

# VISUAL WIRELESS SENSOR NETWORKS FOR MISSION-CRITICAL SURVEILLANCE APPLICATIONS

CRAN LABORATORY  
MARCH 8TH, 2012  
NANCY, FRANCE

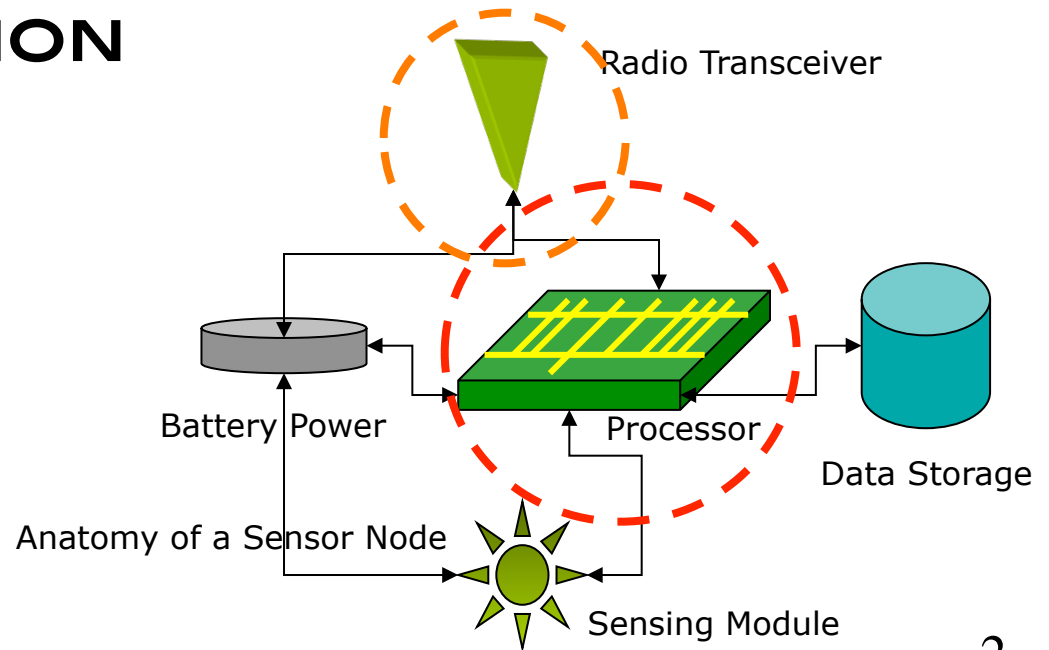
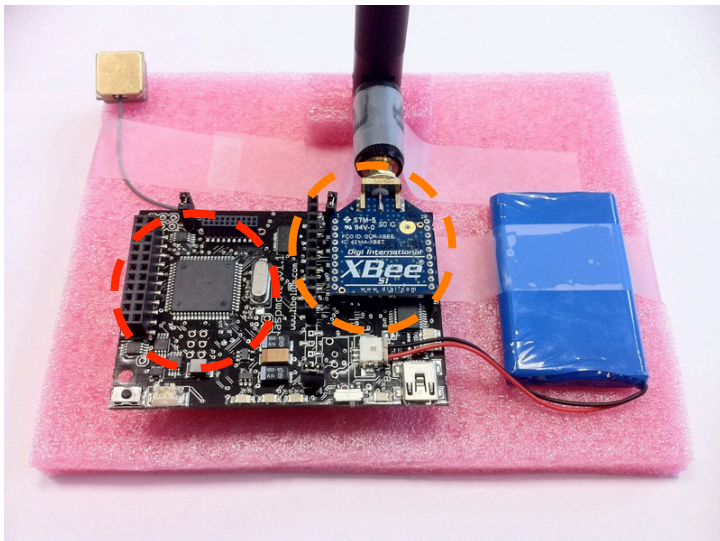


PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)  
UNIVERSITÉ DE PAU, FRANCE



# WIRELESS AUTONOMOUS SENSORS

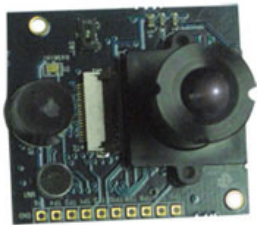
- ❑ IN GENERAL: LOW COST, LOW POWER (THE BATTERY MAY NOT BE REPLACEABLE), SMALL SIZE, PRONE TO FAILURE, POSSIBLY DISPOSABLE
- ❑ ROLE: SENSING, DATA PROCESSING, COMMUNICATION



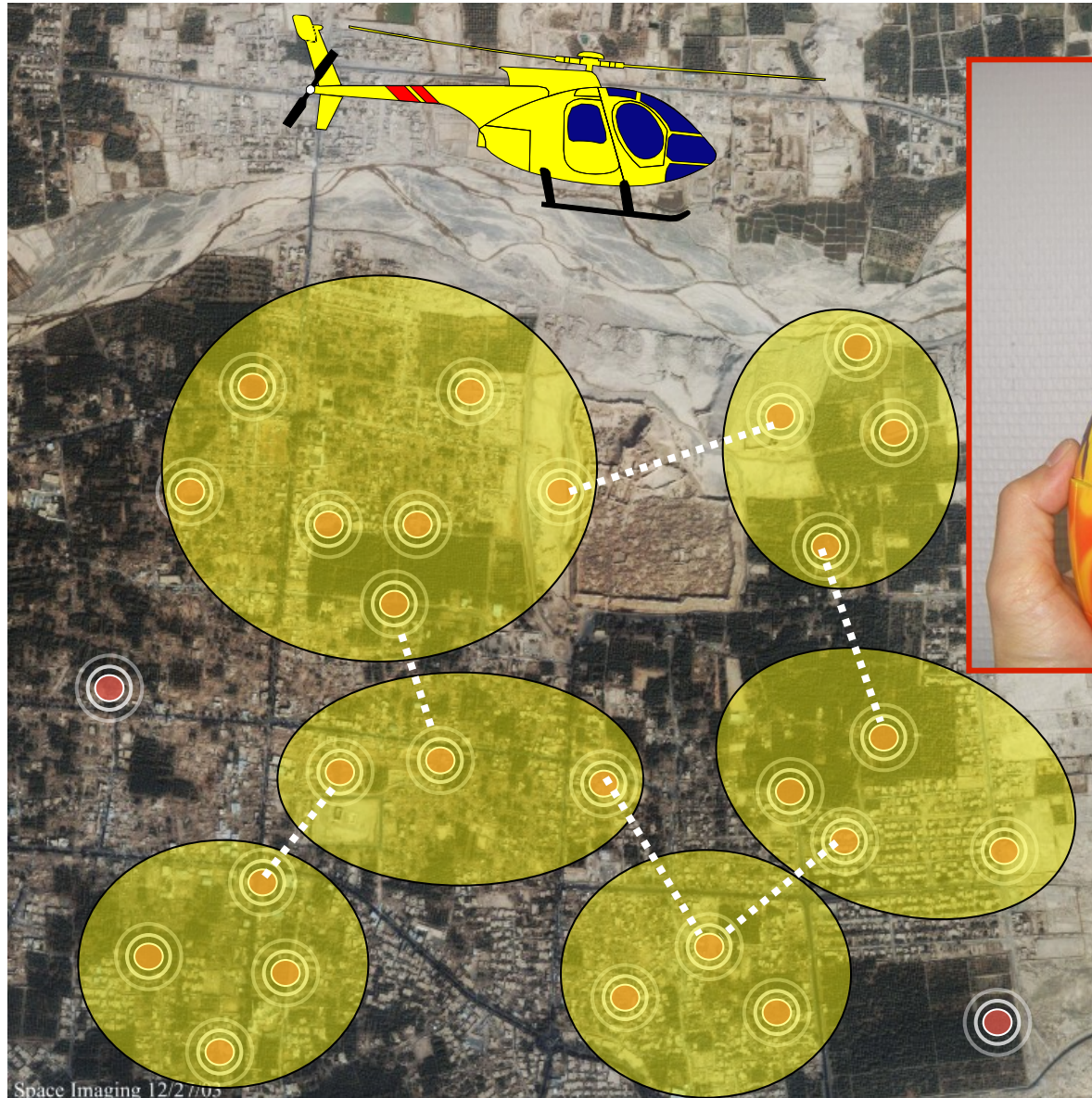
# SEARCH&RESCUE, SECURITY



Imote2



Multimedia board



Space Imaging 12/2/03



# DON'T MISS IMPORTANT EVENTS!



WHOLE  
UNDERSTANDING  
OF THE SCENE IS  
WRONG!!!

