

VISUAL WIRELESS SENSOR NETWORKS FOR MISSION- CRITICAL SURVEILLANCE APPLICATIONS: PERSPECTIVES WITH MOBILE ROBOTS INTEGRATION

LORIA LABS
MARCH 9TH, 2012
NANCY, FRANCE

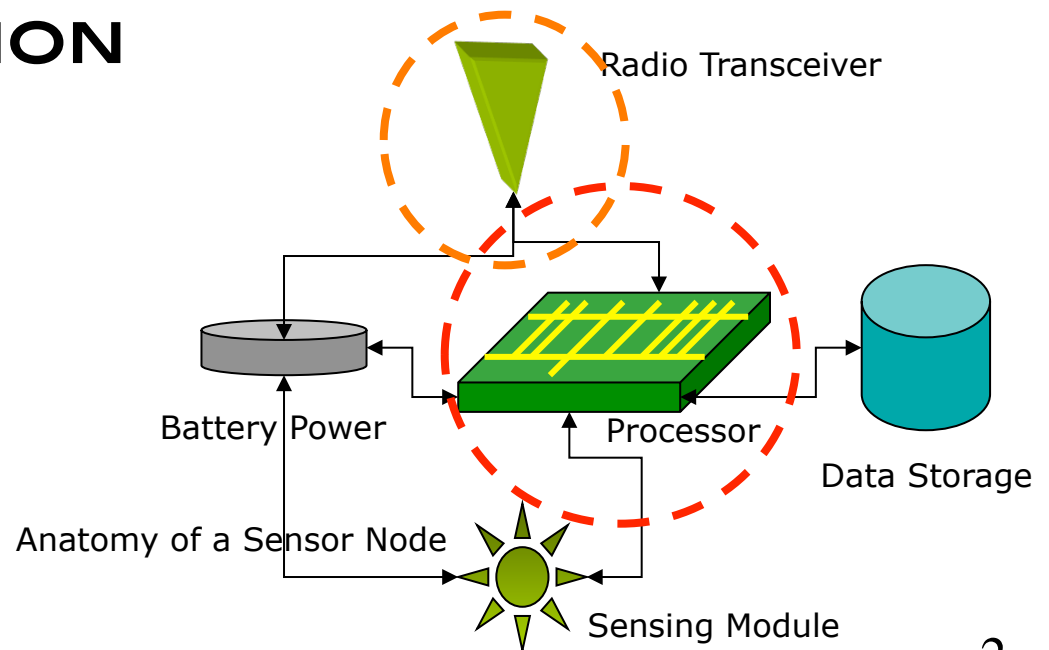
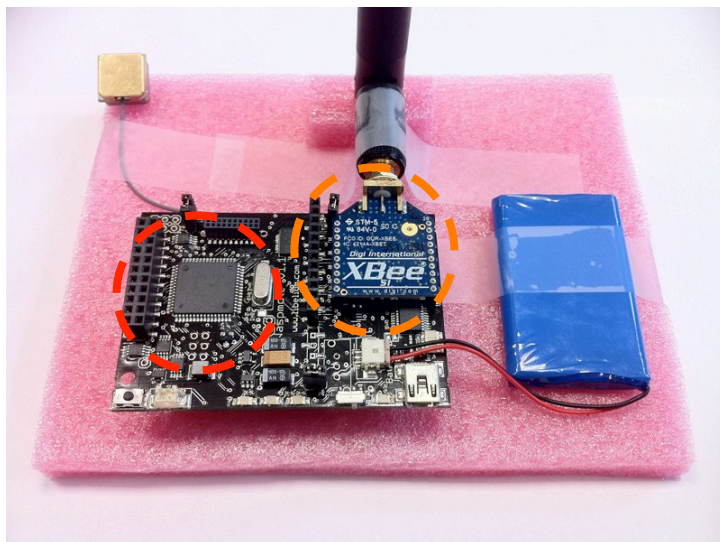


PROF. CONGDUC PHAM
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)
UNIVERSITÉ DE PAU, FRANCE



WIRELESS AUTONOMOUS SENSOR

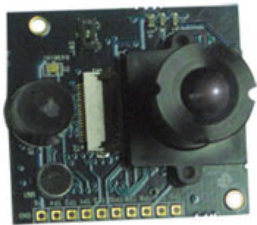
- ❑ IN GENERAL: LOW COST, LOW POWER (THE BATTERY MAY NOT BE REPLACEABLE), SMALL SIZE, PRONE TO FAILURE, POSSIBLY DISPOSABLE
- ❑ ROLE: SENSING, DATA PROCESSING, COMMUNICATION



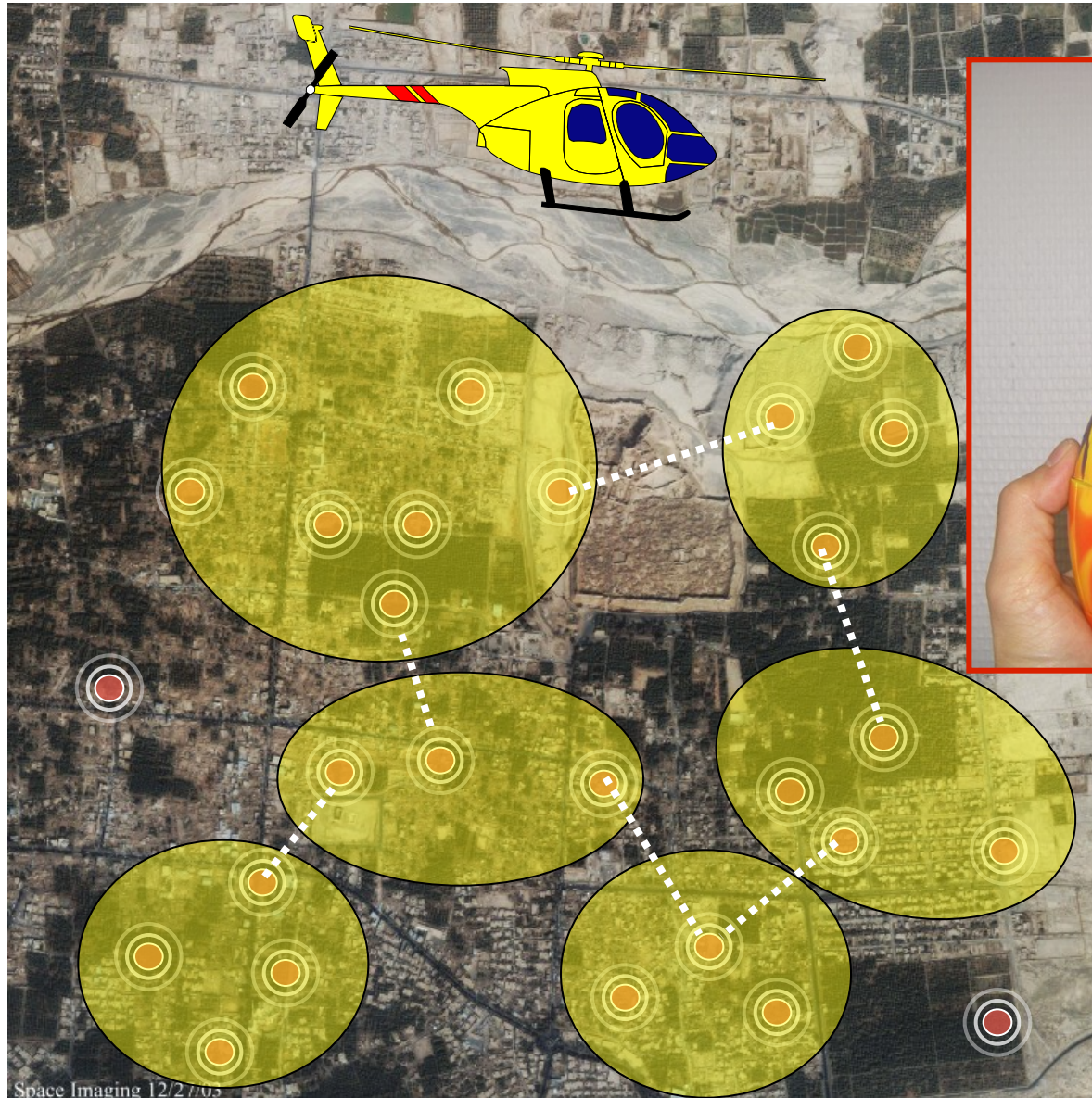
SEARCH&RESCUE, SECURITY



Imote2



Multimedia board



DON'T MISS IMPORTANT EVENTS!



WHOLE
UNDERSTANDING
OF THE SCENE IS
WRONG!!!

