



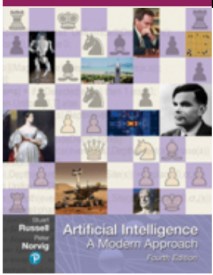
# Role of multi-agent systems in a future fleet

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](#))

[Preface \(pdf\)](#); [Contents with subsections](#)

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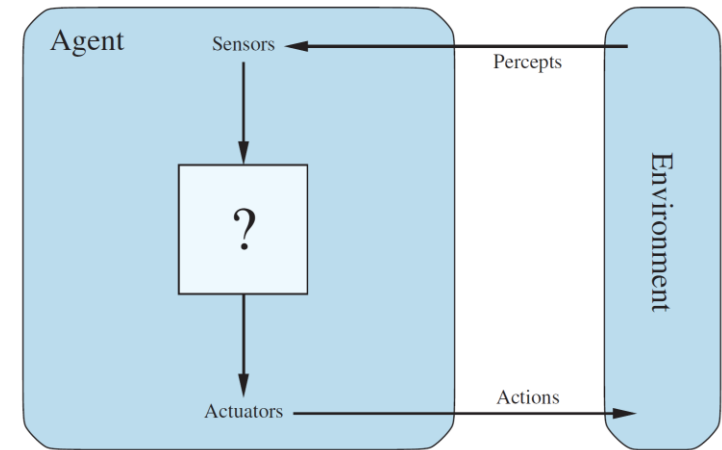
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[Figures \(pdf\)](#)  
[Code \(website\)](#); [Pseudocode \(pdf\)](#)  
 Covers: [US](#), [Global](#)



# Synopsis

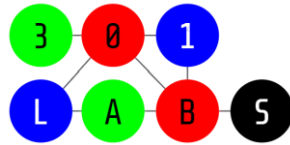
Multi-agent or "swarm" systems have drawn the military's attention over the last two decades due to their potential **expendability, redundancy, and expanded sensor coverage**. This interest can primarily be attributed to the dynamic field of **unmanned systems technology**, which has been rapidly developing 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



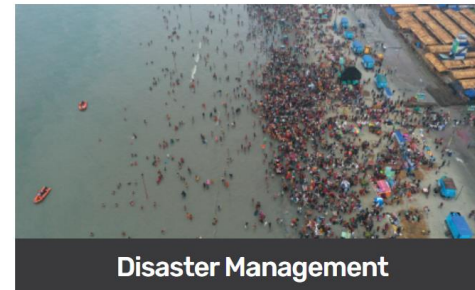
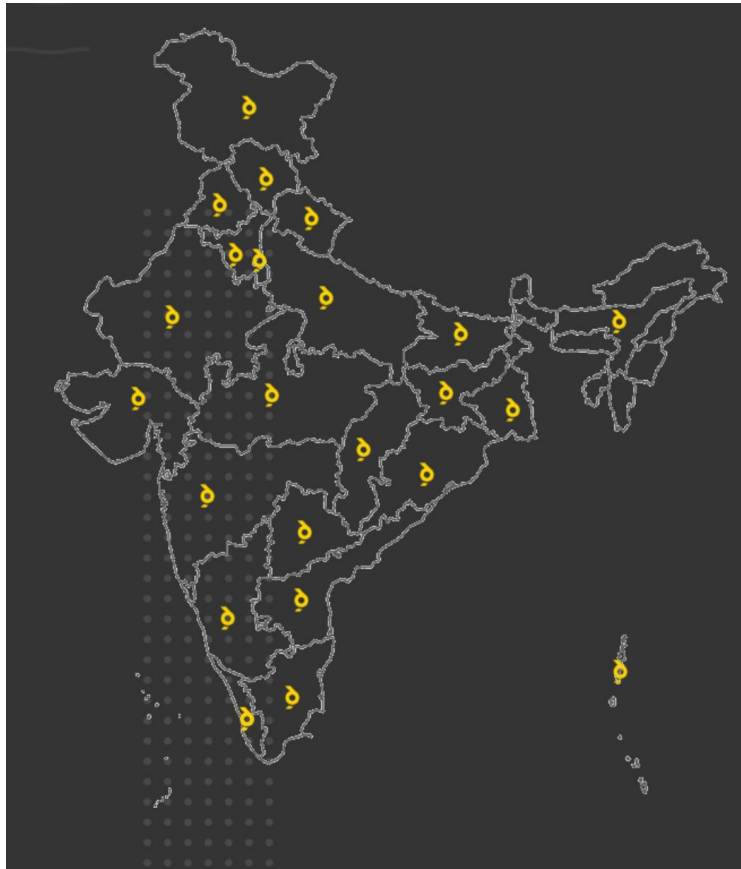
Autonomous vehicles  
Multi-agent systems





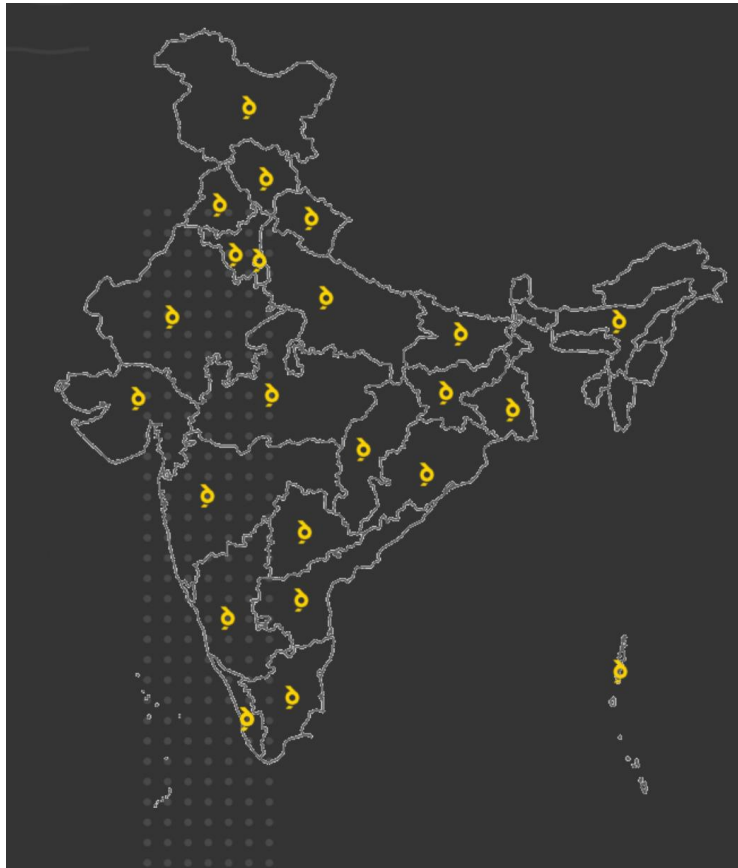
# About us

## #rapidgroundtruthing



# About us

## #rapidgroundtruthing



# About us

## Drones



Sigma 25



Sigma 75



Vector VTOL

## DaaS

Inflight

Inspect

Incharge

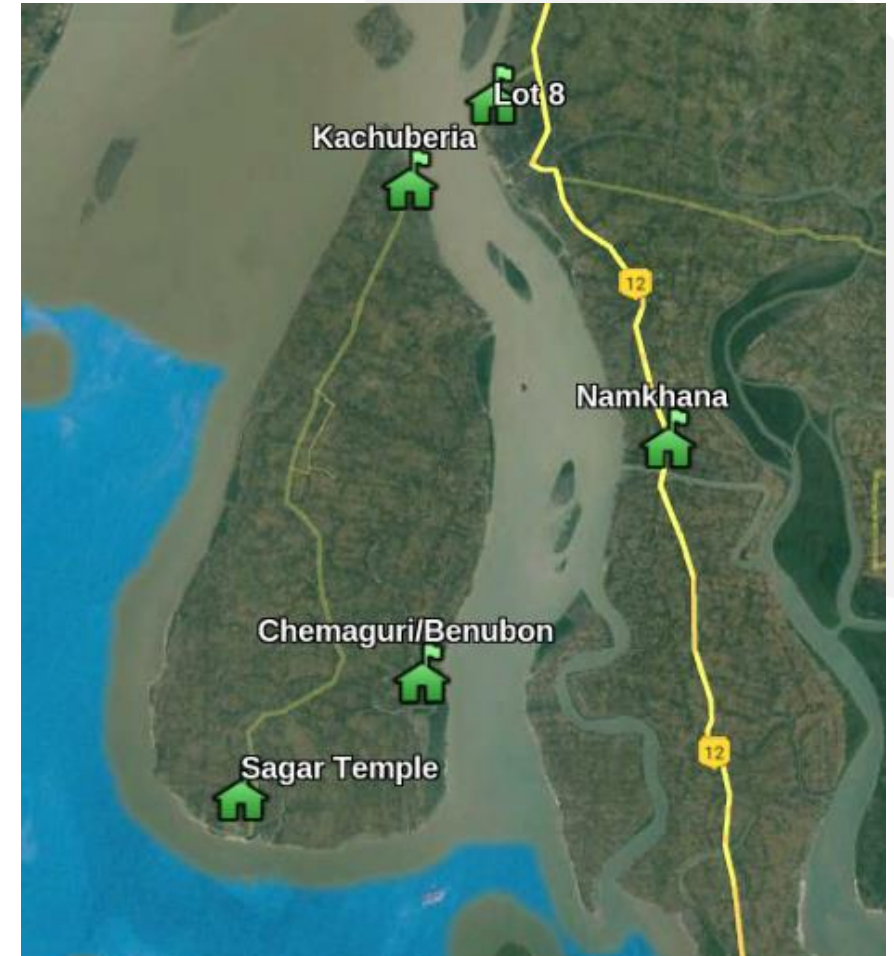


# Inflight Disaster Management

The screenshot shows a web browser window with the URL 'inflight.live'. The page features a yellow header with the text 'Welcome to Gangasagar 2023' and a logo. Below the header, there is a sidebar on the left with 'inFlight.live', 'Live Stream', and 'Previous Streams' options. The main content area is titled 'Live Streams' and contains a table with the following data:

NAME	STATUS	STREAMID	PLAY STREAM	START STREAM	COPY PUBLISH URL	CROWD COUNTING BETA
Lot 8 Ghat	broadcasting	qspskpv2			<a href="#">Copy URL</a>	<a href="#">Count</a>
Namkhana Ghat	broadcasting	jbn13sfj			<a href="#">Copy URL</a>	<a href="#">Count</a>
Sagar Temple	broadcasting	rgd4z7hf			<a href="#">Copy URL</a>	<a href="#">Count</a>
Kachuberia Ghat	started	y5pcrkks			<a href="#">Copy URL</a>	<a href="#">Count</a>
Sagar Bus Stand	started	stygyspm			<a href="#">Copy URL</a>	<a href="#">Count</a>
Chemaguri Ghat	started	z0ttjzsp			<a href="#">Copy URL</a>	<a href="#">Count</a>

At the bottom left of the interface, there is a yellow circle with the letter 'E' and the text 'Engineer' next to it.




