Fixed Image Sensors and Mobile Camera Robots Interactions for Mission-Critical Surveillance Applications

IROS'2012, ROSIN workshop
October 11th, 2012
Vilamoura, Portugal

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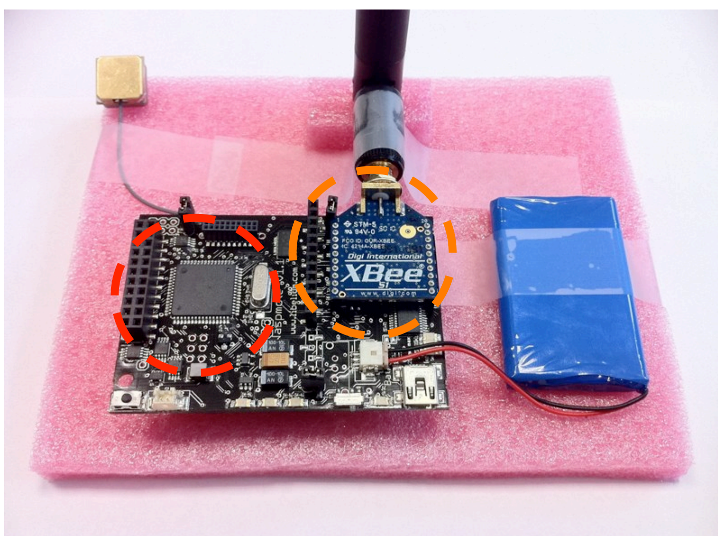
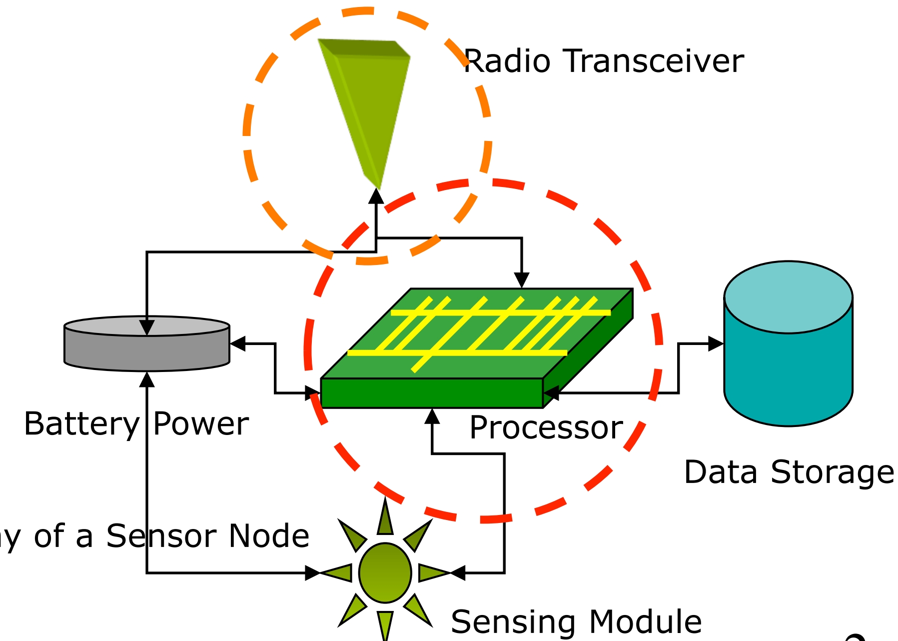
Wireless autonomous sensor

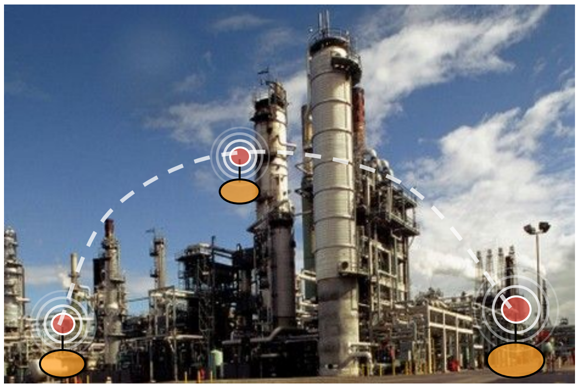
- In general: low cost, low power (the battery may not be replaceable), small size, prone to failure, possibly disposable
- Role: sensing, **data processing**, communication





Anatomy of a Sensor Node

Monitoring/Surveillance



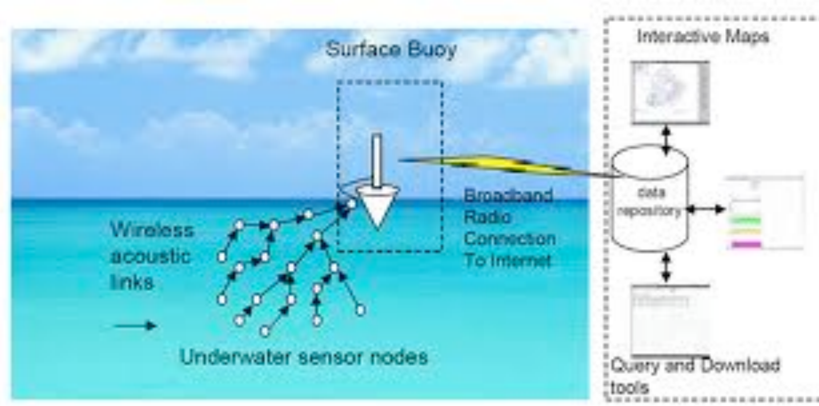
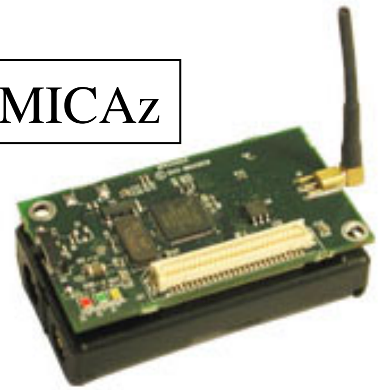


Image sensor motes

iMote2



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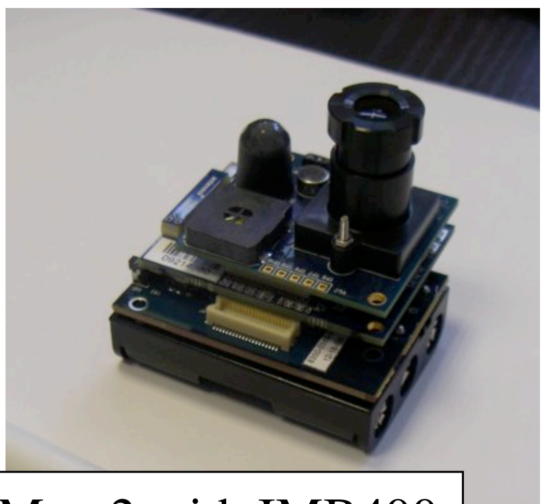
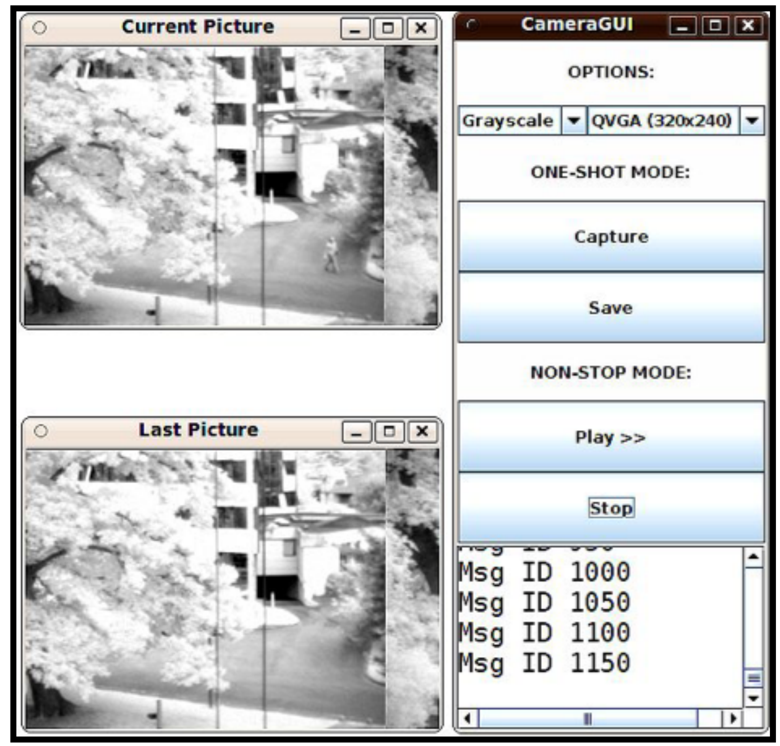
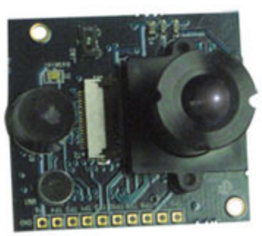


