UAV-assisted Multi-hop Multi-path Routing in Millimeter Wave Networks

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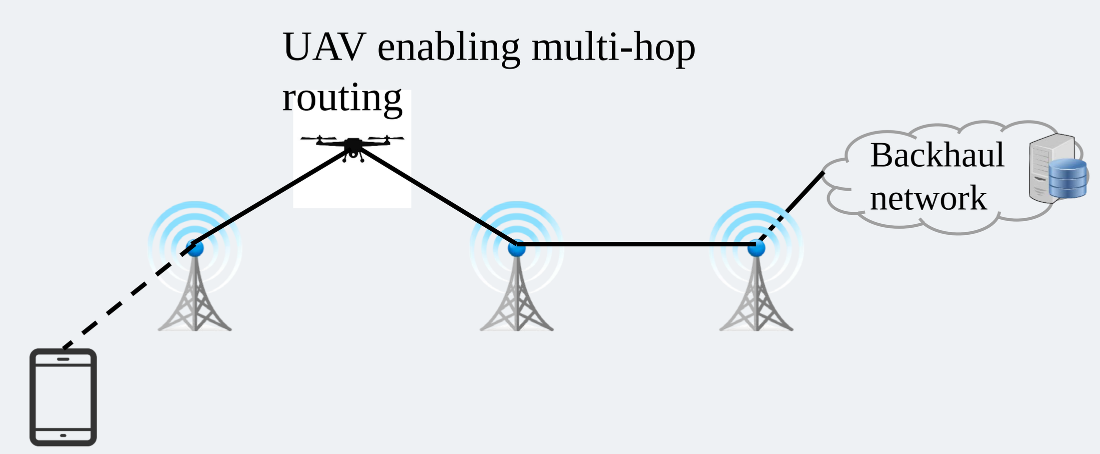
5th NSF Millimeter-Wave RCN Workshop, Jan. 2019

Motivation and Objective

- **Motivation:**
  - High-bandwidth Millimeter Wave (**mmWave**) communication can satisfy the demand for large data rate.
  - However, it suffers from **short-range** communication which can lead to backhaul network disconnection.



- **Solution Idea:** Network connectivity and long-range **multi-hop multi-path** mm-wave communication can be enhanced via the **deployment of UAVs.**
- **Objective:**
  - We aim to find the optimal **locations** and transmission **powers**, for the minimum number of needed UAVs, which to maximize the network **connectivity** while maintaining a specific **end-to-end (E2E) delay** constraint.
  - It is a PHY/NET cross-layer optimization problem.

Problem Formulation and Proposed Solution

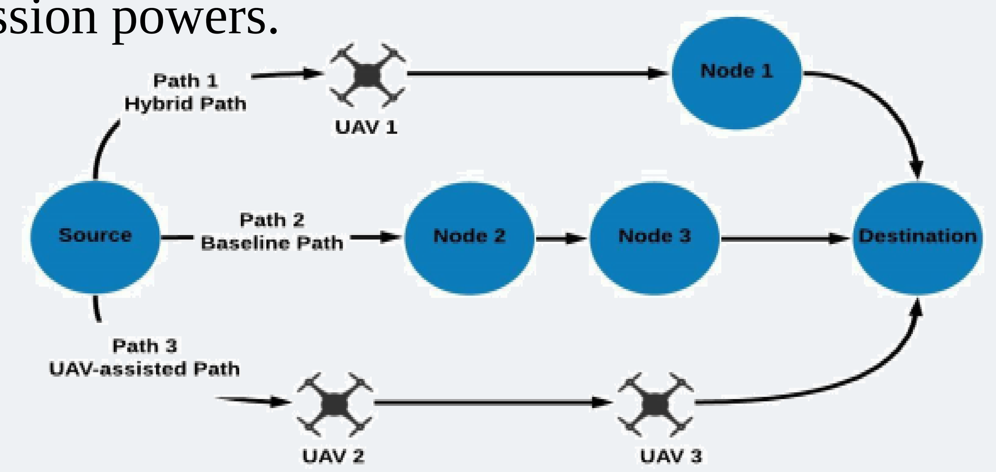
- Network connectivity is characterized by the second smallest eigenvalue (**Fiedler value**) of its graph Laplacian matrix, $\lambda_2(L)$.
- The **E2E delay** (D_{ETE}) includes transmission delay, propagation delay, and queuing delay.
- A constrained **optimization** problem, aiming to find the minimum number of **K** UAVs, their locations, and transmission powers, is formulated as

$$\max_{U,K,P} \lambda_2(L'(U))$$

$$s.t. D_{ETE} \leq D_{th}$$

where U is the discrete 3 x K UAVs position matrix and D_{th} is the ETE delay threshold.