WHAT IS CAPTURED

HOW TO MEET SURVEILLANCE APP'S CRITICALITY

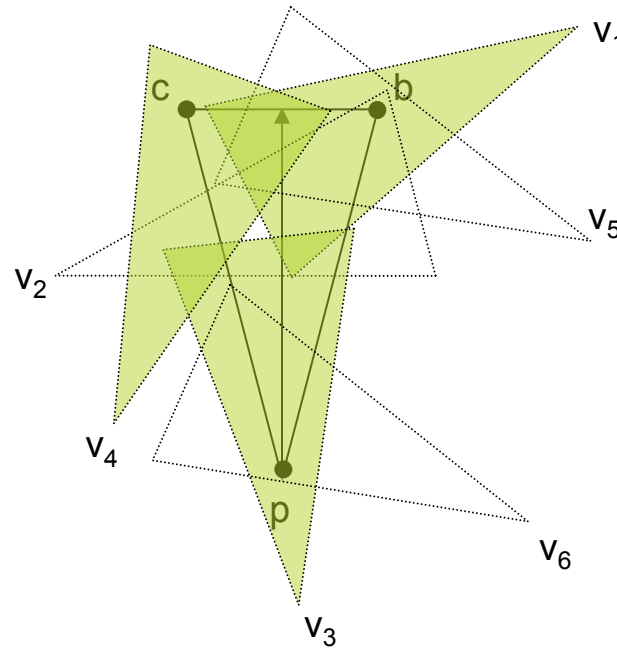
- ❑ CAPTURE SPEED CAN BE A « QUALITY » PARAMETER
- ❑ CAPTURE SPEED FOR NODE V SHOULD DEPEND ON THE APP'S CRITICALITY AND ON THE LEVEL OF REDUNDANCY FOR NODE V
- ❑ V'S CAPTURE SPEED CAN INCREASE WHEN AS V HAS MORE NODES COVERING ITS OWN FOV - COVER SET

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

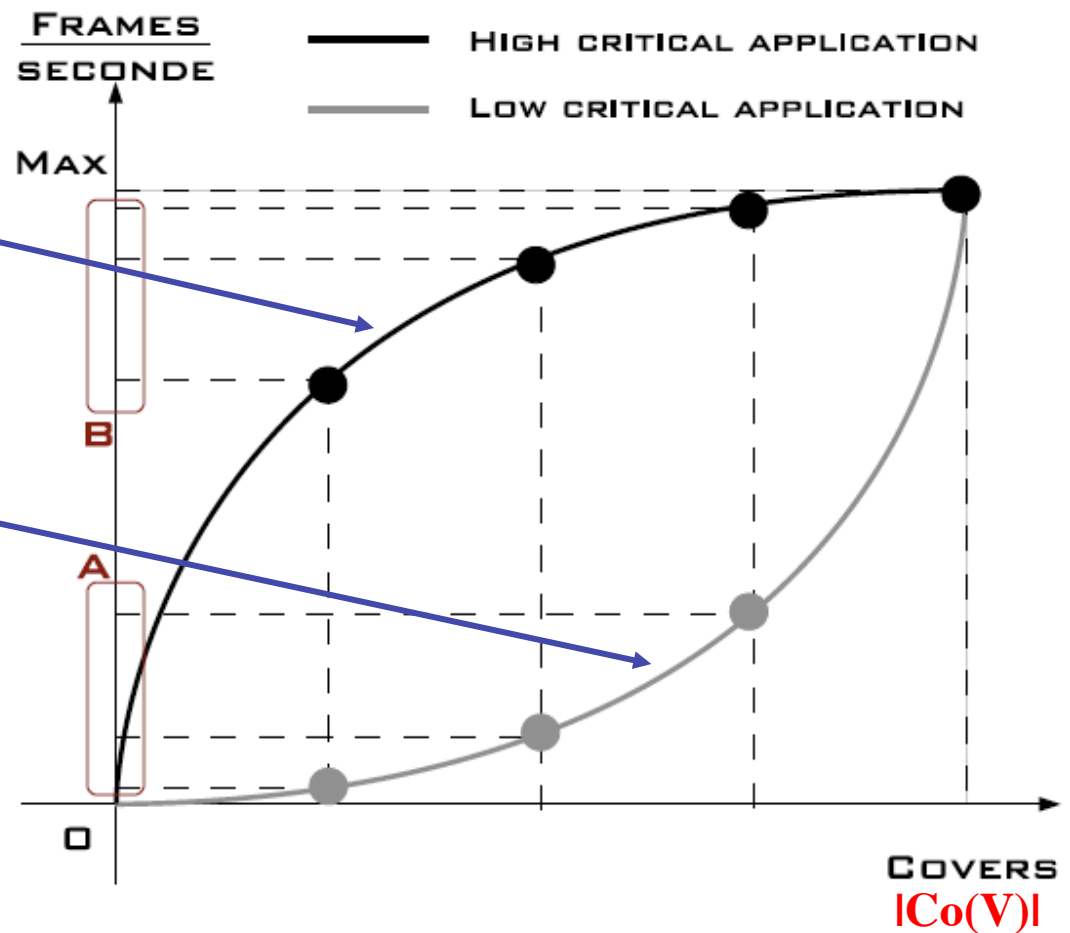
- HIGH CRITICALITY

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

- LOW CRITICALITY

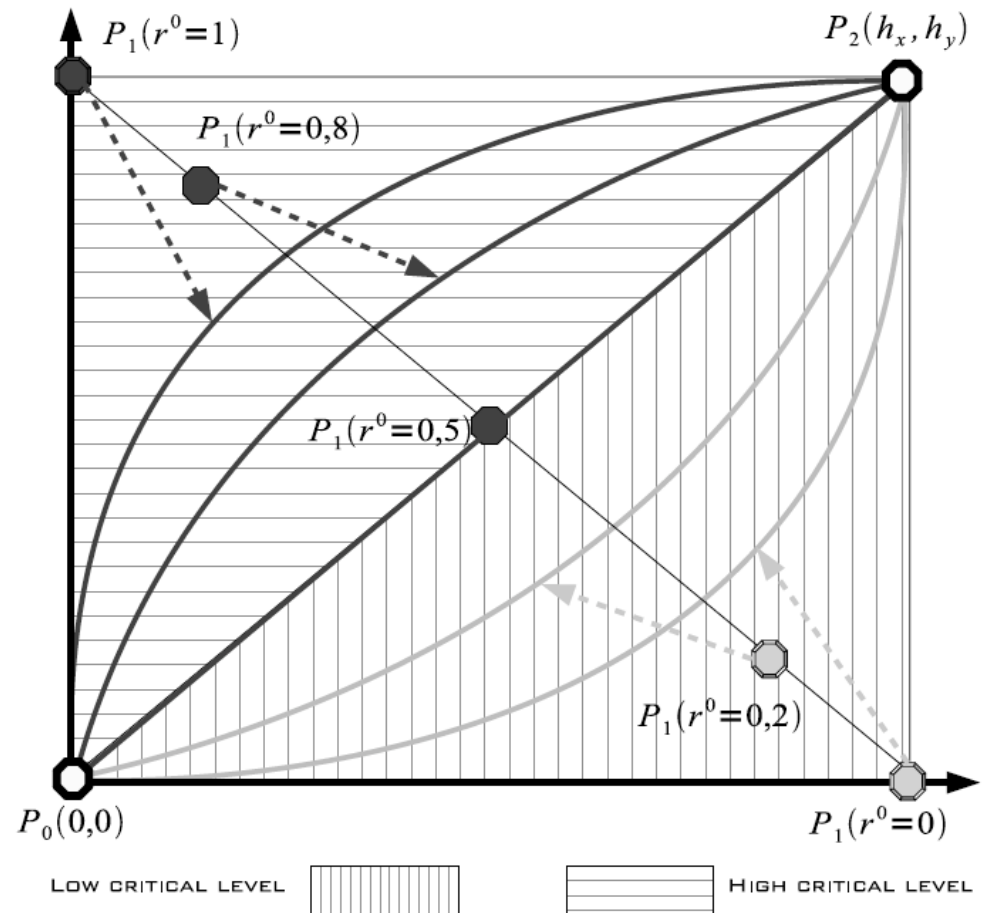
- CONCAVE SHAPE
- MOST PROJECTIONS OF X ARE CLOSE TO THE MIN CAPTURE SPEED

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



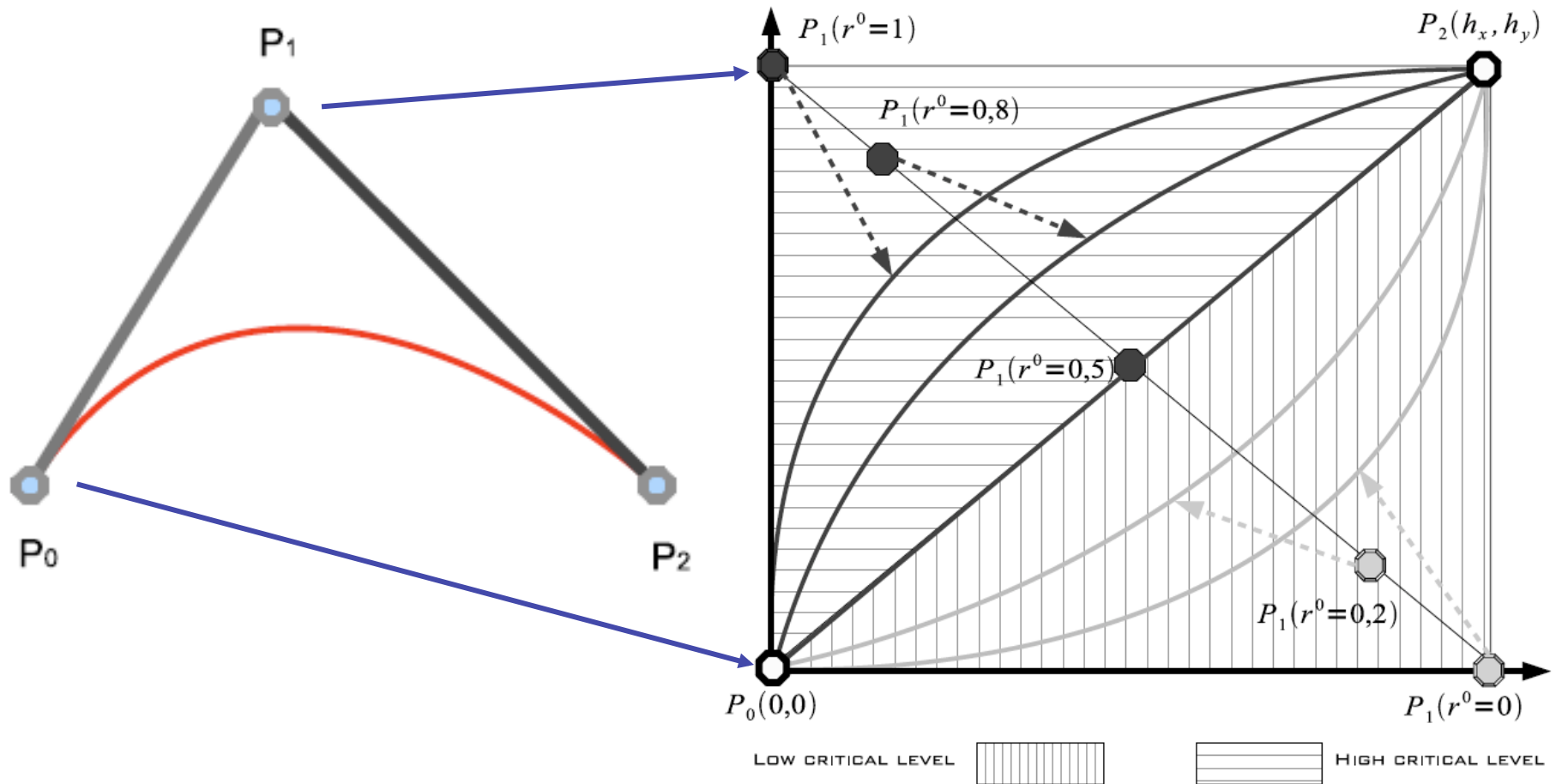
CRITICALITY MODEL (2)