# Inflight

## Disaster Management

inFlightLive

Welcome to Gangasagar 2023

Lot 8 Ghat on Jan 16, 2023



• Kachuberia Ghat

• Benubon Ghat

• Lot 8 Ghat

• Namkhana Ghat

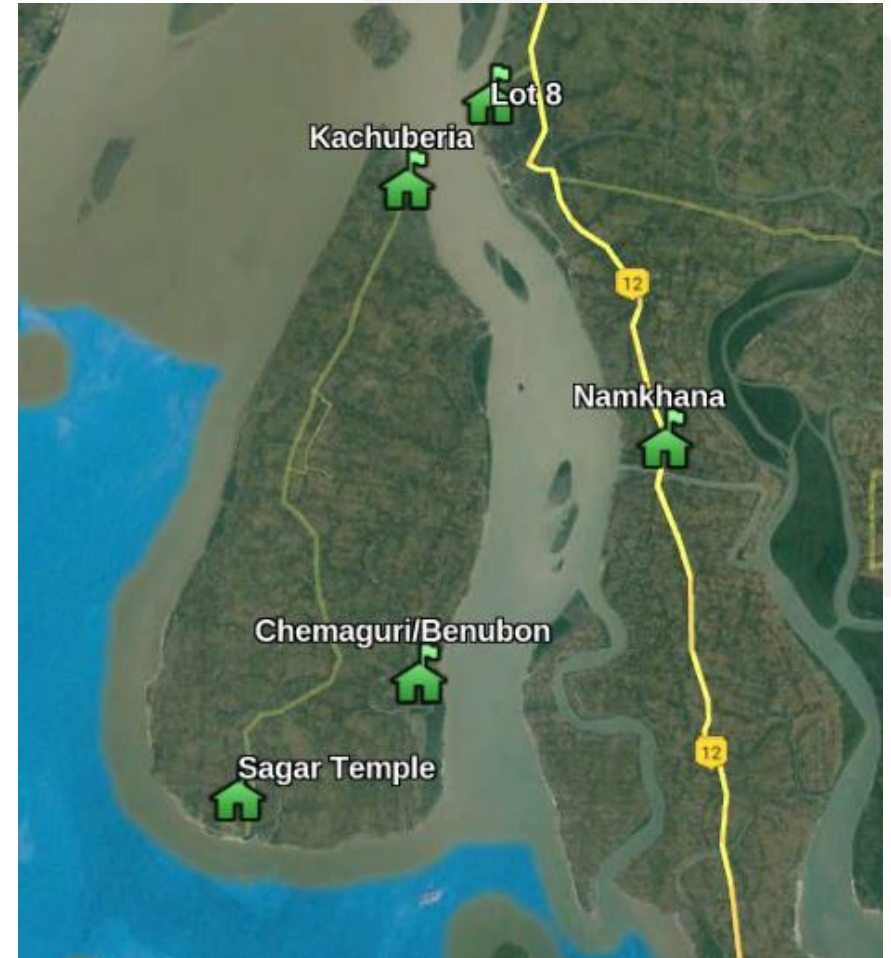
• Sagar Bus Stand

• Sagar Temple

Viewer

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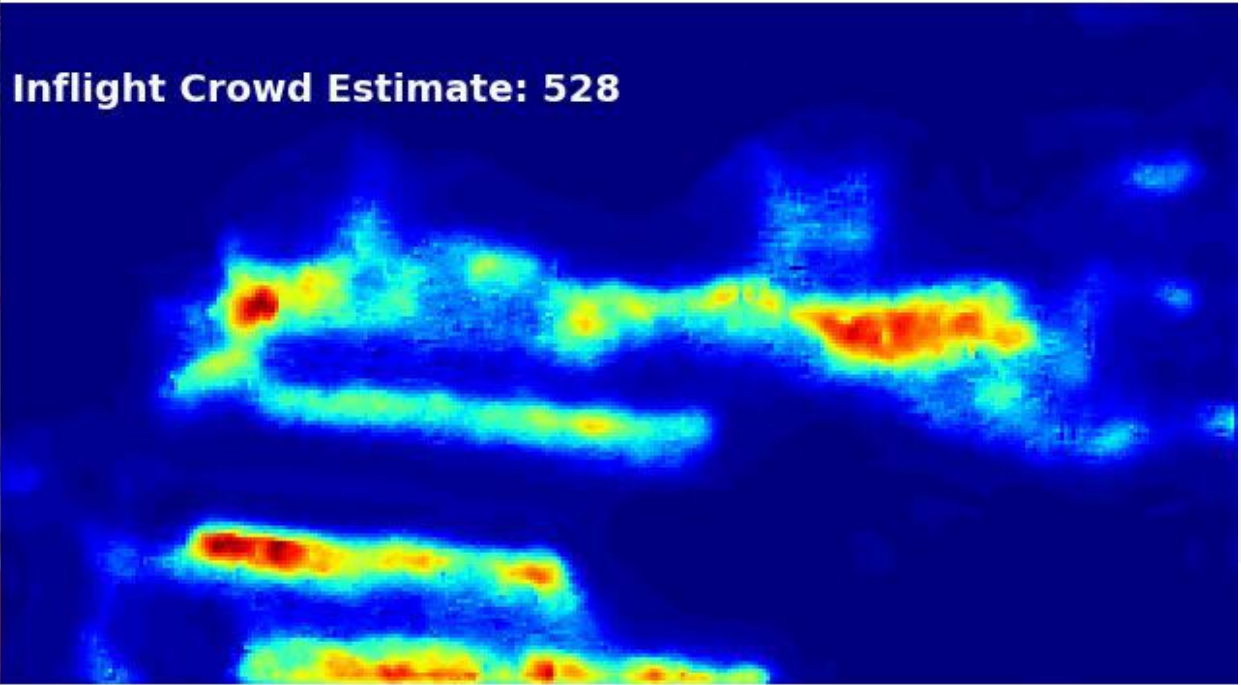
The image shows a screenshot of a live video feed from a drone. At the top, there is a yellow banner with the text 'Welcome to Gangasagar 2023' and a logo for 'GANGASAGAR 2023'. Below the banner, the video title is 'Lot 8 Ghat on Jan 16, 2023'. The video content shows an aerial view of a wide river with two ferries. One ferry is in the foreground, and another is further down the river. The video player interface at the bottom shows a play button, a progress bar, and a timestamp of -30:34. On the left side, there is a sidebar with the 'inFlightLive' logo and a list of locations: Kachuberia Ghat, Benubon Ghat, Lot 8 Ghat, Namkhana Ghat, Sagar Bus Stand, and Sagar Temple. At the bottom left, there is a 'Viewer' icon and a copyright notice: '© 2022 Indrones Solutions Pvt Ltd. All rights reserved.'





# Inflight

Crowd estimation



Time: Friday, 13th Jan 2023,  
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



# Inspect

## Linear Asset Management

### Change detection

21st July 2021

4th August 2021

Change detection

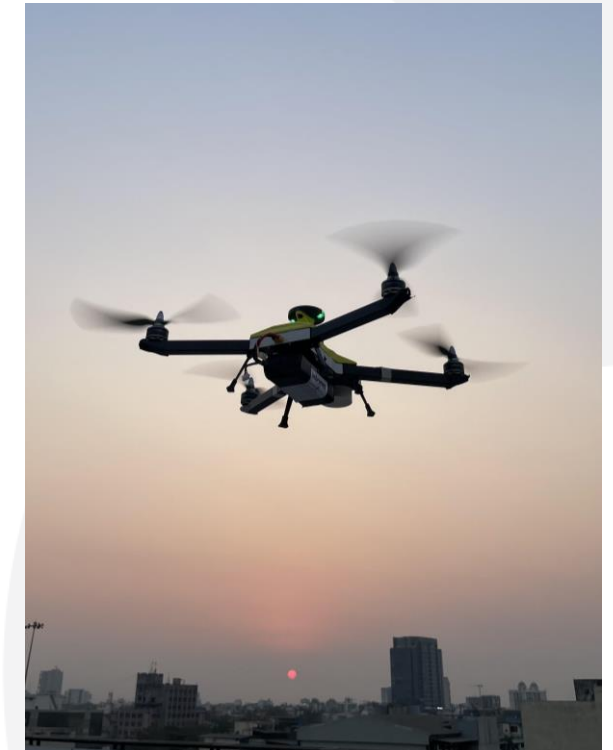
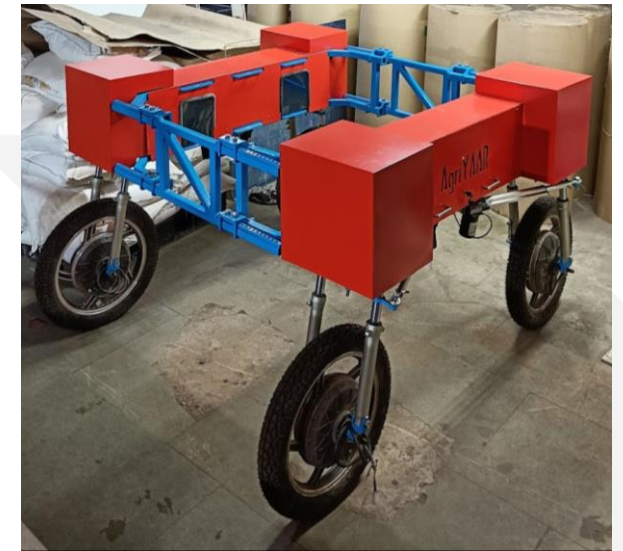
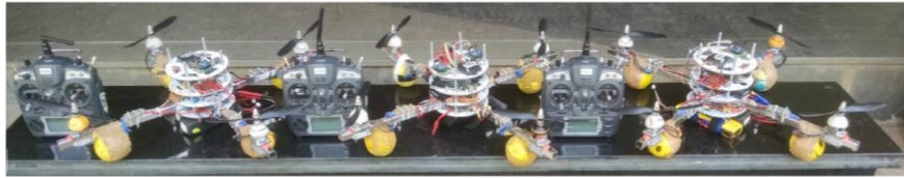


Detecting changes between two drone runs

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

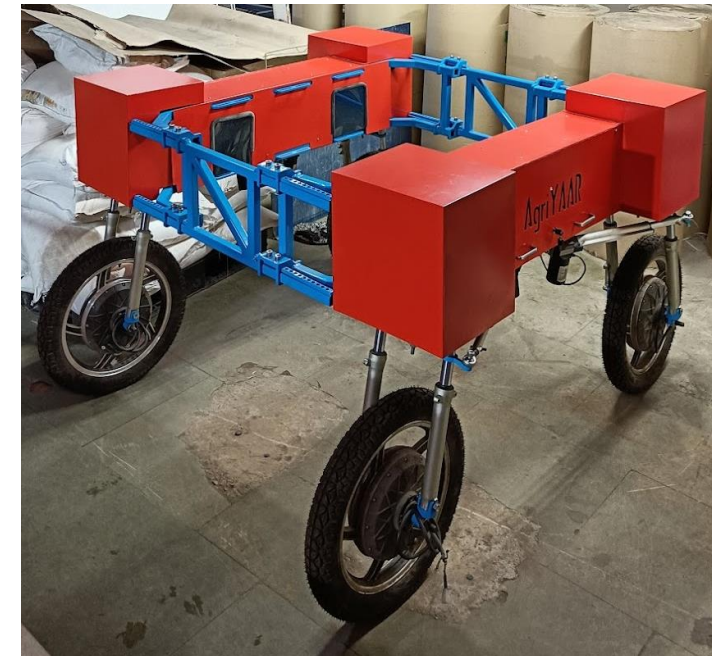
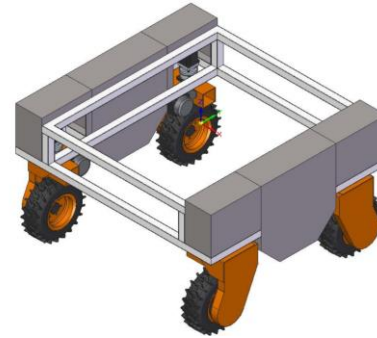
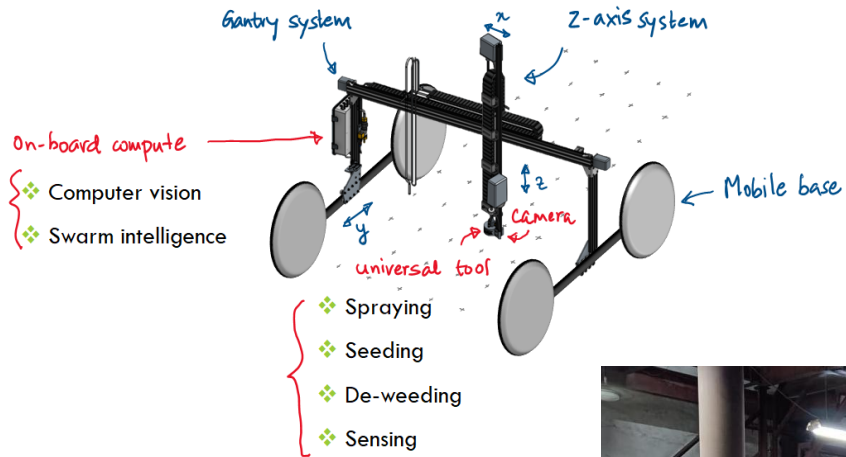


VTOL prototype at IIT Bombay





# Tech demos and prototypes



Project AgriYAAR

# Tech demos and prototypes



^ Precise payload delivery

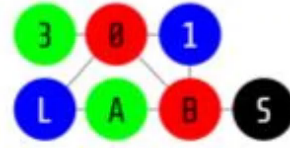


Real time onboard object detection >



^ Prototype delivery drone

# Tech demos and prototypes



## Vision based drone detection

Dr. Apurva Joshi  
[apurva.joshi@301labs.com](mailto:apurva.joshi@301labs.com)

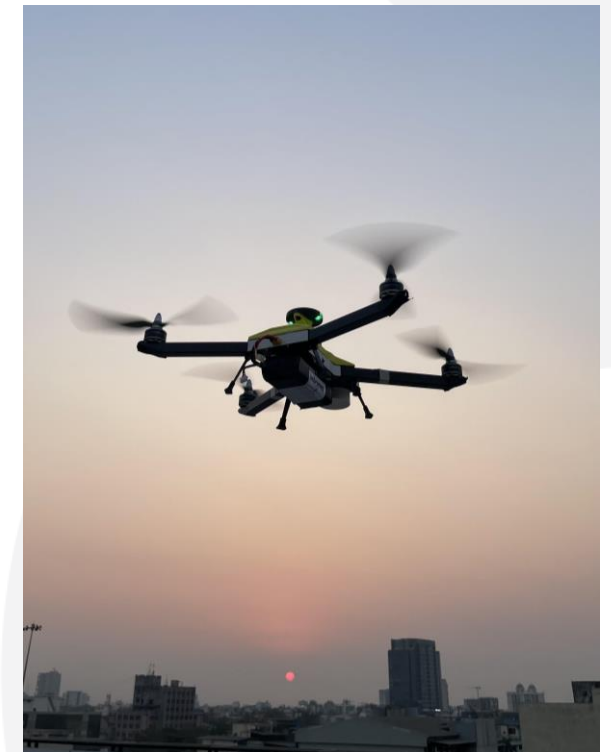
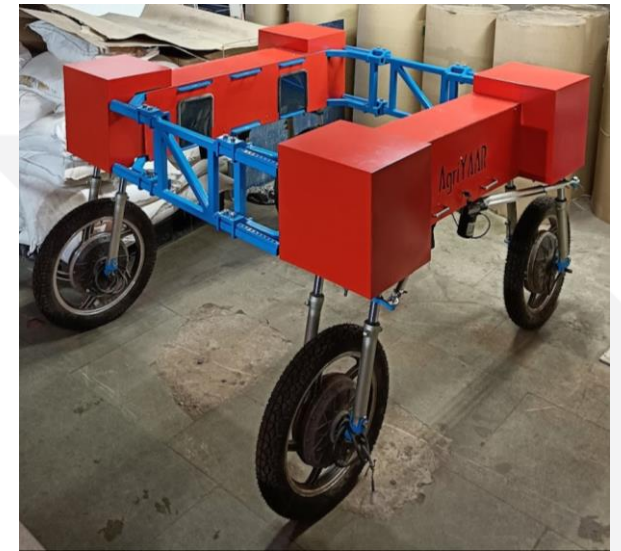
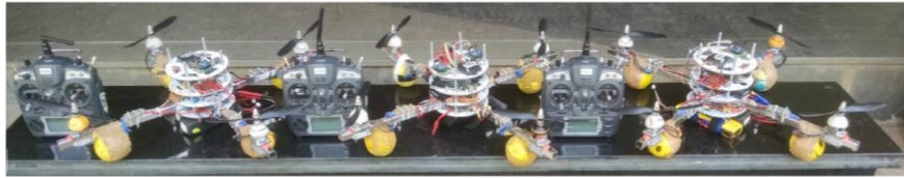
Dr. Swaroop Hangal

