Drone Communication Networks summary

Aristidis Pavlidis, Prof. Ioannis Pitas
Aristotle University of Thessaloniki
pitas@csd.auth.gr
www.aiia.csd.auth.gr

Version 2.5.1

Artificial Intelligence &
Information Analysis Lab

Drone Communication Networks

- Drones
- FANET
- FANET Features
- FANET Architectures
- Mobility Models
- FANET Routing Protocols
- Civilian Drones: Safety and Security Aspects
- Open issues and challenges

Drones

- An UAV (Unmanned Aerial Vehicle) is an aerial vehicle that can fly without any crew or pilot on board.

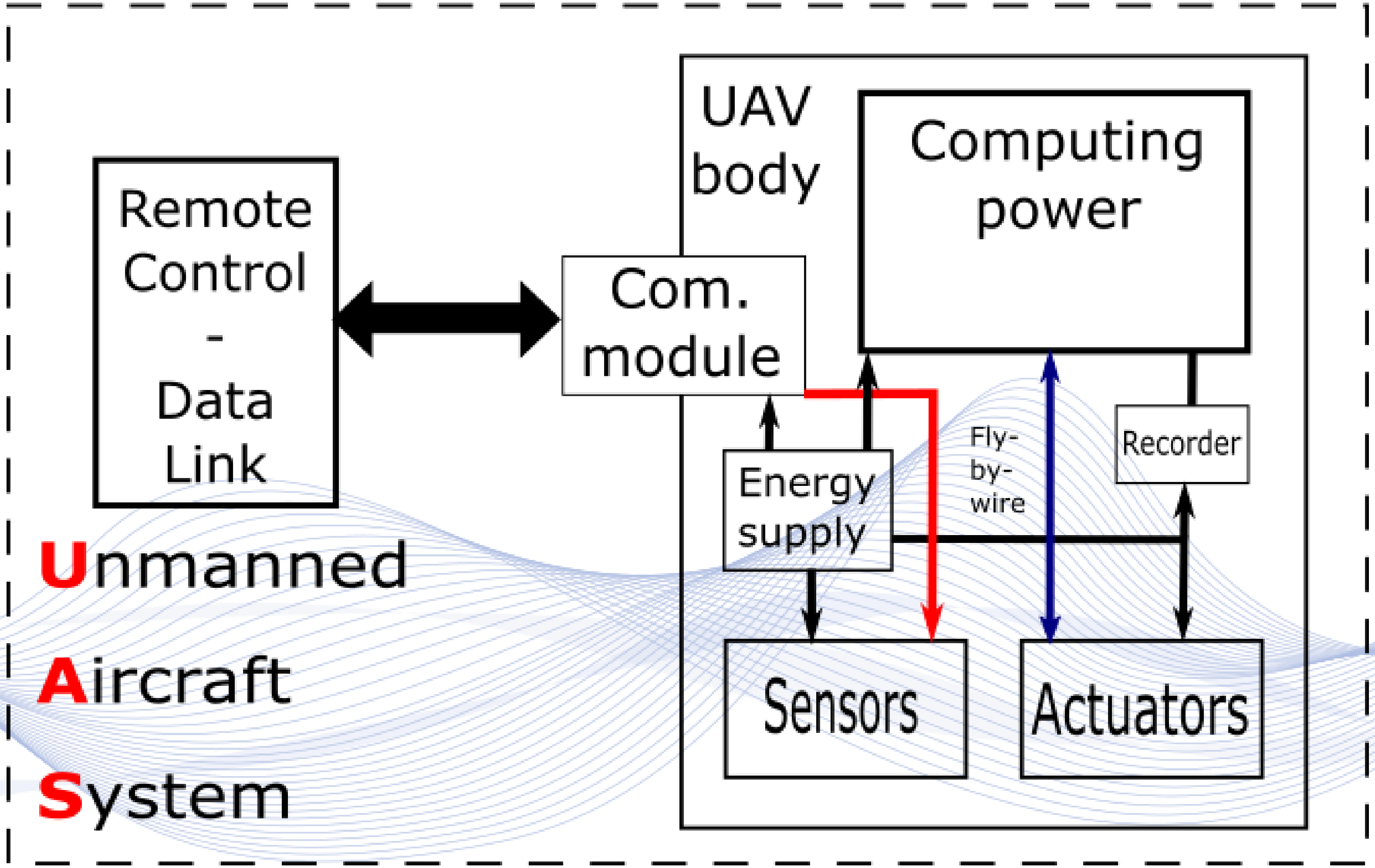
- UAV belongs to a system called Unmanned Aircraft System (UAS).

- Unmanned Aircraft System (UAS) consist of:
  - At least one UAV.
  - A Ground Station.
  - A communication system among them (UAV to UAV or UAV to UAS).

- UAVs can do "dull, dirty or dangerous" jobs.

Drones

UAV parts



Comparison of Single UAV & Multi-UAVs Systems

Features	Multi-UAVs	Single UAV
Antenna	Directional	Omni-directional
Bandwidth	Medium	High
Control complexity	High	Low
Cost	High	Medium
Coordinate failure	Present	Low

Features	Multi-UAVs	Single UAV
Failures	Low	High
Mission speed	Fast	Slow
Scalability	High	Limited
Survivability	High	Poor

Drones

Categories of UAVs

Fixed wings

[HT]

Drones

Categories of UAVs

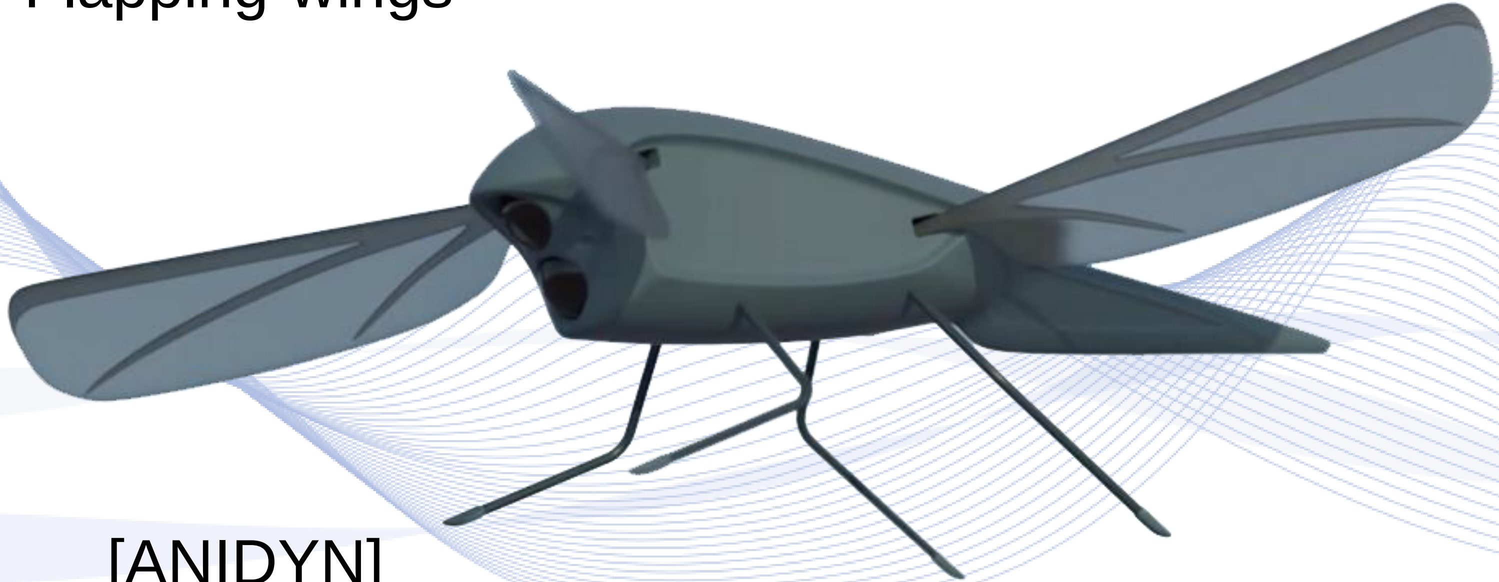
Multicopters (Multirotors)

[ARDU]