- ❑ 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

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

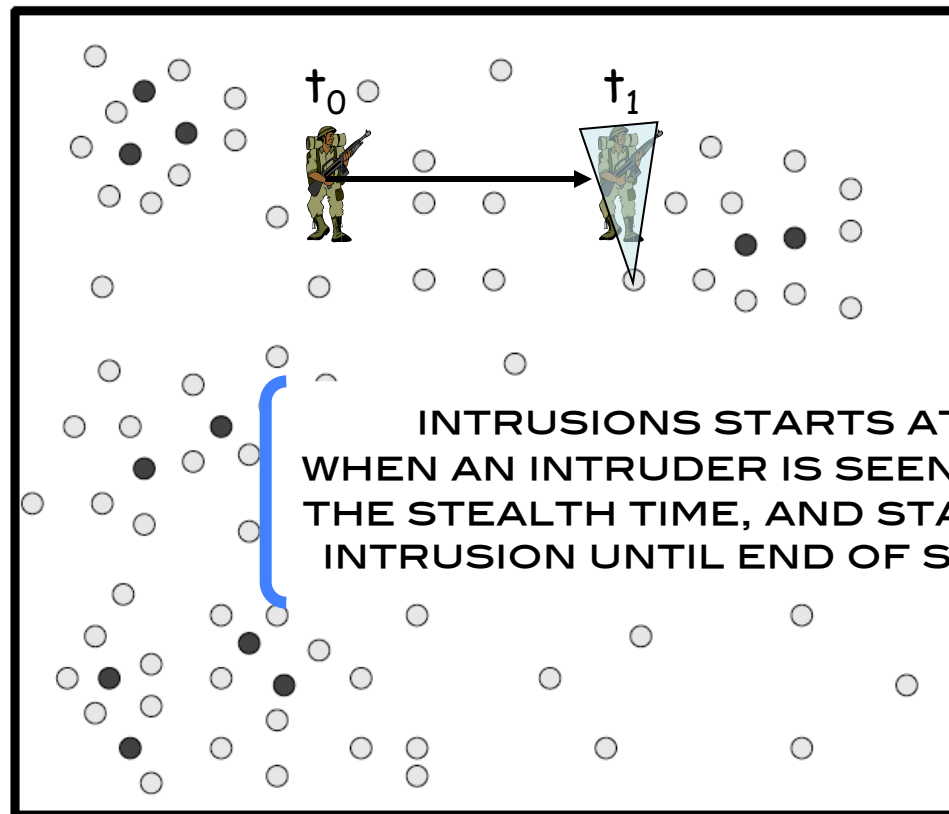


RISK-BASED SCHEDULING

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

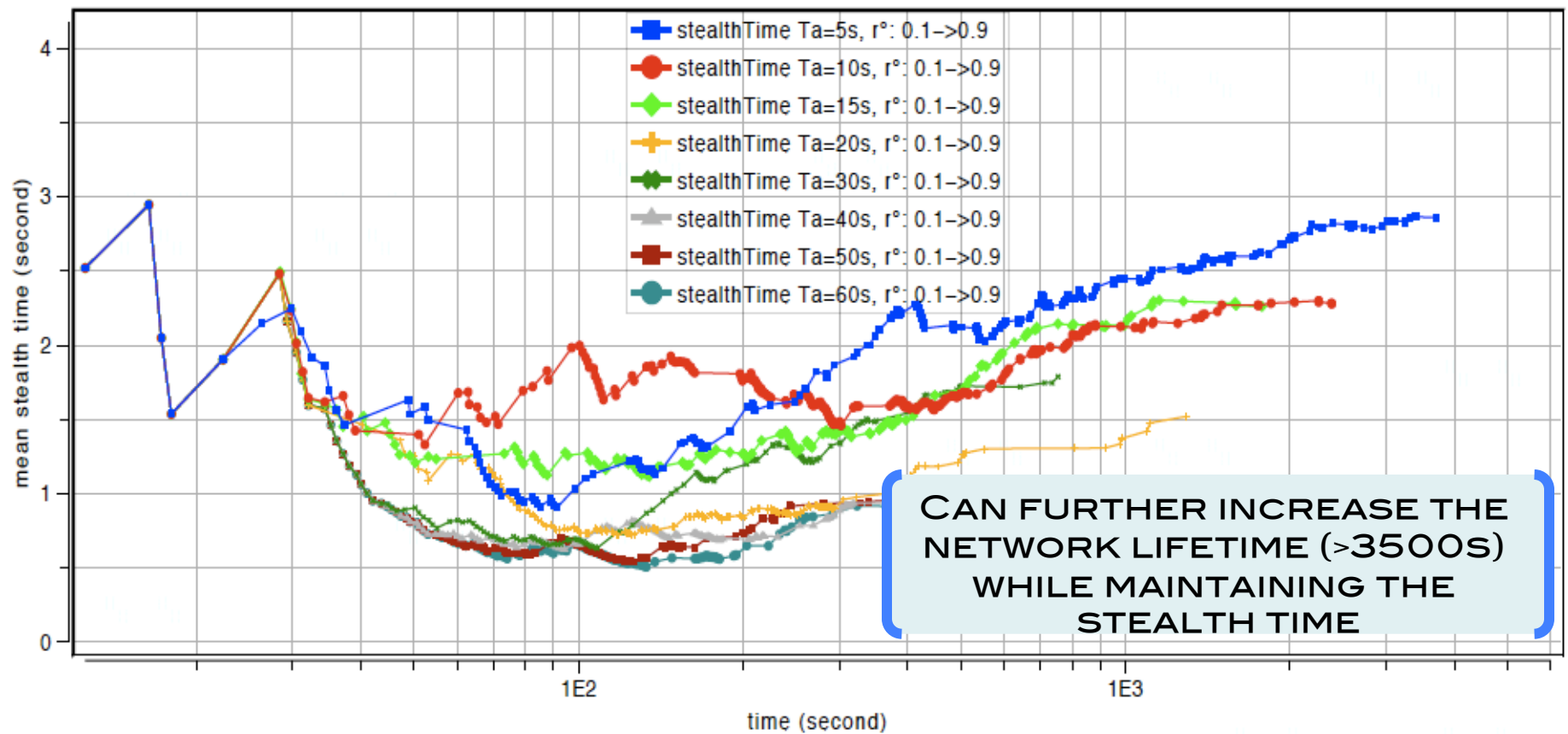
MEAN STEALTH TIME

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



DYNAMIC SCHEDULING

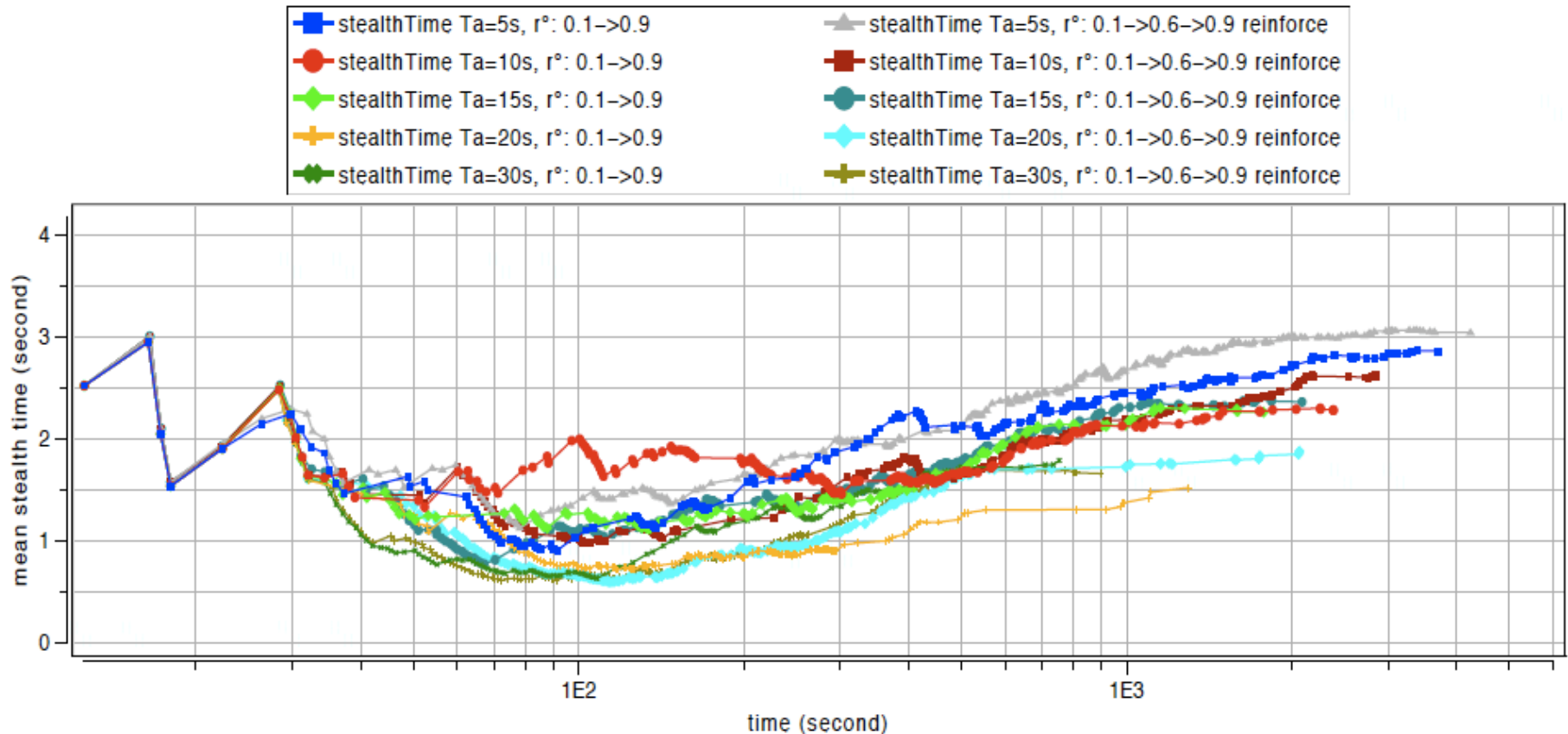
□ $R^0=0.1$, $R_{MAX}=0.9$, $T_A=5,10,15,20..60s$



