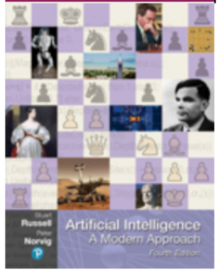
Role of multi-agent systems in a future fleet

Dr. Apurva Joshi
VP - R&D
Indrones Solutions Pvt. Ltd

- ⌂ US Edition
- ⌂ Global Edition
- Acknowledgements
- Code
- Courses
- Editions
- Errata
- Exercises
- Figures
- Instructors Page
- Pseudocode
- Reviews



Artificial Intelligence: A Modern Approach, 4th US ed.

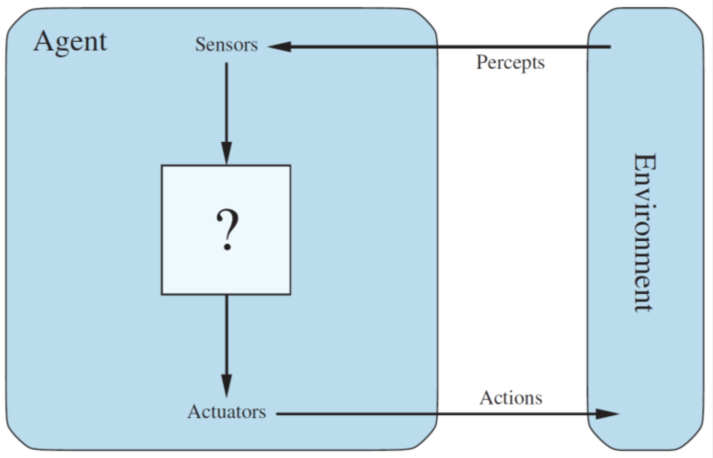
by Stuart Russell and Peter Norvig

The authoritative, most-used AI textbook, adopted by over 1500 schools.

Table of Contents for the US Edition (or see the Global Edition)

Exercises (website)
Figures (pdf)
Code (website); Pseudocode (pdf)
Covers: US, Global

⌂ *AI: A Modern Approach* Modified: Aug 22, 2022



Synopsis

Multi-agent or "swarm" systems have drawn the military's attention over the last two decades due to their potential **expendability, redundancy, and expanded sensor coverage**. This interest can primarily be attributed to the dynamic field of **unmanned systems technology**, which has been rapidly developing both in government and in the private sector. In this talk, we will go through the research and development in this field and discuss initiatives that need to be taken to advance from the current unmanned systems paradigm in which a single pilot controls a vehicle or a few vehicles at most, to remotely supervised swarms.

Background

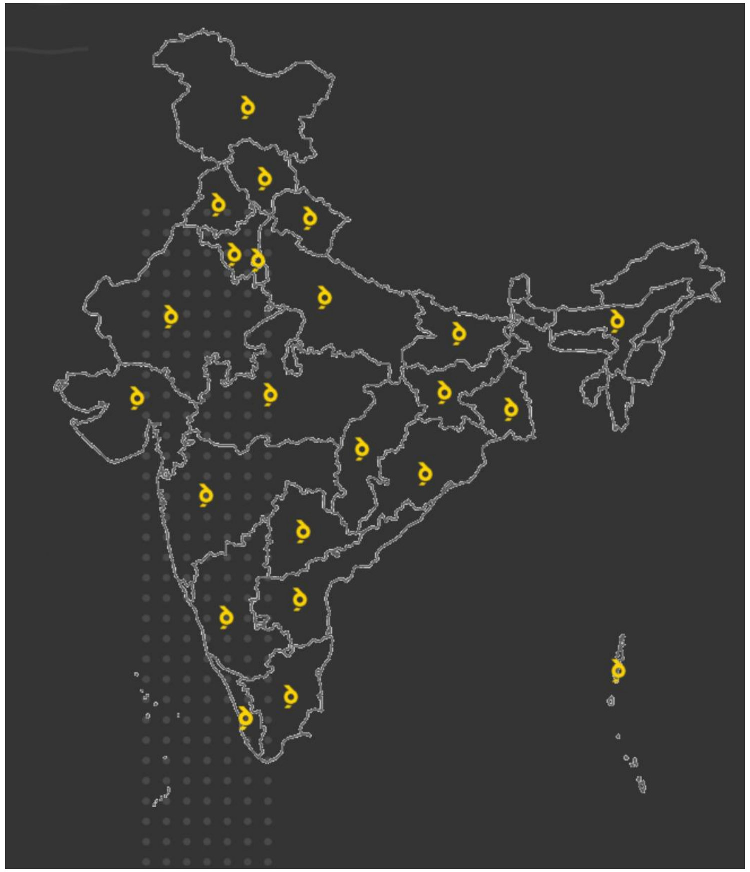
Prototype ---------------------------------→ Product