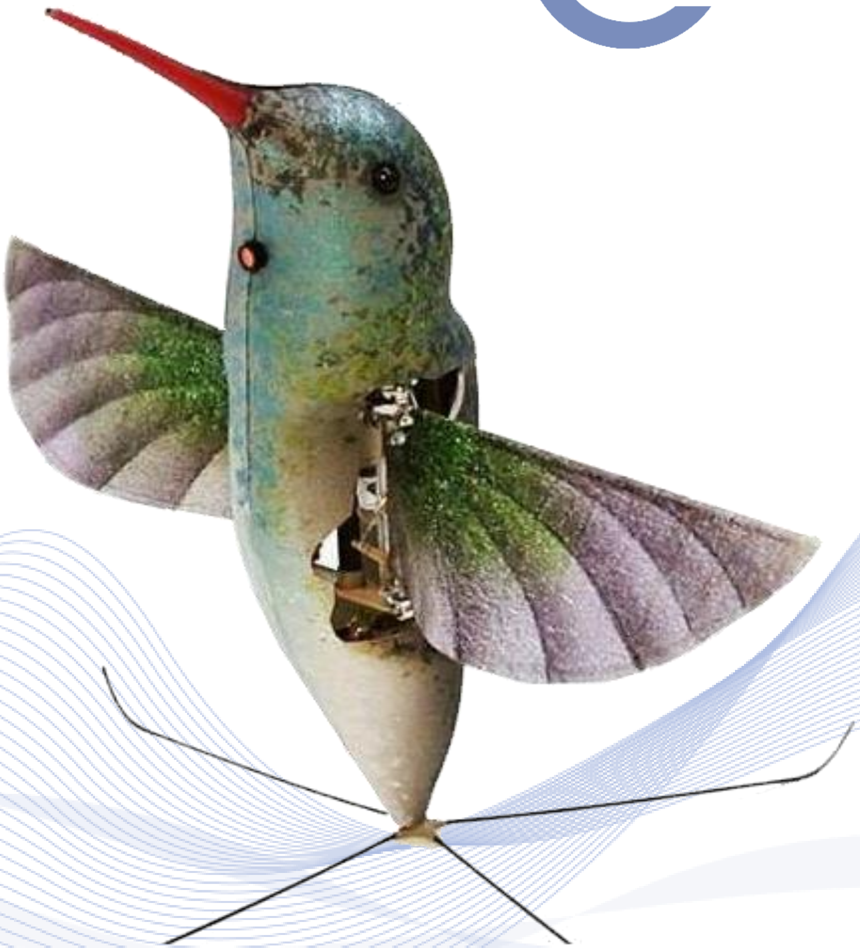
Drones

Categories of UAVs

Flapping-wings



[ANIDYN]



[RGFW]

FANET

Artificial Intelligence &
Information Analysis Lab

VML

4G/LTE

- What is 4G/LTE
- Quality of Service for 4G/LTE

5G

- What is 5G
- 5G Types
- How 5G works
- How is 5G better than 4G?
- 5G technology components
- Quality of Service

Internet of Things

- What is IoT
- Characteristics
- Applications
- Baseline Technologies
- Sensors

FANET

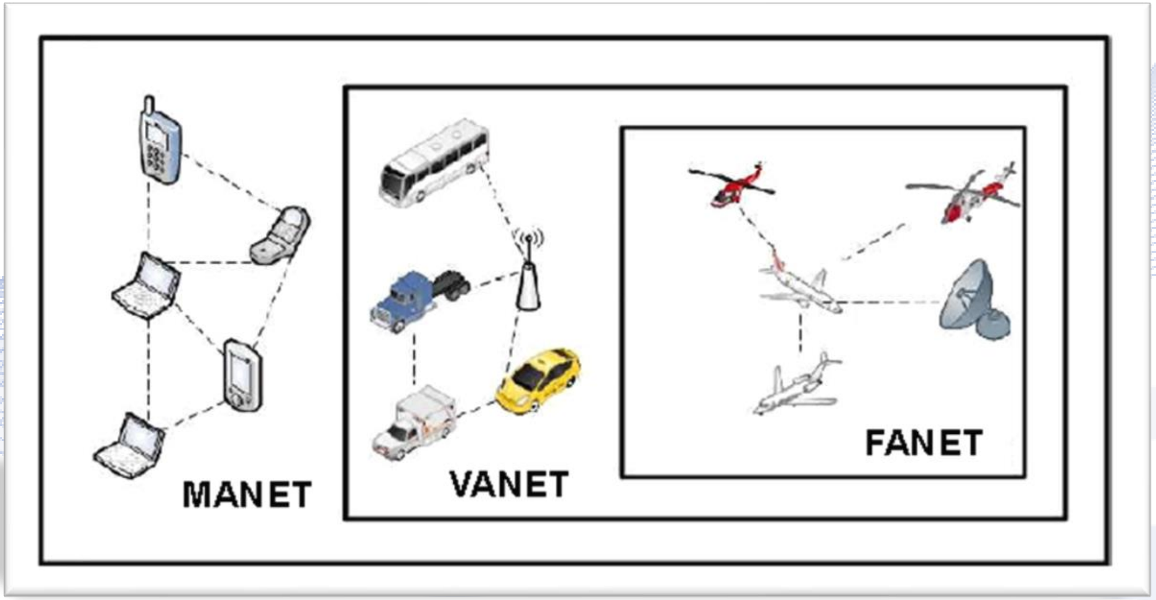
- Drones
- Features
- Architectures
- Mobility Models
- Routing Protocols
- Safety and Security Aspects

Ad-Hoc networks

- Ad-hoc networks

  Signifies a solution designed for a specific problem or task and it not generalize.

- 3 kinds of Ad-hoc networks
  - MANET (Mobile Ad-hoc NETworks)
  - VANET (Vehicle Ad-hoc NETworks)
  - FANET (Flying Ad-hoc NETworks)



[NADEEM2018]

FANET features

- Mobility features: Nodes in FANET can move in 3D space instead of MANET and VANET.
- FANET's nodes mobility schemes can be different than the other.
- Number of nodes: FANET has smaller number of nodes. This is caused because the distance between UAVs of a swarm can span up to several kilometers. So the transmitter must have similar transmission range.

FANET features

- Transmission speed: The information must be transmitting in a certain delay bound among the UAVs, especially the information which is about real-time applications or collisions avoidance, etc.
- Line of Sight: The line of sight (LoS) in FANETs is easiest to exist, instead of MANETs or VANETs.

MANET vs VANET vs FANET

Node Characteristics	MANET	VANET	FANET
Network Connectivity	High	Medium	Low
Density	Low	High	Very Low
Mobility Model	Random	Regular	Predetermined Paths – Regular; Autonomus UAV – Special Model
Topology Change	Very Less Change	Frequent	Very Frequent
Radio Propagation Model	Very Close To Groung	Very Close To Groung	High Above The Groung

MANET vs VANET vs FANET

Node Characteristics	MANET	VANET	FANET
Energy Utilization	Low, Energy Efficient Protocols	Not Required	Very High
Computational Power	Low	High	High
Scalability	Average	High	Low
QoS	Low	High	High
Localization	GPS	GPS, AGPS, DGPS	GPS, AGPS, DGPS, IMU

Artificial Intelligence & Information Analysis Lab

Technical specifications

Communication Technology	IEEE Standard	Frequency/ Medium	Network Typology	Latency	Theoretical Data rate	Range Indoor/Outdoor	Spectrum Type	Device Mobility	Advantages	Limitations
	802.11	2,4GHz IR	Ad-hoc, hybrid, mesh, star		Up to 2 Mbps	20 m – 100 m	Unlicensed	Yes		
	802.11a	5 GHz	Ad-hoc, hybrid, mesh, star		Up to 54 Mbps	35 m – 120 m	Unlicensed	Yes		
Wi-Fi	802.11b	2,4 GHz	Ad-hoc, hybrid, mesh, star	< 5ms	Up to 11 Mbps	35 m – 140 m	Unlicensed	Yes	High speed and low cost	Limited range
	802.11g	2,4 GHz	Ad-hoc, hybrid, mesh, star		Up to 54 Mbps	70 m – 250 m	Unlicensed	Yes		
	802.11n	2,4/5 GHz	Ad-hoc, hybrid, mesh, star		Up to 600 Mbps	38 m – 140 m	Unlicensed	Yes		
	802.11ac	5 GHz	Ad-hoc, hybrid, mesh, star		Up to 3466 Mbps	35 m – 120 m	Unlicensed	Yes		

