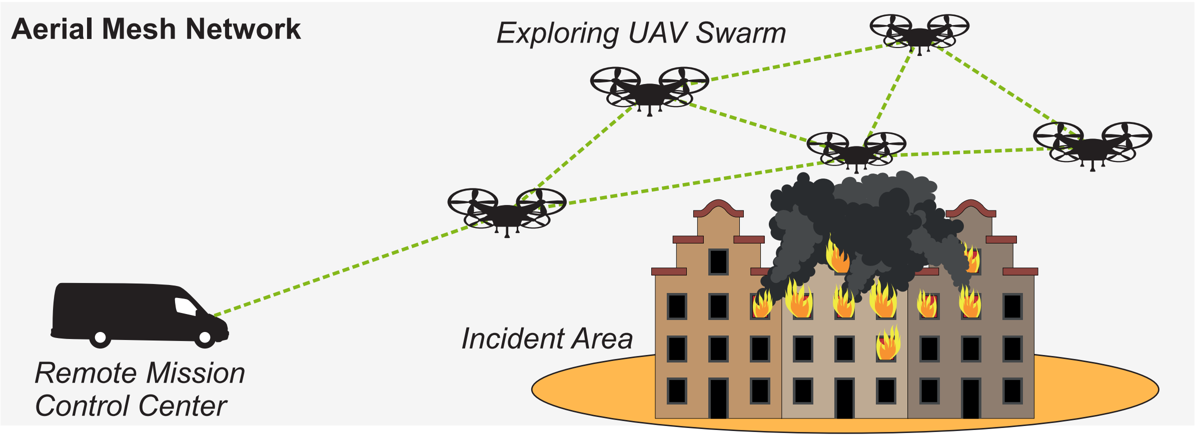
- **ZRP** – Zone Routing Protocol
- **TORA** – Temporarily Ordered Routing Algorithm

A proactive example

B.A.T.M.A.N.
(Better Approach To Mobile Ad-hoc Networking) Protocol

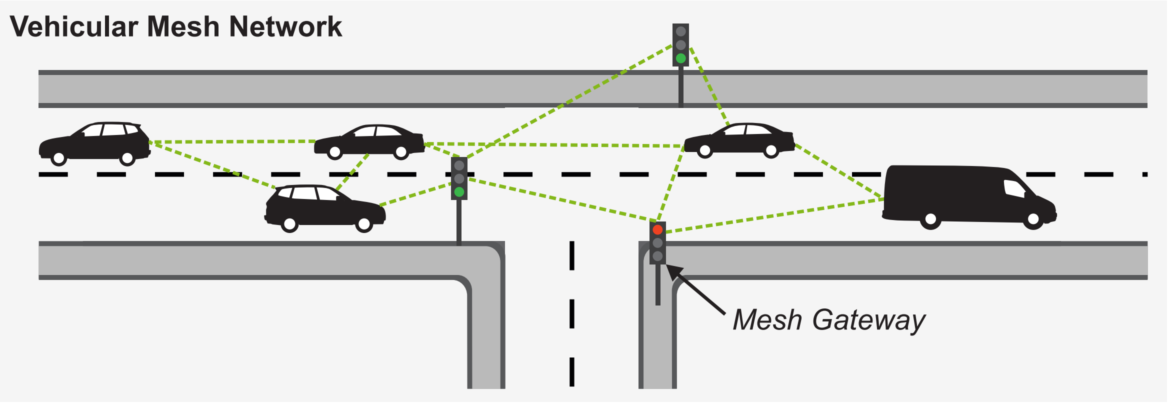
Distributed and Efficient **Mesh Routing Protocol**

Mesh network



- Each node in a mesh network can act as a router, forwarding data on behalf of others

- a type of network topology where each node (device) is connected to multiple other nodes, allowing data to be routed between nodes in multiple ways.



Introduction to B.A.T.M.A.N.

What is B.A.T.M.A.N.?

- A proactive, distance-vector routing protocol for **Mobile Ad-hoc Networks (MANETs)** and **Mesh Networks**.
- Designed for **decentralized** decision-making and **self-organizing** networks.
- **Purpose**: To ensure **robust communication** in dynamic networks where topology frequently changes.
- Emphasis on link quality and robustness

Key Features of B.A.T.M.A.N.

- **Decentralized Routing**:
  - No node has global knowledge of the entire network.
- **Next-Hop Based**:
  - Nodes only know their best next-hop neighbor for reaching a destination.
- **Link Quality Driven**:
  - Decisions are based on the quality of the link between nodes (measured through OGMs).
- **Self-Healing**:
  - Adapts dynamically to network changes, maintaining efficient routing in real time.

How B.A.T.M.A.N. Works

Originator Messages (OGMs):

- Periodically broadcast by each node to announce its presence.
- OGMs are forwarded by neighbors to propagate through the network.

Sequence Numbers:

- Each OGM carries a sequence number to ensure the information is up-to-date and avoid routing loops.

Link Quality Evaluation:

- Nodes evaluate how frequently they receive OGMs from their neighbors to determine the **link quality**.

Routing Table:

- Each node maintains a routing table with the best next-hop neighbor based on link quality.

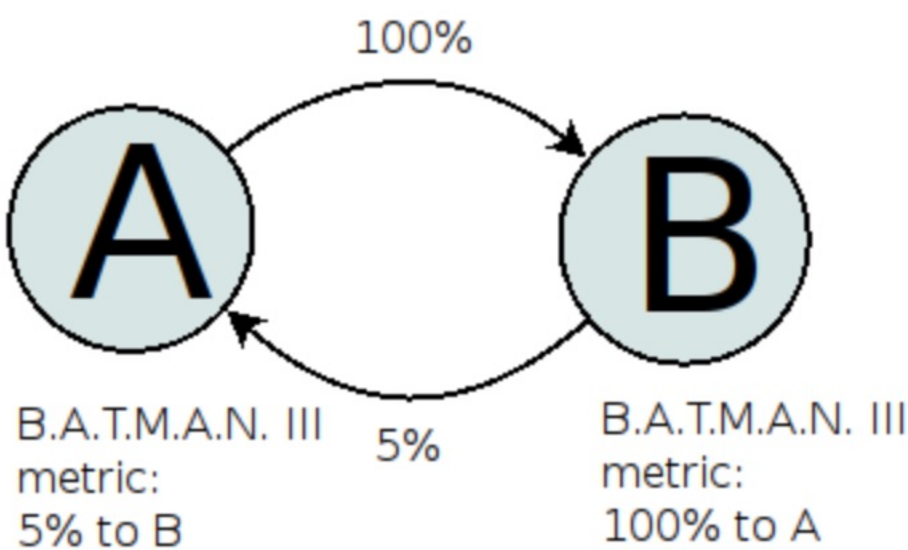
B.A.T.M.A.N. Packet Structure: OGM

Information Inside OGM:

1. **Originator Address**: The address of the node that generated the OGM.
2. **Sequence Number**: A unique identifier for the OGM to ensure freshness.
3. **Time-to-Live (TTL)**: Limits the number of hops the OGM can traverse.
4. **Link Quality Indicator (LQ)**: Measures the quality of the link between the sender and the originator.
5. **Hop Count**: The number of hops the OGM has traveled so far.

