Supporting degraded mode of operation in swarms/fleets of unmanned (aerial) vehicles: theoretical issues and illustrative scenarios

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Goals and research topics of our research group at LaBRI

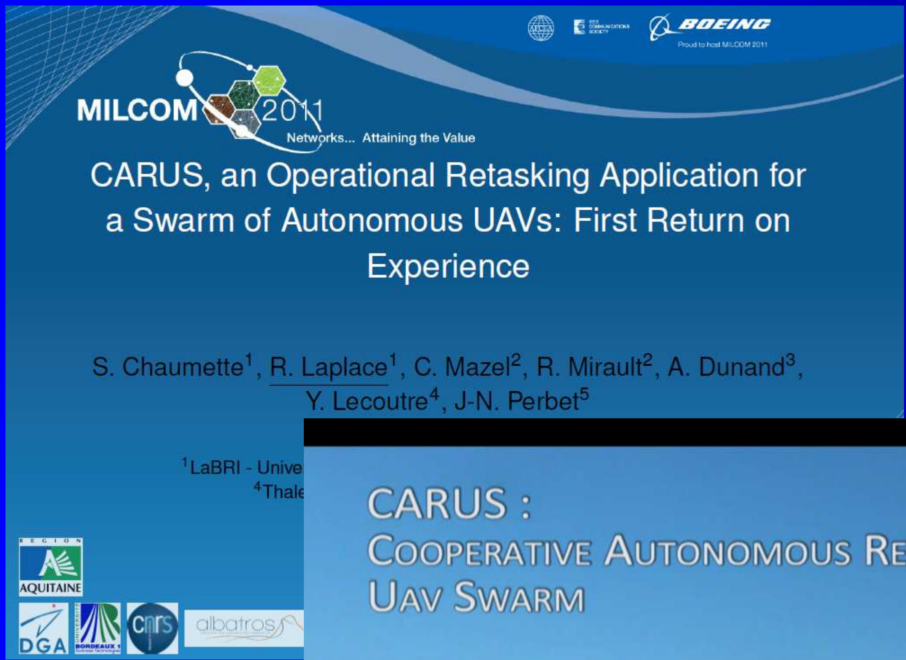
Contribute to the definition and development of supporting middleware, tools and mechanisms formally validated that make it possible to take advantage of the mobile resources of a wireless network; develop scenarios/applications on top of these resources.

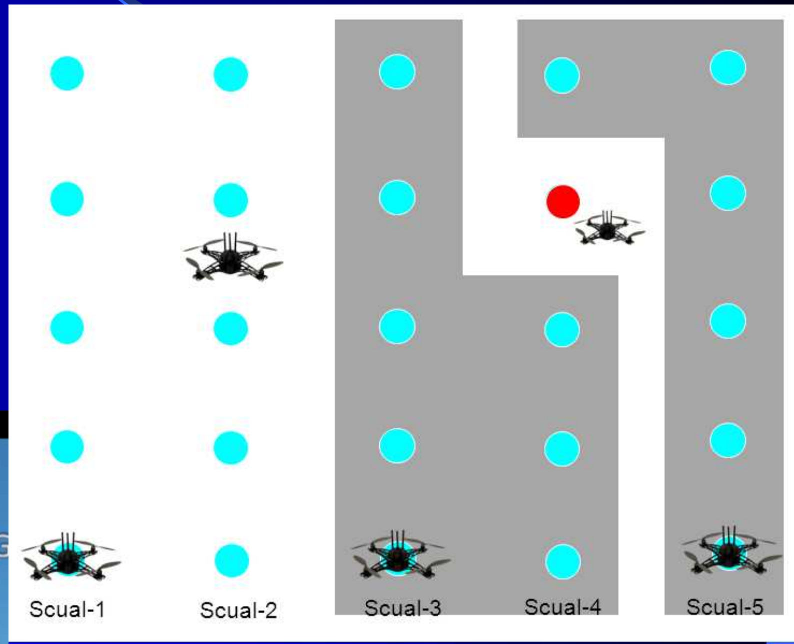
Target systems

Secured fleets/swarms of autonomous communicating mobile terminals

Ref : 0006@2014-nov-04@14-27-CET@1-1-1 ; From-ref: previous talks + new material; Author: Serge Chaumette

Initial project: CARUS → RETEX





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Swarming raises a number of new operationnal issues

- safety and emergency procedures

- ground control stations, operators, regulation
  swarming today is unfeasable (in the real world)
- …

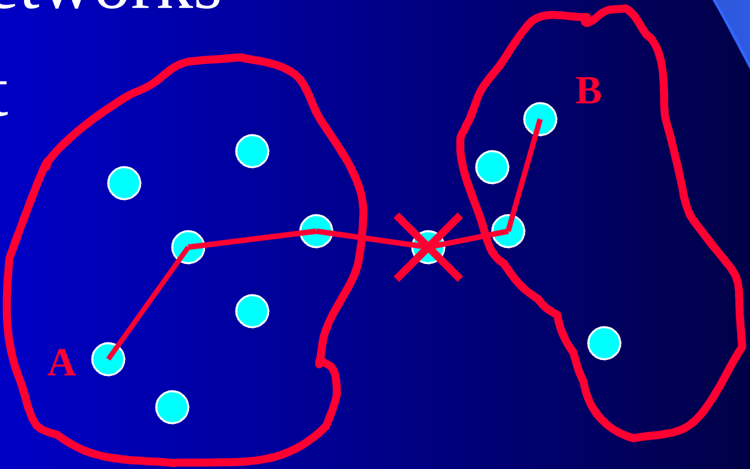
Swarming raises a number of new mission oriented/algorithmic issues

distributed system, local computation based algorithms, construction of a global view of the overall system based on local information, service location, security, unsecure boundaries, ground control stations, data fusion for situation management, etc.

Autonomous systems in the real life

- Example:
  - Network of cars
  - Students on a campus
  - Tactical military networks
  - Crisis management
  - Home networking
  - …

Paper by Dana angluin
(population protocols)



The nature of the network changes

- The nature of applications changes
  group/community based, dynamic, …

- The management/requirements of security changes

Degraded mode (scalability)

- *“classical separation between “nominal operation" and "faults" becomes untenable; system is continuously operating under faults”*

Werner J.A. Dahm, Arizona State University
in his keynote at
AIAA Guidance, Navigation, and Control Conference
19 - 22 August 2013, Boston , Massachusetts

- Among the “faults” are
  - Loss of a UAV
  - Loss of a communication link

→ Think localy

- Neither rely on communication, nore on the stability of your neighbourhood
  - this is most of the time ignored
  - this leads to probabilistic mission sucess

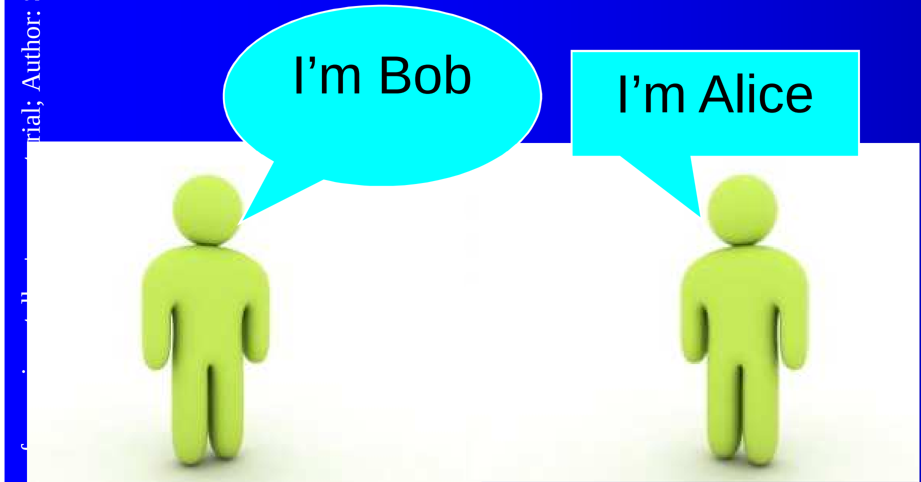
« Always consider other scenarios – ‘’What if ?’’ »