WHAT IS CAPTURED



# HOW TO MEET SURVEILLANCE APP'S CRITICALITY

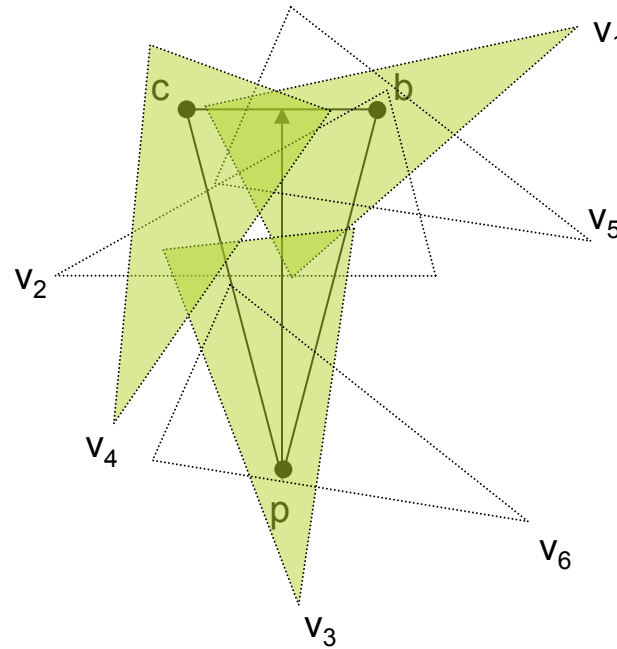
- ❑ CAPTURE SPEED CAN BE A « QUALITY » PARAMETER
- ❑ CAPTURE SPEED FOR NODE V SHOULD DEPEND ON THE APP'S CRITICALITY AND ON THE LEVEL OF REDUNDANCY FOR NODE V
- ❑ V'S CAPTURE SPEED CAN INCREASE WHEN AS V HAS MORE NODES COVERING ITS OWN FOV - COVER SET

# NODE'S COVER SET

$\text{Co}(V) = \{$   
 $\{V\},$   
 $\{V_1, V_3, V_4\},$   
 $\{V_2, V_3, V_4\},$   
 $\{V_3, V_4, V_5\},$   
 $\{V_1, V_4, V_6\},$   
 $\{V_2, V_4, V_6\},$   
 $\{V_4, V_5, V_6\}$   
 $\}$



