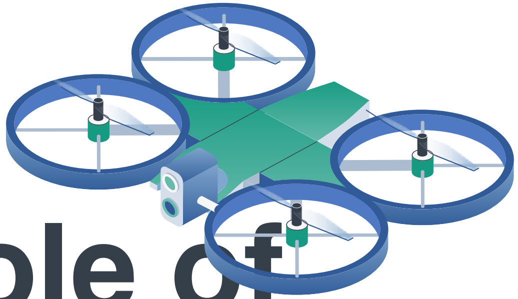
Harmony in Motion: The Role of Model-Driven Design for Drone Swarms



By *Rizwan Parveen*, Postdoc

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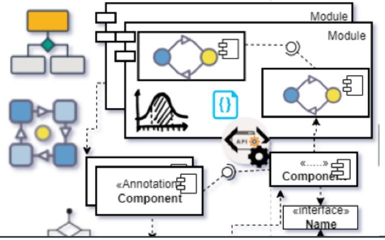


Postdoc Objective

Background:

PhD Topic: : Model Driven Approach For Healthcare Cyber Physical Systems

Defended: March 2023

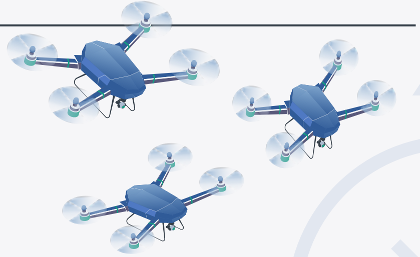
University: BITS Pilani K K Birla Goa Campus, India

Postdoc: Aims at modeling a drone architecture in AADL in order to be less dependent from the underlying system (ROS), leverage code generation

Objective of this talk

- Present my background to show how it can be applicable to drone swarm design.
- Discussing the critical properties that demand consideration for drone swarms systems,
- Role of model-driven design in drone swarm system.

Agenda



01

INTRODUCTION

Model-driven approach

02

BACKGROUND

I will explain my Ph.D. Thesis work

03

MDD in Drone Technology

Model-Driven Design formalisms/Paradigm

04

Example

Verifying role and energy management in a swarm of drones using UPPAAL

05

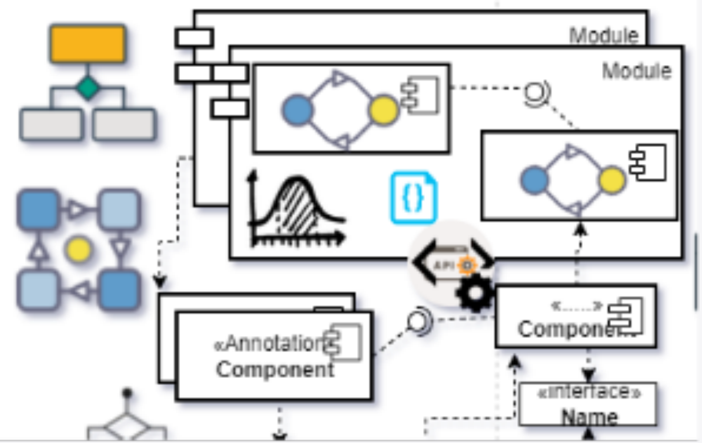
Discussion and Directions?

How MDD is useful for properties (Characterstics,Aspects (i.e., coordination, collaboration))?

06

Conclusion

Architectural centric approach for analysis and verification of swarm



01

INTRODUCTION

Model-driven Desing

Model: Blueprint of a system

Abstraction of system components

Identify and abstract the essential components of the system, e.g., communication protocol, process, control module, constraints, sensors, actuators…

Modeling and Simulation

Creating a model (each component and their interactions in an abstract way). Use of modeling languages, UML, AADL…
Simulate the behavior of the system in different scenarios to verify that the designed model behaves as expected

Verification/Validation

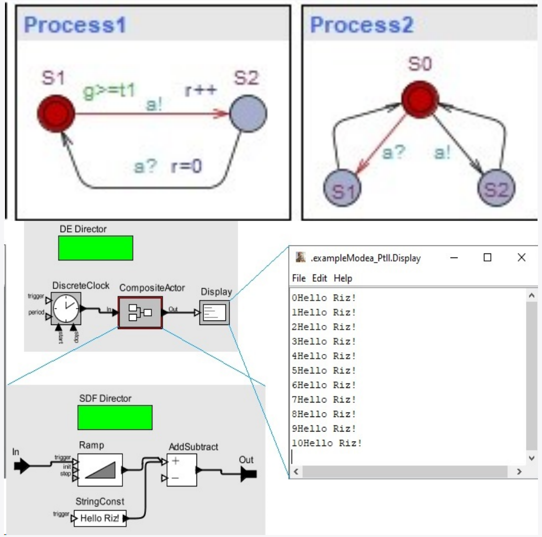
Validating correctness, code generation, model refinement (iterative)

02

BACKGROUND

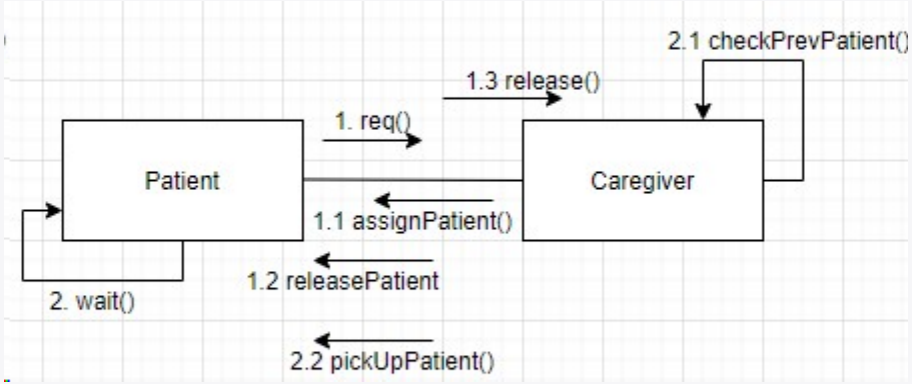
MY PHD WORK

Model Driven Approach For Healthcare Cyber Physical Systems



$\square$ (Obstacle $\rightarrow \Diamond \leq 5$ STOP)