Georges T. Schmidt, Editor-in-chief,
AIAA Journal of Guidance, Control and Dynamics

in his keynote on lessons learned in the Apollo GN &C Program

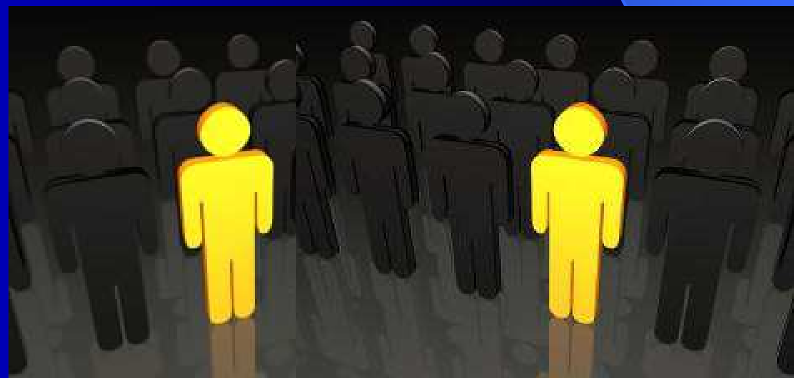
AIAA Joint Conferences
19 - 22 August 2013, Boston , Massachusetts

Paradigm shift for security



Share keys, authenticate

Recognize
- individually
- group/topic based



Impact on security

- The objectives must be lowered because of unsecure boudaries
- Examples:
  - entity based keyes → group/topic based keyes
  - authenticate → recognize
- But … this is real life (as in human crowds) ☺

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Paradigm shift for applications

How many people are there ?

Are there many people ?
(or approximate number, lower bound)

Impact on applications

- The objectives must be lowered because of high instability
- Examples:
  - counting → lower bound
  - covering tree→ covering forest
- But .. this is real life (as in human crowds) ☺

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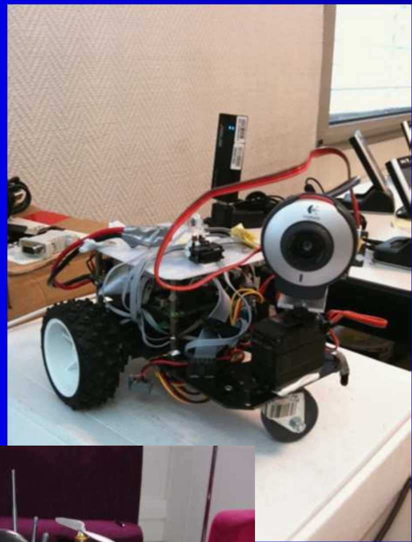
Our approach

- Our approach
  - We work above the air frame level (mission oriented)
  - Algorithms always assume degraded mode of operation
  - We garantee the missions are achieved
  - We use simulation and formal validation
  - We run real experiments

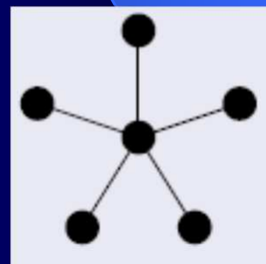
- Impact of the « think localy » precept
  - local computation based algorithms
  - construction of a (by nature partial/false) global view of the overall system based on local information
  - underlying model based on graph relabeling (or similar approach)

Physical systems/fleets



(image courtesy the
Smart Surface project)

Underlying dynamic graphs

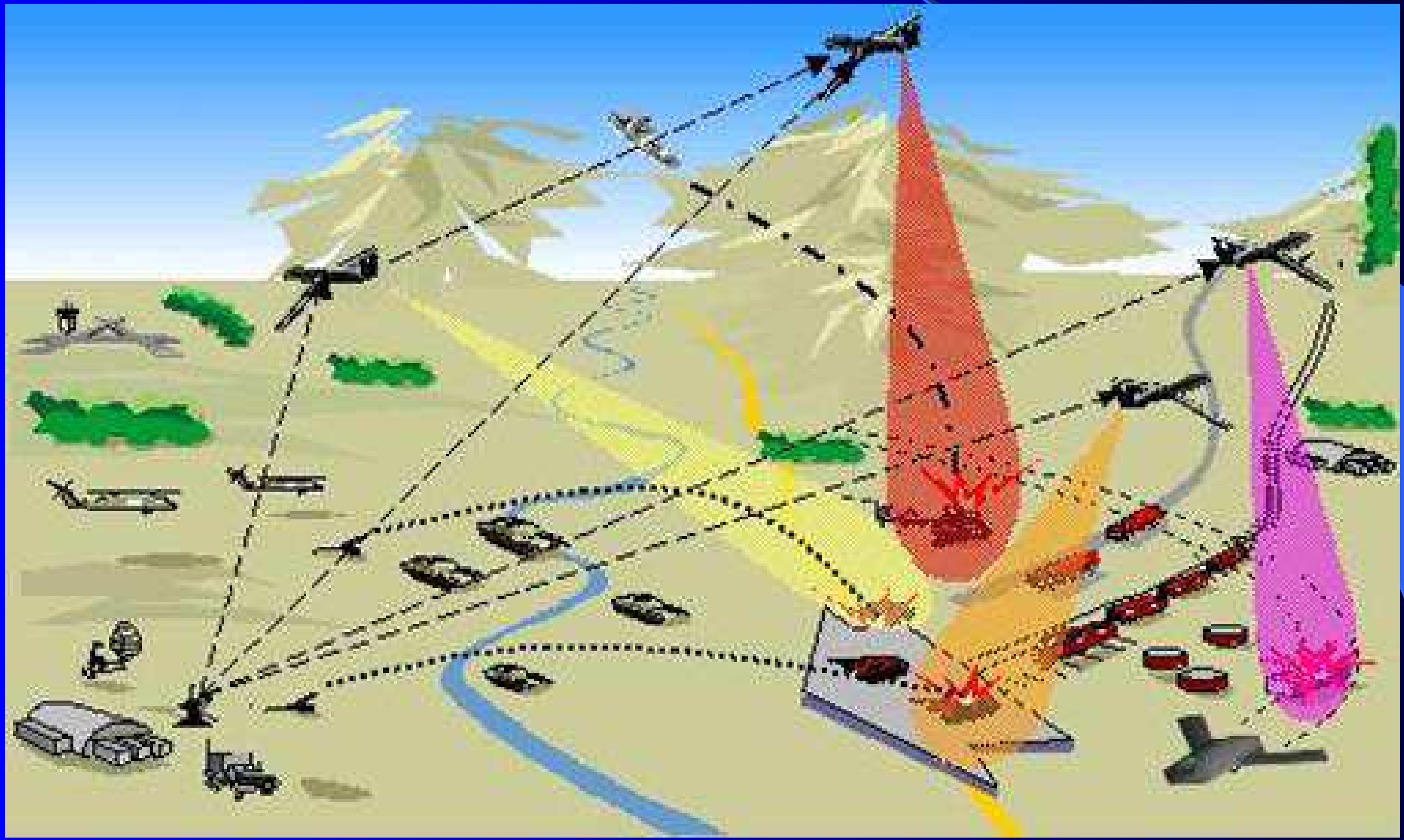


The swarms that we target

- Airborne systems
- Ground systems
- Surface systems
- Underwater systems
- Sensor systems/embedded PDAs

- (micro level: MEMS, smart dust, etc.)