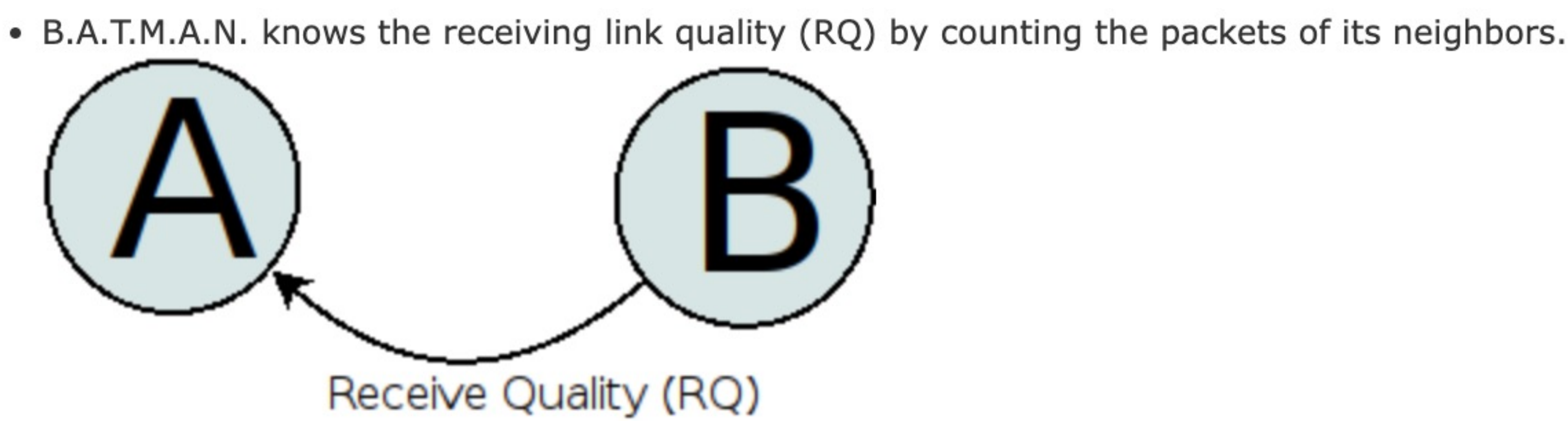
Asymetric links

- OGMs from Node A propagate to B. The link is asymetric, therefore B receives all packets from A in contrast to A which receives almost nothing from B.
- As all the packets from A get to B the packet count at B's side goes up. B will assume that it has a perfect link towards A which is not the case.



The Transmit Quality

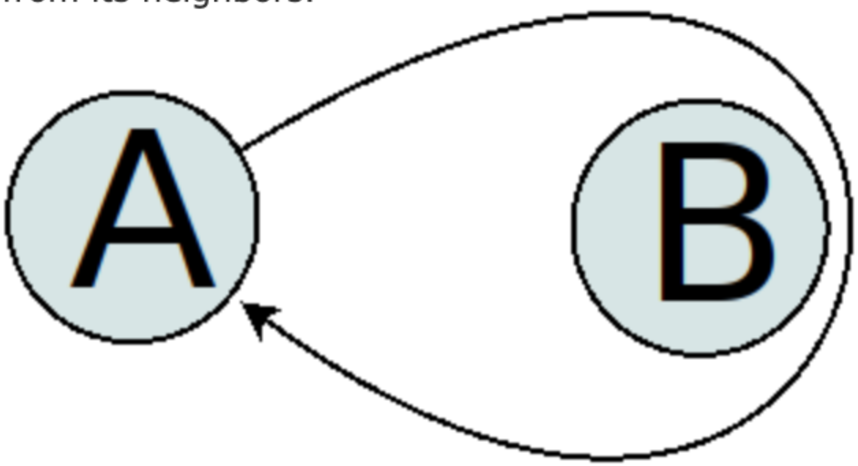
- To overcome the asymmetry flaw B.A.T.M.A.N. IV has been enhanced with the Transmit Quality (TQ) algorithm.



  - RQ = $\#OGM_B$

The Transmit Quality

- B.A.T.M.A.N. knows the echo link quality (EQ) by counting rebroadcasts of its own OGMs from its neighbors.

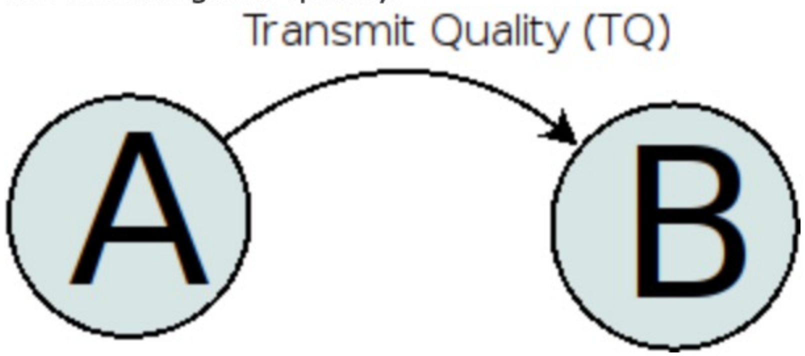


Echo Quality (EQ)

- EQ = #rebroadcast(OGM_A)

The Transmit Quality

- B.A.T.M.A.N. can calculate the transmit link quality (TQ) by dividing the echo link quality by the receiving link quality.