Problem: No formal approach to model medical resource allocation

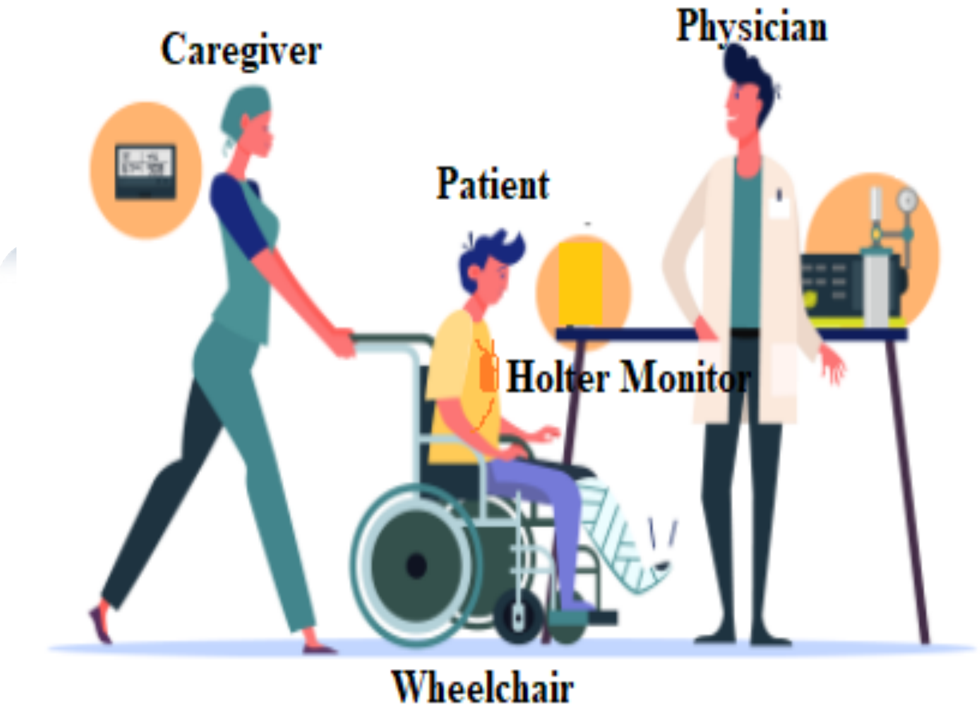


I. Handling of the idle time of the resources to reduce the ***interruption*** during the treatment time.
II. Having **non-identical treatment time** in patient scheduling process

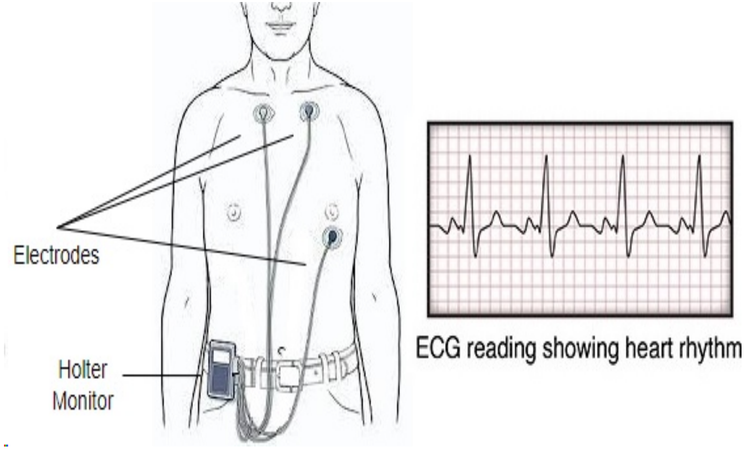
Timing parameters (idle time of caregiver, waiting time of patient, and treatment duration)

Goal: having a balance between the `idle time' of the medical resource and `waiting time' of the patient

Two Case Studies



Resource Allocation Problem
Modeling Formalism: UPPAAL



Problem: Continuous Monitoring

Modeling Formalism: Ptolemy, UPPAAL

I

A formal approach

to model individual components and their interaction which satisfies the system's overall behavioural aspect.

