

Assessing the Controllability of Modular UAV Swarms over 5G Networks via ROS2

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Abstract

Multi-UAV operations are constrained by legacy point-to-point radio links that scale poorly in range, bandwidth management, and quality of service. In this feasibility study, the controllability and reliability of a highly modular ROS 2 based UAV swarm interconnected via private 5G cellular networks are evaluated. After integrating multiple aerial vehicles into a 5G architecture, the communication performance is compared against standard WLAN by profiling end-to-end latency and throughput under representative mission and sensor traffic. The findings provide practical design guidelines for deploying UAV swarms over cellular infrastructure, particularly in Beyond-Line-of-Sight (BLoS) scenarios, where scalability and coverage outweigh raw latency performance.

System Architecture

The experimental setup involves interconnecting the Ground Control Station (GCS), designated as the benchmark node, and the UAVs via three different physical layers for comparison: LAN, WLAN, and a private 5G campus network at Helmut-Schmidt-University (HSU). Fig. 2 illustrates the communication pathways and protocols between the vehicles and the GCS. The system consists of a Holybro X650 UAV equipped with a Pixhawk 6X flight controller, a Jetson Orin NX, and a 5G modem. ROS 2 communication is bridged via Zenoh to provide lightweight, UDP-based transport. For latency measurement, an NTP-synchronized framework tracks one-way end-to-end latency using a 20 Hz probe.

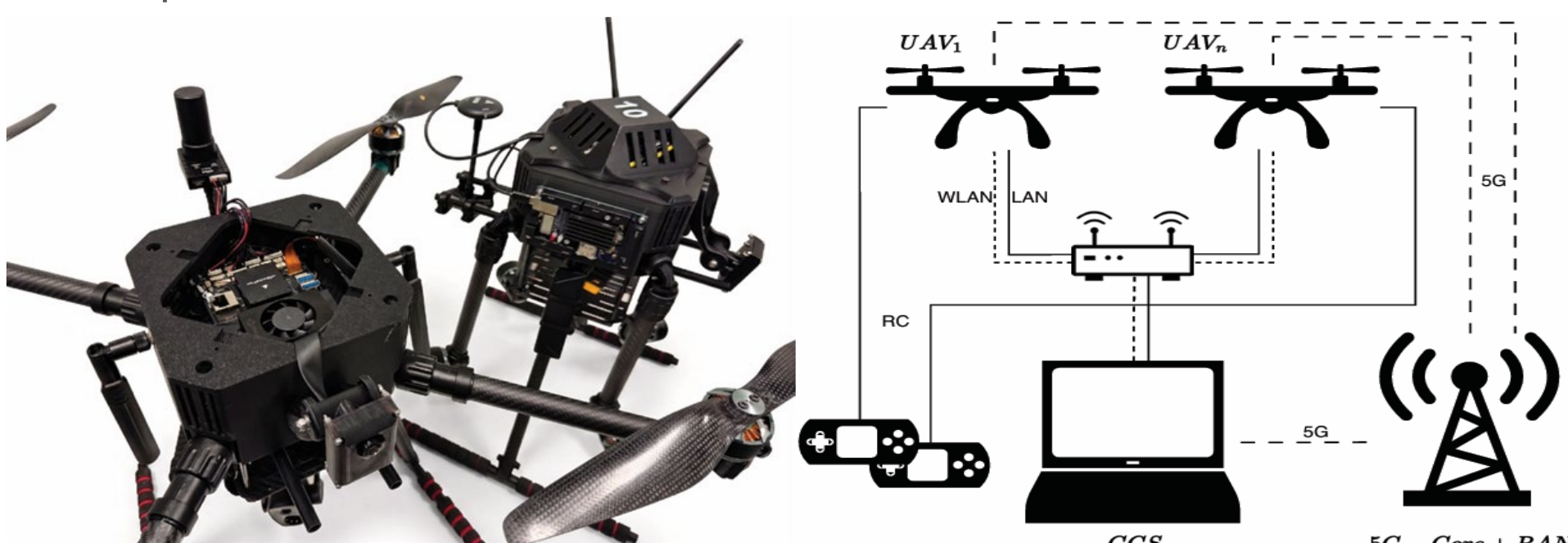


Fig. 1: Modular UAV Setup

Fig. 2: Logical Setup Overview

Measurements

WLAN achieved a median latency of 1.31 ms with no packet loss, serving as the baseline. Private 5G showed a higher median latency of 15.46 ms and 0.035% packet loss. Overall, 5G latency was approximately 12× higher and more variable, mainly due to RAN traversal and the 4:1 TDD uplink pattern.

