Flying Ad-hoc Networks and Position-based routing

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Introduction

Drone - Flying Device

- Unmanned Aerial Vehicle (UAV)
- Unmanned Aircraft System (UAS)
- Remotely Piloted Aircraft (RPA)

Flying controllable/independent device without a human pilot aboard.

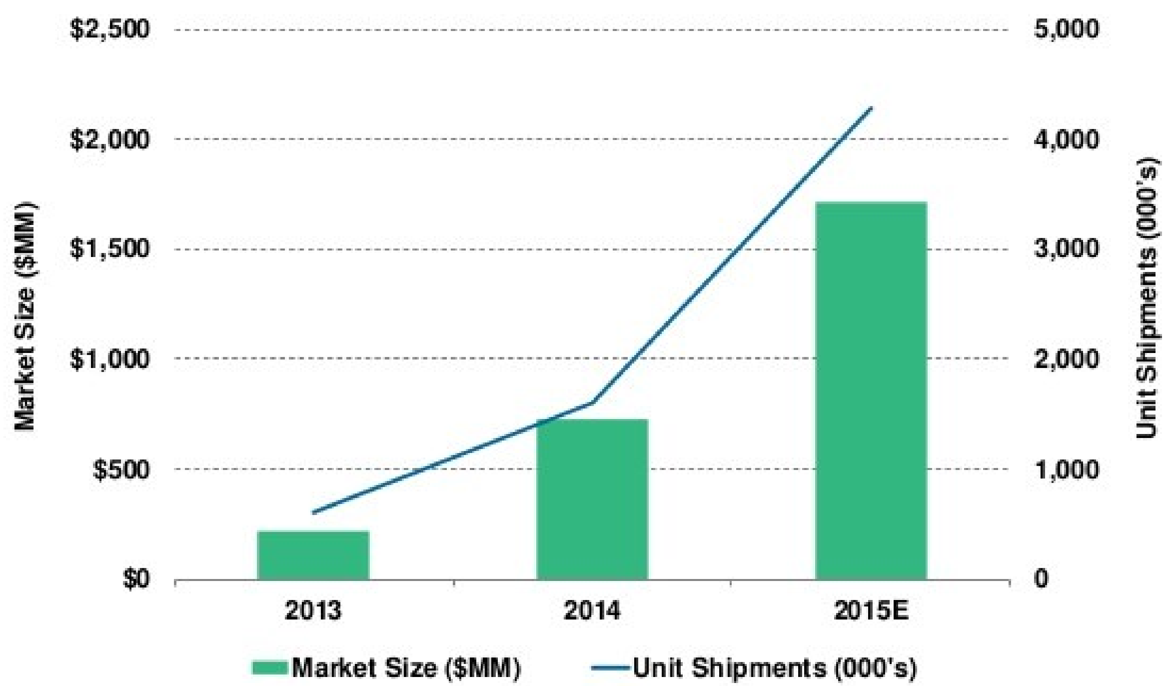
- Several application scenarios
  - Originated for military applications
  - Expanded in commercial, scientific, civil, ...
- Characteristics of UAVs
  - Typically use Wi-Fi technology (802.11) to communicate
  - Equipped with GPS, camera, sensors
  - Energy consumption recovery
  - Can be part of a **network**

Introduction

In recent years, drones business employs a tremendous growth, with estimates of over 1,5 billion sold by 2015.

Consumer Drone Shipments = Rising Rapidly...
@ 4.3MM Units in 2015E, + 167% Y/Y, Revenue to $1.7B

Global Consumer Drones – Revenue & Unit Shipments, 2013 – 2015E



@KPCB Source: KPCB estimates.

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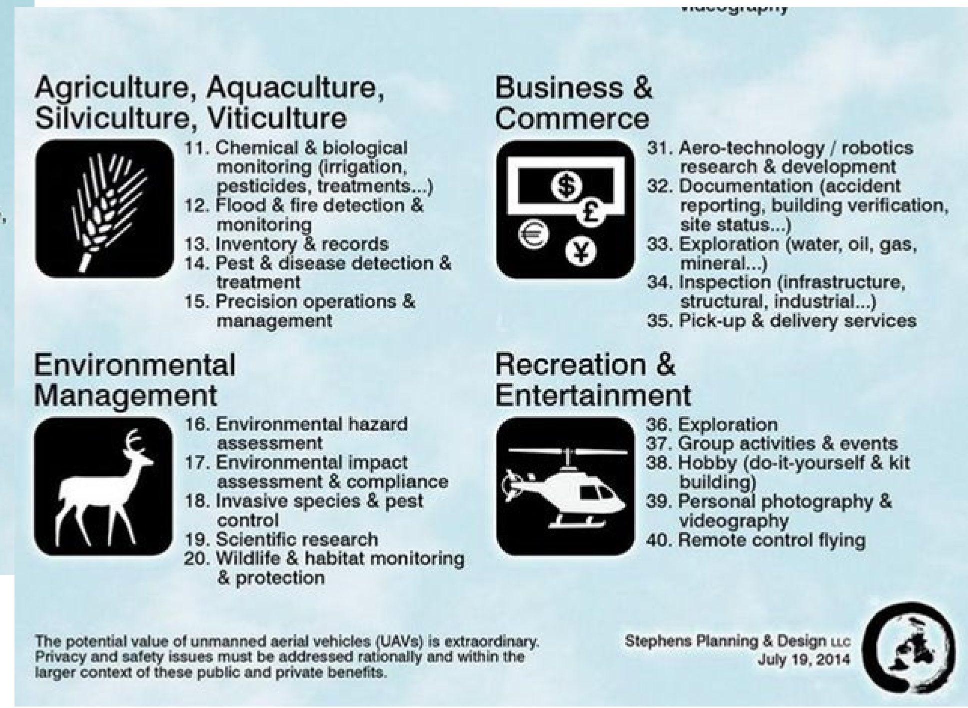
Application of drones

- Military
- Civil
- Business
- Scientific Research
- Hobby



Flying Ad-Hoc Networks (FANETs)

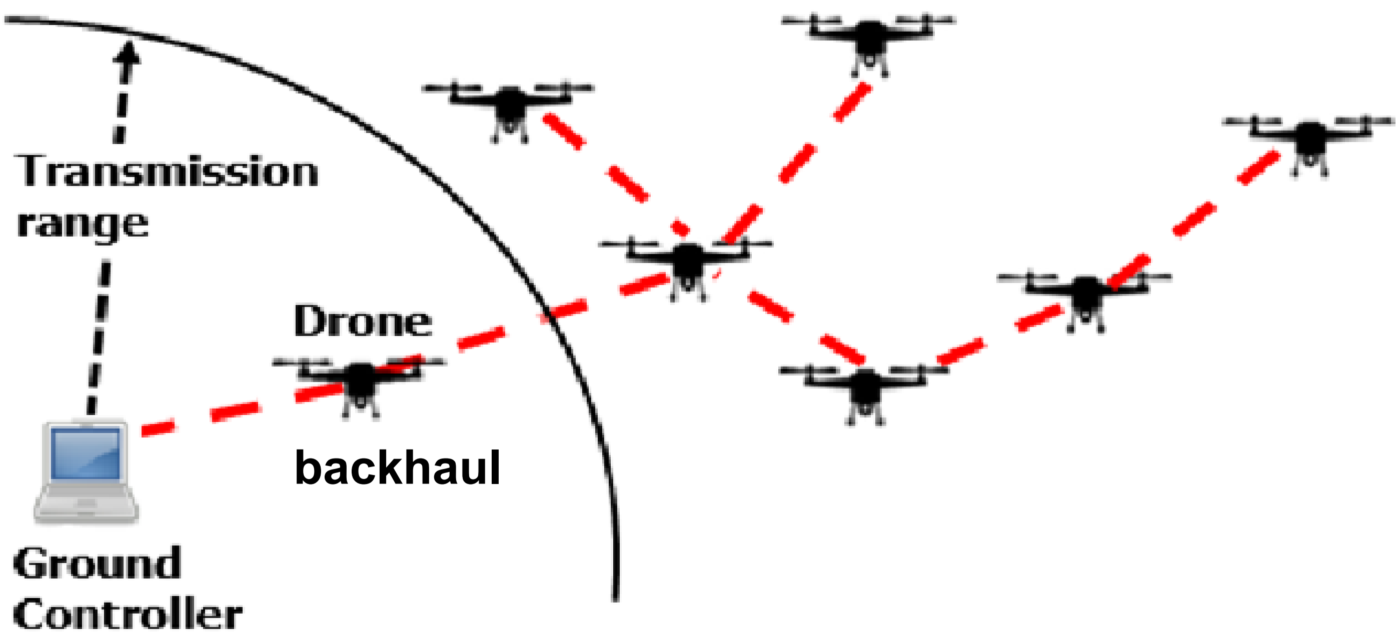
- Interaction without *strict* infrastructure reliance
  - Exploit **ad hoc** connectivity to exchange data
  - Content produced/consumed locally
- Other terminologies
  - Drone ad-hoc Networks (DANETs) / Unmanned Aerial ad-hoc Networks (UAANETS)

- <u>Scope</u>: *military, transportation, environmental monitoring, crisis and disaster management*

Flying Ad-Hoc Networks (FANETs)

Two parts:

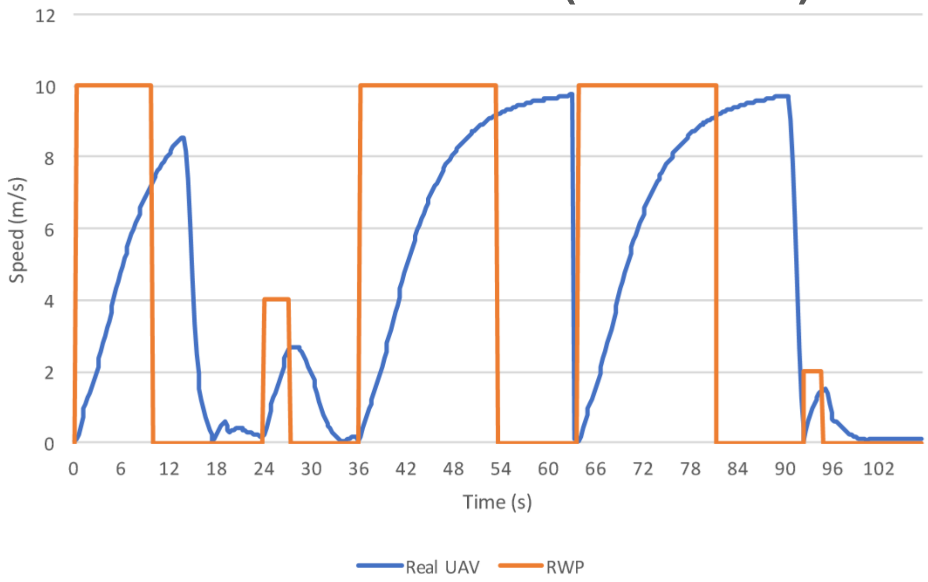
- Ad-hoc network
- Access point (satellite, ground base, laptop, ...)

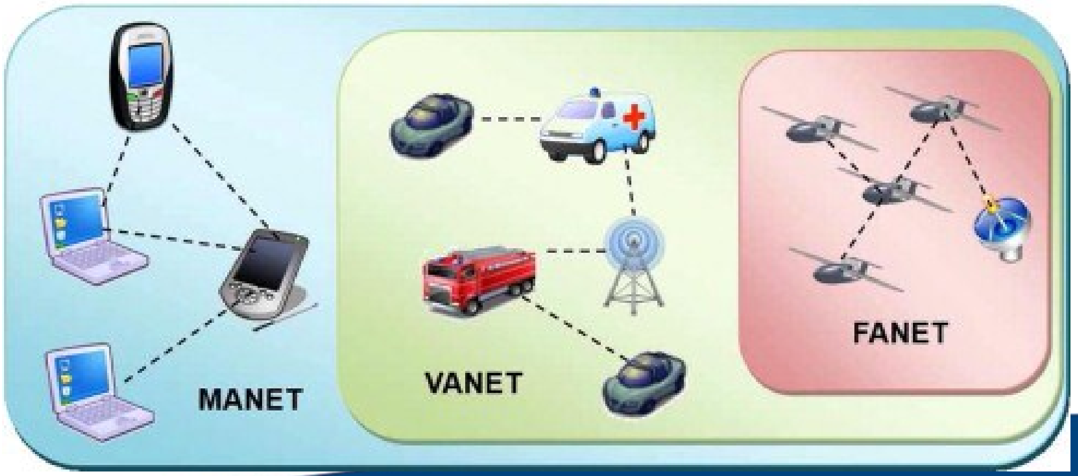


Differences between MANET and FANET

FANETs are a special case of mobile ad hoc networks (MANETs)

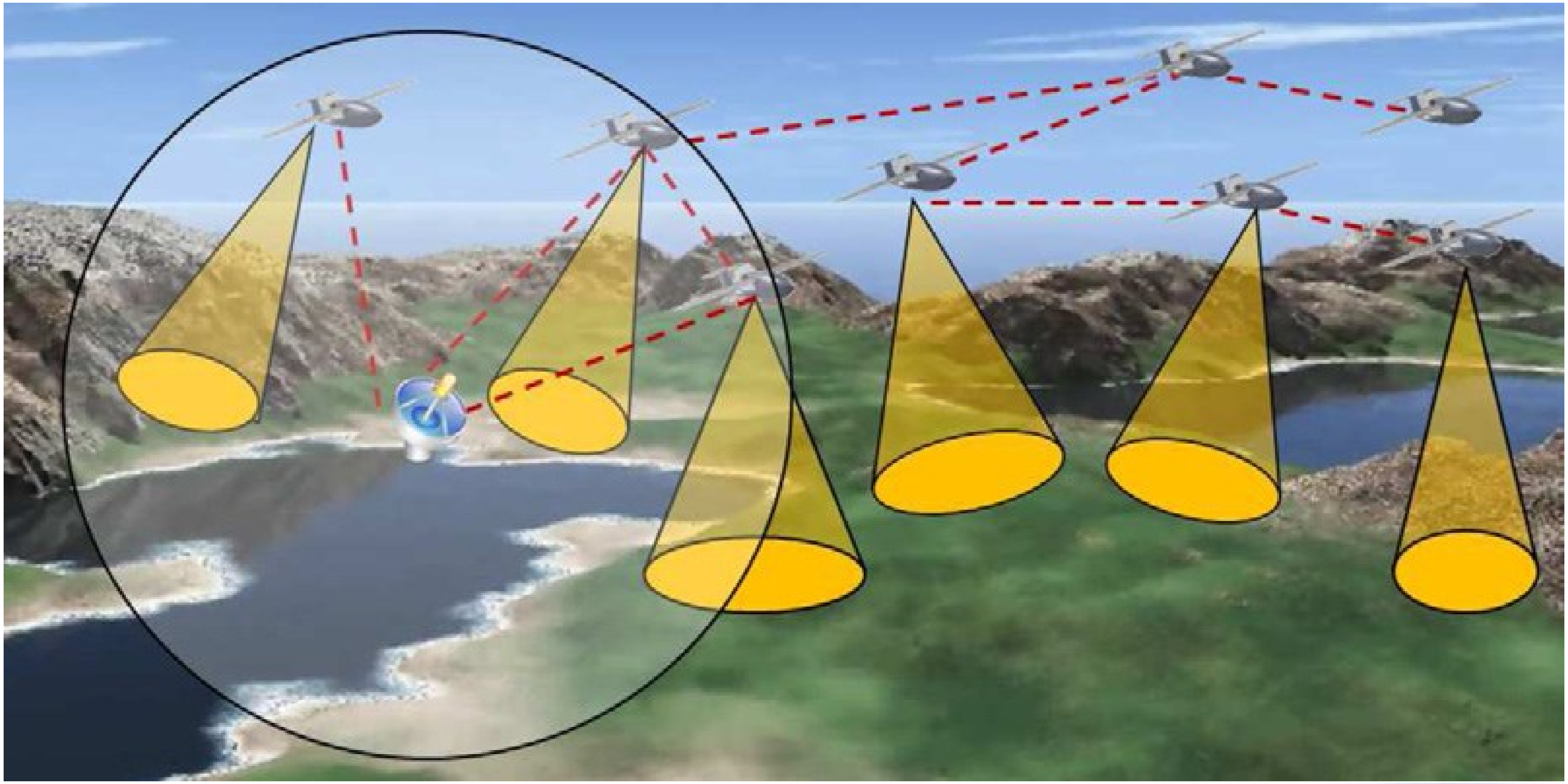
- Mobility model
  - Different speed
  - Different topology
  - Different movement
- Topology changes
  - More frequently link failures
  - Link quality changes
- Distances
- Equipments