DYNAMIC WITH REINFORCEMENT (1)

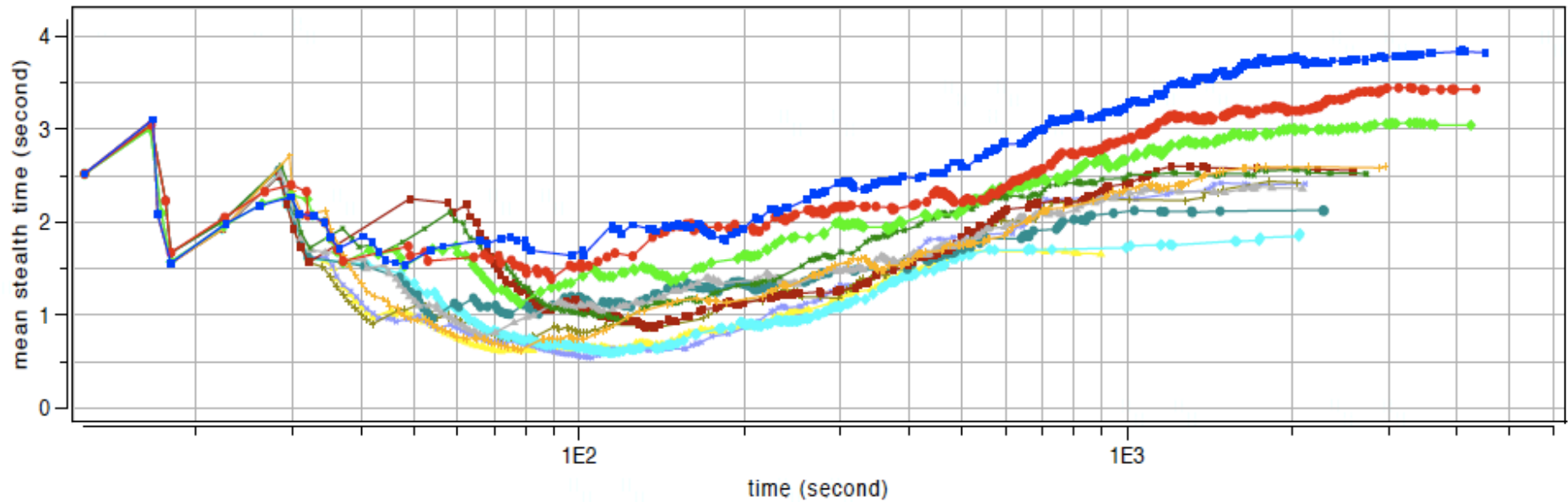
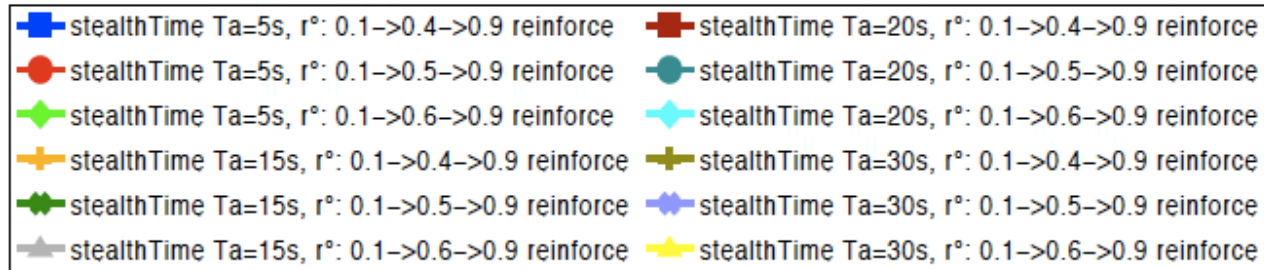
□ $R^0 = 0.1 \rightarrow I_R = 0.6 \rightarrow R_{MAX} = 0.9$

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

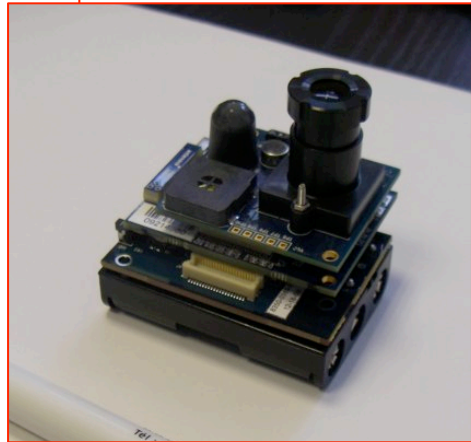
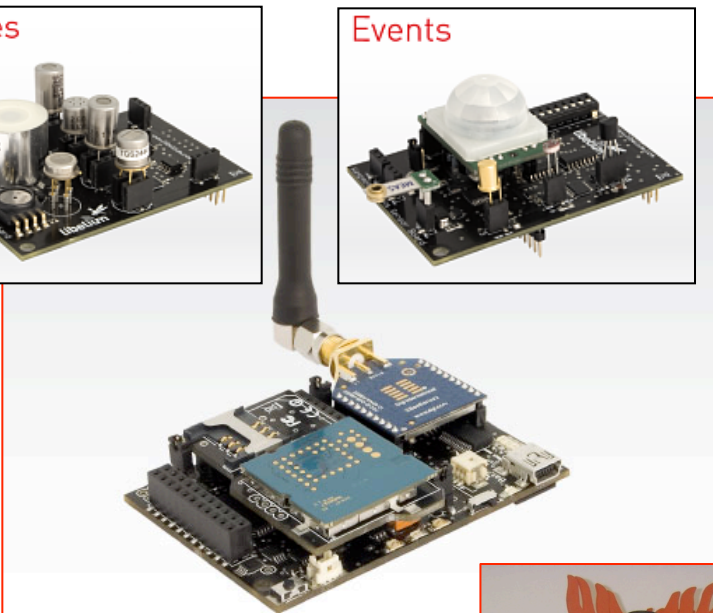
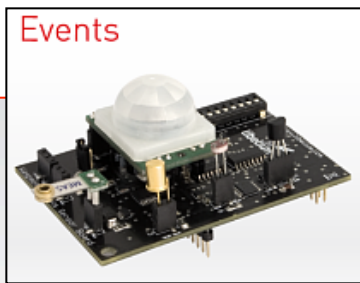


DYNAMIC WITH REINFORCEMENT (2)

- $R^0 = 0.1 \rightarrow I_R = 0.4/0.5/0.6 \rightarrow R_{MAX} = 0.9$
- 2 ALERT MSG TO HAVE $I_R = I_R + 0.1$



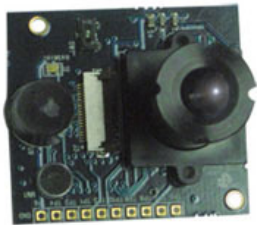
CHALLENGING COOPERATION IMPLIES DIFFERENCES!



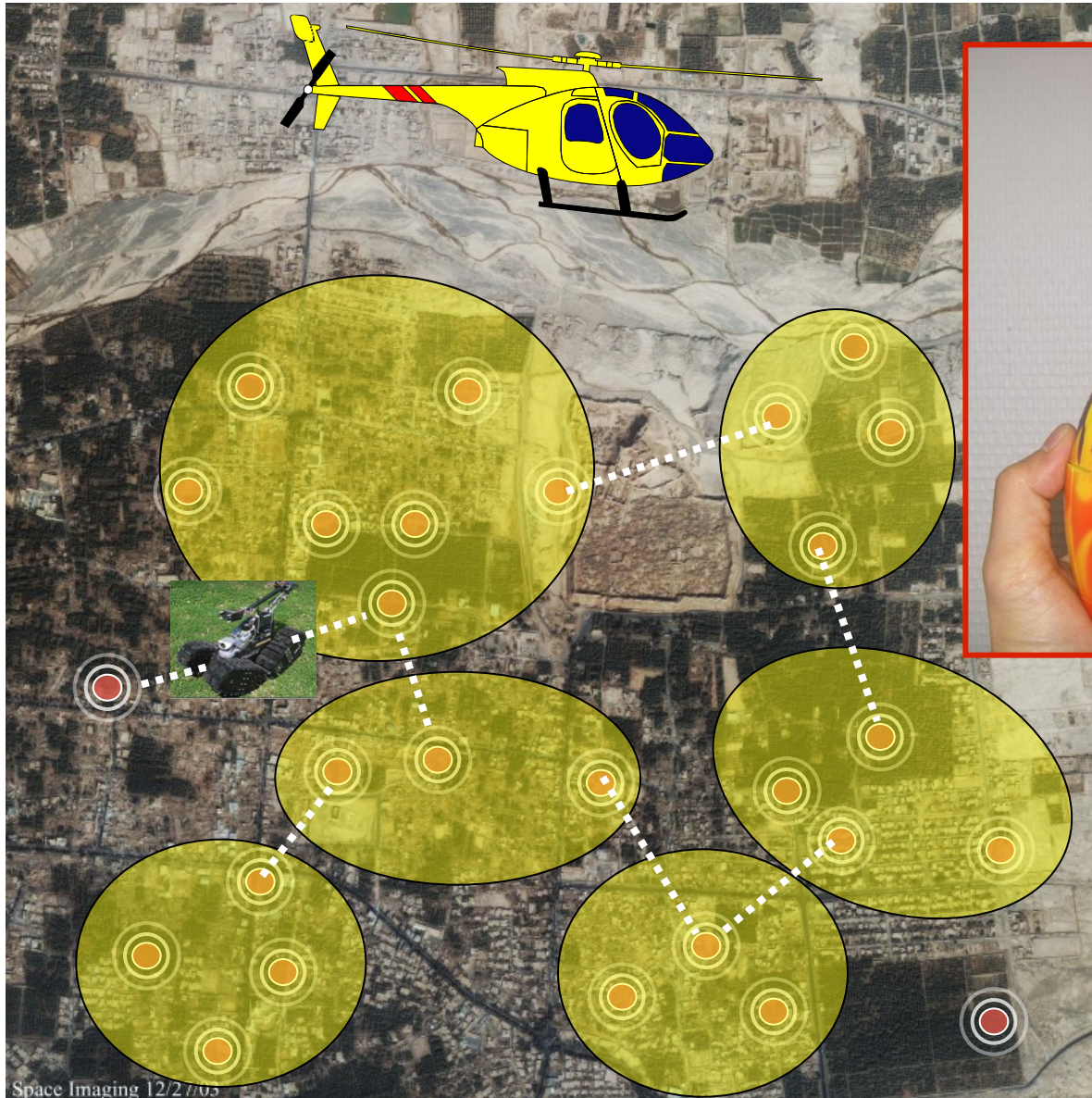
ROBOT'S MOBILITY TO PRESERVE CONNECTIVITY