- TQ = EQ/RQ

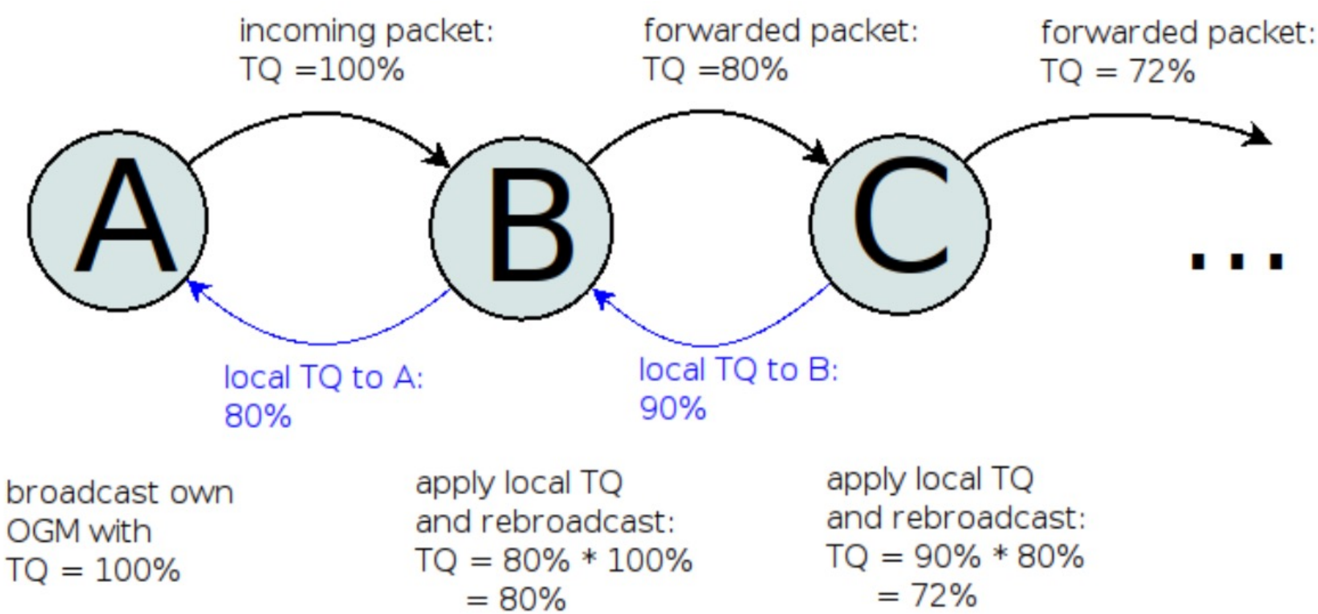
Transmit Quality Propagation

- Whenever the OGM is generated this field is set to maximum before it is broadcasted. The receiving neighbor will calculate their own local link quality into the received TQ value and rebroadcast the packet. Hence, every node receiving a packet knows about the transmit quality towards the originator node.

- To add the local link quality in the TQ value the following calculation is performed:

  TQ = TQ_{incoming} * TQ_{local}

- Example: Node A broadcasts the packet with TQ max. Node B receives it, applies the TQ calculation and rebroadcasts it. When node C gets the packet it knows about the transmit quality towards node A.

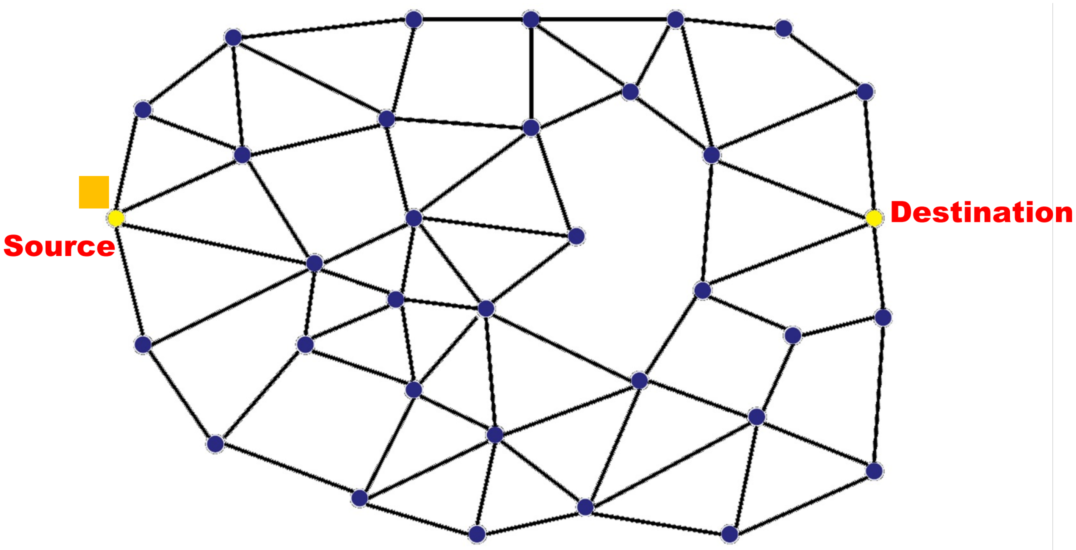


Geographic Protocols

- The **geographical position information of the nodes is utilized for data packet forwarding decisions**
- Each UAV knows its own location using the **GPS device** embedded on board or any other means of positioning system
- Geographic routing schemes **do not need** the **entire network information**
- No Route discovery
- No routing tables
- Use local information to forward the data packets
- Routing overhead, bandwidth, and energy consumption are reduced
- For routing decisions, only the neighbor UAVs and destination UAV position information are required.