Autonomous vehicles
Multi-agent systems ----------→

inDrones

About us

#rapidgroundtruthing

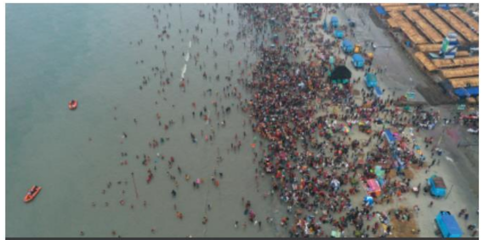



Railways


Oil & Gas


Agriculture


Mining


Disaster Management

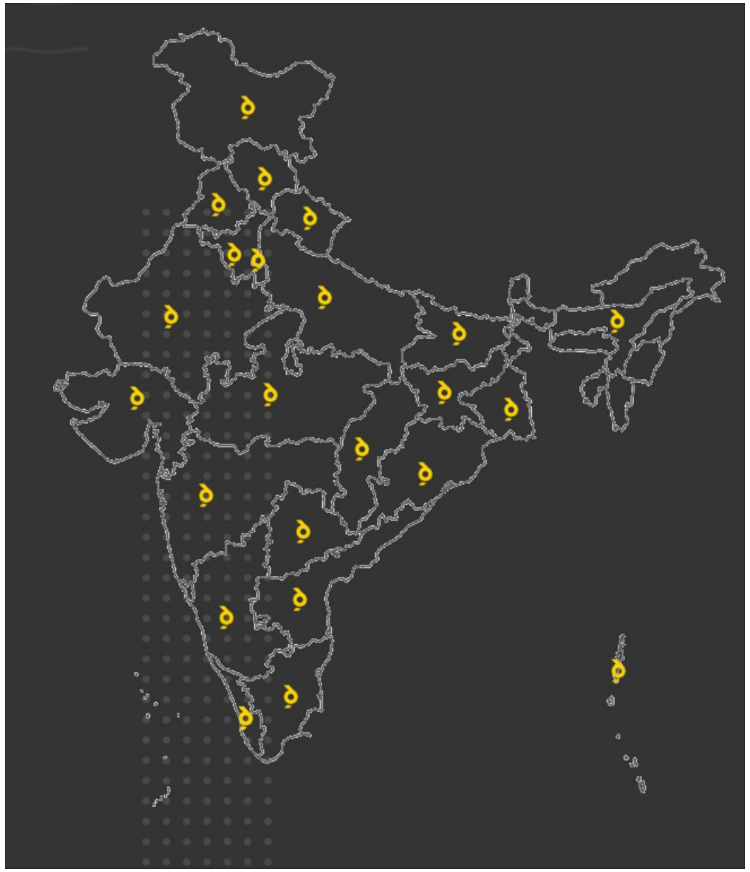

Telecommunication


Construction & Infrastructure


Government & Smart Cities

About us

#rapidgroundtruthing

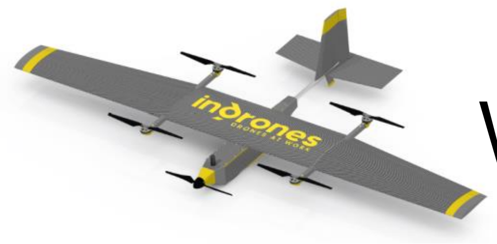


About us

Drones

Sigma 25

Sigma 75



Vector VTOL

DaaS

Inflight

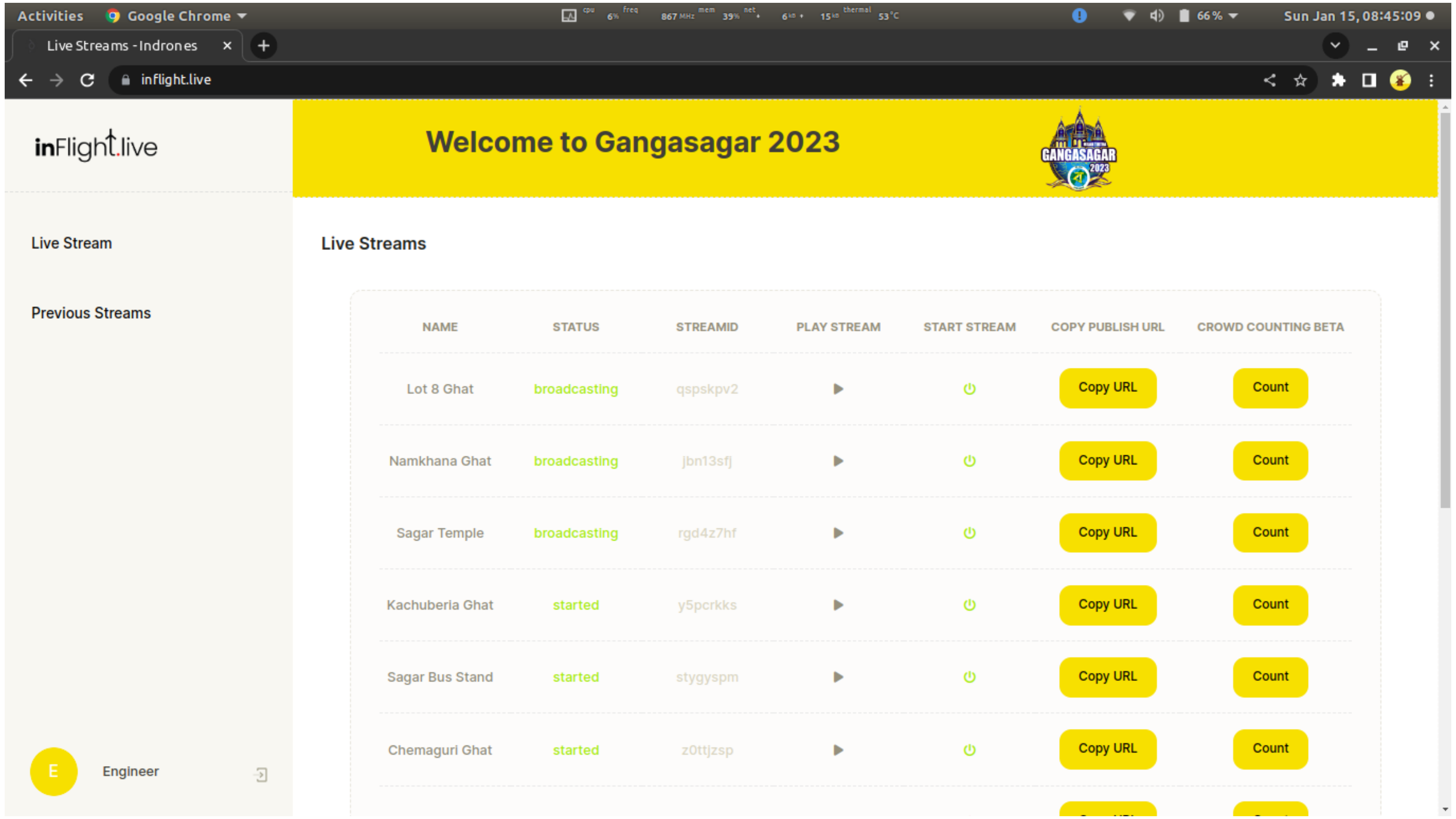
Inspect

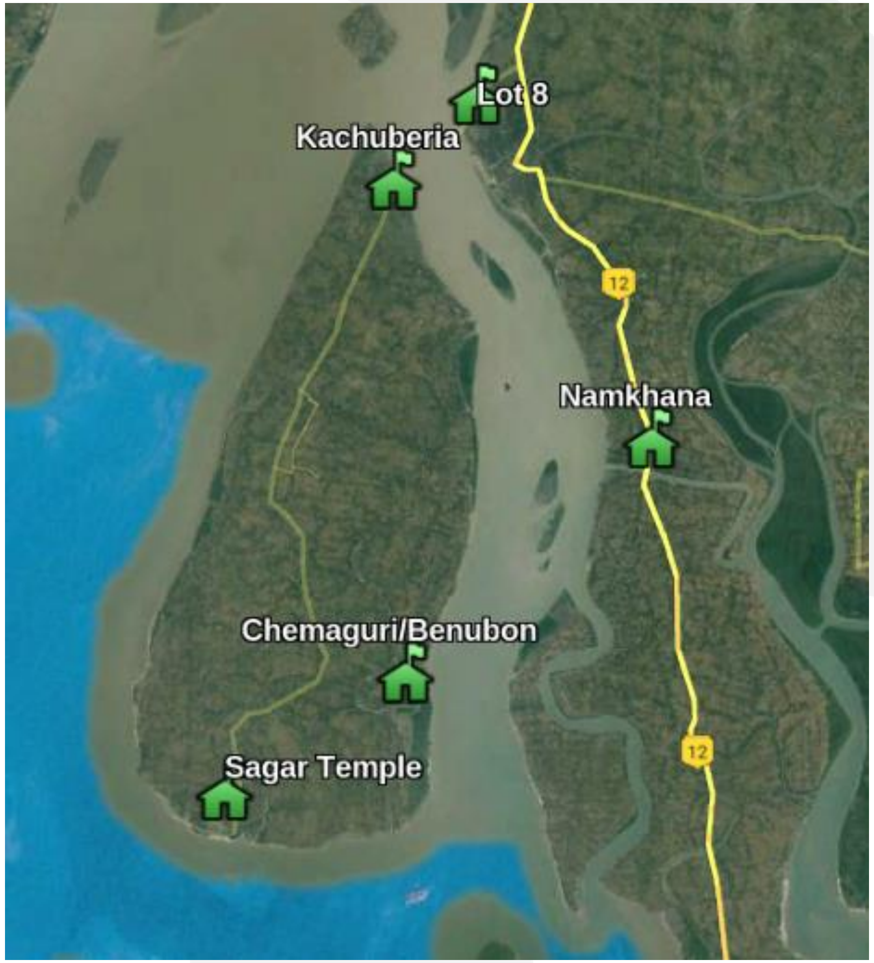
Incharge

indrones

Inflight

Disaster Management

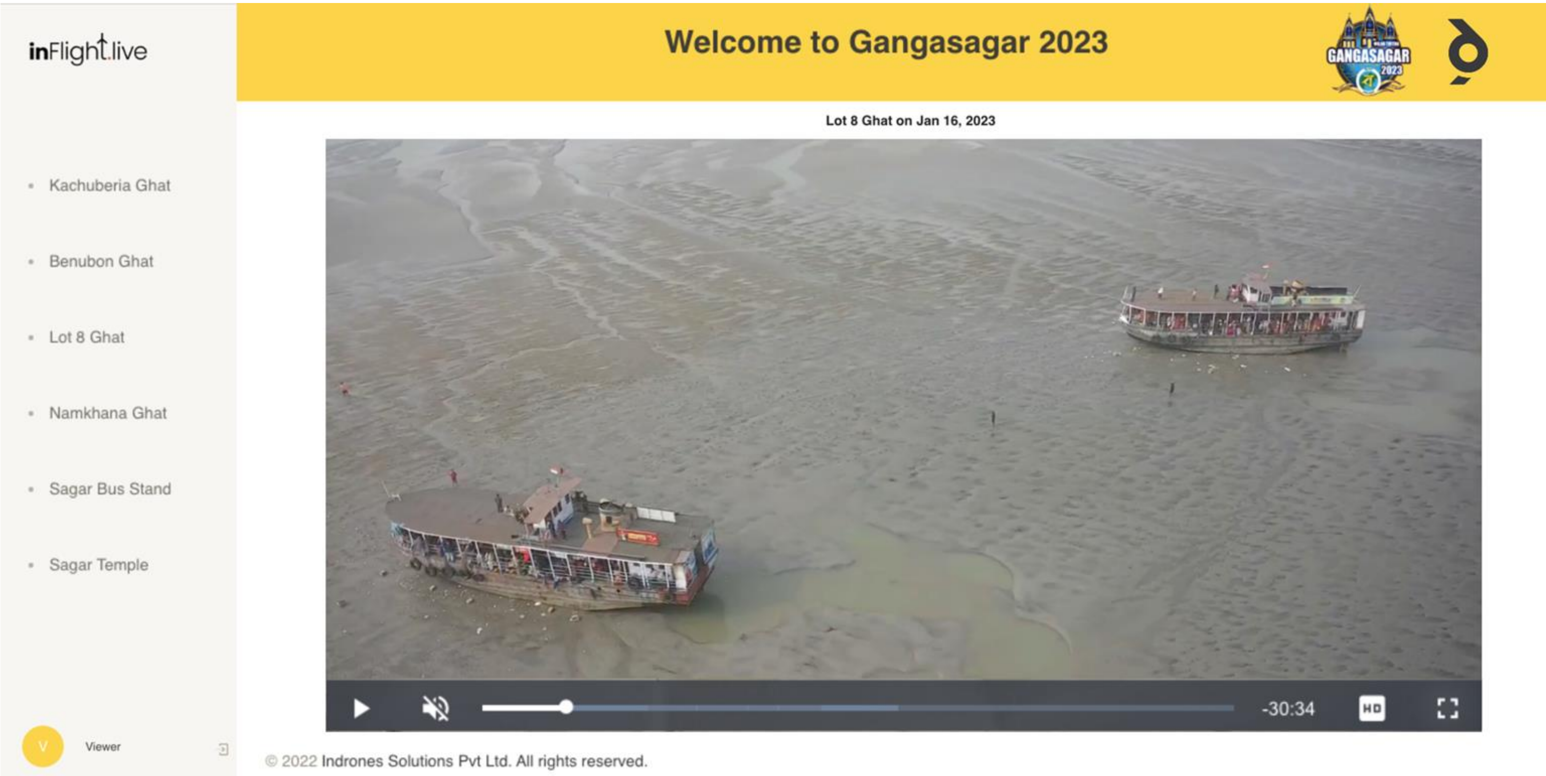


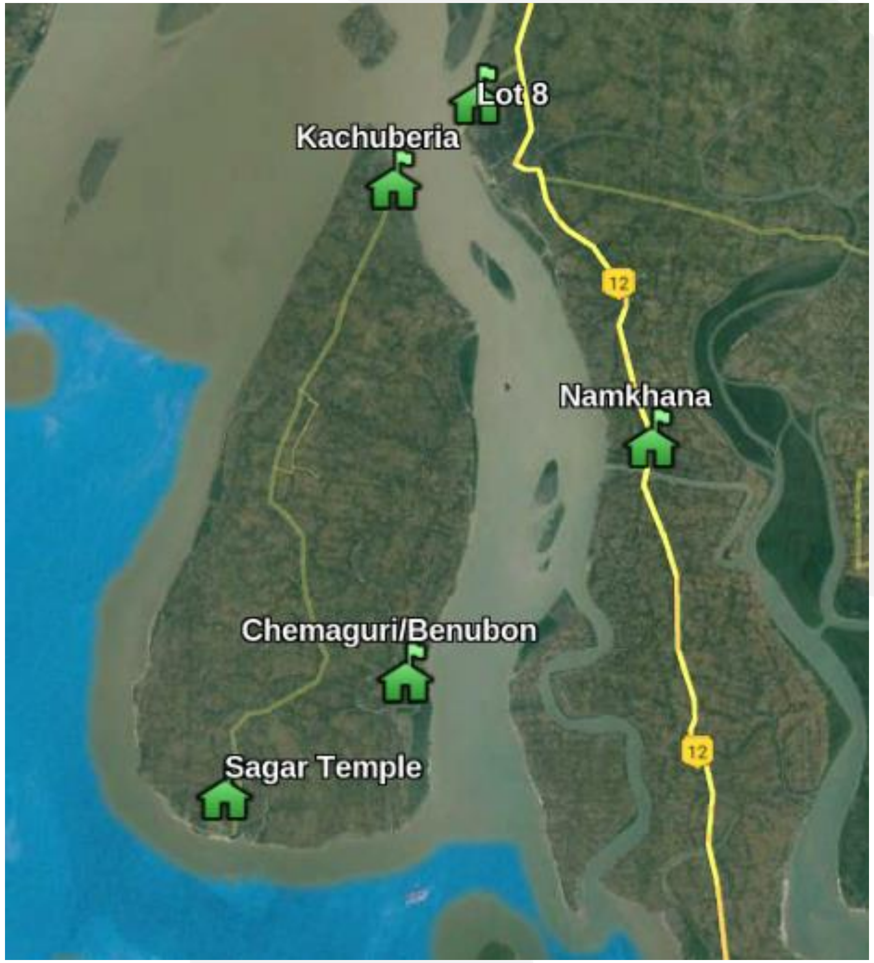


indrones

Inflight

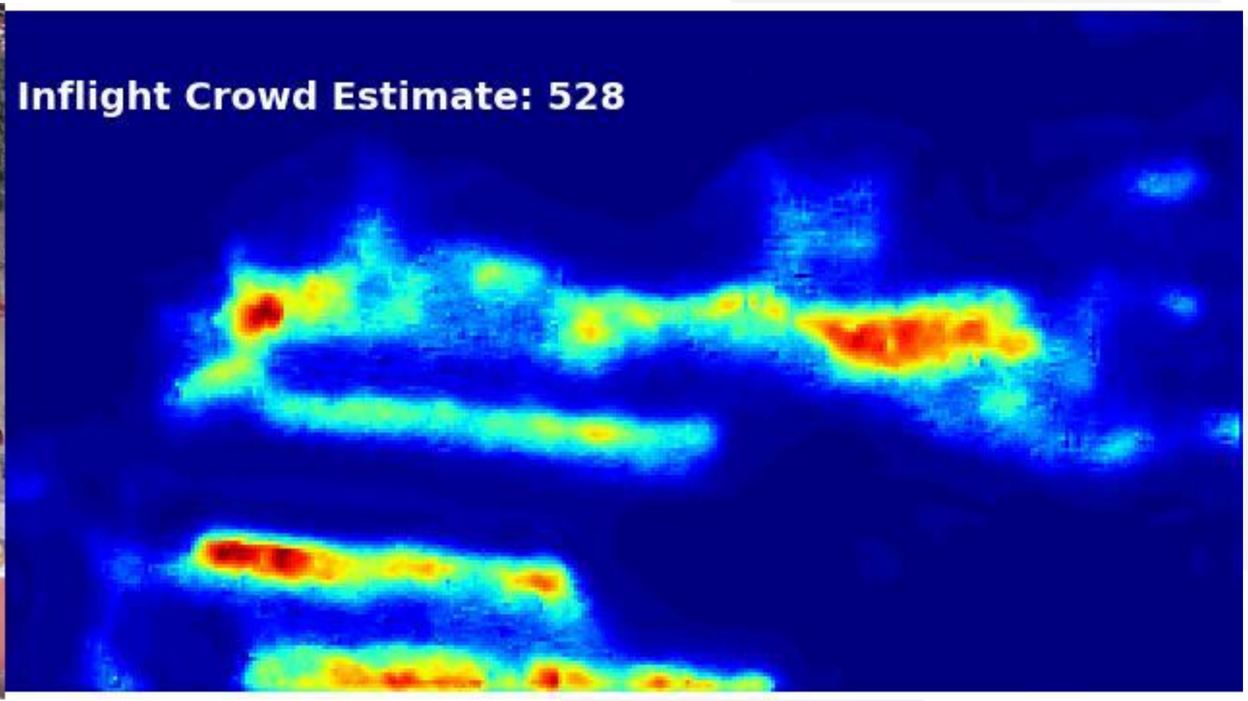
Disaster Management





Inflight

Crowd estimation



Time: Friday, 13th Jan 2023, 12:17 pm

Inflight crowd estimate ~ 528 people

Inspect

Linear Asset Management

Change detection

21st July 2021

4th August 2021

Change detection

Detecting changes between two drone runs

IOCL: Delhi - Panipat Section

inDrones

Inspect

Linear Asset Management

Change detection

21st July 2021

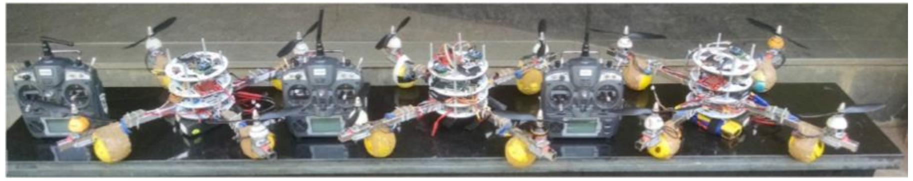
4th August 2021

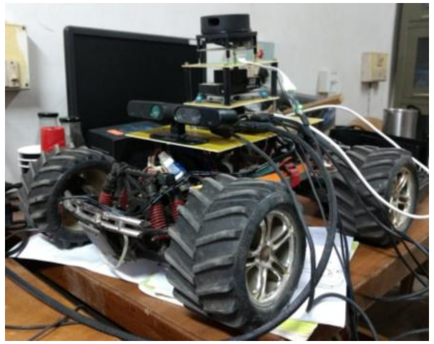
Change detection

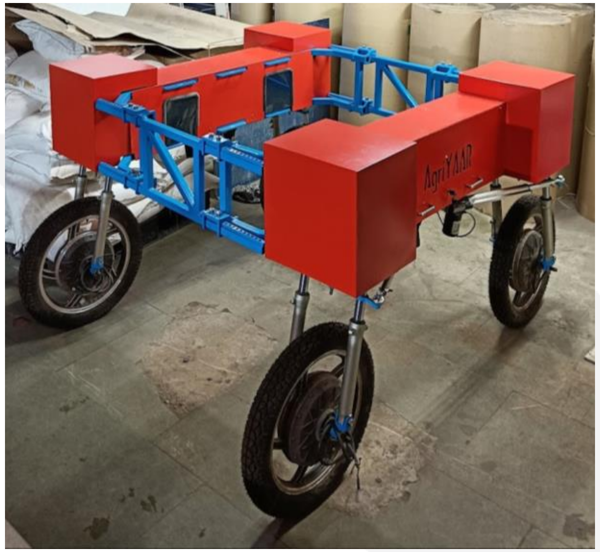
Detecting changes between two drone runs

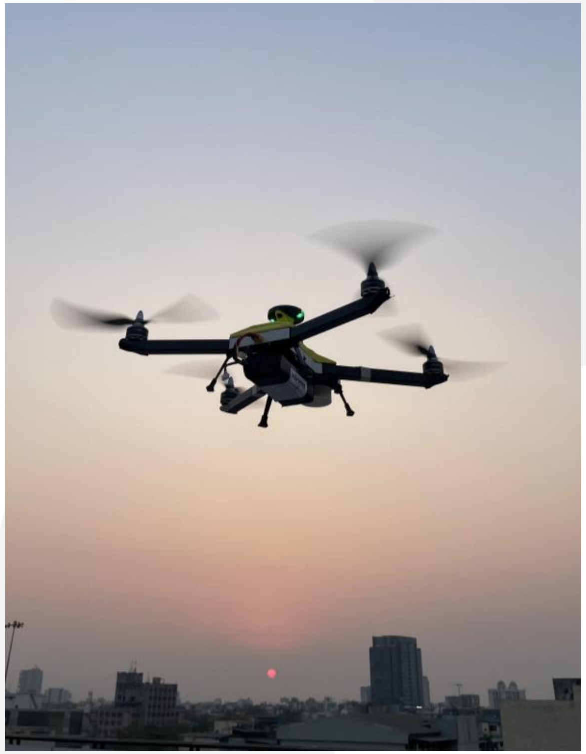
IOCL: Delhi - Panipat Section

indrones









Autonomous Vehicles

- Vehicles that can perform tasks with minimal human intervention
- Add value to the mission/goal

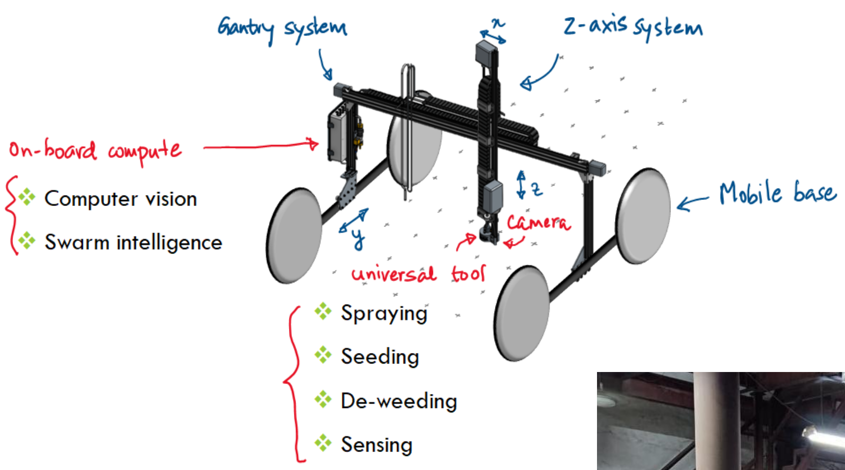
Tech demos and prototypes

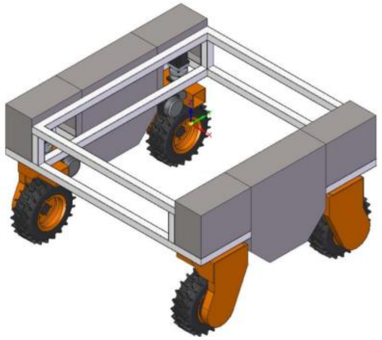


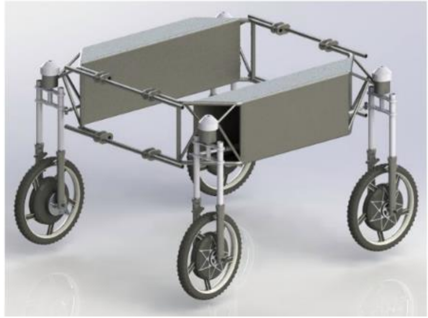

VTOL prototype at IIT Bombay

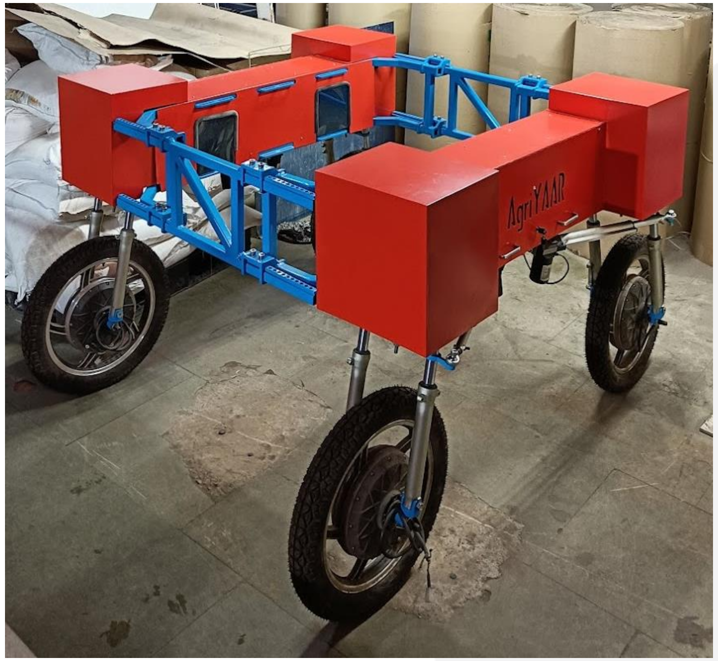
inDrones

Tech demos and prototypes









Project AgriYAAR

Tech demos and prototypes

^ Precise payload delivery

Real time onboard object detection >

^ Prototype delivery drone

Tech demos and prototypes

NCETIS

Vision based drone detection

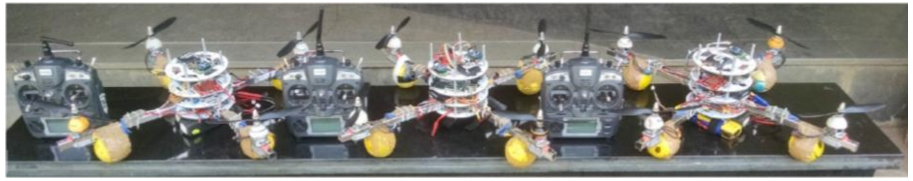
Dr. Apurva Joshi
apurva.joshi@301labs.com