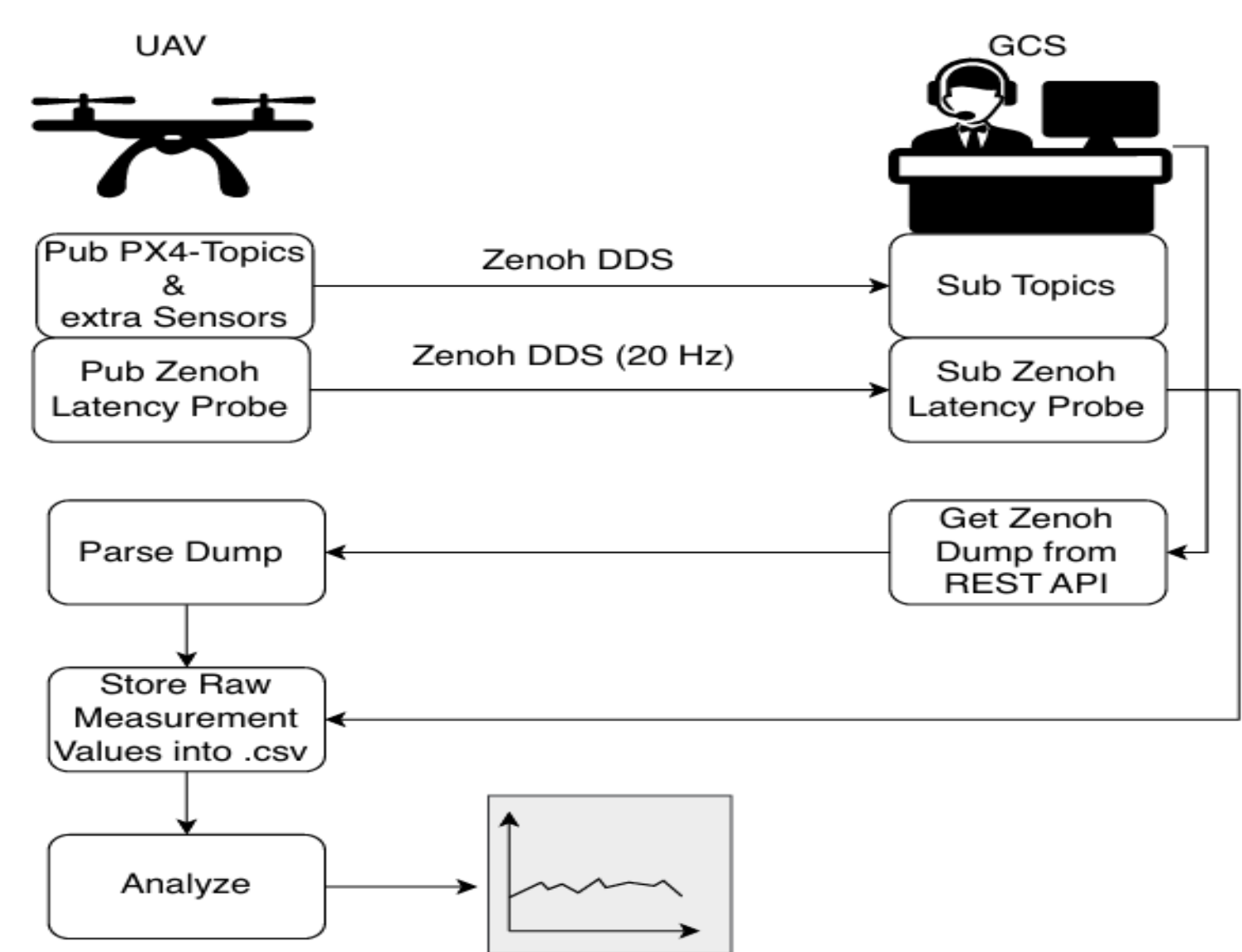


Fig. 3: Benchmark Setup

Conclusion

Although WLAN provided lower latency in local tests ($p_{95} \approx 2.31$ ms), Private 5G ($p_{95} \approx 24.58$ ms) is the superior choice for operational swarms due to its managed spectrum, mobility support (handover), and scalability over large areas. While WLAN