Heterogeneous/multi swarms

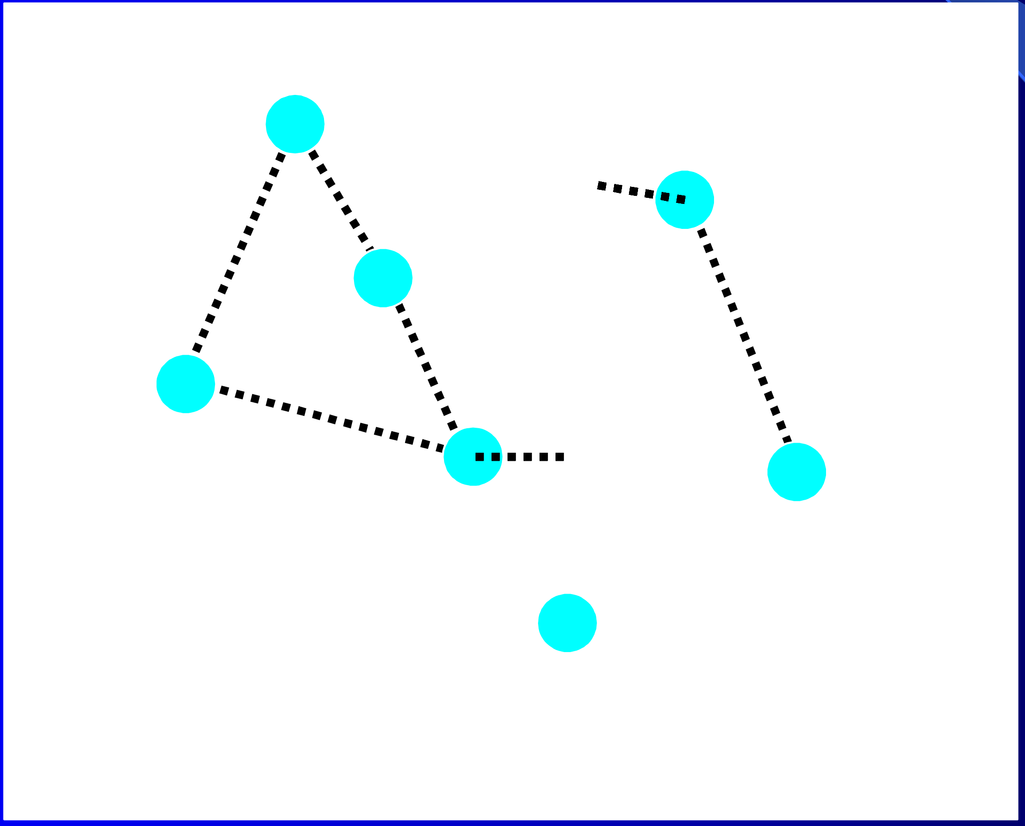


Source : http://www.cds.caltech.edu/~murray/projects/darpa01-mica/

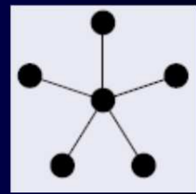
Multi-swarms issues

- Inter swarm relationships
  - What can we expect in terms of communication?
- Different swarms, different models
  - mobility models
  - underlying graphs
  - how to combine them ?
  - How do they impact each other ?
- What are the guarantees we can give about missions?

Our approach: taking advantage of the dynamic of the underlying graph

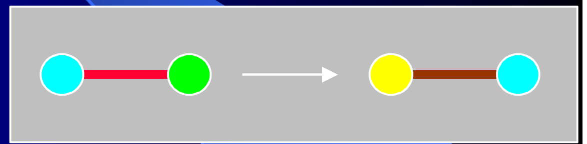


Our approach: local computations as relabelings over graphs



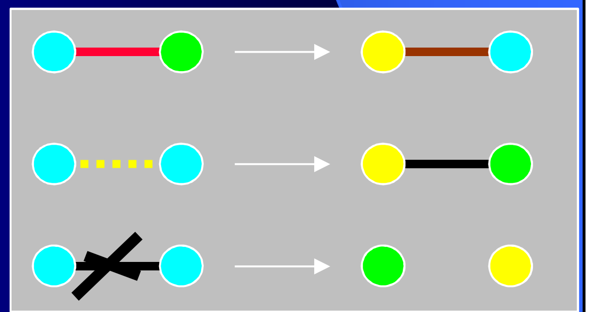
→ static graphs

→see [Litovsky, Metivier, Sopena 1999]



→ extension to dynamic graphs

→see [Casteigts, Chaumette, Ferreira 2009]



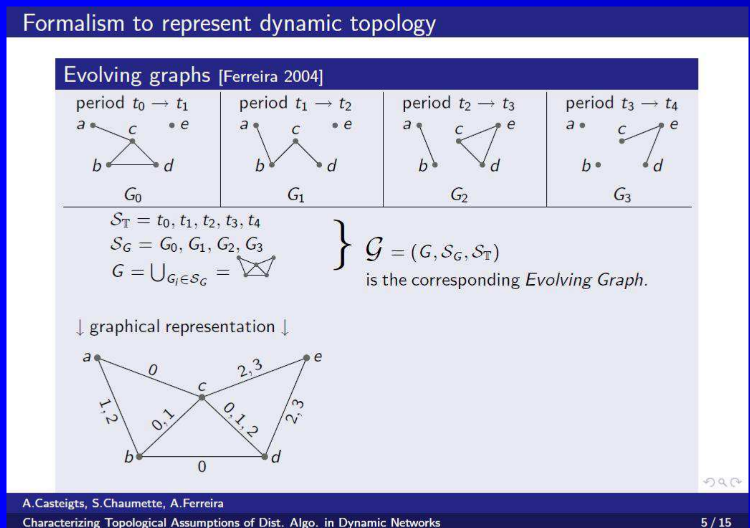
Selected references

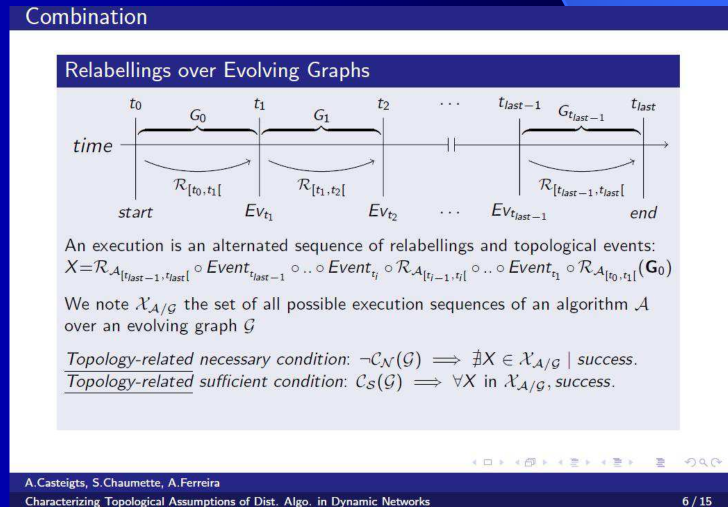
[I. Litovsky, Y. Metivier, and E. Sopena]

Graph relabelling systems and distributed algorithms. In World Scientic Publishing, editor, Handbook of graph grammars and computing by graph transformation, volume III, Eds.

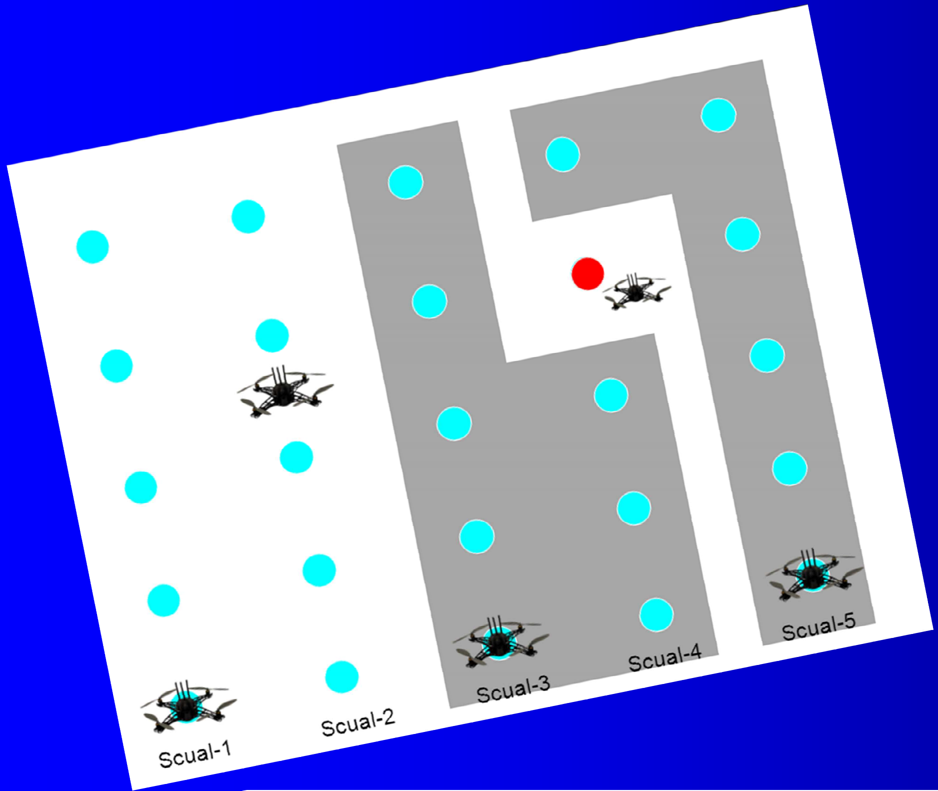
[Arnaud Casteigts, Serge Chaumette, Afonso Ferreira]