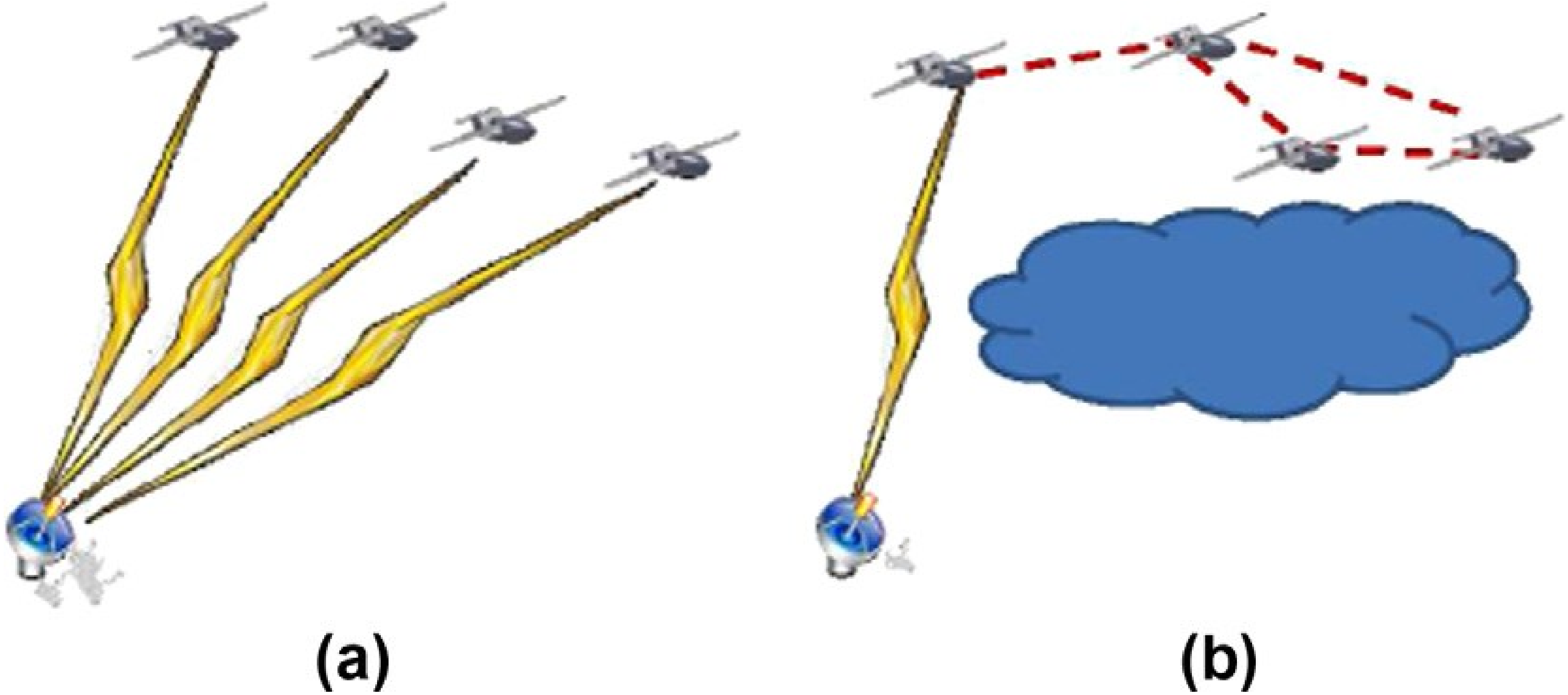
Motivation of FANETs

- Extend the work coverage and range
  - Chain of UAVs
  - Larger operation area



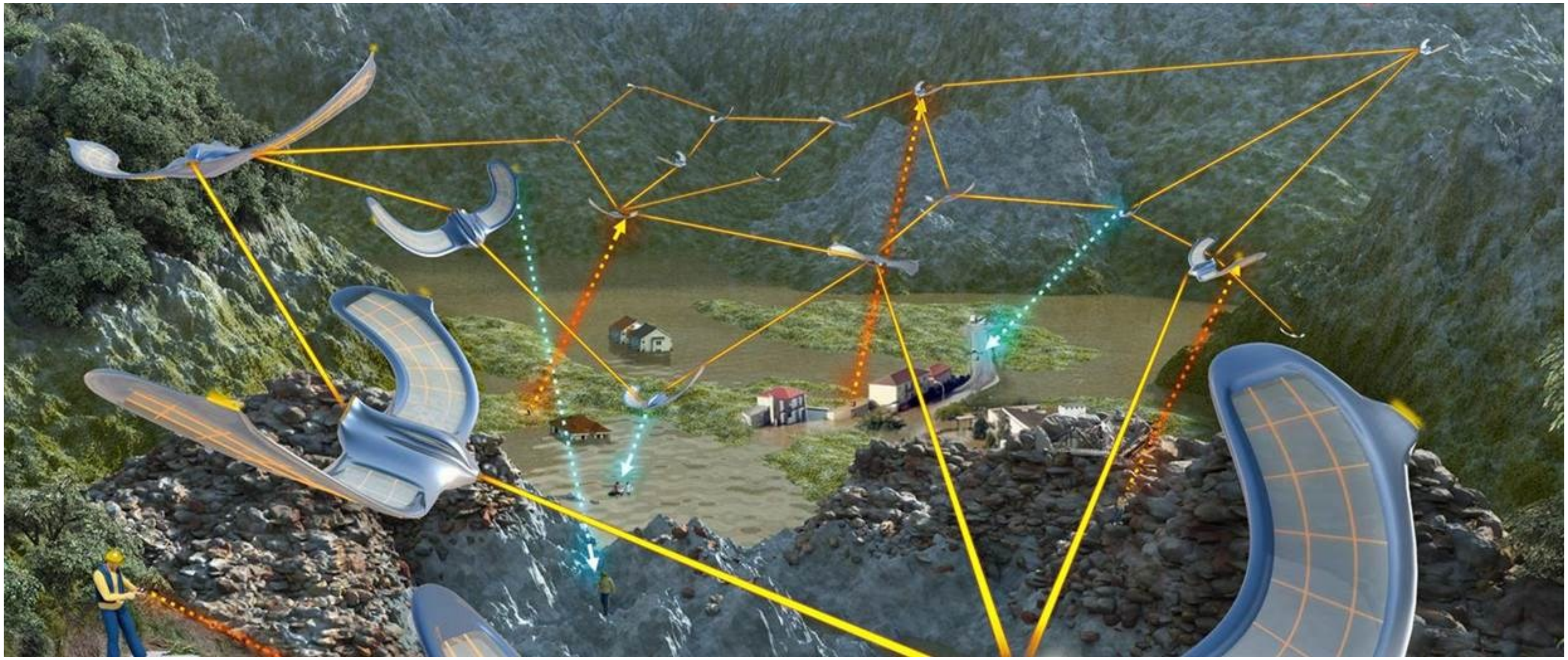
Motivation of FANETs

- Reliable UAV system and communication
  - Loss/broken link substitution
  - Obstacle bypass

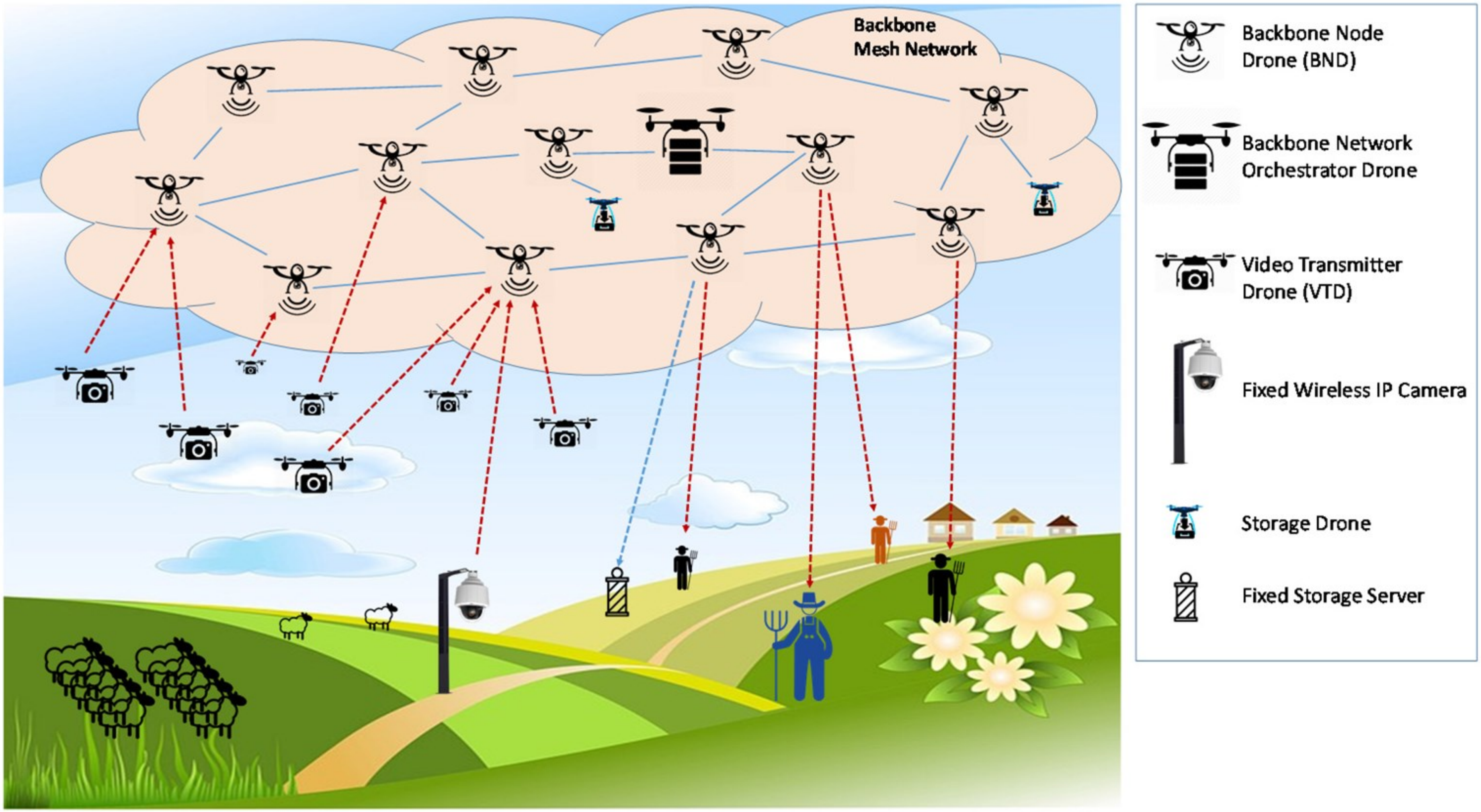


Motivation of FANETs

- Cooperation, sustainability and distributed working
  - Completing missions in short time
  - Maximization of the operations by adding more UAVs



A FANET in a IoT scenario



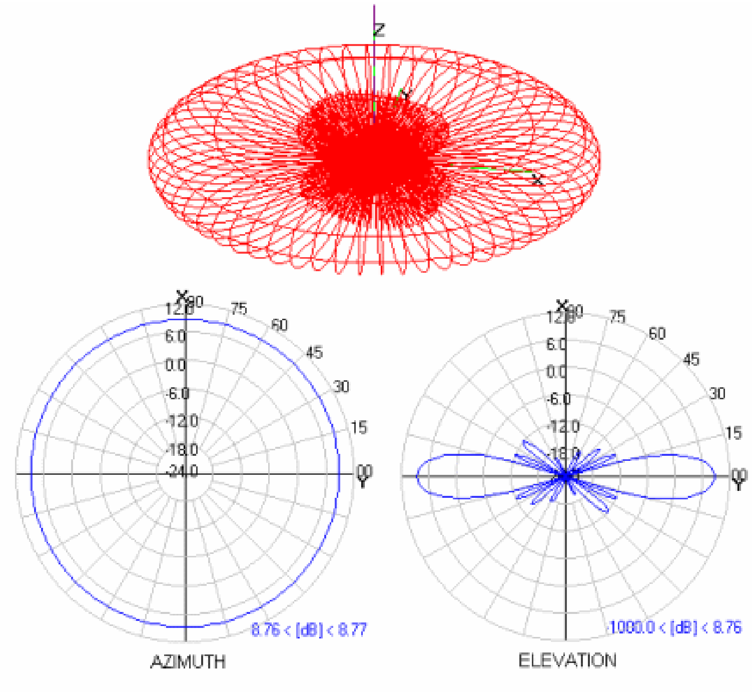
Communication in FANETs

Communication protocols in FANETs have still open research challenges

- Physical layer
  - Radio propagation
  - Antenna structure
- MAC layer
  - Link quality degradation
  - Adaptive MAC Protocol Scheme for UAVs (AMUAV)
- **Network layer**
  - Packet forwarding decision is more difficult
  - Maintaining of routing tables
- Transport layer
  - Reliability
  - Disconnections

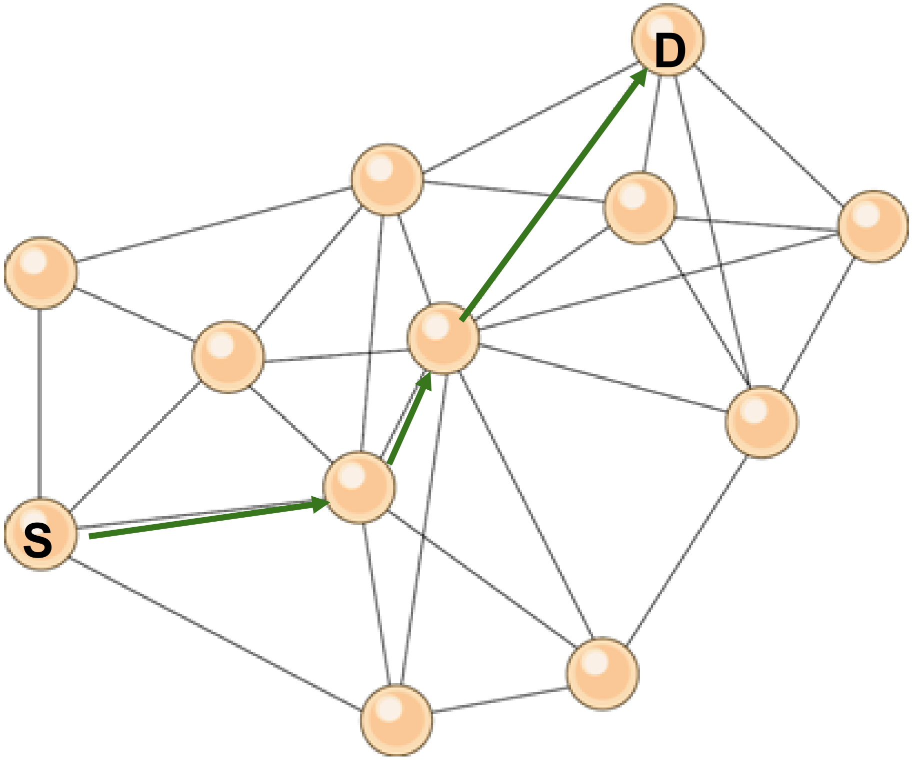
Routing in FANETs

- Routing in a MANET needs a multi-hop forwarding of packets
  - Difficult due to the continuous change of topology
- Routing in a FANET is even more difficult ...
  - More speed
  - Different density
  - 3D topology
  - Different radio propagation
  - Power consumption
  - ....