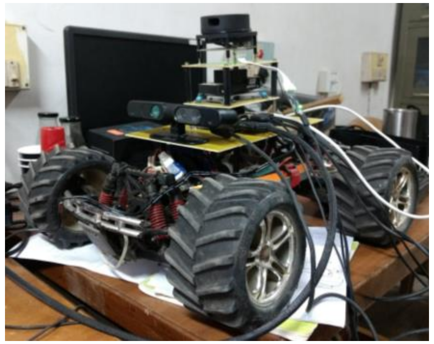
Dr. Swaroop Hangal

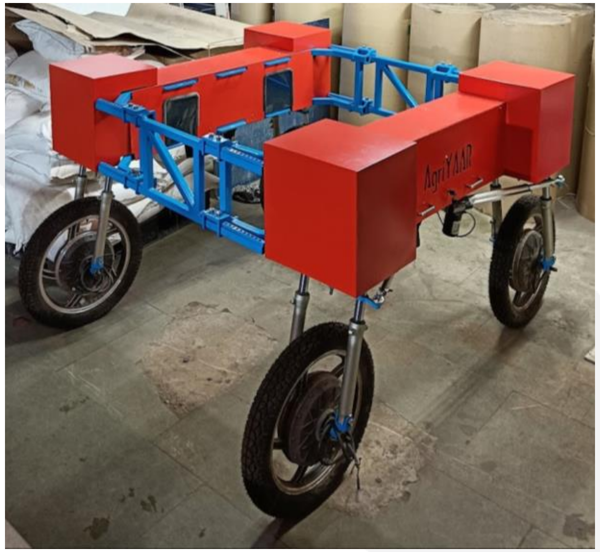
301 Labs,
NCETIS - IIT Bombay

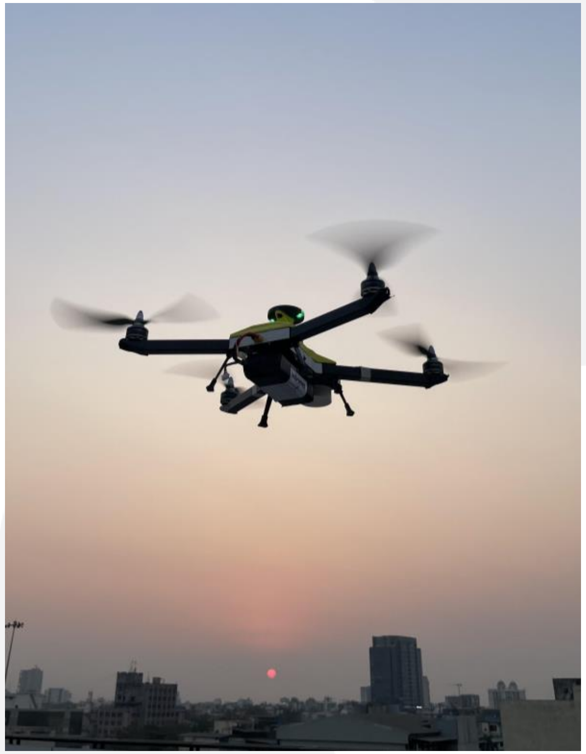
[CONFIDENTIAL]

indrones









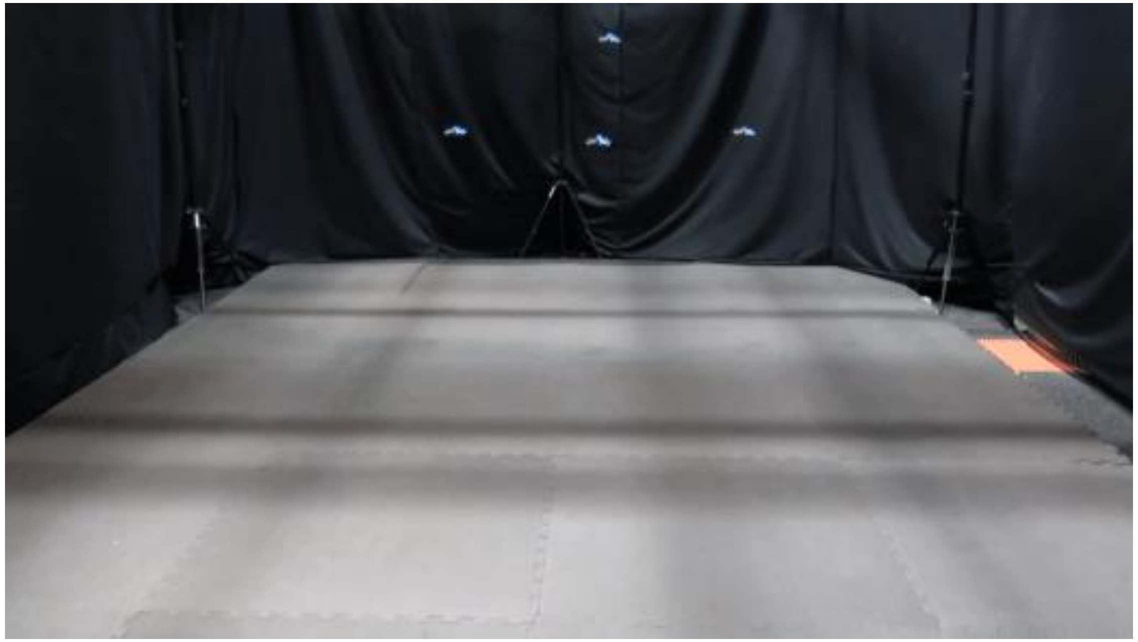
Multi-agent systems

- Perform tasks through cooperation with minimal human intervention
- Add value to the mission/goal

Cooperative control algorithms

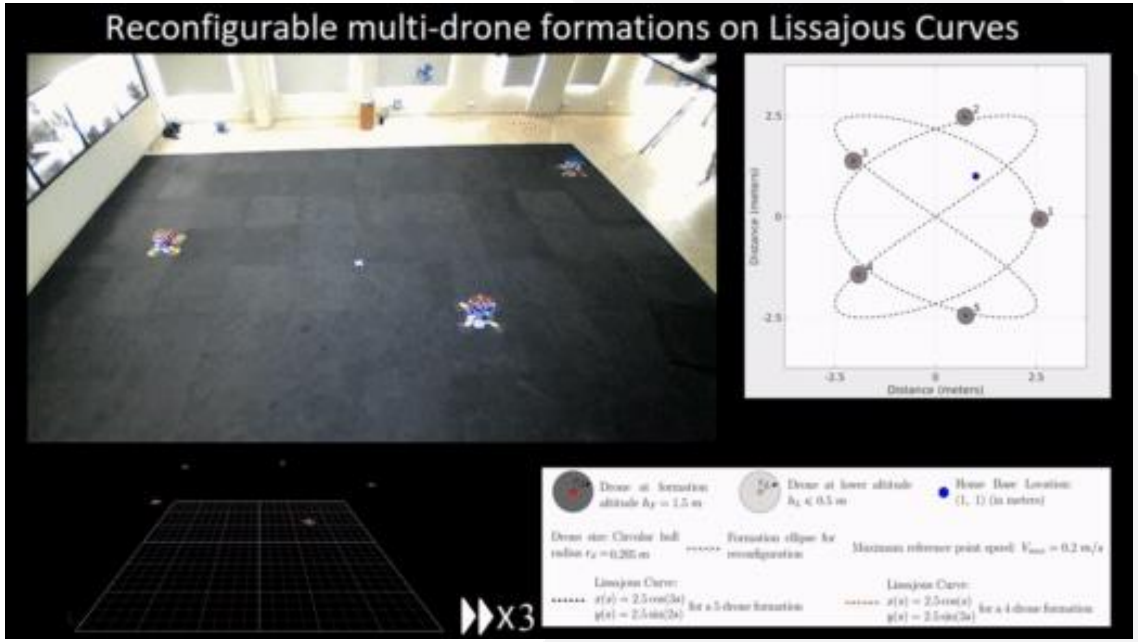
- Flocking
- Boids
- PSO
- Levy Flight
- Scheduling
- Sorting
- Collective consensus
- Artificial potential fields
- Brownian motion
- Leader-follower

Cooperative control algorithms



Formation flight (Joshi et. al.)

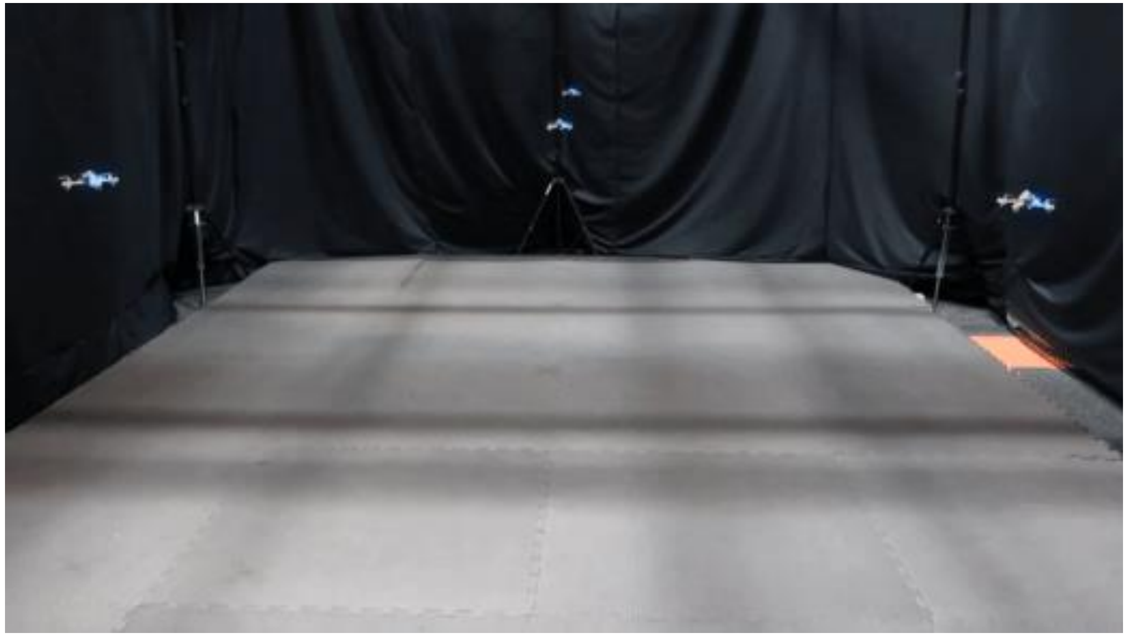
A human pilot commands one robot, the autonomous robots hold formation and follow



Coverage and Search (Borkar et. al.)

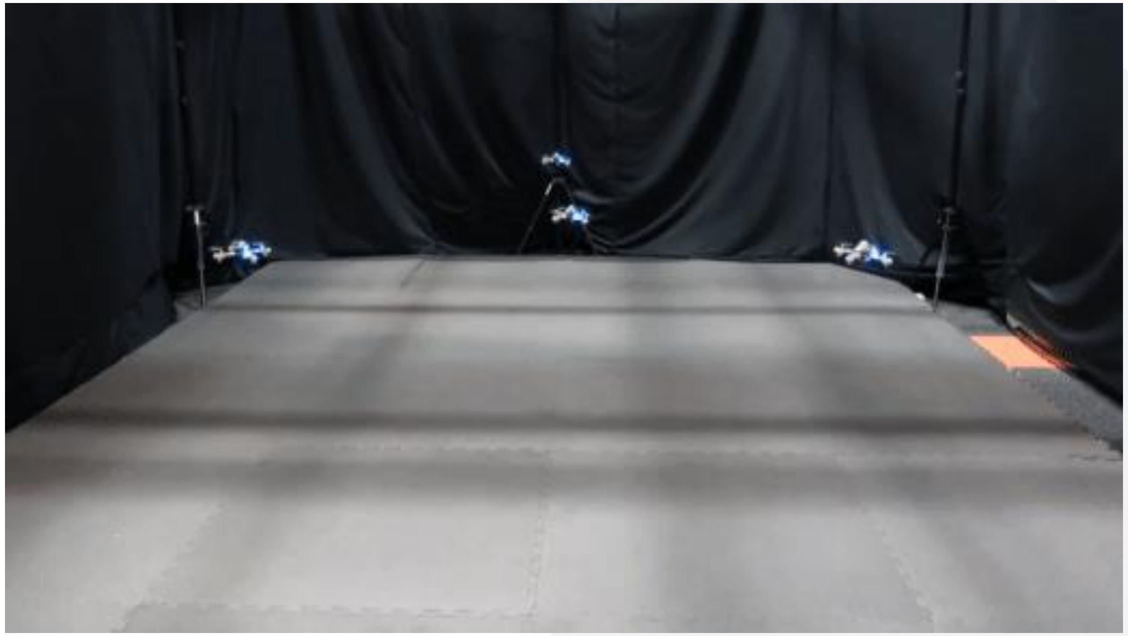
A team of robots follow a coverage pattern and search for specific targets

Cooperative control algorithms



Capture (Joshi et. al.)

