# CORNET: A Co-Simulation Middleware for Robot Networks

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# Introduction

Autonomous robots has enormous potential in several domains like search & rescue, surveillance, transport and infrastructure etc.

V2X use-cases: remote-controlled autopilot systems, situation aware driver assistance systems.

Performance evaluation of such networked systems requires appropriate tools

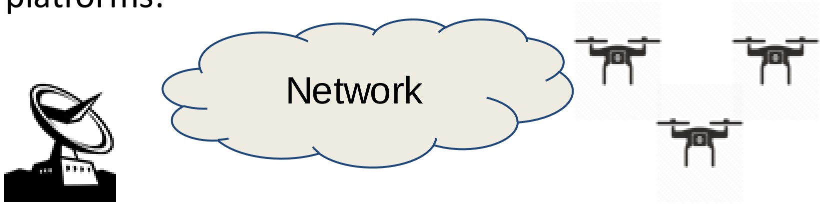
**For example: impact of communication artifacts like packet losses, congestion and routing overheads on the control system of the robots.**

# Problem Statement

Develop a co-simulation framework that integrates simulation of flight dynamics and network related aspects.

The solution should satisfy the following criteria

- Lightweight and scalable to handle complex real-world scenarios
- There should be a common notion of time and position across the two simulation environments and
- Provides APIs to port control algorithms to a real platforms.



# Related work

UAV Simulators :

- human operating flight simulators - Microsoft flight simulator  FlightGear
- autopilot frameworks - PX4 and Ardupilot Software in the loop(SITL)
- Robotic Simulators (3D) - AirSim and Gazebo

Network Simulators:

- commercial network simulators - QualNet and OPNET
- open-source simulators  - NS-3 and OMNET++
- network emulator - Mininet

# Related work

**Joint UAV-Network Simulators :**

**AVENS :** Developed based on X-Plane and OMNET++.

- *HICSS, 2017*

**CUSCUS - ** Developed based on FL-AIR and NS-3.

- *Ad Hoc Networks Volume 68, January 2018, Pages 33-47*

**FlyNetSim -** Developed based on Dronekit SITL and NS-3.

- *MSWIM, 2018*

# Related work

## Application Specific Drone Simulators: Recent Advances and Challenges

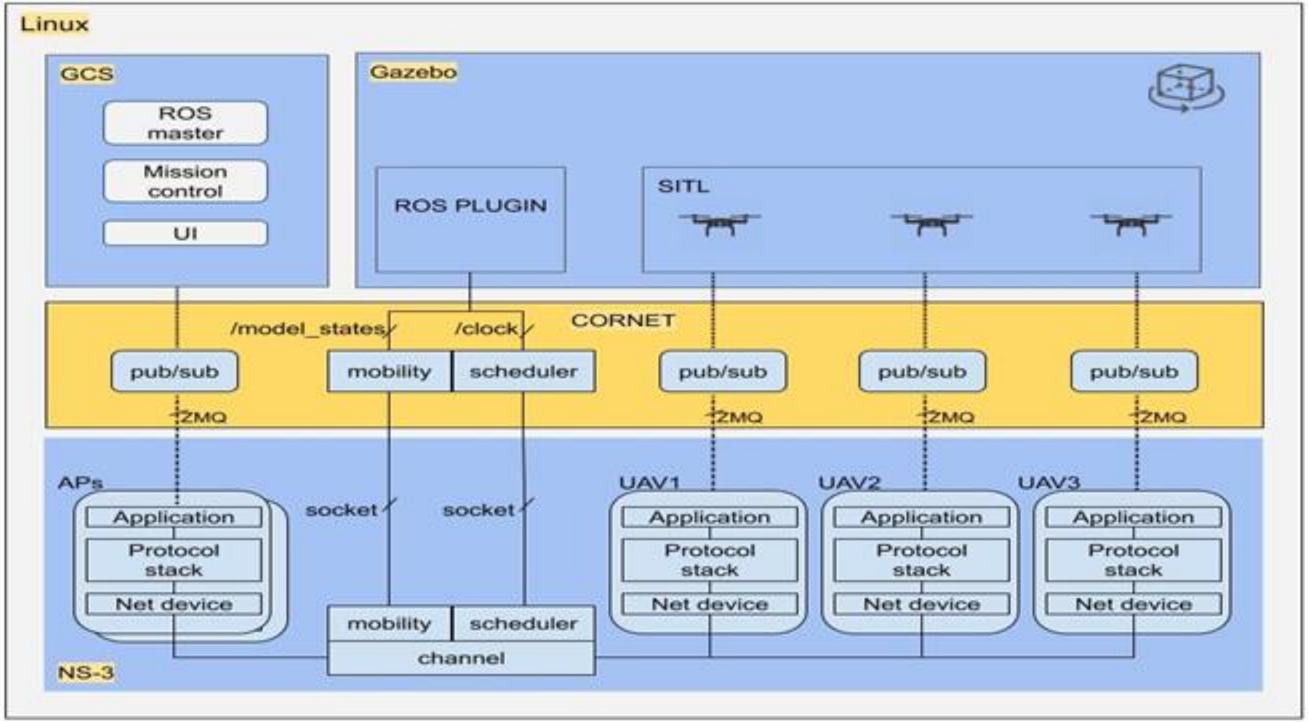
| | Open Source | Network simulation | |
|---|---|---|---|
| HEXAGON | No | No | LabVIEW based GUI, Mathematical Models |
| Simbeeotic | Yes | Limited | Java and uses Maven build system |
| MS Flight Simulator X | No | No | proprietary software by microsoft |
| AirSim | Yes | No | useful tool for AI research |
| AVENS | Yes | Yes | Doesn't provide data path for control, telemetry to and from UAVs |
| UAVSim | Yes | Yes | Focus on UAVNet Attacks and security aspects |
| D-MUNS | No | Yes | NS3 based network simulator |
| ROTORS | Yes | No | AseTec, Gazebo project for multi UAV systems. |