Tools: *UPPAAL, Ptolemy-II*

II

Satisfying system's properties

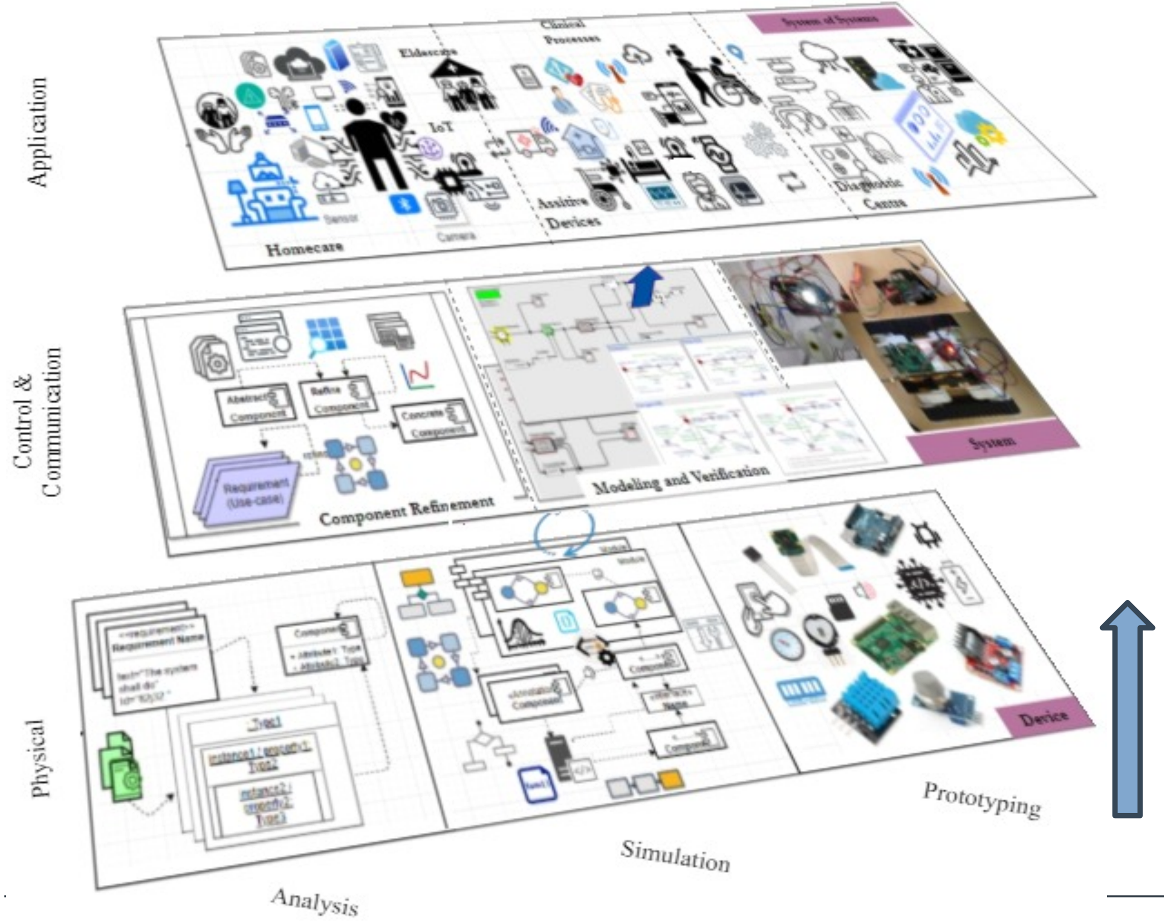
A method for formally specifying the requirements and verification of the model to check the system's properties

III

Assuring validity

An analysis to perform the validity of the model, which assures the correct ordering and execution of the events.

My Process: Bottom up approach



Application

Model

Capturing control, communication

Healthcare Resource Allocation Problem

Safety: Non-availability of healthcare resources (even temporarily) due to disorderly assignment, unfair allocation (over- and under-utilization), can violate the basic properties of the system.

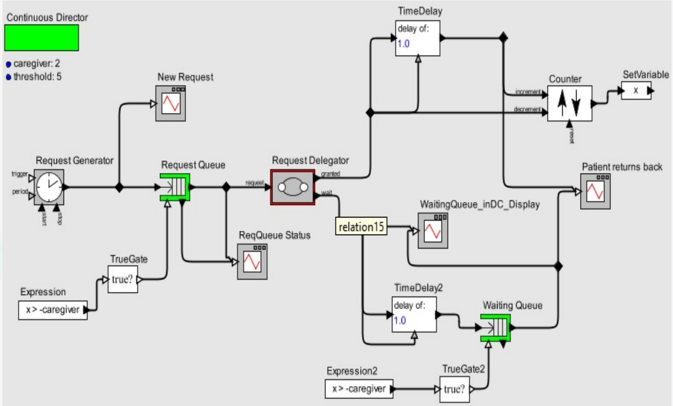
For example, the safety of the system can be violated if the treatment stages are disorganized.

The aim of my research was to address the following design questions using the model driven approach:

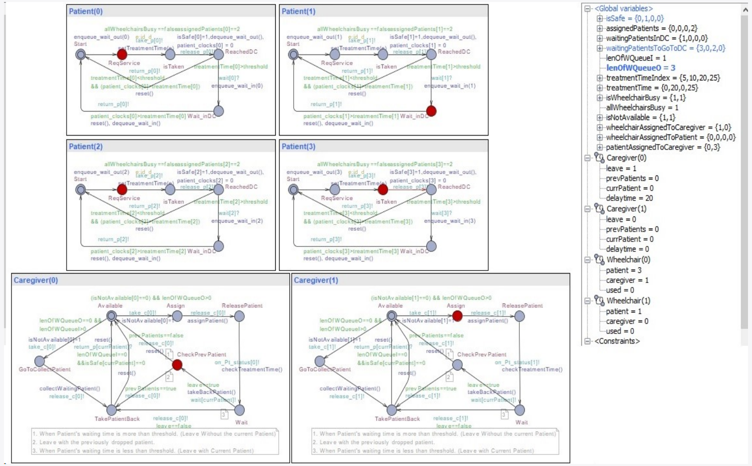
1. How to incorporate and verify safety requirements in a system?

2. How to assure the correctness (validity) of the model behaviour when this model is executed
for a large number of components or input parameters?

Case study –I : Why Automata?



Patient,
Caregiver,
Medical
assistive
devices



Pros: Pre-built actors, e.g. Queues
Cons: Difficult to modify these actors, e.g. building priority queue.
-Difficult to analyze Patient-Caregiver mapping
- Verifying properties.

Why Automata?
- To support a variety of temporal requirements (to model non-identical treatment time for different patients)
- time-bound allocation, such as the allocation of a treatment duration for a patient and the release of resources once the treatment duration has elapsed.