$|\text{Co}(V)| = 7$



# CRITICALITY MODEL (1)

- LINK THE CAPTURE RATE TO THE SIZE OF THE COVER SET

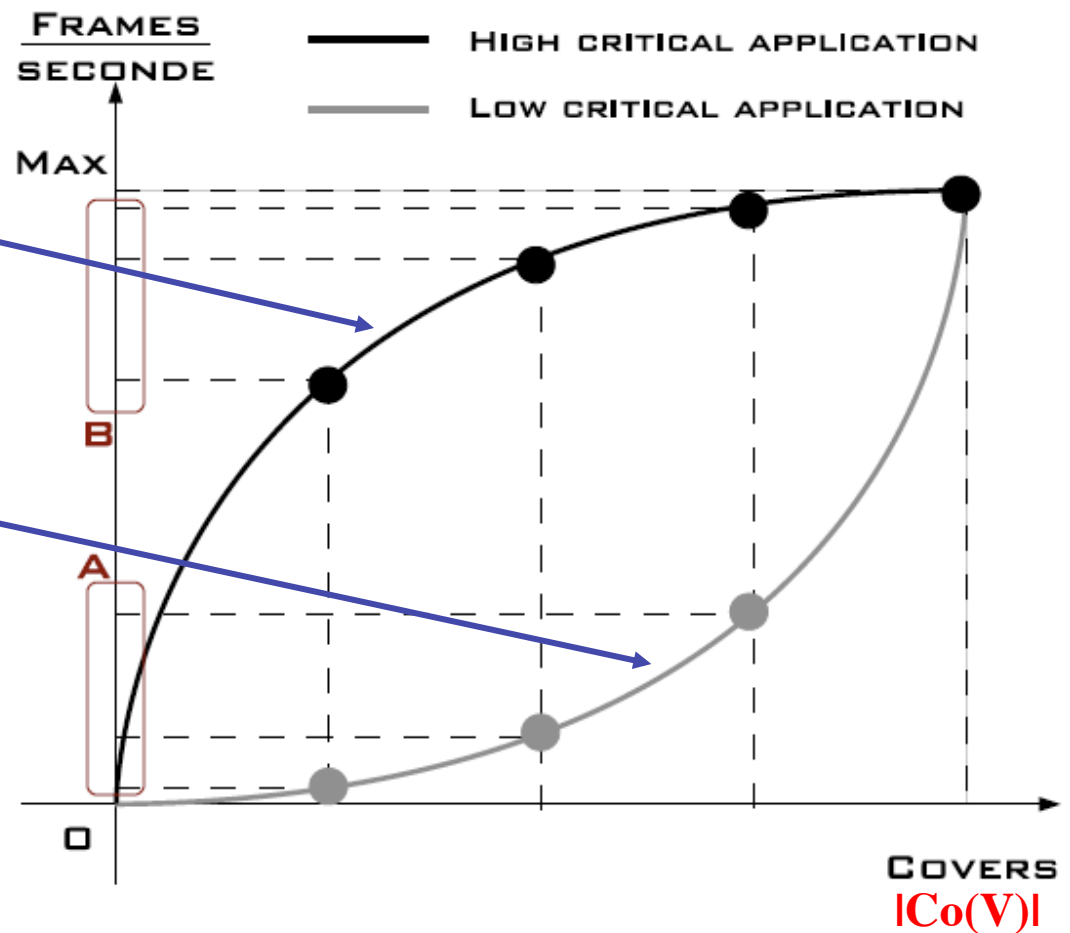
- HIGH CRITICALITY

- CONVEX SHAPE
- MOST PROJECTIONS OF X ARE CLOSE TO THE MAX CAPTURE SPEED

- LOW CRITICALITY

- CONCAVE SHAPE
- MOST PROJECTIONS OF X ARE CLOSE TO THE MIN CAPTURE SPEED

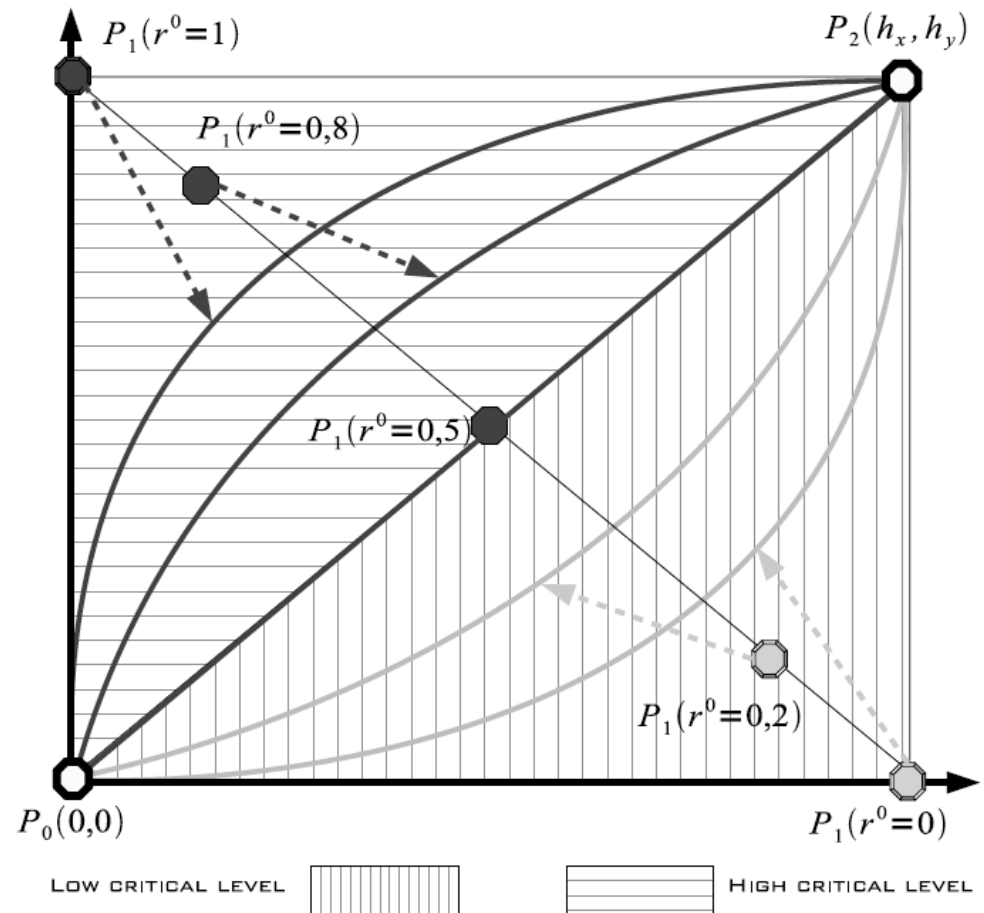
- CONCAVE AND CONVEX SHAPES AUTOMATICALLY DEFINE SENTRY NODES IN THE NETWORK





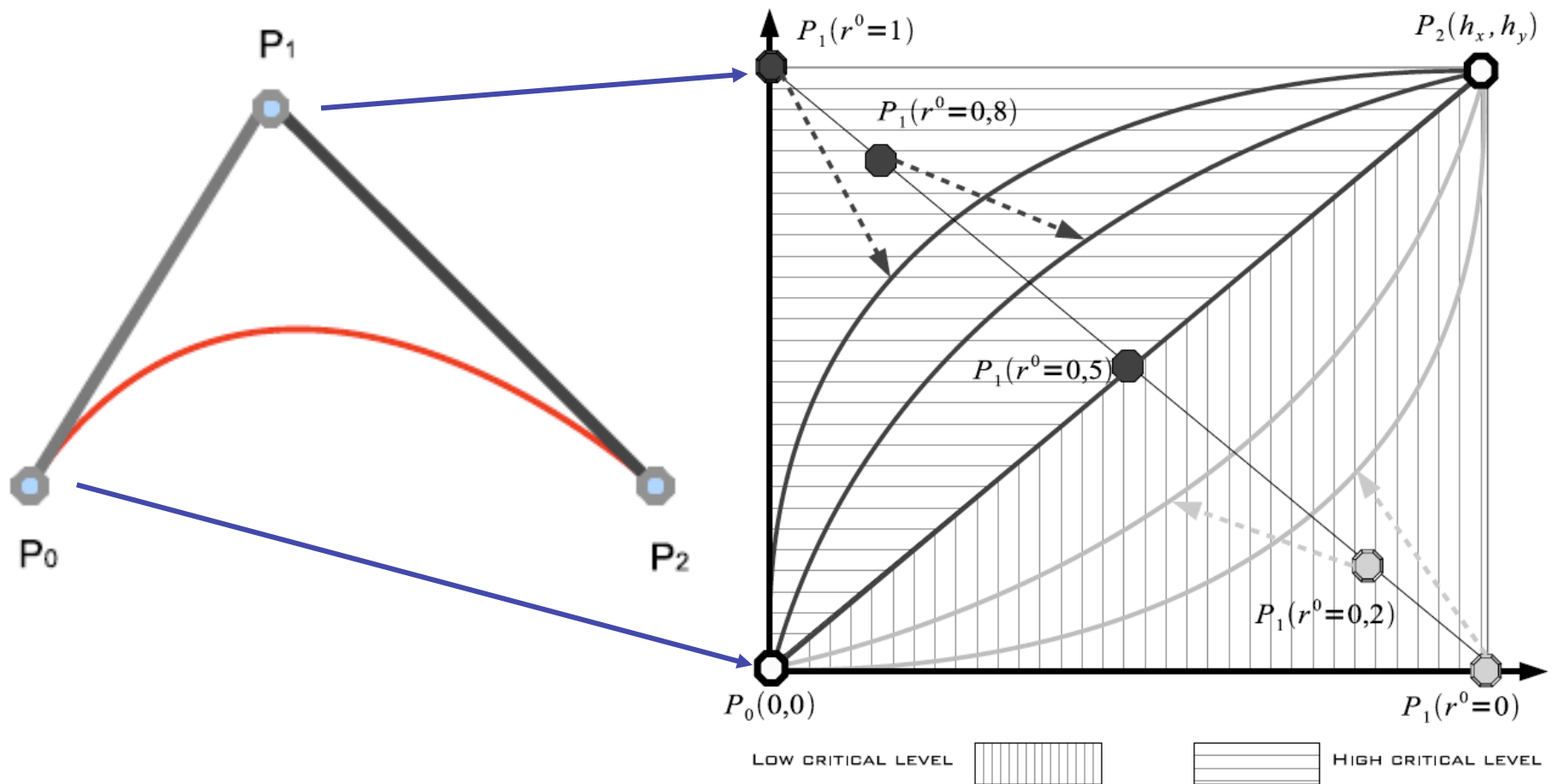
# CRITICALITY MODEL (2)

- ❑  $R^0$  CAN VARY IN  $[0,1]$
- ❑ BEHAVIOR FUNCTIONS (BV) DEFINES THE CAPTURE SPEED ACCORDING TO  $R^0$
- ❑  $R^0 < 0.5$ 
  - ❑ CONCAVE SHAPE BV
- ❑  $R^0 > 0.5$ 
  - ❑ CONVEX SHAPE BV
- ❑ WE PROPOSE TO USE BEZIER CURVES TO MODEL BV FUNCTIONS



# BEHAVIOR FUNCTION

$$B(t) = (1 - t)^2 * P_0 + 2t(1 - t) * P_1 + t^2 * P_2$$



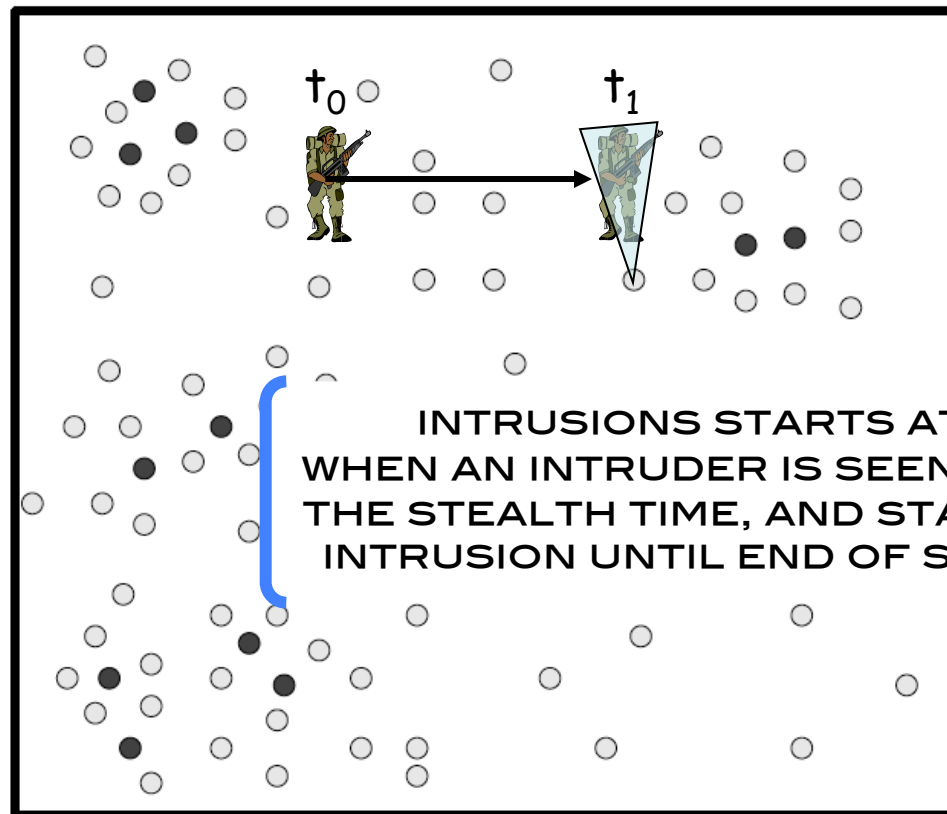
# RISK-BASED SCHEDULING

- ❑ **STATIC RISK-BASED SCHEDULING**
  - ❑  $R^{\circ} = \text{CTE}$  IN  $[0,1]$
- ❑ **DYNAMIC RISK-BASED SCHEDULING**
  - ❑ STARTS WITH A LOW VALUE FOR  $R^{\circ}$  (0.1)
  - ❑ ON INTRUSION, ALERT NEIGHBORHOOD AND INCREASES  $R^{\circ}$  TO A  $R_{\text{MAX}}$  VALUE (0.9)
  - ❑ STAYS AT  $R_{\text{MAX}}$  FOR  $T_A$  SECONDS BEFORE GOING BACK TO  $R^{\circ}$
- ❑ **DYNAMIC WITH REINFORCEMENT**
  - ❑ SAME AS DYNAMIC BUT SEVERAL ALERTS ARE NEEDED TO GET TO  $R^{\circ} = R_{\text{MAX}}$
  - ❑ GOING BACK TO  $R^{\circ}$  IS DONE IN ONE STEP