301 Labs,  
NCETIS - IIT Bombay

[CONFIDENTIAL]



indrones



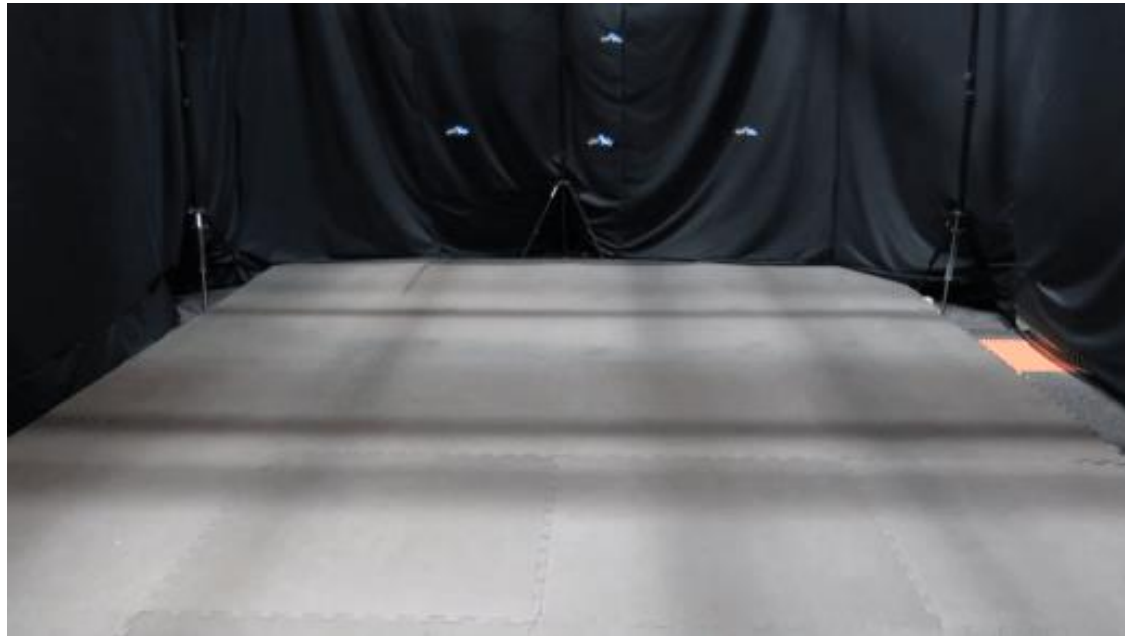
# Multi-agent systems

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

# Cooperative control algorithms

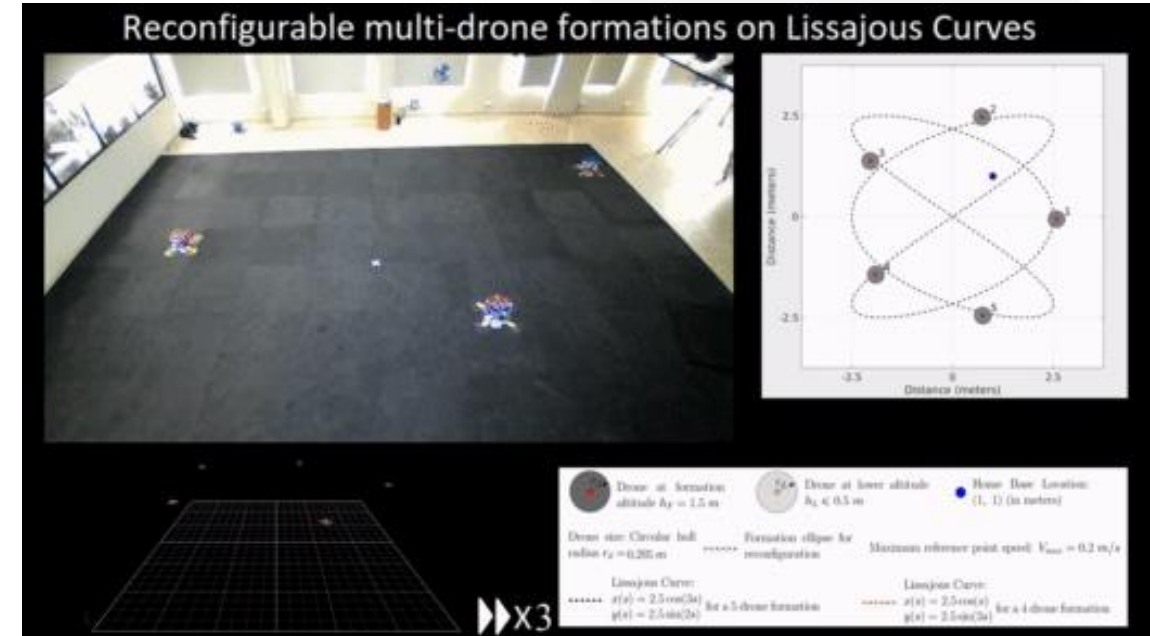
- Flocking
- Boids
- PSO
- Levy Flight
- Scheduling
- Sorting
- Collective consensus
- Artificial potential fields
- Brownian motion
- Leader-follower

# Cooperative control algorithms



Formation flight (Joshi et. al.)

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

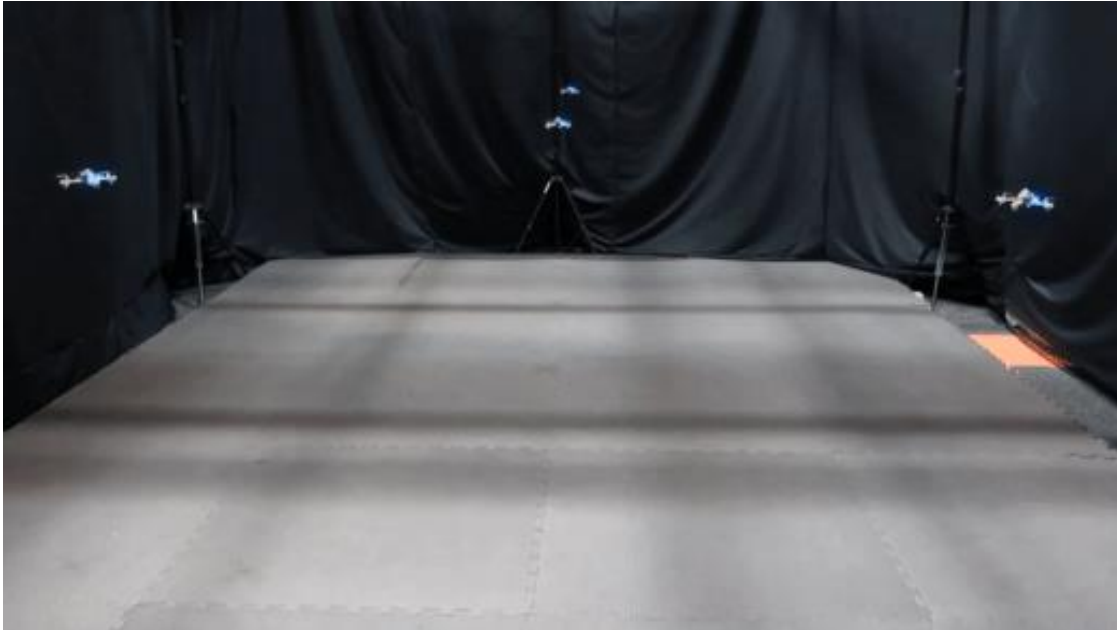


Coverage and Search (Borkar et. al.)

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

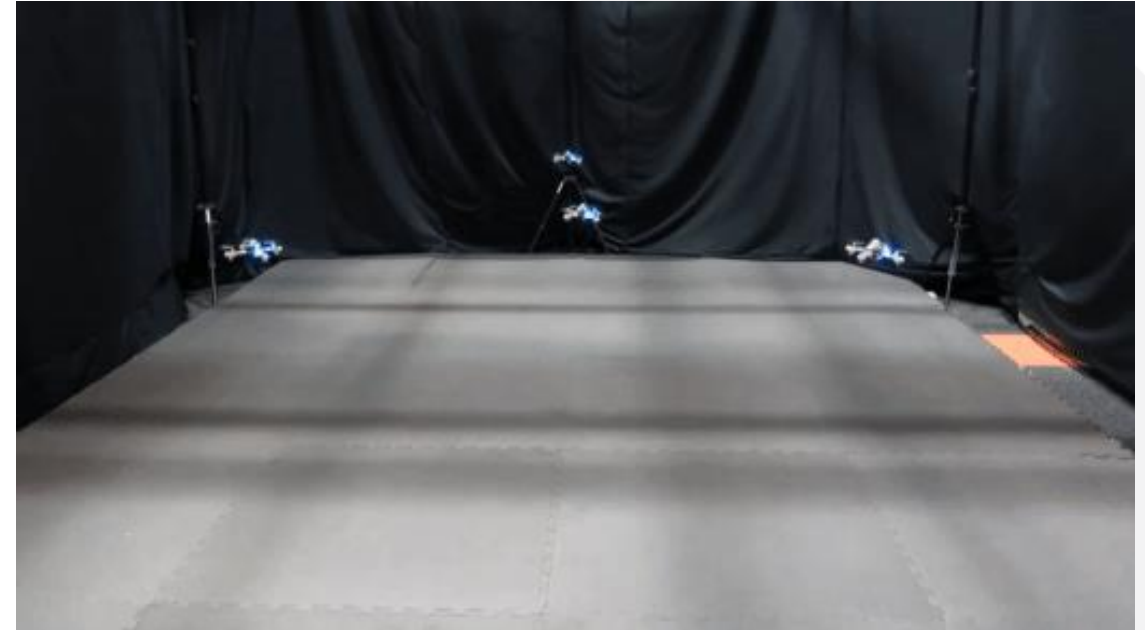


# Cooperative control algorithms



Capture (Joshi et. al.)

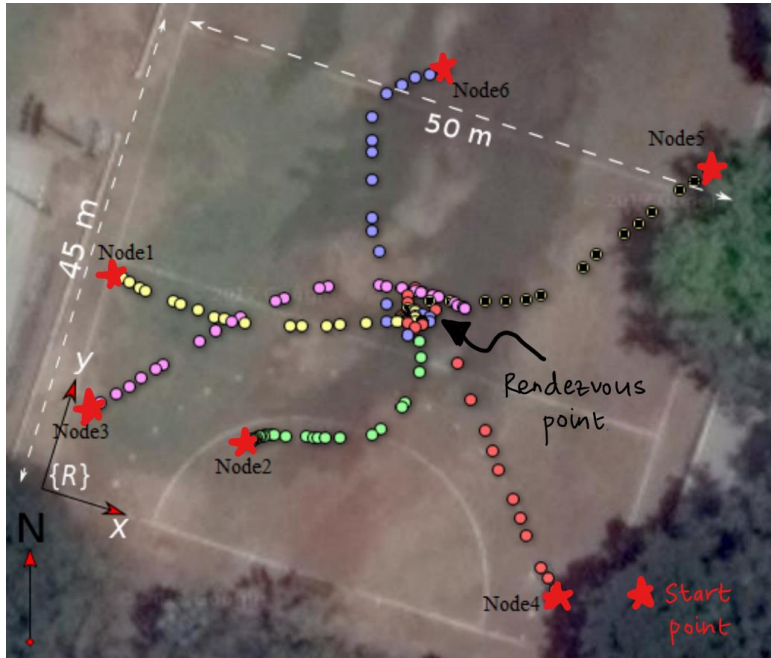
Autonomous robots detect an invading robot and surround it in minimum time



Pursue (Joshi et. al.)

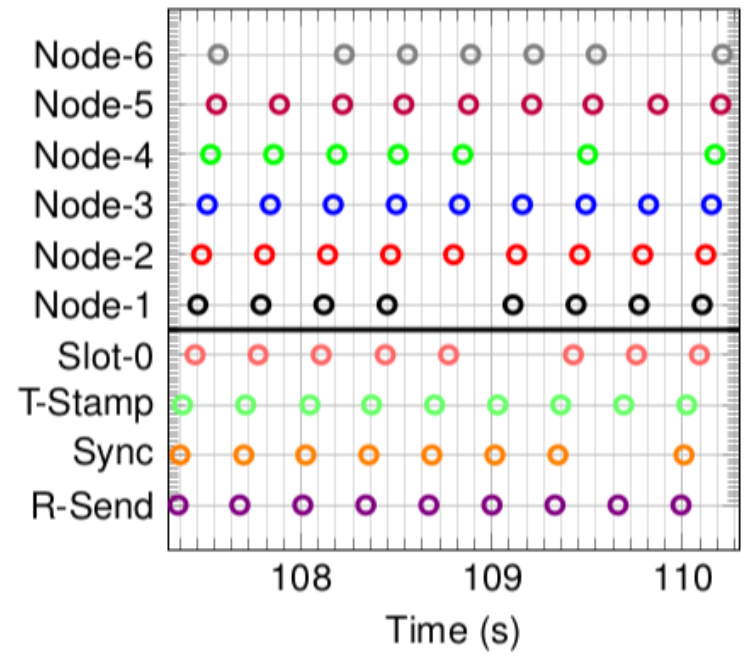
Autonomous robots track the evading robot so that it cannot escape

# Cooperative control algorithms



Consensus (Joshi et. al.)