Characterizing Topological Assumptions of Distributed Algorithms in Dynamic Networks. SIROCCO 2009: 126-140





Scenario 1: **CARUS**



Cooperative
Autonomous
Reconfigurable
UAV Swarm

Investigate: swarming, construction of a global view from local views, retasking

SCUAL

Swarm of Communicating UAVs at LaBRI

Swarm of Communicating UAVs at LaBRI

Swarm of 5 autonomous UAVs deployed at LaBRI thanks to a partnership with the Fly-n-Sense company.

Fly-n-Sense Products: Scancopter 4X

- rotary wings (stationary flight)
- MTOW: 2 kg
- payload: up to 500g
- wing span: 80cm
- manual max speed: 15m/s
- automatic max speed: 5m/s
- endurance: up to 20min

Fly-n-Sense LaBRI

CARUS

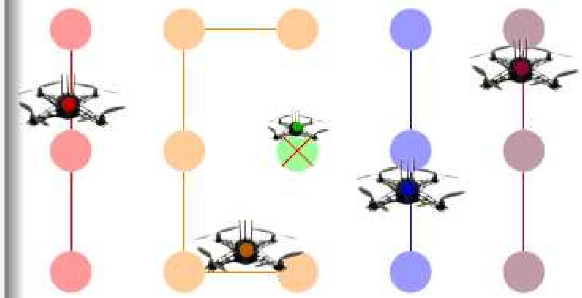
Cooperative Autonomous Reconfigurable UAV Swarm

MILCOM 2011 Networks... Attaining the Value

CARUS

Project of the LaBRI, conducted in the framework of the GIS Albatros, made available to *Aetos*, the UAV cluster of the Région Aquitaine.

- 5 UAVs sharing the visit of a 15 points grid.
- When an *incident* appears on a point, a UAV detects it and lands.
- The rest of the fleet shares the set of points that are no longer assigned.
- All decisions are taken in the air without any ground intervention thanks to broadcast communications.



RÉGION AQUITAINE

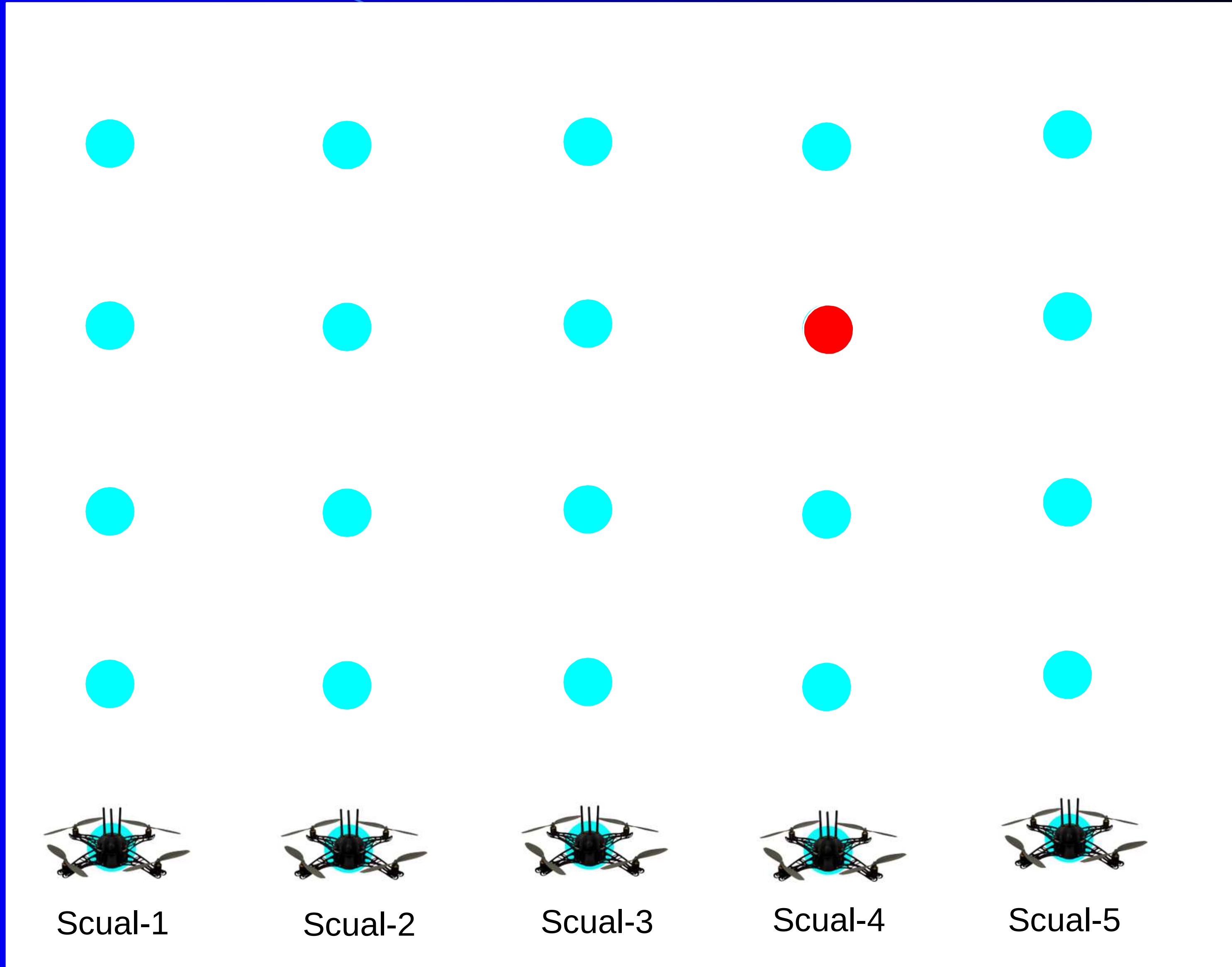
AETOS

DGA · Université Bordeaux 1 · cnrs · albatros · Bordeaux Technowest · THALES · Fly-n-Sense UAV Systems · LaBRI

CARUS : Cooperative Autonomous Reconfigurable UAS Swarm

A project of LaBRI conducted in the gramework of the GIS Albatros, made available to Aetos, the UAV cluster of Région Aquitaine