Technical specifications

Communication Technology	IEEE Standard	Frequency/ Medium	Network Typology	Latency	Theoretical Data rate	Range Indoor/Outdoor	Spectrum Type	Device Mobility	Advantages	Limitations
Bluetooth 5	802.15.1	2,4 GHz	Ad-hoc, piconet	3 ms	Up to 2 Mbps	40 m – 200 m	Unlicensed	Yes	Energy efficient	Low data rate
ZigBee	802.15.4	2,4 GHz	Ad-hoc, cluster, mesh, star, tree	15 ms	250 Kbps	10 m – 100 m	Unlicensed	Yes	Low cost	Low data rate
WiMAX	802.16a	2 to 11 GHz	Wide area, wireless backhaul	30 ms	Up to 75 Mbps	Up to 48 Km	Licensed	Yes	High throughput	Interference issues
LTE	LTE	Up to 20 GHz	Flat, IP based	5 ms	Up to 300 Mbps	Up to 100 Km	Licensed	Yes	High bandwidth	Expensive
5G	5G (eMBB)	28 GHz	IP based	1 ms	Up to 20 Gbps	Wide area	Licensed	Yes	High data rate	Expensive
Satellite	Satellite	Up to 40 GHz	-	550 ms	Up to 1 Gbps	World wide	Licensed	Yes	Wide coverage	High delay and Expensive

Technical specifications

FANET Architectures

Artificial Intelligence & Information Analysis Lab

FANET Architectures

- Communication Architecture
- Application Architecture

FANET Architectures

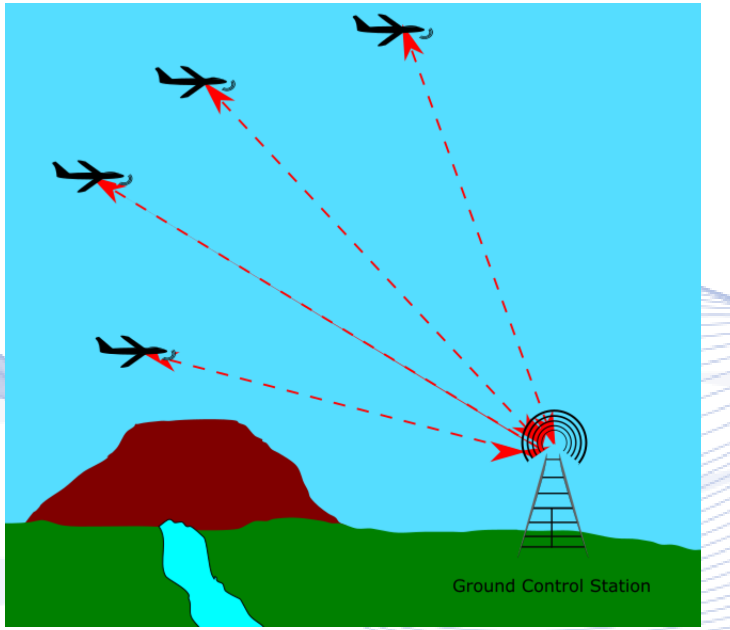
Communication Architecture

- Centralized
- Single Layer – Single Group
- Single Layer – Multi Group
- Multi Layer – Multi Group

FANET Architectures

Communication Architecture

Centralized Architecture



Communications Technologies

- IEEE 802.11 n/b/g/a
- IEEE 802.14.4
- IEEE 802.15.4
- WAVE

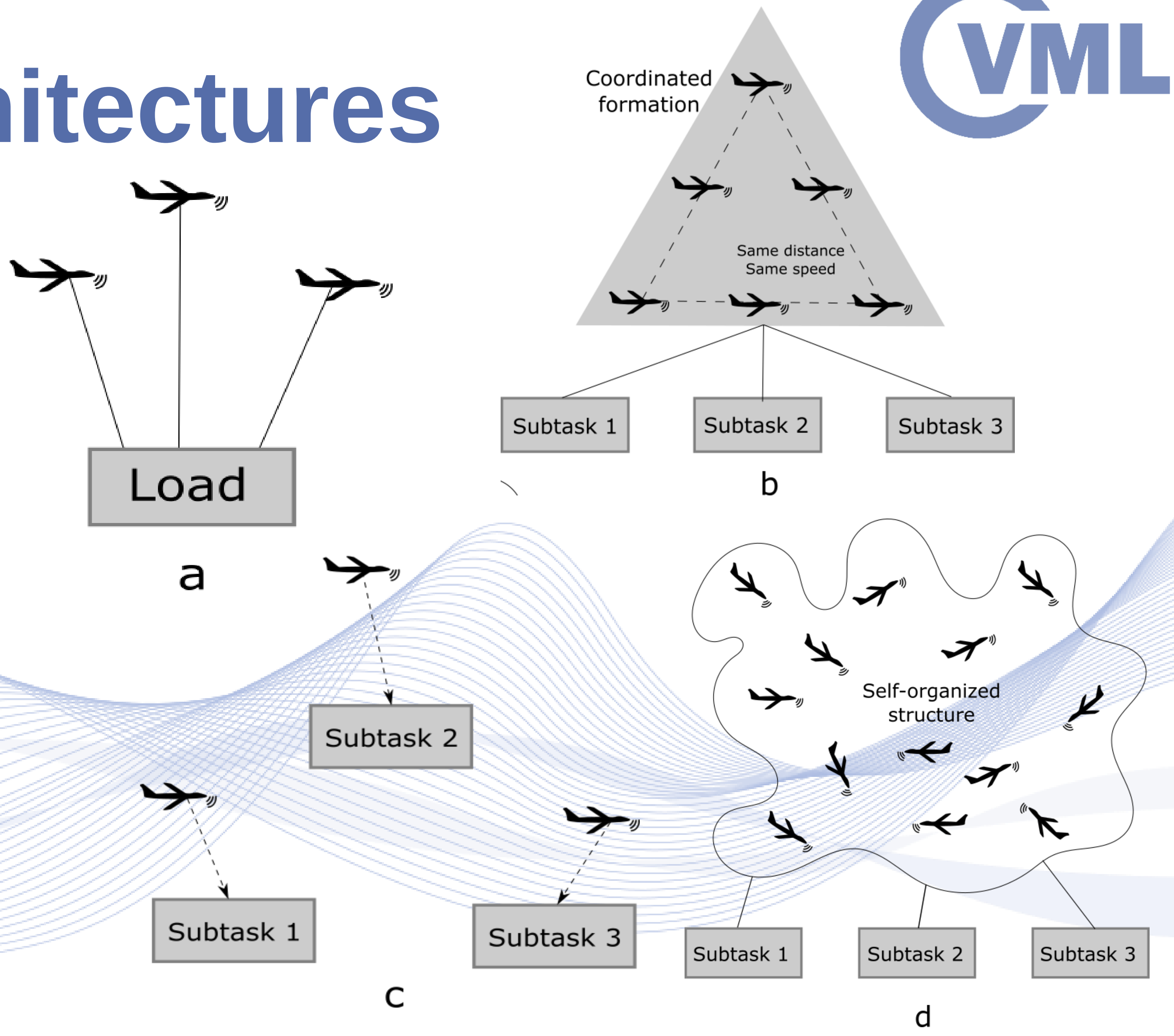
Last two technologies provides a less complicated and low power consumption.

FANET Architectures

<u>Application Architectures</u>

- Tightly Coupled Nodes
  - Physically – Linked (a)
  - Formation – Based (b)

- Loosely Coupled Nodes
  - Labor Division (c)
  - Swarm Cooperation (d)



Applications

- Forest Fire Monitoring
- Search And Rescue (SAR)
- Cooperative Aerial Surveillance
- Load transportation

Mobility Models

Mobility Models

- Characterize the movements of mobile users with respect to their location, velocity and direction over a period of time.