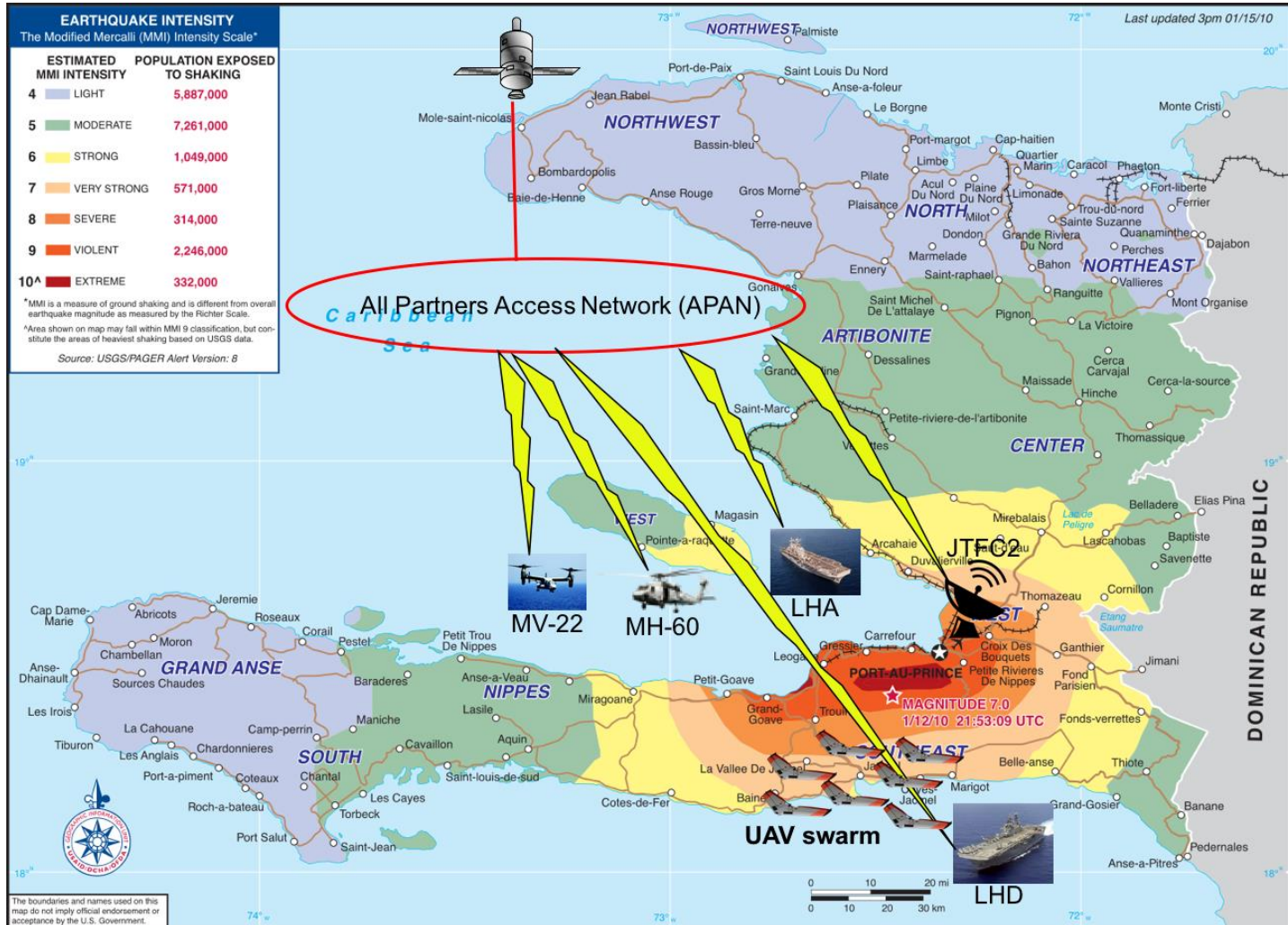
Robots communicate with their neighbours and autonomously navigate to a rendezvous point



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

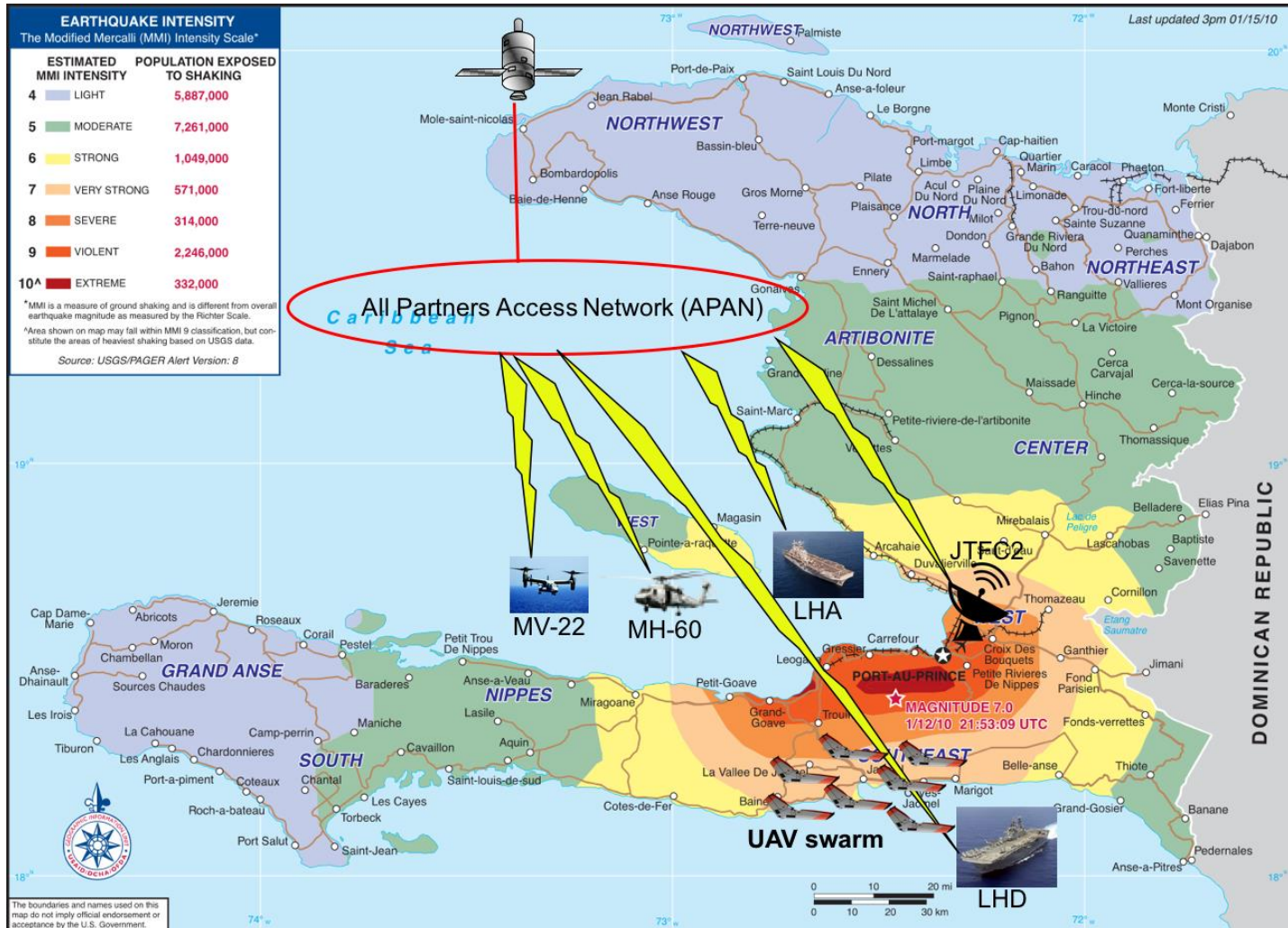
**MV-22 for transport, lift**

\* Giles, Kathleen. "Mission-based Architecture for Composable Systems". PhD thesis



# Missions \*

## HADR



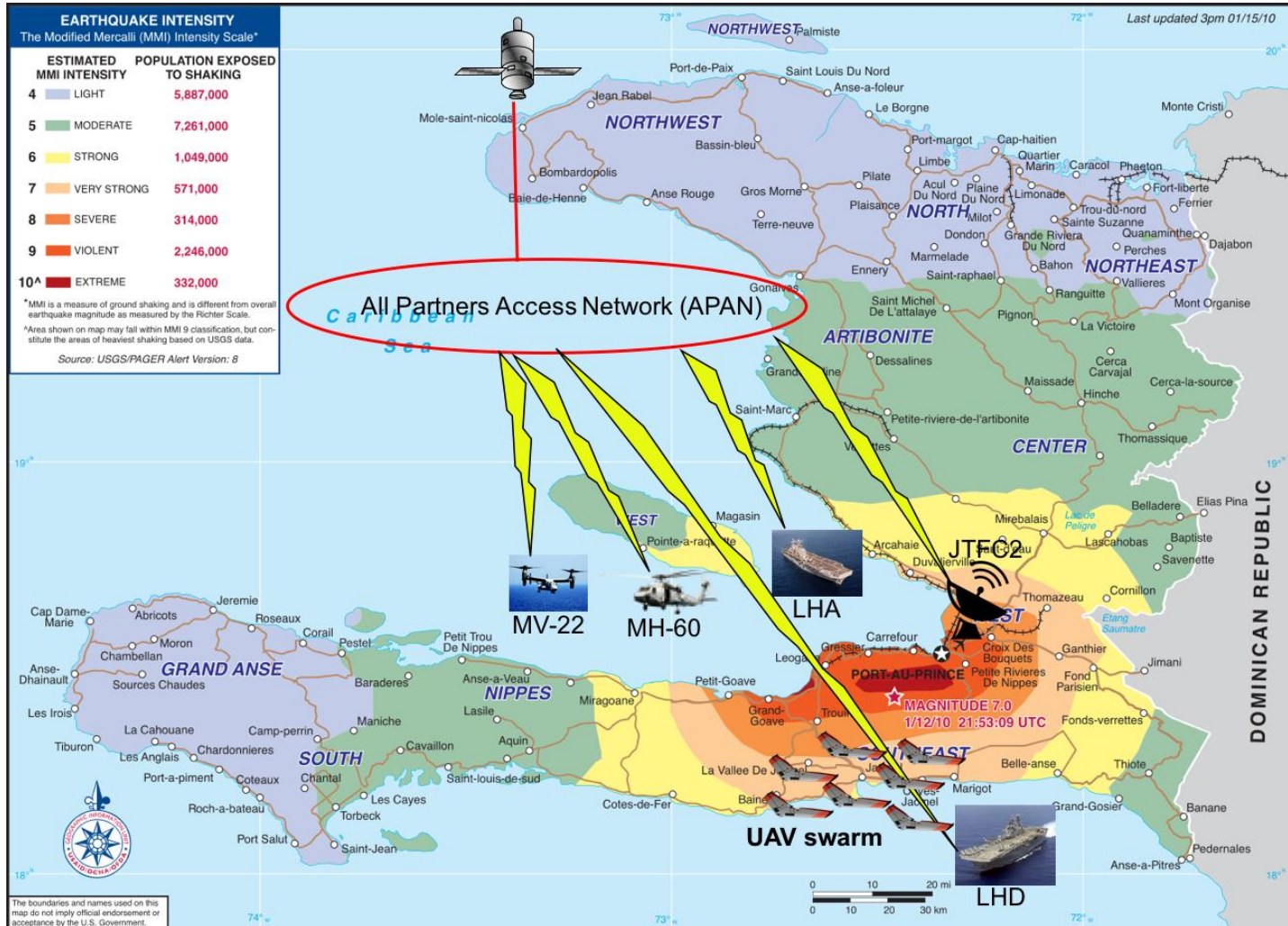
Assets:

- 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

# Missions \*

## HADR



Assets:

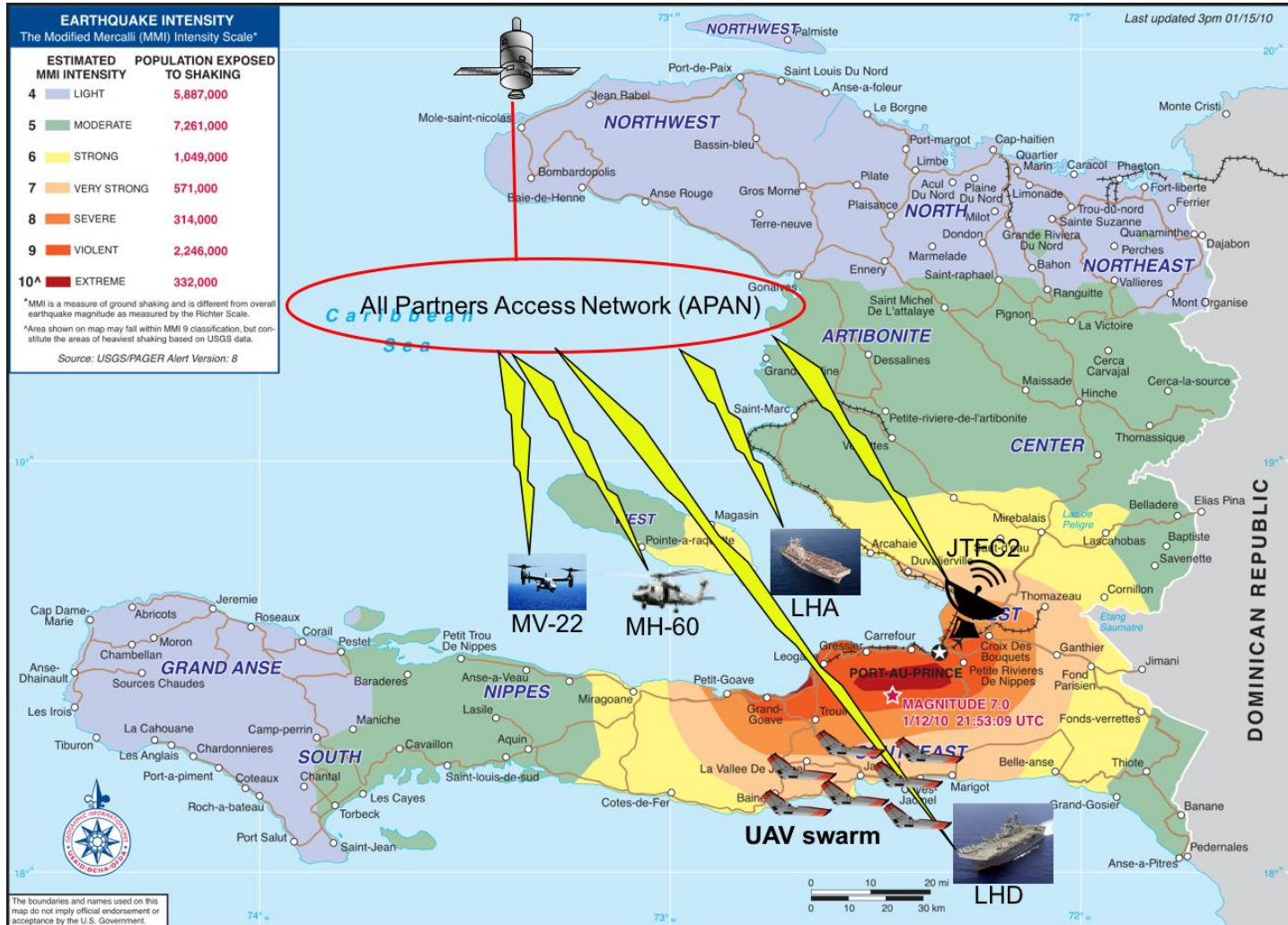
- UAV swarm consists of a collection of identical UAVs launched from the LHD, a GCS, launch, and recovery systems, capable of providing:
  - streaming IR, video for detecting, classifying and identifying targets in the IR spectrum, during wide-area, day or night search
  - EO video for detecting, classifying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