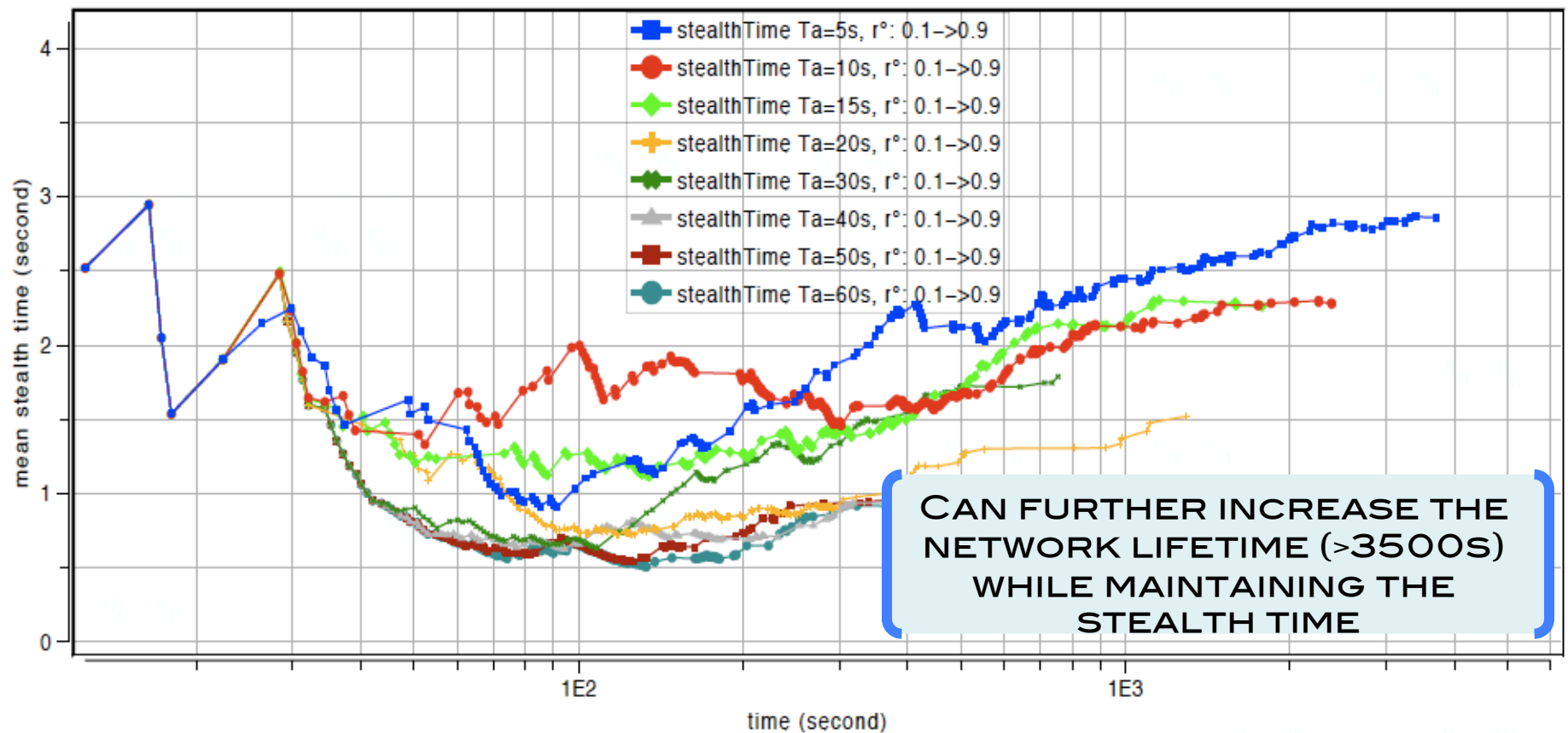
# MEAN STEALTH TIME

$T_1 - T_0$  IS THE INTRUDER'S  
STEALTH TIME  
VELOCITY IS SET TO 5M/S



# DYNAMIC SCHEDULING

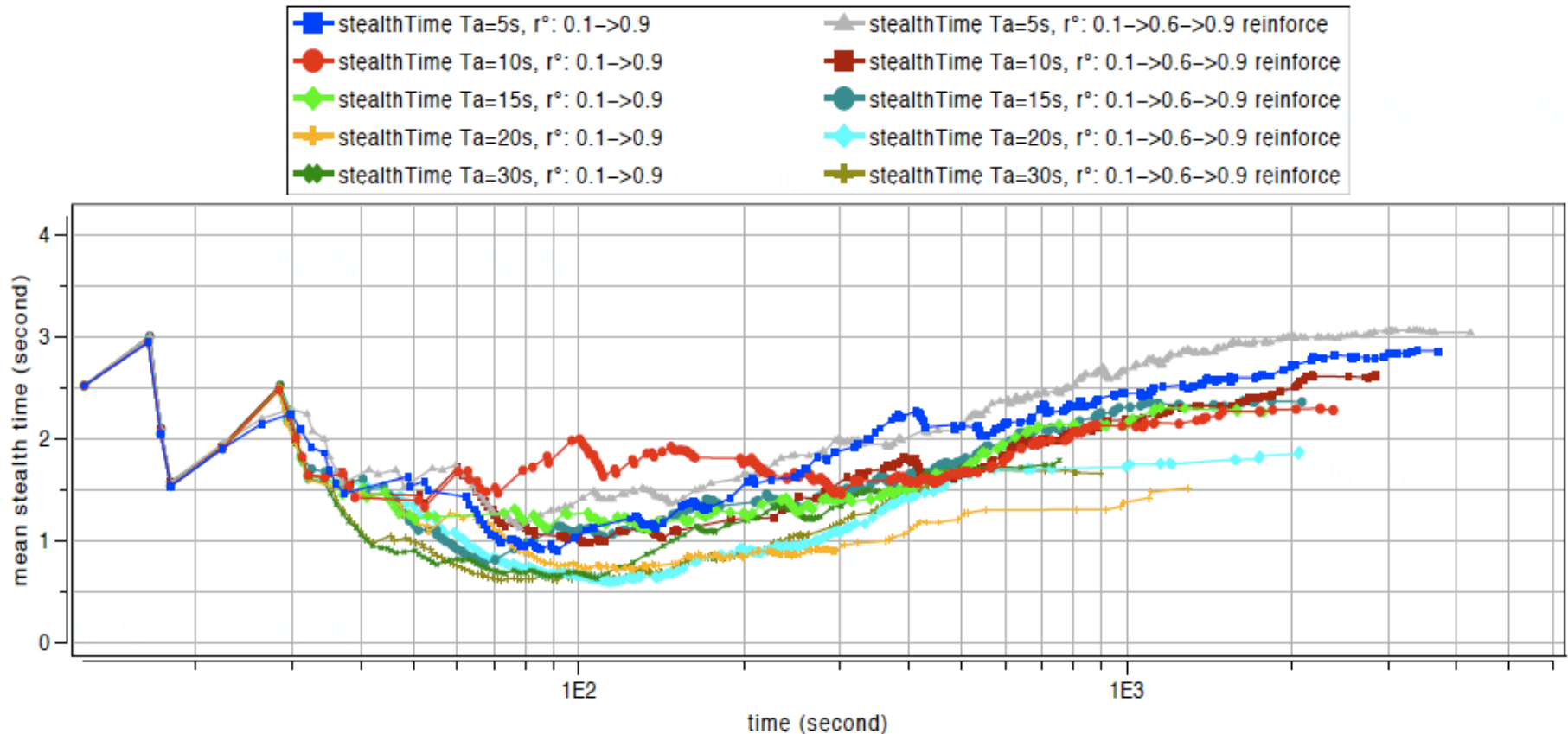
□  $R^0=0.1$ ,  $R_{MAX}=0.9$ ,  $T_A=5,10,15,20..60s$



# DYNAMIC WITH REINFORCEMENT (1)

□  $R^0 = 0.1 \rightarrow I_R = 0.6 \rightarrow R_{MAX} = 0.9$

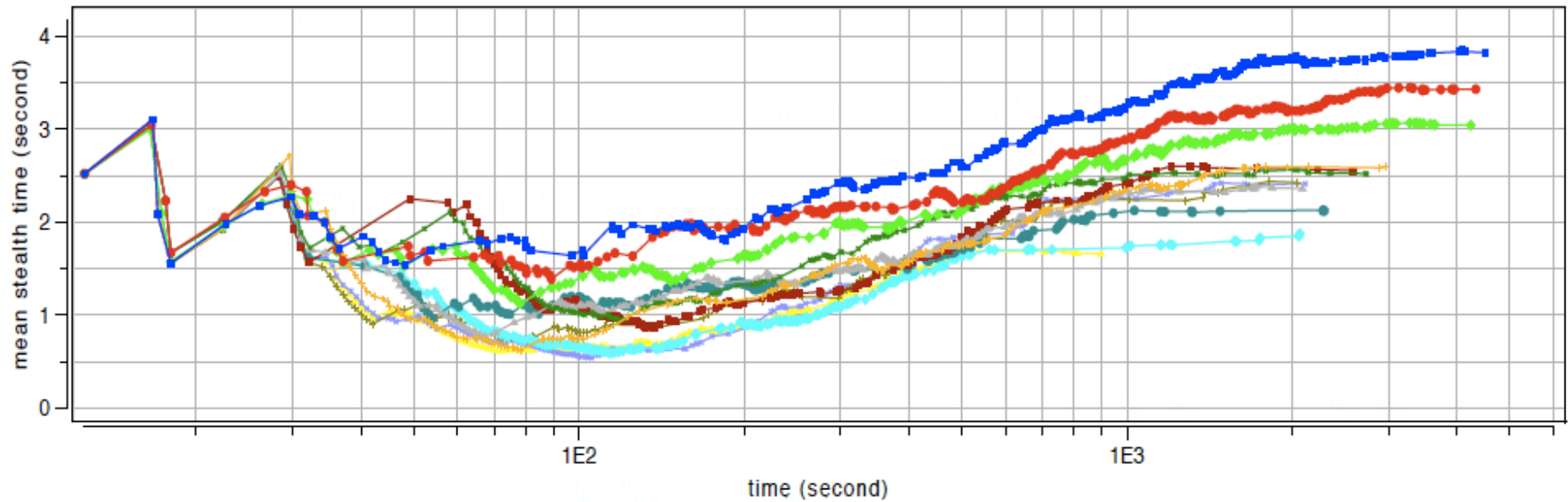
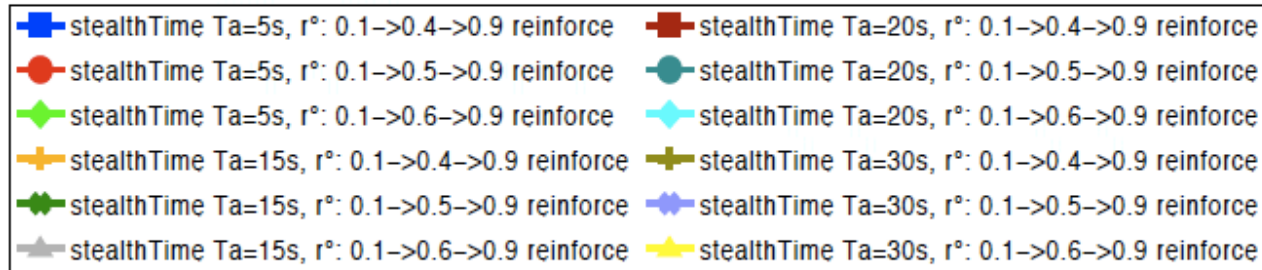
□ 2 ALERT MSG TO HAVE  $I_R = I_R + 0.1$



