Midterm Update

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1. Update Overview

This project focuses on establishing an emergency communication network using a multi-UAV network in disaster and military scenarios where conventional infrastructure has been destroyed. When local ground base stations (GBS) are unavailable or inaccessible, a UAV-based Flying Ad Hoc Network (FANET) is deployed to maintain communication using a hybrid network structure. The key goal is to connect UAVs to an operational GBS and relay LTE/5G services to ground users via an airborne base station UAV.

2. Network Components

The network consists of the following key components:

1) Local Ground Base Station (GBS)

- Function: Acts as the primary backhaul for the UAV network.
- Connection: Directly communicates with a gateway UAV.
- Purpose: Provides access to the internet and external communication networks.

2) Gateway UAV (GBS-to-FANET Connection)

- Function: Serves as the primary link between the GBS and the mesh UAV group.
- Operation: The UAV closest to the GBS dynamically assumes the gateway role.
- Purpose: Relays network traffic between GBS and other UAVs in the FANET.

3) Mesh UAV (FANET Communication Nodes)

- Function: Maintains network connectivity between UAVs and enables multi-hop relaying.
- Operation: Uses mesh networking to find the optimal path for packet transmission.
- Purpose: Expands network coverage and prevents single points of failure.

4) LTE/5G Base Station UAV (Airborne Base Station)

- Function: Directly provides LTE/5G connectivity to ground users.
- Operation: Acts as a mobile base station, ensuring direct smartphone and device compatibility.
- Purpose: Provides internet and real-time communication to end-users.

5) Ground Users (Smartphones, Military Devices, IoT Sensors)

- Function: Connects to the network via the LTE/5G base station UAV.
- Operation: Uses existing LTE/5G-enabled devices to communicate without additional hardware.
- Purpose: Ensures immediate access to communication services in an emergency scenario.

3. Simulation using OMNeT++

We implement and test our proposed network architecture using OMNeT++, focusing on dynamic gateway UAV selection, mesh UAV routing, and caching mechanisms to optimize network performance. For the OMNeT++ simulation, the following network modules are implemented:

Network Modules:

1. Ground Base Station: Provides an internet backhaul and connects to the gateway UAV.
2. UAV:
   - Gateway UAV: Directly connects to the GBS and relays data to the FANET.
   - Mesh UAV: Maintains network links and optimizes packet routing.
   - LTE/5G UAV: Serves as an airborne base station, ensuring connectivity for ground users.
3. Ground User: Represents smartphones, military terminals, and IoT devices.

Network Model Concept:

`Local GBS ↔ Gateway UAV ↔ Mesh UAV ↔ LTE/5G Base Station UAV ↔ Ground Users`

4. Network Operation & Data Flow

Step 1: Dynamic Gateway UAV Selection

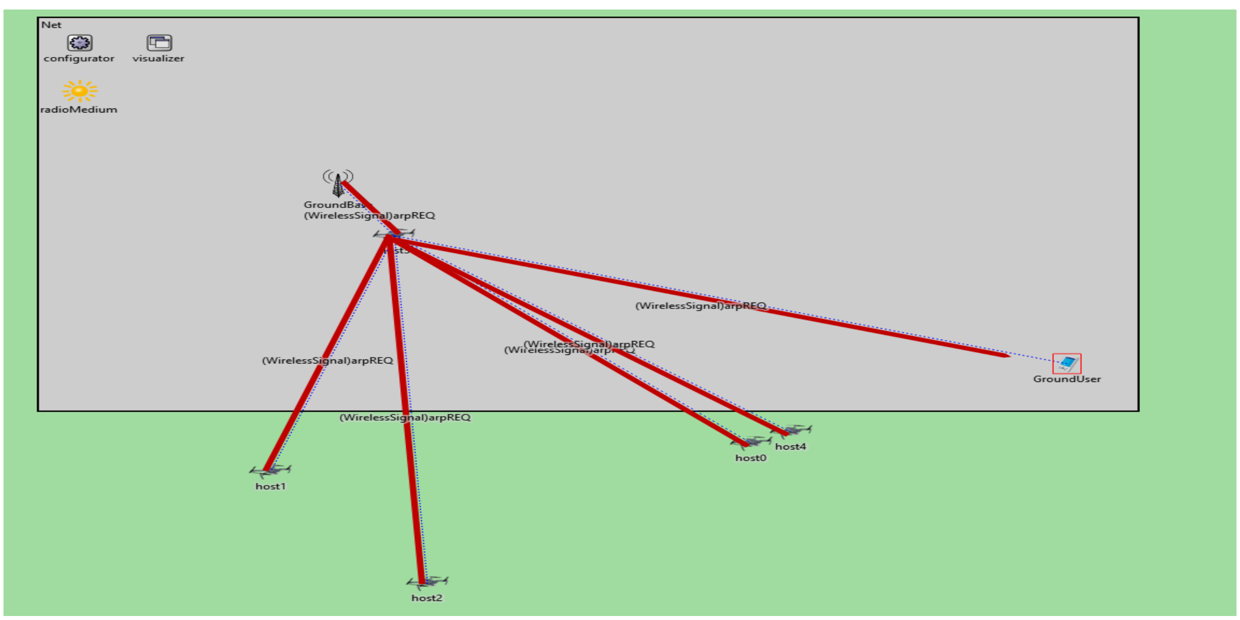
- The UAV closest to the GBS is automatically selected as the gateway UAV.
- If the gateway UAV moves away, another UAV dynamically assumes the role.