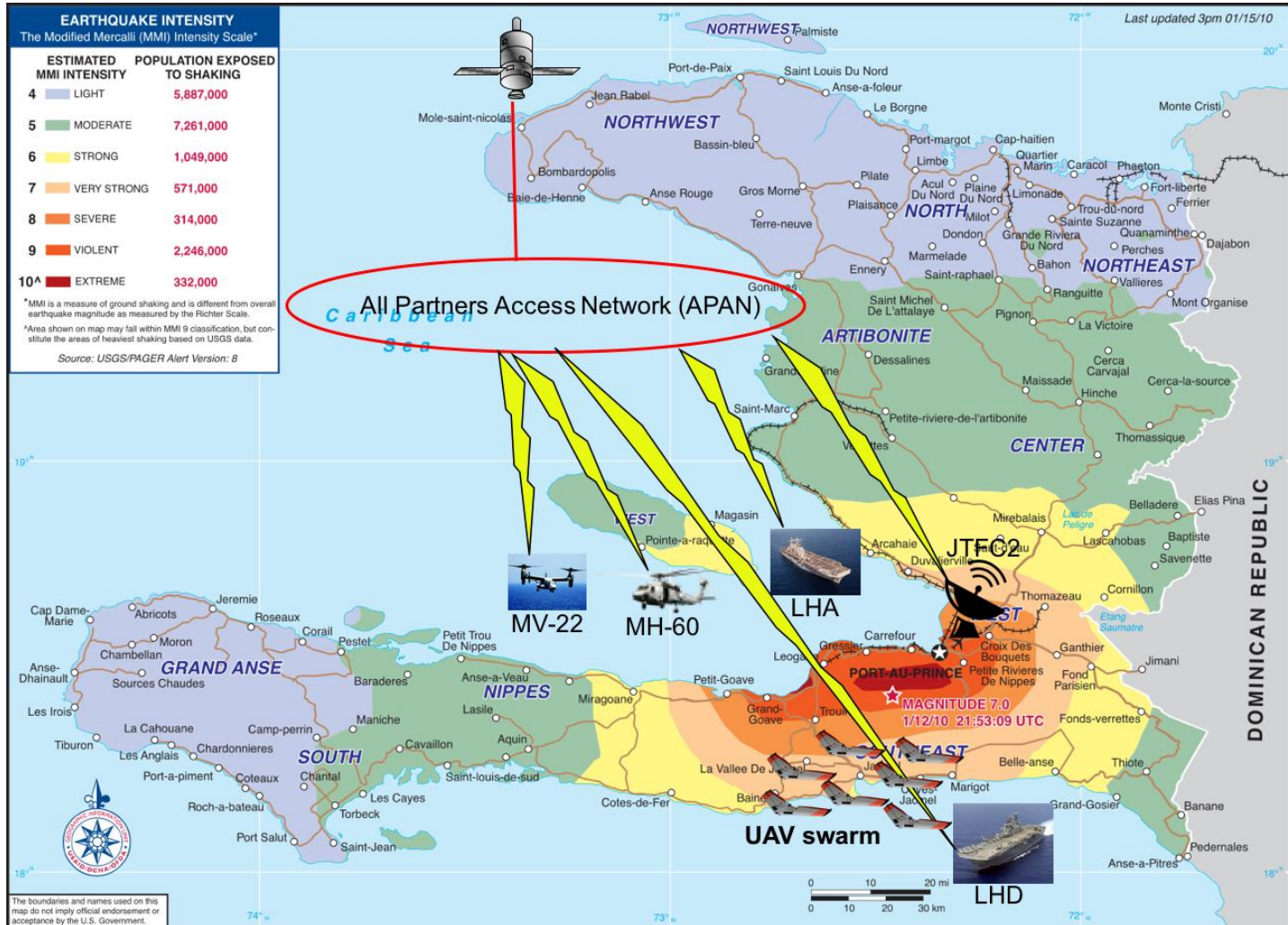


Assets:

- 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.

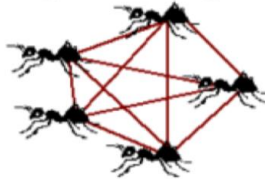
\* Giles, Kathleen. "Mission-based Architecture for Swarm Composability". PhD thesis



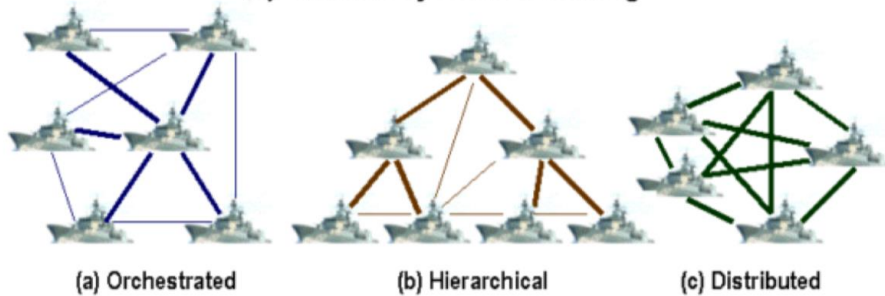
# Designing a Swarm \*

## C2 Architectures

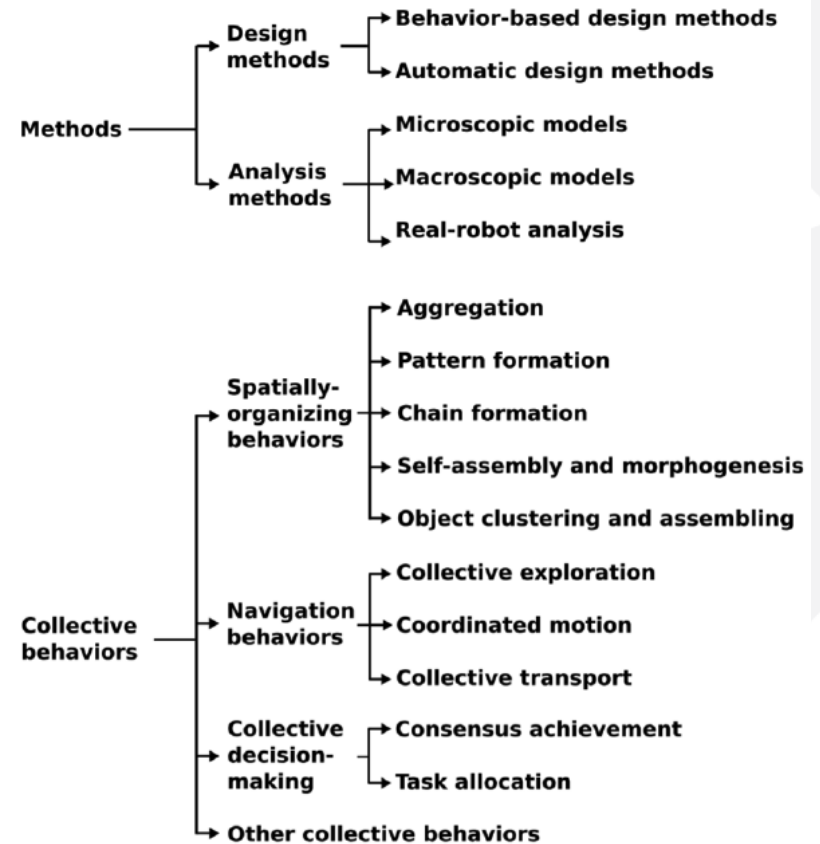
(1) Emergent Swarming



(2) Situationally Aware Swarming



## Taxonomies



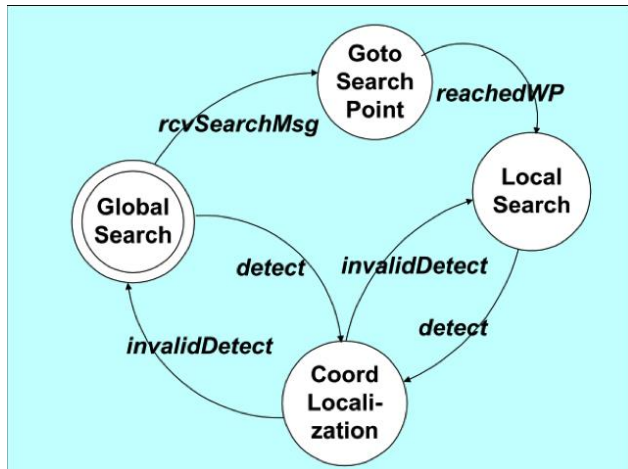
\* Giles, Kathleen. "Mission-based Architecture for Swarm Composability". PhD thesis



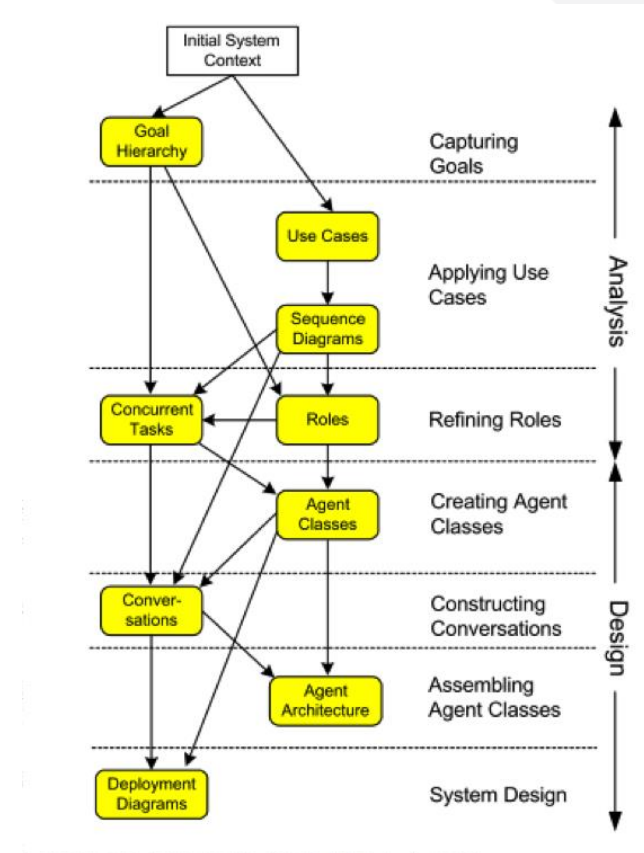
# Designing a Swarm \*

## 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

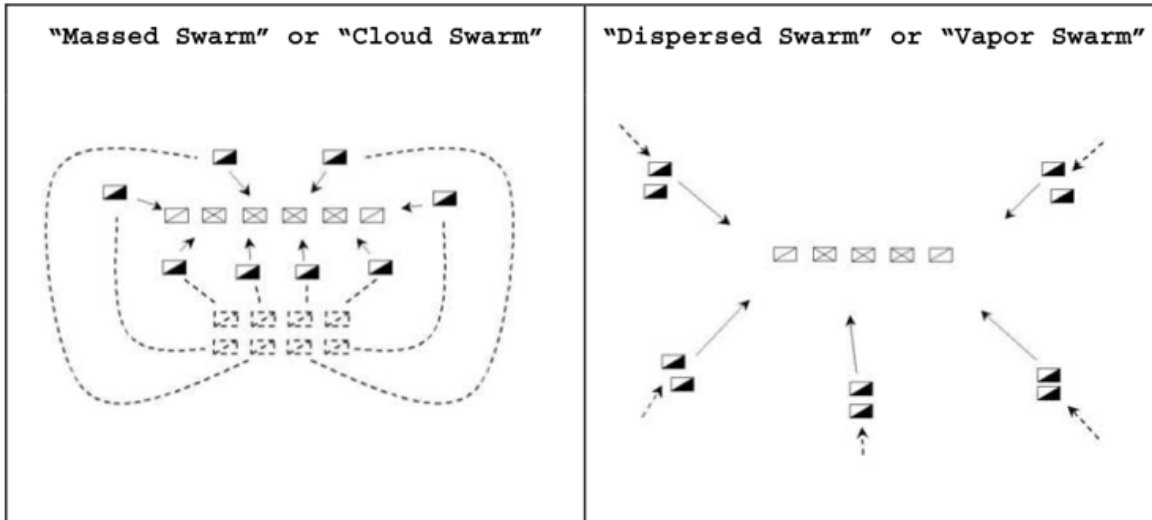
- ❑ Microscopic: Agent
- ❑ Macroscopic: Collective

## Swarm System V&V

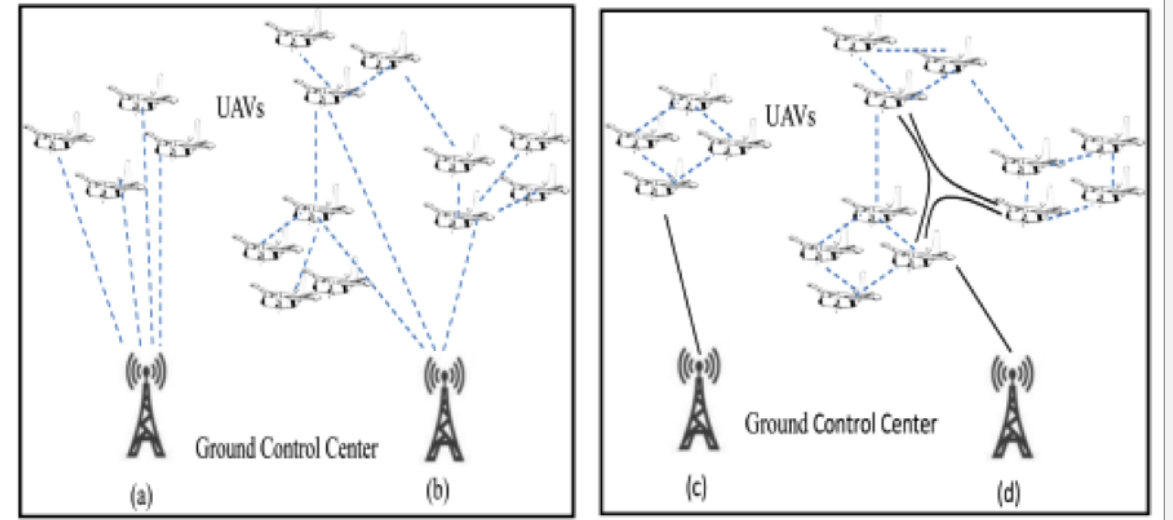
- ❑ Lightweight Formal Methods
- ❑ Experimentation