Explanation of UPPAAL Model

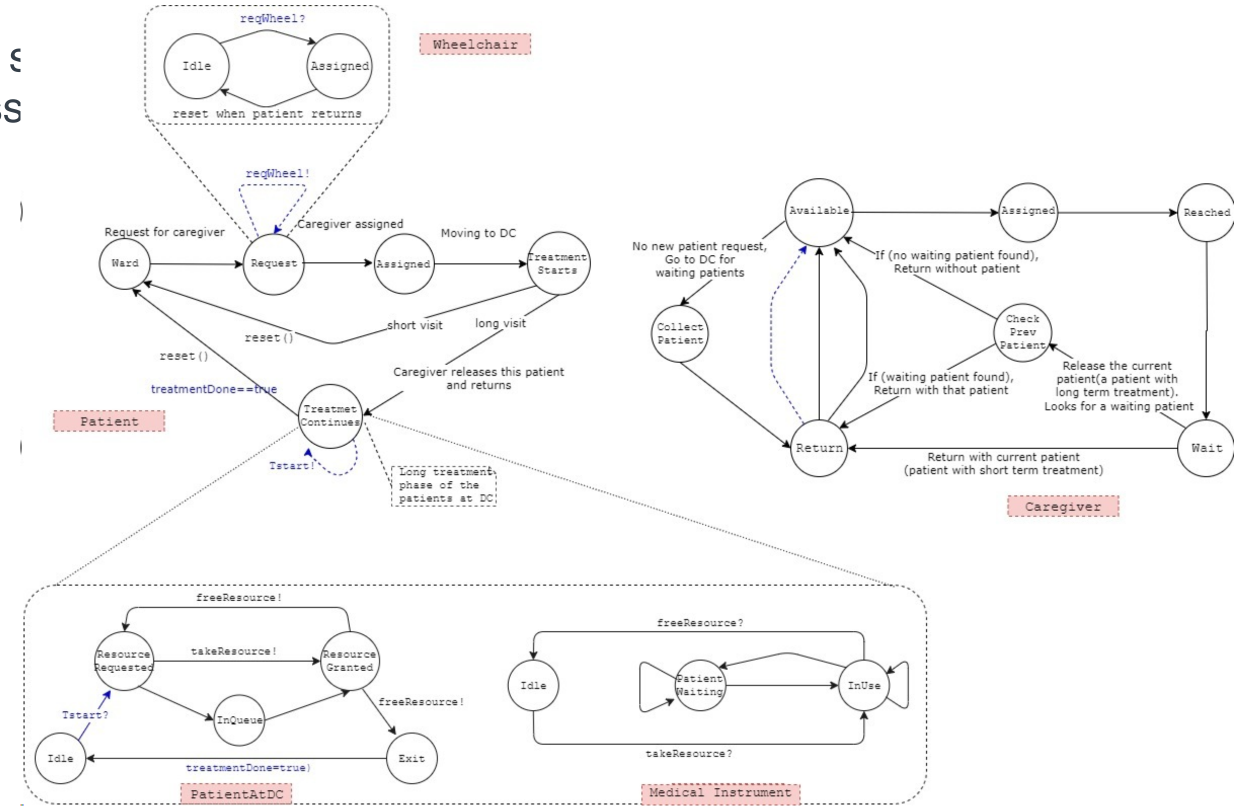
- Formal verification offers s
  guarantees of correctness
- Extensibility

E.g.: A □ forall (i : id_p) (treatmentTime[i] ≥ 5 && treatmentTime[i] ≤ 100)

Pr[#<=20](◇ forall (i:id c)

(Caregiver(i).prevPatients == true) imply Caregiver(i).TakePatientBack)>= 0.98

(Within 20 discrete transitions, the probability of taking the patient back is larger than 98%.)



03

MDD in Drone Swarms

Drone Swarm Application Domain

Literature review

Surveillance Swarm	Exploration and Rescue, e.g. scanning the area for potential survivors
Disaster Response Swarm	Monitoring, inspection, reporting
Payload Delivery Swarm	Dispensing medical supplies, dispensing (during fire incidents), and chemical dispensing (agriculture)
Environmental Monitoring Swarm	Crop monitoring, irrigation, and pest control
A counter-drone system	A. UAV detection and tracking, and B. mitigation or neutralization systems

Ref:

Anam Tahir, Jari Böling, Mohammad-Hashem Haghbayan, Hannu T. Toivonen, Juha Plosila, Swarms of Unmanned Aerial Vehicles — A Survey, Journal of Industrial Information Integration, Volume 16, 2019, 100106, ISSN 2452-414X, https://doi.org/10.1016/j.jii.2019.100106.

Aspects of Design (Concerns)

Dynamic Swarm Formation

Reconfigurability (drone allocation)

Collaborative Task Execution

Flying, achieving mission

Fault Tolerance and Redundancy

Uninterrupted Op in the event of failures
Switch to a redundant drone and resume the mission

Coordination

Collision Avoidance (safe distance), Velocity/speed matching, Flock centering (moving cohesively)

Adaptive Sensing and Task Allocation

dynamically adapting to the criticality modes based on environmental conditions

Communication and Connectivity

Path planning and control

Common Challenges

To address any of the aspect of design in drone based system (or a swarm) using MDD, we need to deal with:

- Capturing domain specific concepts and requirements.

  - E.g., Using drones in Urban area (high density of area), means selecting/building appropriate algorithm for obstacle avoidance. Path planning using Genetic Algo [Mac].

  - E.g. Using drones in Flat field, A* algo for path finding problem in static environments), low density of obstacles.

- Managing Uncertainity
- Managing Heterogeneity of drone swarm

04

Example of Modeling

Example of a drone connectivity scenarios, designed using UPPAAL

Example Scenario

Drones have two roles (Master and Salve):

Master

The master drone will disconnect when its battery reaches to a certain point (consider as insufficient battery to act as master).

Slaves

A separate control for notifying low battery status (to controller).

Controller

Responsible for starting/selecting Master.
Then sending another command to start drones.