iMote2 with IMB400 multimedia board

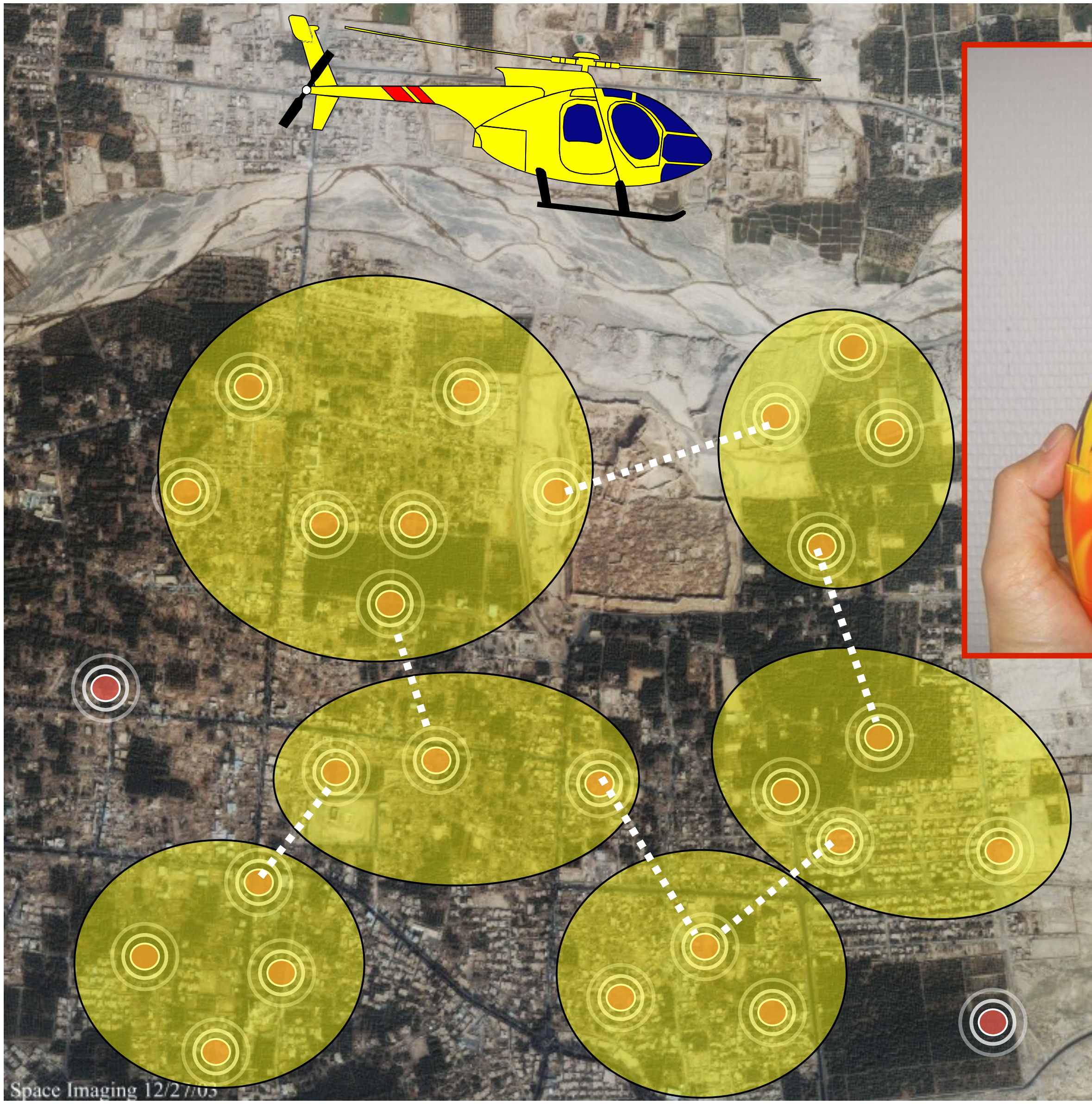


Search & Rescue

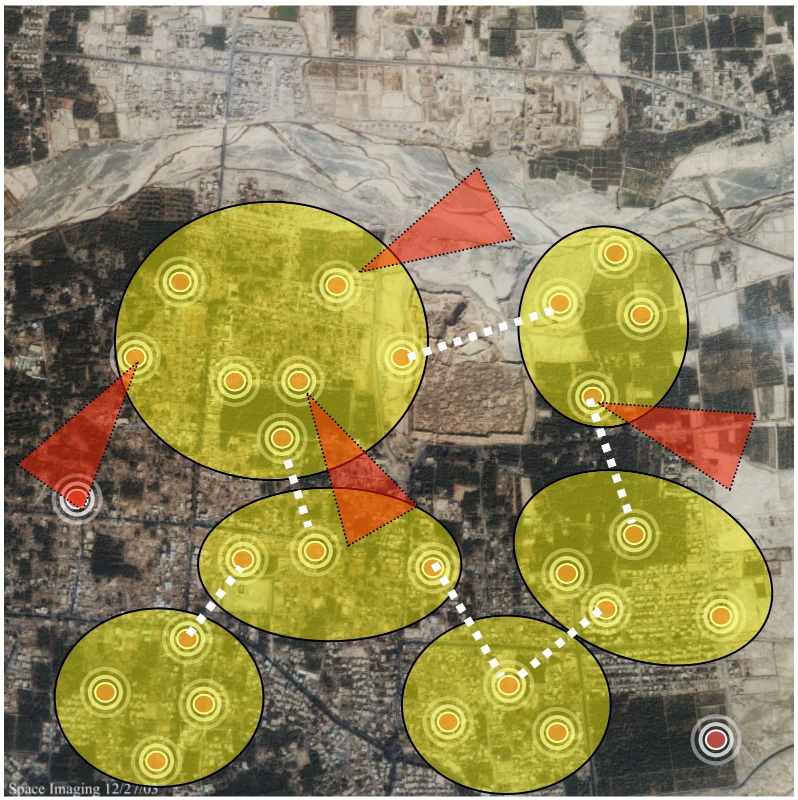
Imote2



Multimedia board

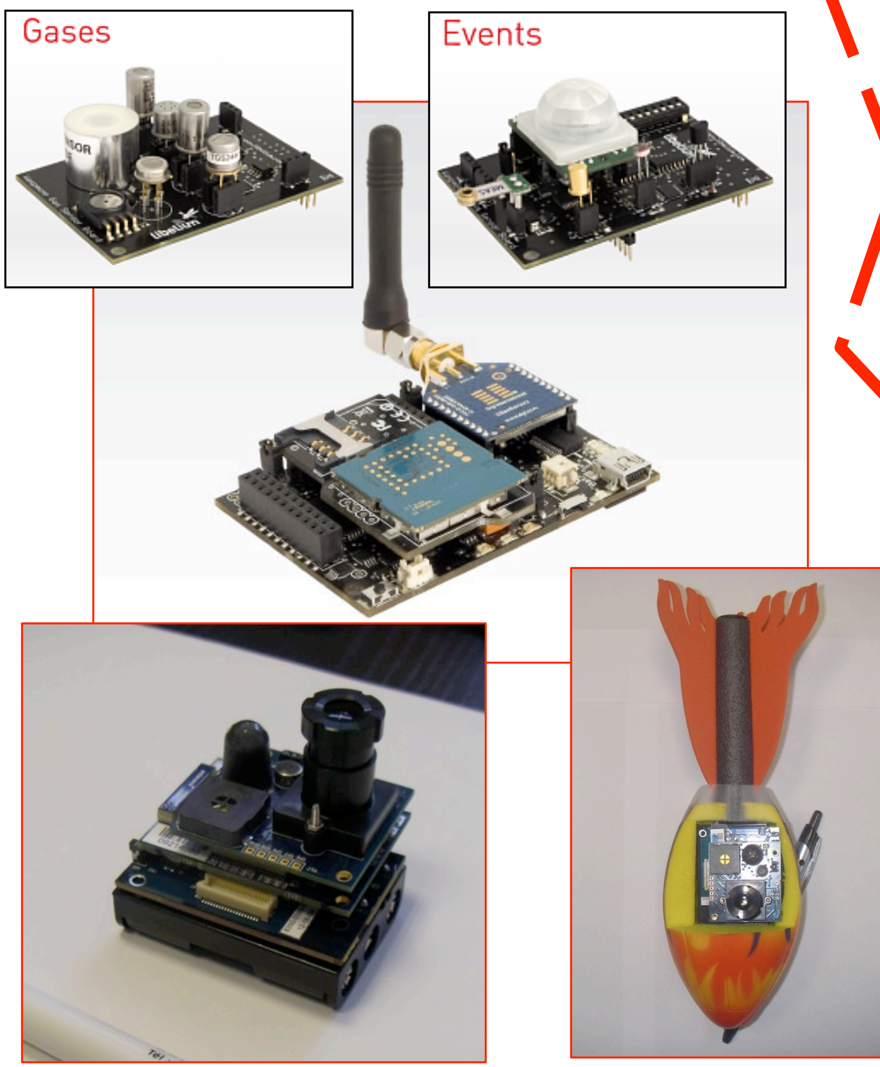


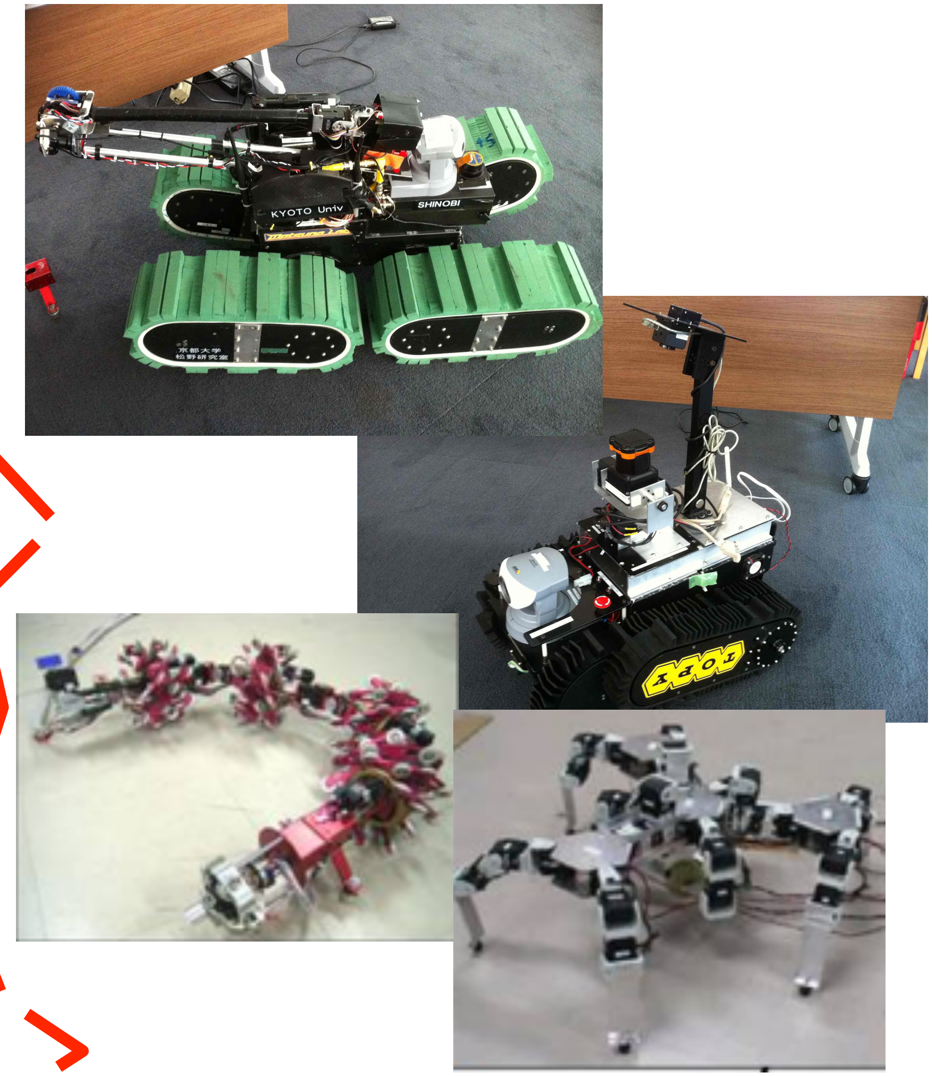
Get images from deployed sensors



Sensors & Robots

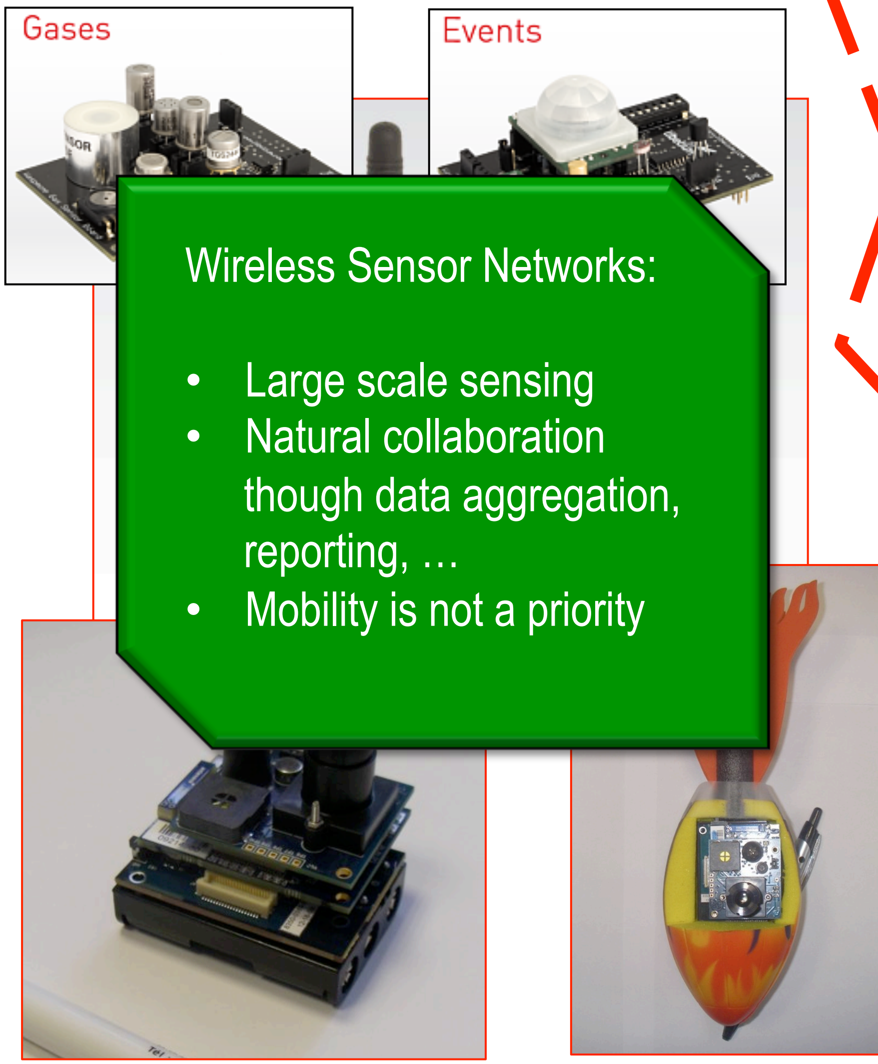
taking advantages of differences!





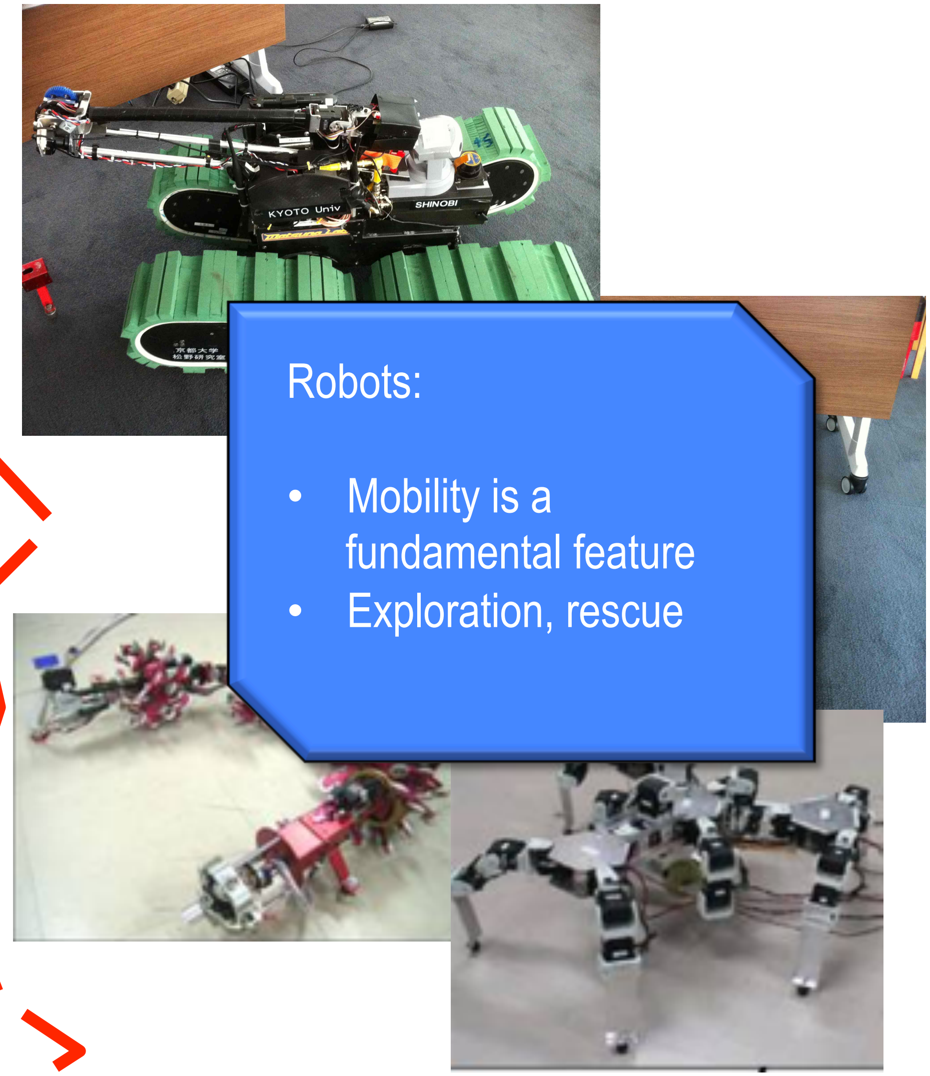
Sensors & Robots

Taking advantages of differences!



Wireless Sensor Networks:

- Large scale sensing
- Natural collaboration though data aggregation, reporting, …
- Mobility is not a priority



Robots:

- Mobility is a fundamental feature