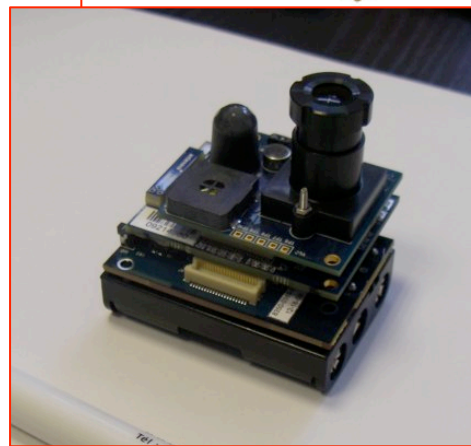
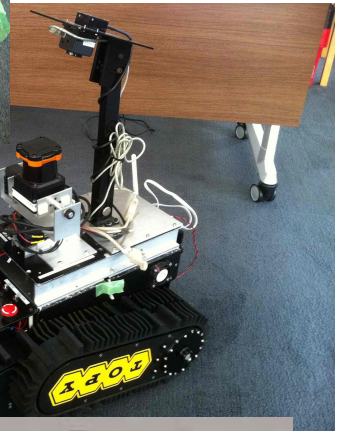
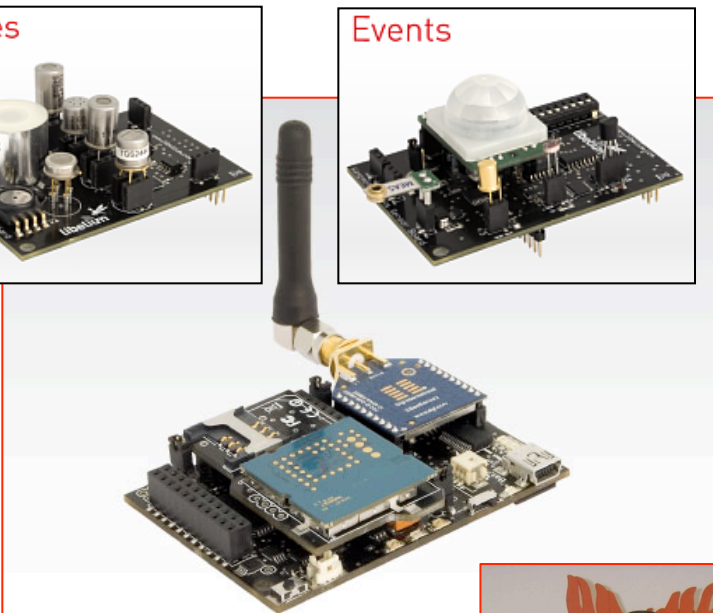
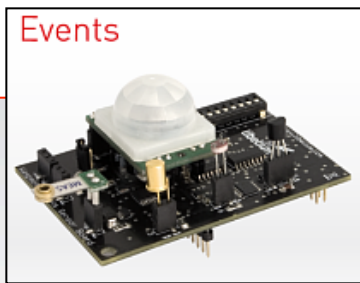


# DYNAMIC WITH REINFORCEMENT (2)

- $R^o = 0.1 \rightarrow I_R = 0.4/0.5/0.6 \rightarrow R_{MAX} = 0.9$
- 2 ALERT MSG TO HAVE  $I_R = I_R + 0.1$



# CHALLENGING COOPERATION IMPLIES DIFFERENCES!





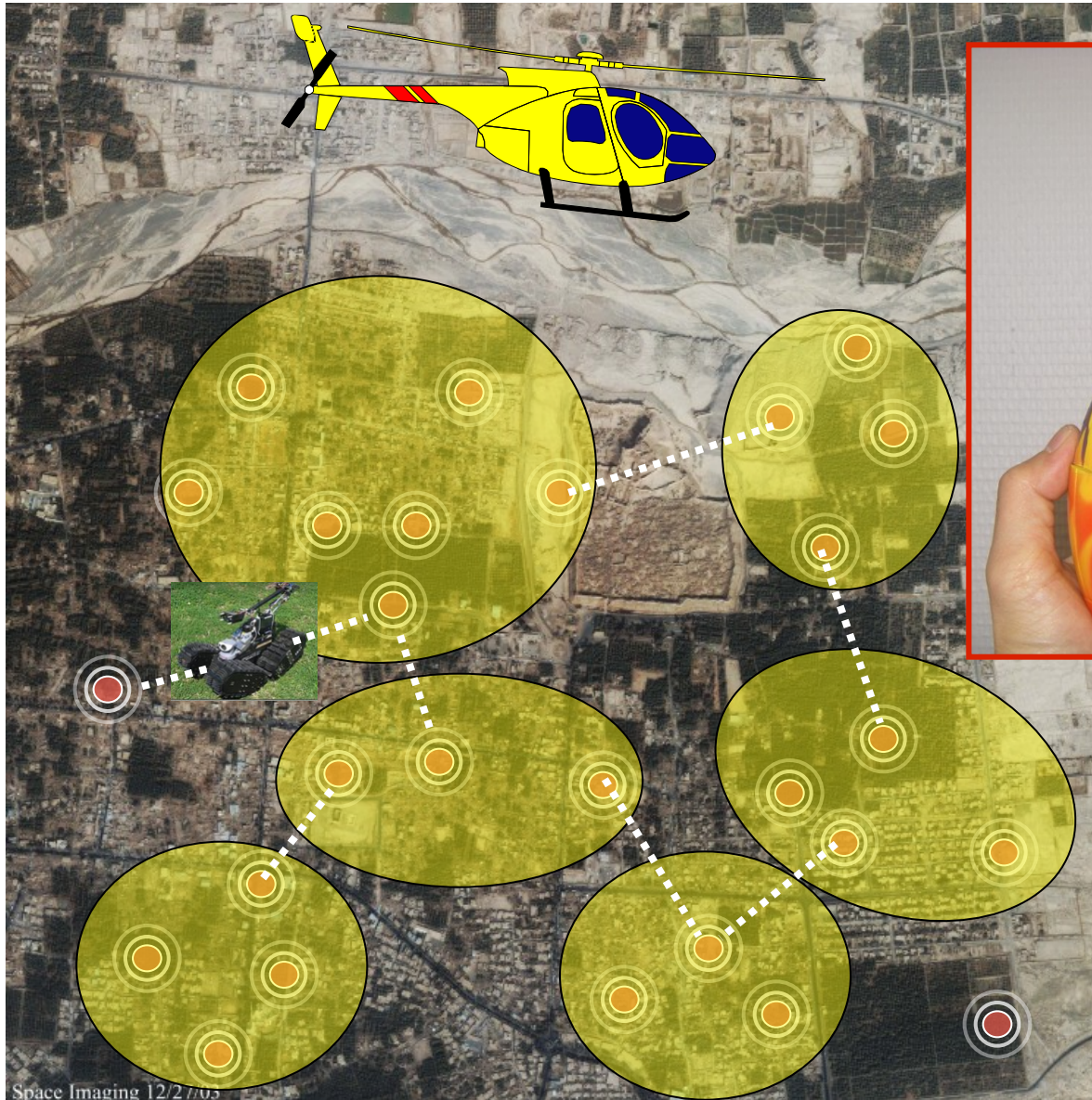
# ROBOT'S MOBILITY TO PRESERVE CONNECTIVITY



Imote2



Multimedia board





# SENSOR & ROBOTS SEARCH & RESCUE

- RESCUE COULD BE OPERATED IN SEVERAL PHASES (1)

Deploy in mass a WSN to get a first snapshot of the situation: images, radiation level, targets,...



# SENSOR & ROBOTS SEARCH & RESCUE

## □ RESCUE COULD BE OPERATED IN SEVERAL PHASES (2)

Based on collected data, optimize deployment/selection of autonomous robots



© Reuters



# SENSOR & ROBOTS SEARCH & RESCUE

## □ RESCUE COULD BE OPERATED IN SEVERAL PHASES (3)

Robots could serve as relay or install communication gateways to maintain WSN connectivity and increase data storage capability



# SENSOR & ROBOTS SEARCH & RESCUE

## □ RESCUE COULD BE OPERATED IN SEVERAL PHASES (4)

Sensor & Robots will continuously collaborate during the rescue process: localization, path optimization, remote sensing,...