# Our Approach

Our choice of Gazebo with ROS and NS-3 in the Linux environment is primarily driven by

1. Better community support,
2. Gazebo has modular software architecture and extended using plug-ins,
3. NS-3 allows interfaces for external systems, applications and libraries.

# Co-Simulation Architecture

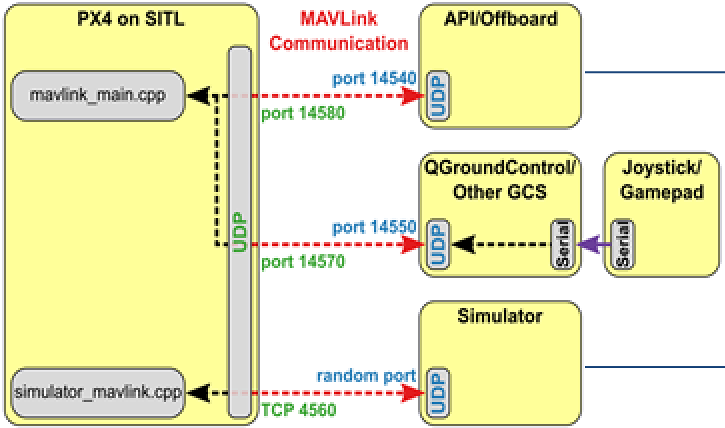


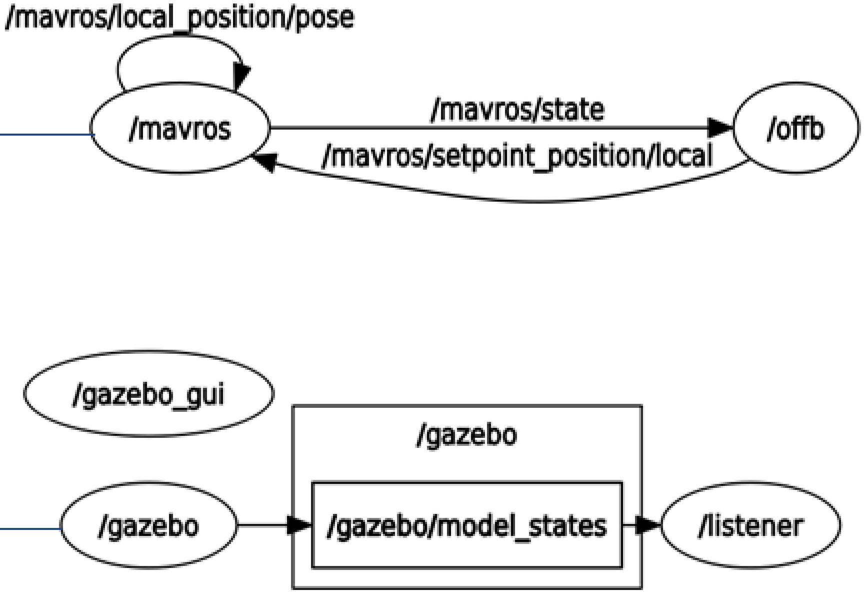
# CORNET Middleware

Middleware interconnect Gazebo and NS-3:

1. ZMQ - end to end data path

1. CORNET ROS plugin - mobility and time sync



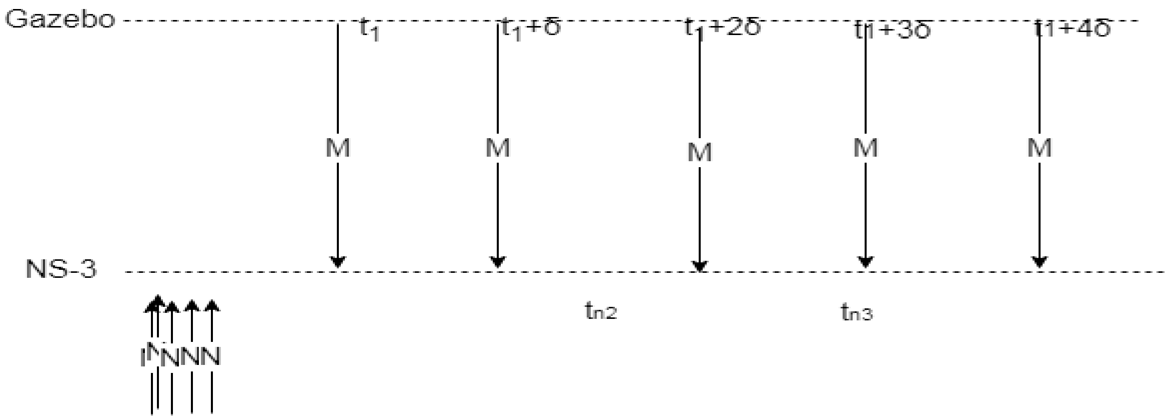



# Why is time synchronization critical

Gazebo simulates physical systems – uses period sampling

NS-3 simulates network systems – deploys event based sampling

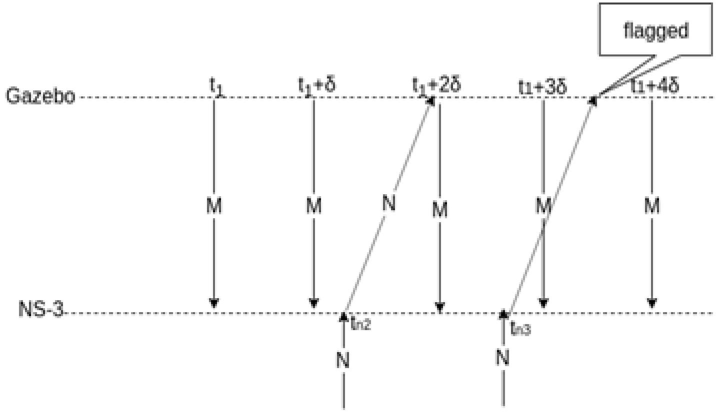
Combination of periodic and event based sampling is not a trivial problem.

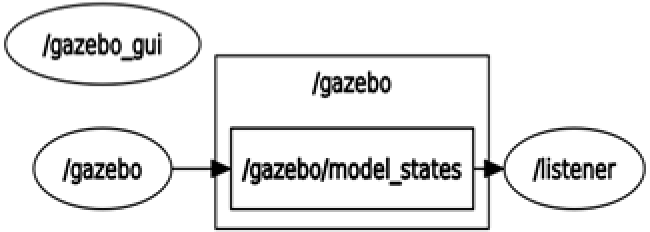


# Time Synchronization

The method we have adopted is referred to as the variable-stepped method:

- Gazebo sim time is reference clock for which NS-3 simulation is tied.
- NS-3 checks for network events and reference clock for execution.
- The middleware checks for the packet leaving NS-3 and releases to Gazebo.
- If the Packet delayed by NS-3 results in delivery after the time lasped in gazebo sim time, we discard these packets.



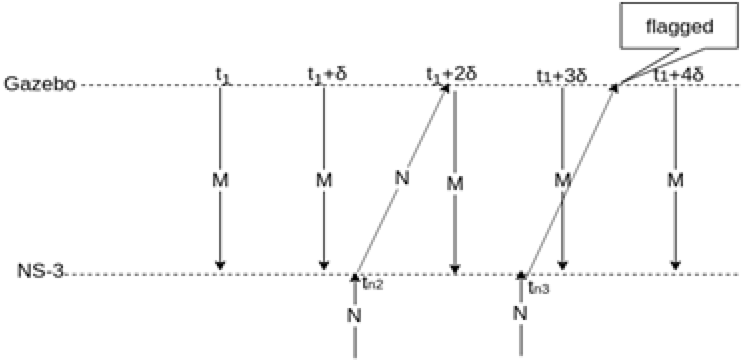



# Criteria for proper functioning

Packet discarding is result of case where NS-3 runs slower than Gazebo simulation.