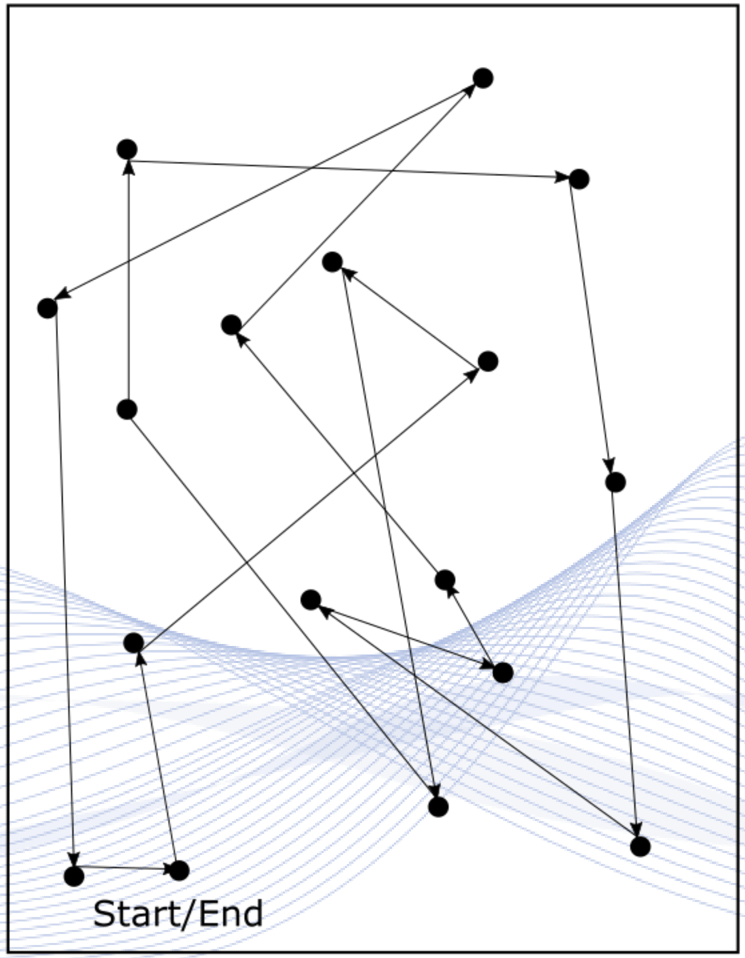
- Play vital role in the design of Flying Ad-Hoc Networks (FANET).

- Simulators like (NS, QualNet, etc) allow the users to choose the mobility models as these models represent the movements of nodes or users.

Mobility Models

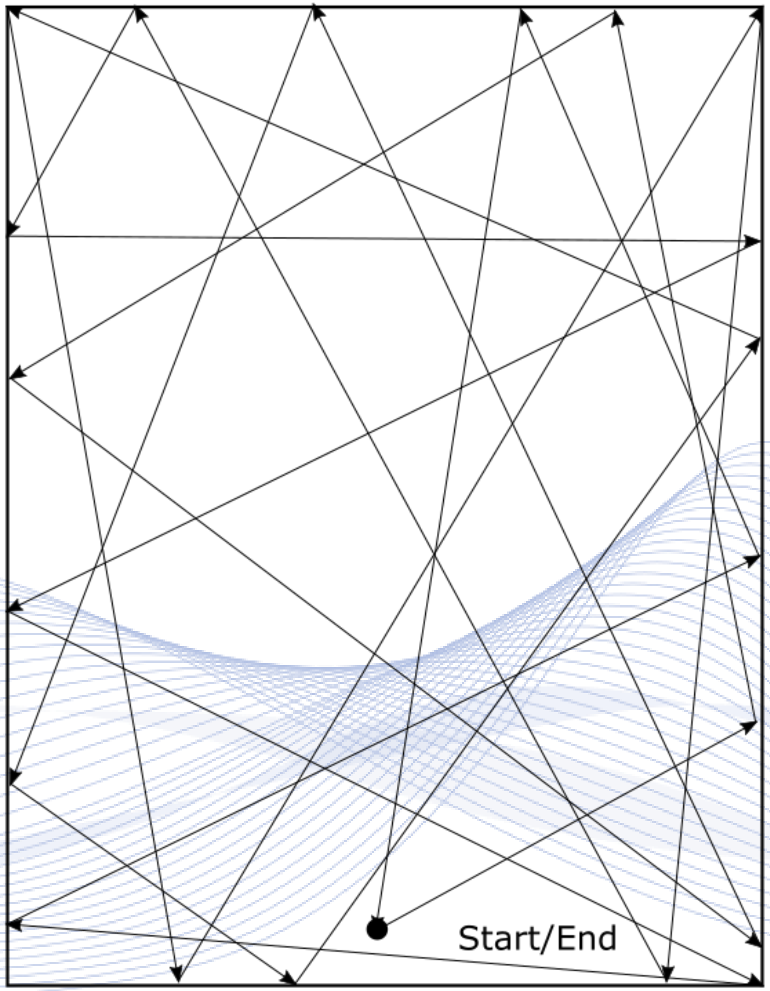
- Random WayPoint (RWP)
- Random Direction (RD)
- Gauss – Markov (GM)
- Distributed Pheromone Repel (DPR)
- Smooth Turn (ST)
- Semi-Random Circular Movement (SRCM)
- Spring Mobility Model (SMM)

Mobility Models



Random WayPoint
Mobility Model

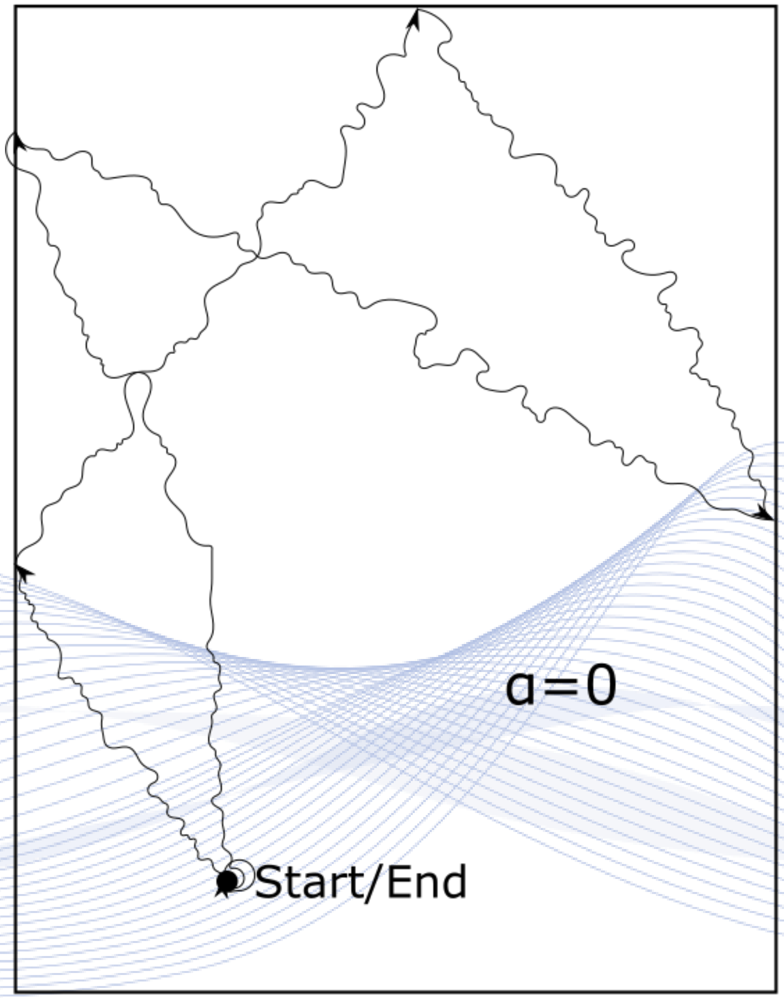
Mobility Models



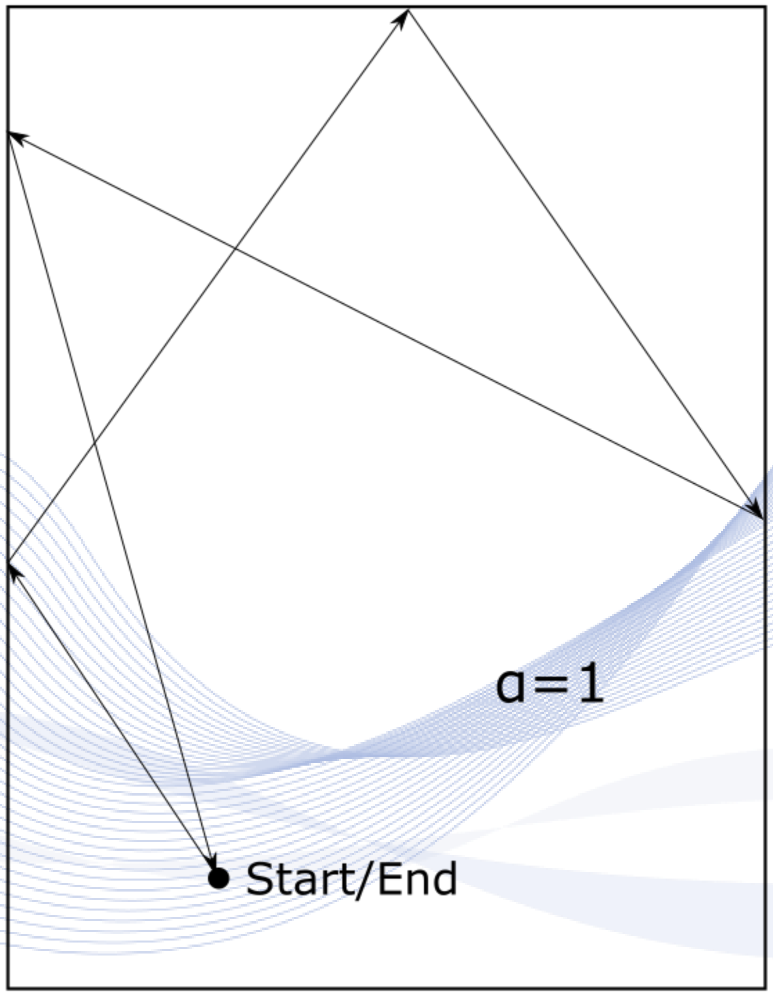
Random Direction
Mobility Model

Mobility Models

Parameter **alpha (α)** in Gauss-Markov Mobility Model determine the amount of **memory** and **variability** in node movement.