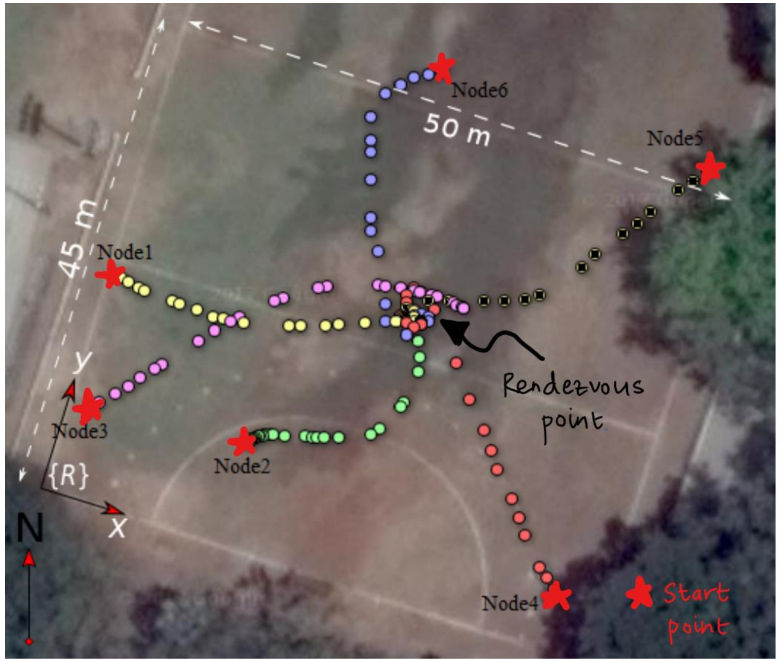
Autonomous robots detect an invading robot and surround it in minimum time



Pursue (Joshi et. al.)

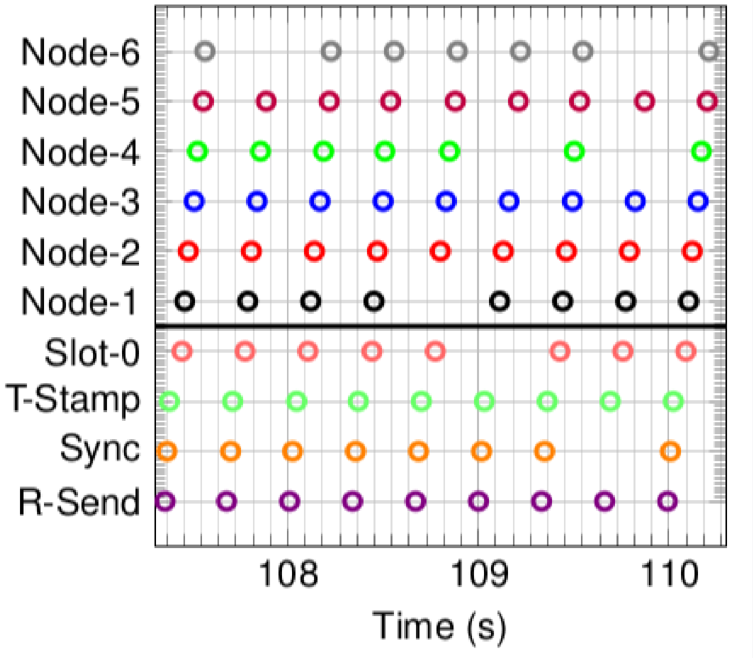
Autonomous robots track the evading robot so that it cannot escape

Cooperative control algorithms



Consensus (Joshi et. al.)

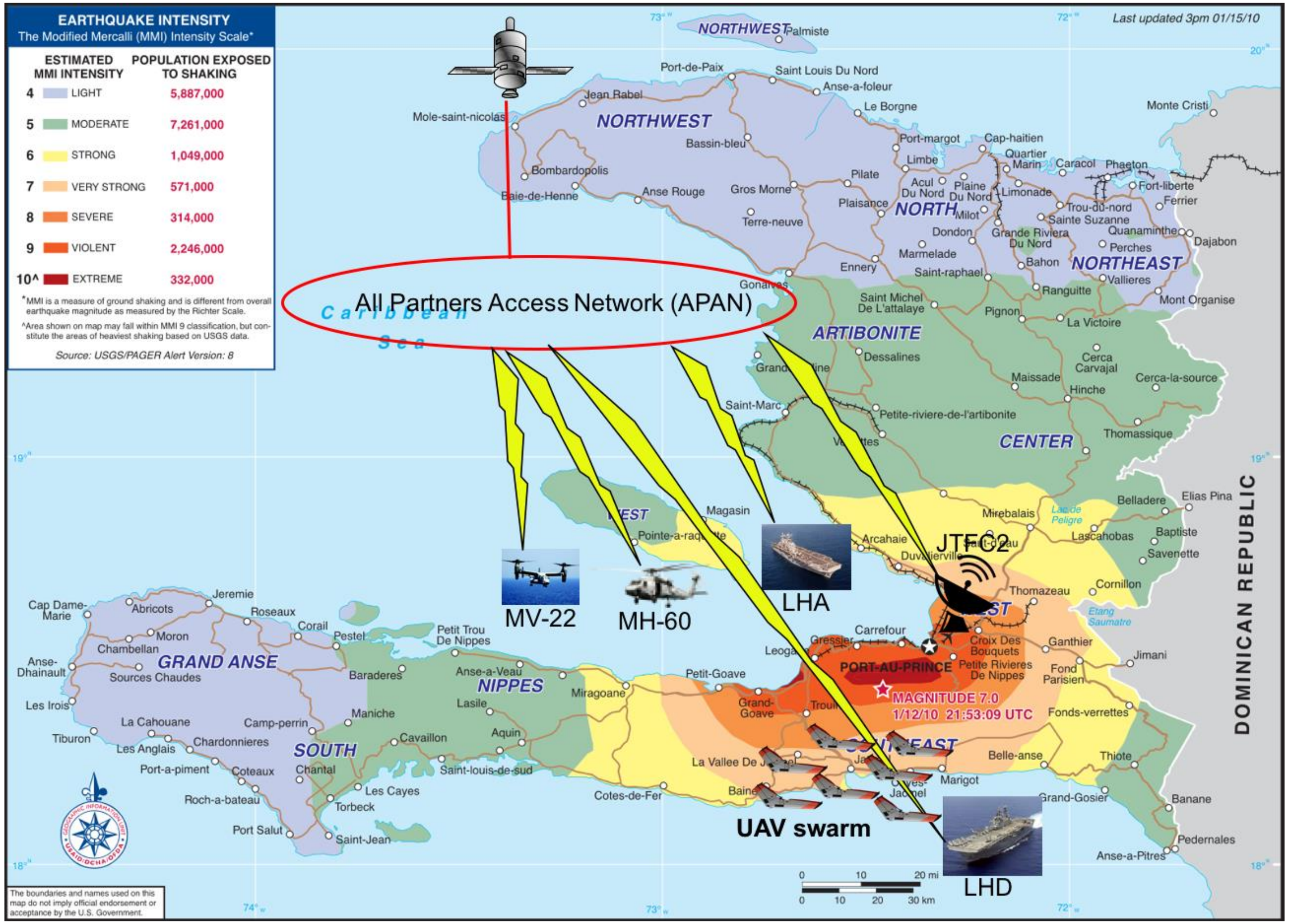
Robots communicate with their neighbours and autonomously navigate to a rendezvous point



Communications (Joshi et. al.)

Collision-free TDMA based communication protocol for multi-agent operations

Missions *

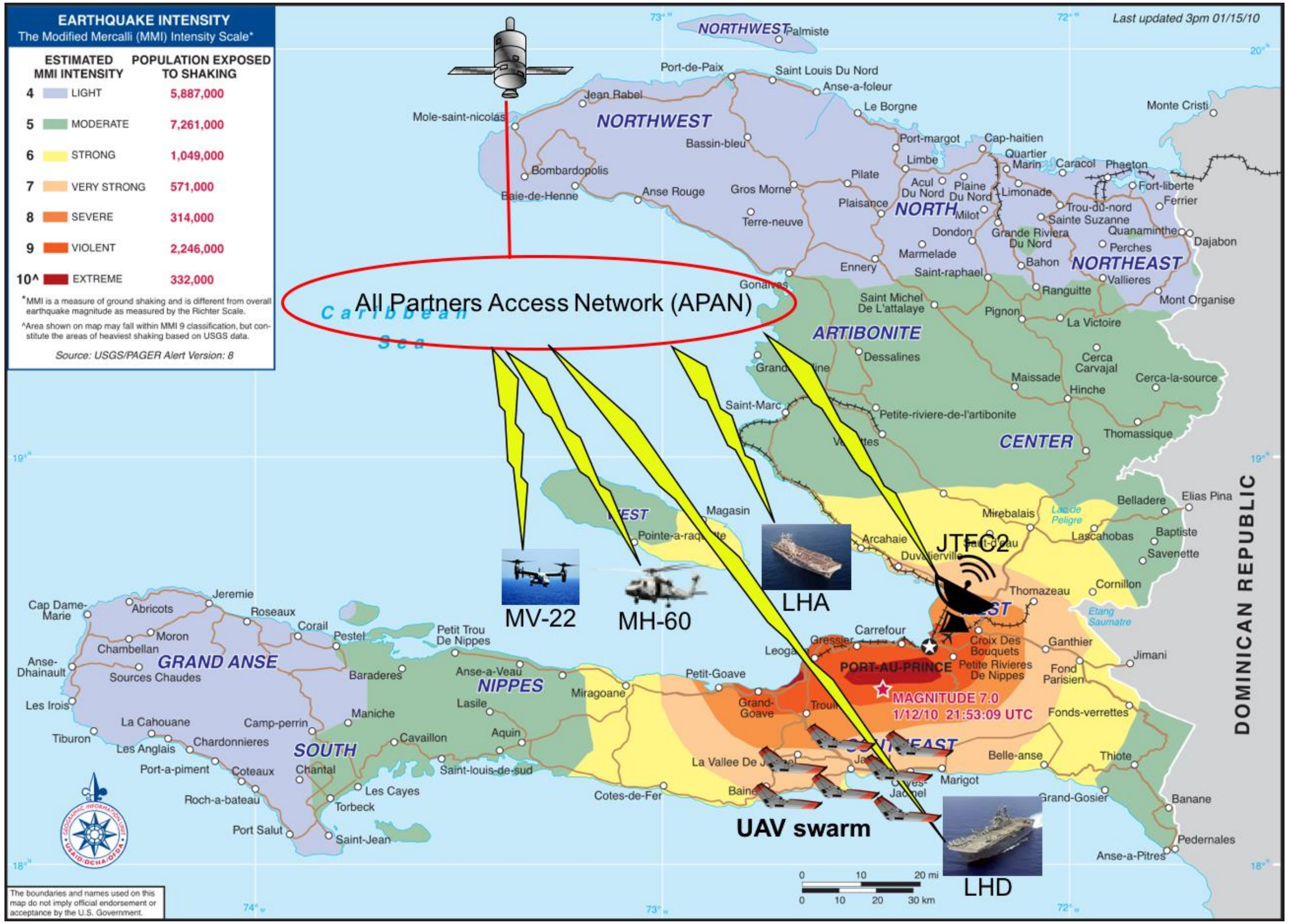


HADR

- Unique; time between notification and deployment is much shorter than most military operations
- Immediate response phase
- Assets:
  - USN Ships:
    - landing helicopter dock (LHD) amphibious assault ship – with medical support, CH-53 and MH-60 variants for transport, lift, and SAR; and landing craft air cushion (LCAC) for ship-to-shore supply delivery
    - landing helicopter assault (LHA) amphibious assault ship - with medical support, CH-53, MH-60 variants, and MV-22 for transport, lift

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

Missions *



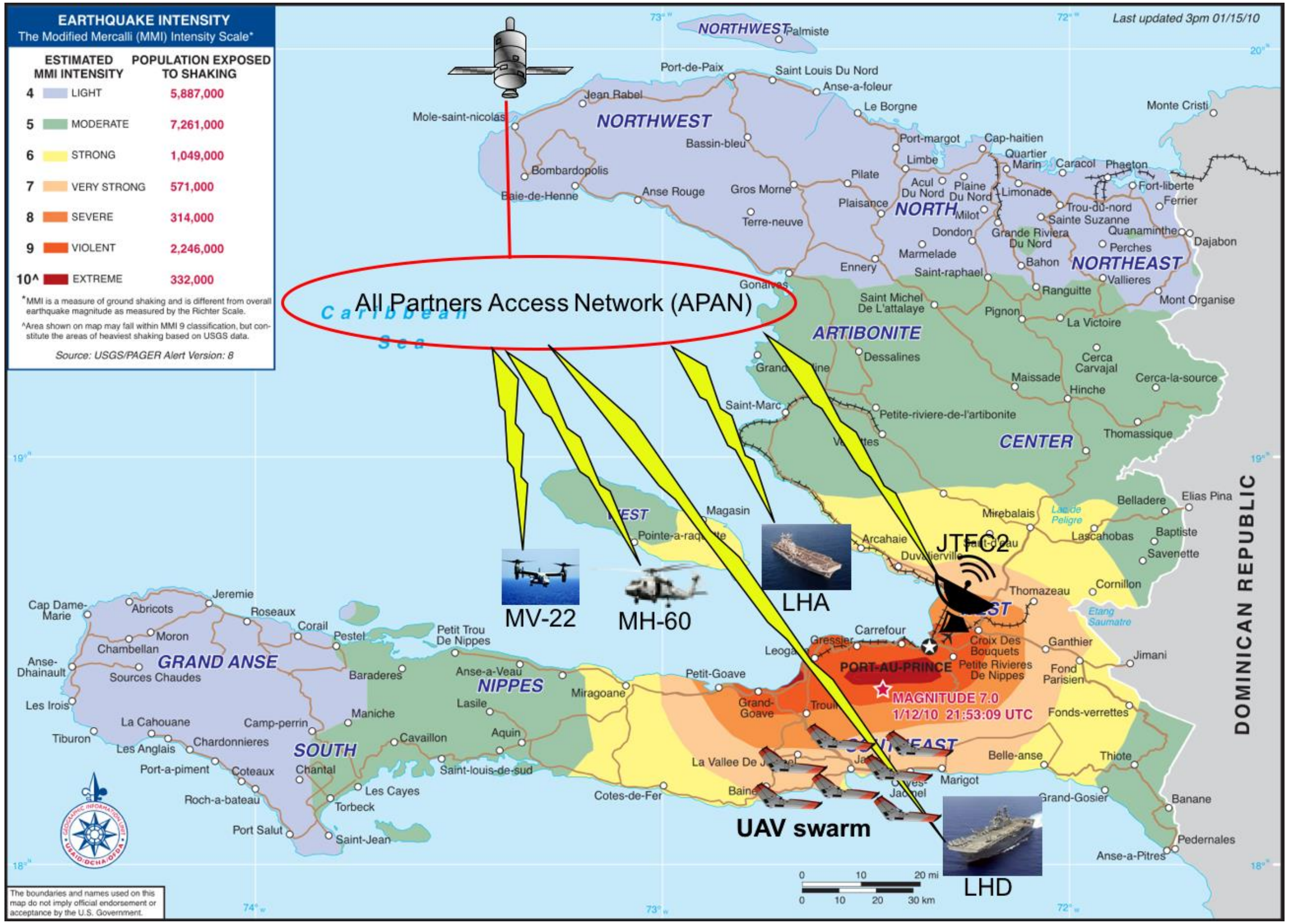
HADR

- Assets:
  - joint task force command and control node (JTFC2)—tactical air control squadron (TACRON), joint force air component commander (JFACC), or other joint task force (JTF) asset who will be providing air traffic control. Responsible for coordination between military and NGO assets.
  - Helicopters—MH-60 variants and CH-53, for SAR and ship-to-shore personnel and supply transport; and C-2 for personnel and supply transport from the LHD