Challenge of routing in FANETs

- Typically connectionless
  - Every packet treated separately
- Main routing challenges
  - Link failures
  - Limited bandwidth
  - Limited energy
- Two main approaches
  - Topology-based
  - **Position-based**



→ Focus on **node's location information to support route decision**

Topology-based

- Use information about links
- Routing table
- Proactive, reactive and hybrid approaches
- Reactive approach is more suitable for MANETs
  - Need route only when required
  - There are not continuous table updates
  - AODV, DSR, etc ..

node 2's route table

seq	dest	next	hop
1	1	1	1
1	3	3	1
1	4	3	2

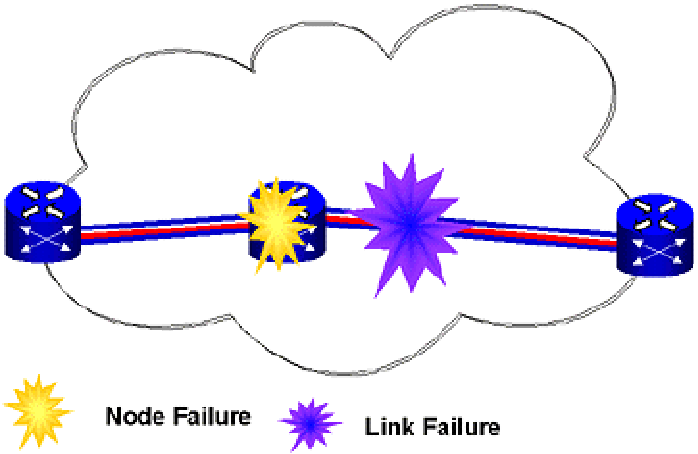
node 1's route table

seq	dest	next	hop
1	2	2	1
1	4	2	3

Topology-based

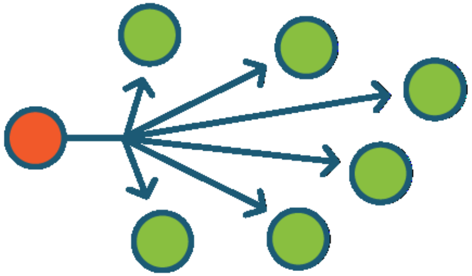
- There are some limitations also using these protocols in FANETs, especially with
  - Limited bandwidth
  - Limited energy
  - Limited memory

Link failures / node failures



Huge amount of control traffic

- Some topology approaches need to **flood** the request packets
- Much information have to be **frequently updated**

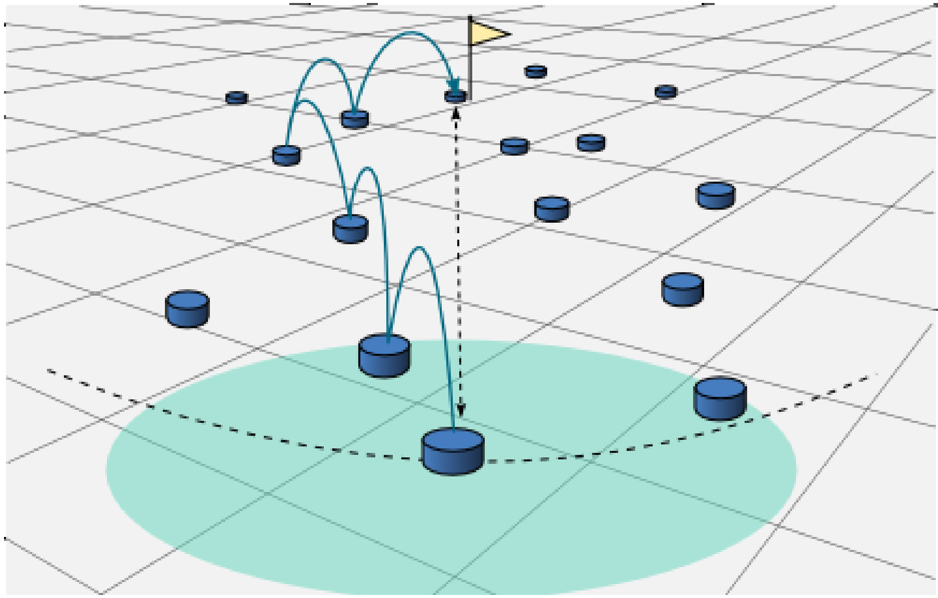


Topology-based solution are not as scalable

Position-based

- Use geographic position information for packet forwarding decision
  - Location service (GPS)
- No need for a routing table
  - Only neighbors' information
  - Limited control overhead

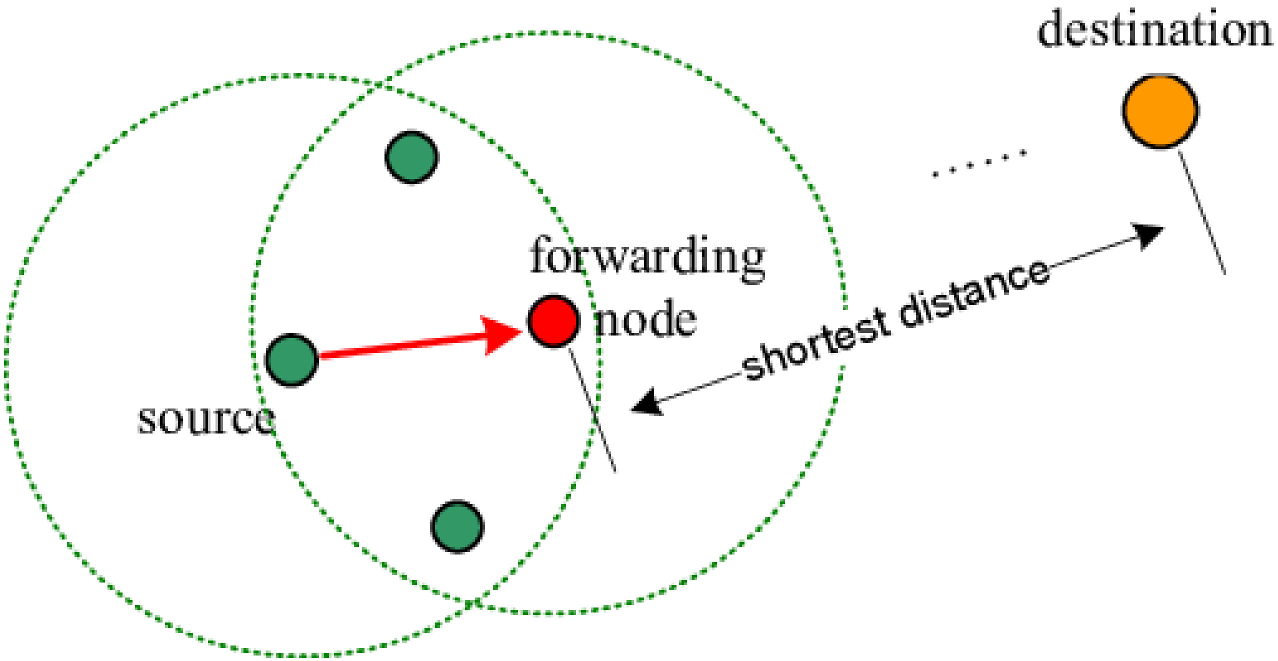
MORE SCALABLE



- Current node chooses the best next-hop node toward the destination node
- But.. the **Hello messages**? --> constant control overhead
  - Adaptive Hello timer

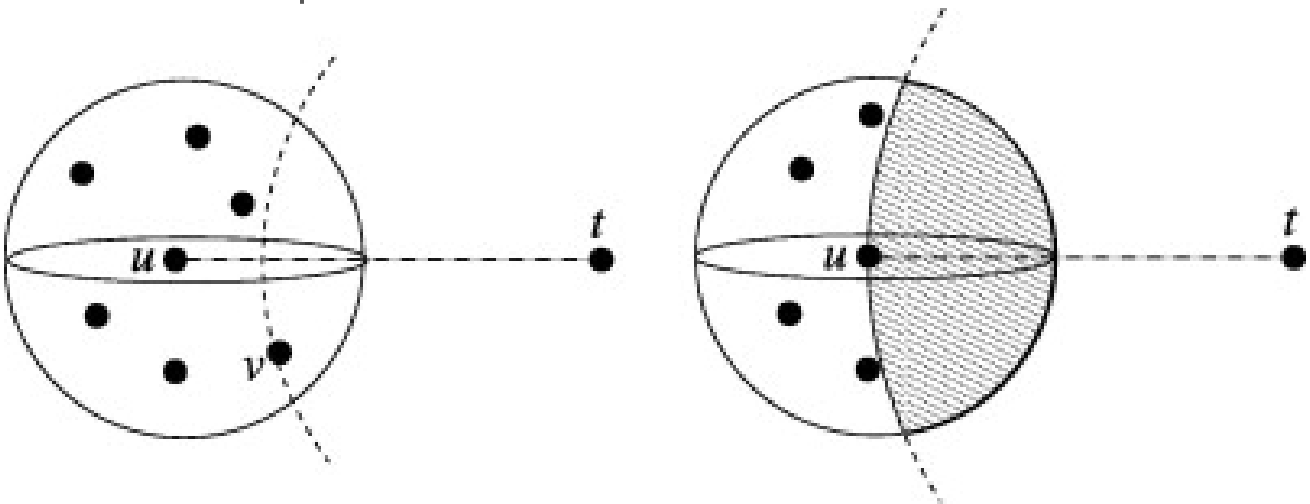
A trivial approach: GREEDY

- A node forwards the packet to one of its neighbors that make **progress** toward the destination (<u>Greedy</u>)
  - Distance
  - Projected distance
  - Angle



A trivial approach: GREEDY

- Greedy approaches suffer of the problem of **local minimum**
  - The packet gets stuck in a node
  - Sometimes the packet does not arrive at destination