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

# Factors affecting Swarm design \*



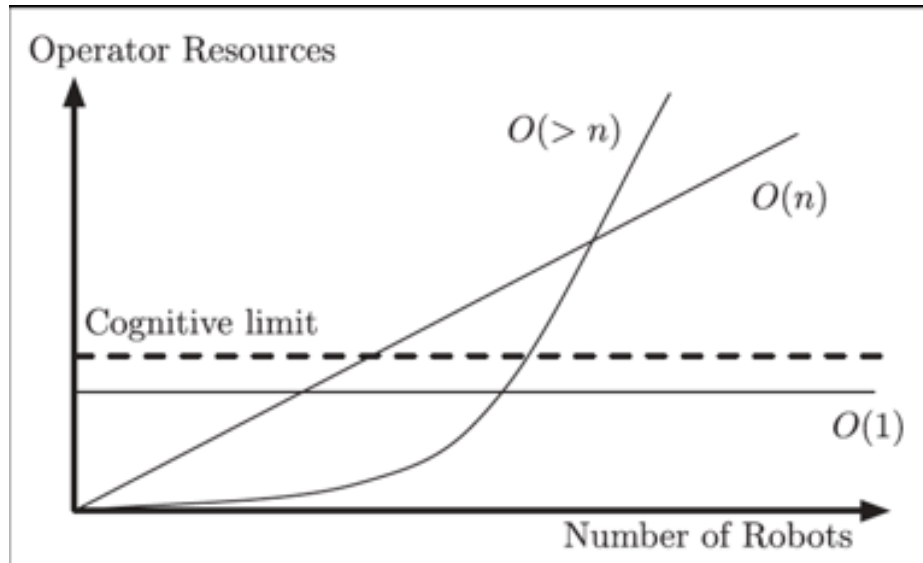
Doctrine, Strategy and Tactics



Communication Architecture

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

# Factors affecting Swarm design \*

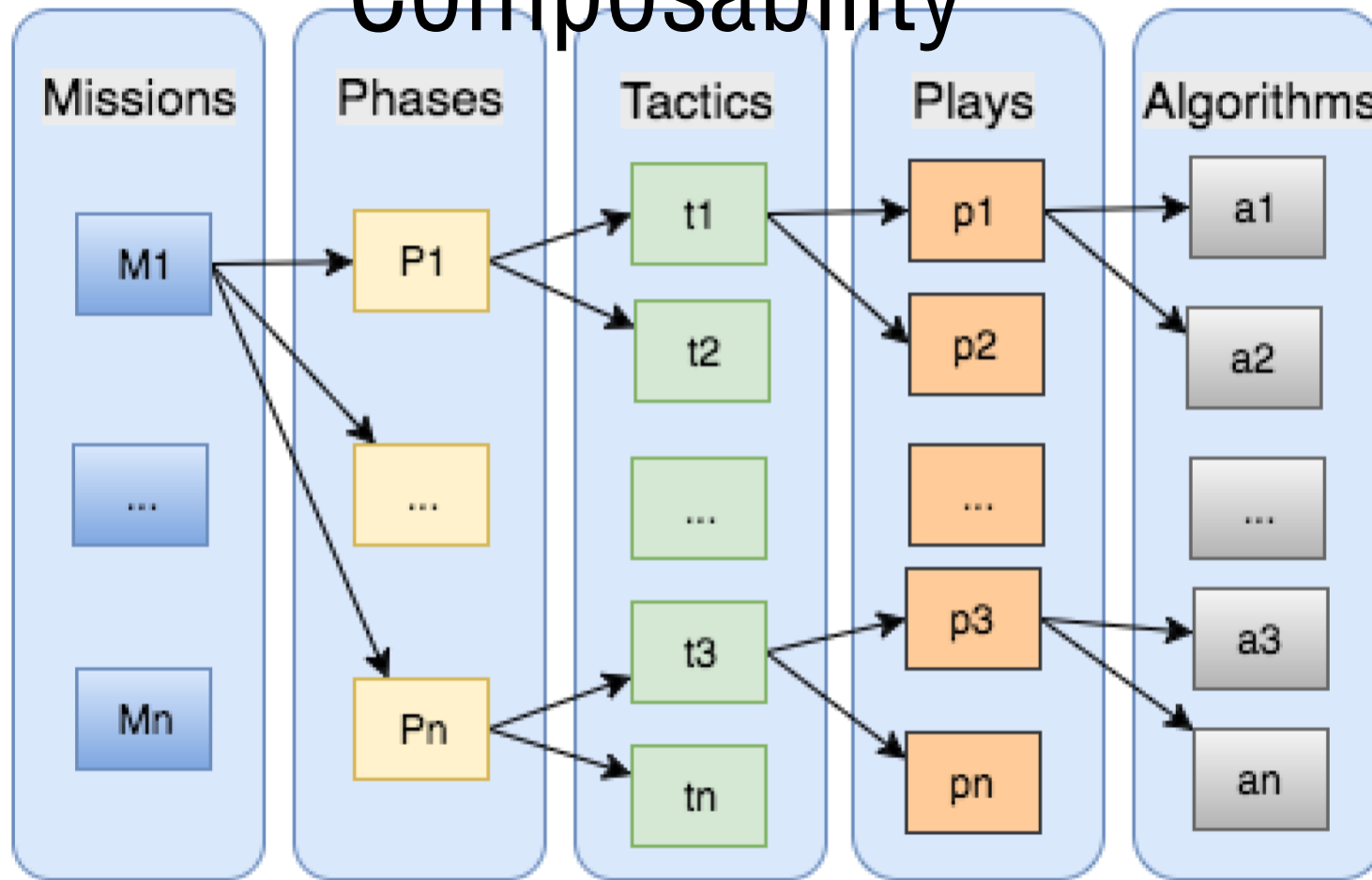


- Fully Autonomous:** UAV swarms perform fully autonomously without any operator interference
- Machine-Oriented Semi-Autonomy:** UAV swarms inform operators of special needs, but make most decisions without operator instruction
- Human-Oriented Semi-Autonomy:** UAV swarms inform operators often and 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

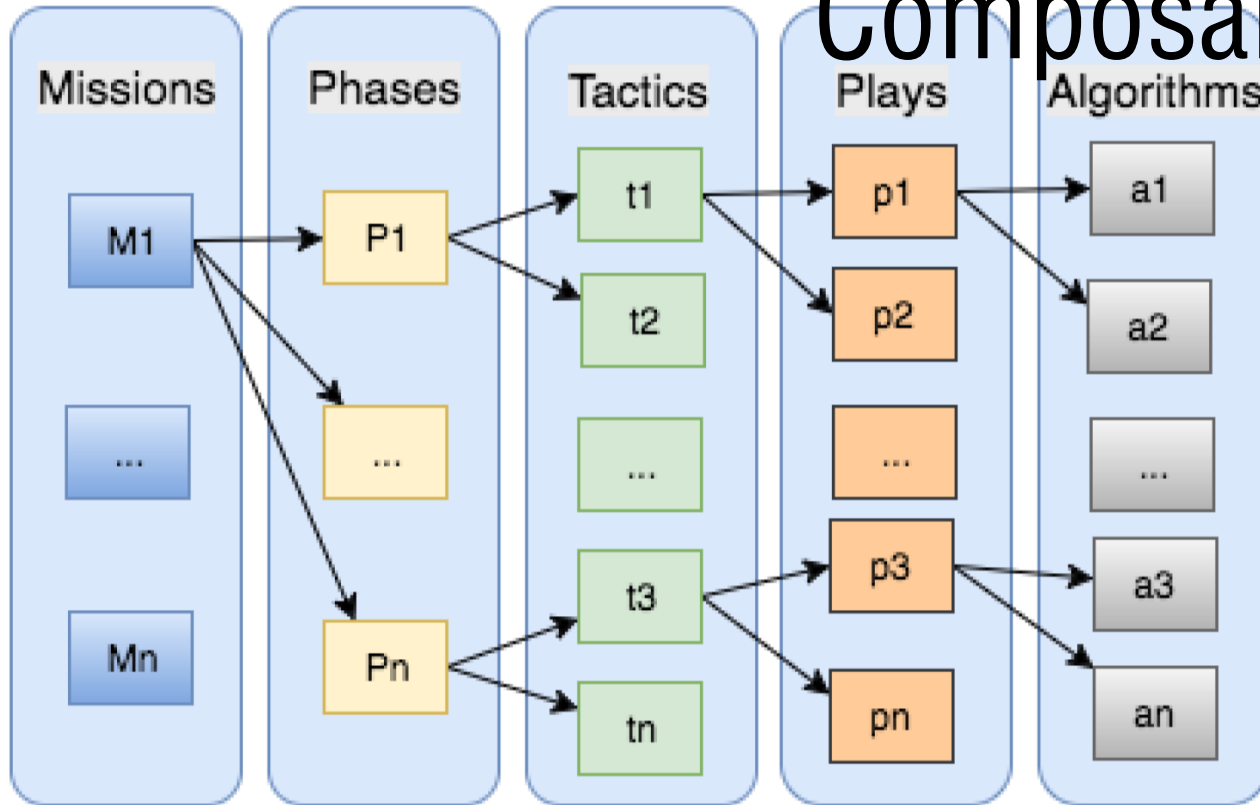
# Mission-based Architecture for Swarm Composability \*



