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

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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

$$\max_{U,K,P} \lambda_2(L'(U))$$
$$s.t. \quad D_{ETE} \leq D_{th}$$

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.

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

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.