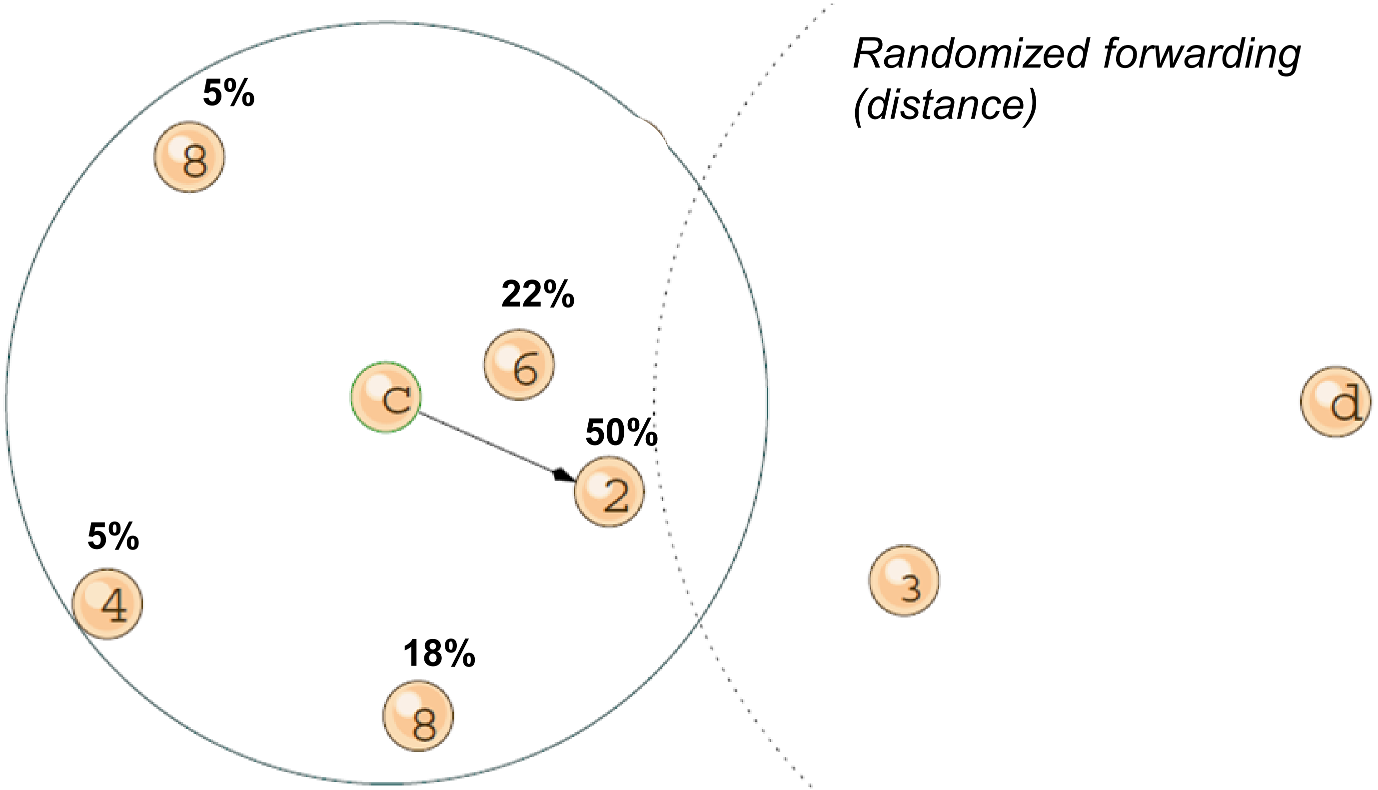


(a) forwarding neighbor (b) local minimum

Greedy approach need to be binded with a <u>recovery strategy</u>

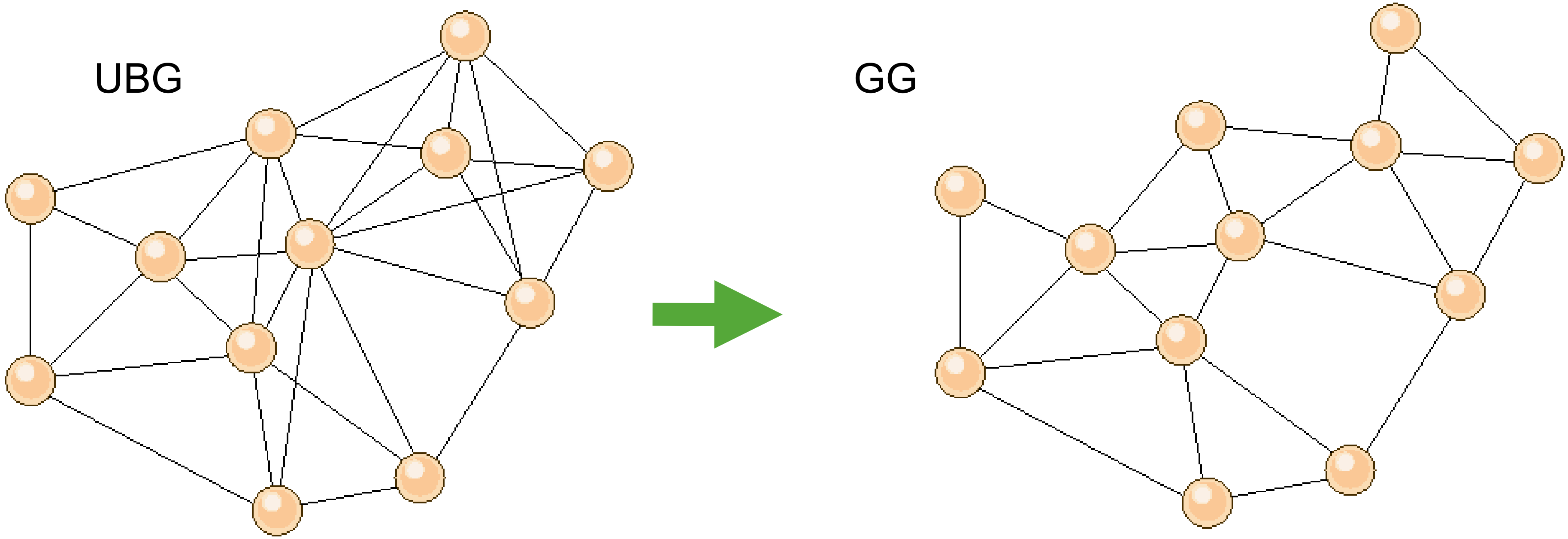
A recovery strategy: Randomized Approach

- The packet is forwarded to a certain node with a **probability** that increases with the **progress** that would be made towards destination



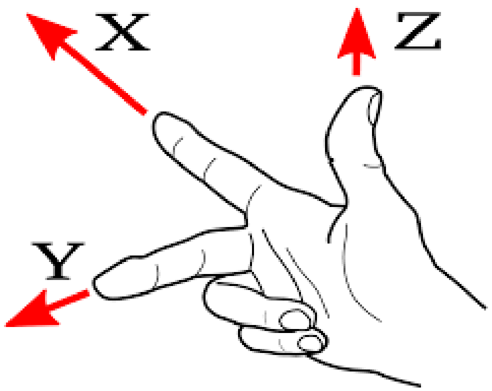
A recovery strategy: Face Routing

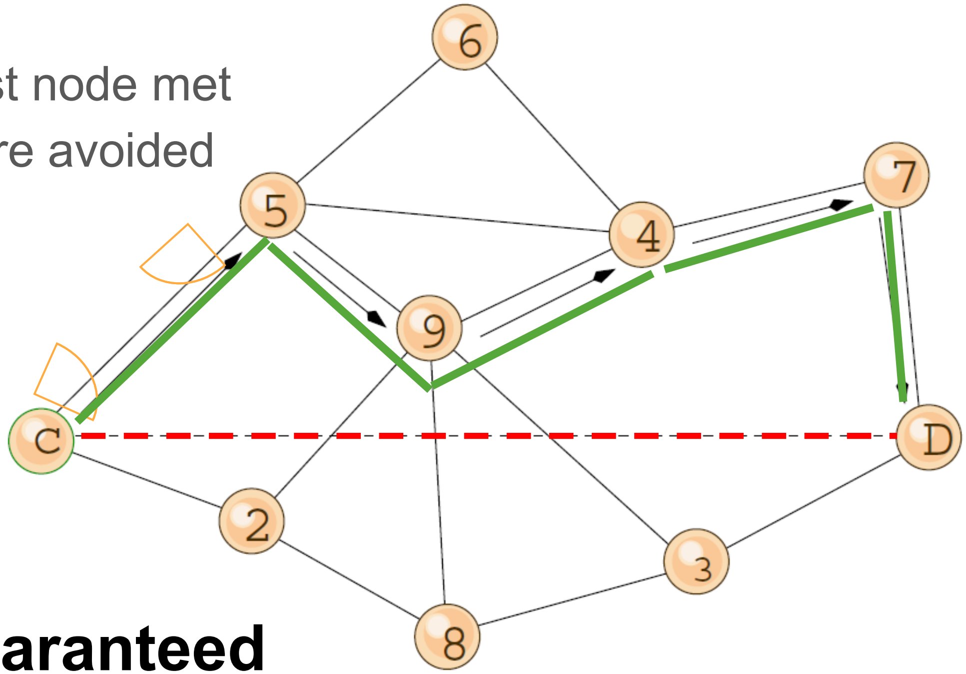
- **Face** routing algorithm
  - The packet walks adjacent faces to reach the destination
  - Graph planarization → planar sub-graph
  - Remove cross-links



Face algorithm

- Right-hand rule (or left-hand rule)
- Looking for the first node at the right (left)
  - Starting from the line represented by the link from where the packet arrived
    - Only the **first iteration** starts from line starting from the local minimum **c** (or source node) and the destination node **D**
  - The packet is sent to the first node met
  - Links crossing the line **cD** are avoided

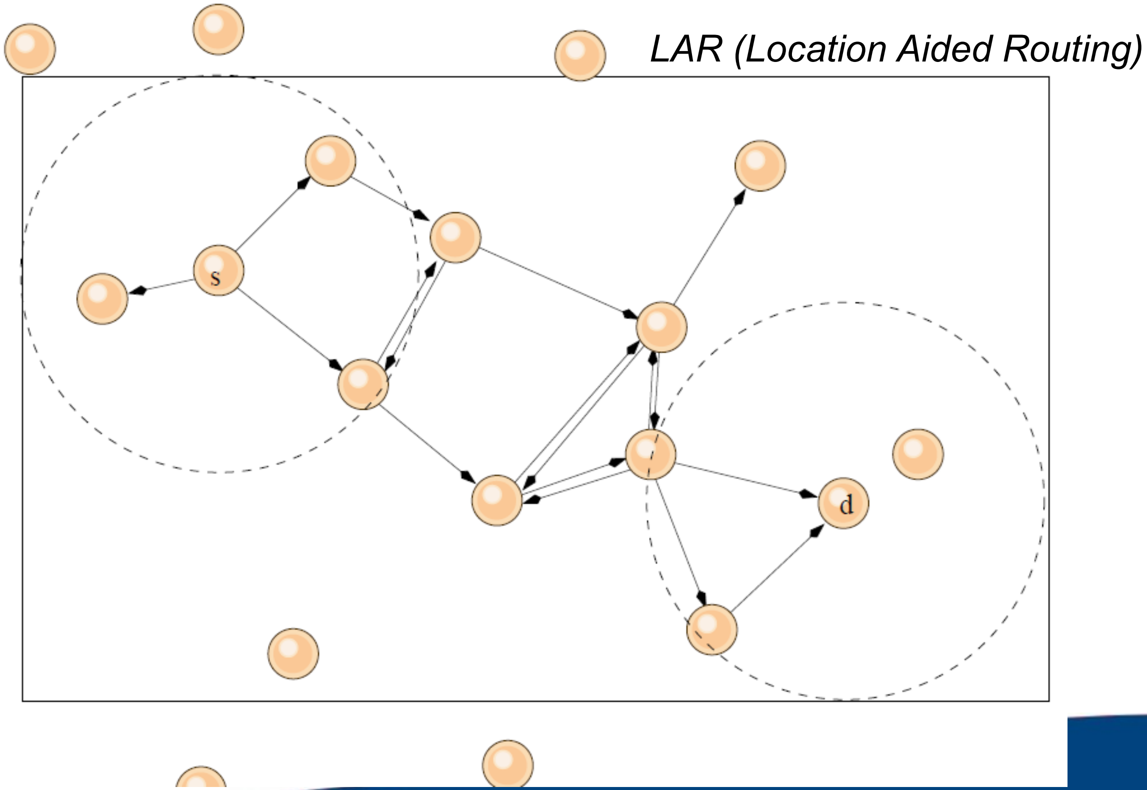




Delivery of packet is guaranteed

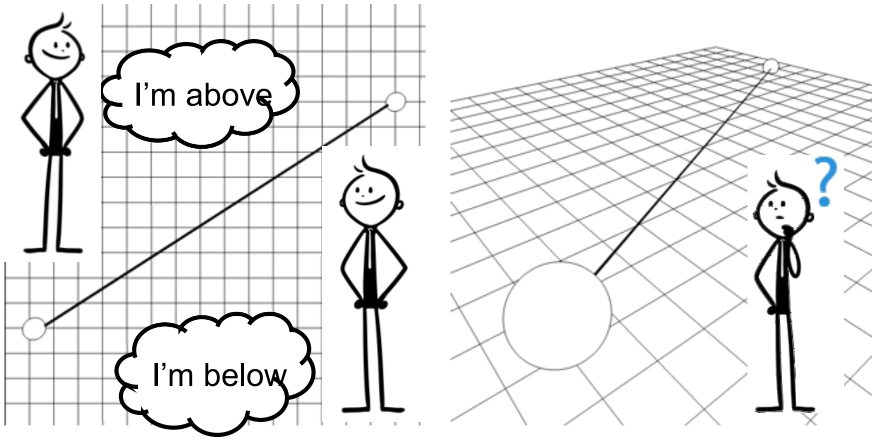
Multi-path forwarding

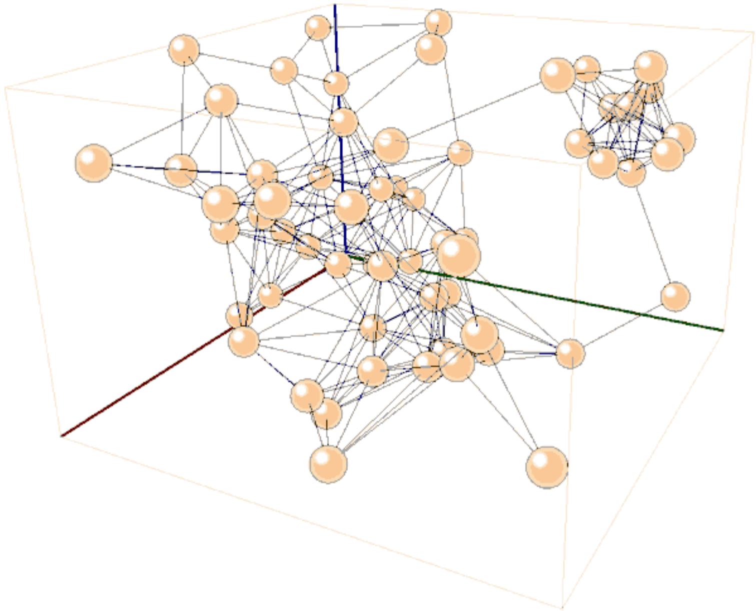
- A node send the same packet to multiple neighbors
- **Location Aided Routing** algorithm: uses a rectangle that includes transmission ranges of source and destination
- Limited flooding



What if 3D networks?

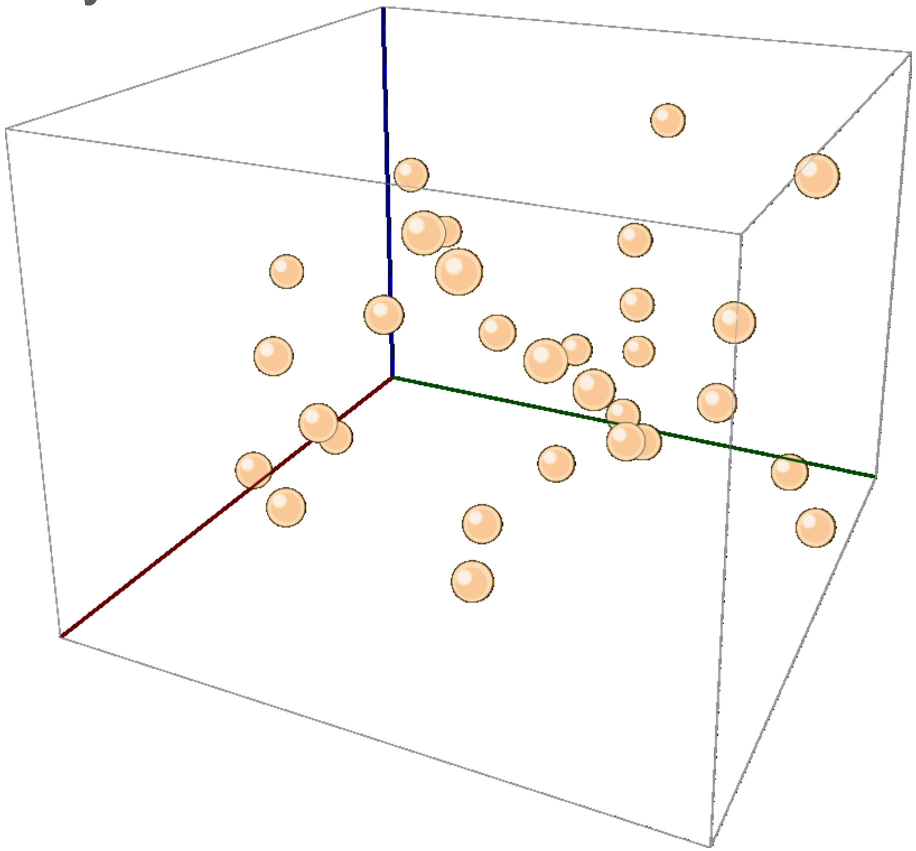
- Many researches on position-based routing focused on 2D networks models
  - E.g., Vehicular Ad-hoc Networks (VANETs)
- FANETs are intrinsically 3D
- Difficult to extend 2D concepts to 3D space
  - NO planarization
  - NO above and below a line