Ideal scenario is to update the clock of Gazebo to match with NS-3.

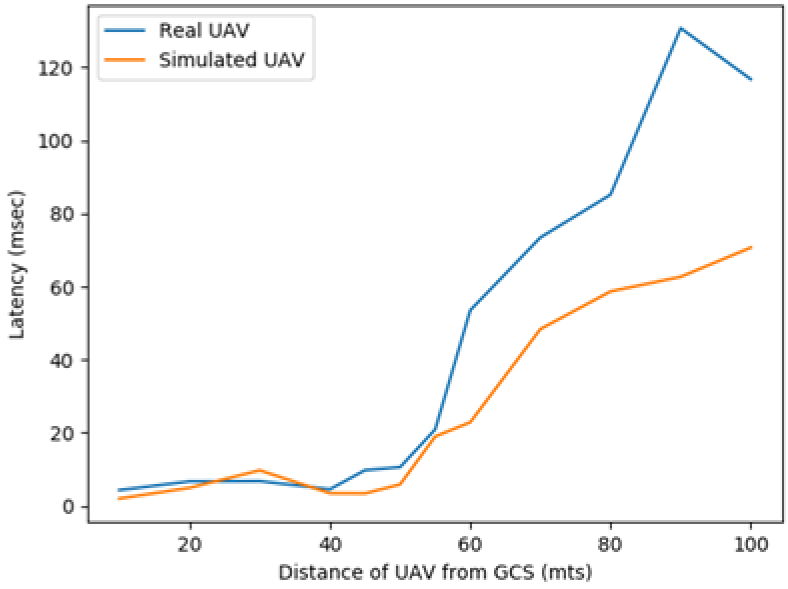
**NS-3 event processing should be faster than Gazebo**, *which is the case in normal execution scenarios.*



# Evaluation

Offboard control of Single UAV:

We measure end-to-end network latency for both the real world and the simulation

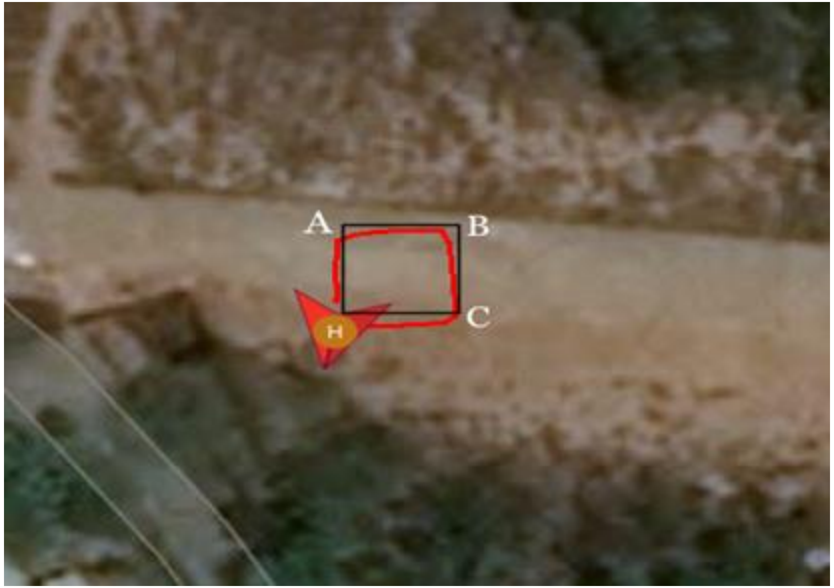


# Evaluation

Fixed Trajectory Control:

GCS sends commands to the UAV to follow a pre-determined trajectory.

This is a way-point based navigation with the controller present in the GCS




Simple evaluation of the framework's ability to develop and test new network functions for UAVNETs.