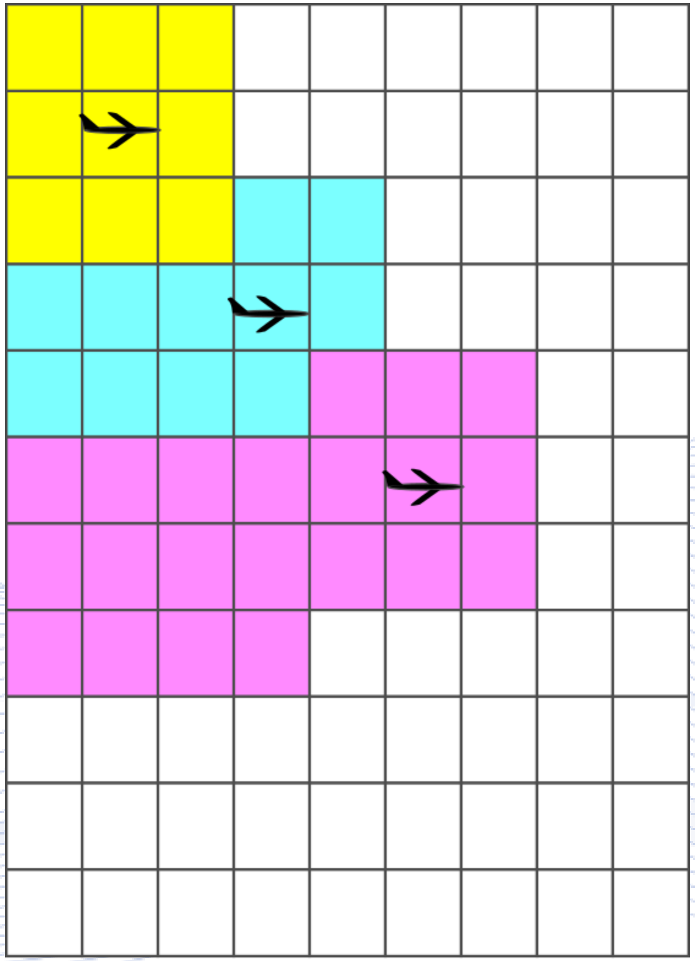


Gauss-Markov
Mobility Model



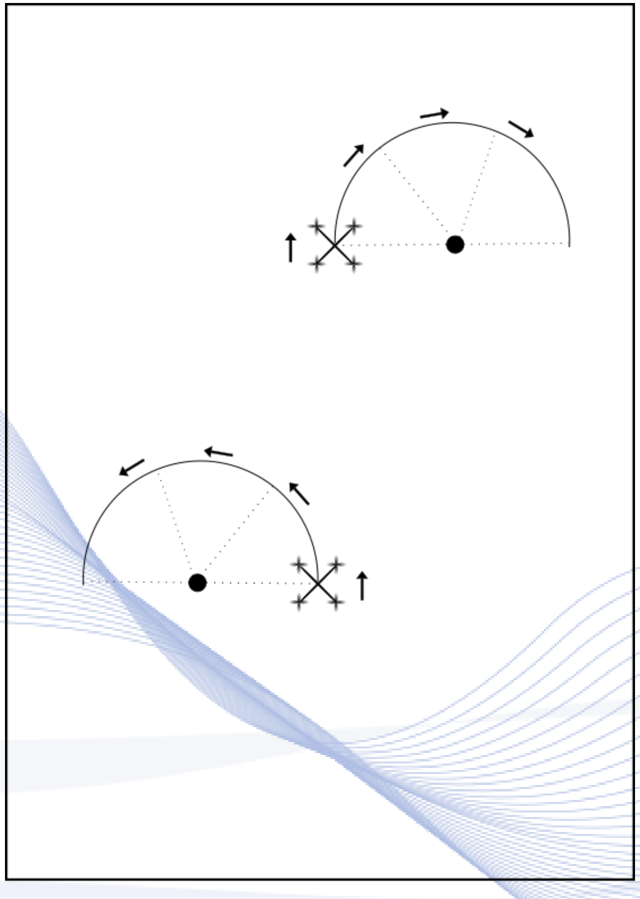
Gauss-Markov
Mobility Model

Mobility Models

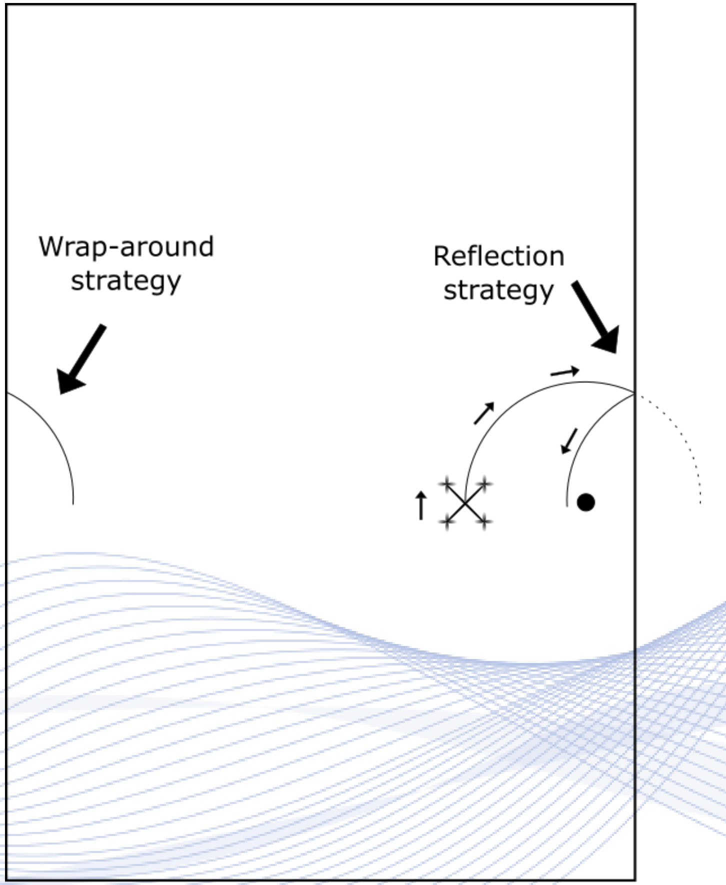


Distributed Pheromone Repel
Mobility Model

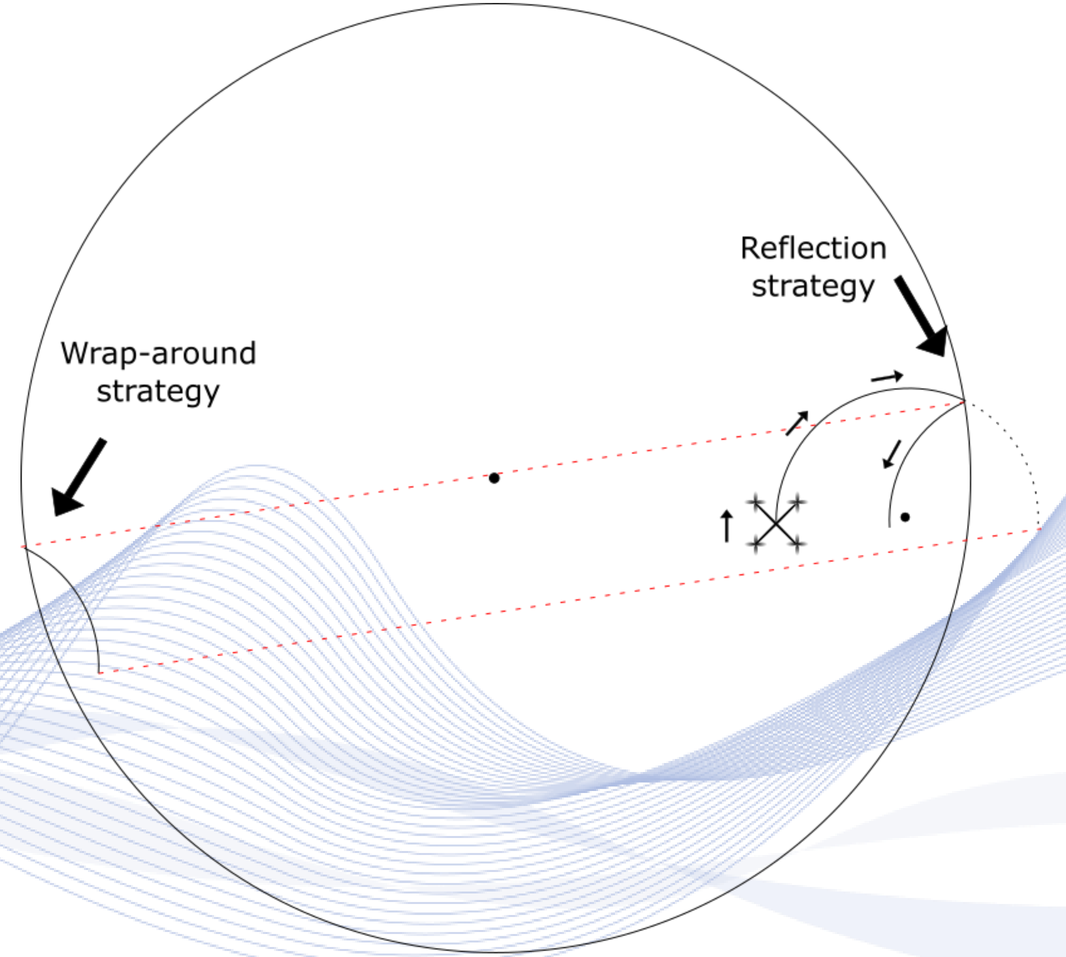
Mobility Models



Smooth Turn
Mobility Model

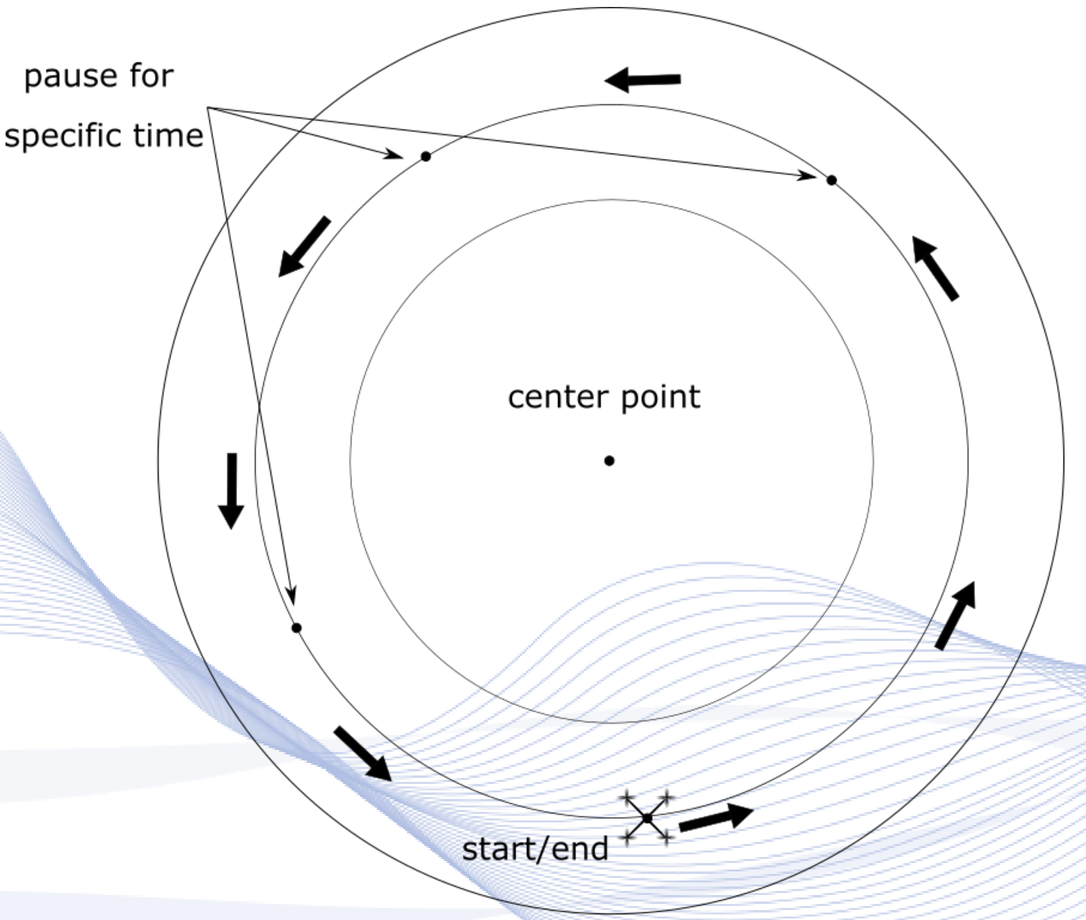


Smooth Turn
Mobility Model

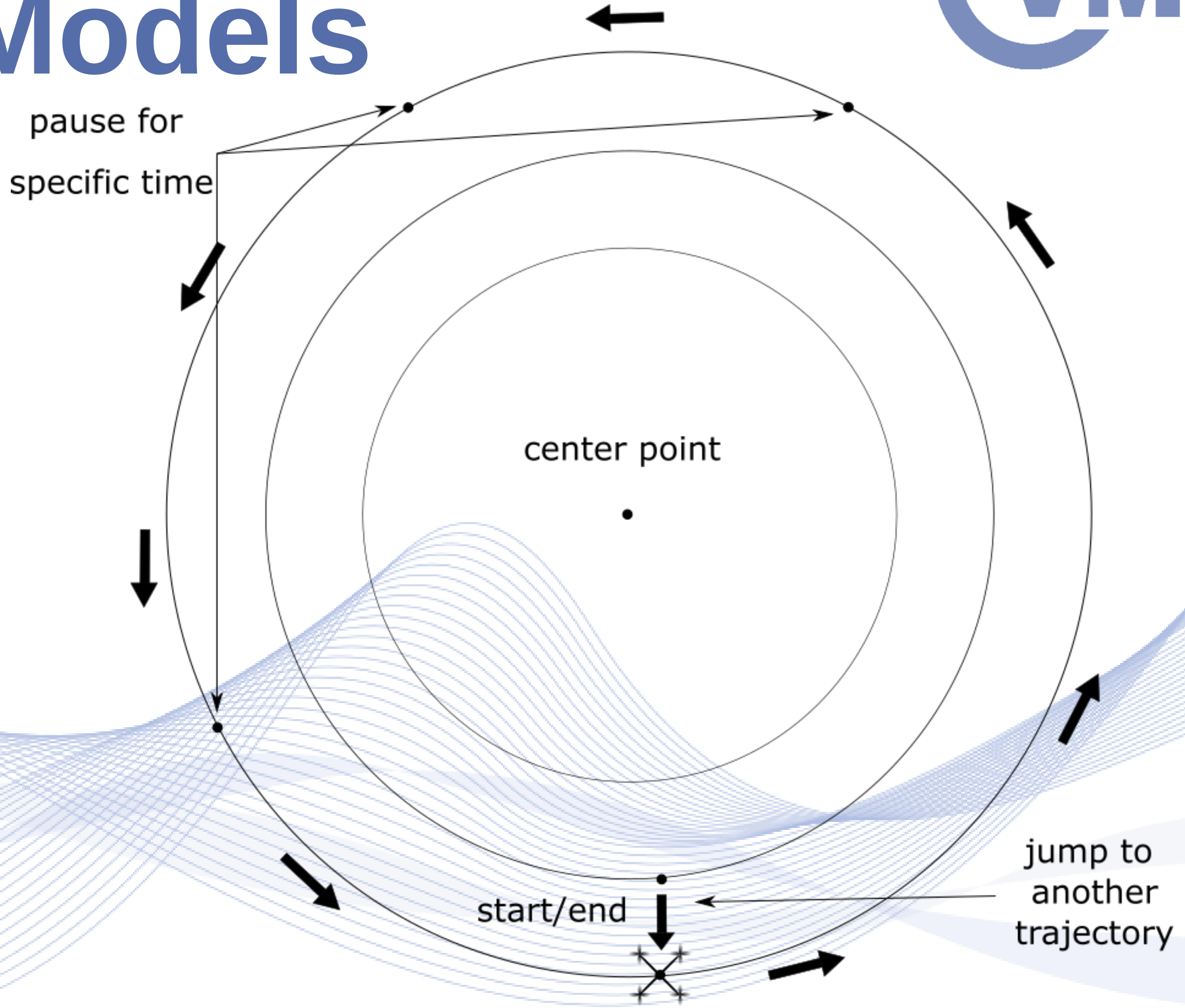


Smooth Turn
Mobility Model

Mobility Models

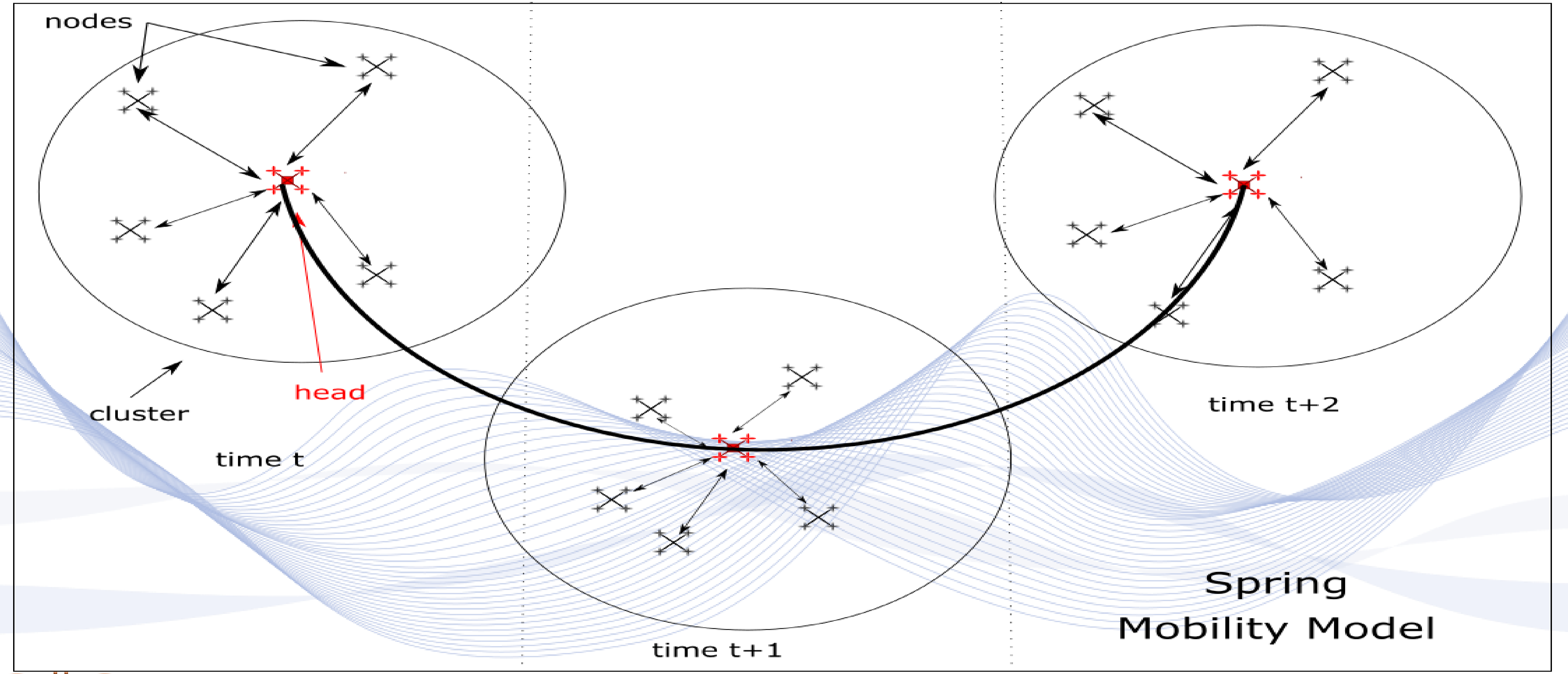


Semi-Random Circular Movement Mobility Model



Semi-Random Circular Movement Mobility Model

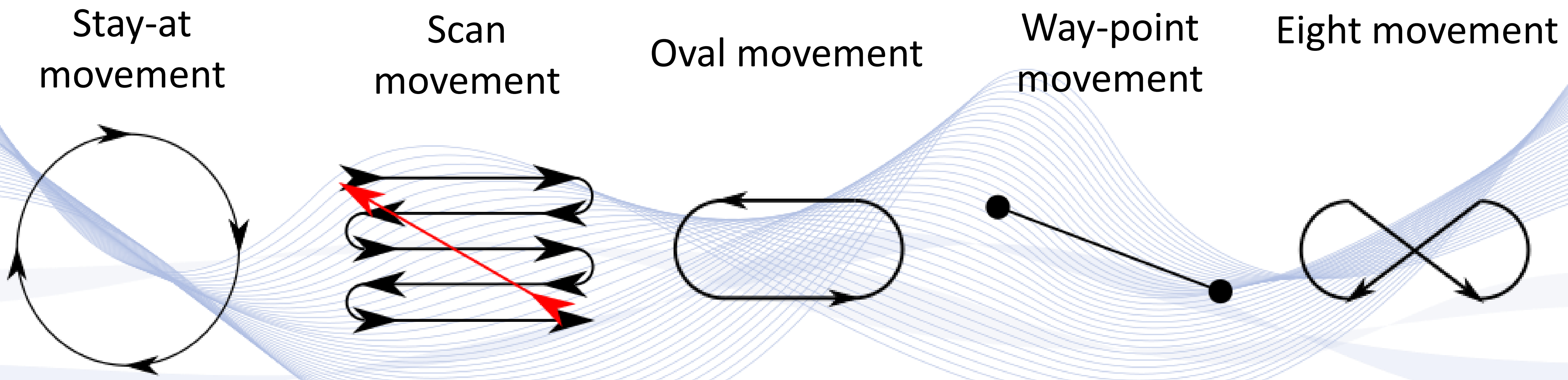
Mobility Models



Mobility Models