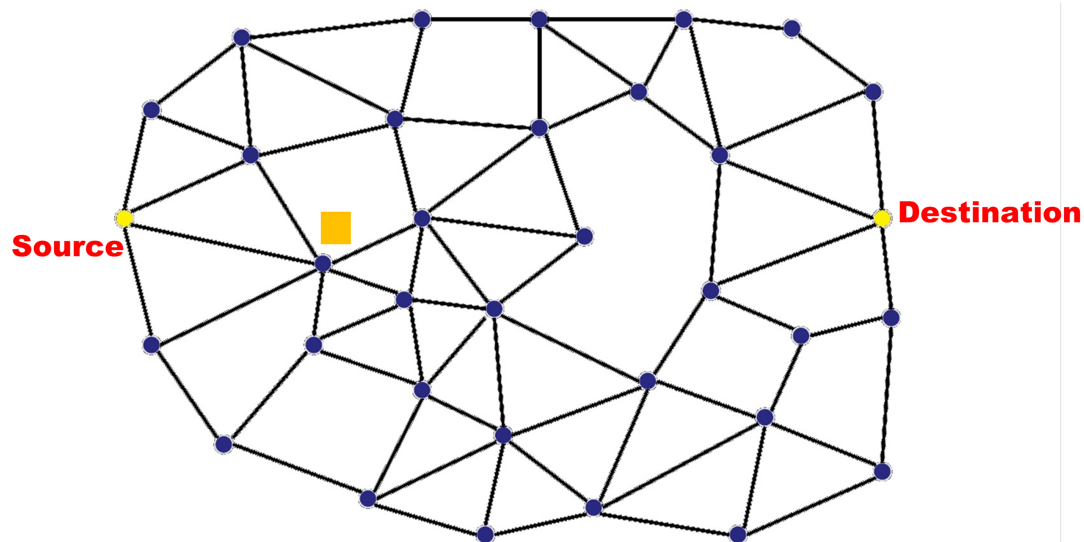
Geographic routing

- Nodes have coordinates of neighbors



GDSTR-3D

- Nodes have coordinates of neighbors
- Node closest to the destination is chosen



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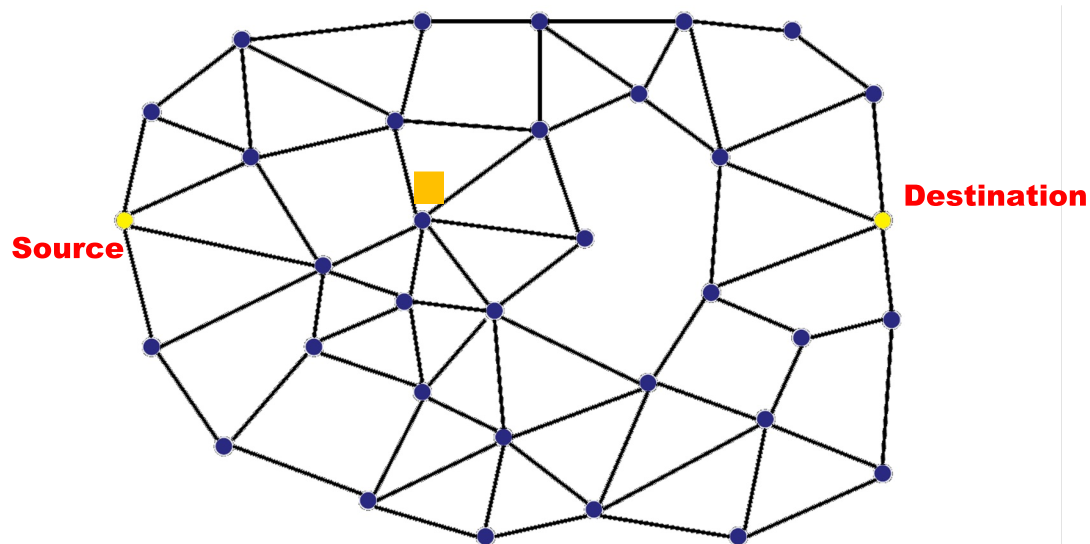

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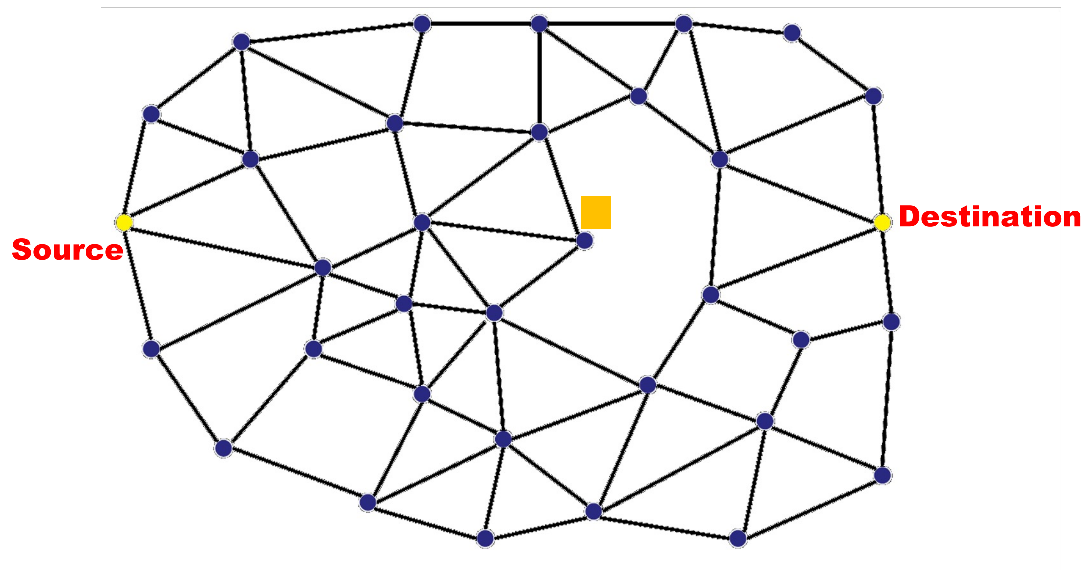


Dead end

- The packet can arrive to a **dead end**, i.e., a node that does not have any neighbor closest to the destination
- Several techniques have been defined in sensor networks to recover from a dead end but they are often not applicable to dronet
- The topology can change fast

Geographic approach in **dronets**

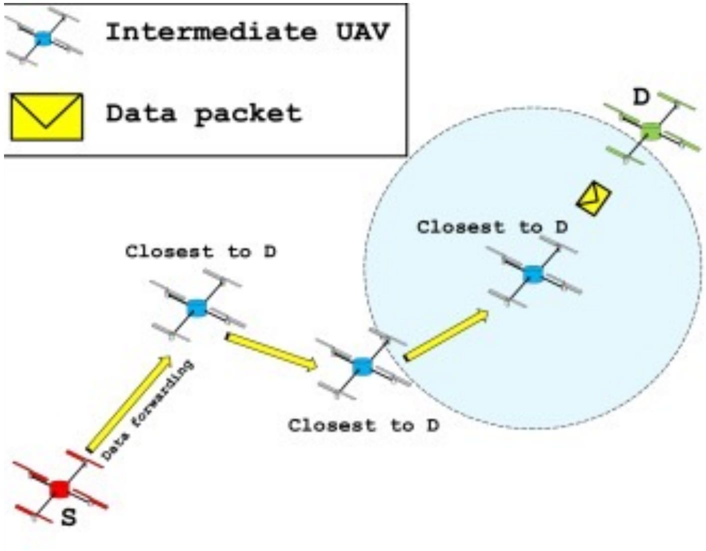
Assume that each **UAV knows its own location** using the GPS device embedded on board or any other means of positioning system