Properties to check

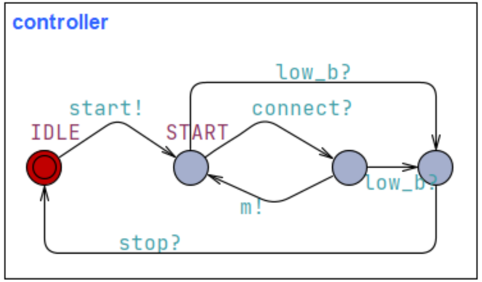
A. **Only one master** at a time in a group (that max or min number of members can decided by designer).
B. The chosen master drone should have **sufficient battery** to carry out the operations.
C. Drones must be disconnected and lands if their battery level reaches to a certain (lower) point.

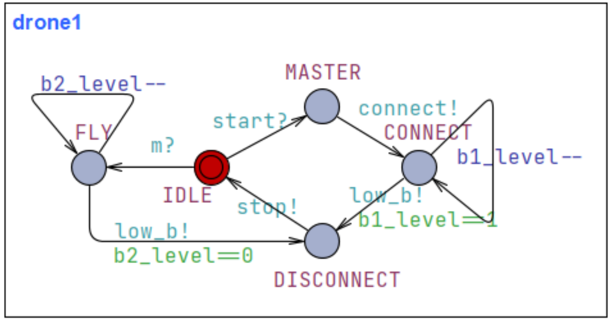
Modeling to verify Drone Connectivity

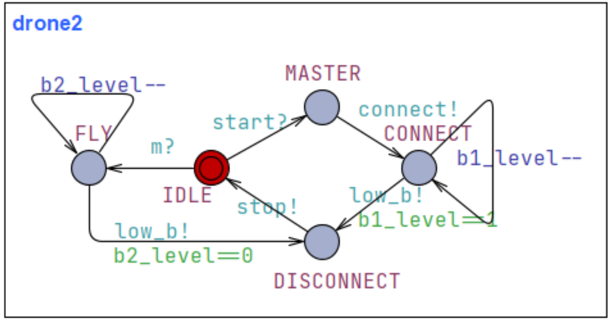
Two-Drone Model*

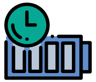
Steps:

1. Choosing master
2. Master initiates connection with other drone
3. The salve drone continue flying untill it's battery level reaches to insufficient level (this value can be modified).
4. Master drone continue being master and flying untill it has sufficient battery.
5. Master and salve both inform controller with low battery signal and disconnects.









Battery

Drone disconnects:

1. While acting as a master and flying simultaneously, battery level reaches to insufficient
2. If in flying mode, battery level reaches to insufficient

Assumpations:

Drones have sufficient battery during IDLE state.

*A model (under development) by me. This model contains

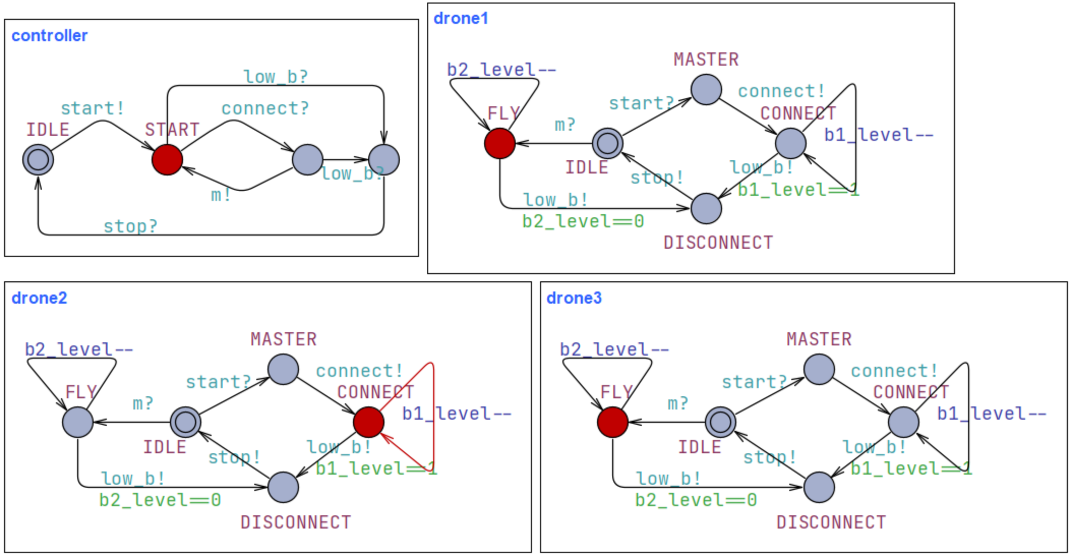
Properties to test

Property check:

- No deadlock.
- Checking sufficient battery level before assigning power consuming task (currently not included in this model).
- There exist a path always when both drone reaches to DISCONNECT state when battery is low.