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

inorones

Missions *

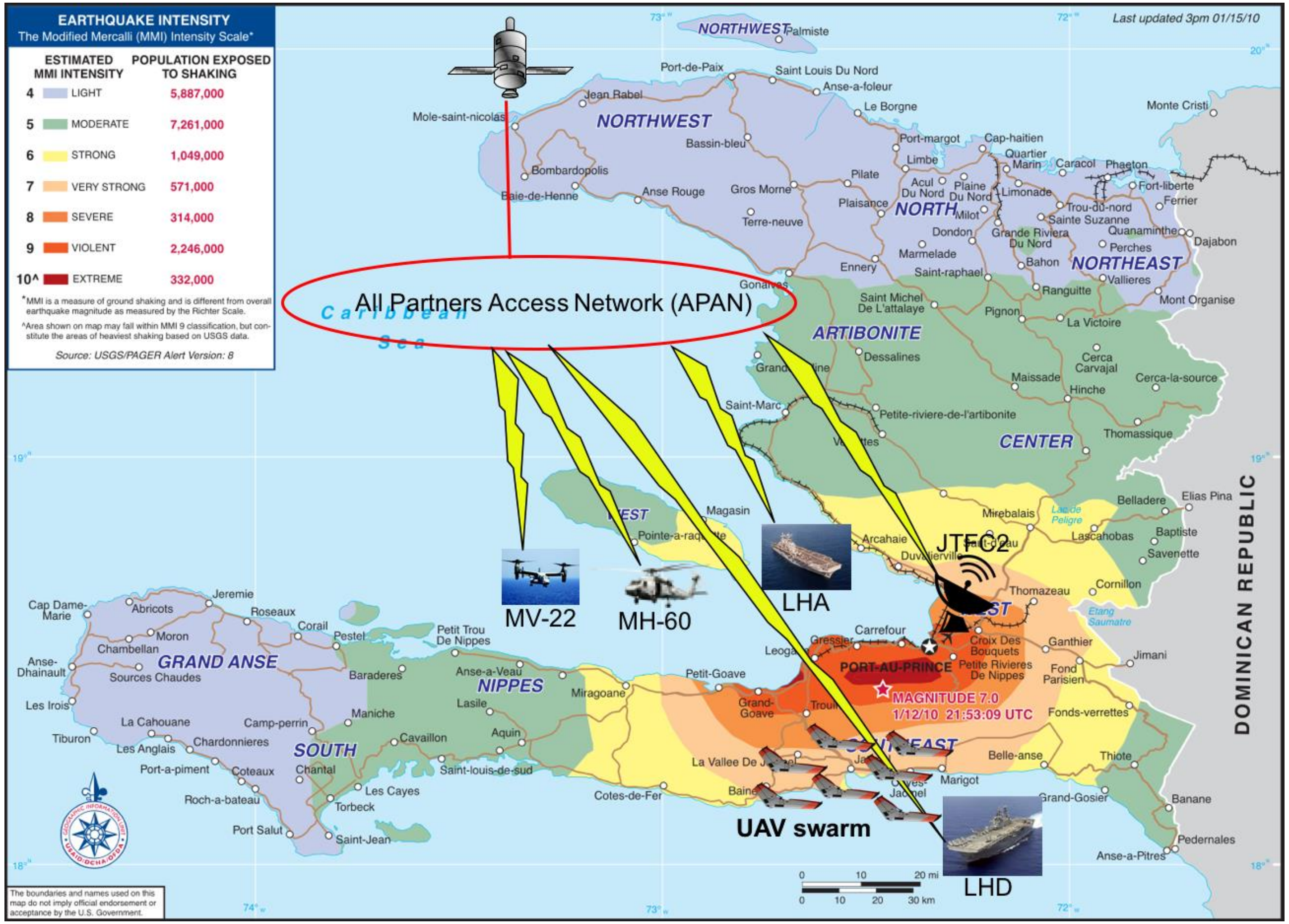


HADR

- ❑ Assets:
  - ❑ UAV swarm consists of a collection of identical UAVs launched from the LHD, a GCS, launch, and recovery systems, capable of providing:
    - ❑ streaming IR, video for detecting, classifying and identifying targets in the IR spectrum, during wide-area, day or night search
    - ❑ EO video for detecting, classifying and identifying targets in the visible light spectrum during wide-area, day-time search in clear atmosphere

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

Missions *

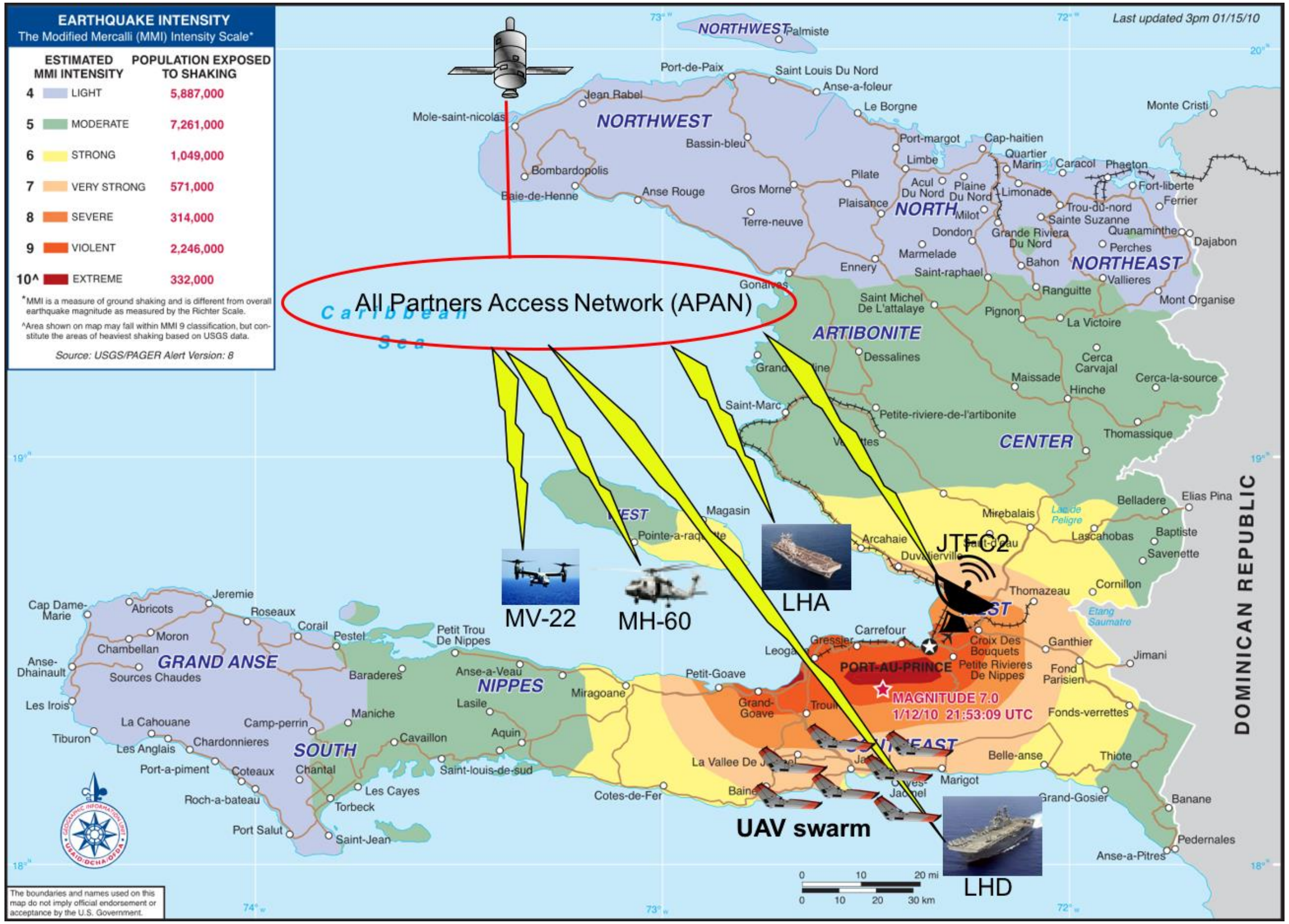


HADR

- ❑ Assets:
  - ❑ UAV swarm consists of a collection of identical UAVs launched from the LHD, a GCS, launch, and recovery systems, capable of providing:
    - ❑ SAR for all-weather detection and classification of stationary objects, and for determining the status of infrastructure such as roads, bridges, and buildings. IR and EO sensors can be cross-cued to and initial SAR target detection.
    - ❑ simultaneous voice relay and data-link communication over VHF, UHF, and military and commercial satellite

* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Missions *



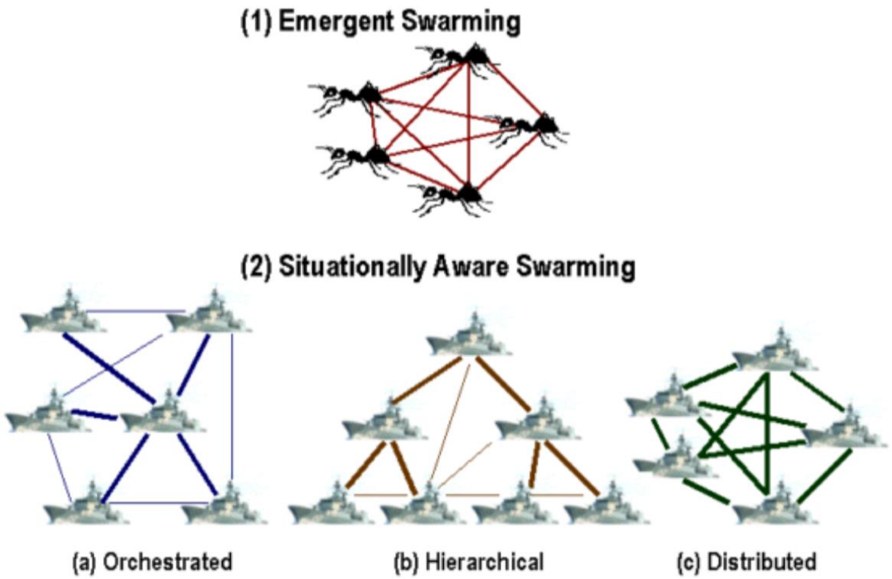
HADR

- Operating Environment, Threat Environment
- Success Requirements:
  - embark on and operate from LPD-19, LHD–5, LHA–6, or LHA-8 class ships
  - collect and disseminate imagery data to military and civilian units to improve timeliness of humanitarian need prioritization and decrease response time to deliver relief supplies
  - provide communication relay to other military and civilian units to improve information dissemination among participating units and decrease response time to deliver relief supplies.

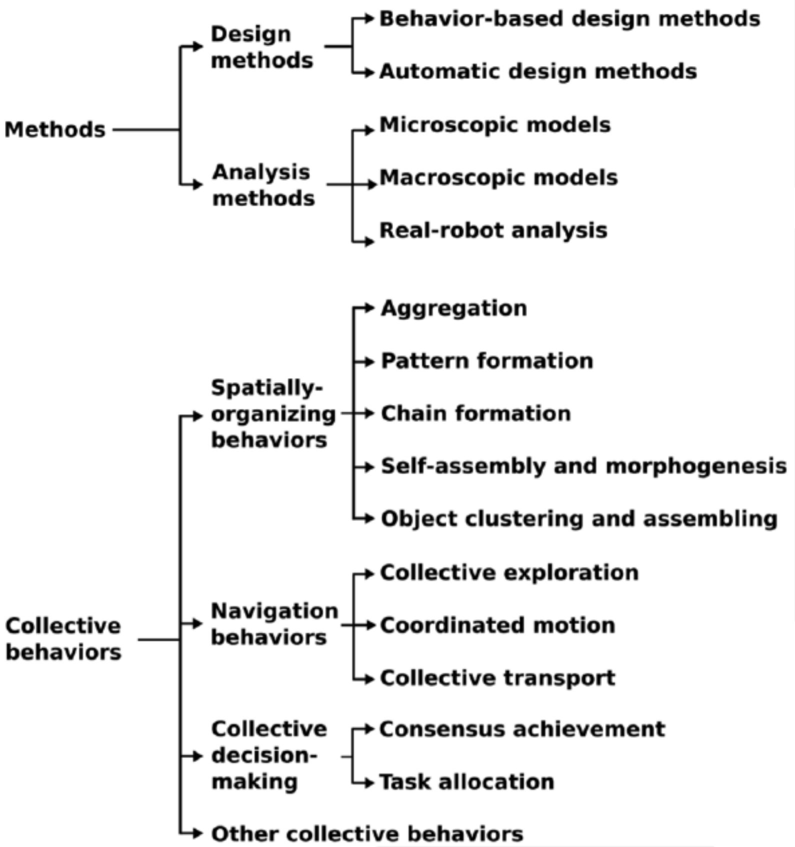
* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

Designing a Swarm *

C2 Architectures



Taxonomies

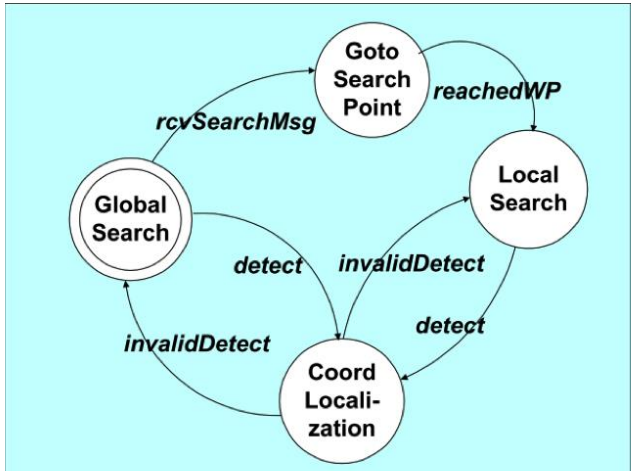


* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

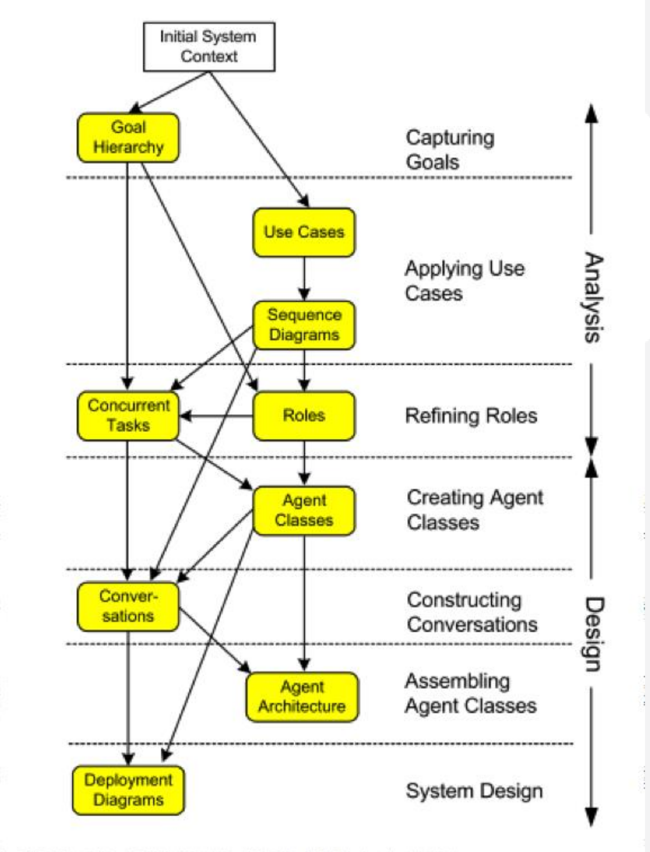
Designing a Swarm *

Bottom-up design

- Agent-based models
- Petri Nets
- Behaviour-based design
- Finite State machines