serves as a high-performance short-range link, 5G enables geographically unbounded operations. The use of private 5G is justified not by minimizing latency in all cases, but by providing a secure, scalable, and professional infrastructure BLoS deployments.

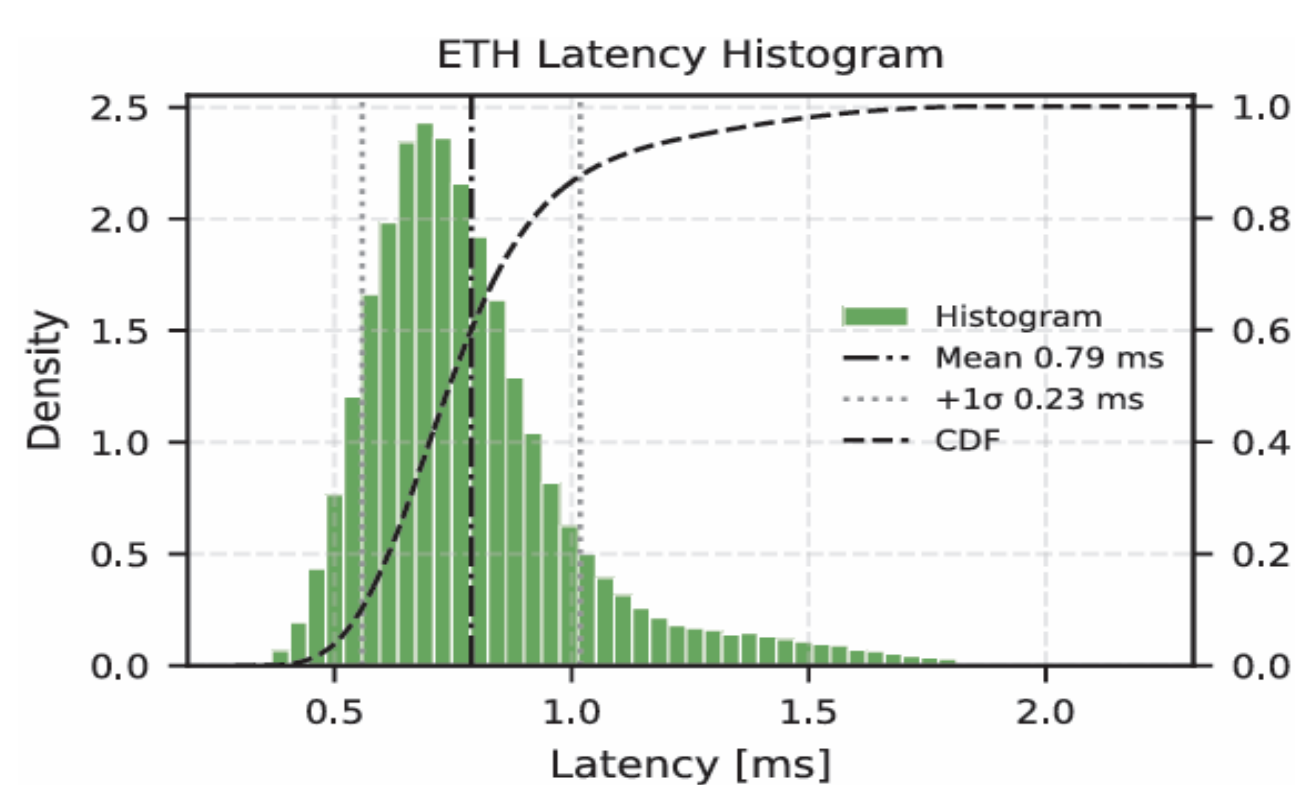


Fig. 4: Ethernet Latency (Median 0.79 ms)