- Exploration, rescue

Sensor & Robots Search & Rescue

- Rescue could be operated in several phases (1)

Deploy in mass a WSN to get a first snapshot of the area conditions: 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, depending on mobility type or embedded hardware.

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

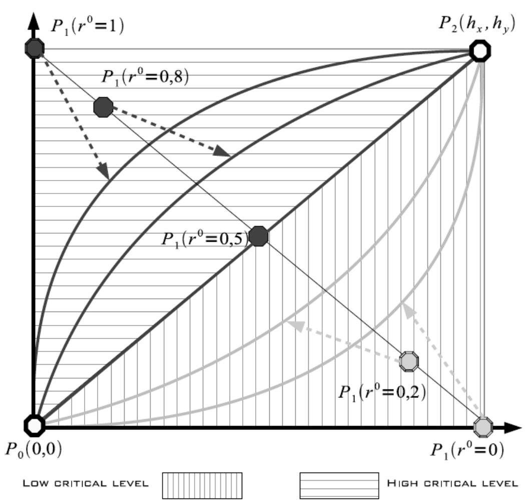
Sensor & Robots
Search & Rescue

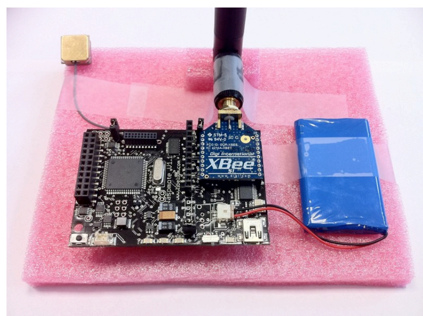
- Rescue could be operated in several phases (4)

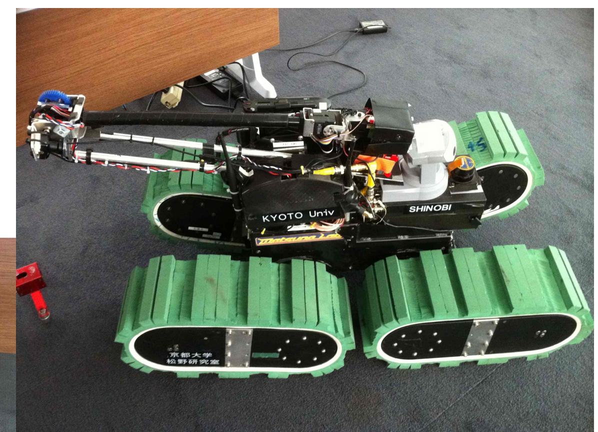
Sensor & Robots will contineously collaborate during the rescue process: localization, path optimization, remote sensing,...