Top-down design



* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

Designing a Swarm *

Requirements Development

- ❑ CONOPS → Conceptual design
- ❑ Physical Architectures → Construction of prototypes
- ❑ Iterations → Detailed design
- ❑ Software
  - ❑ Agile dev
  - ❑ Automatic testing
  - ❑ Continuous Integration

Modelling Swarm systems

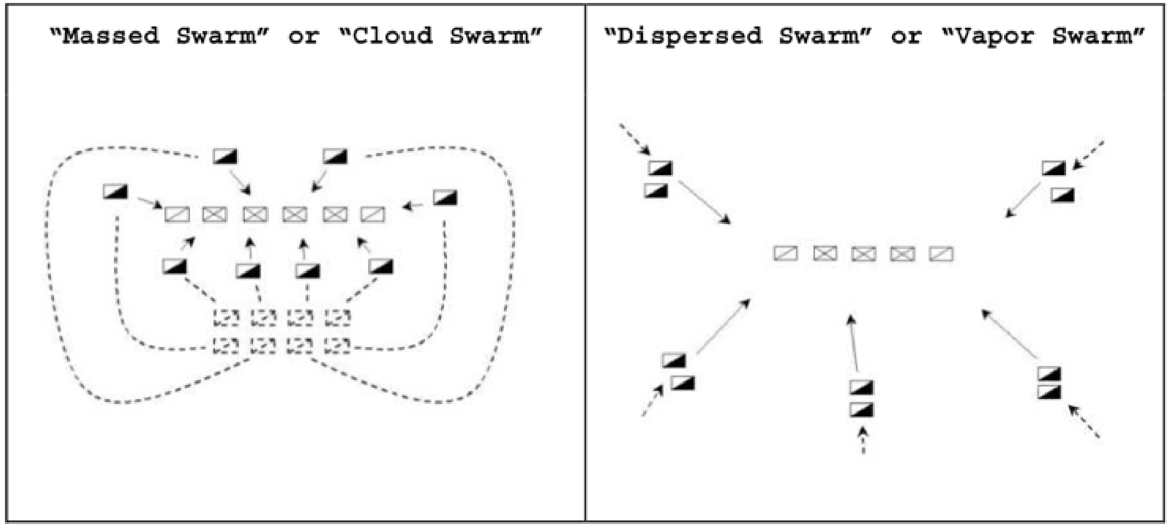
- ❑ Microscopic: Agent
- ❑ Macroscopic: Collective

Swarm System V&V

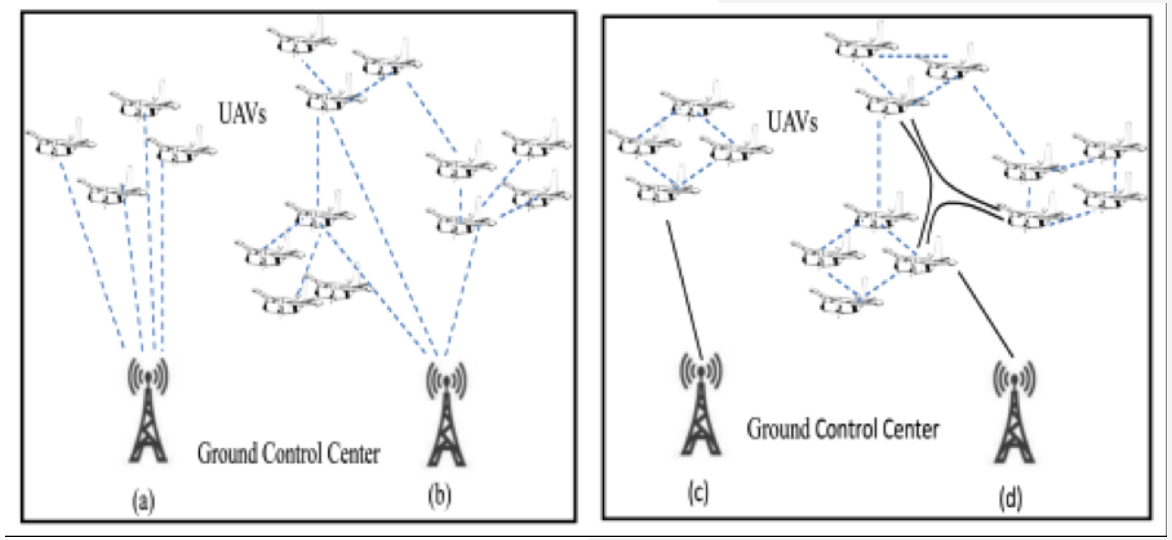
- ❑ Lightweight Formal Methods
- ❑ Experimentation

* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Factors affecting Swarm design *



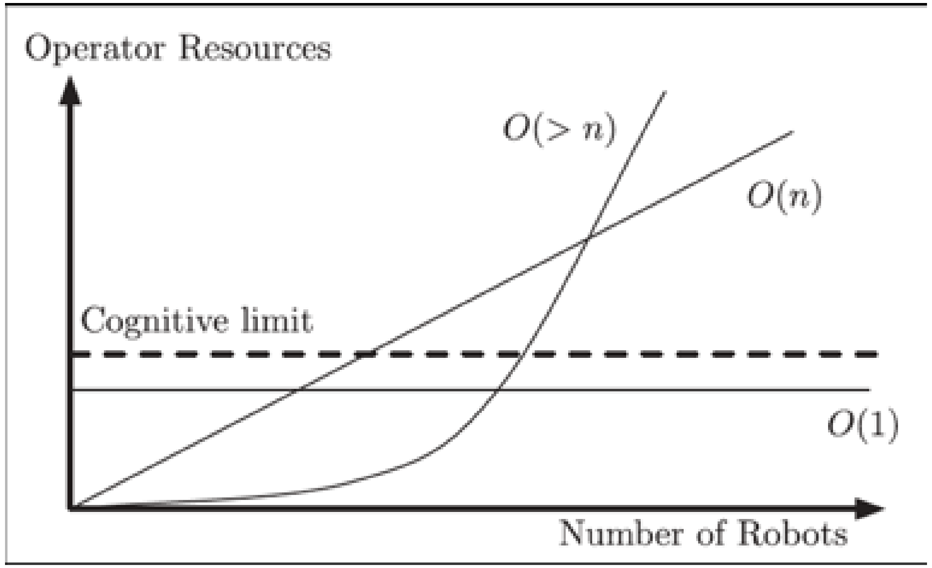
Doctrine, Strategy and Tactics



Communication Architecture

* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Factors affecting Swarm design *



Fully Autonomous: UAV swarms perform fully autonomously without any operator interference

Machine-Oriented Semi-Autonomy: UAV swarms inform operators of special needs, but make most decisions without operator instruction

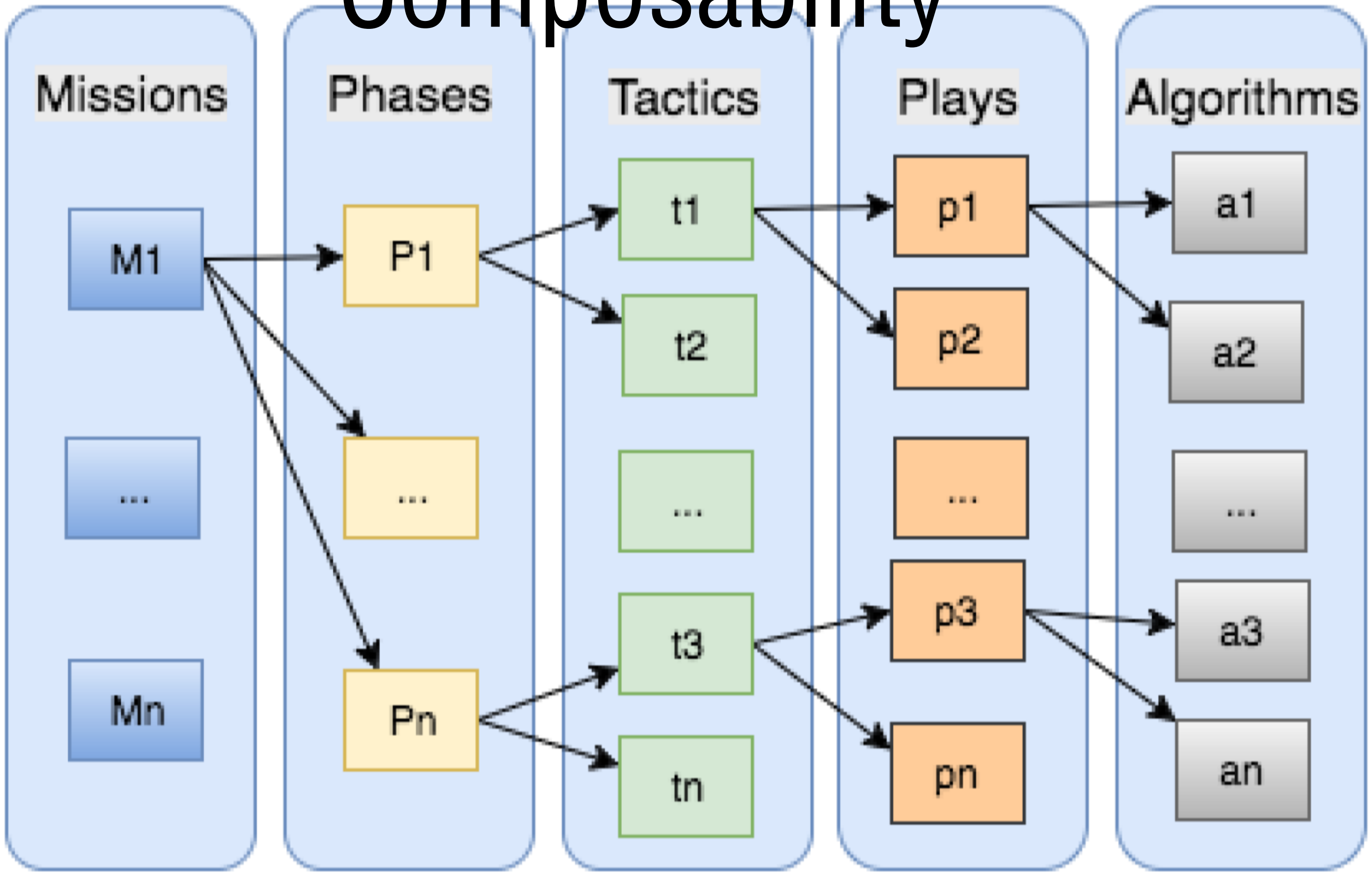
Human-Oriented Semi-Autonomy: UAV swarms inform operators often and rely on instructions for most decision making

Manual Operation: Operators make all decisions and actions for UAV swarms

The Human component and autonomy

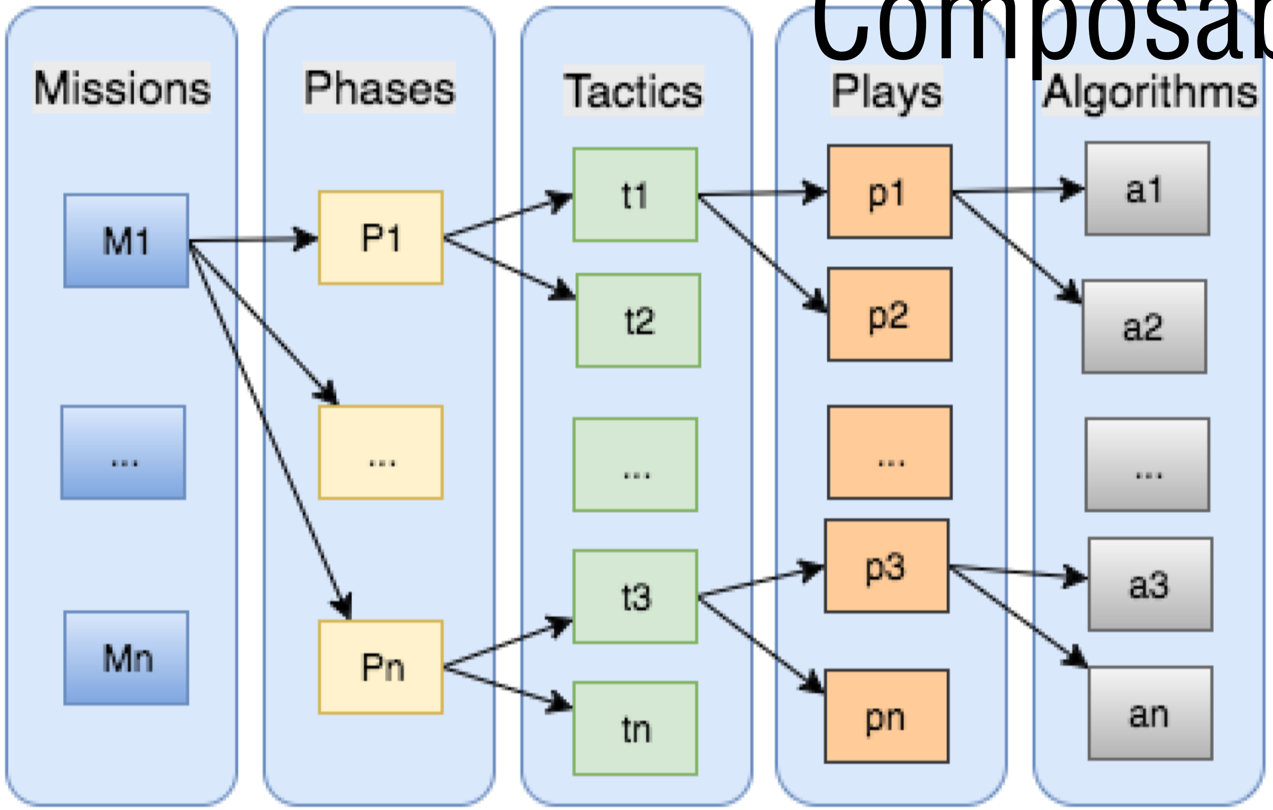
* Giles, et. al. “Expanding domains for multi-vehicle unmanned systems”. ICUAS

Mission-based Architecture for Swarm Composability *



* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Mission-based Architecture for Swarm Composability *

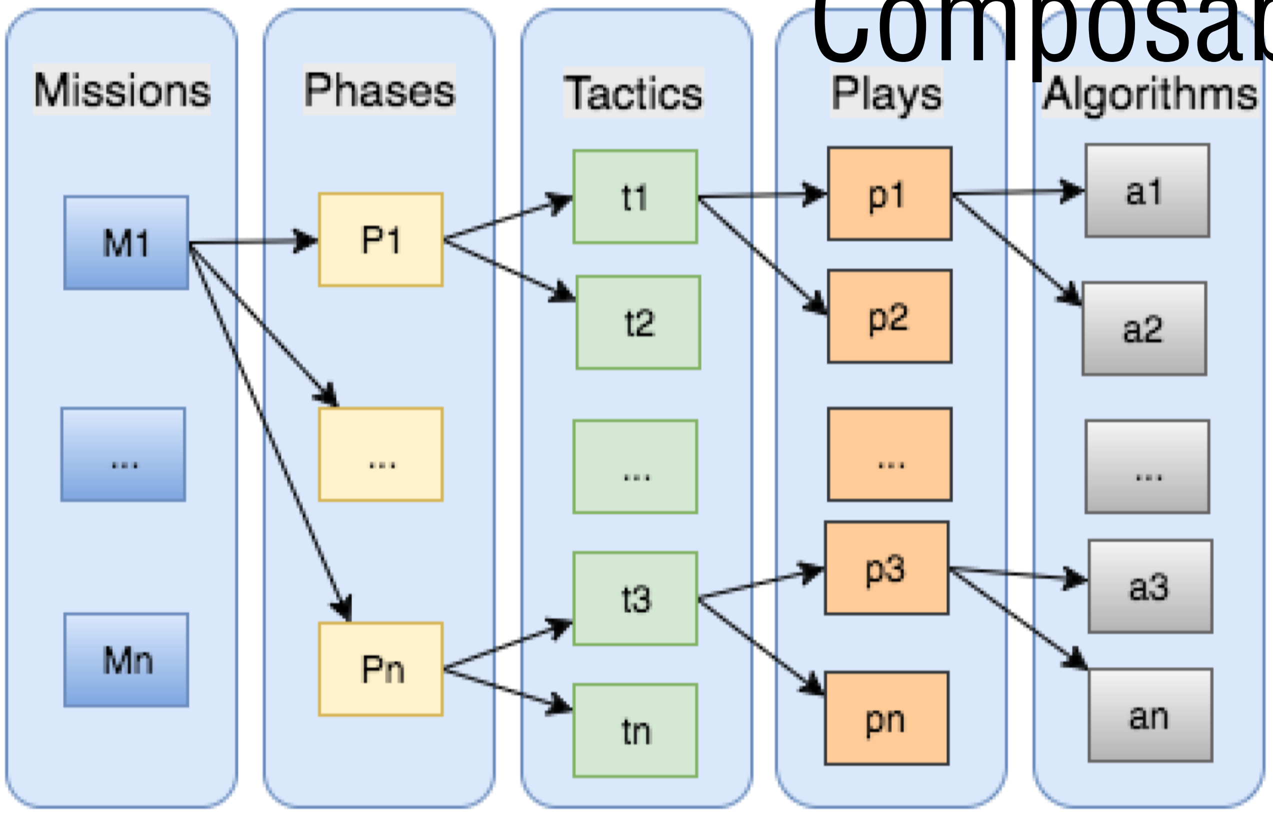


Missions

- The swarm mission is the highest level element of the architecture, and describes the overall task or objective assigned to the swarm
- HADR, MIO, ISR, SAR, ASW, etc.

