

SwarmSYM: A Simulator for Swarm Network-as-a-Service

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Abstract. UAV swarms can provide rapidly deployable and resilient communication in infrastructure-sparse or disrupted environments, yet their evaluation requires jointly capturing embodied mobility, wireless conditions, relay topology, and service continuity. Existing wireless simulators often abstract UAV execution, whereas robotics simulators rarely represent communication-service state as a runtime variable. We present SwarmSYM, a high-fidelity simulator for Swarm Network-as-a-Service (SNaaS) that bridges this gap by coupling embodied swarm execution with communication-aware networking. Unlike conventional workflows that evaluate link quality independently of execution, the proposed framework makes communication feasibility part of the runtime service state. The platform enables repeatable evaluation of communication-aware re-configuration, service continuity, and resilient UAV-assisted networking under dynamic operating conditions.

Demo video: YouTube.

Keywords: UAV-assisted networks · airborne communication networks · NTNs · 3D simulation · fault tolerance

1 Introduction

UAV-assisted networks are increasingly investigated as agile non-terrestrial infrastructure where terrestrial connectivity is unavailable, overloaded, damaged, or unsafe to access. Their performance depends on three-dimensional placement, mobility, user association, and link quality [1], while propagation, interference, latency, energy, regulation, and security remain practical challenges [2]. In parallel, Drone-as-a-Service (DaaS) reframes UAVs as service providers [3], while Swarm Network-as-a-Service (SNaaS) extends this abstraction to coordinated swarms delivering drone-to-device and drone-to-drone communication [4]. SNaaS evaluation therefore requires runtime coupling of swarm execution, relay topology, communication state, and service continuity.

Existing platforms address only part of this coupling. Drone-service simulators mainly target delivery, skyway routing, and navigation [5], while recent wireless and digital-twin frameworks improve channel awareness through multimodal visual/RF information [6], Isaac Sim-PX4-Sionna integration [7], or ray-traced channels in ns-3 [8]. These approaches improve embodied or wireless fidelity, but omit key SNaaS runtime semantics, including relay-topology state,

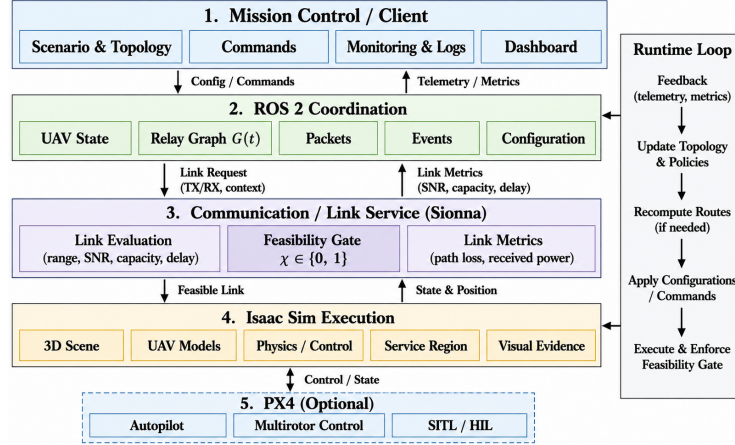


Fig. 1. SwarmSYM architecture and runtime communication loop.

per-UAV state dissemination, branch-level packet execution, and communication aware service behavior.

We present SwarmSYM, a high-fidelity SNaaS simulator coupling embodied UAV execution, ROS 2 coordination, telecom-aware link evaluation, runtime re-configuration, and structured evidence collection. Relay execution follows the active communication graph: packet streams advance only over feasible hops, while infeasible links suspend forwarding and expose an outage state. The modular runtime supports interchangeable topology, mobility, traffic, and recovery policies under common communication-execution semantics, enabling repeatable evaluation of airborne communication services under dynamic swarm and network conditions.

2 Simulator Architecture

SwarmSYM implements a layered runtime architecture for repeatable evaluation of SNaaS and UAV-assisted networking experiments (Figure 1). Mission Control provides scenario and topology configuration, runtime commands, monitoring, and dashboard access. ROS 2 maintains UAV state, relay graph $G(t)$, packet streams, configuration updates, failure events, and metric dissemination. The Sionna-based communication service evaluates active transmitter–receiver pairs using geometry and link parameters, producing path loss, received power, SNR, capacity, delay, and a binary feasibility state. Isaac Sim provides embodied execution through the 3D scene, UAV motion, physics/control integration, service regions, and visual evidence, while PX4 offers an optional autopilot-compatible path for multirotor control and SITL/HIL execution.

Communication model and execution gate. For each active transmitter–receiver pair (i, j) , the communication layer evaluates instantaneous geometry together with the configured propagation and antenna parameters. Depending

on the experiment, PL_{ij} is obtained from free-space, log-distance, or probabilistic air-to-ground propagation models. Received power, SINR, and capacity are evaluated as

$$P_{r,ij}^{\text{dBm}} = P_t^{\text{dBm}} + G_{t,i} + G_{r,j} - PL_{ij}, \quad \gamma_{ij} = \frac{p_{r,ij}}{I_{ij} + N_0 B}, \quad C_{ij} = \eta B \log_2(1 + \gamma_{ij}), \quad (1)$$

where $p_{r,ij}$ denotes received power in linear units, $I_{ij} = 0$ yields the SNR case, and η is the configured capacity-efficiency factor. Let $F(t)$ denote failed UAVs and $V_a(t) = V(t) \setminus F(t)$ the active set. Packet execution is governed by the failure-aware feasibility gate

$$\chi_{ij}^F(t) = \mathbf{1}[i, j \in V_a(t) \wedge d_{ij}(t) \leq d_{\max} \wedge \gamma_{ij}(t) \geq \gamma_{\min} \wedge C_{ij}(t) \geq C_{\min}]. \quad (2)$$