LaBRI



CARUS : Cooperative Autonomous Reconfigurable UAS Swarm

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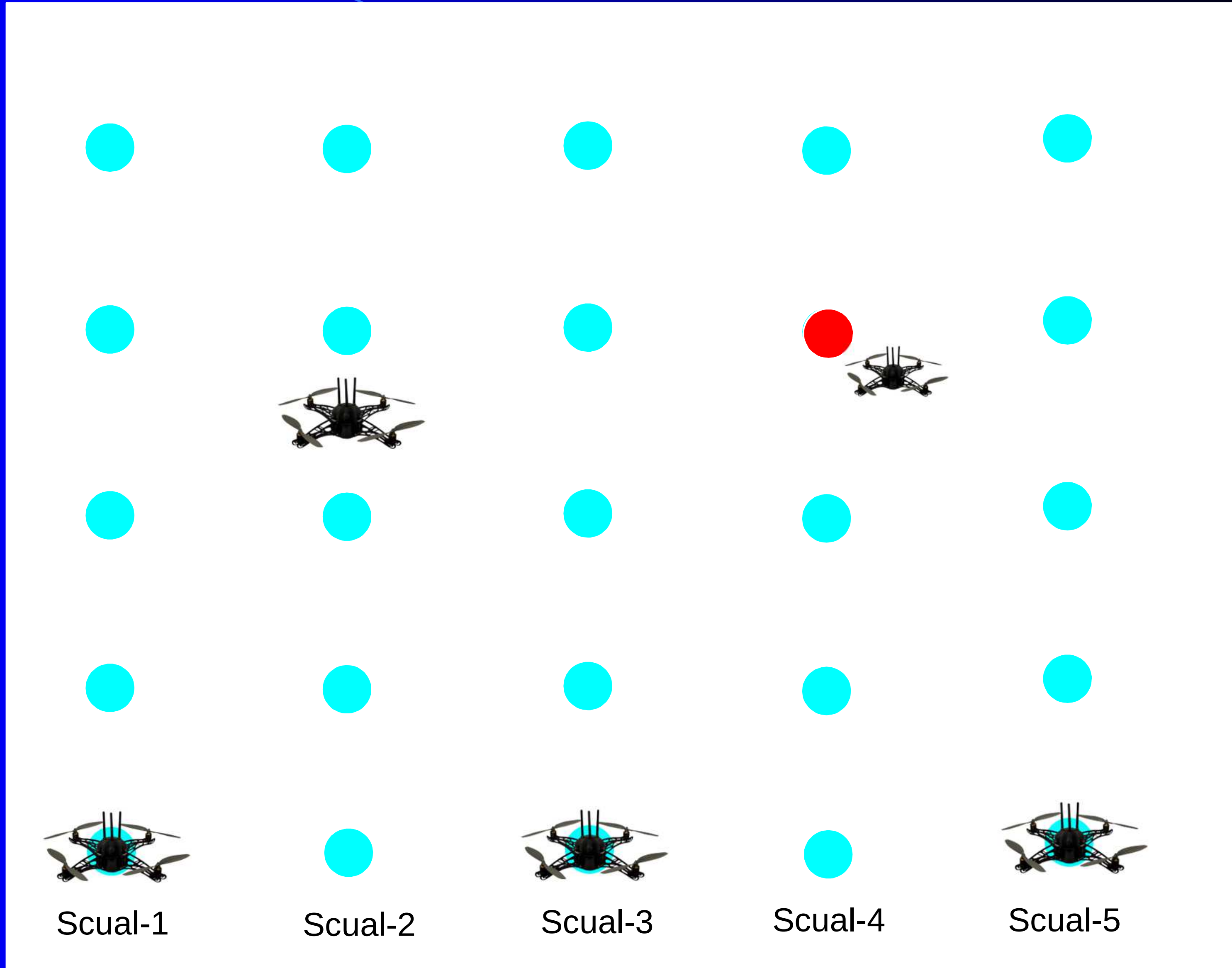

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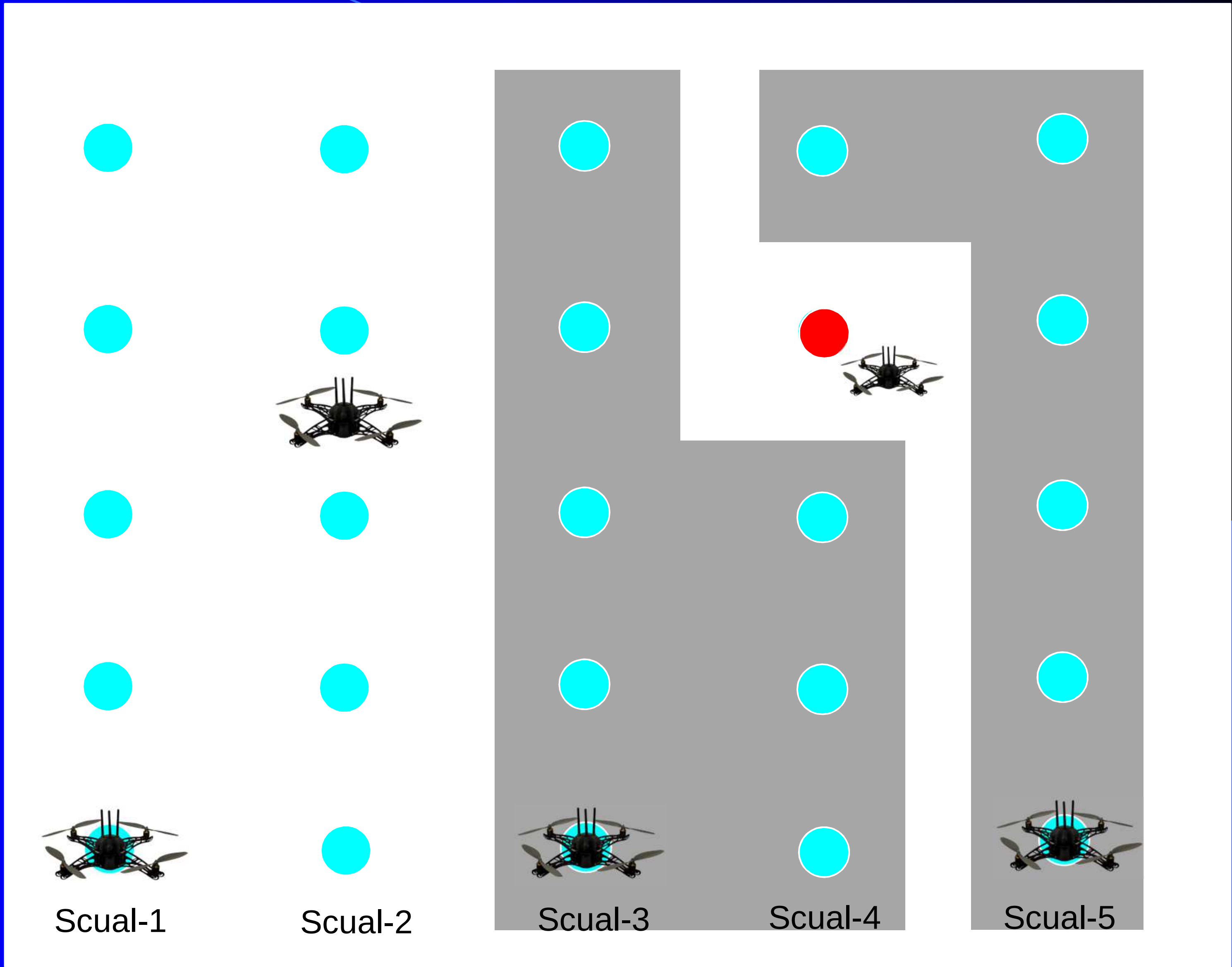


CARUS :
COOPERATIVE AUTONOMOUS RECONFIGURABLE
UAV SWARM
DEMONSTRATION EN VOL
ZONE D'ESSAIS DRONE
DU CAMP DE SOUGE

Scenario 2 : ASIMUT

ICET 2 project

Aid to SItuation Management based on MUltimodal, MUltiUAVs, MUltilevel acquisition Techniques