Sensors & Robots Propose new interaction schemes

- Use the criticality model to control both sensors and robot
- Save energy of sensor nodes





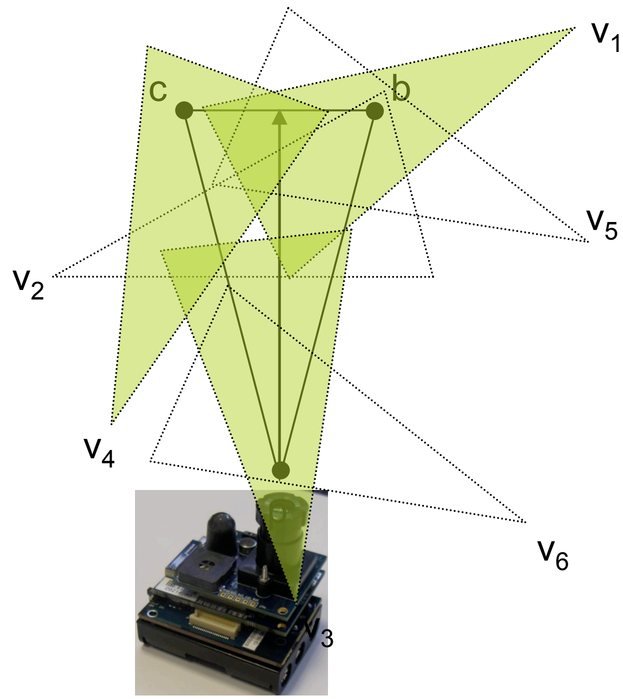


Sensor node's cover set

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

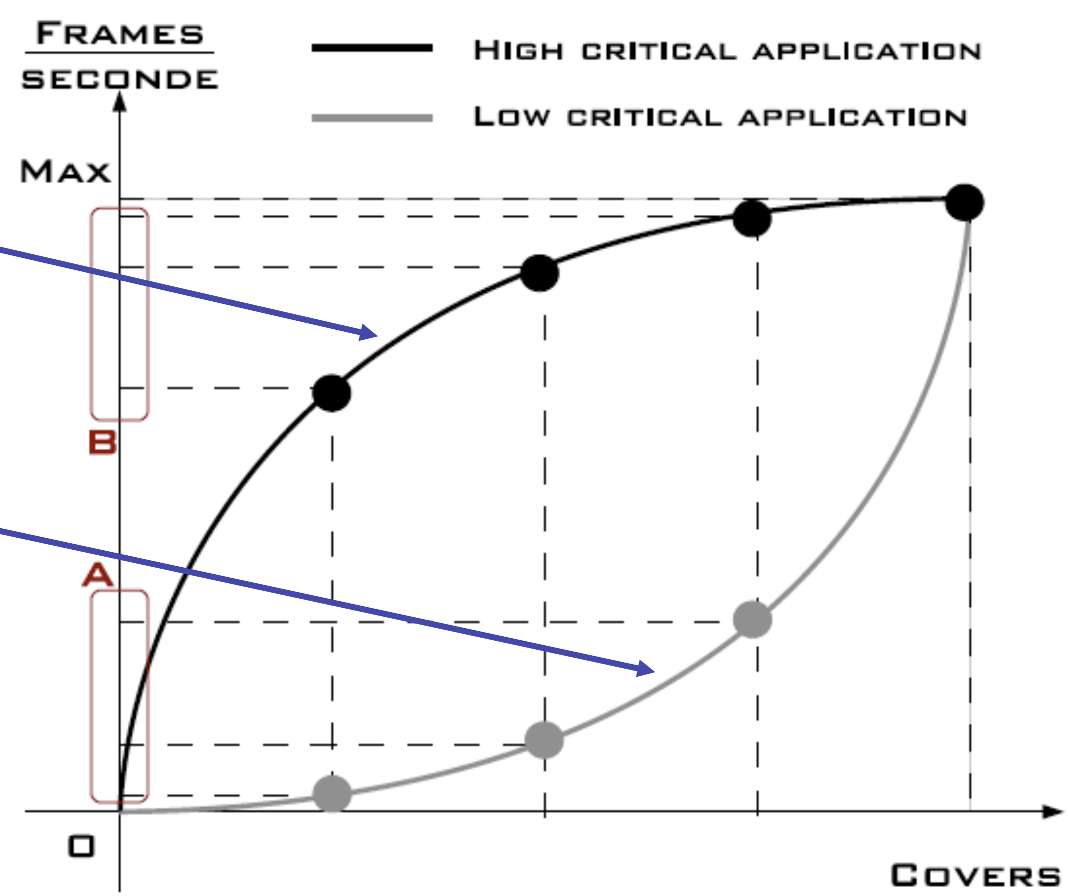
⇩

|Co(V)| = 7



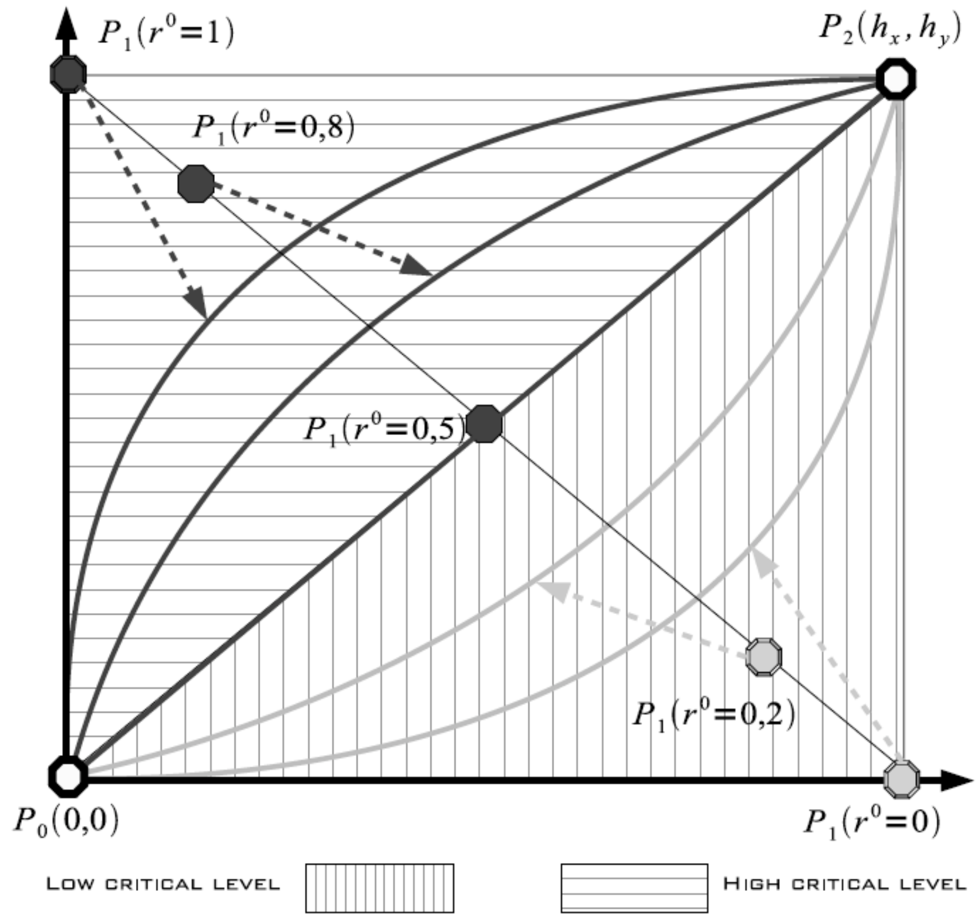
Criticality model (1)

- 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



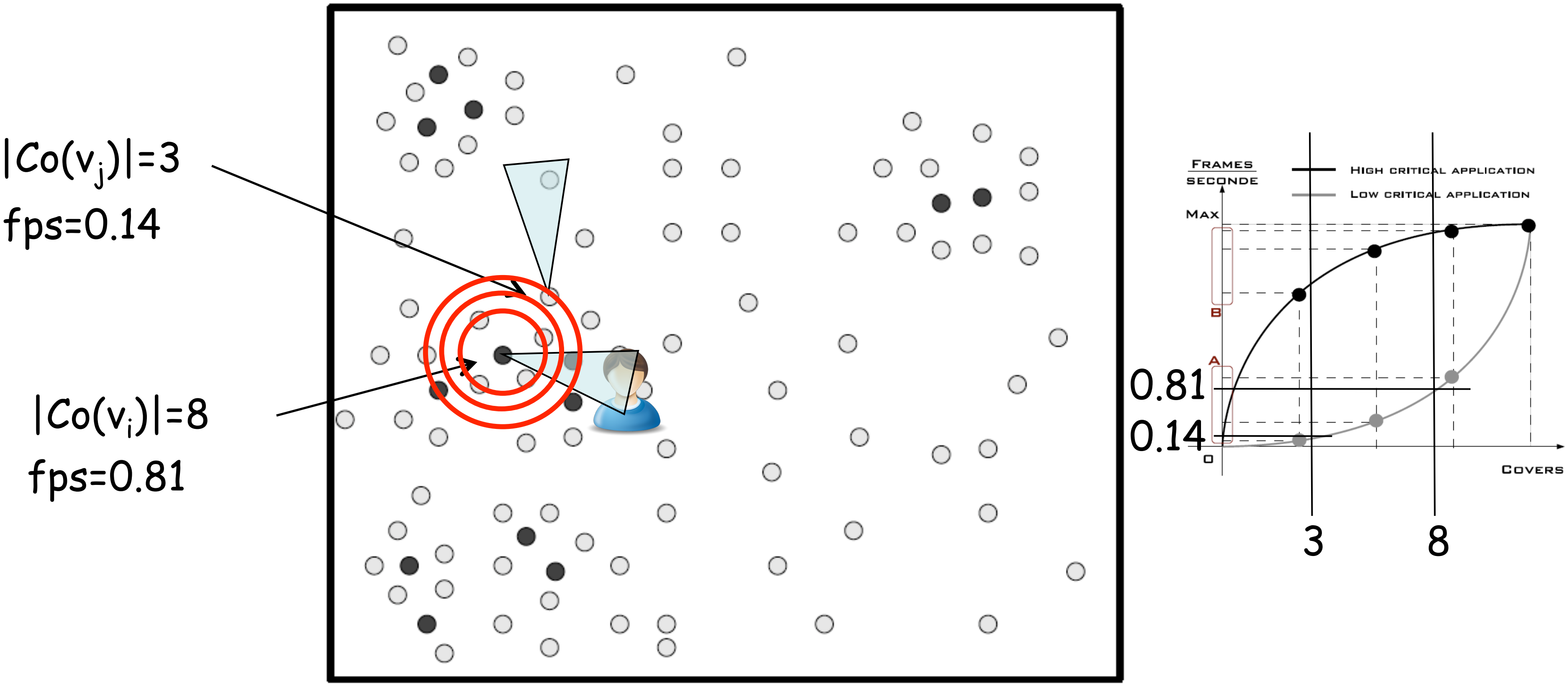
Criticality model (2)