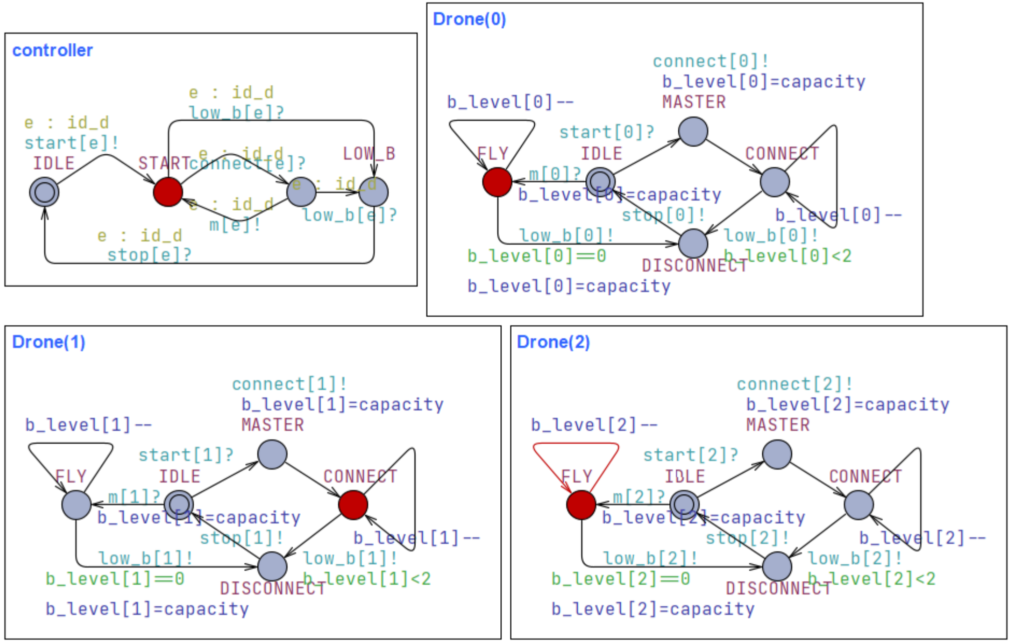
These properties must also be satisfied when we scale from two drones to three or more.

Three-Drone Model



Multiple Drones (Swarm)

Having a separate battery control for each drone



Switching between task?

Planning — Objective-based planning

Control — Control algorithm to fullfill the objective

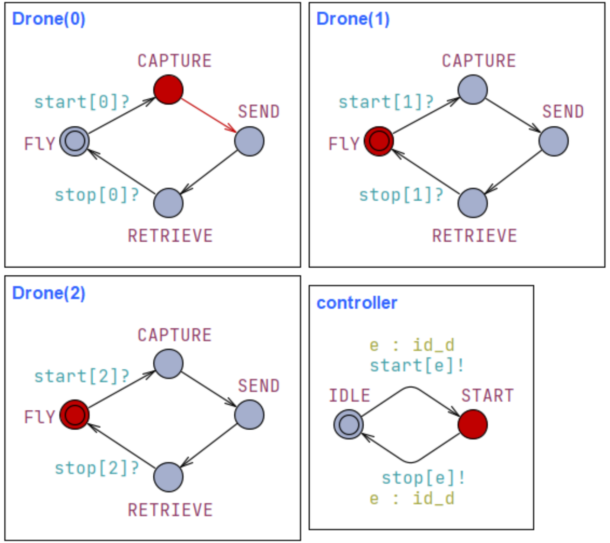
Task 1 — Survilliance

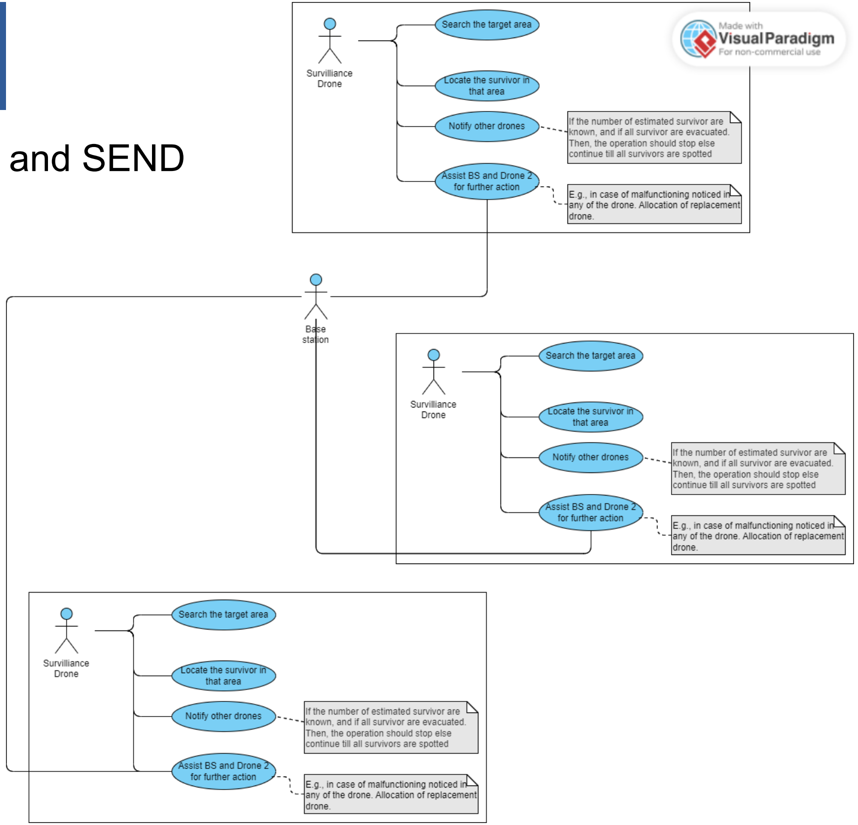
Task 2 — Capturing images (can be part of sub-task)

Consider single drone, performing two task at different times.