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

# Mission-based Architecture for Swarm

## Composability \*

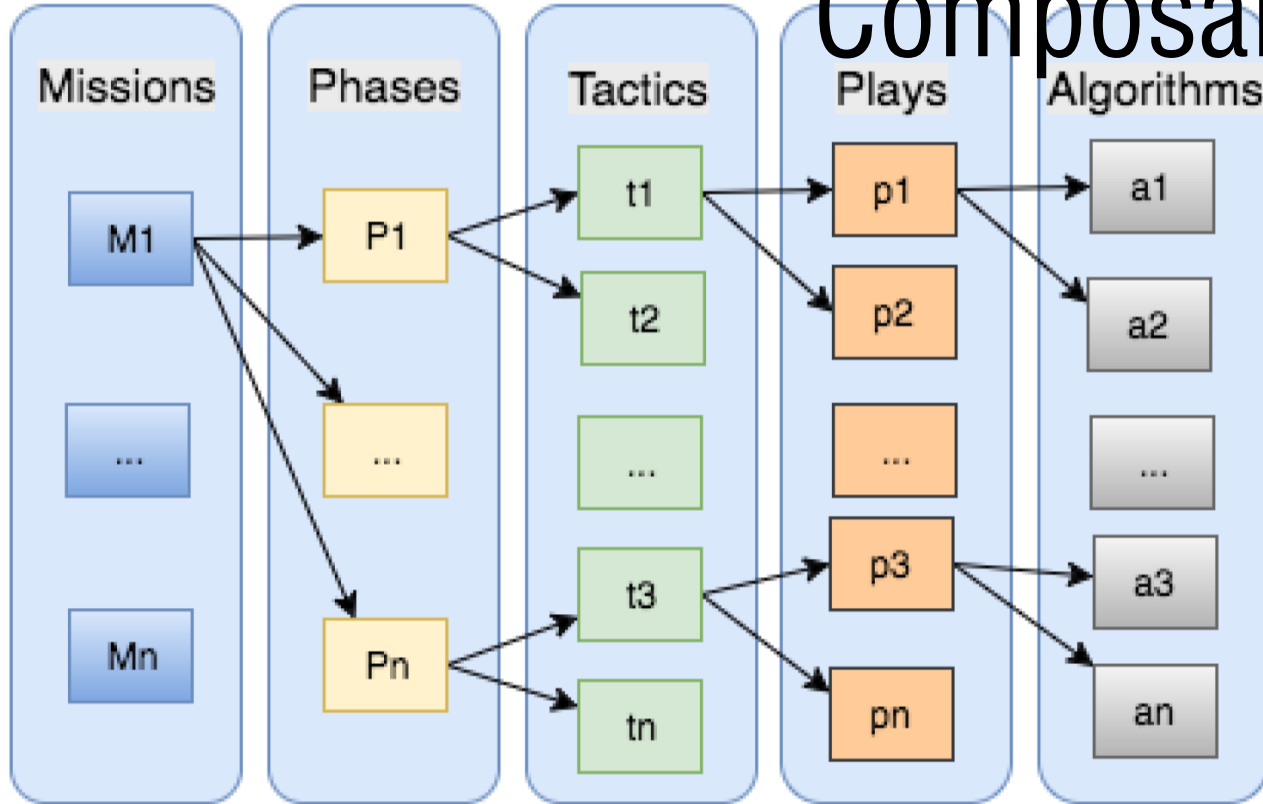


## Missions

- ❑ 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 \*



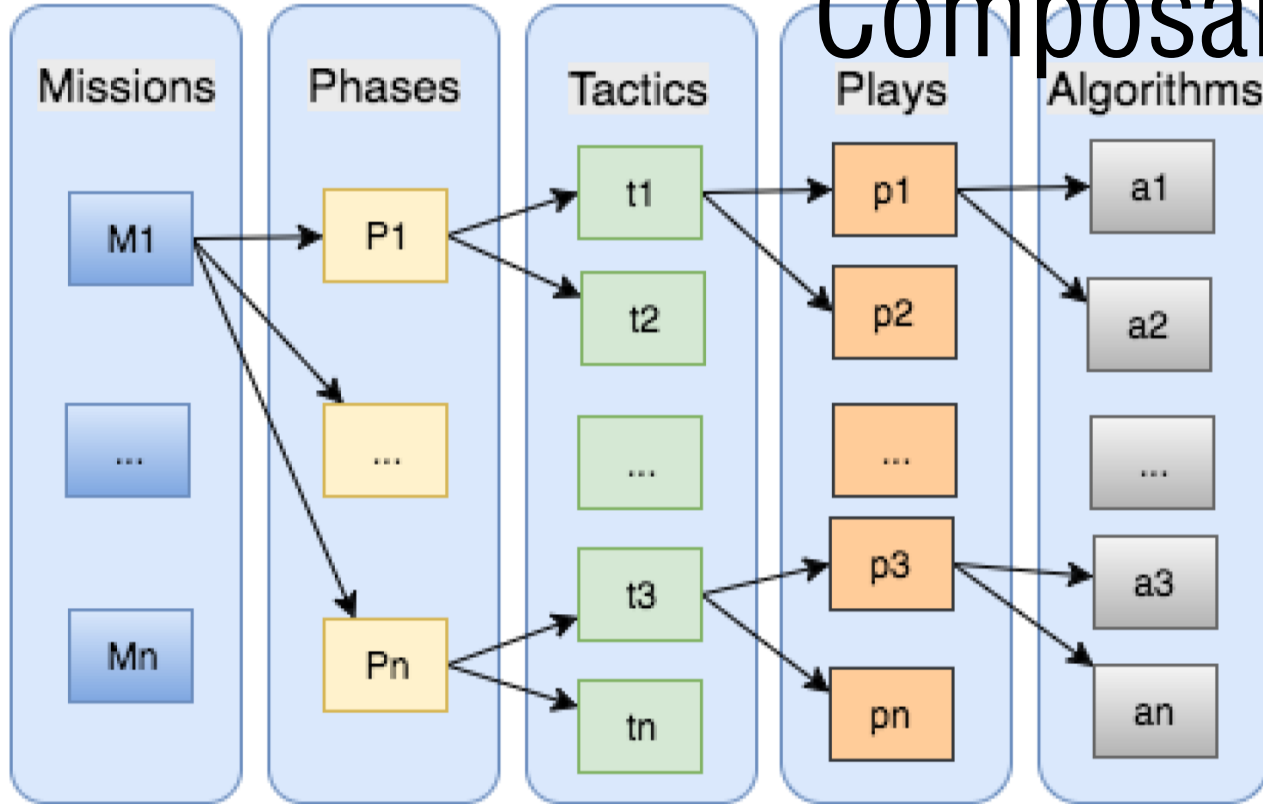
Phases

- 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 \*



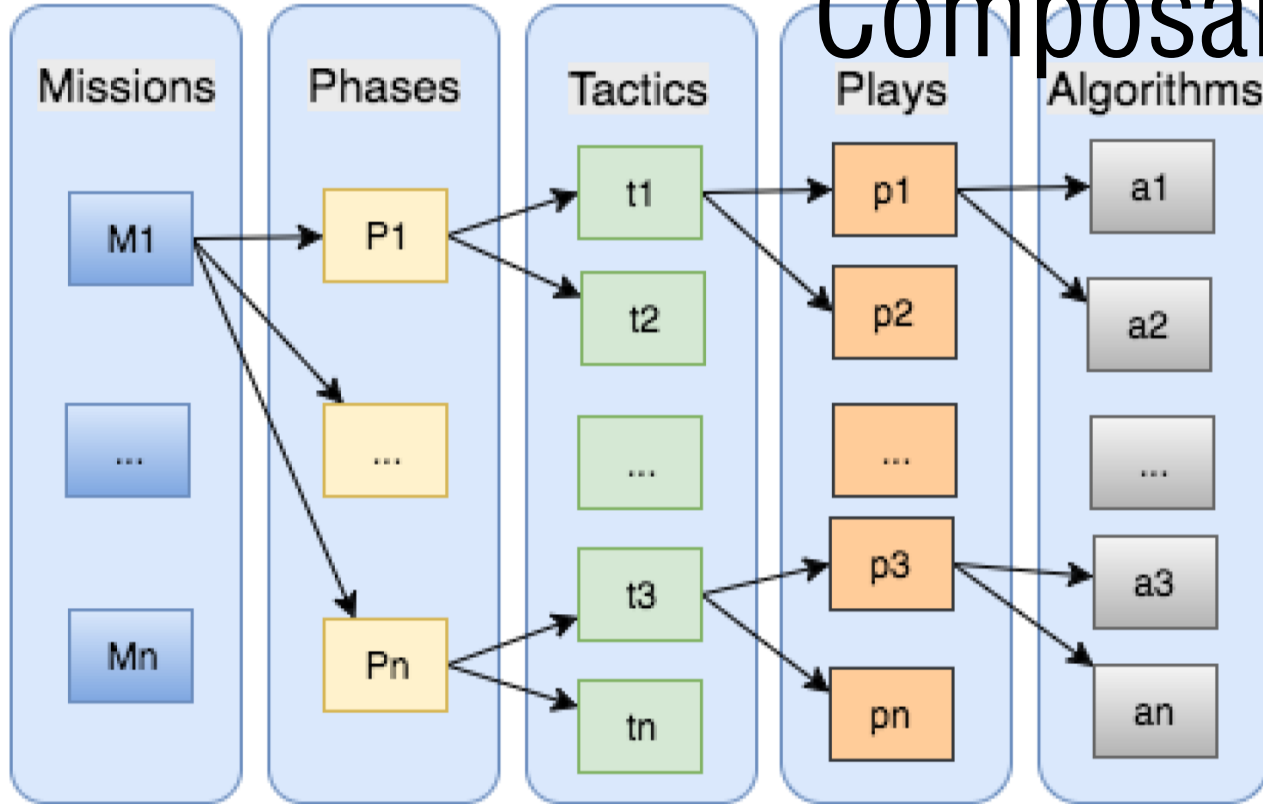
## Tactics

- 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 \*

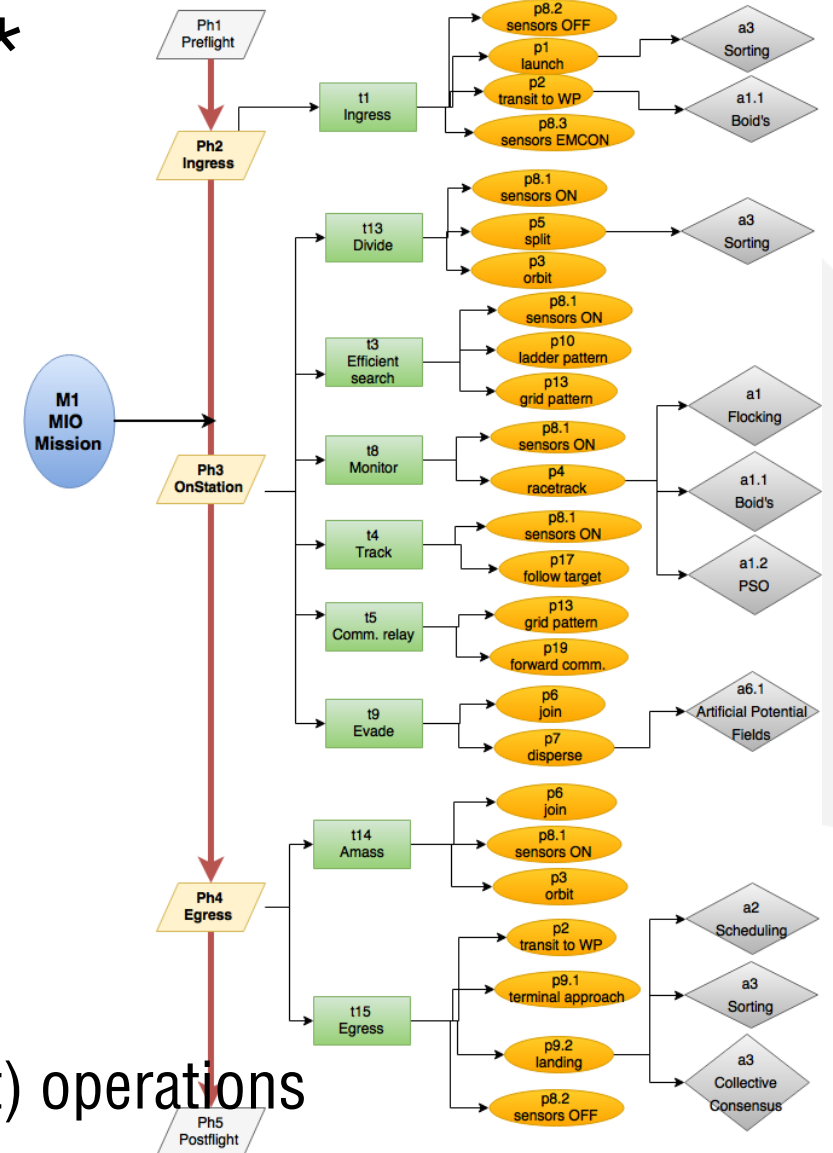
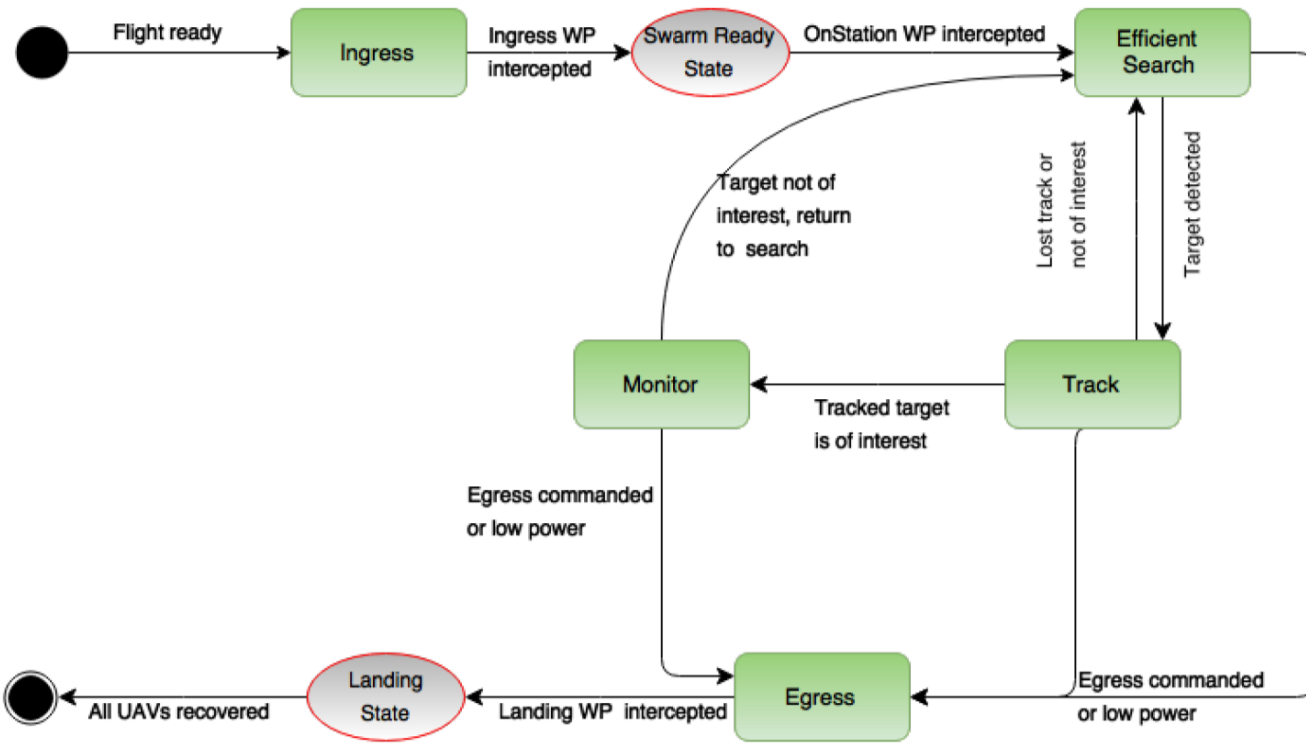


Plays

- 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

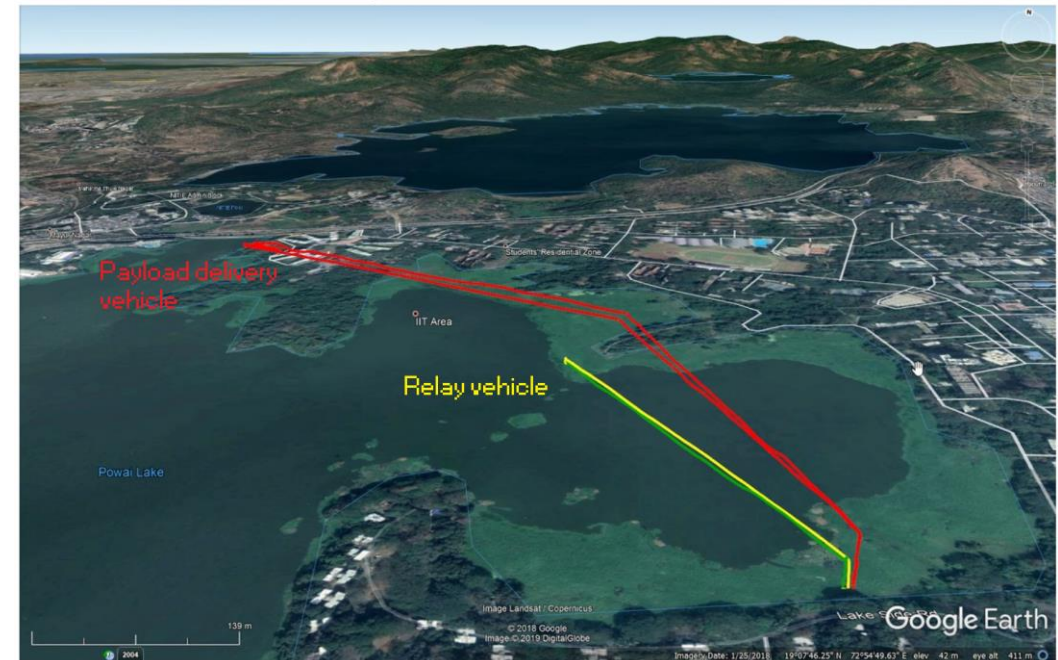
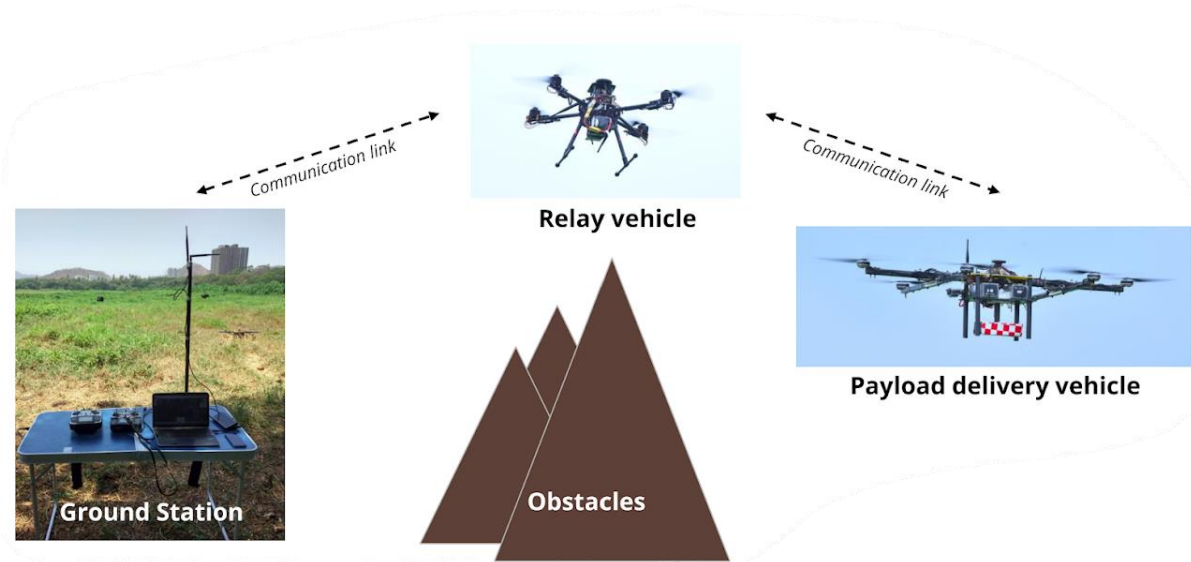
# MASC examples \*