- 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



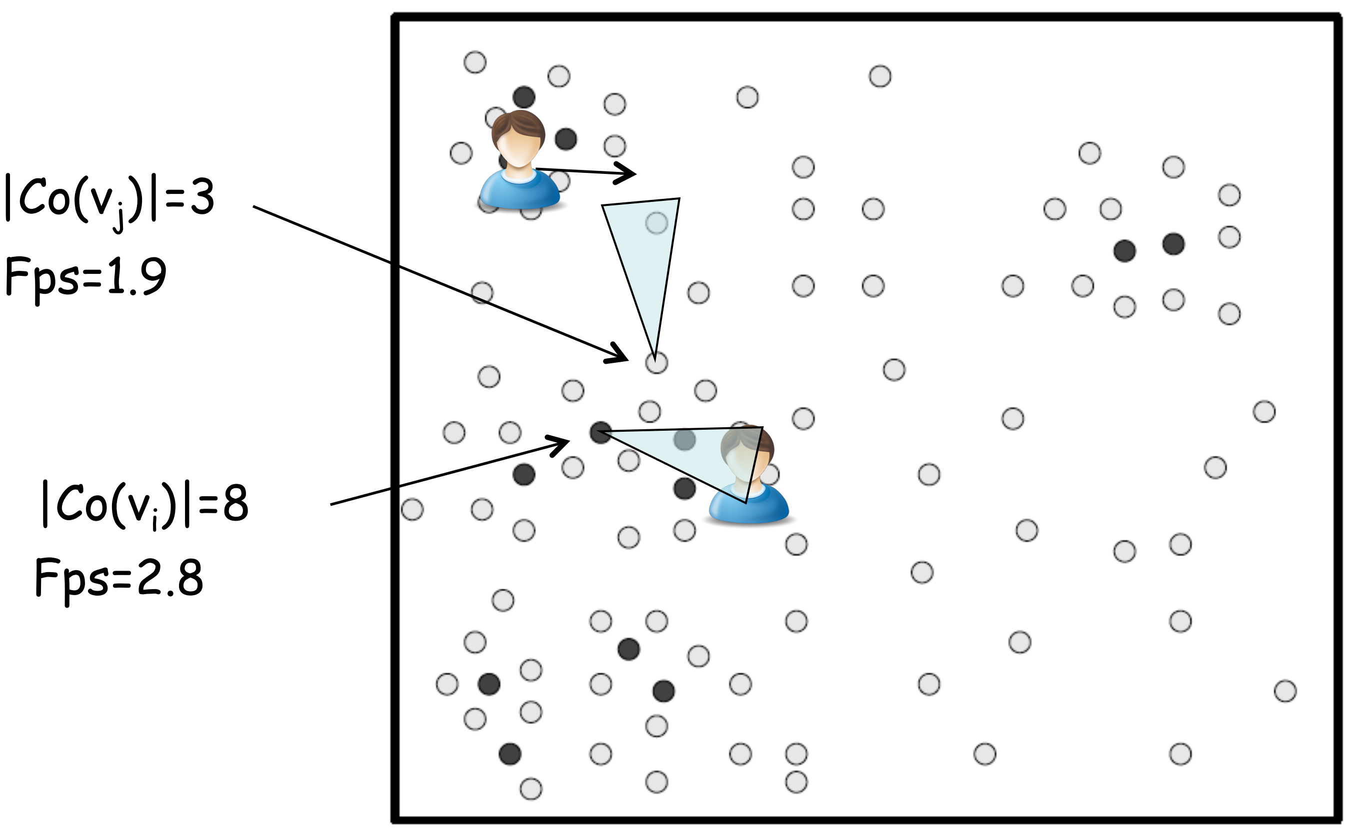
Risk-based scheduling in images (1)

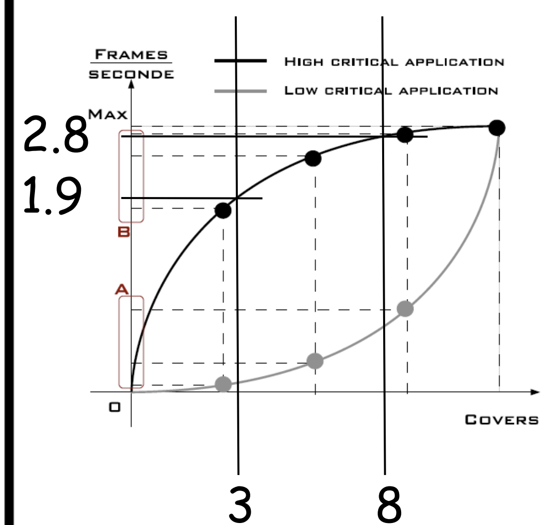
- R°=R°$_{MIN}$=0.1, R°$_{MAX}$=0.9, no alert



Risk-based scheduling in images (2)

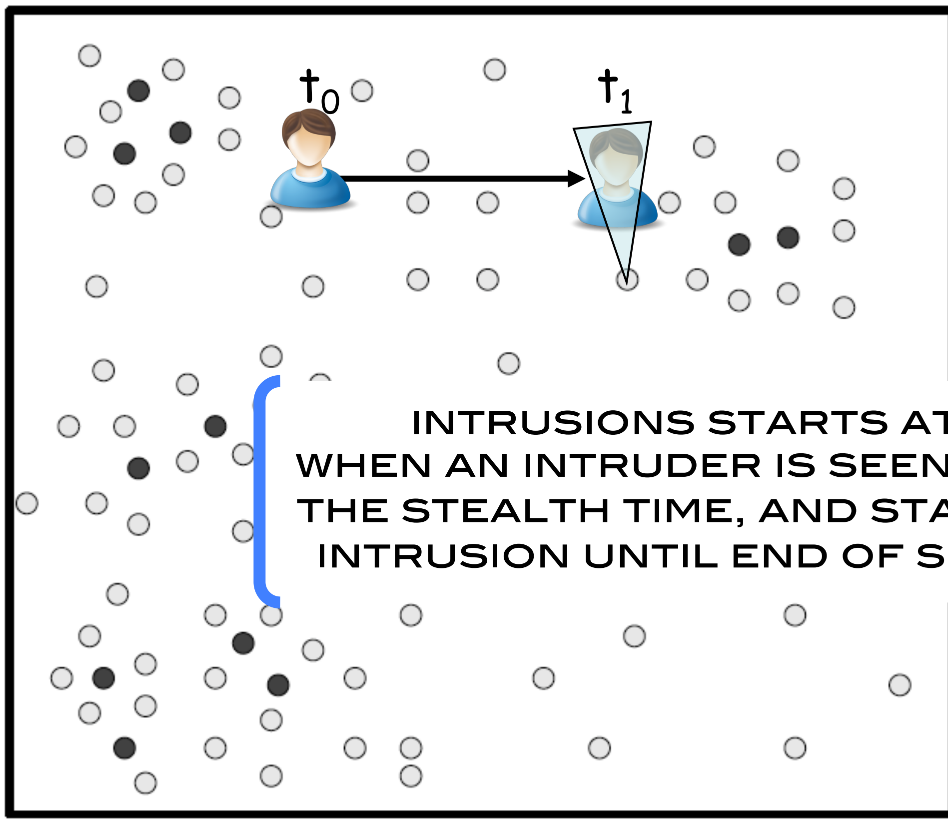
- $R° \rightarrow R° = R°_{MAX} = 0.9$





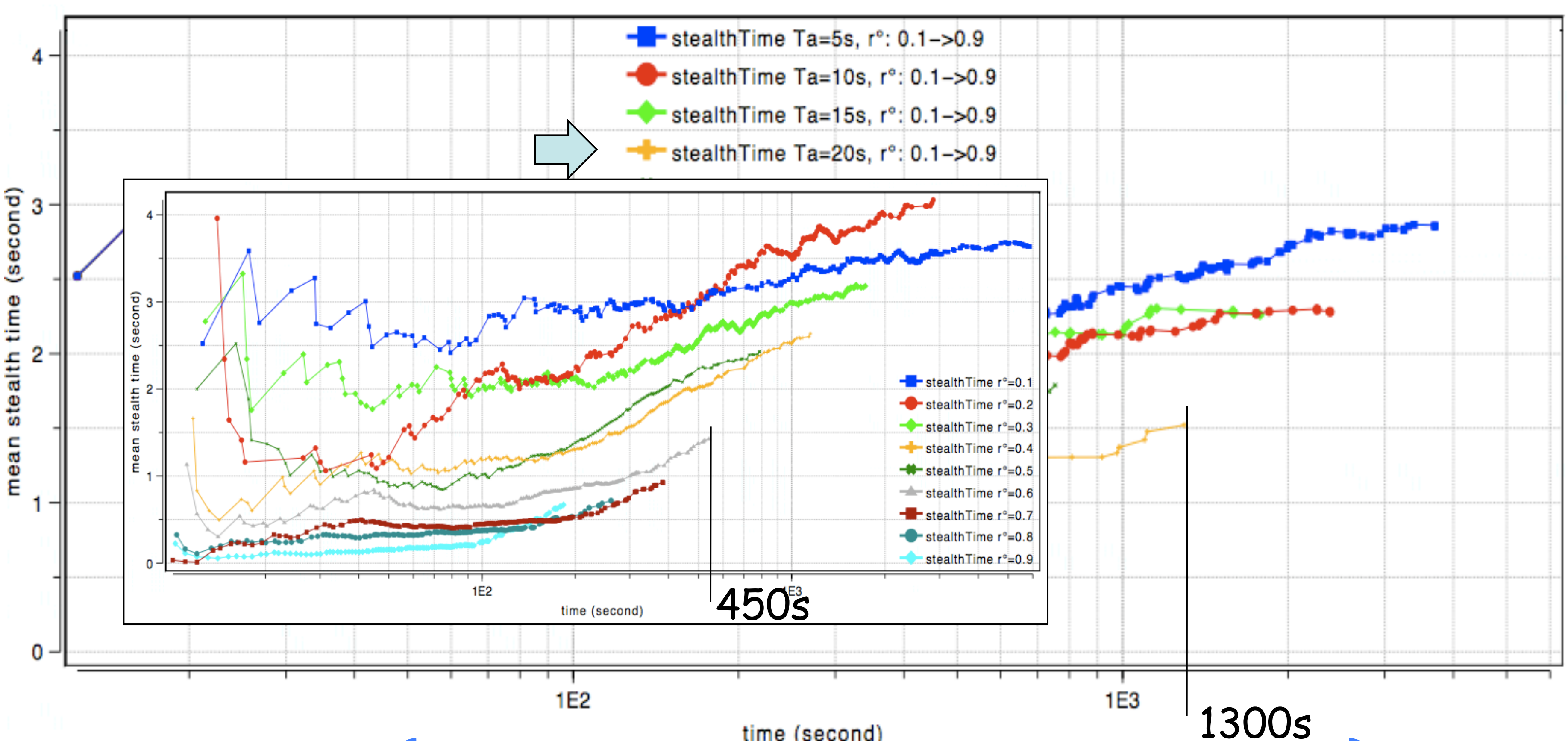
MEAN STEALTH TIME

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



INTRUSIONS STARTS AT T=10S
WHEN AN INTRUDER IS SEEN, COMPUTE THE STEALTH TIME, AND STARTS A NEW INTRUSION UNTIL END OF SIMULATION