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



SENSOR & ROBOTS SEARCH & RESCUE

□ RESCUE COULD BE OPERATED IN SEVERAL PHASES (3)

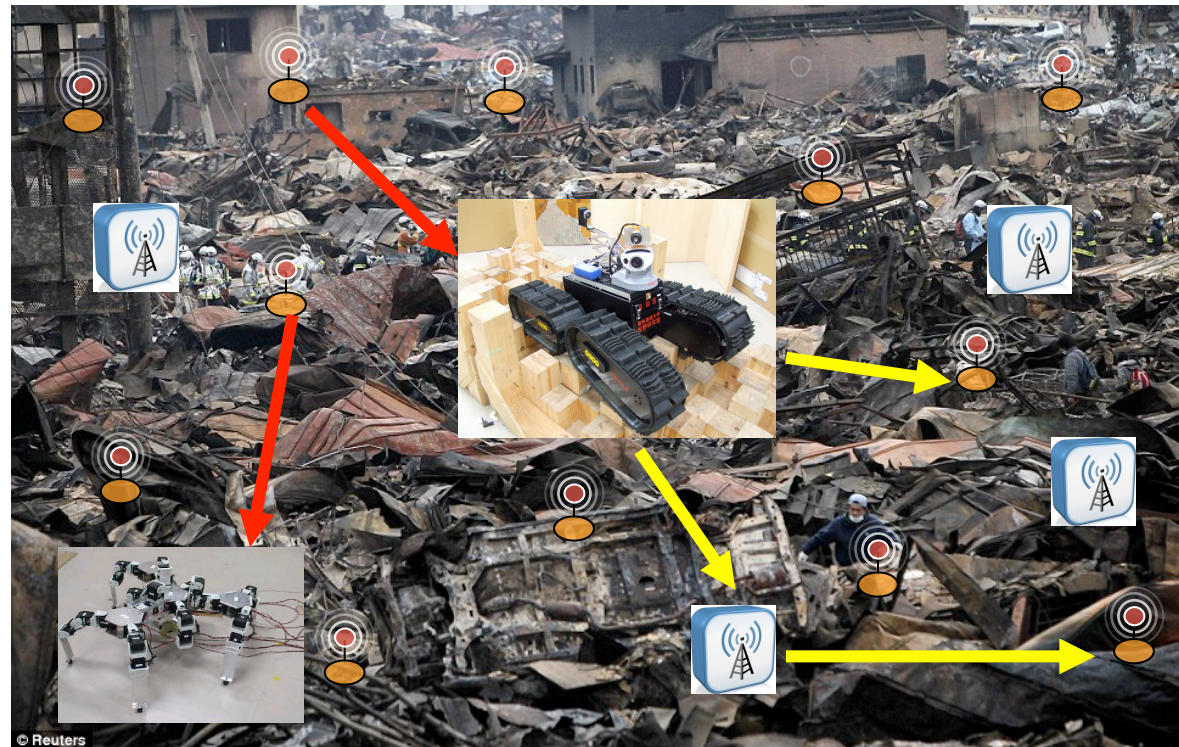
Robots could serve as relay or install communication gateways to maintain WSN connectivity and increase data storage capability



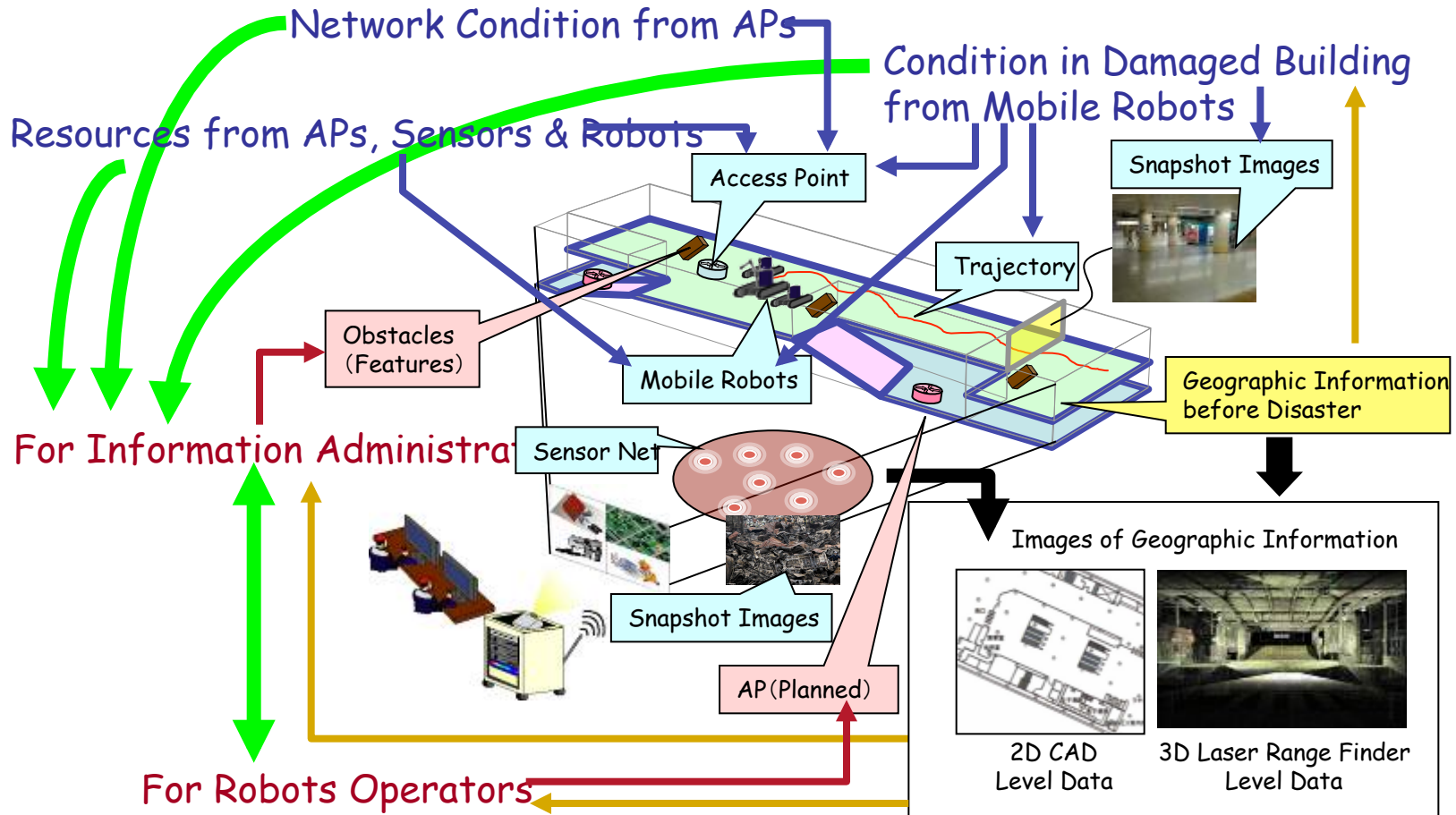
SENSOR & ROBOTS SEARCH & RESCUE

□ RESCUE COULD BE OPERATED IN SEVERAL PHASES (4)

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



DISASTER MANAGEMENT INFORMATION SYSTEMS



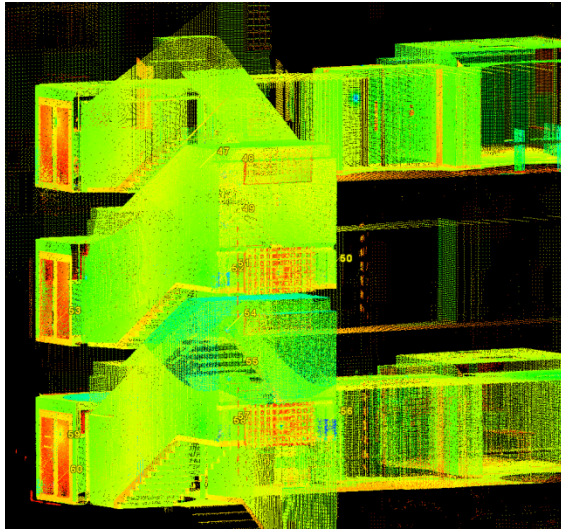
From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System », Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10. Modified by C. Pham with sensor nets.