Modeling different aspects

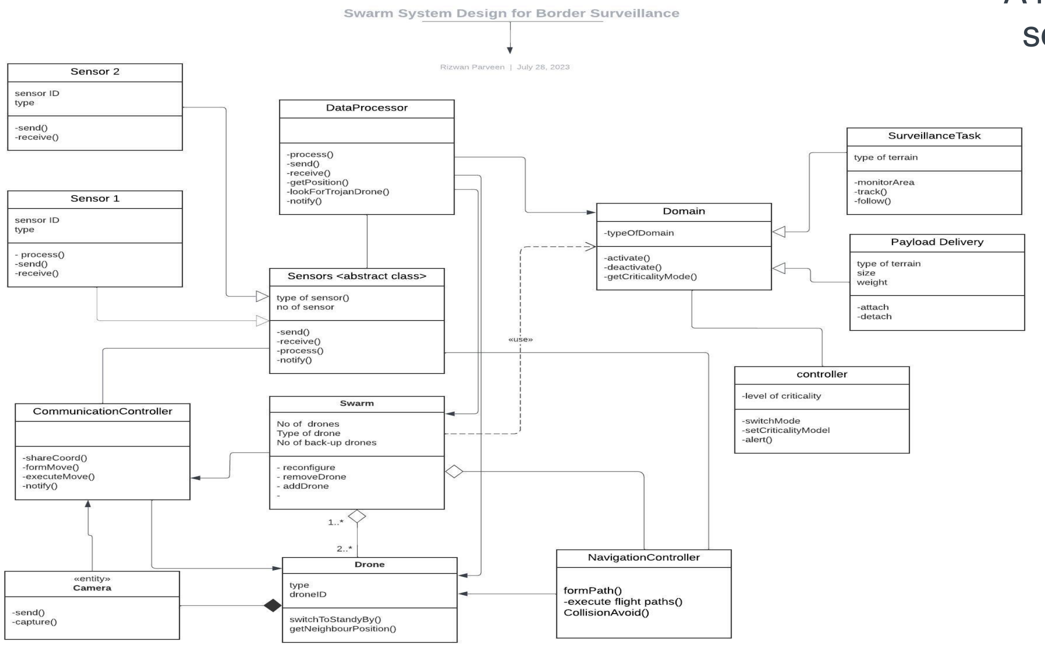
No master drone, however only one drone will CAPTURE and SEND images while other one engage in exploration



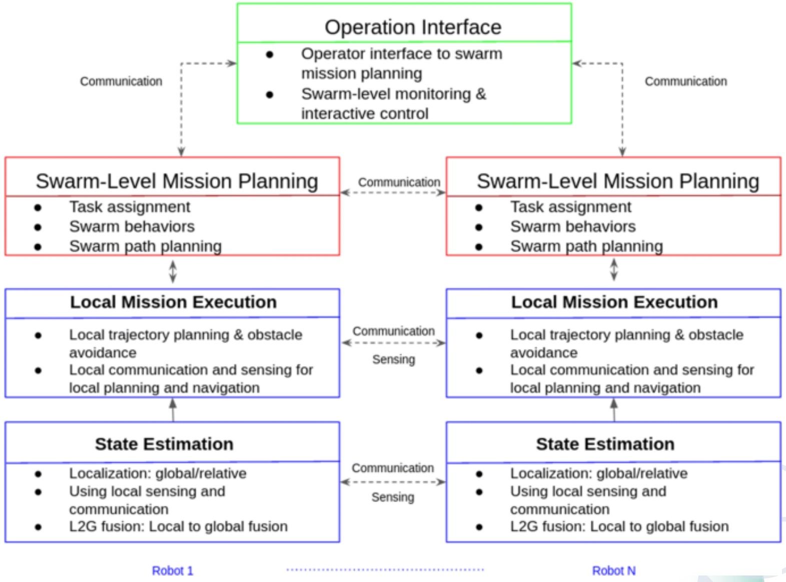


Scenario: when other drones are flying, one of drone is engagged in capturing images. The task is distributed among three drones. For example, Search and Rescue alert by one drone.

Task Hierarchy



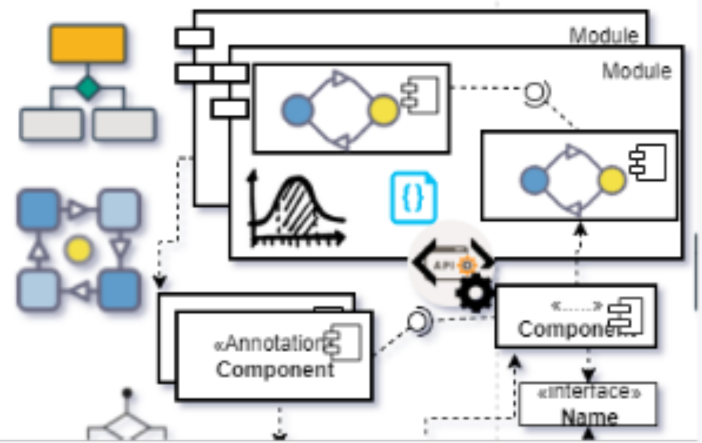
A mission is decomposed into multiple task set where each task set can have one or more tasks.



Three Layer:

Bottom: camera, sensors, drone, swarm, **Mid:** NavigationController, DataProcessor, CommunicationController, **Top:** Domain

Ref: Abdelkader, M., Güler, S., Jaleel, H. *et al.* Aerial Swarms: Recent Applications and Challenges. *Curr Robot Rep* **2**, 309–320 (2021). https://doi.org/10.1007/s43154-021-00063-4



