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
In recent years, drones business employs a tremendous growth, with estimates of over 1.5 billion sold by 2015.
Application of drones

40 Uses for Drones
Practical applications for Unmanned Aerial Vehicles

Military
Civil
Business
Scientific Research
Hobby

Emergency Services & Disaster Recovery
1. Disaster & hazmat monitoring
2. Emergency delivery (medicine, equipment, supplies...)
3. Emergency response coordination (situational awareness)
4. Disaster relief & post-disaster assessment
5. Search & rescue

Urban Planning, Real Estate, Architecture & Engineering
21. Construction management
22. Environmental design (architecture, engineering, landscape architecture, urban design)
23. Mapping (archaeology, resource, topography...)
24. Marketing
25. Site analysis, planning & design

Security Services
6. Crime scene investigation
7. Criminal surveillance & tracking
8. Police response coordination
9. Security surveillance
10. Training & evaluation

Media & Communications
26. Advertising & marketing
27. Art (commercial design, fine art, social practices...)
28. Entertainment (film, television, Internet...)
29. Investigative journalism
30. News photography & videography

Agriculture, Aquaculture, Silviculture, Viticulture
11. Chemical & biological monitoring (irrigation, pesticides, treatments...)
12. Flood & fire detection & monitoring
13. Inventory & records
14. Pest & disease detection & treatment
15. Precision operations & management

Business & Commerce
31. Aero-technology / robotics research & development
32. Documentation (accident reporting, building verification, site status...)
33. Exploration (water, oil, gas, mineral...)
34. Inspection (infrastructure, structural, industrial...)
35. Pick-up & delivery services

Environmental Management
16. Environmental hazard assessment
17. Environmental impact assessment & compliance
18. Invasive species & pest control
19. Scientific research
20. Wildlife & habitat monitoring & protection

Recreation & Entertainment
36. Exploration
37. Group activities & events
38. Hobby (do-it-yourself & kit building)
39. Personal photography & videography
40. Remote control flying

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The potential value of unmanned aerial vehicles (UAVs) is extraordinary. Privacy and safety issues must be addressed rationally and within the larger context of these public and private benefits.

Stephens Planning & Design LLC
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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)

- **Scope:** military, transportation, environmental monitoring, crisis and disaster management
Flying Ad-Hoc Networks (FANETs)

Two parts:

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

![Diagram of flying ad-hoc networks](image)
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 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..
There are some limitations also using these protocols in FANETs, especially with
- Limited bandwidth
- Limited energy
- Limited memory

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 (**Greedy**)
  - 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

**Greedy approach need to be binded with a recovery strategy**
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 $\rightarrow$ 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 sends 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

Packet Delivery Rate %

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

Performance results (3D topology)
Performance results (3D topology)

Path Dilation (\#hops / \# min path length)

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

![Graph showing path dilation for different algorithms and packet sizes.](image)
Performance results in IoV environment

**Topology vs Position**

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

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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
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)
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 \(\rightarrow\) Closer Request phase
  - High density \(\rightarrow\) Greedy phase

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