Making Base GIS Data

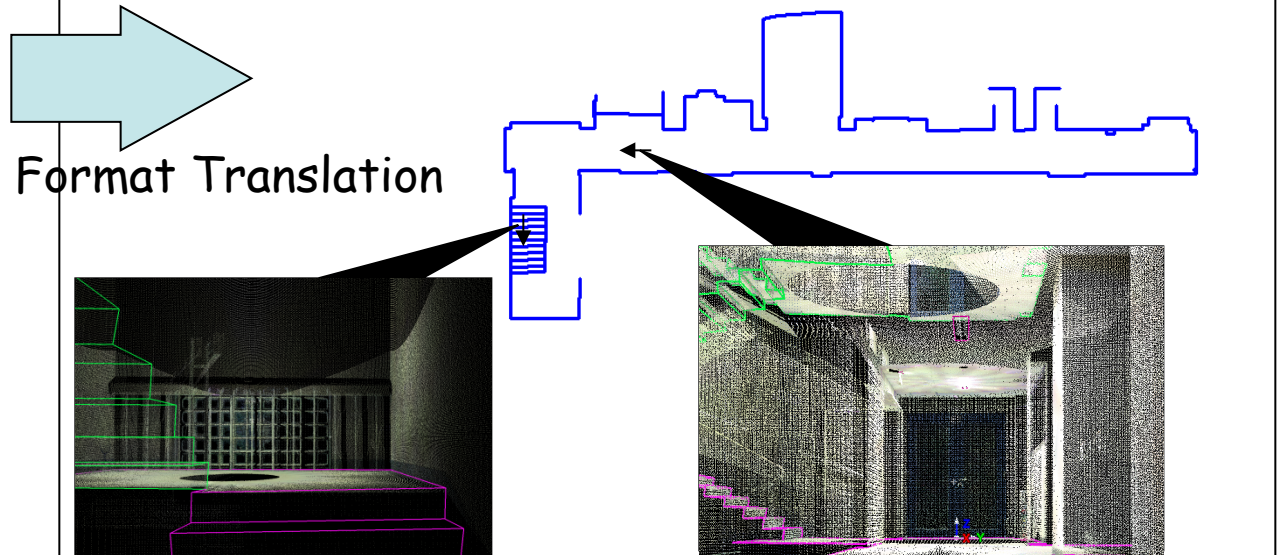
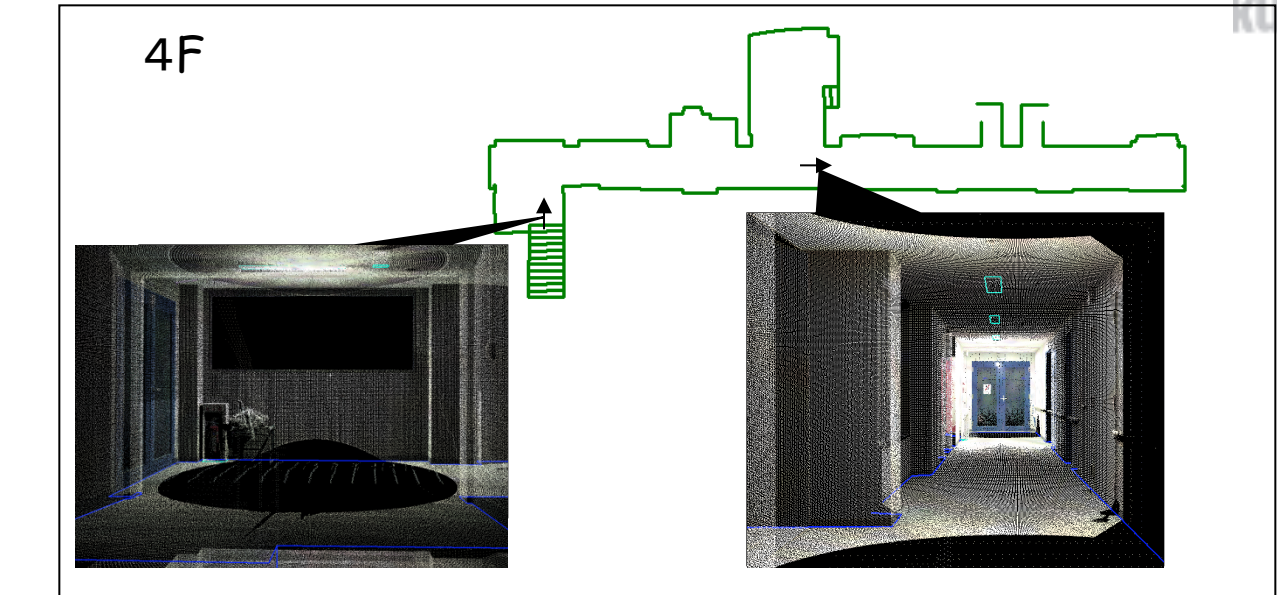
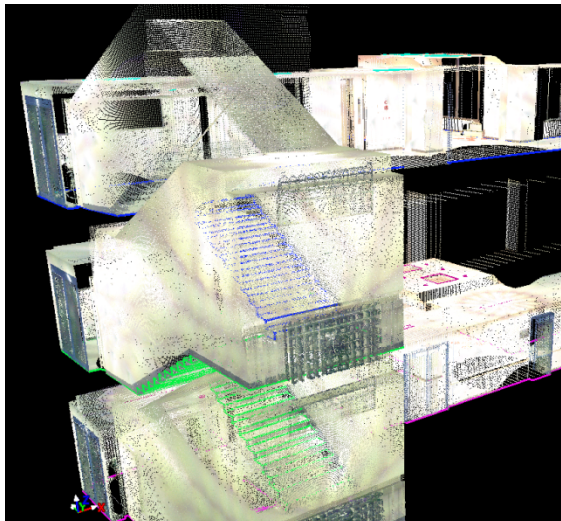


3D Laser Range Finder

accuracy: mm



Points to Polygons



From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System », Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10

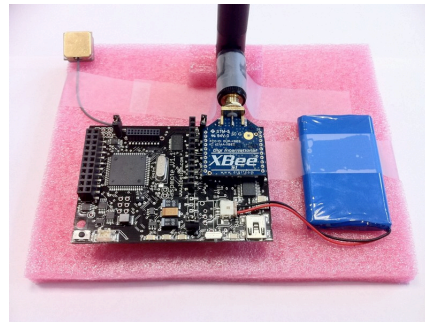
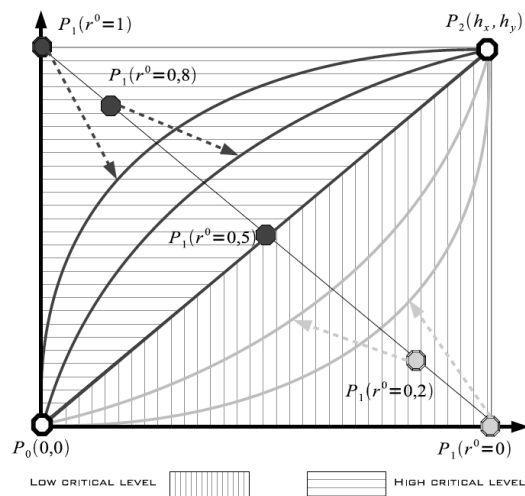


From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System », Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10

SENSORS & ROBOTS

PROPOSE NEW INTERACTION SCHEMES

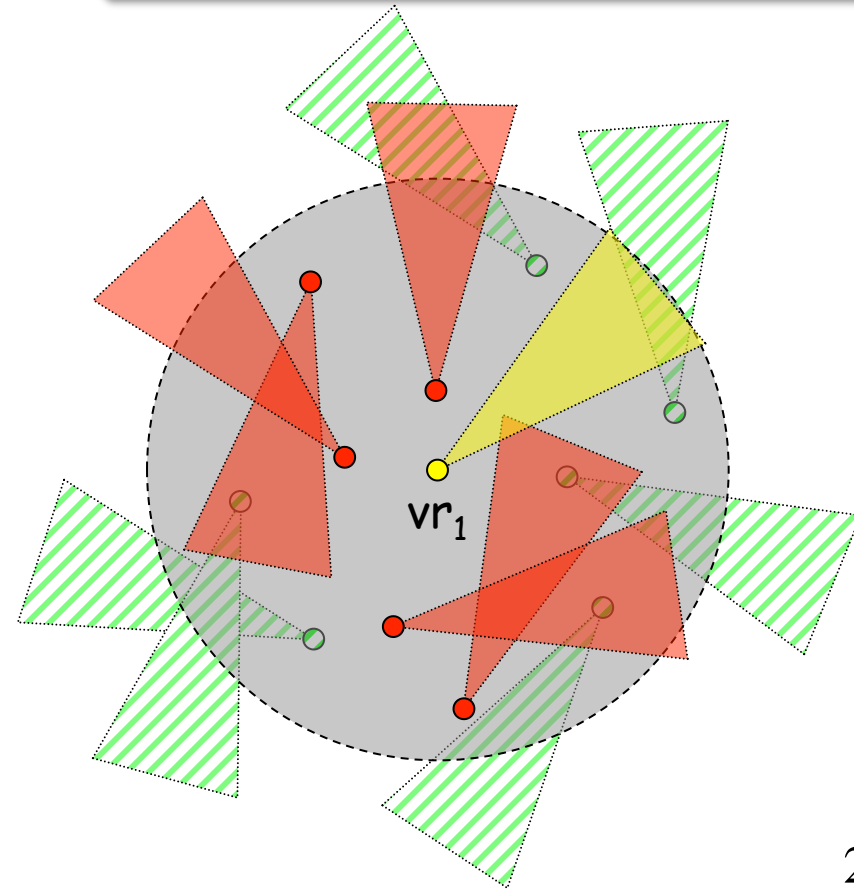
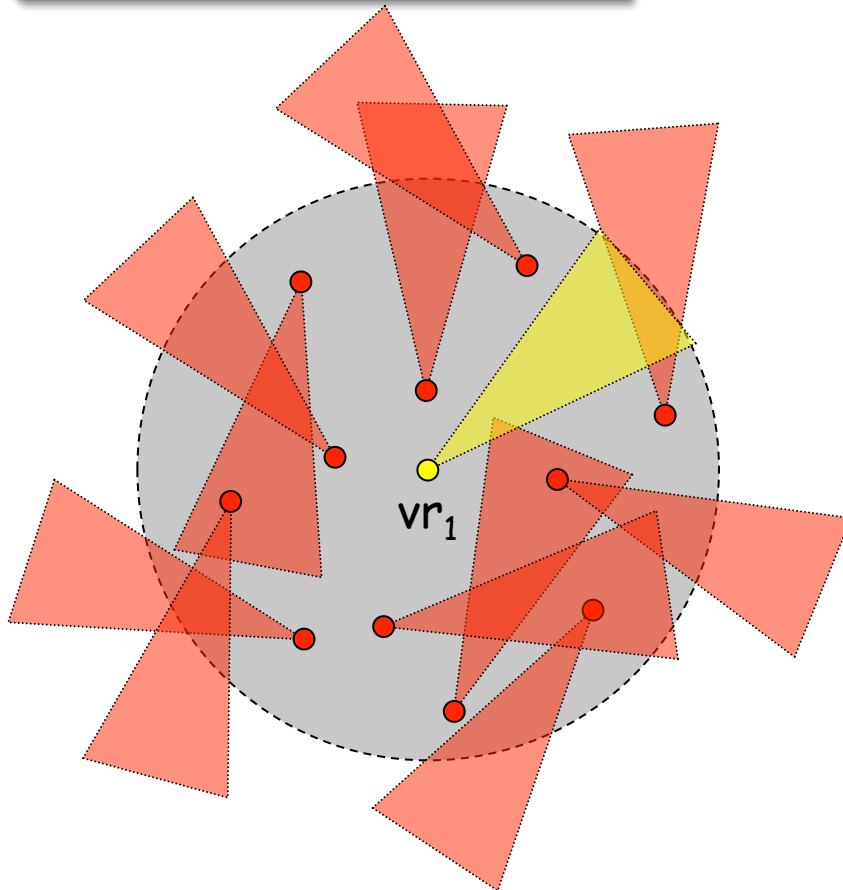
- ❑ USE THE CRITICALITY MODEL TO CONTROL BOTH SENSORS AND ROBOTS
- ❑ PROTOTYPING ON REAL HARDWARE, COLLABORATION WITH U. KYOTO, JAPAN