Paparazzi Mobility Model (PPRZM)

- Imitates paparazzi's movement and contains five possible UAVs' movements.



FANET Routing Protocols

Artificial Intelligence &
Information Analysis Lab

FANET Routing Protocols

Swarm-Intelligence based

- Inspired from behavior of various insects like firefly, ants, bees, fishes etc, routing protocols of this category provides optimal solutions for UAV routing.
- The algorithms that we commonly meet in this category are **Ant Colony Optimization** and **Bee Colony.** Routing protocols belonging to this category are **APAR** and **BeeAdHoc**

FANET Routing Protocols

- Topology based
  - Proactive Routing
  - Reactive Routing
  - Hybrid Routing

Criteria	Types of Protocols			
	Static	Proactive	Reactive	Hybric Protocols
Main idea	Static Table	Table Driven	On Demand	Proactive and Reactive combination
Complexity	Less	Moderate	Average	Average
Route	Static	Dynamic	Dynamic	Dynamic
Topology Size	Small	Small	Large	Small or Large
Memory Size	Extensive	Extensive	Least Memory Space	Medium Memory Space
Fault Tolerant	Missing	Missing	Missing	Mostly Present
Bandwidth Utilization	Best possible	Least	Best possible	Moderate
Convergence Time	Quicker	Slower	Mostly fast	Medium
Signaling Overhead	Missing	Existing	Existing	Existing
Communication Latency	Less	Less	High	High
Mission Failure Rate	High	Low	Low	Very low
Popularity	Least	Medium	Medium	Best
Operation	Fixed Mission	Dynamic Mission	Dynamic Mission	Dynamic Mission