Fly-n-Sense · uni.lu UNIVERSITÉ DU LUXEMBOURG · Fraunhofer · LaBRI · THALES

Coordination: THALES Systèmes Aéroportés SAS.
Name : Gilles Guerrini
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Technical and scientific lead: LaBRI, Université de Bordeaux
Name: Serge Chaumette
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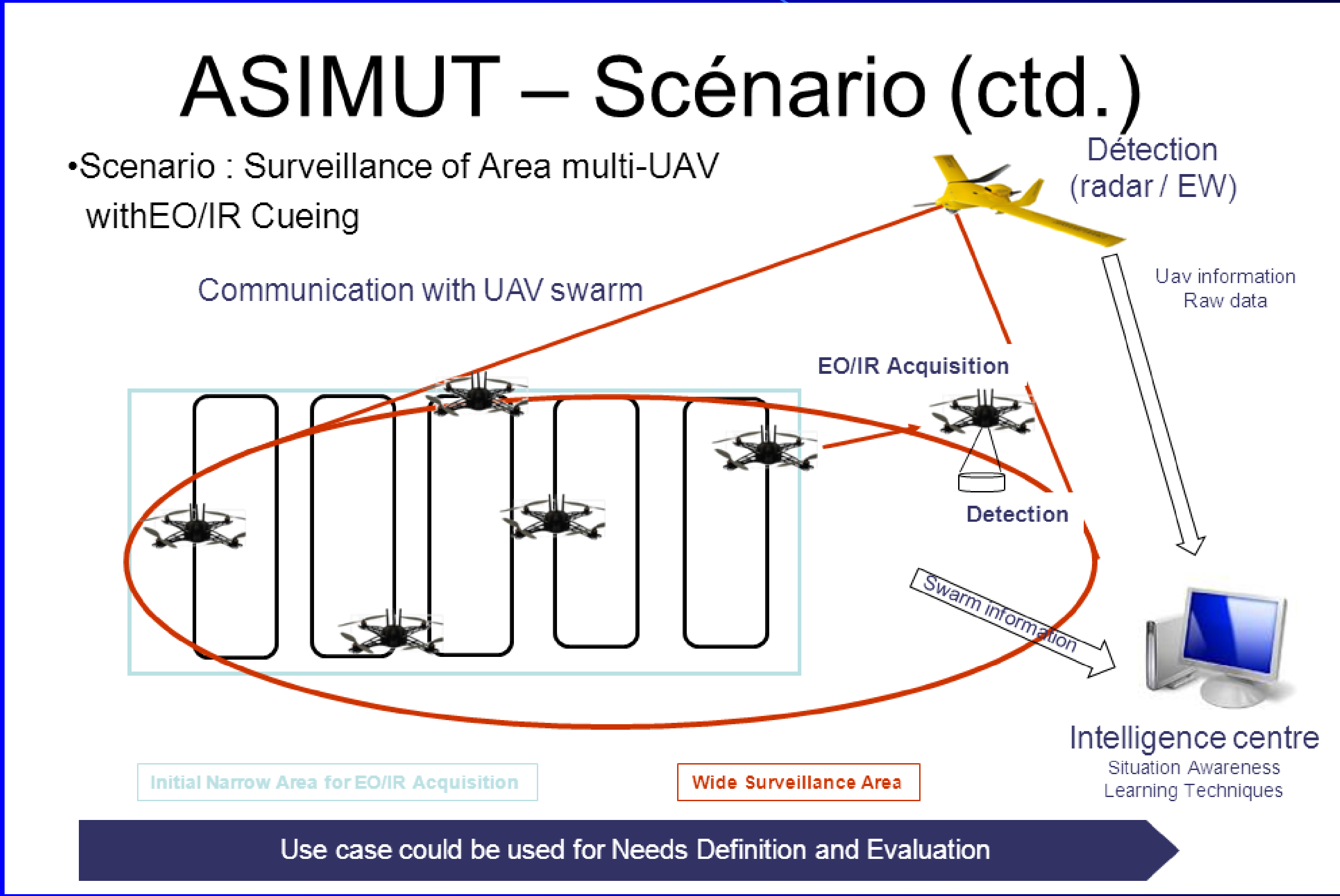
Investigate: multi-level swarming and load sharing

ICET 2 Programme

- Second Joint Investment Programme on Innovative Concepts and Emerging Technologies (ICET 2)
- European Defense Agency
  www.eda.europa.eu
- The second Joint Investment Programme on Innovative Concepts and Emerging Technologies (ICET 2) aims at fostering the development of new, innovative technologies that have great potential for future military development.

ASIMUT – Scénario



Asimut - Scenario

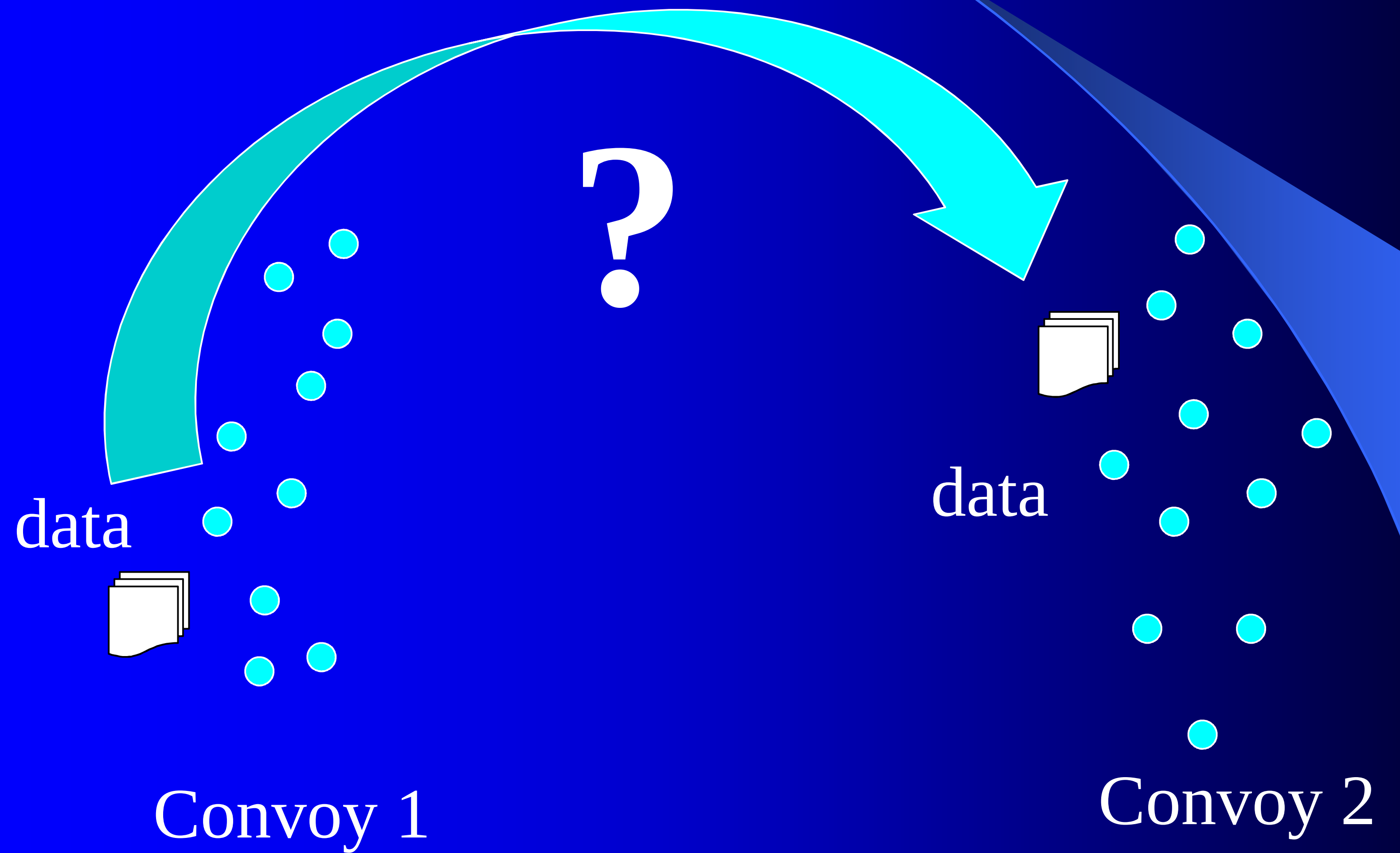
– A high altitude UAV is equipped with detection means giving a broad view of the field. Following the acquisition of a measure indicating the occurrence of an event it 'directs’ a swarm of medium or low altitude UAVs to a specific geographical area in order to refine the measures or to achieve additional acquisitions with other kinds of sensors (optical, ESM, …).