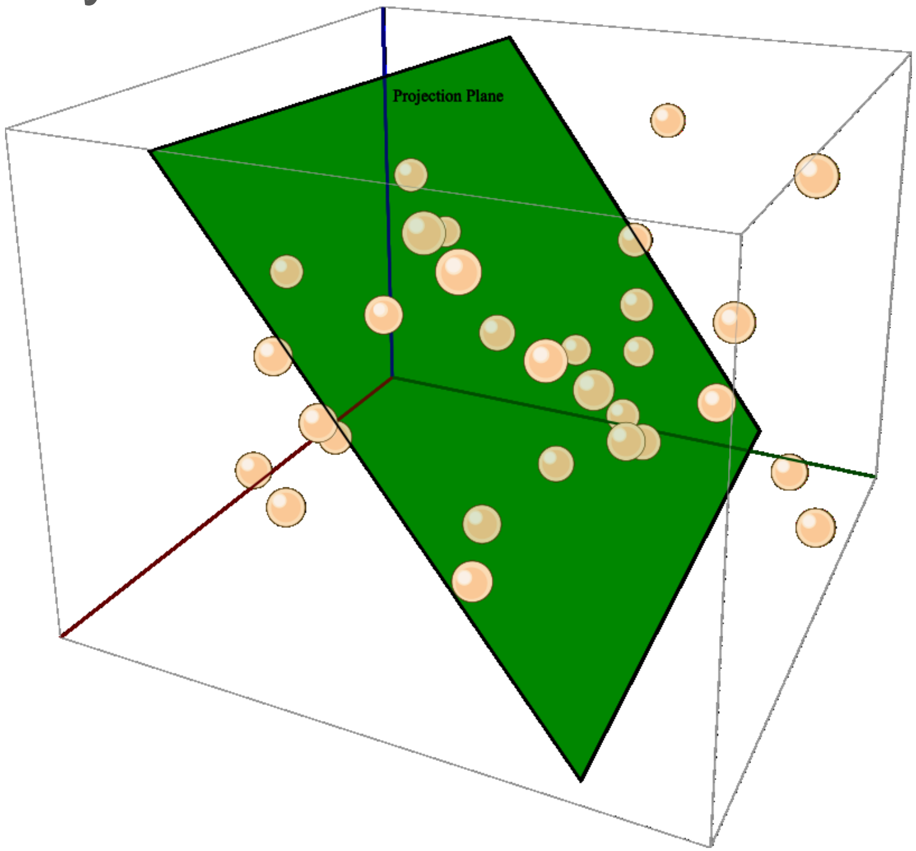
3D version of Face algorithm

- 2D Face cannot be used directly in 3D



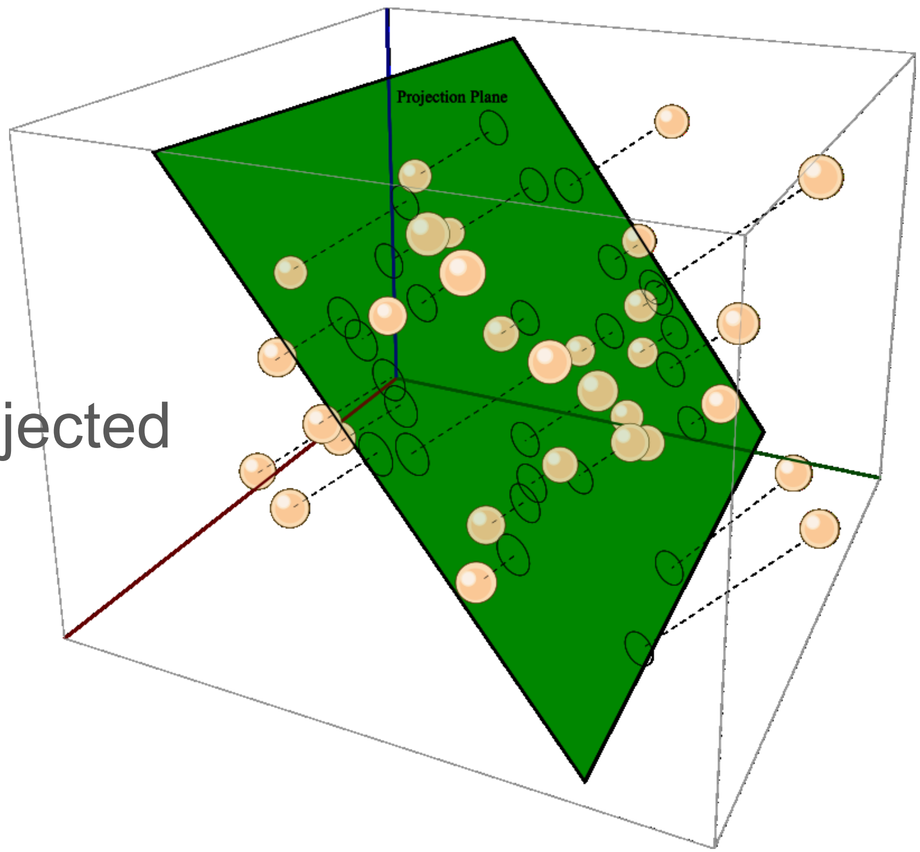
3D version of Face algorithm

- 2D Face cannot be used directly in 3D
- A 3D plane is created
  - Random plane
  - Source-dest-random point
  - ALSP



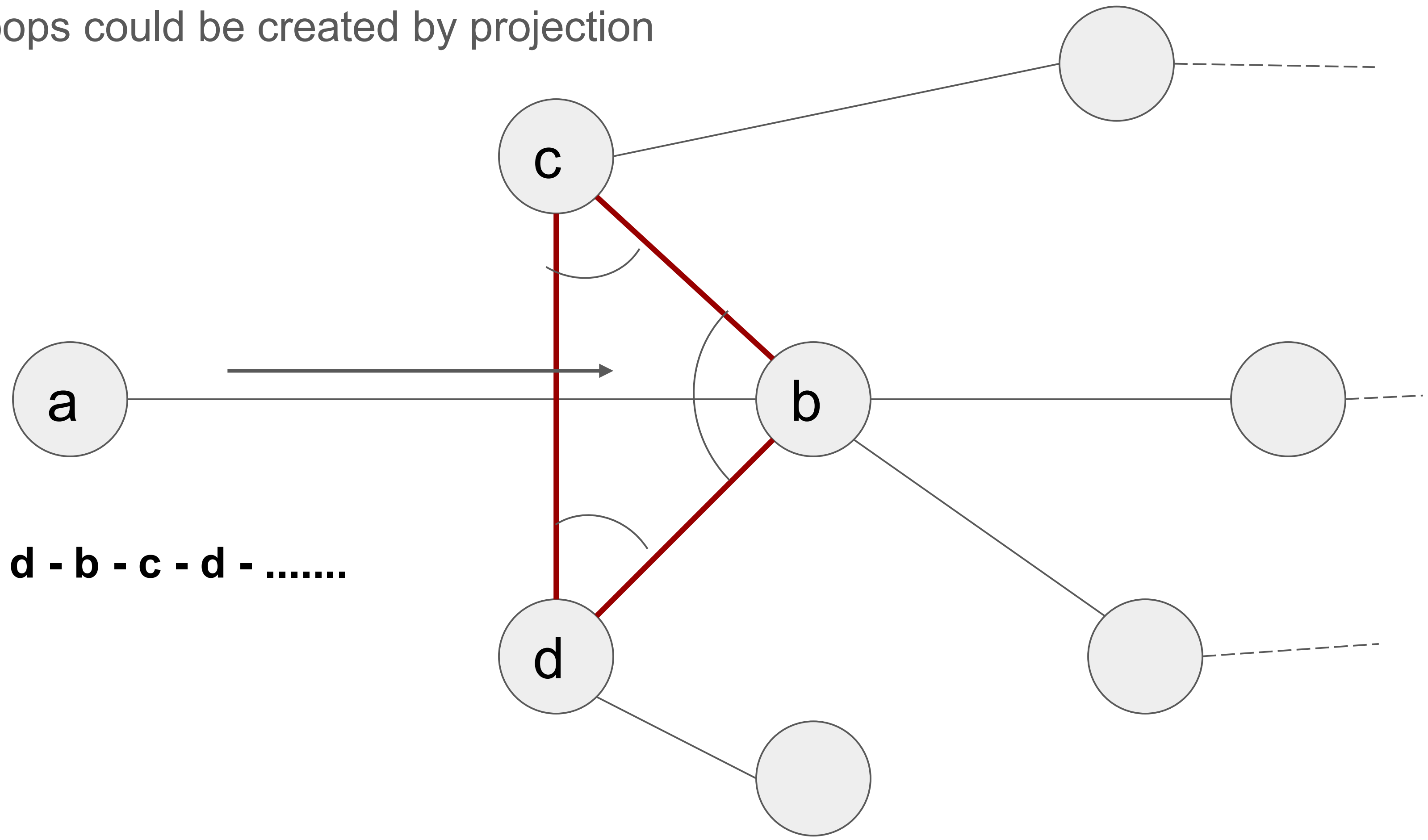
3D version of Face algorithm

- 2D Face cannot be used directly in 3D
- A 3D plane is created
  - Random plane
  - Source-dest-random point
  - ALSP
- Project nodes on a plane
- Start face routing on this projected graph



3D version of Face algorithm

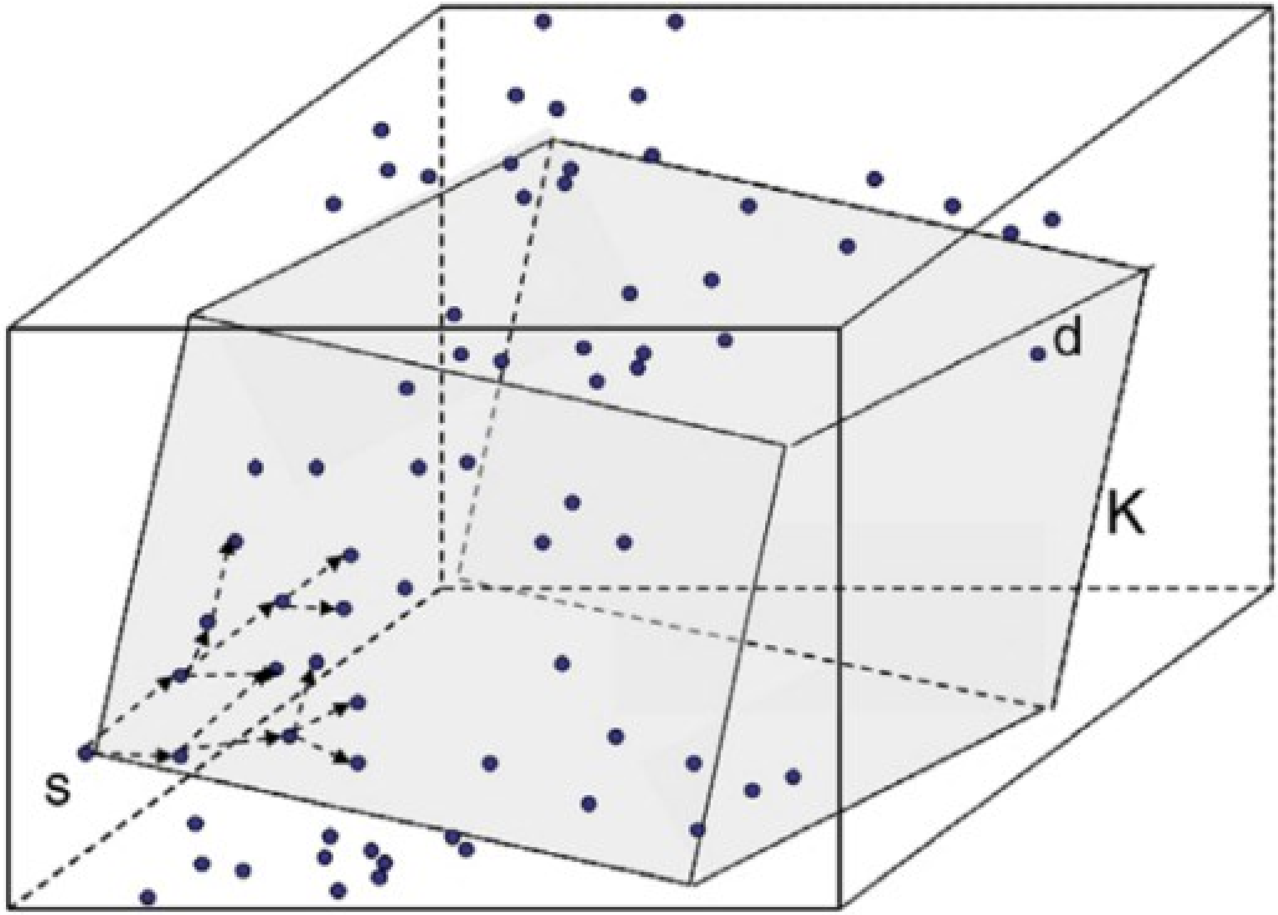
- Packet delivery is not guaranteed!!
  - Loops could be created by projection



a - b - c - d - b - c - d - ....