05

Direction

Suitability of existing Model-driven Approaches

IMPORTANT POINTS

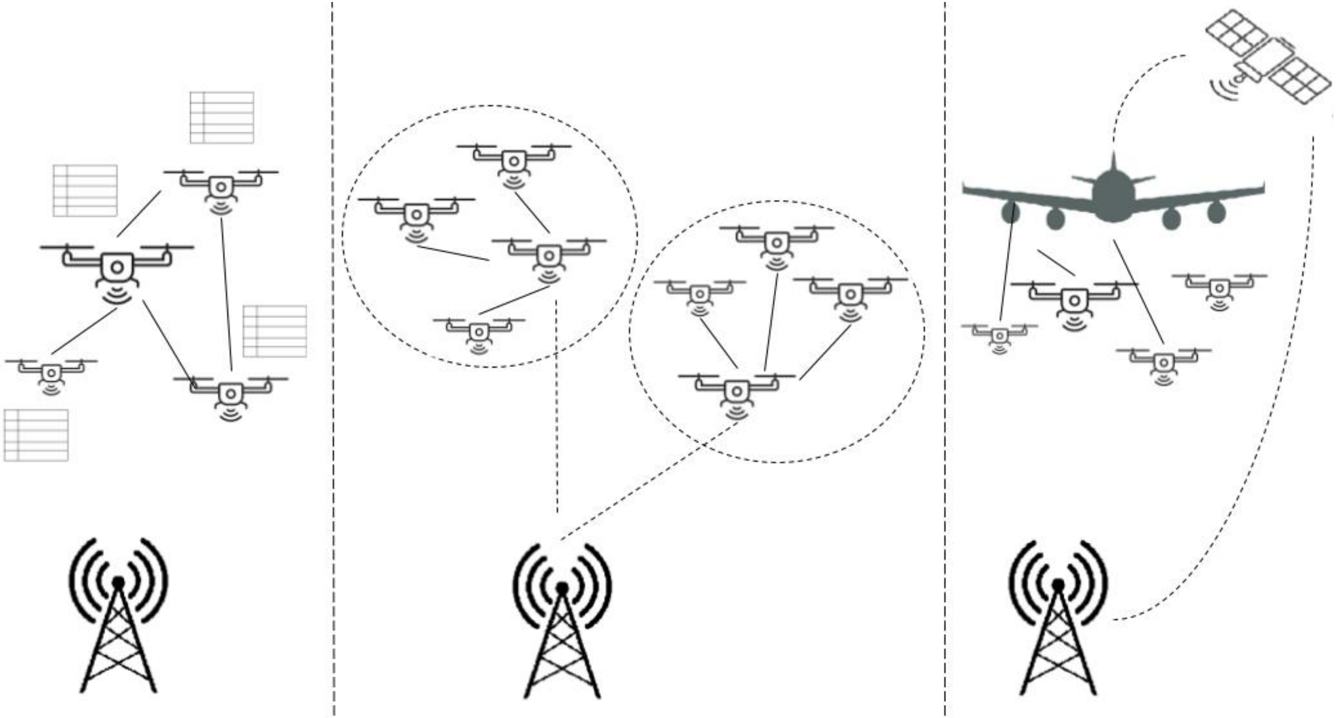
Communication Protocols:
RQ1: What communication protocols are most suitable for efficient and reliable communication among drones in a swarm?
RQ2: How can communication protocols be optimized to minimize latency and maximize bandwidth utilization in a drone swarm?

Interference and Signal Strength:
RQ3: What methods/algorithm to be applied for reducing the affect of interference and signal strength in drone-to-drone communication due to environmental challenges?

Scalability:
RQ4: What are the scalability limits concerning the number of drones in a swarm, and how does the density of drones impact communication reliability? Use of MCTS?

Mixed Criticality:
RQ5: How to generalize mixed criticality to drone swarm?

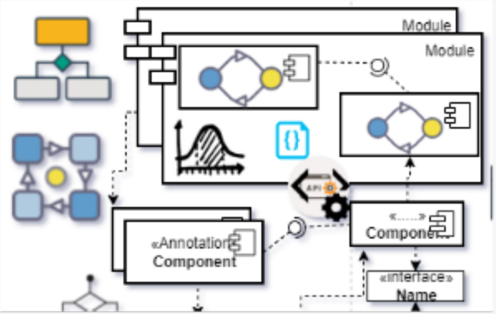
E.g. Types of Connectivity



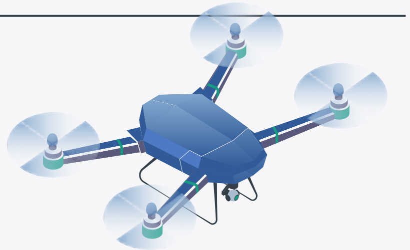
06

Conclusion

- Timed Automata based modeling suitable for formally verifying properties of interest.
- Good for modeling a swarm system with hierarchy of task (Drone level, Group level, Swarm level)
- Modeling individual components of a system which is decomposed at various level of abstraction.
- Scalability can be concern if using UPPAAL based modeling.
- How about **AADL** based modeling?



OUR TEAM

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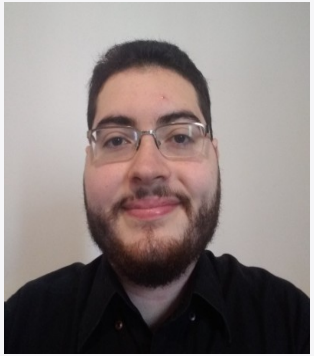
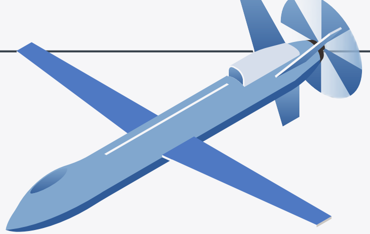
Samuel Tardieu


Dominique Blouin


Franco Cordeiro


It’s me



THANKS!

DO YOU HAVE ANY QUESTIONS?

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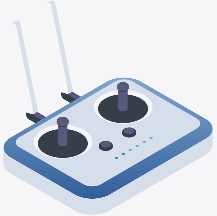

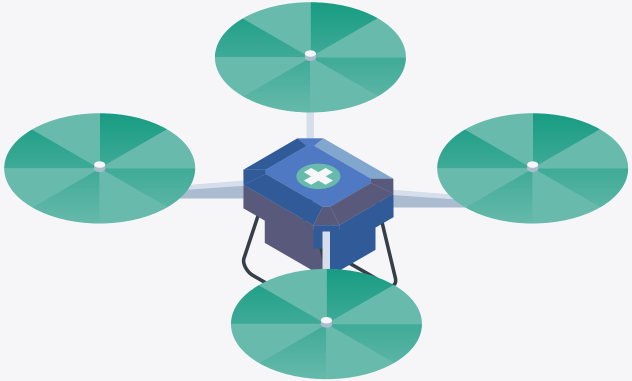

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