– The system can partially rely on multimodal acquisition which requires to merge the collected pieces of information (a UAV can have multiple sensors and the sensors of the UAVs of the swarm may be different), to support situation management.

– The swarm (or the set of swarms), in total autonomy from the ground and even though experimenting external disturbances (loss of messages for instance), must (i) reconfigure itself according to the new area to be monitored and (ii) reorganize itself based on the embedded sensors, so as to best achieve the measurements (and resulting identifications), which also depends on the measurements already performed (feedback loop: a measurement made by a UAV in the swarm can lead to the decision to reroute another drone with another type of sensor to explore a specific site). Information are partly processed locally and / or returned to the Fulmar type UAV or to a ground station.

– The implementation of this system requires proper management of communications and data exchanges (interoperability), modeling and formal validation of the procedures and algorithms that are implemented.

Scenario 3: **information sharing between loosely coupled convoys**



- funded by the French Army (DGA)
  - one postdoc hired at Bordeaux and located at USMA West Point
- funded by ONRG under grant / award N62909 - 13 - 1 - N193 and ARL
  - one postdoc in Bordeaux (open position !)

Investigate: communication between loosely coupled swams

Issues and solutions

- Cannot rely on opportunistic approach

  this could work for VANets for instance but not in our context

  →A data mule can be used

- Assumptions found in the litterature
  - Asumption 1: There is a single authority in play
  - Asumption 2: The mules are stable nodes
  - Asumption 3: RV can be planned in space and time

Our goal

We wish to propose a system in which mules can belong to different authorities, we have no expectation about their stability, and there is no scheduled rendezvous between them.

When a piece of information has to be delivered to a remote convoy, it is given to a mule which carries it to a predefined (delivery) point.

Two configurations are then possible:

- ground relay
- mule-mule RDV ⇐

The weak rendezvous approach

- The usual rendezvous is replaced by a waiting time at the rendezvous point (we call it *weak rendezvous*) to wait for the possible arrival of the other mule.
- This waiting time is computed localy by the mule based on the global view of the system that it has been able to build.

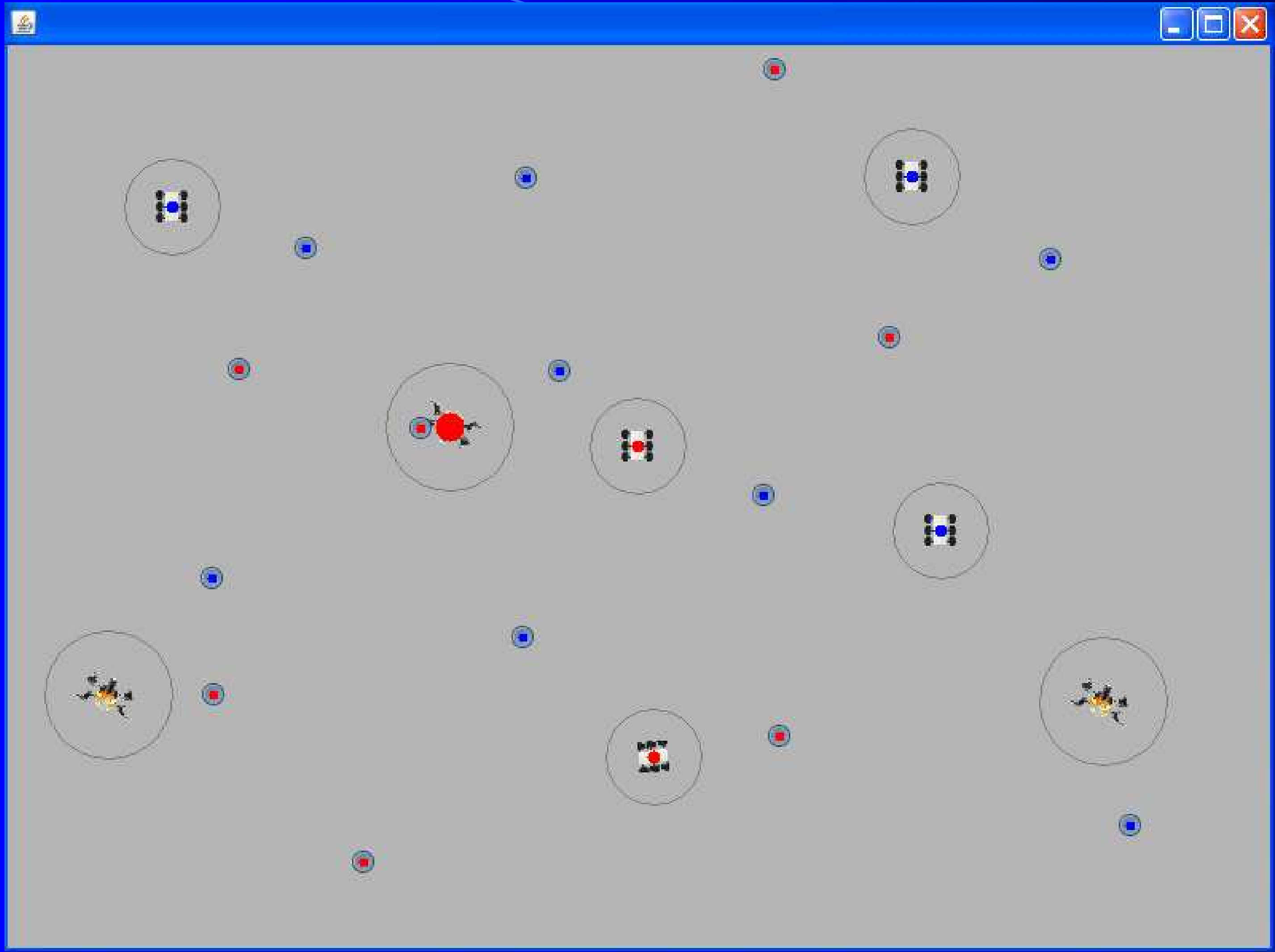
Scenario 4:
Current work on a set of collaborative heterogeneous swarms

- Scenario A: **garbage collection in a park**
  funded by the French Army (DGA) and Région Aquitaine

- Scenario B: **garbage/mines search and destroy with UAVs, UGVs, UUVs**
  funded by the French Army (DGA), Région Aquitaine and Thales

Scenario 4.A: ParC-S2

Investigate: service discovery/location and GCS for swarms



- Blue garbage
- Red garbage

- Blue robot
- Red Robot

- UAV

The JBotSim Library (Arnaud Casteigts)