3D LAR

- 3D version of LAR



Performance Comparison Evaluation

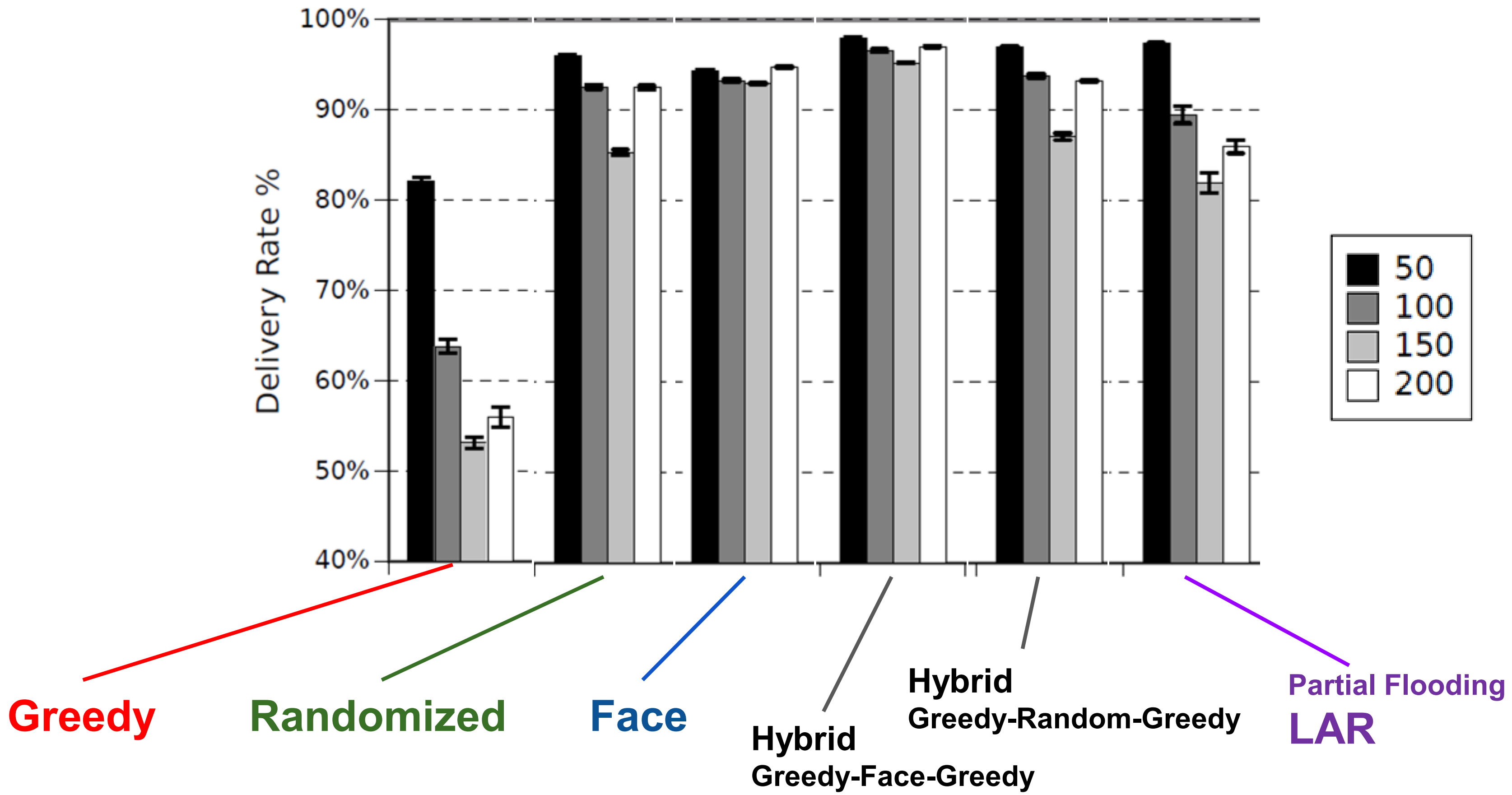
- NS-2 simulation environment
- Cube of 500 meters of side length
- Transmission range of 100 meters
- Network sizes: 50, 100, 150, 200 nodes
- Performance metrics
  - Delivery Rate
    - Percentage of delivered packets at the recipient
  - Path Dilation
    - Average ratio of the number of hops traveled to the minimum path length

- A. Bujari, C. E. Palazzi and D. Ronzani, "A Comparison of Stateless Position-based Packet Routing Algorithms for FANETs," in *IEEE Transactions on Mobile Computing*, vol. 17, no. 11, pp. 2468-2482, 1 Nov. 2018, doi: 10.1109/TMC.2018.2811490.

Performance results (3D topology)

Packet Delivery Rate %

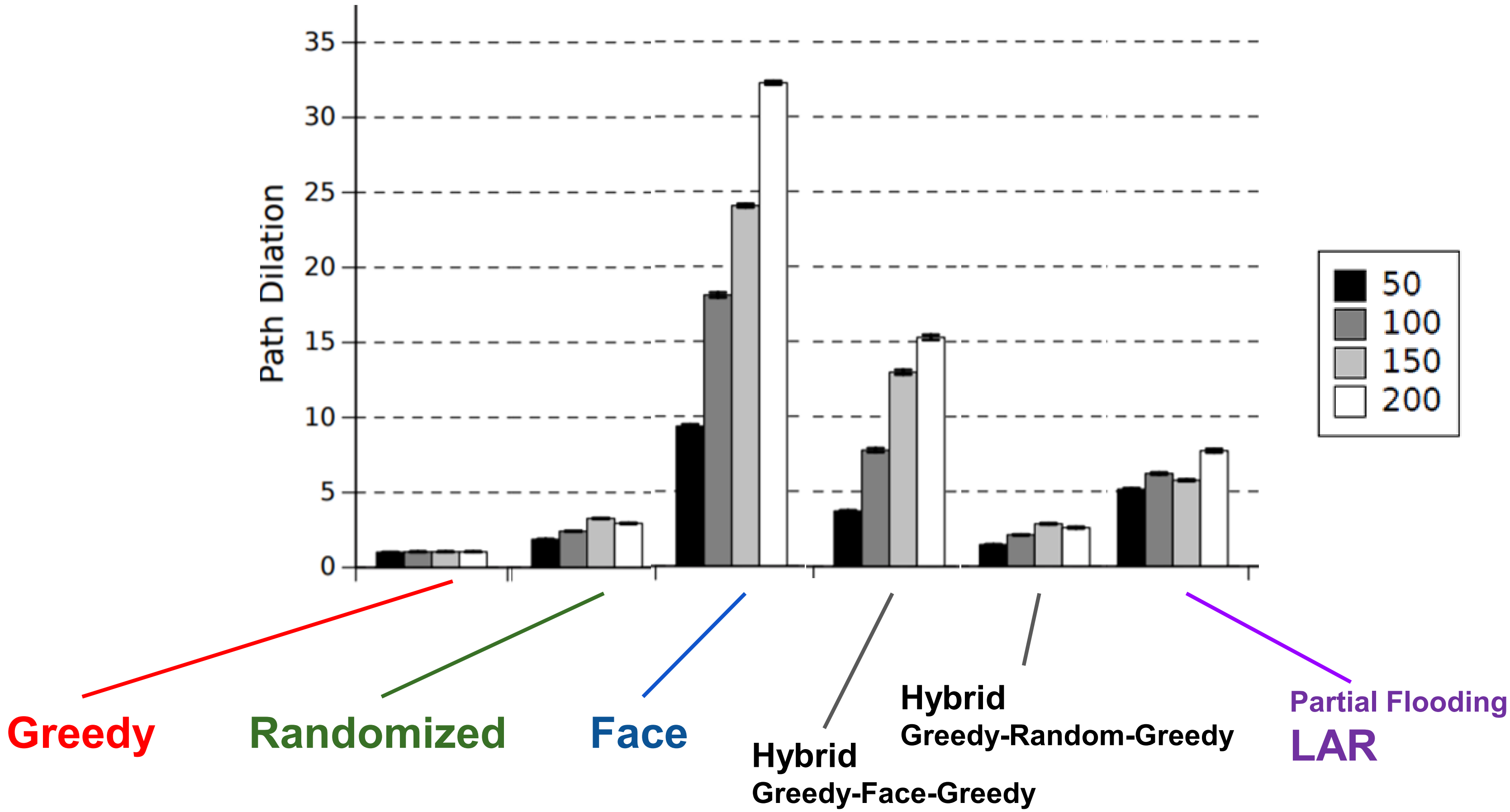
- Single Packet – 50, 100, 150, 200 nodes



Performance results (3D topology)

Path Dilation (#hops / # min path length)

- Single Packet – 50, 100, 150, 200 nodes



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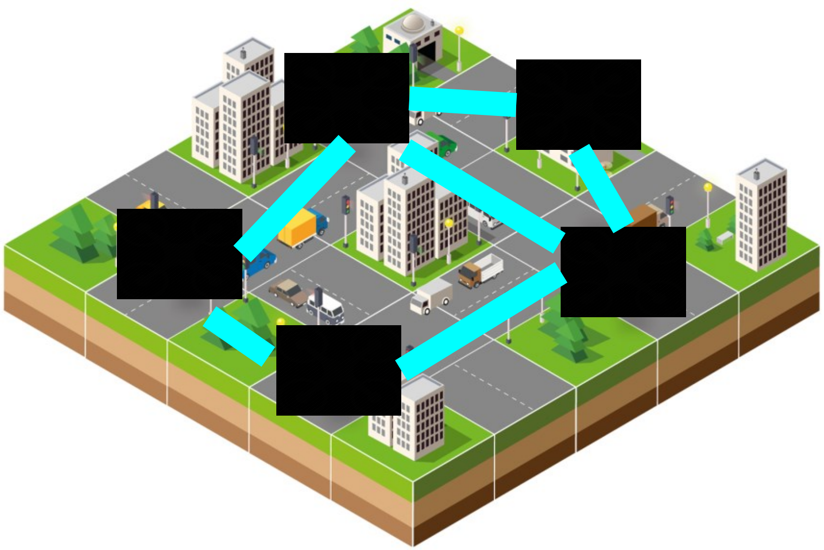
Performance results in IoV environment

Topology vs **Position**

- NS-2 simulations
- Urban environment
- Vehicles and UAVs
- Realistic scenario



- A. Bujari, C. E. Palazzi, D. Ronzani, "Would Current Ad-Hoc Routing Protocols be Adequate for the Internet of Vehicles? A Comparative Study", in IEEE Internet of Things Journal, 2018
- Bujari, M. Furini, F. Mandreoli, R. Martoglia, M. Montangero, D. Ronzani "Standards, Security and Business Models: Key Challenges for the IoT Scenario", Mobile Networks and Applications, (first online) Feb. 2017. ISSN: 1383-469X (print). ISSN: 1572-8153 (online)

Greedy Closer Request (GCR)

- A Hybrid Reactive and Position-based Approach to packet routing in mobile networks
    - Tentative to hybridize topology-based and position-based protocols in order to compensate for the shortcomings of each one
    - In particular we hybridize **AODV mechanism with Greedy protocol**
    - It is designed to
        - fill up the weak delivery rate of Greedy
        - reduce the control overhead generated by AODV
    - AODV acts like the recovery phase so far as Greedy gets stuck into a local minimum.

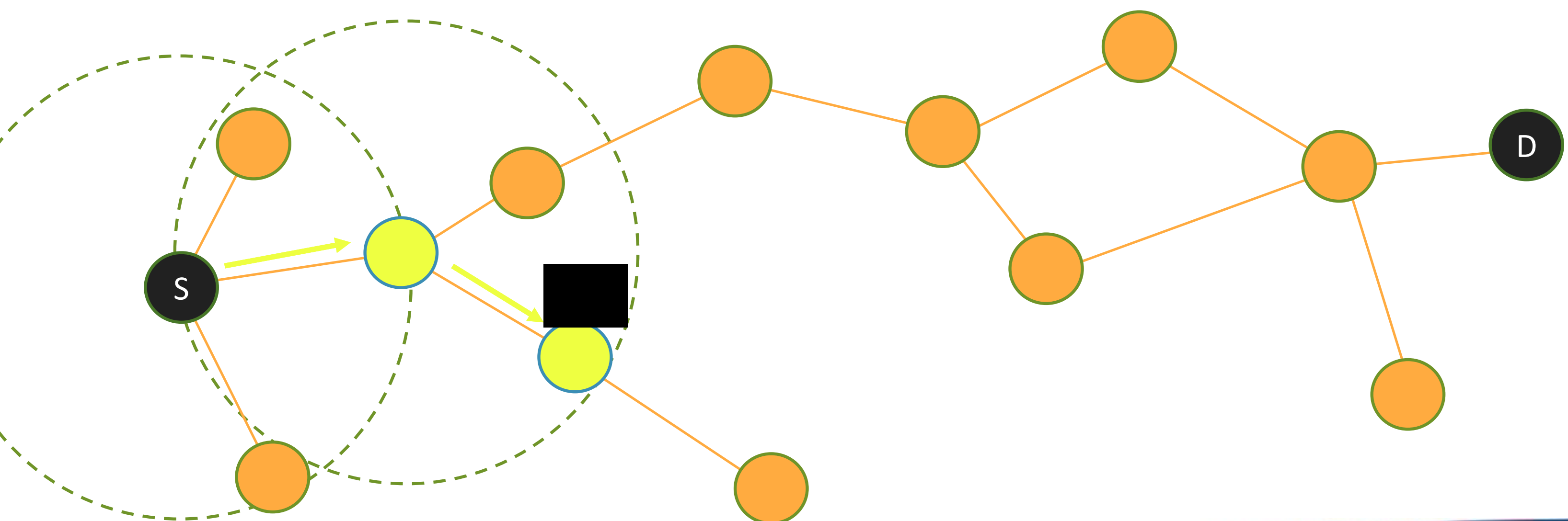
Greedy Closer Request (GCR)

Two phases

1. Start with Greedy, forwarding the packet to the closest node to the destination among its neighbors, until it arrives at the destination or a local minimum
2. If the packet reaches a local minima, AODV phase starts sending request packets in order to find a path to recover from the local minima

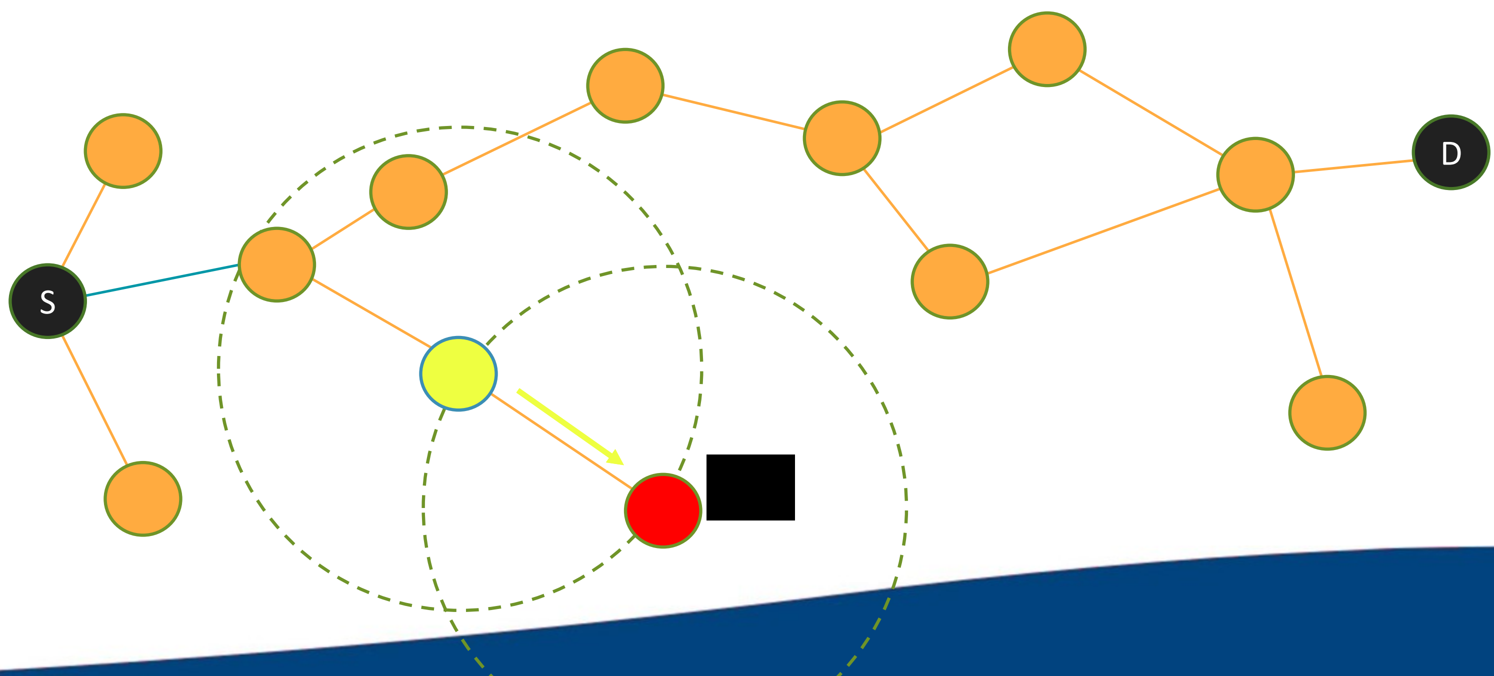
1. Greedy phase

- Location information is received by Hello messages containing neighbors' coordinates
- At each node, Greedy finds the closest node towards the destination among the node's neighbors