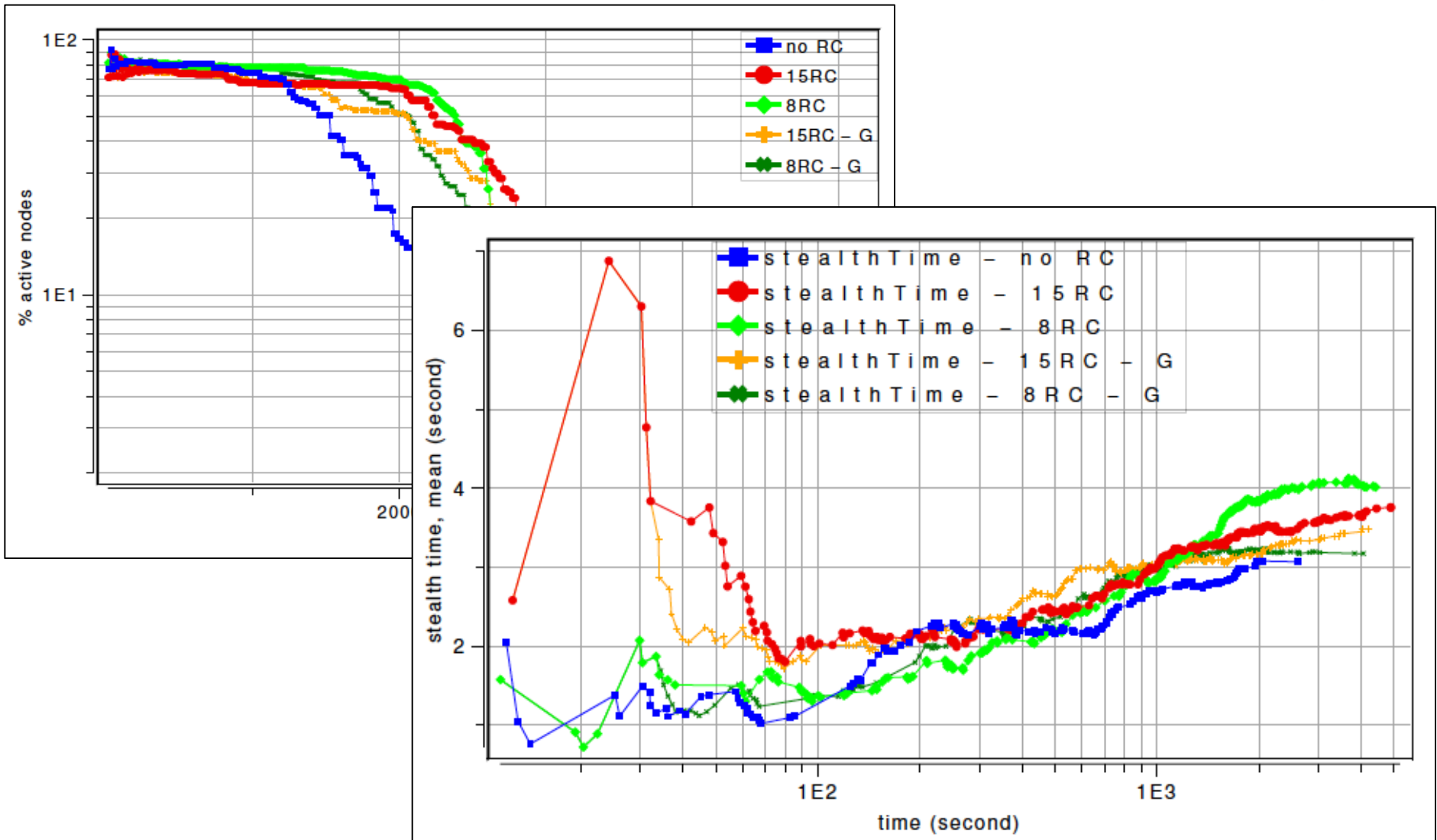
COOPERATION WITH CAMERAS ON MOBILE ROBOTS

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

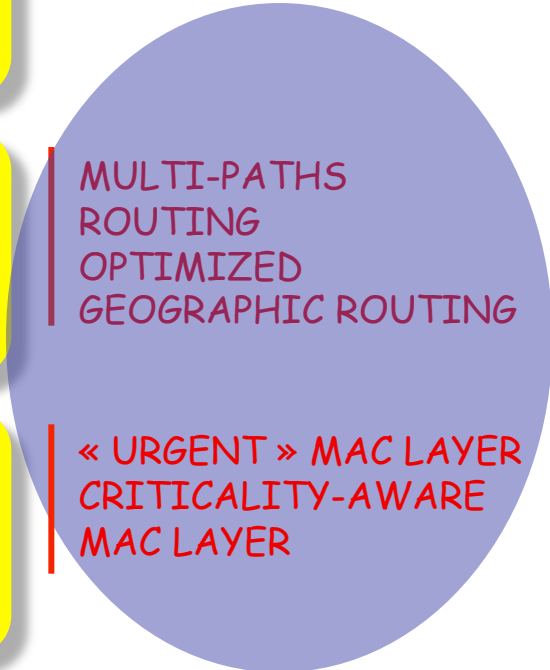
LOAD-REPARTITION
CONGESTION CONTROL

ROUTING

MULTI-PATHS
ROUTING
OPTIMIZED
GEOGRAPHIC ROUTING

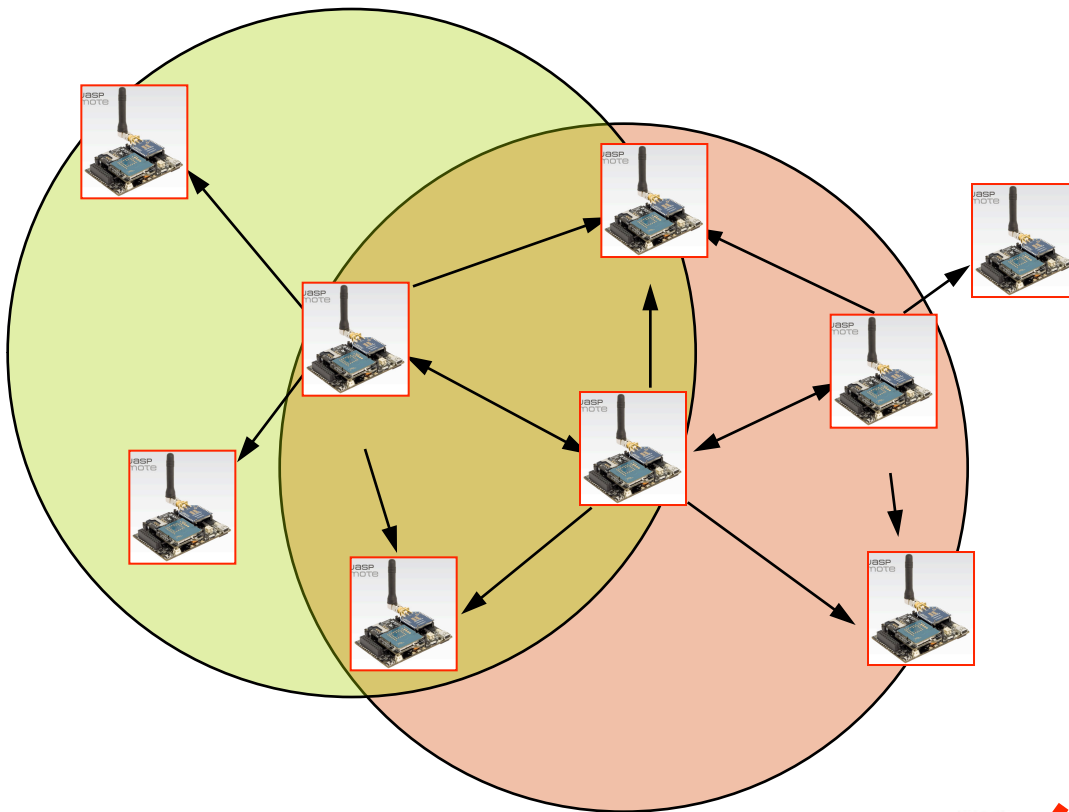
MAC
RESOURCES
ALLOCATION

« 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



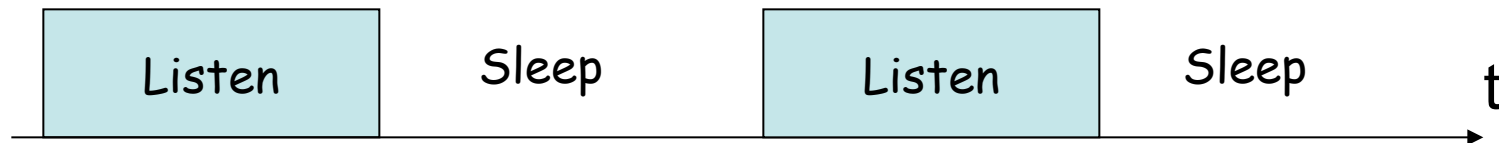
WiFi transmission power is too energy-consuming for WSN!