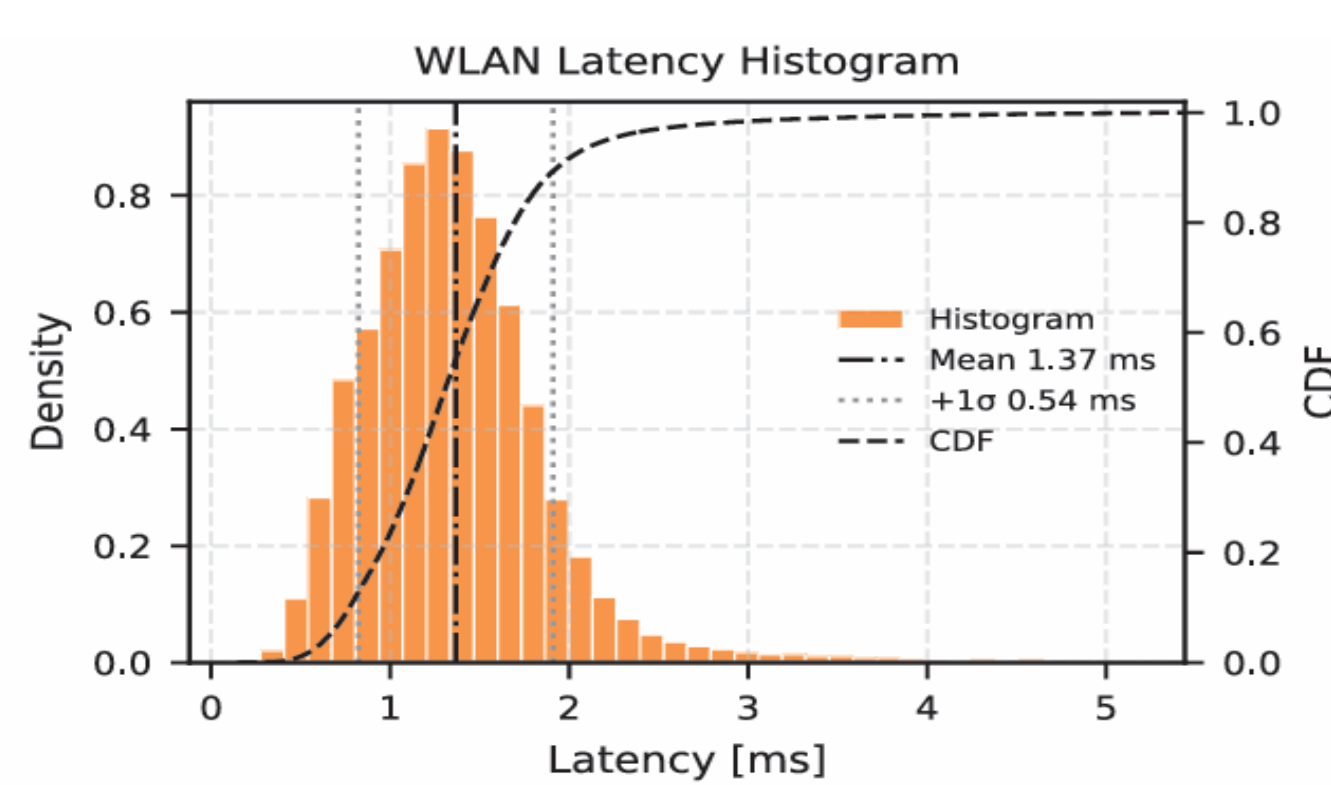


Fig. 5: WLAN Latency (Median 1.37 ms)