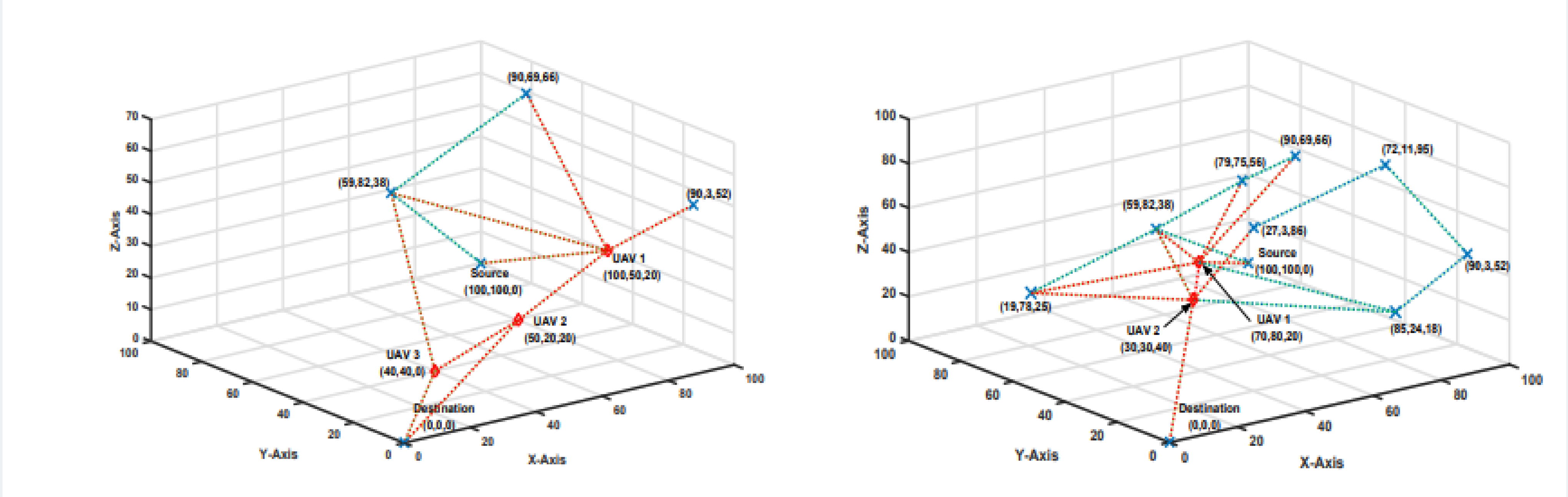
- The optimization problem is relaxed as a convex **Semi-Definite Programming** (SDP) problem, which is numerically solved to find the UAVs positions and transmission powers.
- Modified **Disjoint vertex routing** technique is then used to create multi-path multi-hop routes through the nodes, given the new locations of the UAVs.



* The work of M. A. Abdel-Malek and A. S. Ibrahim is supported in part by the **National Science Foundation** under Award No. **CNS-1618692**. For further information, please contact Dr. Ahmed Ibrahim at **aibrahim@fiu.edu**.