Huge cost of passive listening!

WSN can be idle for a long period!

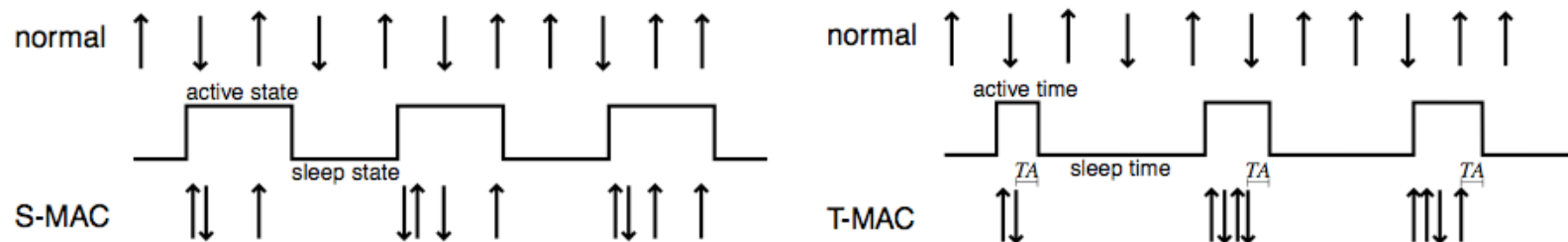
S-MAC - SENSOR MAC

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



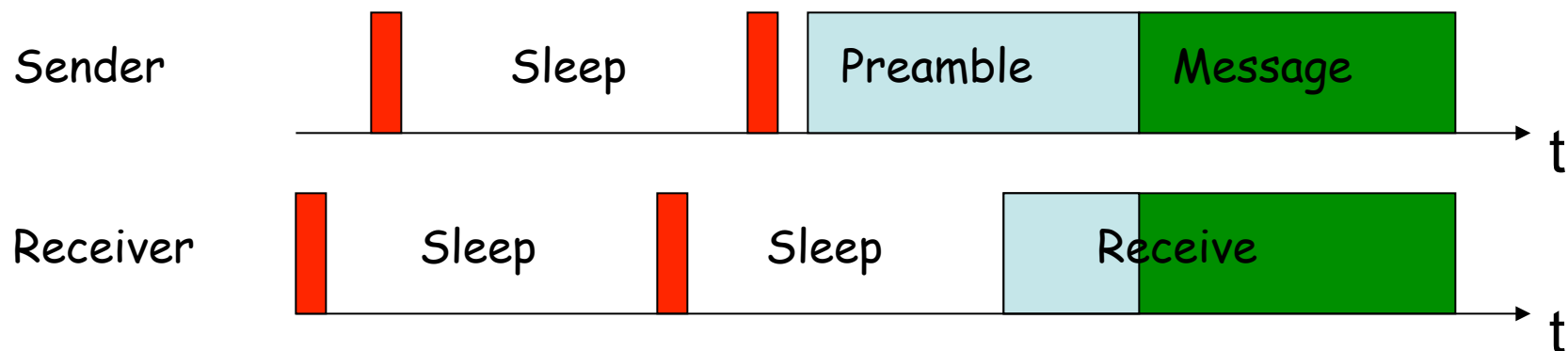
T-MAC - TIMEOUT MAC

- 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**

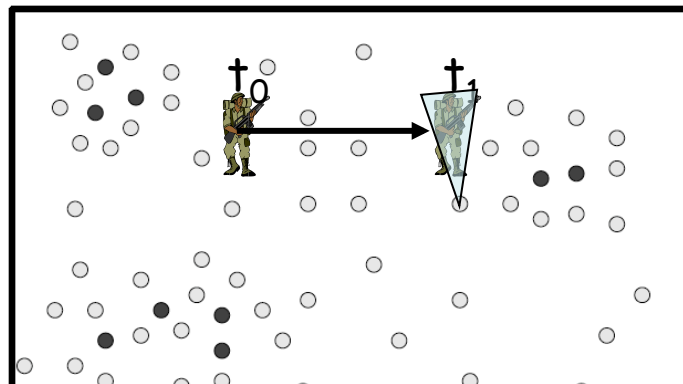


CHALLENGES FOR MAC PROTOCOLS IN WSN

- ❑ 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 image displays two screenshots from the OMNeT++ simulation environment. The left screenshot shows the internal structure of a node (SN.node[0]), highlighting the communication layer components: Radio, MAC, and Routing. The right screenshot shows a network topology with multiple nodes (node0 to node59) and a console window displaying simulation logs. An orange callout box is overlaid on the right screenshot, containing the text: "Need to know the power consumption for capturing an image, processing/compressing an image & transmitting an image...". A small inset image in the bottom left corner shows a physical sensor module.

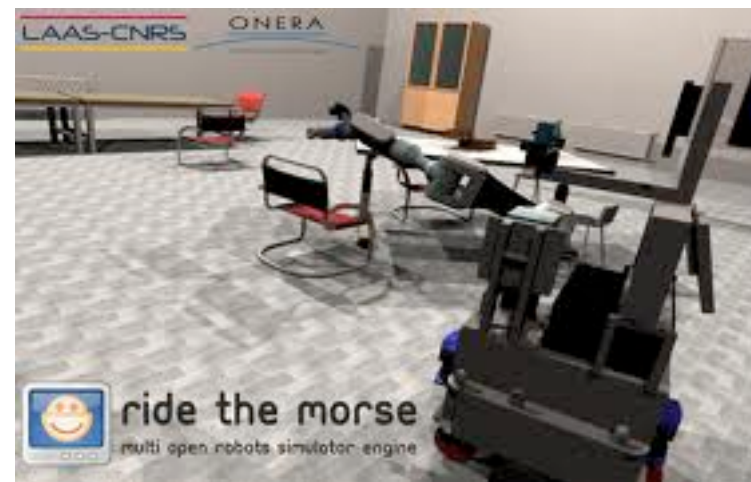
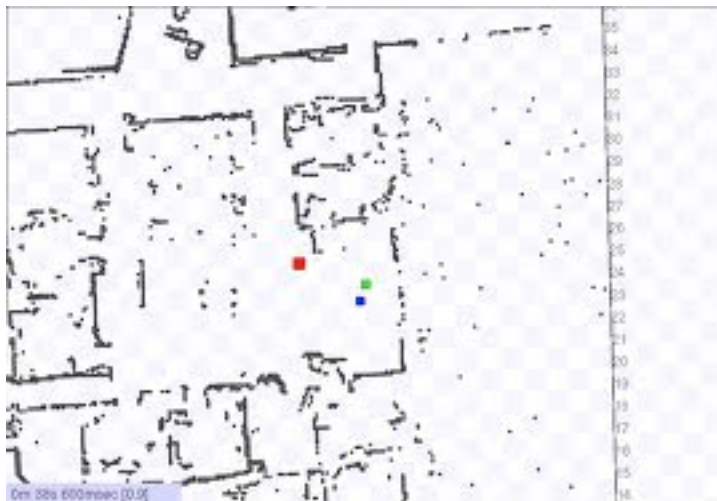
STUDY THE IMPACT OF COMMUNICATION LAYER ON SURVEILLANCE QUALITY

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" controls. The zoom level is set to 0.79x. The map shows various nodes with associated IP addresses and status indicators.
- Right:** A terminal window titled "OMNeT++/Tkenv - SN" showing the simulation's output. The terminal displays the following information:
 - Simulation time: T=31.118698566965
 - Running status: Running...
 - Messages created: 667040
 - Messages present: 1867
 - Simulation time per second: 0.778365
 - Events per simulation second: 15059.8The terminal output shows a series of log messages, including:
 - SN.node[46].Application Sending [image] of size 288 bytes to communication layer
 - SN.node[148].Application Node 148: INTRUSION SEEN
 - SN.node[5].Application Node 5: INTRUSION SEEN
 - SN.node[6].Application Node 6: INTRUSION SEEN
 - SN.node[124].Application Node 124: INTRUSION SEEN
 - SN.node[79].Application Node 79: WRITES IMAGE FILE(1) from node 10
 - SN.node[79].Application Node 79: 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 a network diagram on the left, titled '(SN) SN', showing a central 'coordinator' node connected to an 'intrusion' node and a 'wirelessChannel' node. Below these are numerous 'node' instances (e.g., node[0], node[1], node[2], node[3], 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]) each represented by a robot icon with a sensor range. On the right, a 3D simulation window shows a red robot on a grassy hillside with a red laser scan. The simulation window includes a 'Camera Control' panel and a 'Scene' panel. Red arrows point from the network diagram to the 3D simulation, indicating the integration of the two systems.