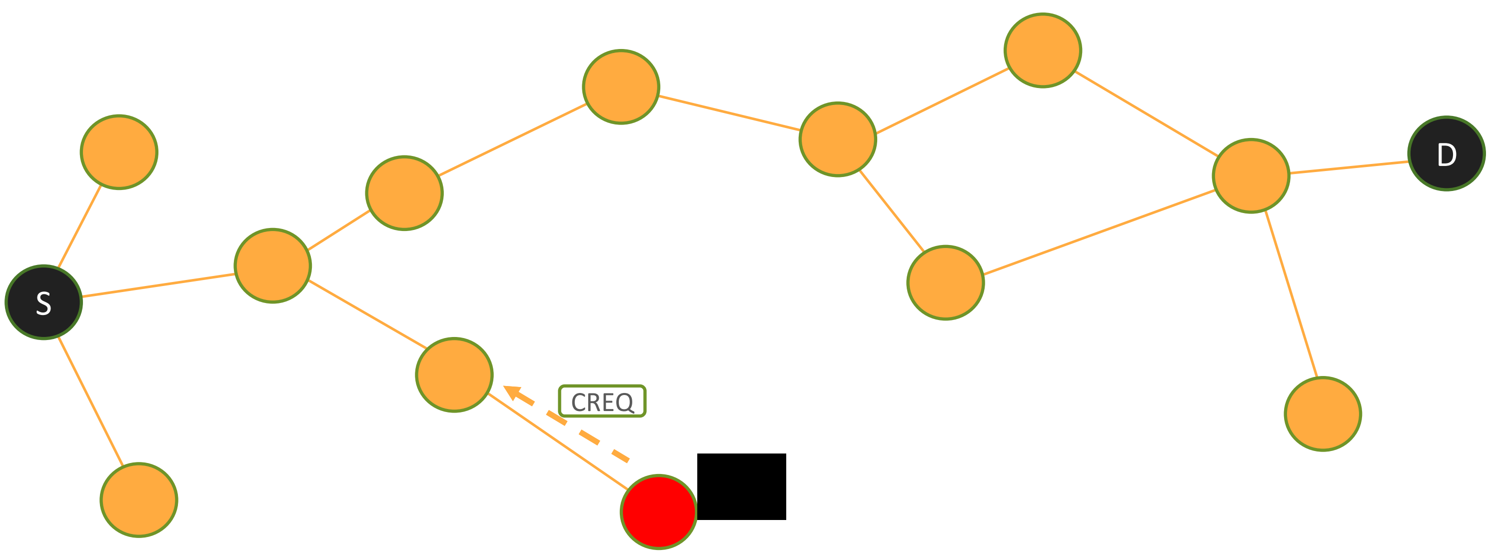
1. Greedy phase: local minimum

- If the packet arrives at a local minimum (a node where there is no local neighbor closest to destination), the GDV switch to AODV phase



2. AODV phase (1)

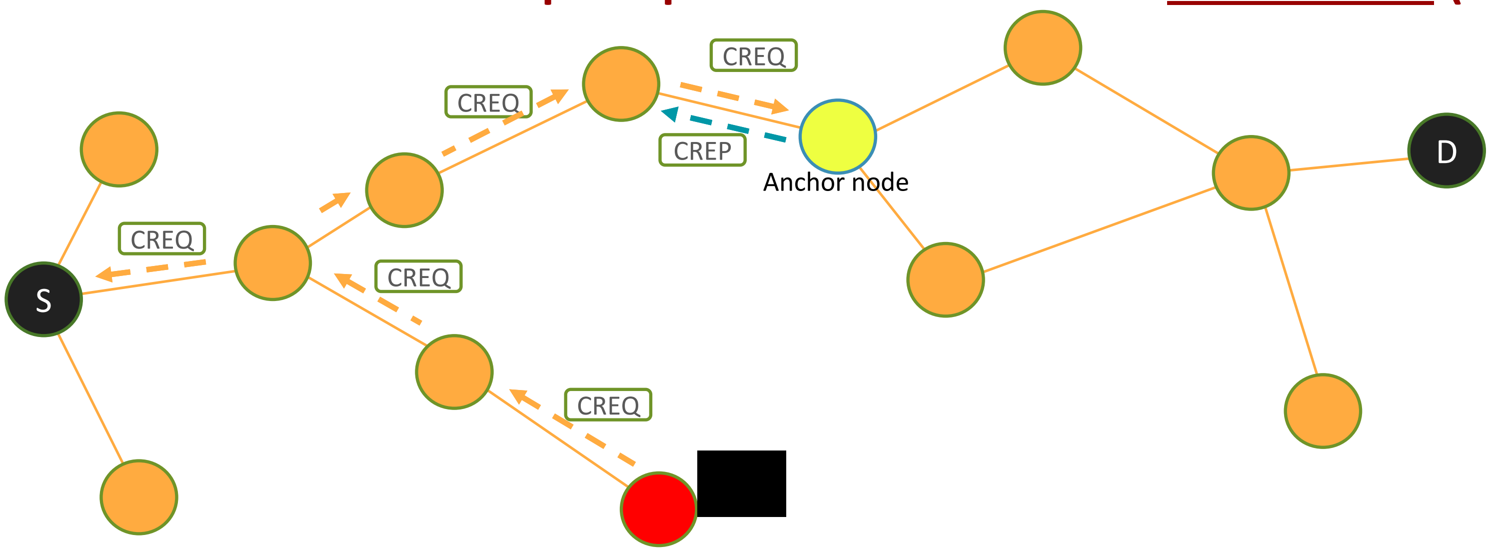
- In this phase, the local minimum node start to send in broadcast a Closer Request Packet (CREQ), looking for a closer node to the destination than the local minimum itself



2. AODV phase (2)

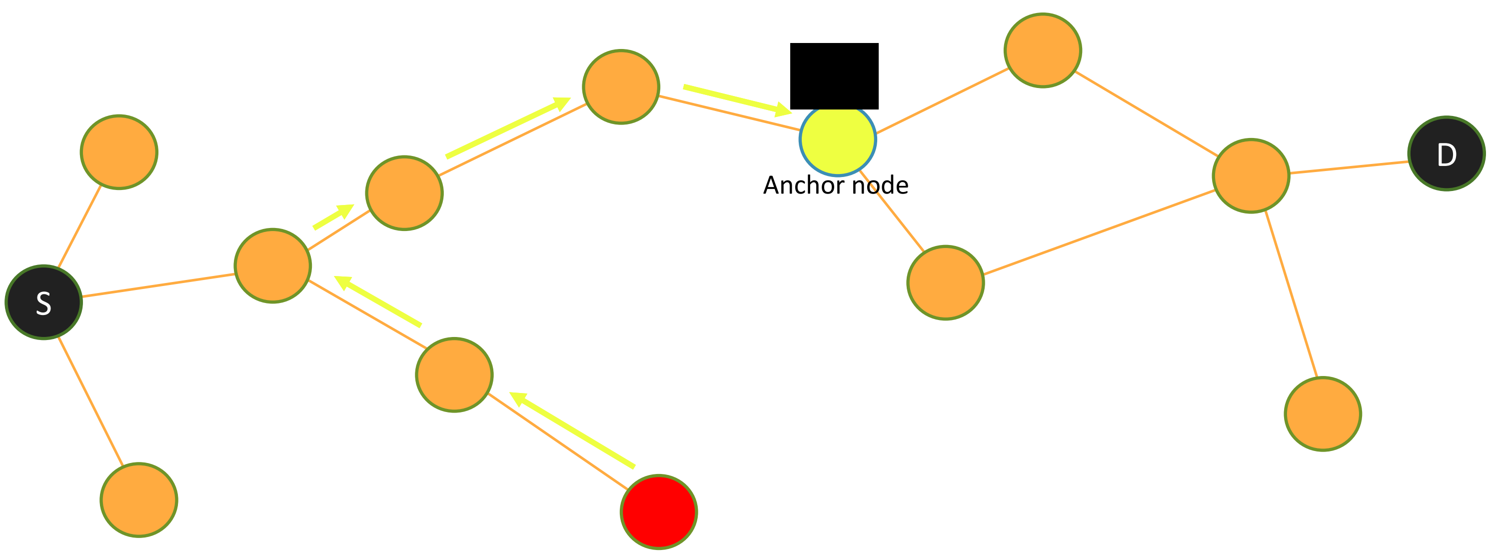
- When a node receiving the CREQ packet is closer to D than the local minima (we call it Anchor Node), it sends a Closer Reply Packet (CREP) to the local minima
  - When an intermediate node receives the CREP, it sets up a forward path entry to the anchor node in its route table (like AODV)

The request packet is sent within a limited area (max hops)



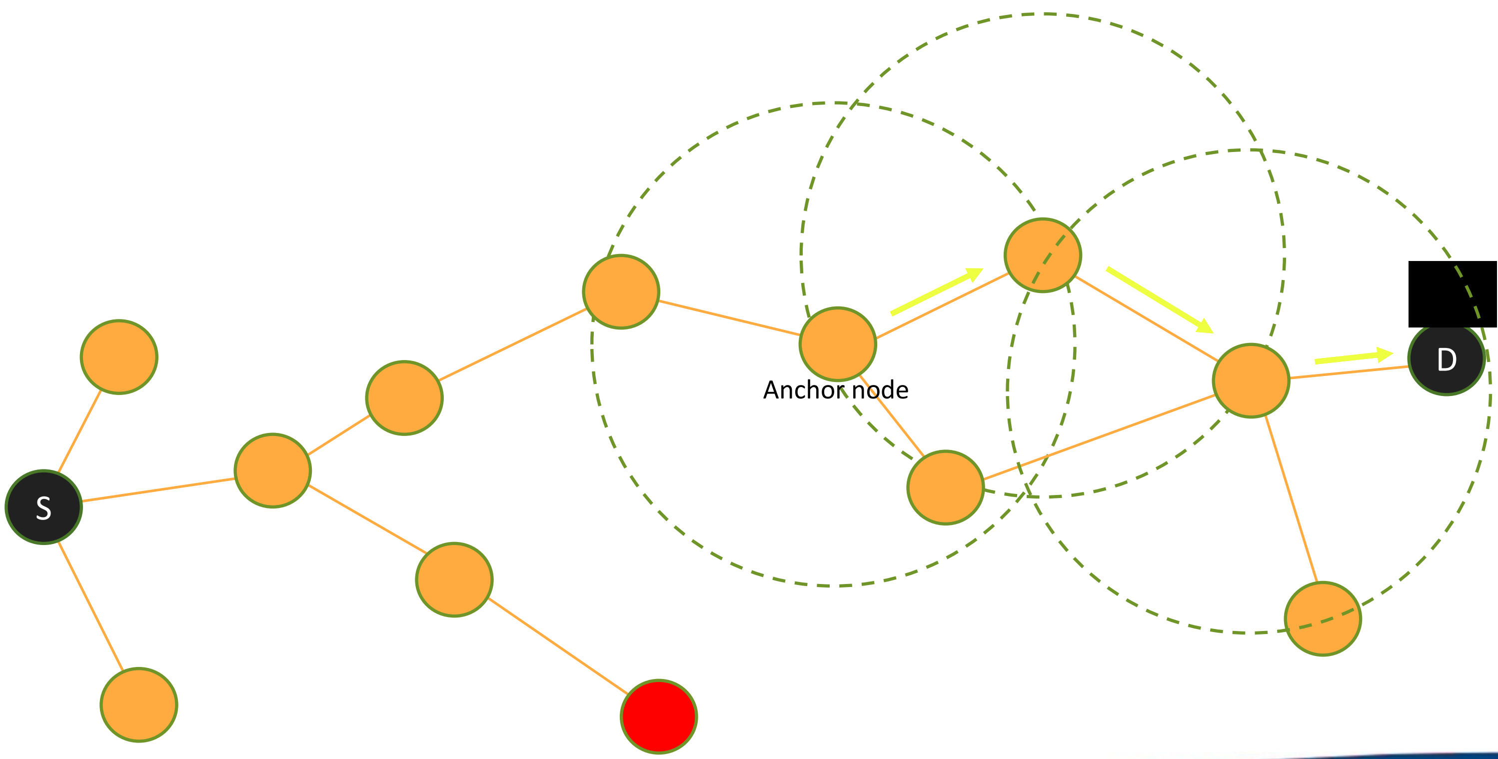
2. AODV phase (3)

- When the local minimum receives the CREP, it forwards the DATA packet following the path from itself to the Anchor Node

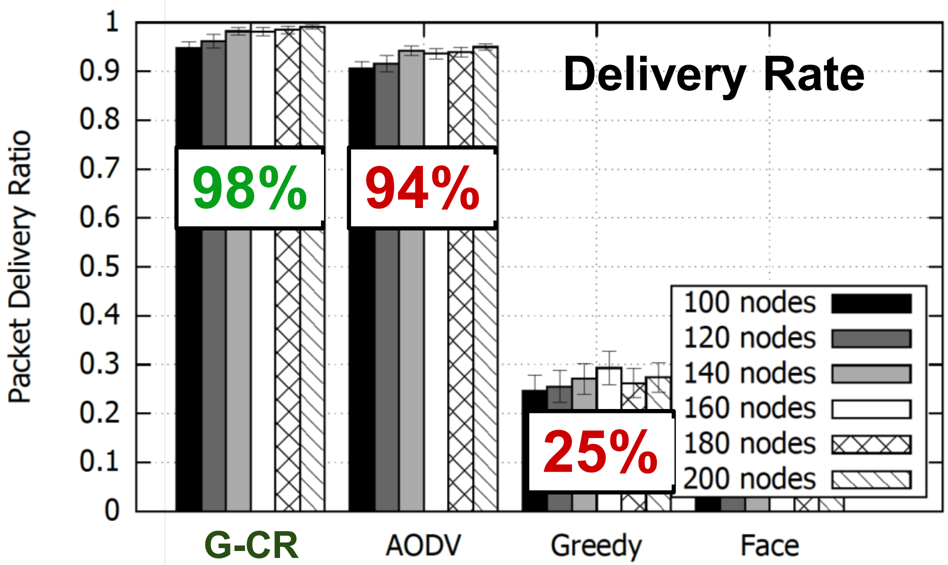


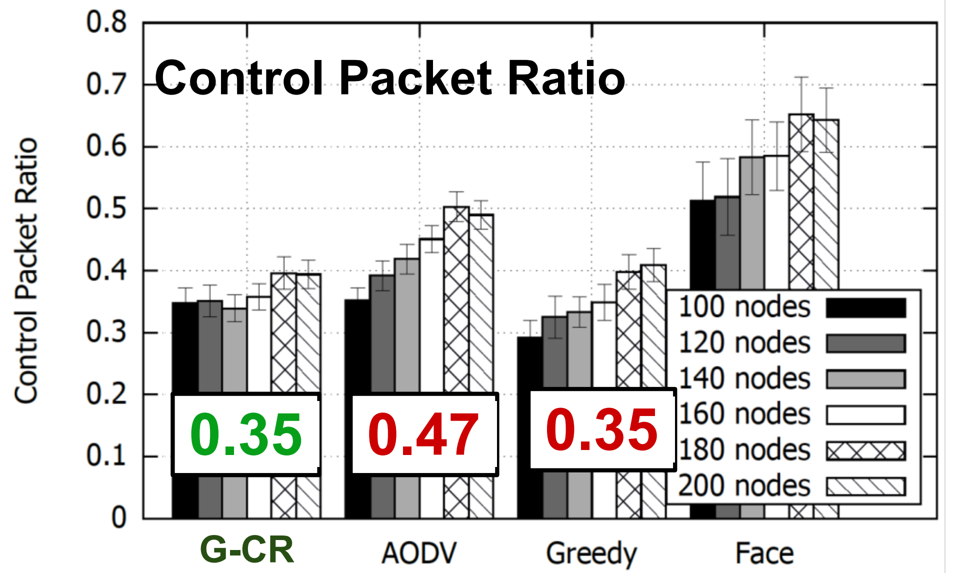
Return to 1. Greedy phase

- At this point Greedy is restored



Performance Outcomes





Control Packet Ratio: $\frac{\text{Control packets transmitted}}{\text{Total packets transmitted (data + control)}}$