Geo routing is based on three main approaches

Store-carry and forward	*Greedy forwarding*	*Prediction*

Greedy forwarding

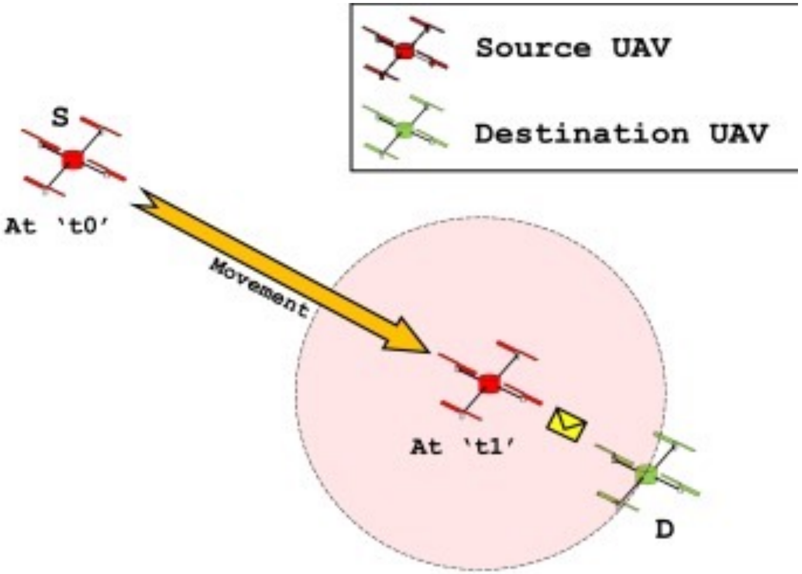
- The principle is to select the **geographically closest node to the target destination** as a relay node and so on until the packet reaches its destination.
- Drawback: local optimum problem, in which the process is blocked at a node which is considered as the closest to the destination and cannot find any relay nodes to reach it
- a combination of other techniques should be used to en-sure the reliability of this technique



(B) Greedy Forwarding technique

Store-carry and forward

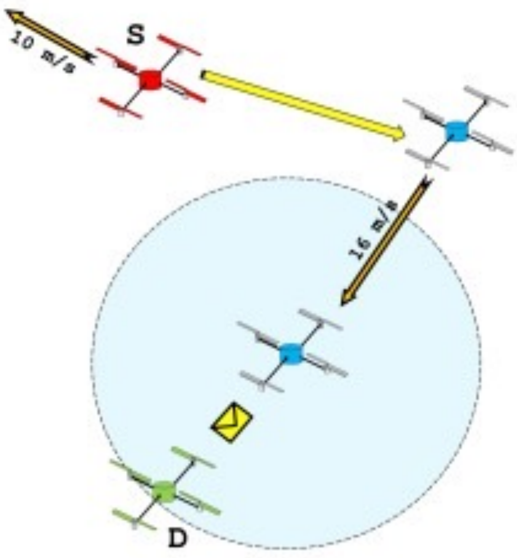
- When the network is intermittently connected, the forwarder nodes do not have any solution to find a relay node
- It is not possible to forward any data packet to a predefined node which does not exist in the transmission range
- In this case, the current node tends to **carry the packet until meeting another node or the target destination itself**



(A) Store-Carry and Forward technique

Prediction

- prediction based on the geographical location, direction, and speed, to predict the future position of a given node
- Prediction technique based on **the future geographical location of a next relay node**.



(F) Prediction technique

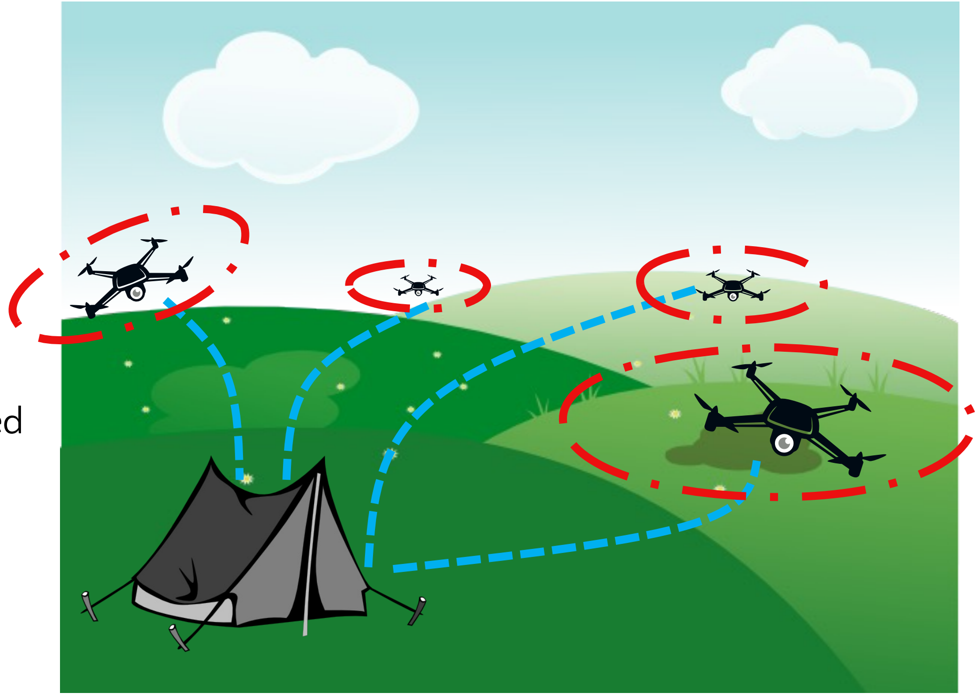
4

- *How to perform periodic data offloading when UAVs are deployed in large and harsh areas?*

Periodic Connectivity Problem

Problem:

- A squad of UAVs in sensing mission over a large area
- A depot
- Short-range high data rate offloading channel (WiFi)
- Localization modules (GPS)



Goal:
Periodically build a network topology to offload gathered data:

- minimizing distance traveled by UAVs
- minimizing time to form connected topology
- maximizing time spent on mission

Try solving it yourself !