Step 2: Mesh UAVs Relay Data Within FANET

- Mesh UAVs establish a multi-hop network to ensure efficient data delivery.
- Uses optimized routing protocols to minimize latency and packet loss.

Step 3: LTE/5G UAV Provides Direct Connectivity to Ground Users

- Mesh UAVs forward data to the LTE/5G UAV, which acts as an airborne base station.
- Ground users connect to this UAV using standard LTE/5G signals, enabling direct internet access.



This OMNeT++ simulation illustrates the network operation in a UAV-assisted communication system. UAV3, the closest UAV to the Ground Base Station (GBS), is automatically selected as the gateway UAV. It establishes a primary connection with the GBS and relays data to other UAVs in the network. The thick red lines represent active wireless communication links, while the dotted blue lines indicate routing paths for network packets. The GroundUser node, representing a mobile ground unit, is connected via multiple UAV hops through the mesh network.

5. Encountered Problems

1. **Trade-off Between Speed, Stability, and Coverage in 3G → LTE → 5G**

- [ ] 3G provides wide-area coverage but has relatively low data transfer speeds.
- [ ] LTE and 5G offer significantly faster speeds, but their coverage is limited, and they are more susceptible to signal attenuation.
- [ ] Particularly, 5G using mmWave is highly vulnerable to obstacles, making it challenging for a single UAV to provide stable coverage over a wide area.
- [ ] A complementary approach is required to maintain network reliability while delivering high-speed communication in UAV-based networks.

2. **Gateway UAV Overload Issue**

- [ ] In a UAV-based network, the gateway UAV serves as the only direct connection to the GBS, leading to a potential traffic bottleneck.
- [ ] If overloaded, the network may experience packet loss, increased latency, and potential disruptions.
- [ ] Furthermore, UAVs operate on limited battery power, and continuous data transmission could lead to excessive energy consumption.
- [ ] A solution is required to prevent gateway UAV congestion and distribute network load efficiently.

3. **Traffic Congestion During Emergency Situations**

- [ ] In emergency scenarios such as natural disasters or warfare, a large number of users may request the same critical information repeatedly.
- [ ] Examples include "evacuation center locations," "first aid procedures," "road closure updates," and "supply distribution points."
- [ ] If all these requests are forwarded through the gateway UAV to the GBS, it could lead to network congestion and increased latency.
- [ ] Therefore, an efficient data management strategy is required to handle frequent user requests.

6. Provisional solutions for Encountered Problems

To address these challenges, we leverage caching to distribute network traffic, reduce the load on the gateway UAV, and enhance response times in emergency situations. Caching temporarily stores frequently requested data within the network, enabling faster access without repeatedly retrieving the same information from the original server (GBS). When implemented in a UAV network, caching is expected to alleviate the burden on the gateway UAV while improving overall network efficiency.

Network traffic can be efficiently distributed through strategic caching. Mesh UAVs locally store and serve frequently accessed data, allowing direct responses without relaying requests through the gateway UAV. This reduces the burden on the gateway UAV, preserving its capacity for high-priority real-time communications such as voice and video transmissions. Additionally, caching enhances the resilience of the UAV network, maintaining service continuity even during temporary GBS disconnections.

In emergency situations, a significant number of users are likely to request the same critical information. Public resources such as evacuation center locations, emergency contact details, medical guidelines, and rescue routes become essential for multiple users simultaneously. By caching this information within the UAV network, unnecessary traffic to the GBS can be minimized, leading to faster response times and reduced congestion. Furthermore, pre-storing navigation maps and rescue routes in UAVs enables rapid data dissemination even under unstable network conditions.

7. Ongoing Work

We are currently learning how to use OMNeT++ to simulate and analyze our proposed UAV-based network architecture. This includes implementing dynamic gateway UAV selection, optimizing mesh UAV routing, and integrating caching mechanisms to enhance network efficiency. Additionally, we are working on developing a 3D visualization of the network using OpenSceneGraph (OSG) to improve the representation of UAV mobility, network topology, and real-time interactions. This visualization will provide better insight into the performance of our network model and facilitate more effective analysis of its operational dynamics.