Results

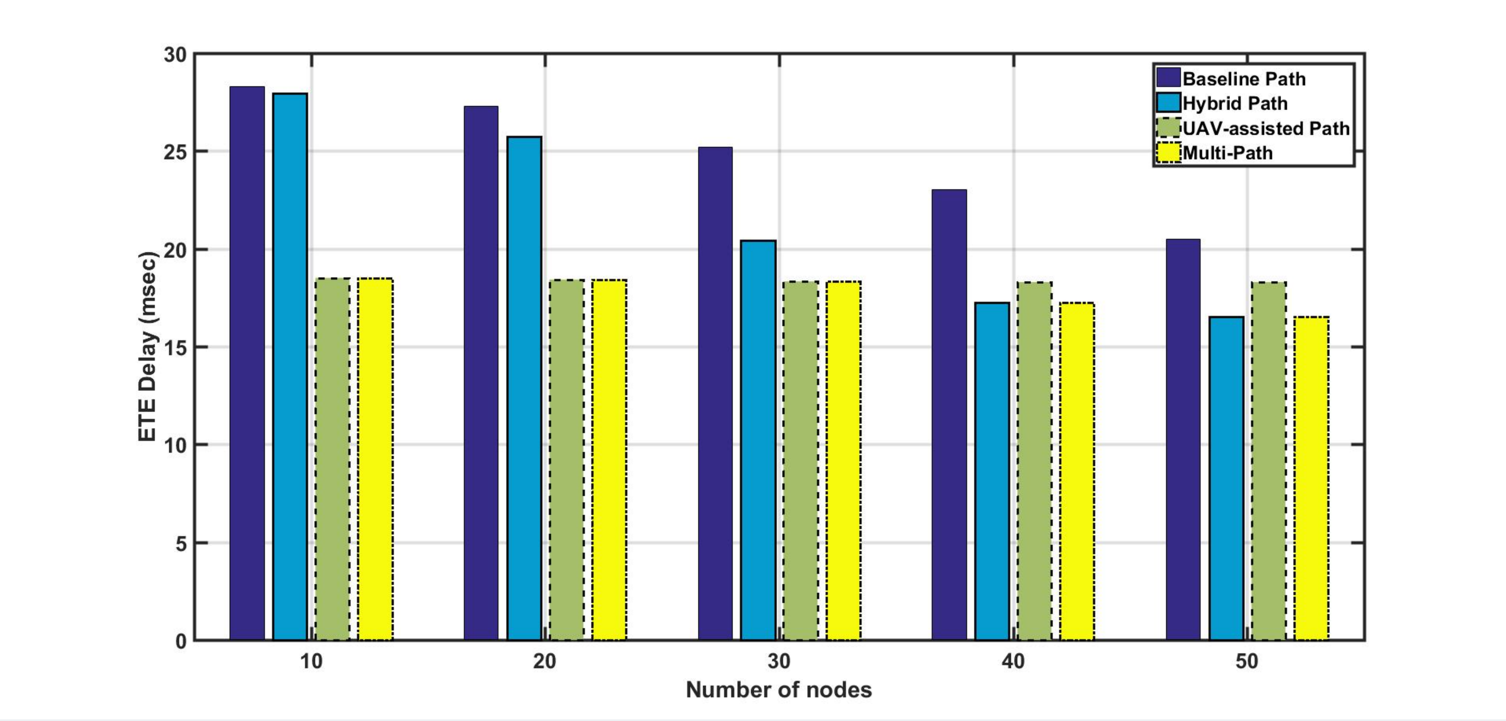
- **Simulation Modeling:** **NS3** simulation platform is used to model an ad-hoc network with N nodes that are communicating using **IEEE 802.11ad** protocol.



(a) $N = 5$ (b) $N = 10$

- UAVs positioning and routing options are shown for 2 network sizes (N= 5 or 10 nodes)
- Having a larger network size decreases the need for UAVs from 3 to 2.

- Baseline path only utilizes the original network nodes.
- Hybrid path utilizes both the original nodes and UAVs.
- UAV-assisted path only utilizes UAVs.
- Multi-path approach uses both the Hybrid and UAV-assisted paths in parallel.



- UAVs **decreases** the E2E delay.
- The ETE delay of the multi-path scheme is equal to the minimum ETE delay over the Hybrid and UAV-assisted paths.

Conclusion

- The proposed work aims to increase the communication **range** and **reliability** of mm-wave communications by deploying additional UAVs.
- We maximize the connectivity of the network by finding the minimum number of UAVs, their positions, and transmission powers, while maintaining an ETE delay constraint.
- Promising results are shown, based on the NS3-based implementation of IEEE 802.11ad protocol.