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

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

# From algorithms to missions

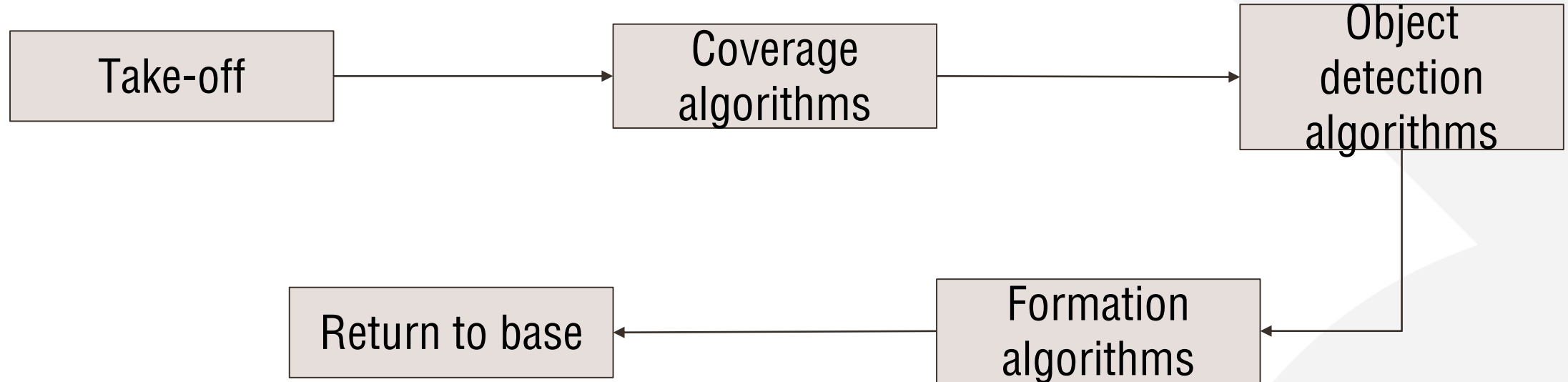


## Beyond line-of-sight delivery mission (Hangal et. al.)

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

# From algorithms to missions



Transition to mission start point

```

swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav0.py
[ator] RTL: Landing at home position.
[ator] RTL: return at 50 m (11 m above destination)
7523032.124153483, 2287.192000000]: CRD: unexpected command 176, result 0
[ator] RTL: Land at destination
7523111.653679692, 2286.664000000]: FCU: RTL: Land at destination
[ator] RTL: Land at destination
[nder] Landing detected
7523124.812379201, 2299.816000000]: FCU: Landing detected
[nder] DISARMED by Auto disarm initiated
7523125.314203176, 2300.316000000]: FCU: DISARMED by Auto disarm initiated
INFO [commander] Landing detected
INFO [commander] DISARMED by Auto disarm initiated
INFO [logger] closed logfile, bytes written: 10676490
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav1.py
2. Pause all nodes
3. Return all nodes to launch position
4. Enter target co-ords (lat,lon,alt(rel to home))
5. select target co-ords by confidence levels
6. Send nodes towards target
7. Autonomous
8. Use set area params
9. Target Test mode
0. Quit
New node 1 : [1, 1597523195, 1, data: 0, 0.50999999904632568, 19.1345501, 72.9122258, -0.043, 93.66, 0.0]
New node 2 : [2, 1597523195, 1, data: 0, 0.50999999904632568, 19.134549, 72.9122245, -0.005, 93.66, 0.0]
New node 3 : [3, 1597523195, 1, data: 0, 0.50999999904632568, 19.1345583, 72.9122272, 0.221, 92.86, 0.0]
New node 4 : [4, 1597523195, 1, data: 0, 0.50999999904632568, 19.1345583, 72.9122367, 0.207, 93.07, 0.0]
New node 5 : [5, 1597523195, 1, data: 0, 0.50999999904632568, 19.1345398, 72.9122183, 0.227, 93.05, 0.0]
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav2.py
File "/usr/lib/python2.7/threading.py", line 801, in __bootstrap_inner
self.run()
File "/usr/lib/python2.7/threading.py", line 754, in run
self._target(*self._args, **self._kwargs)
File "/home/swaroop/catkin_ws/src/formationcontrol_l1tb/src/vehiclenode_uav0.py", line 479, in send_pos
self.pos_setpoint_pub.publish(self.pos)
File "/opt/ros/melodic/lib/python2.7/dist-packages/rospy/topics.py", line 882, in publish
self.impl.publish(data)
File "/opt/ros/melodic/lib/python2.7/dist-packages/rospy/topics.py", line 1041, in publish
raise ROSException("publish() to a closed topic")
ROSException: publish() to a closed topic
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav3.py
File "/usr/lib/python2.7/threading.py", line 801, in __bootstrap_inner
self.run()
File "/usr/lib/python2.7/threading.py", line 754, in run
self._target(*self._args, **self._kwargs)
File "/home/swaroop/catkin_ws/src/formationcontrol_l1tb/src/vehiclenode_uav1.py", line 479, in send_pos
self.pos_setpoint_pub.publish(self.pos)
File "/opt/ros/melodic/lib/python2.7/dist-packages/rospy/topics.py", line 882, in publish
self.impl.publish(data)
File "/opt/ros/melodic/lib/python2.7/dist-packages/rospy/topics.py", line 1041, in publish
raise ROSException("publish() to a closed topic")
ROSException: publish() to a closed topic
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav4.py
File "/usr/lib/python2.7/unittest/case.py", line 418, in fail
self.failException(msg)
.....
FAIL
1
0 []
S: 1 [test_l1ssajou_pos_setpoints]
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav5.py
File "/usr/lib/python2.7/unittest/case.py", line 418, in fail
self.failException(msg)
.....
SUMMARY:
* RESULT: FAIL
* TESTS: 1
* ERRORS: 0 []
* FAILURES: 1 [test_l1ssajou_pos_setpoints]
swaroop@thebadbeast:~/catkin_ws$ rosrun formationcontrol_l1tb vehiclenode_uav6.py
position:
latitude: 19.1356989244
longitude: 72.9115830018
altitude: 10.0
---
Sys_id: 5
position:
latitude: 19.1357613652
longitude: 72.911494
altitude: 10.0
^Cswaroop@thebadbeast:~$

```



On-board sensors search for target



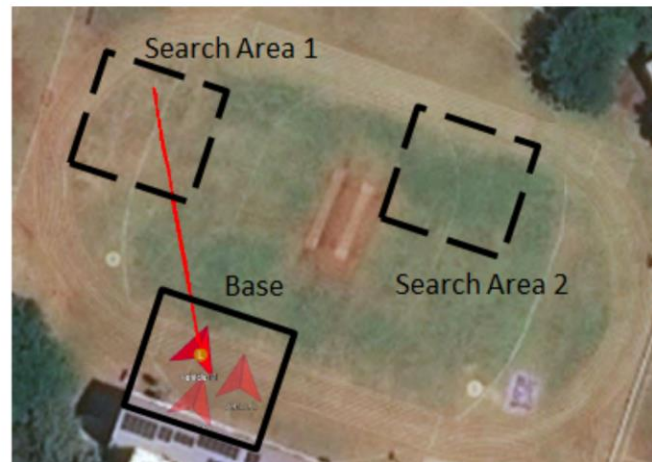
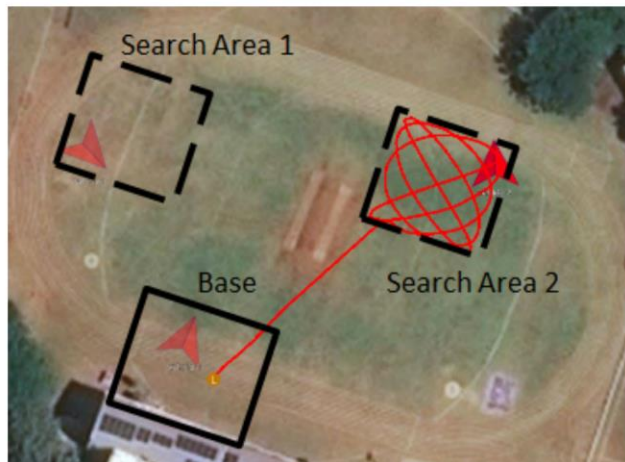
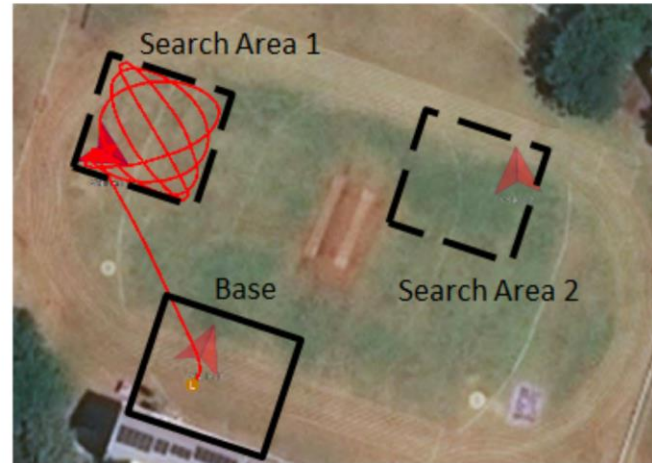
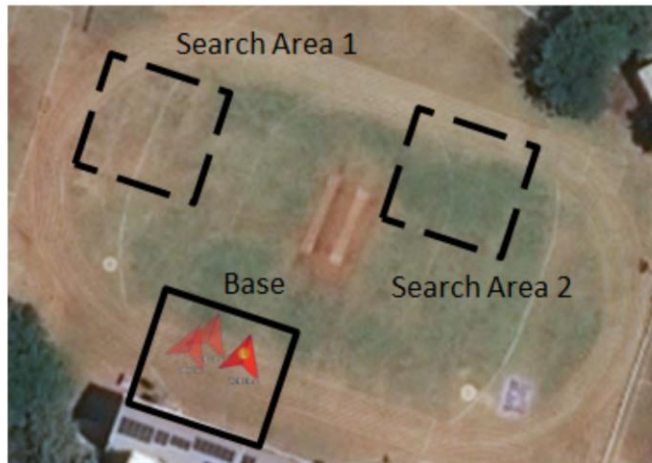
Take-off from base station



Real-time video stream received at base station



# From algorithms to missions





# Future work

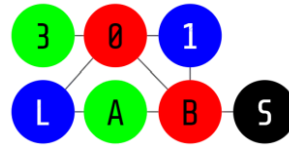
Depth

Holistic

Engage

Deploy

# Collaborators



NCETIS



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Prof. Hoam Chung



Prof. Hemendra Arya



Dr. Swaroop Hangal

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



Pravin Prajapati



Ravi Singh



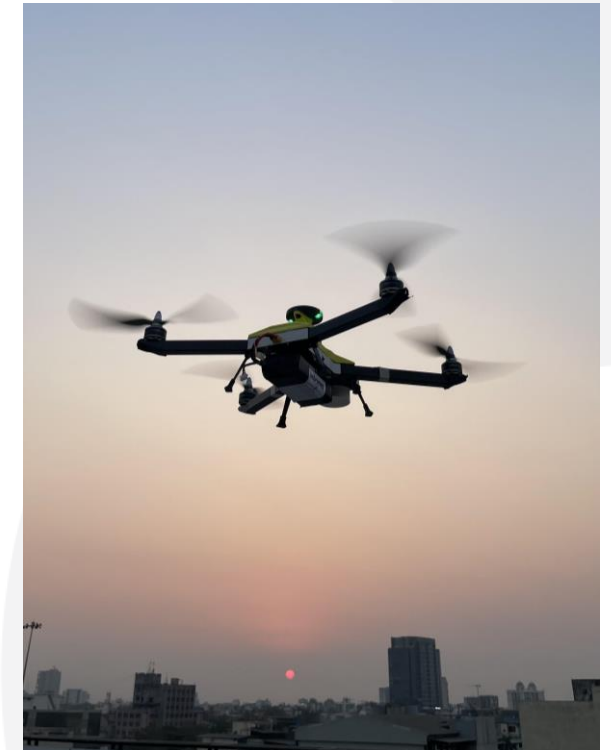
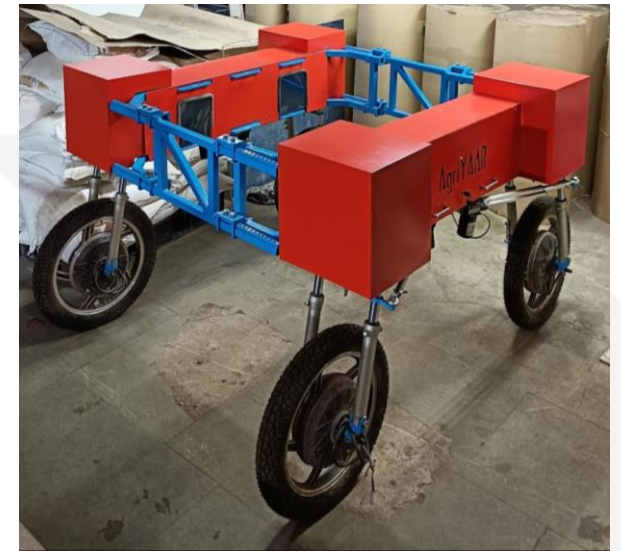
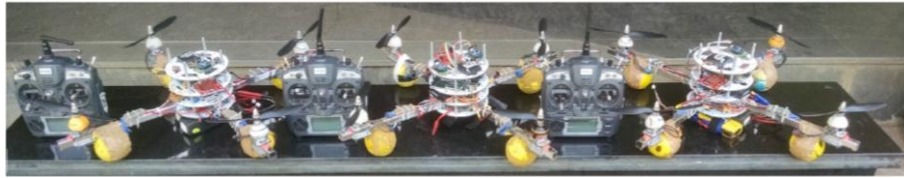
Harshad Bhanushali



Aakash Sinha

Chittaranjan, Dhananjay Kulkarni

indrones



# Thank you

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