Mean stealth time risk-based scheduling

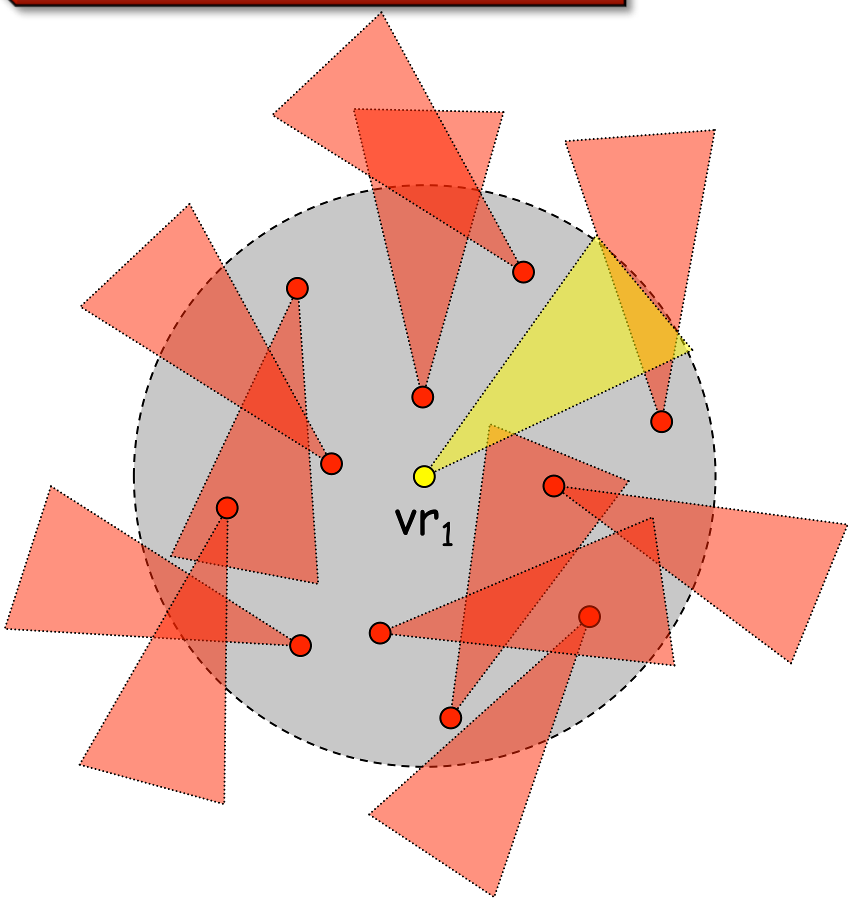


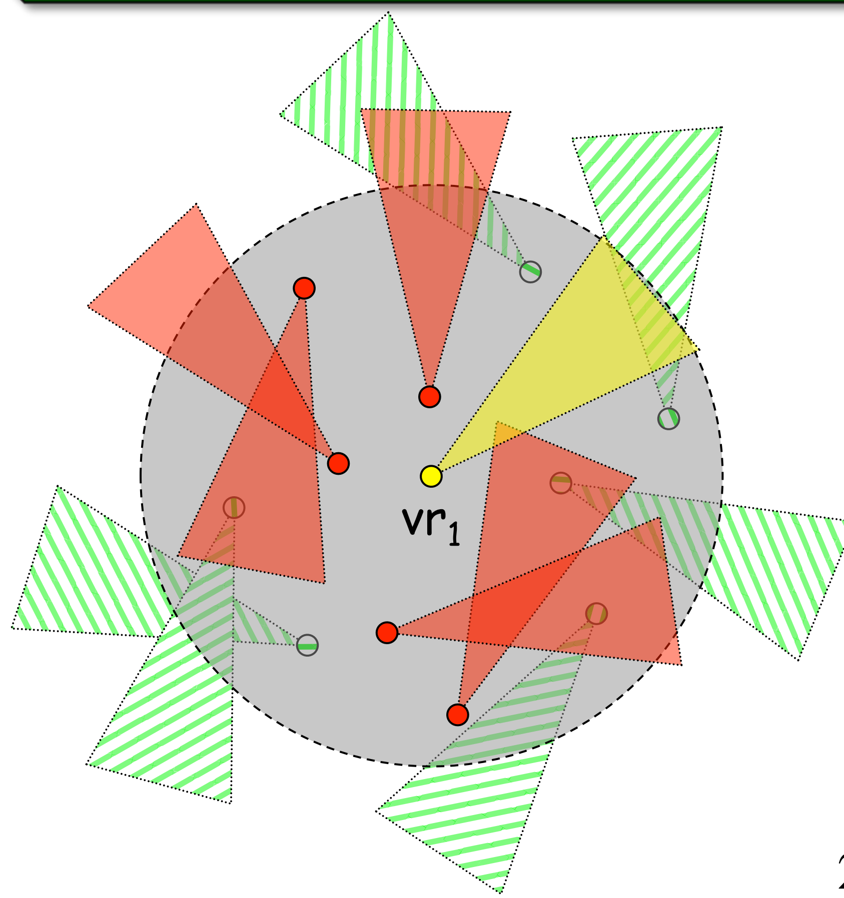
Sensor nodes start at 0.1 then increase to 0.9 if alerted (by intruders or neighbors) and stay alerted for Ta seconds

Cooperation with cameras on mobile robots

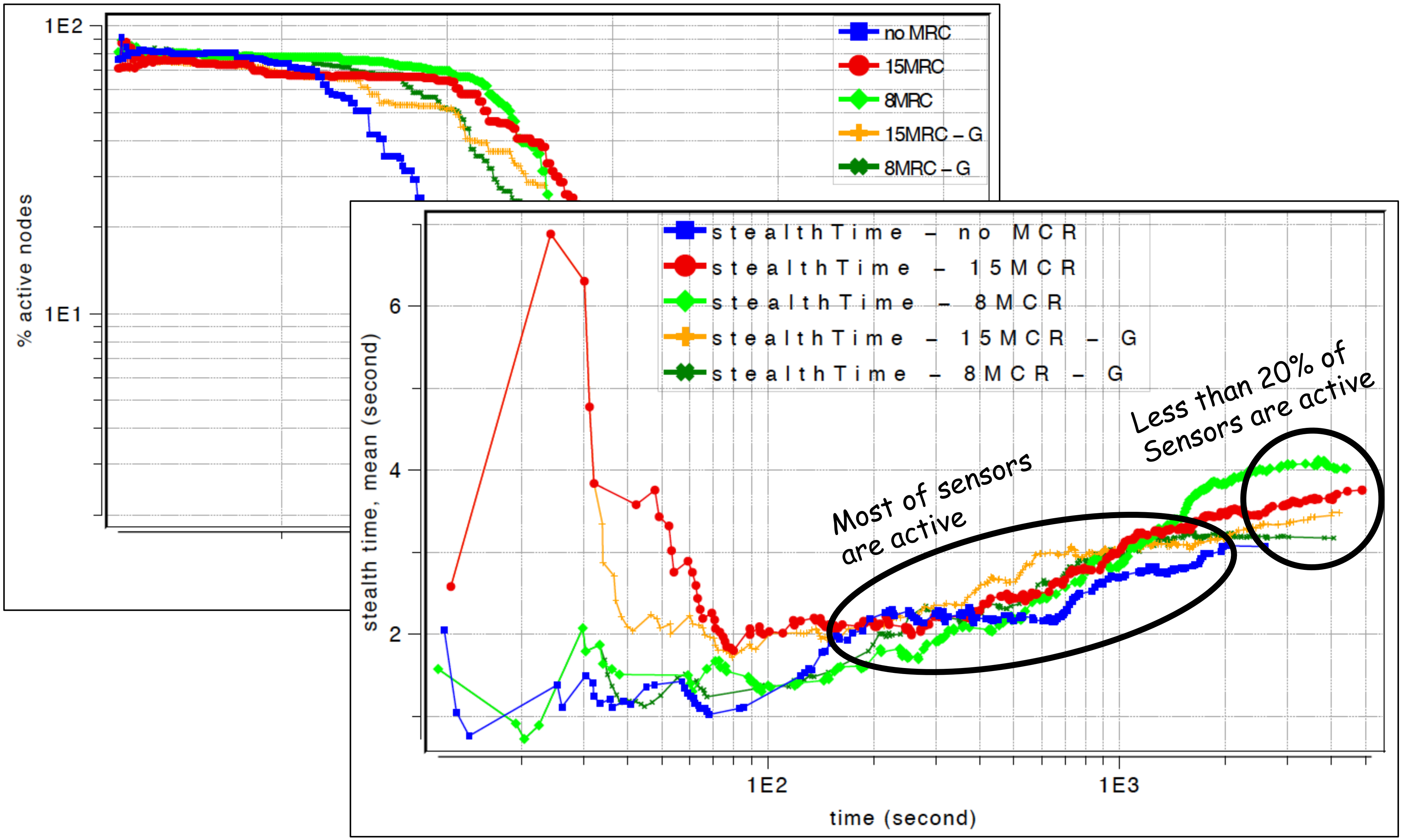
Fixed image sensors near a mobile camera can decrease their criticality level to $R°_{min}$

ONLY fixed image sensors whose FoV's center is covered by a mobile camera **CAN** decrease their criticality level to $R°_{min}$