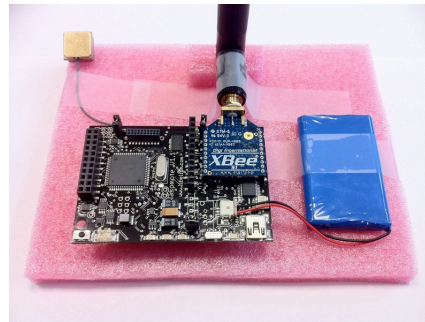
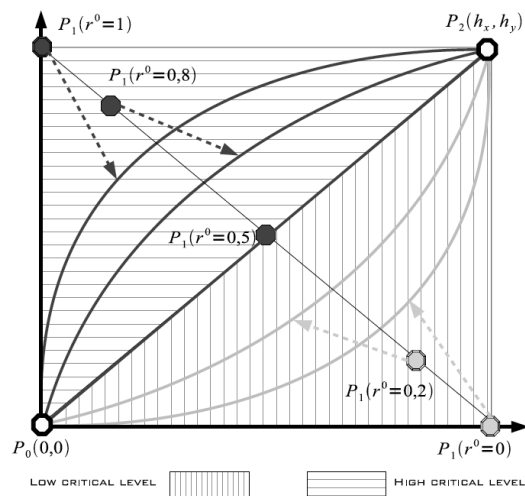




# SENSORS & ROBOTS

## PROPOSE NEW INTERACTION SCHEMES

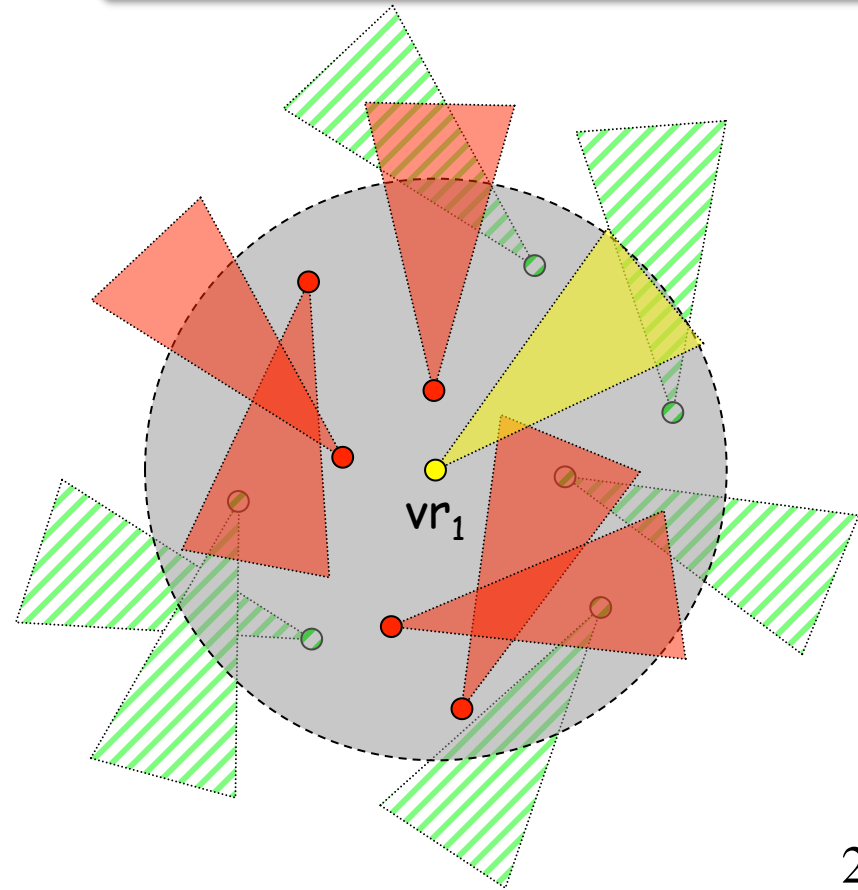
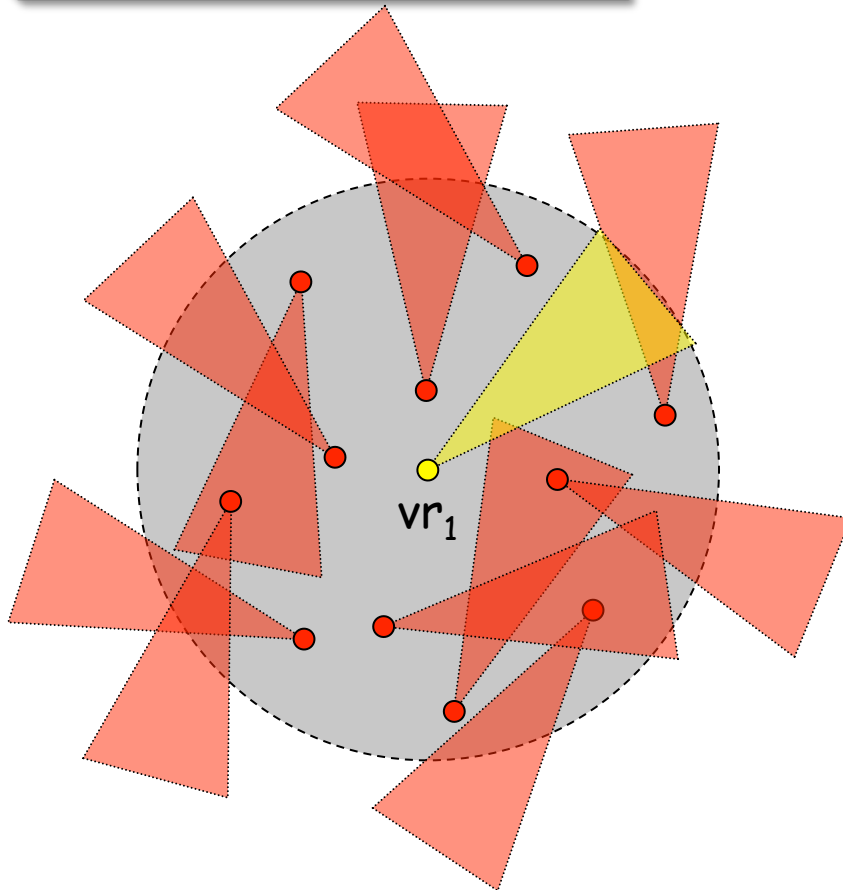
- ❑ USE THE CRITICALITY MODEL TO CONTROL BOTH SENSORS AND ROBOTS
- ❑ PROTOTYPING ON REAL HARDWARE, COLLABORATION WITH U. KYOTO, JAPAN



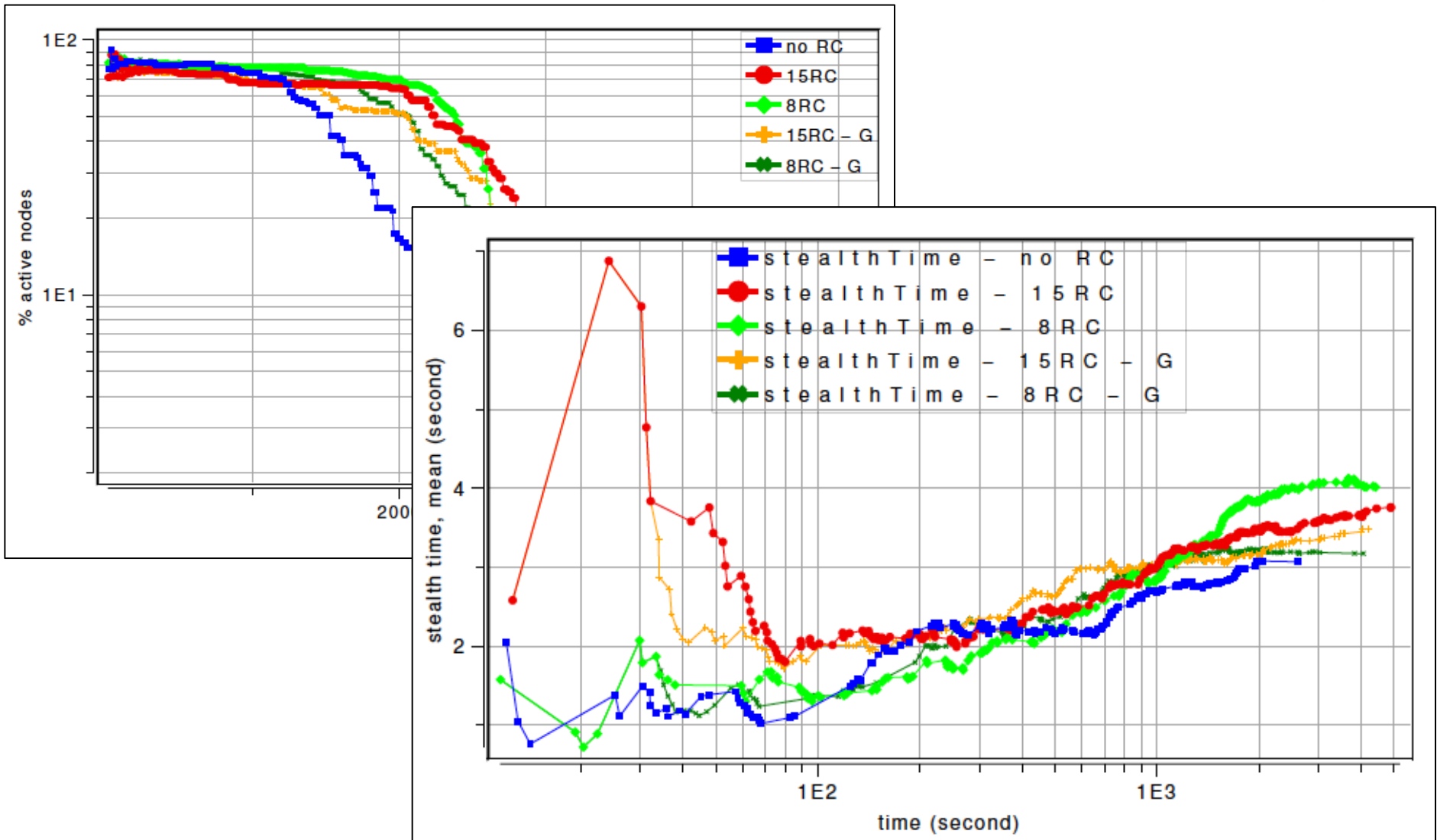
# COOPERATION WITH CAMERAS ON MOBILE ROBOTS

Fixed image sensors near a mobile camera can decrease their criticality level

**ONLY** fixed image sensors whose FoV's center is covered by a mobile camera **CAN** decrease their criticality level



# IMPACT ON LIFETIME & STEALTH TIME



ENERGY  
CONSIDERATIONS

NETWORK

SIGNAL  
IMAGE/VIDEO  
PROCESSING

OS  
MIDDLEWARE  
SOFT. ENG.