Stop & Route: Periodic Data Offloading in UAV Networks

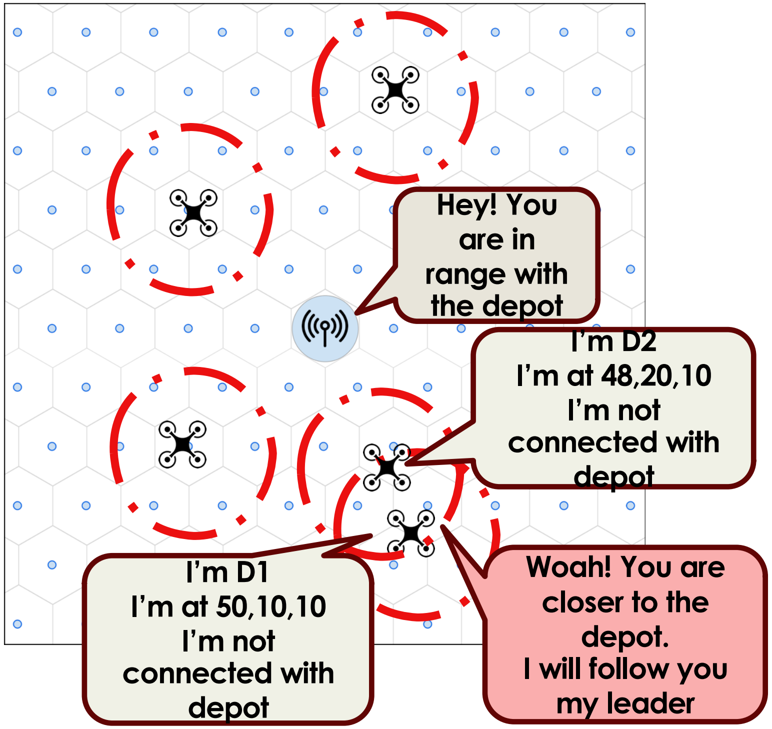
Novella Bartolini, Andrea Coletta, Flavio Giorgi, Gaia Maselli, Matteo Prata, Domenicomichele Silvestri

IEEE 18th Wireless On-Demand Network Systems and Services Conference (WONS) 2023

Stop & Route –Distributed Solution: Assumptions

Assumptions for distributed solution:

- Area is discretized
- Only short-range high data rate offloading channel (Wi-Fi)
- UAVs are lazy-synchronized
- Depot periodically send *heartbeat packets*
- UAVs periodically sends an *hello packet*
- Follow-Leader mechanism

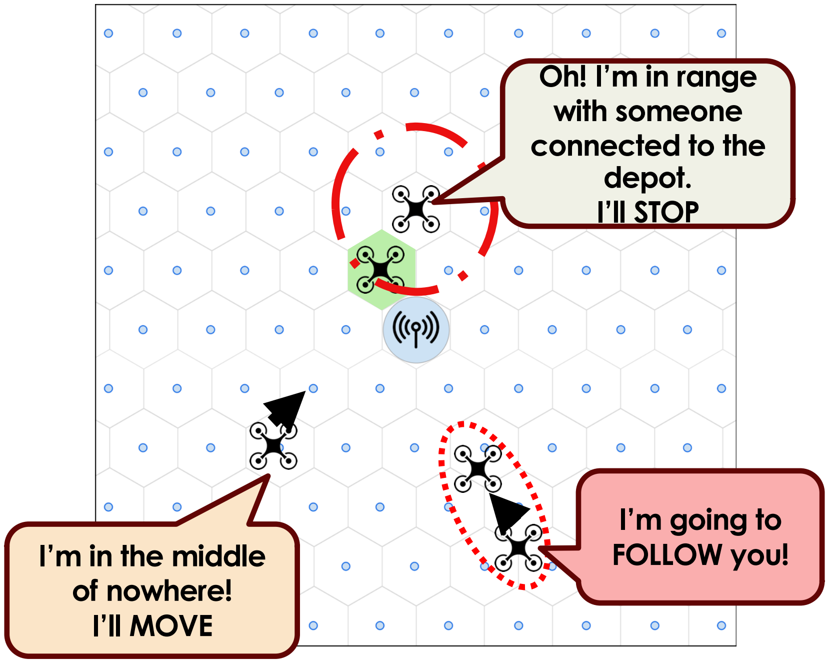


Stop & Route – Distributed Gathering Algorithm (DGA)

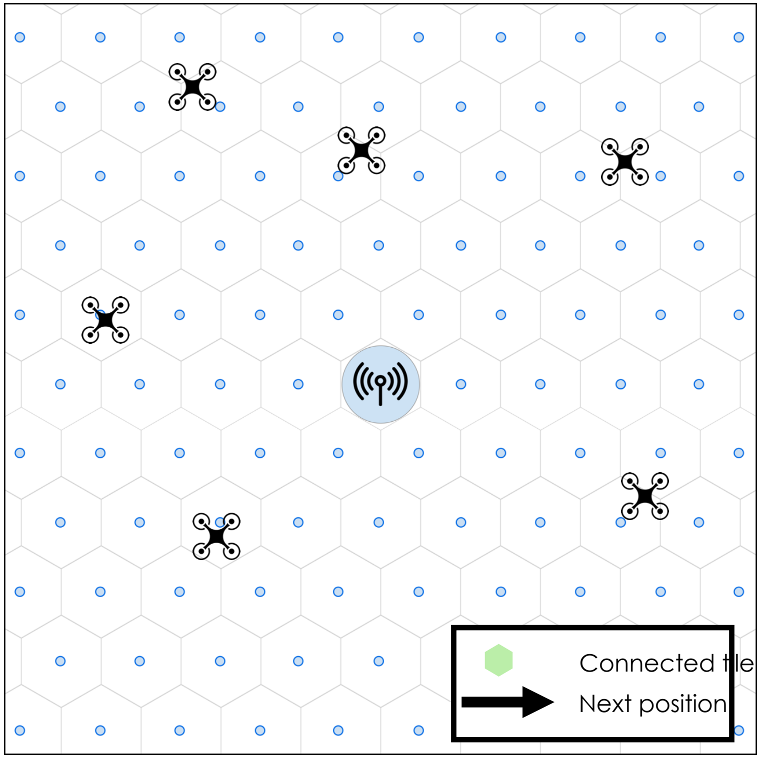
Distributed Gathering Algorithm (DGA)