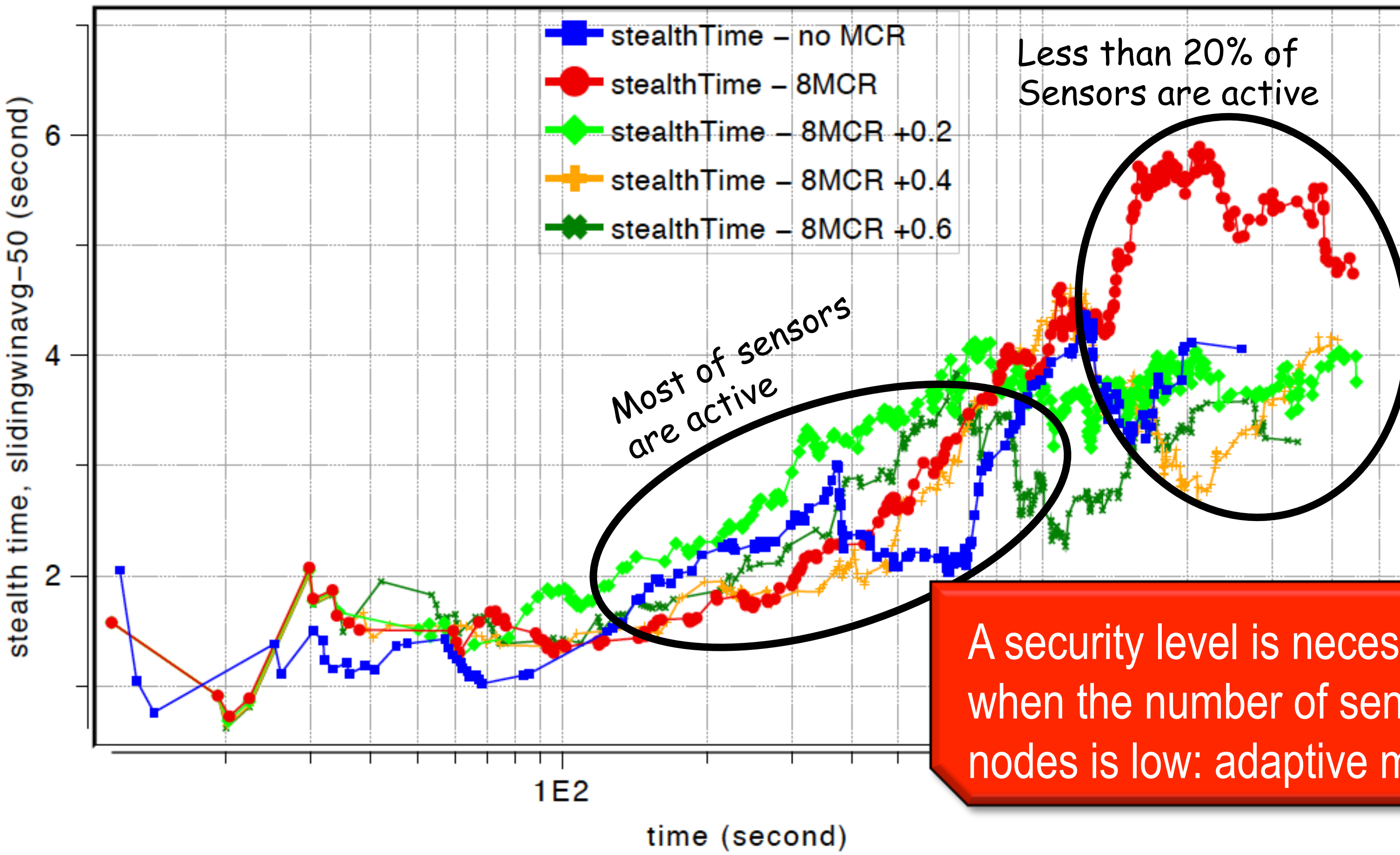


Impact on lifetime & stealth time



How low the criticality level could be reduced?

- We add a security level: $R°_{MIN}$+S

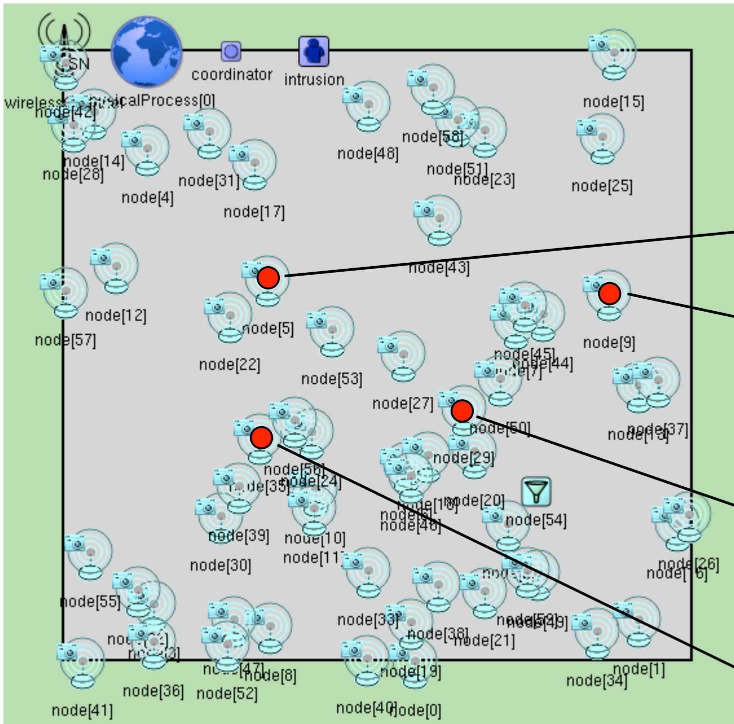


A security level is necessary when the number of sensor nodes is low: adaptive method

Conclusions

- Sensors & Robots are complementary technologies for mission-critical applications
- We propose that both sensors and mobile robots share the same criticality model
- Then Mobile robots can help fixed sensor nodes to save their energy without degrading the surveillance quality
- There are a lot of variants that could be implemented
- Energy saving is not the only gain
  - Fewer congestions, less contention on radio medium, more image packets received at the sink
  - Synchronous MAC layer could use camera rotation time to adapt the listening interval or determine NAV-like reservation vectors
  - Nodes could rather focus on relaying packets

A simulator for image sensors



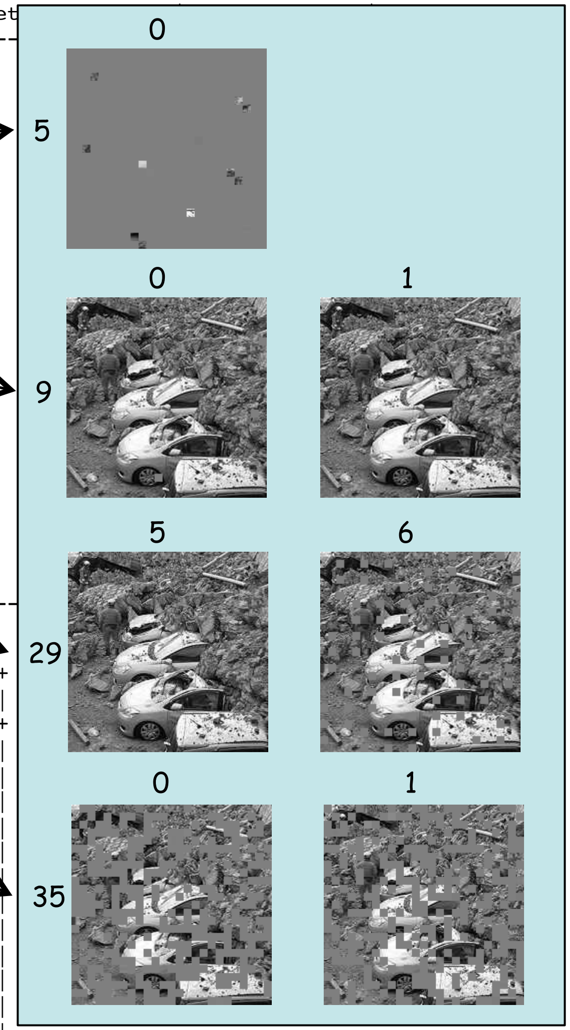
60 image sensor nodes
75mx75m
1 sink (node 54)

Application:Image sent

	Images	Packets	by coverset
node=2	1	206	0
node=5	4	824	0
node=9	2	412	2
node=10	6	1236	6
node=12	1	206	0
node=15	2	412	2
node=17	1	206	0
node=19	3	618	0
node=22	4	824	0
node=23	2	412	0
node=24	6	1236	0
node=26	1	206	1
node=27	6	1236	0
node=29	7	1442	6
node=33	6	1236	6
node=35	12	2472	0
node=37	5	1030	0
node=40	8	1648	3
node=46	2	412	2
node=48	2	412	0
node=50	2	412	2