DATA MNGT

HARDWARE  
RADIO

# NETWORK ISSUES WE ADDRESS

ORGANIZATION  
OVERLAYS

VIDEO COVERAGE  
SELECTION &  
WAKE-UP MECHANISM

TRANSPORT

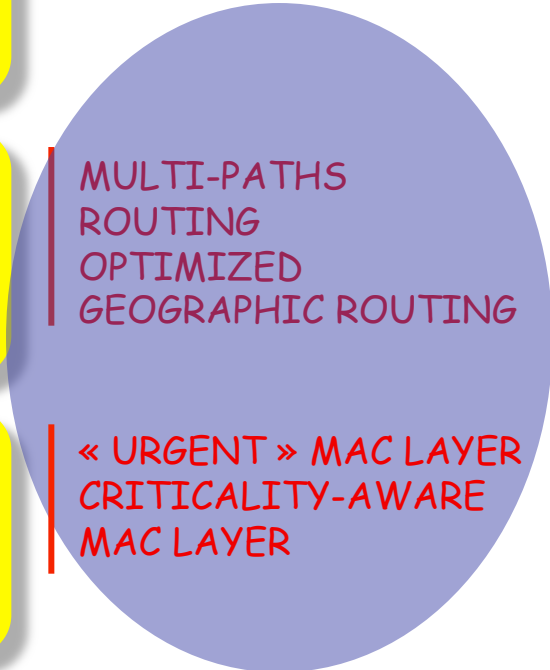
LOAD-REPARTITION  
CONGESTION CONTROL

ROUTING

MULTI-PATHS  
ROUTING  
OPTIMIZED  
GEOGRAPHIC ROUTING

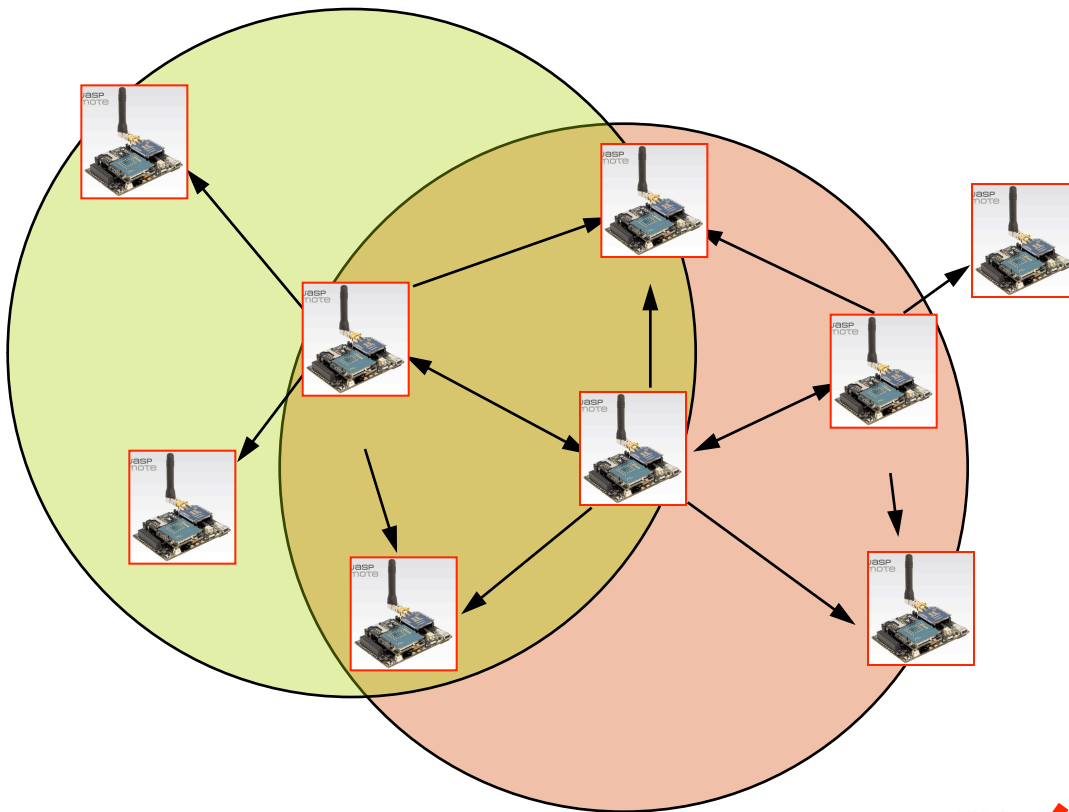
MAC  
RESOURCES  
ALLOCATION

« URGENT » MAC LAYER  
CRITICALITY-AWARE  
MAC LAYER



QoS

# WIRELESS MEDIUM IS A SHARED MEDIUM



Collisions when multiple transmissions

Hidden terminal problem

TDMA is usually not used because of waste of resource



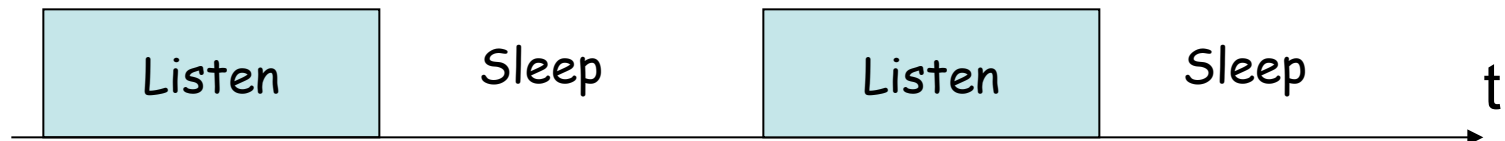
WiFi transmission power is too energy-consuming for WSN!

Huge cost of passive listening!

WSN can be idle for a long period!

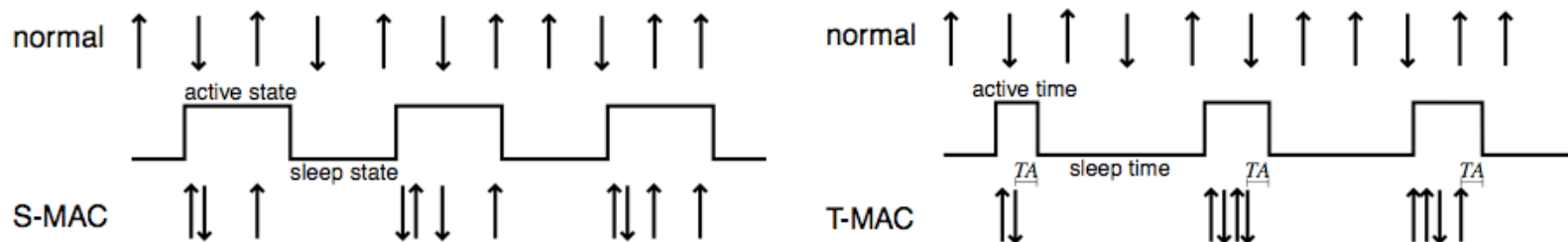
# S-MAC - SENSOR MAC

- **NODES PERIODICALLY SLEEP**
- **TRADES ENERGY EFFICIENCY FOR LOWER THROUGHPUT AND HIGHER LATENCY**
- **SLEEP DURING OTHER NODES TRANSMISSIONS**



# T-MAC - TIMEOUT MAC

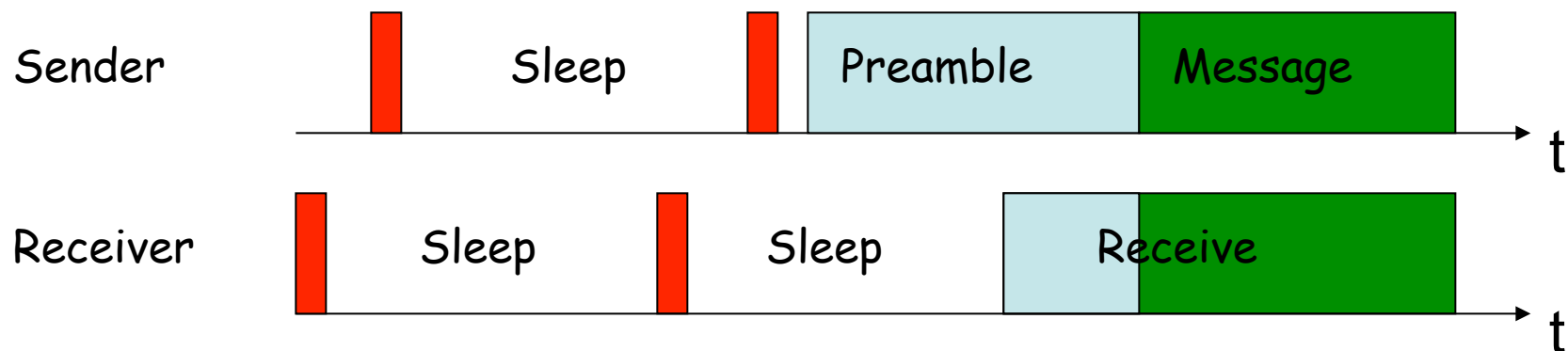
- TRANSMIT ALL MESSAGES IN BURSTS OF VARIABLE LENGTH AND SLEEP BETWEEN BURSTS
- RTS / CTS / ACK SCHEME
- SYNCHRONIZATION SIMILAR TO S-MAC