Hence, geometry and radio state are coupled directly to execution: geometry $\rightarrow PL_{ij} \rightarrow P_{r,ij} \rightarrow \gamma_{ij} \rightarrow C_{ij} \rightarrow \chi_{ij}^F \rightarrow$ packet advancement. A stream advances only when $\chi_{ij}^F(t) = 1$; otherwise forwarding is suspended and an outage is recorded until topology recomputation or standby-drone promotion restores a feasible route. Runtime checks additionally reject invalid routes or stale link state, while deterministic, Poisson, and bursty traffic with FIFO or priority queues can be used to exercise the same communication-execution semantics.

The layers operate as a closed loop: physical state determines link conditions, link feasibility governs packet progression, and runtime configuration or policy updates modify the active relay graph. Consequently, communication is an execution constraint rather than an offline metric: infeasible hops suspend the affected stream and expose an outage state. The same semantics remain valid across different topology, mobility, traffic, and recovery policies, allowing the platform to support multiple SNaaS experiments without changing its underlying execution model. *code repository: GitHub.*

3 Demonstration

The demonstration evaluates the simulator as a runtime SNaaS experimentation environment using a multi-UAV relay service. Figure 2 shows a three-branch forest topology executed consistently across Isaac Sim and Mission Control, where the logical relay graph, UAV roles, branch structure, and standby state remain synchronized with the embodied swarm.

Nominal and reconfigured operation. During nominal execution, packet streams traverse the active relay topology while ROS 2 disseminates UAV state and the communication layer evaluates each hop. Runtime changes in geometry or topology directly modify link feasibility and packet progression. Figure 3 illustrates one recovery policy used to demonstrate this modular behavior: UAV failures alter the active relay graph, the affected route is recomputed, and forwarding resumes only when the resulting path again satisfies the communication-feasibility gate.

During the interactive demonstration, attendees can modify the relay topology, initiate packet traffic, inspect per-hop communication metrics, inject a UAV

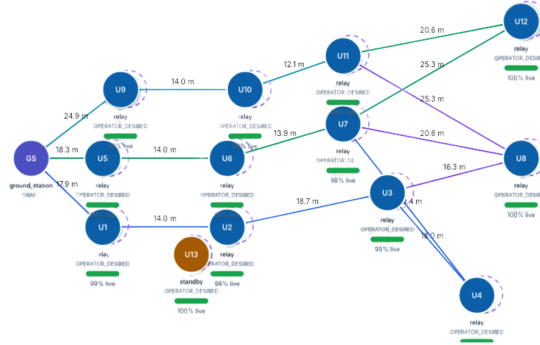


Fig. 2. Forest-mode SNaAS execution. Isaac Sim and Topology Studio expose the same three-branch relay structure, including active relays and standby UAV state.

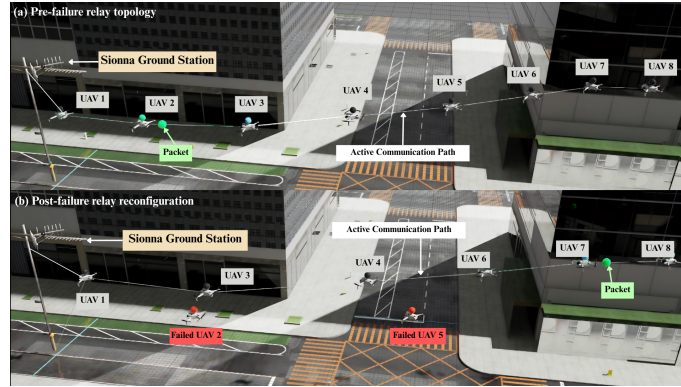


Fig. 3. Runtime relay execution before and after UAV failures. The active communication path is reconfigured while failed nodes are excluded from service.

failure, and observe the resulting outage and topology reconfiguration. Forwarding resumes only after the recovered route satisfies the same communication-feasibility gate used during nominal operation.

Runtime evidence. Mission Control exposes topology state, packet progression, link feasibility, and associated communication metrics during execution. Together, the two views demonstrate that logical topology, embodied swarm state, and communication-aware service behavior remain synchronized within the same reproducible workflow.

4 Demonstration Requirements

This demonstration will showcase the simulator and provide attendees with the opportunity to test and interact with it. We will utilize our laptops for this purpose. To facilitate the demo, a standard booth set up at the conference venue

is necessary with electricity outlets and Wi-Fi connectivity. Having a screen projector is preferable to enhance visibility for the audience.

5 Conclusion and Future Work

We presented SwarmSYM, a high-fidelity simulator for SNaaS and demonstrated its ability to couple relay topology, communication feasibility, runtime observability, and reconfiguration within a unified workflow. The generated evidence supports analysis of packet progression, outages, topology evolution, and service continuity. Future work will incorporate richer physical and communication models, evaluate user experience, and validate simulator outputs against real UAV-based wireless multimodal measurements.

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