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

Mission-based Architecture for Swarm Composability *

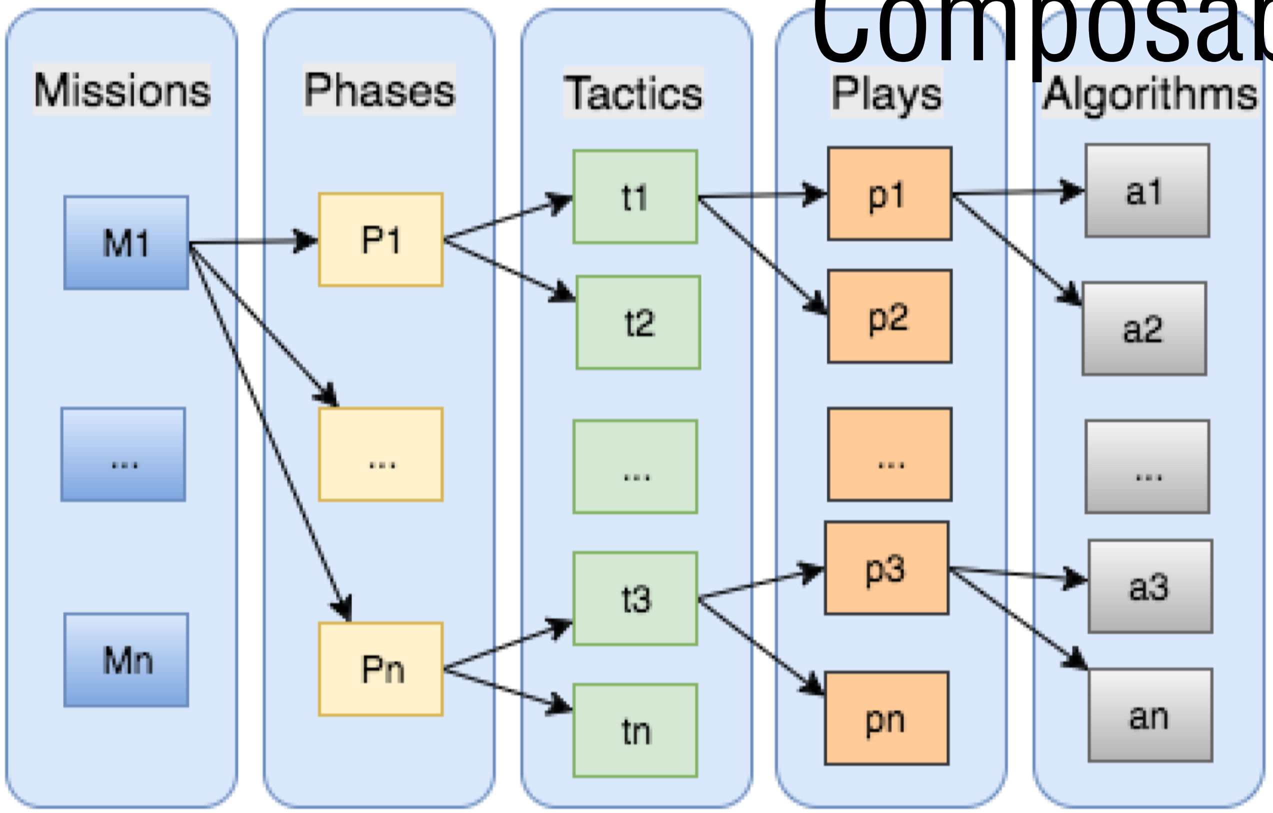


Phases

- ❑ Staging
- ❑ Mission Planning
- ❑ Pre-flight
- ❑ Ingress
- ❑ On-Station
- ❑ Egress
- ❑ Postflight

* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Mission-based Architecture for Swarm Composability *

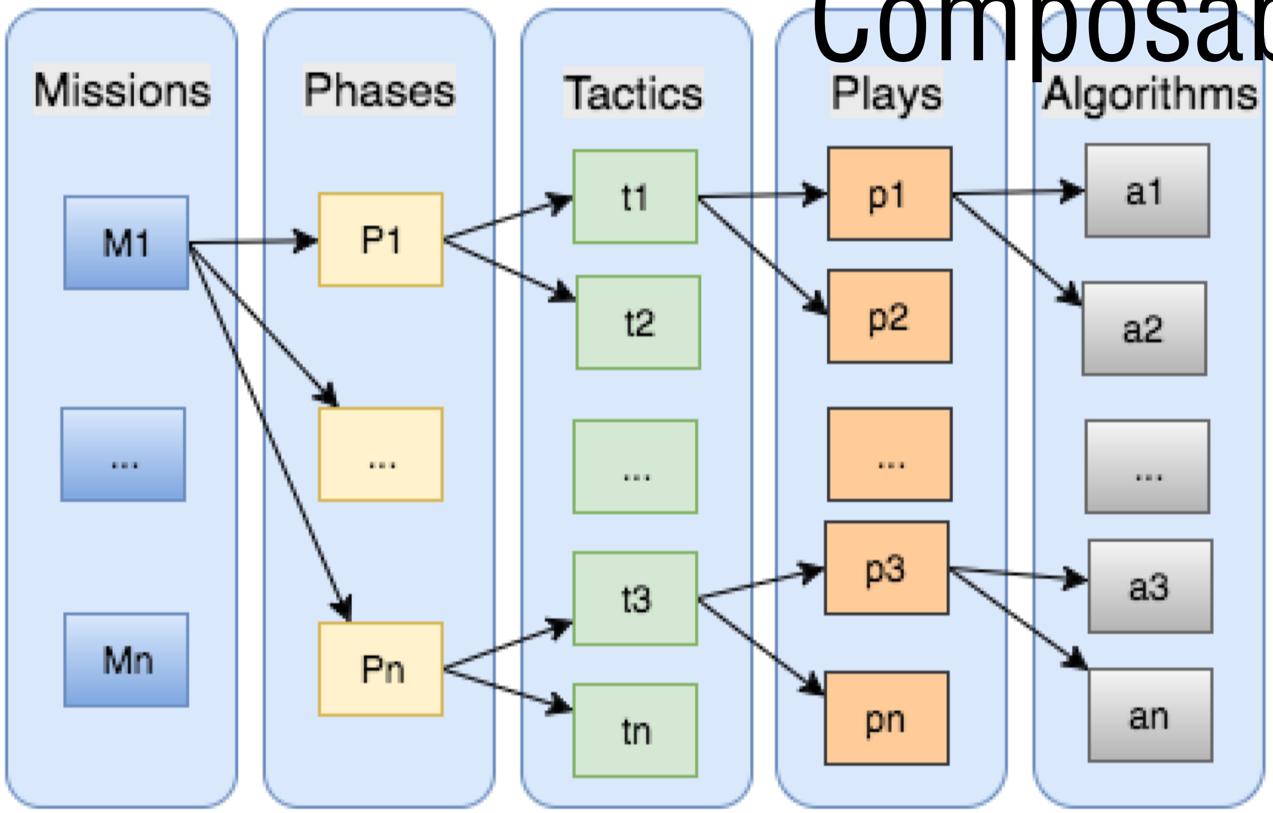


Tactics

- ❑ Ingress = {Launch, Transit to WP, Sensors ON}
- ❑ Evasive Search = {Random Pattern, Sensors ON/EMCON}
- ❑ Efficient Search = {Sensors ON, Ladder, Expanding square, Constricting square, grid}
- ❑ Track = {Sensors ON, Follow target}
- ❑ Comm relay
- ❑ Attack
- ❑ BDA
- ❑ Monitor
- ❑ Evade
- ❑ Harass
- ❑ Defend
- ❑ Deter
- ❑ Divide
- ❑ Amass

* Giles, Kathleen. "Mission-based Architecture for Swarm Composability ". PhD thesis

Mission-based Architecture for Swarm Composability *

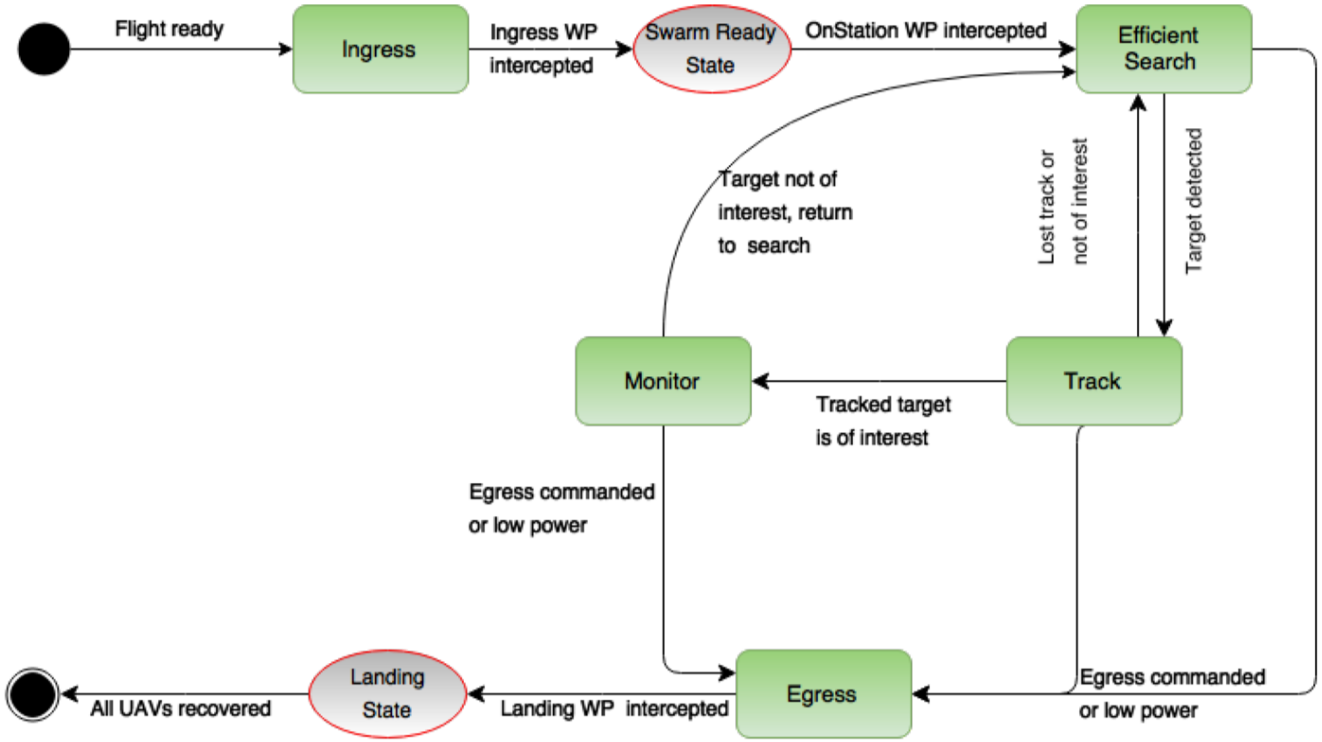


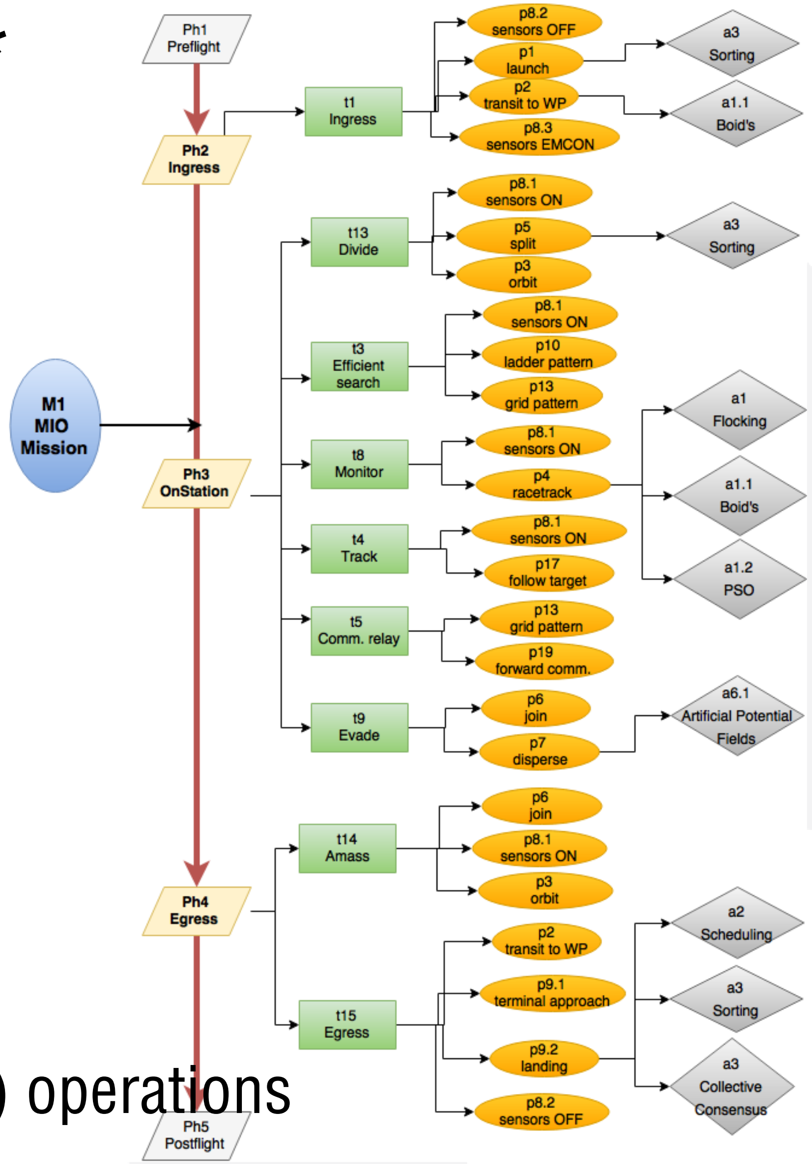
Plays

- ❑ Launch
- ❑ Transit to WP
- ❑ Orbit
- ❑ Racetrack
- ❑ Split
- ❑ Join
- ❑ Disperse
- ❑ Sensors ON/EMCON/OFF
- ❑ Expanding/constricting square/grid/random search
- ❑ Weapon arm/fire
- ❑ Follow target
- ❑ Forward communication
- ❑ Jam