During connected formation building phase, each UAV check if:

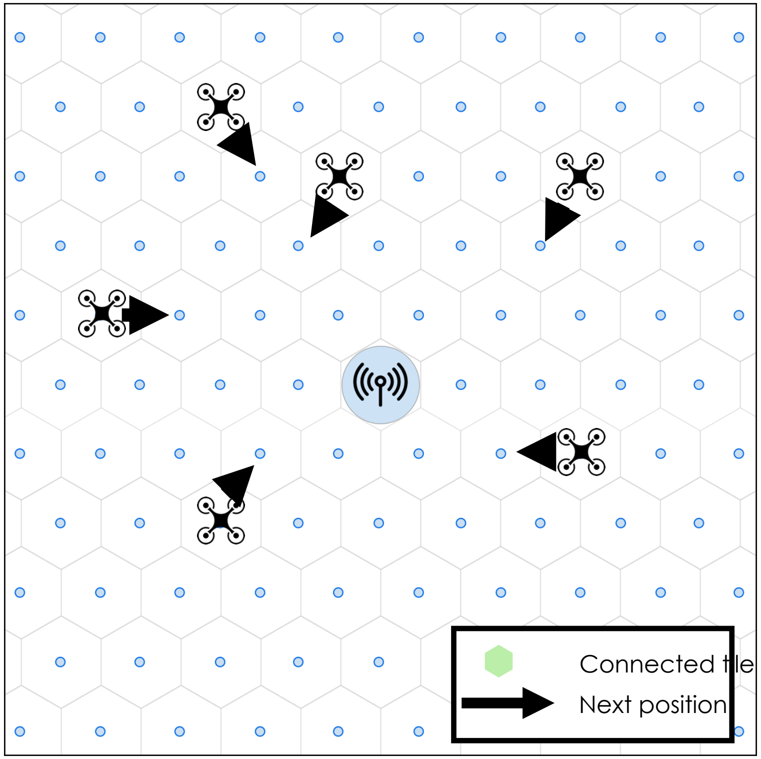
- In communication range with depot or with other UAVs connected with depot -> **STOP**
- In communication range with a non-connected UAV closer to the depot -> **FOLLOW LEADER**
- Isolated -> **KEEP MOVING TOWARDS NEXT CLOSER TO THE DEPOT RENDEZVOUS POINT**



Stop & Route – DGA example



Stop & Route – DGA example



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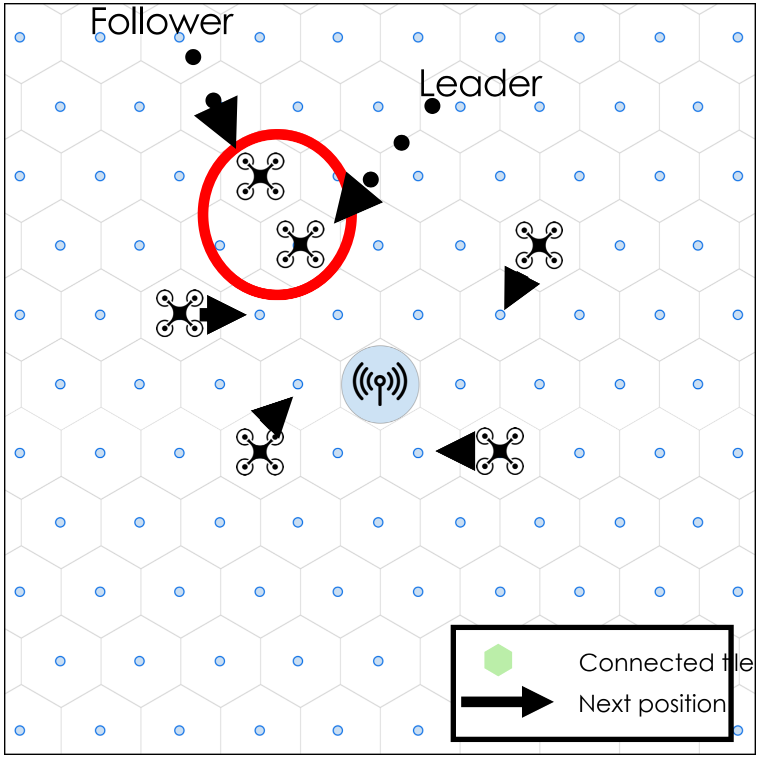

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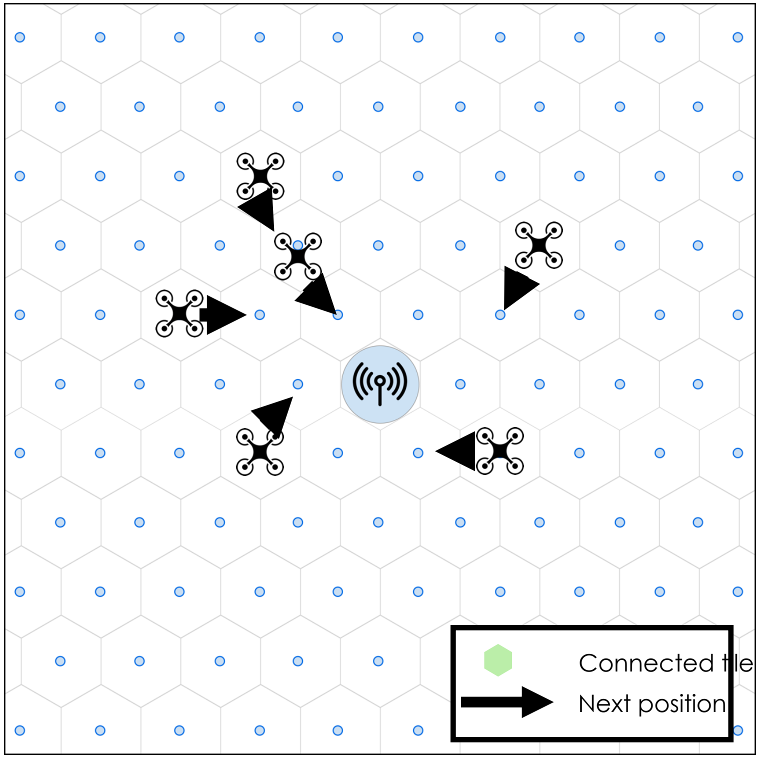