Civilian Drones: Safety and Security Aspects

Artificial Intelligence &
Information Analysis Lab

Civilian Drones: Safety and Security Aspects

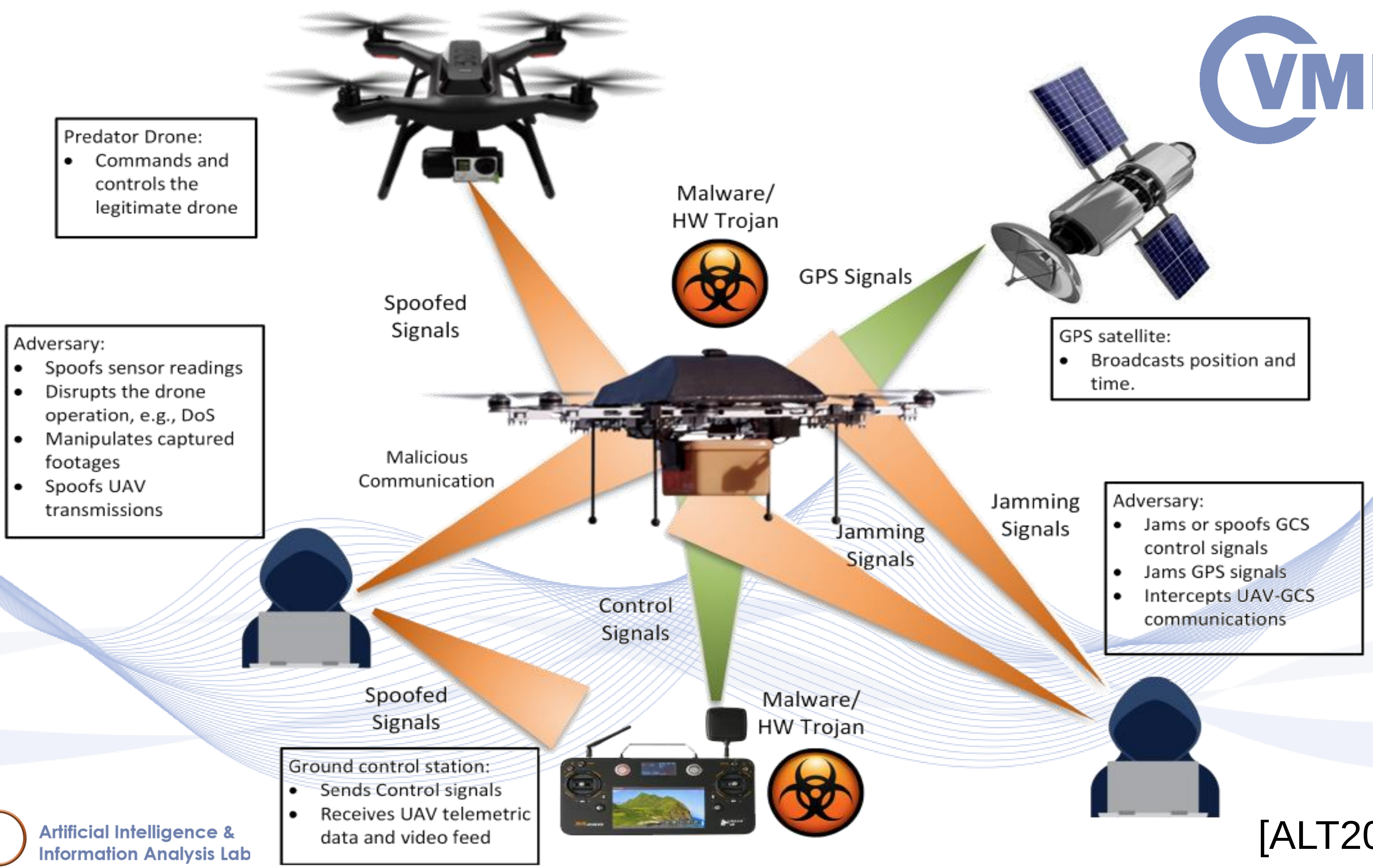
- Cyber-Physical Threats
- Vulnerabilities and Physical Challenges
- Security

Civilian Drones: Safety and Security Aspects

Cyber-Physical Threats

There are three generally categories of Cyber-Physical attacks.

- **Disruption capabilities:** Allows to the attacker to interrupt the normal operation of the system.
- **Revelation capabilities:** Gives the ability to the invader to reveal all the unencrypted information which are sending to the data link.
- **Knowledge capability:** Refers to the ability of the invader to gain access to the onboard flight controller as authorized person.



[ALT2017]

Artificial Intelligence & Information Analysis Lab

Civilian Drones: Safety and Security Aspects

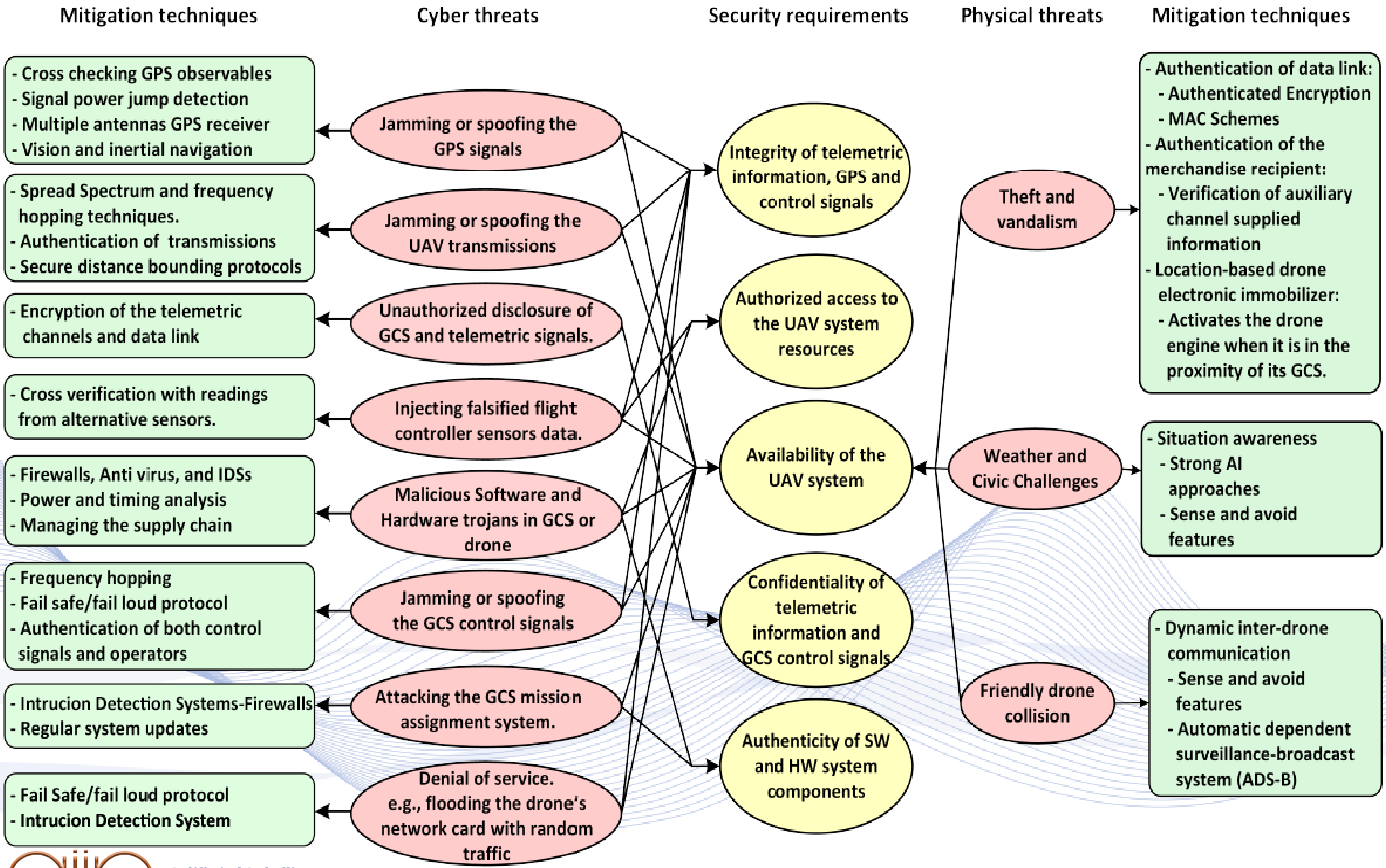
Vulnerabilities and Physical Challenges

- Civic Challenges
- Friendly Drones Collision
- Theft
- Vandalism
- Weather

Civilian Drones: Safety and Security Aspects

Security

- Authorized access
- Information confidentiality
- Information integrity
- Record actions
- System integrity



Artificial Intelligence & Information Analysis Lab

[ALT2017]

Open issues and challenges

Open issues and challenges

- National Regulations
- Routing
- Path Planning
- Quality of Service (QoS)
- Integration with a Global Information Grid (GIG)
- Coordination of UAVs and manned aircrafts
- Standardize FANETs
- UAV mobility and placement

Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

Contact: Prof. I. Pitas
pitas@csd.auth.gr