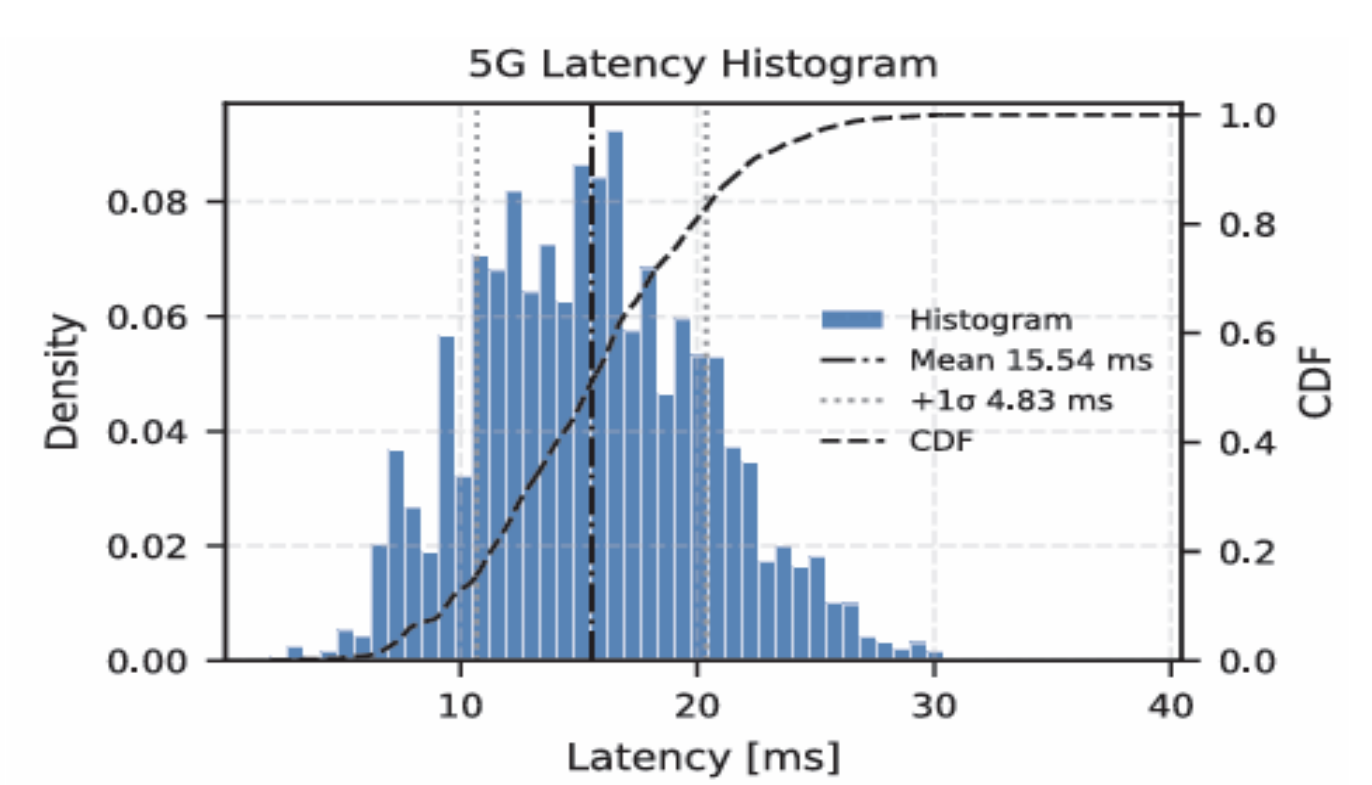


Fig. 6: 5G Latency (Median 15.54 ms)

Added Value for the German Armed Forces

Private 5G offers significant advantages for military UAV operations by enabling **scalable swarm communication** across larger fleets. Its wide-area coverage supports **Beyond-Line-of-Sight (BLoS) operations**, extending mission range beyond direct radio links. Combined with onboard failsafe systems, 5G provides resilient and flexible UAV control even during temporary network latency spikes.



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