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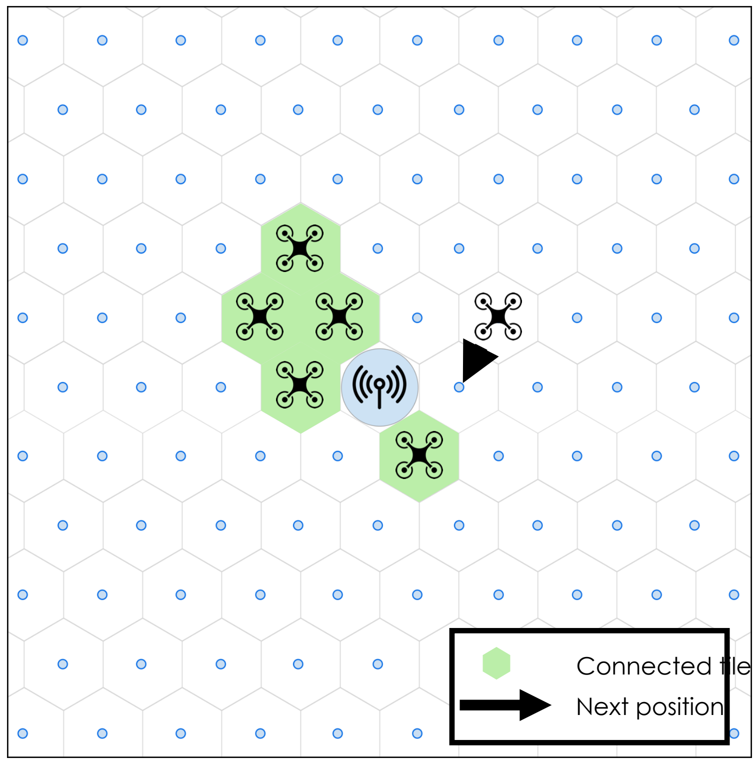
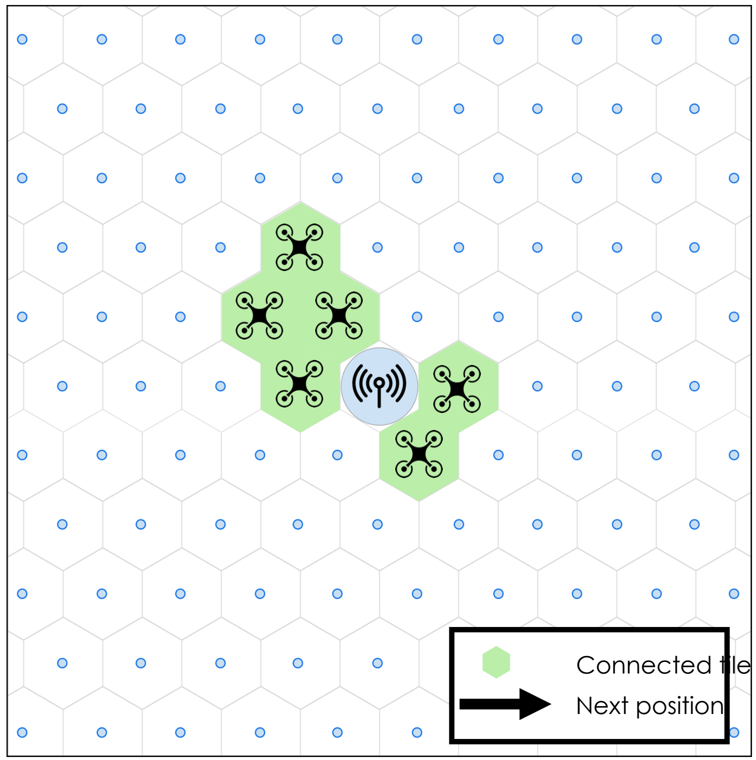
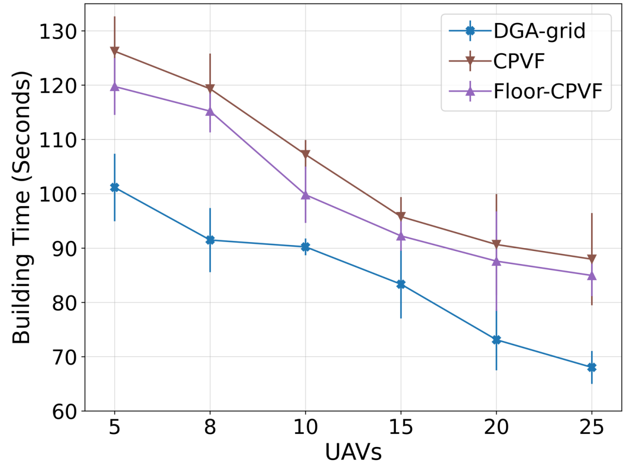


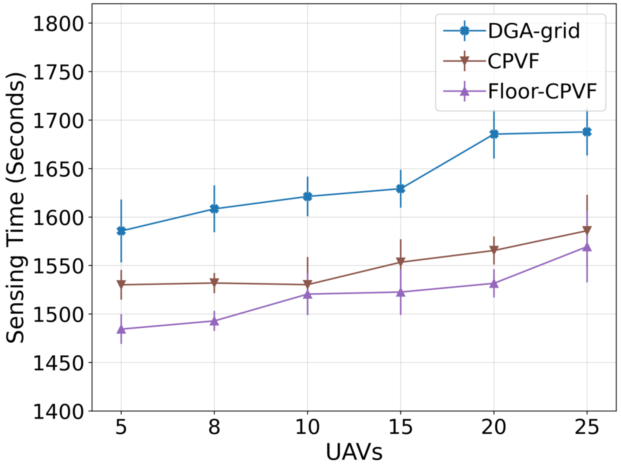
Stop & Route – DGA example



Stop & Route – Perfomance Evaluation

Simulation Testbed	
squared area	2.25 km^2
speed	8 m/s
transmission range	100 m
packet time to live	300 s
mission duration	37 min.
runs	50





CPVF and Floor-CPVF algorithms: G. Tan, S. A. Jarvis, and A.-M. Kermarrec, "Connectivity-guaranteed and obstacle-adaptive deployment schemes for mobile sensor networks," IEEE Transactions on Mobile Computing