- General improvement of performance using **hybrid solutions**, in scenarios with dynamic density
  - Low density -> Closer Request phase
  - High density -> Greedy phase

- A. Bujari, C. E. Palazzi, D. Ronzani, "A Hybrid Reactive and Position-based Approach to Packet Routing in 3D Topology Networks". *In Proc. of 2018 Wireless Days (WD'18),* Dubai, United Arab Emirates, 2018

Memory-based routing approaches

- **Stateless** routing protocols are based on **current** local information
  - Stateless characteristic makes them more scalable

HOWEVER

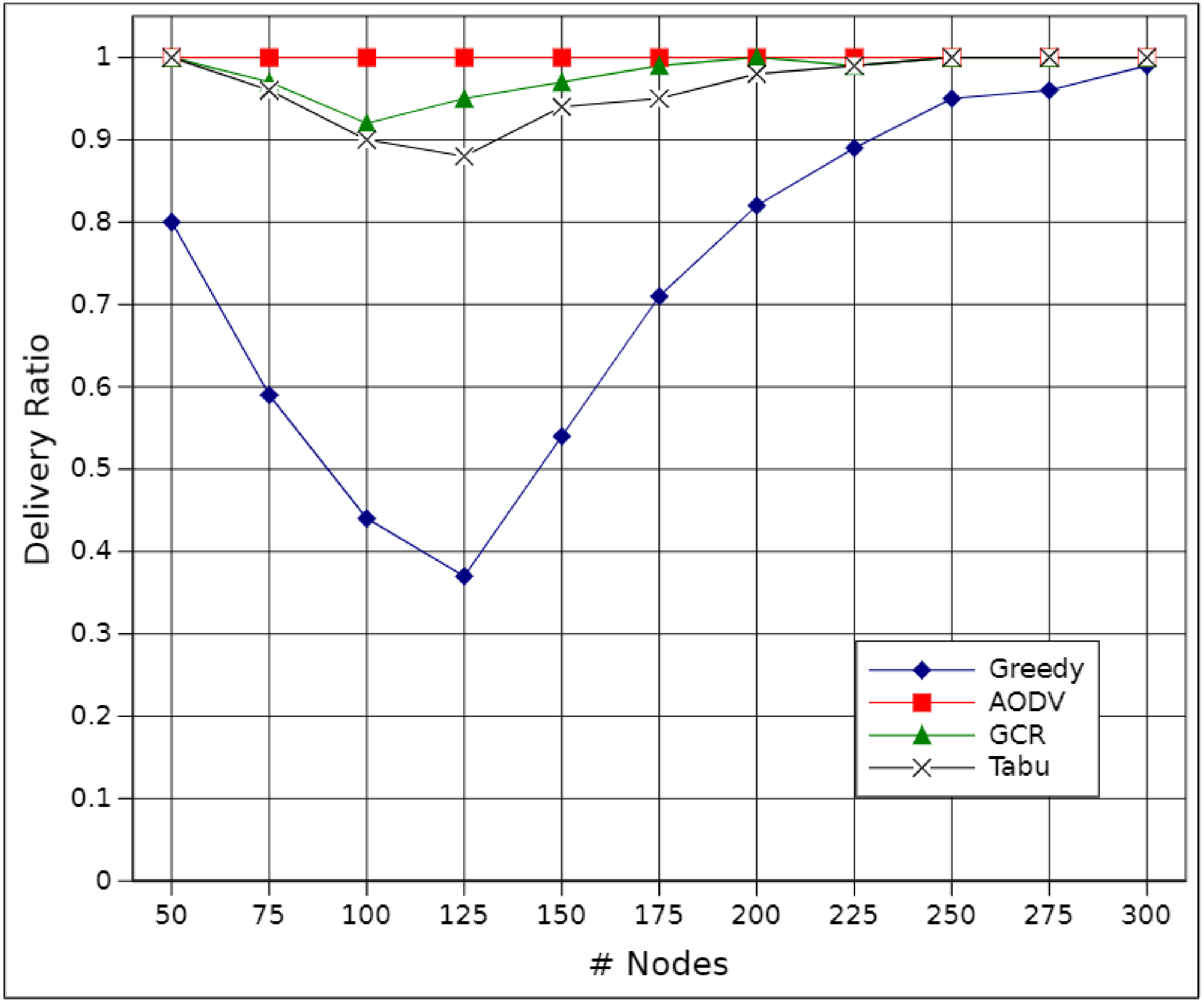
Make use of a little **memory** could help to hold more information and make routing protocols more efficient

- **Memory-based routing protocols**
  - Topology or past actions information is stored into
    - **Nodes**, or
    - **Packets**
  - Typical approach
    - Store the travelled nodes id into the packet's header
    - Avoid to return back

Location Tabu-based routing approach

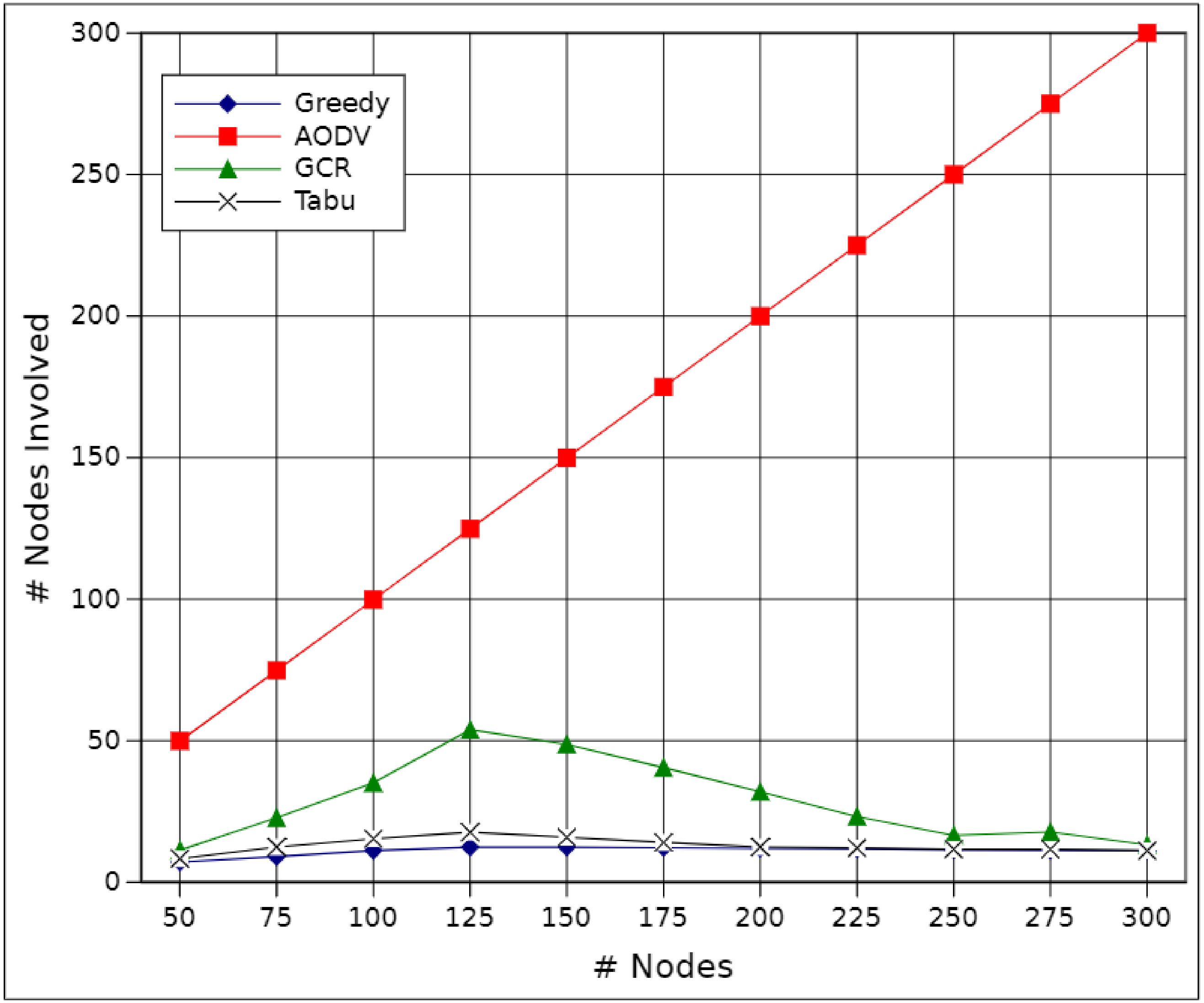
- **Location Tabu-based Routing Protocol**
  - Greedy algorithm as packet forwarding
  - Tabu List set on the data packet header
    - Stores the past travelled nodes
    - The nodes in the tabu list are not chosen as next hop
  - Tabu List paradigm makes Greedy more efficacy in terms of delivery
    - If the packet reaches a local minimum, Greedy chooses the next best node
- Algorithm steps
  1. Start with sabu list size L (e.g., 3)
  2. Perform Greedy algorithm
     a. Put the current node into the tabu list
     b. If all the current neighborhood is into the Tabu list
        i. Reset tabu list (tabu list gets empty)
        ii. Restart Greedy
     c. If the packet doesn't get more close
        i. Increase the tabu list size L (e.g., L = L x 2)

Performance Results - Tabu Routing (1)



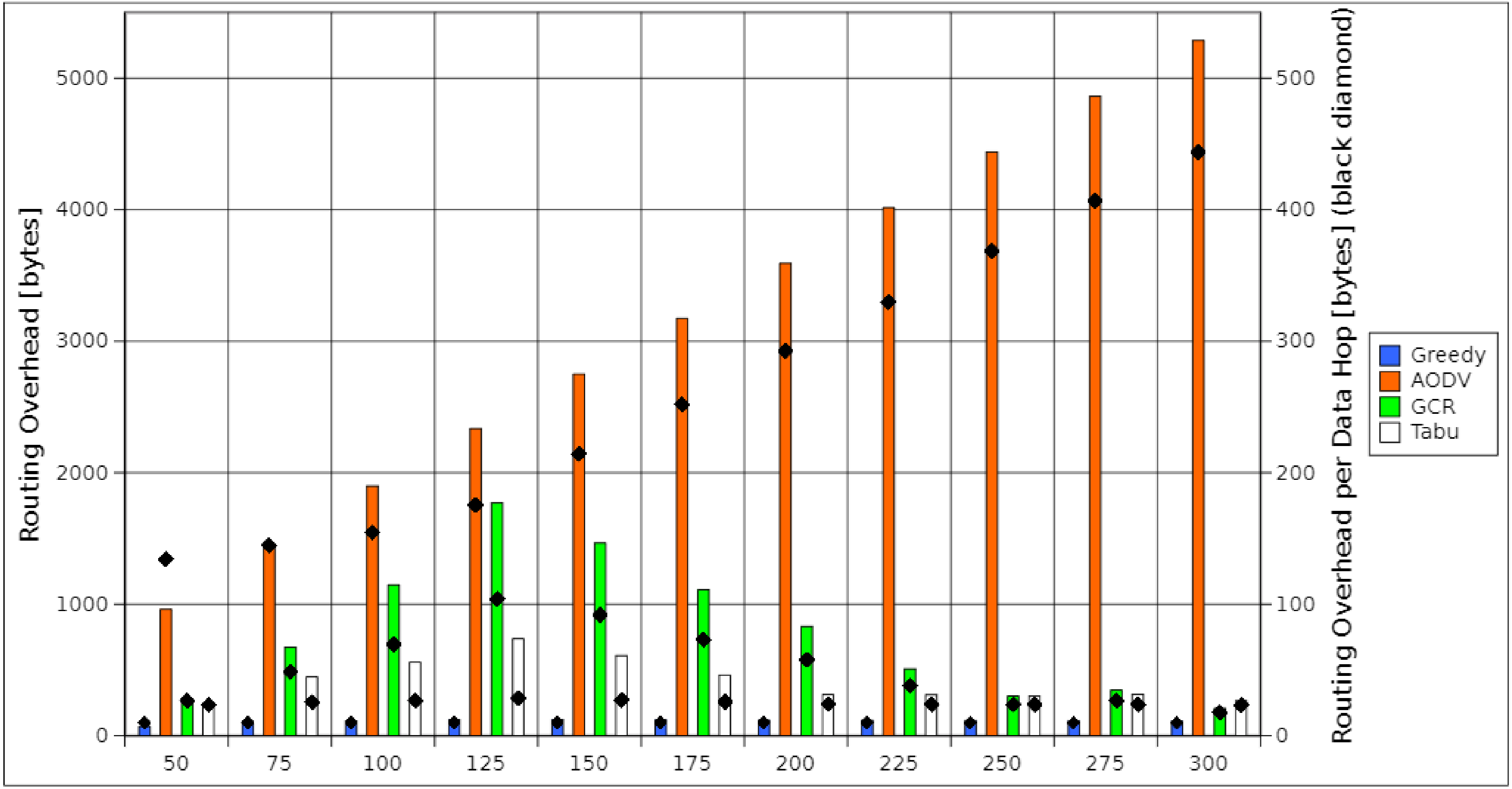
(a) Delivery ratio

Performance Results - Tabu Routing (2)



(c) Number of involved nodes in the routing process (number of nodes that actively transmit at least one routing or data packet.

Performance Results - Tabu Routing (3)



(e) Routing overhead in terms of bytes forwarded for the routing process. The diamond refers to the right axis, showing the bytes overhead for a single data packet hop.

Some References

- I. **Bekmezci**, O. K. Sahingoz, S. Temel, "Flying Ad-Hoc networks (FANETs): A survey", *Ad Hoc Networks*, vol. 11, no. 3, pp. 1254-1270, Mar. 2013.
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