# Comparison Table

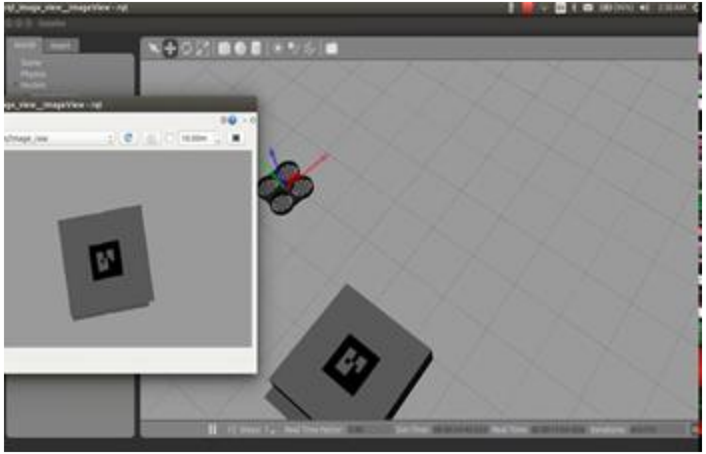
| | FlyNetSim | CUSCUS | AVENS | CORNET |
|---|---|---|---|---|
| Network simulator | NS-3 | NS-3 | OMNET++ | NS-3 |
| Physics simulator | Dronekit SITL | FL-AIR | X-Plane | Gazebo |
| Mobility | Deep packet inspection | Shared memory | XML based | ROS topic |
| Data-path | ZMQ | Ns-3 bridge | - | ZMQ |
| Time Sync | Yes | No | No | Yes |

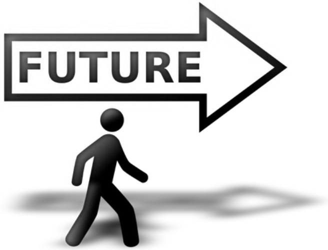
# Future Work

Modeling latency requirements for Droneport to control drone to enable precise landing,

Extend the framework to support LTE and 5G to enable multi-technology networking,

Evaluate routing algorithms for UAVNETs specifically position-based routing protocols.





# Acknowledgment

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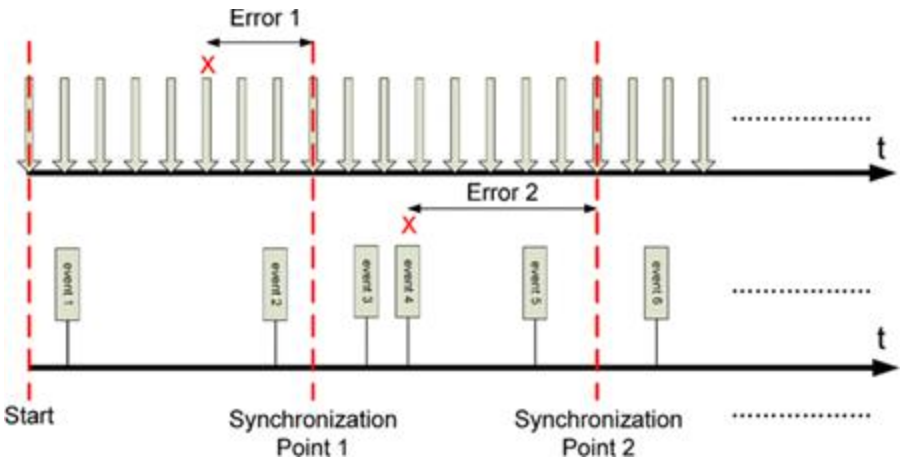
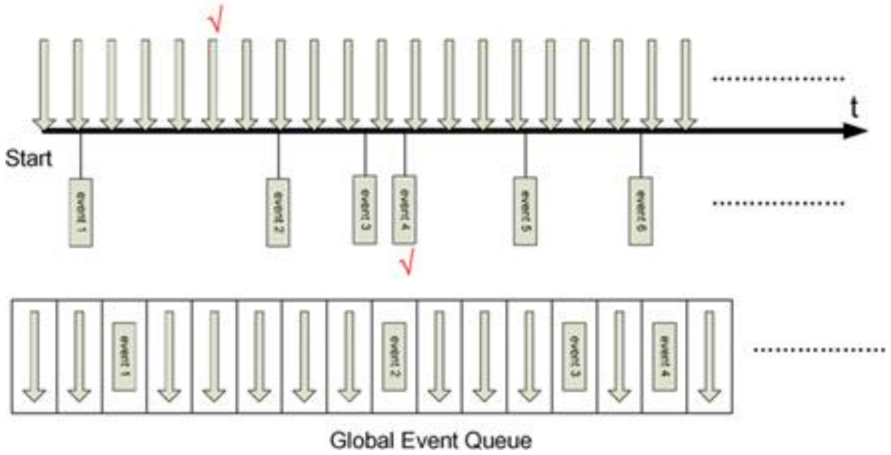
We are grateful to our project staff, especially Varun, who provided expertise in Gazebo simulation that greatly assisted the research.

**Questions ?**

# Time Synchronization




Time-stepped method




Global-event driven method