http://jbotsim.sourceforge.net/

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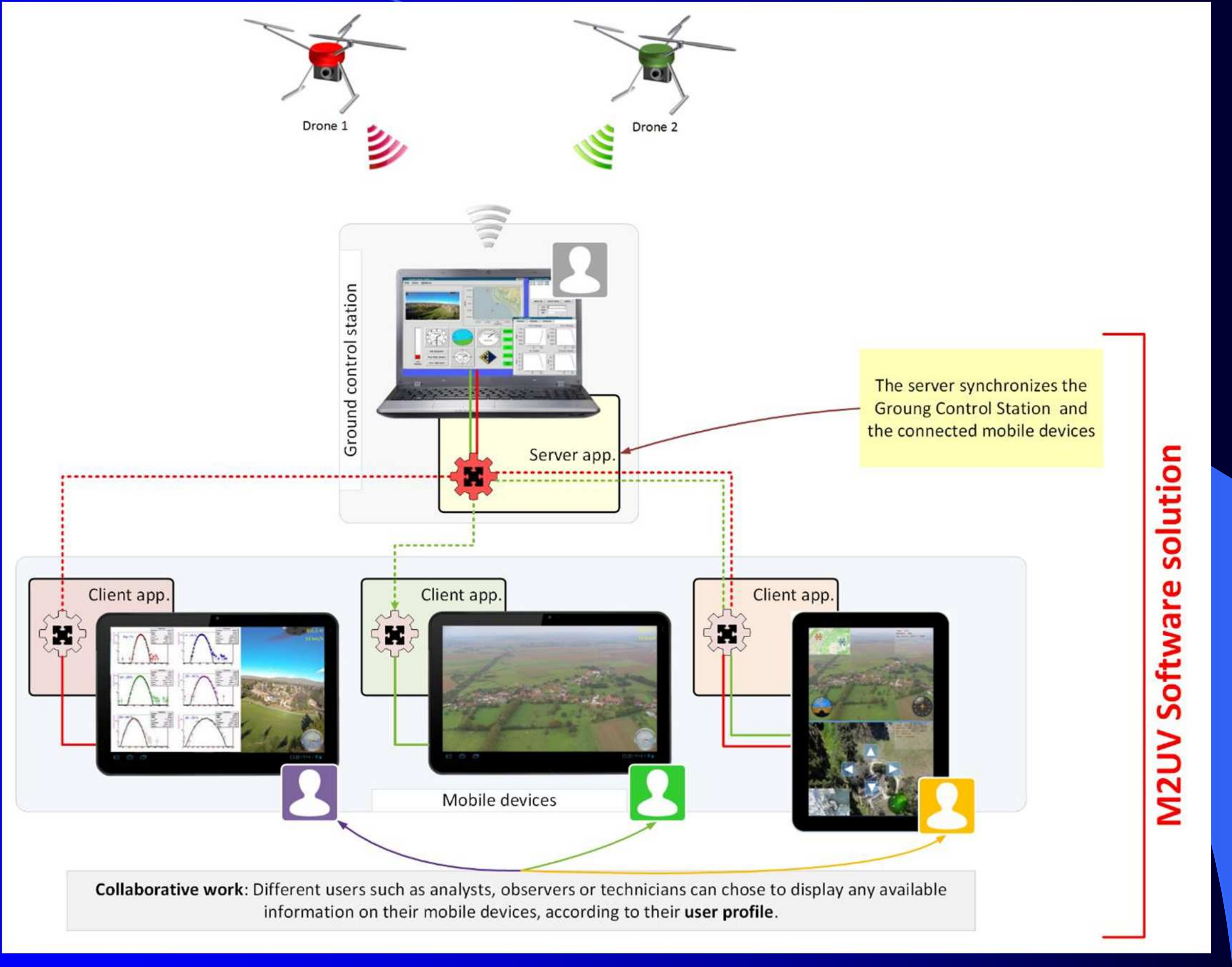

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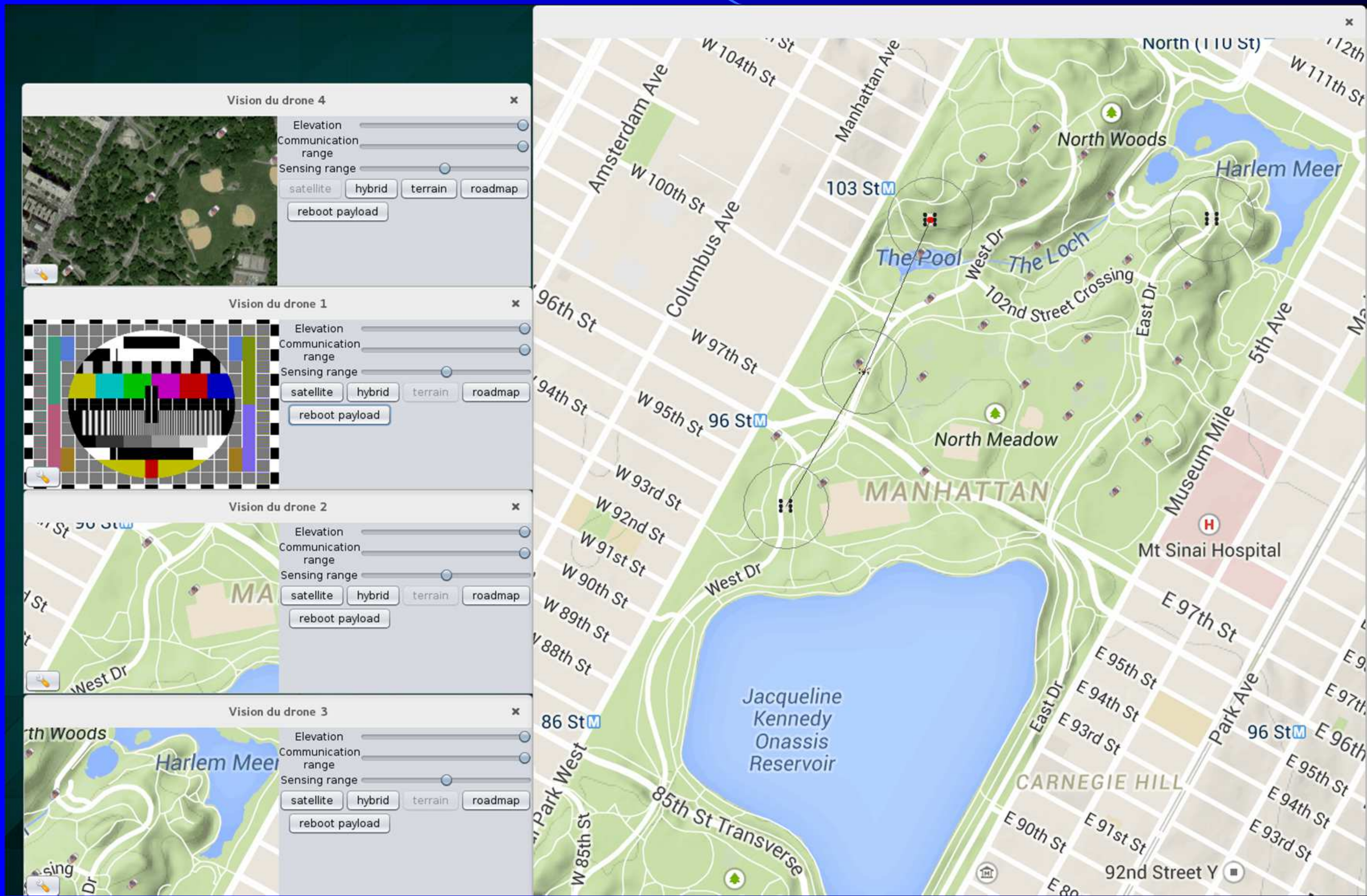
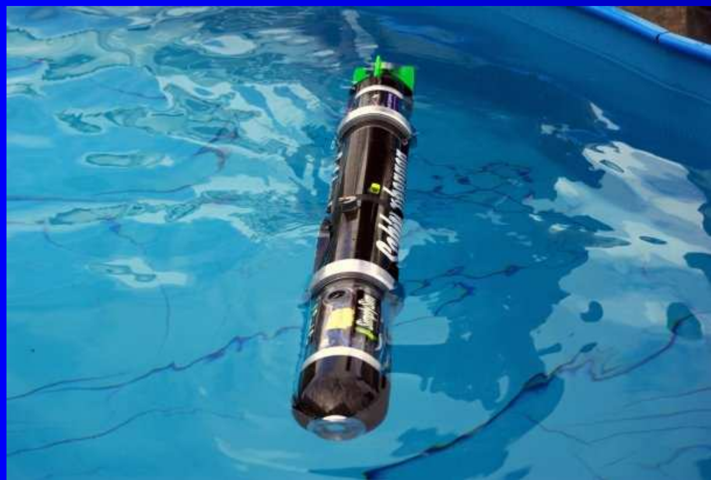


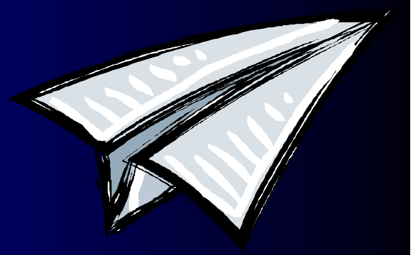
Conclusion



- We are facing extreme conditions and we must still guarantee
  - Succes of missions
  - Safety of the persons,
    safety of the vehicles

and this is enforced by stric regulations

Major directions that should be further explored



- Hardware and operation
  - Localization, sense and avoid
  - Management by ground operator(s) + regulation (which we can impact)
- Application level
  - Authentication, id. management
  - (local) computation under mobility and communication constraints

Selected references

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