# B-MAC

- **LOW POWER LISTENING (LPL) USING PREAMBLE SAMPLING**
- **HIDDEN TERMINAL AND MULTI-PACKET MECHANISMS NOT PROVIDED, SHOULD BE IMPLEMENTED, IF NEEDED, BY HIGHER LAYERS**

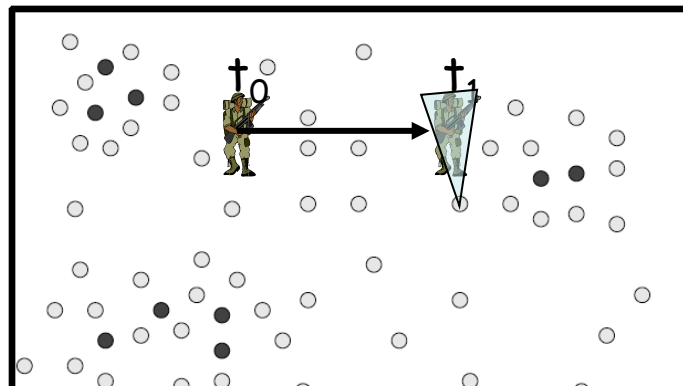


# CHALLENGES FOR MAC PROTOCOLS IN WSN

- ❑ ENERGY EFFICIENCY
- ❑ LOW LATENCIES
- ❑ FAIRNESS



A CHALLENGE FOR MISSION-CRITICAL APPLICATION

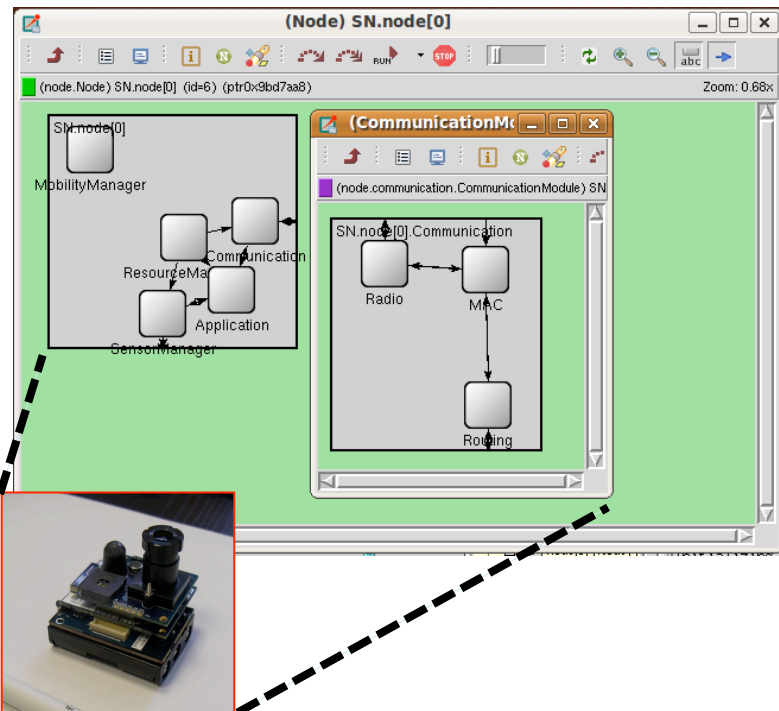




# SIMULATION TOOLS

# IMAGE SENSOR SIMULATION MODEL UNDER OMNET++

- ❑ COMMUNICATION LAYERS ARE VERY IMPORTANT FOR WSN
- ❑ USE SPECIFIC SIMULATOR



The screenshot shows the OMNeT++ simulation environment. The main window is titled "OMNeT++/Tkenv - SN". It displays a network topology with several nodes (SN) and their connections. The console window shows the simulation output, including the initialization of nodes and the start of the simulation. An orange callout box is overlaid on the simulation, containing the text: "Need to know the power consumption for capturing an image, processing/compressing an image & transmitting an image...".

# STUDY THE IMPACT OF COMMUNICATION LAYER ON SURVEILLANCE QUALITY

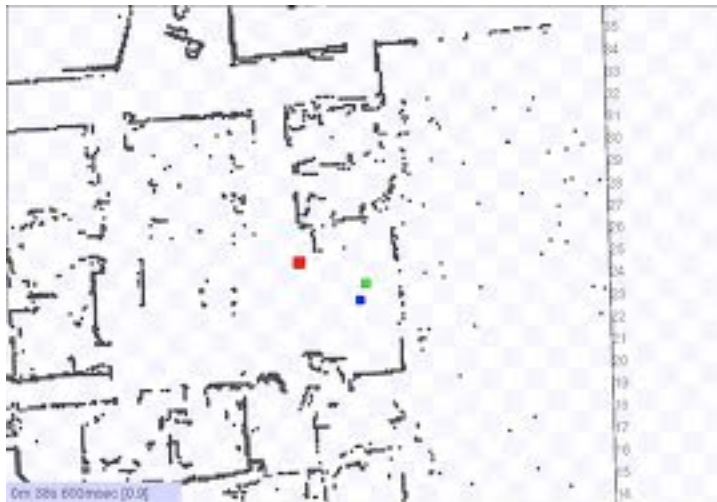
The image displays a simulation environment for a network-based surveillance system. It consists of three main components:

- Top Left:** A small window titled "79(33.8) <-46(1)" showing a real-time video feed of a desert landscape with a road and some vegetation.
- Center:** A network map window titled "(SN) SN" showing a complex network of nodes (represented by colored circles) and links. The map includes a toolbar with "RUN", "STOP", and "Zoom: 0.79x". Nodes are labeled with IDs like node[105], node[67], node[138], etc., and some have associated numerical values.
- Right:** A terminal window titled "OMNeT++/Tkenv - SN" showing simulation logs. The logs include:
  - Simulation statistics: "Msgs created: 667040", "Msgs present: 1867", "insec/sec: 0.778365", "Ev/simsec: 15059.8".
  - Log entries showing "Timer message" and "capture" events.
  - Log entries for "Application" actions, such as "Sending [image] of size 288 bytes to communication layer" and "Node 46 -> REAL IMAGE(1) to node 79".
  - Log entries for "INTRUSION SEEN" at various nodes (e.g., Node 96, Node 148, Node 5, Node 6, Node 124, Node 5, Node 24, Node 6).
  - Log entries for "WRITES IMAGE FILE(1) from node 10" and "DISPLAY REAL IMAGE(1) from node 10".



# ROBOT SIMULATORS

- ❑ MOBILITY, EXPLORATION, NAVIGATION, TRACKING, CONTROL AND DESIGN ARE VERY IMPORTANT FOR ROBOTS
- ❑ USE SPECIFIC ROBOT SIMULATORS



# SENSORS & ROBOTS ENABLE REALISTIC INTERACTION STUDIES

Sensor specific simulator for communication stack

Get robot's position from robot simulator

Re-use fine-grained communication protocols and complex radio models

Re-use complex hardware (laser scan, ...) and control software (navigation stacks,...)

The image displays two main components. On the left is a network diagram window titled '(SN) SN' showing a central 'SN' node connected to a 'coordinator' and 'intrusion' node, with numerous other nodes (e.g., node[0], node[1], node[2], node[4], node[5], node[7], node[9], node[12], node[13], node[14], node[15], node[17], node[20], node[21], node[22], node[23], node[25], node[27], node[28], node[29]) arranged in a grid. On the right is a 3D robot simulator window titled 'Blender' showing a red robot on a grassy hillside. Red arrows point from the network diagram to the 3D simulator, indicating data flow. A blue callout box on the left contains the text 'Re-use fine-grained communication protocols and complex radio models'. A green callout box on the right contains the text 'Re-use complex hardware (laser scan, ...) and control software (navigation stacks,...)'. The text 'Get robot's position from robot simulator' is positioned above the 3D simulator window.



# RESEARCH COLLABORATION

- ❑ VISUAL SENSORS AND ROBOTS INTRODUCES NEW INTERACTION SCHEMES BUT RELIABILITY/QUALITY OF IMAGES ARE OF UTMOST IMPORTANCE
- ❑ ROUTING AND MAC LAYERS ARE LAYERS IN THESE APPLICATIONS
- ❑ IMAGE ENCODING TECHNIQUES CAN CONTRIBUTE TO IMPROVE IMAGE ROBUSTNESS
- ❑ ISSUES:
  - ❑ IMPACTS OF LOSSES ON IMAGE QUALITY?
  - ❑ NEW ENCODING TECHNIQUES FOR SENSOR-ROBOTS?