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

MASC examples *

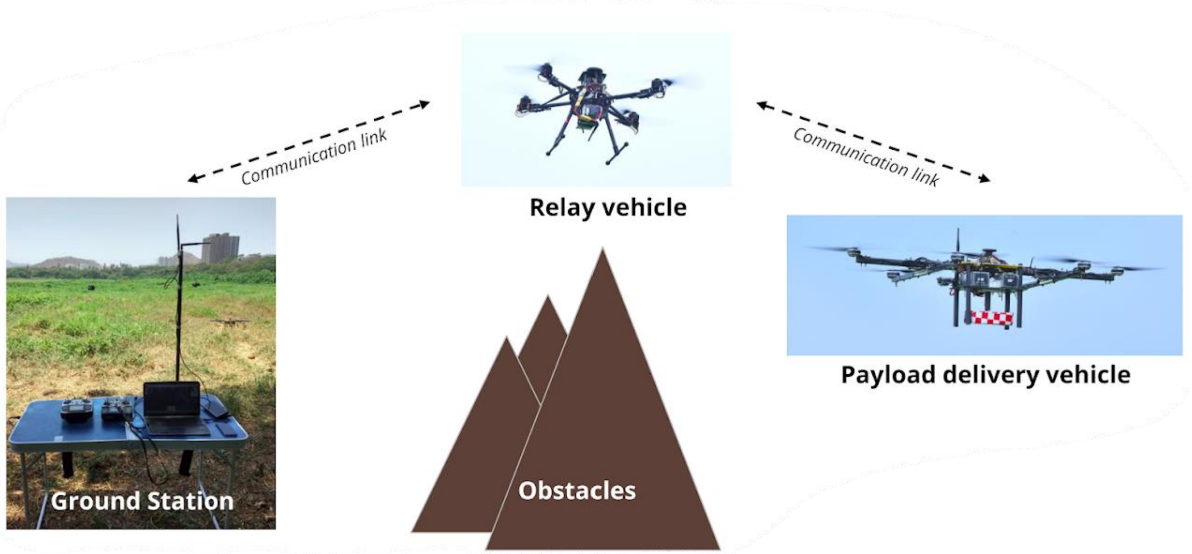


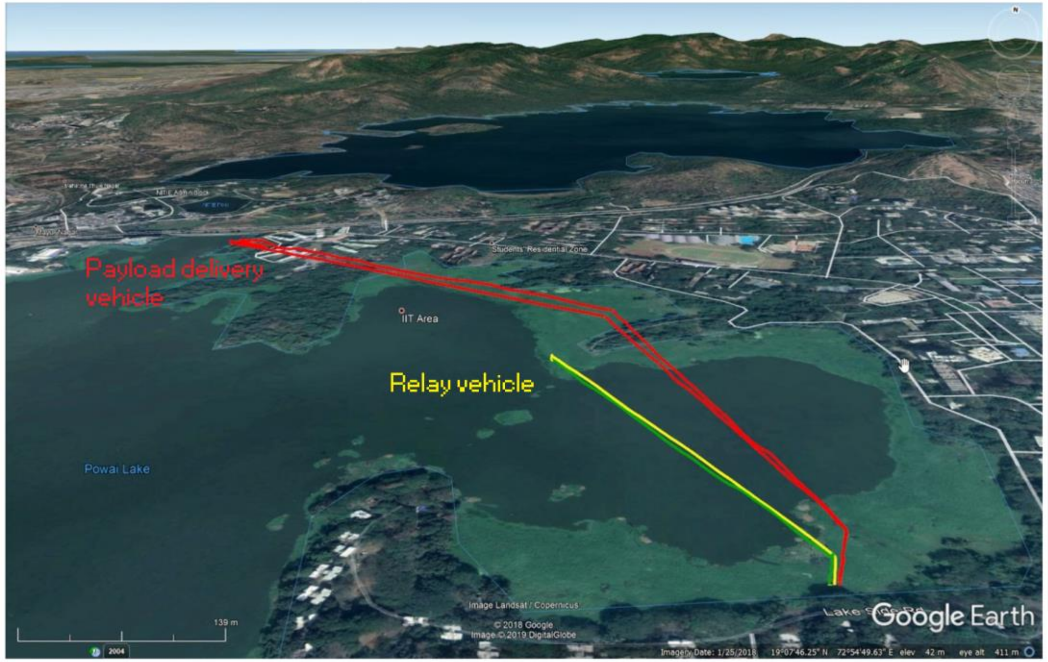


MASC for HADR (left) and MIO (right) operations

* Giles, Kathleen. “Mission-based Architecture for Swarm Composability ”. PhD thesis

From algorithms to missions

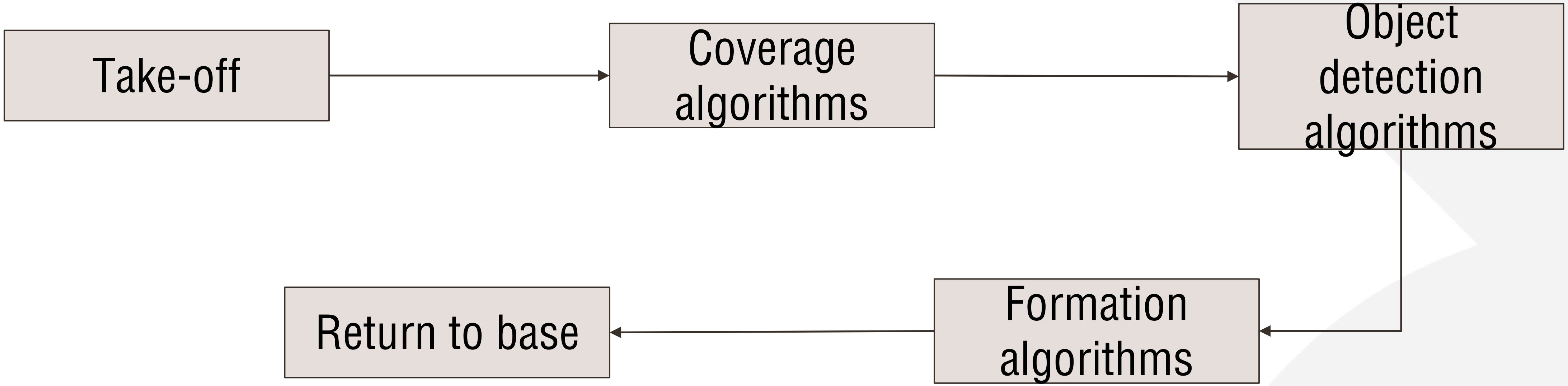




Beyond line-of-sight delivery mission (Hangal et. al.)

A team of robots cooperate on a BVLOS delivery mission. An intermediate agent acts as a communications relay between the ground station and the payload delivery vehicle

From algorithms to missions



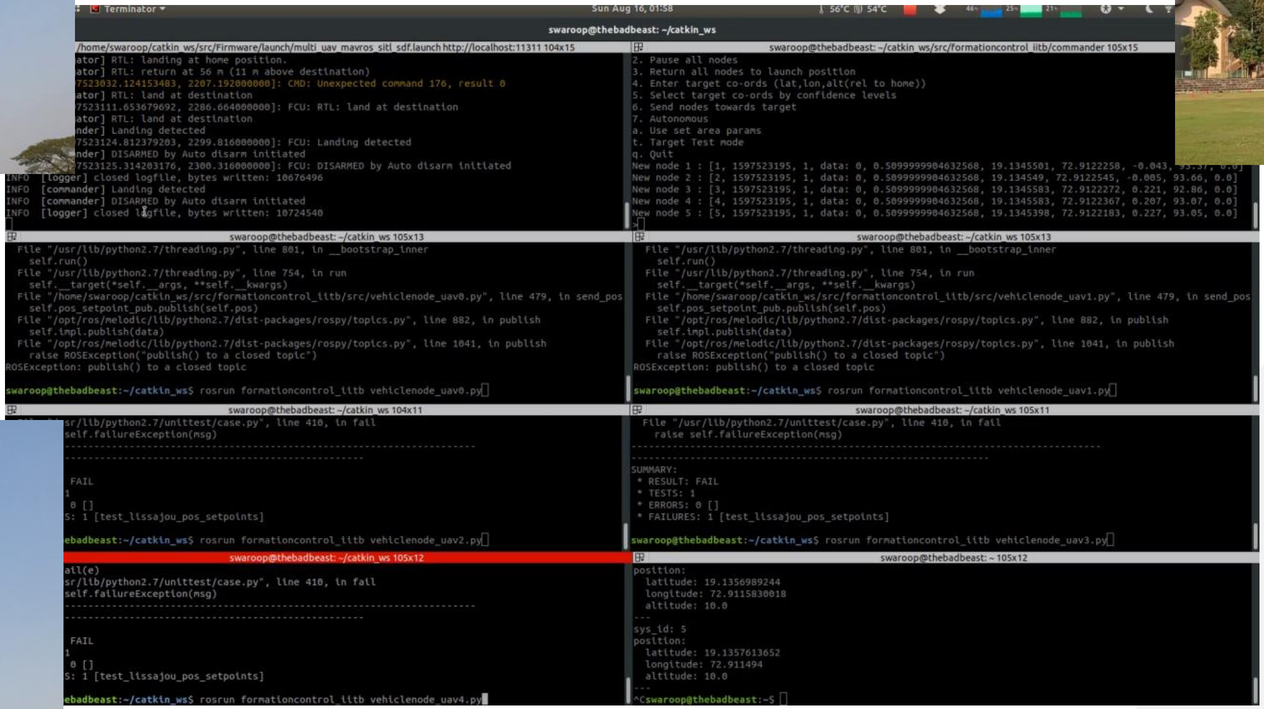
Coverage and search mission (Hangal et. al.)

A team of agents take-off from a base station and flock to a designated area, which they optimally sweep. Each agent is "trained" to detect targets of interest. Once the target is found, the agents rendezvous at the target, ready to engage

inDrones

From algorithms to missions


Transition to mission start point




On-board sensors search for target


Take-off from base station

Real-time video stream received at base station

From algorithms to missions

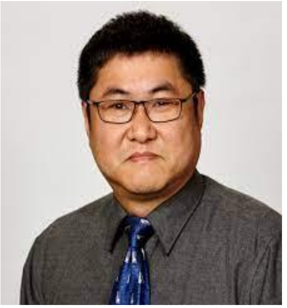
Future work

- Depth
- Holistic
- Engage
- Deploy

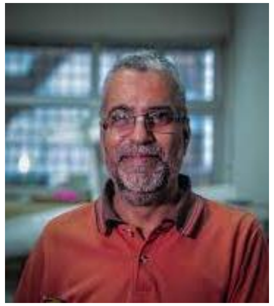
inδrones

Collaborators

Prof. Debraj Chakraborty



Prof. Hoam Chung



Prof. Hemendra Arya

Dr. Swaroop Hangal

Prof. Ameer Mulla, Prof. Chayan Bhawal, Prof. Megha Kolhekar

inδrones DRONES AT WORK

Pravin Prajapati

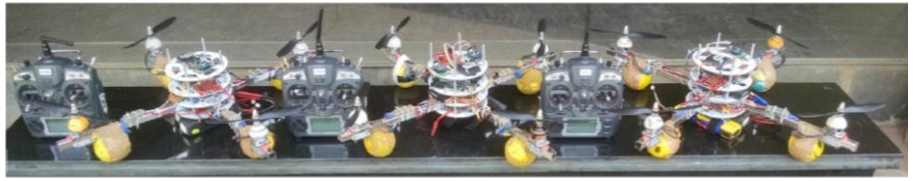
Ravi Singh

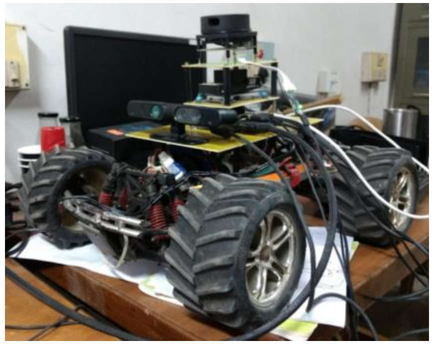
Harshad Bhanushali

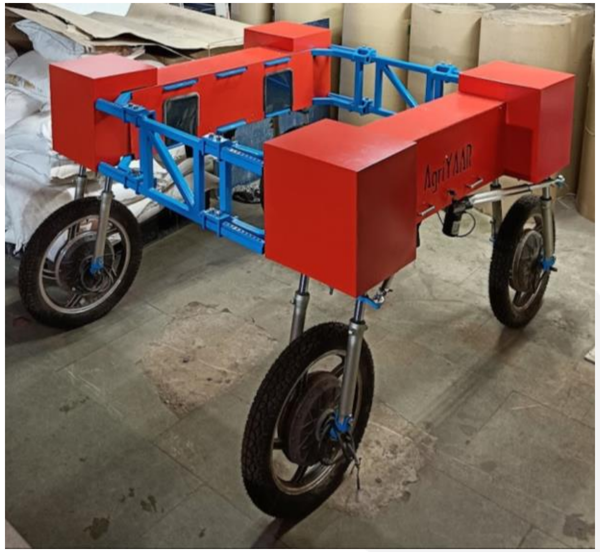
Aakash Sinha

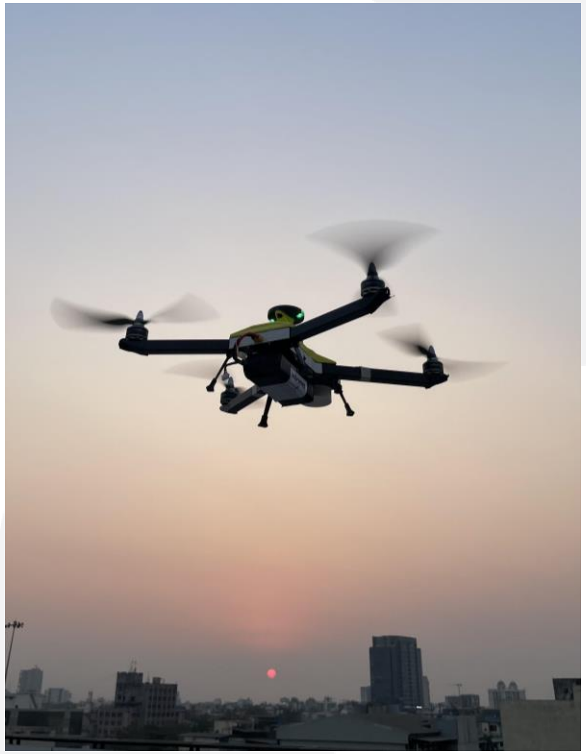
Chittaranjan, Dhananjay Kulkarni

indrones









Thank you

For R&D collaborations please write to
apurva@indrones.com

For products and services please write to
info@indrones.com