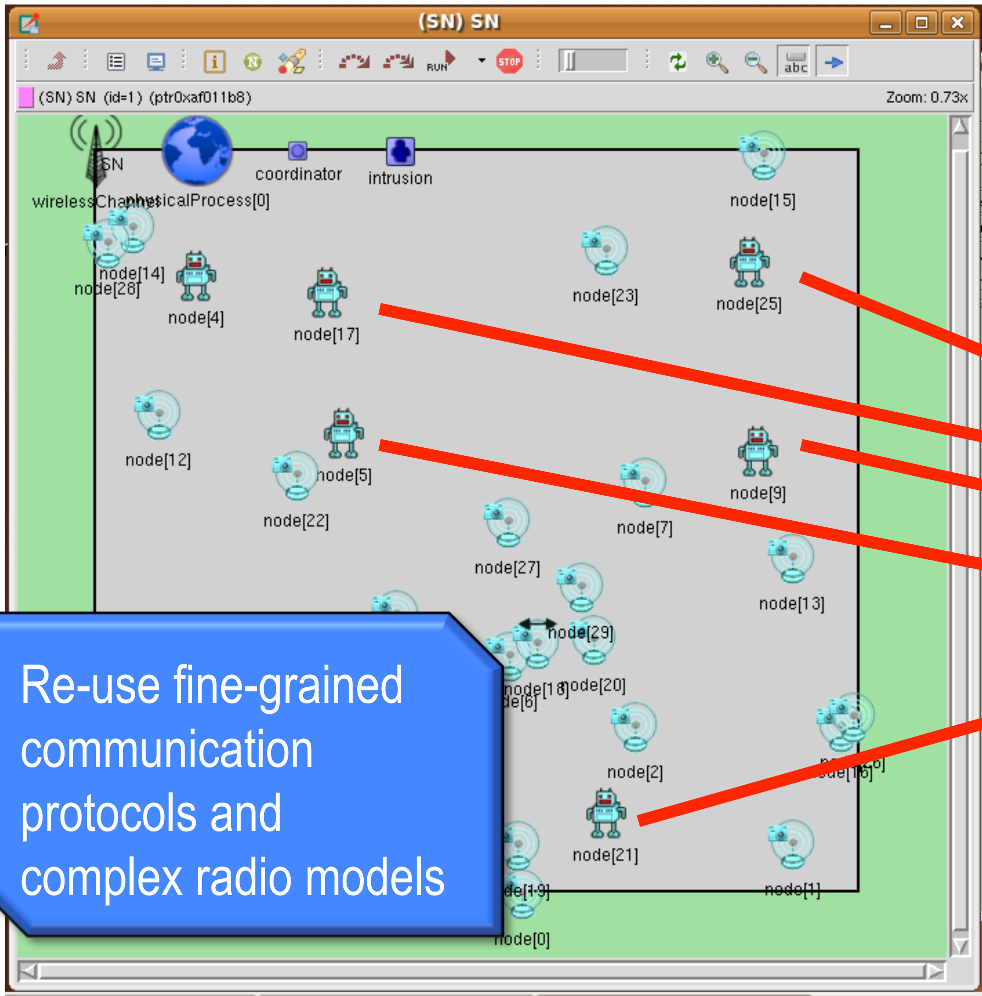
Application:Image displayed

	all	complete	truncated
index=-1	39	21	18
index=5	1	0	1
index=9	2	1	1
index=10	6	3	3
index=23	2	0	2
index=24	3	0	3
index=27	4	4	0
index=29	7	6	1
index=33	3	3	0
index=35	4	0	4
index=37	5	3	2
index=50	2	1	1

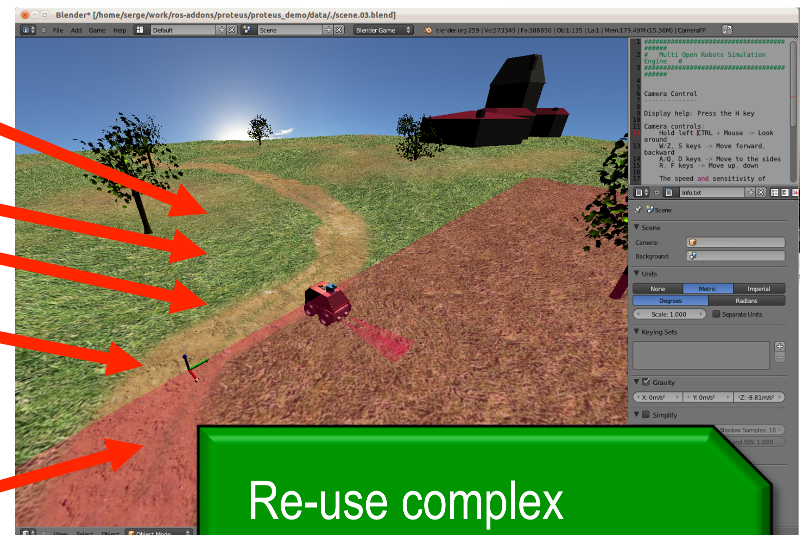


[Sensors & Robots enable realistic interaction studies]

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,…)

Additional slides

BehaVior function

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

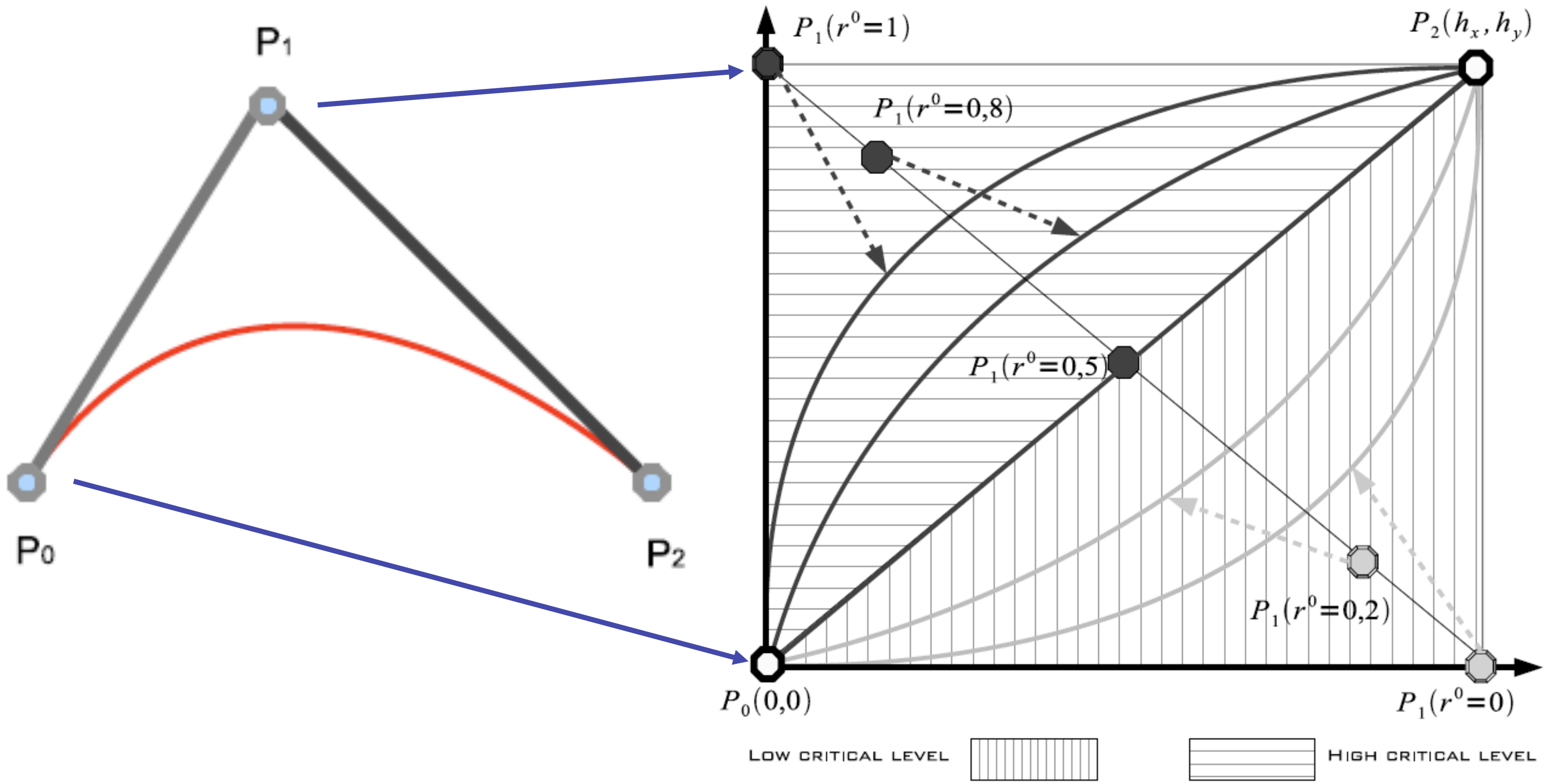
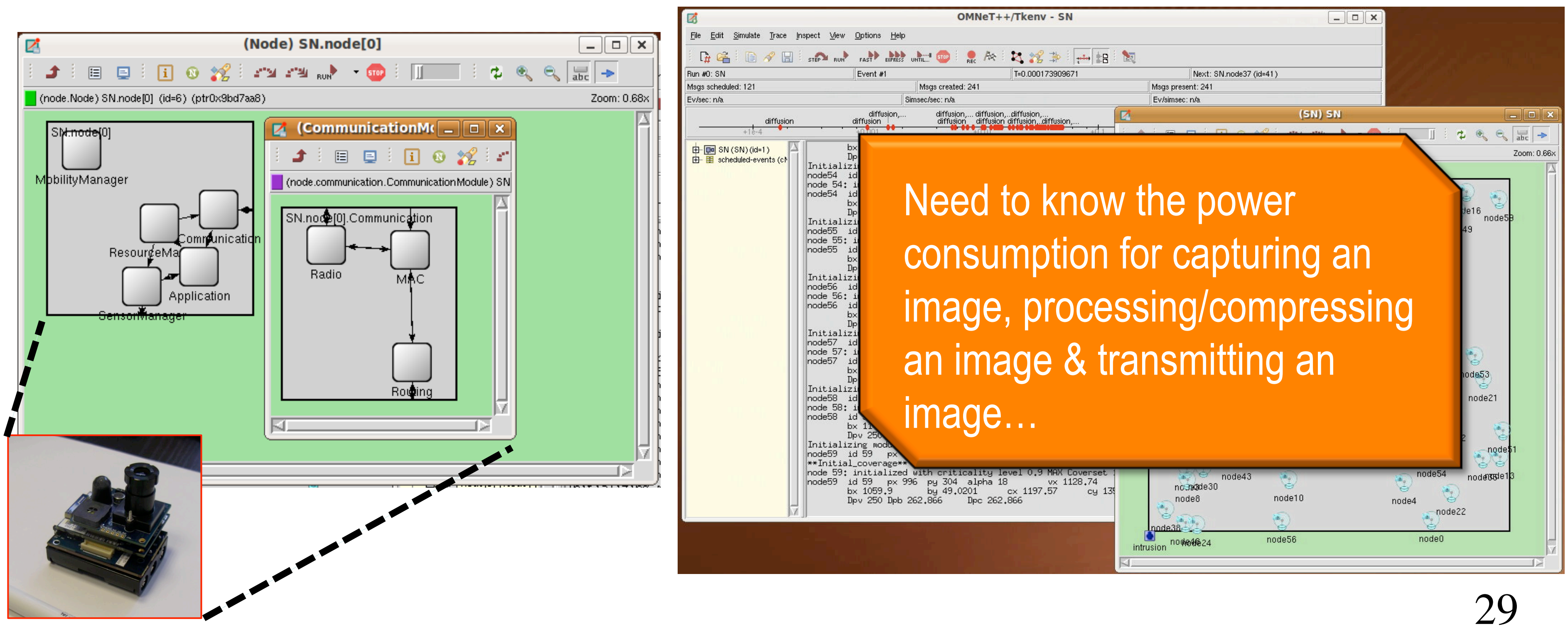
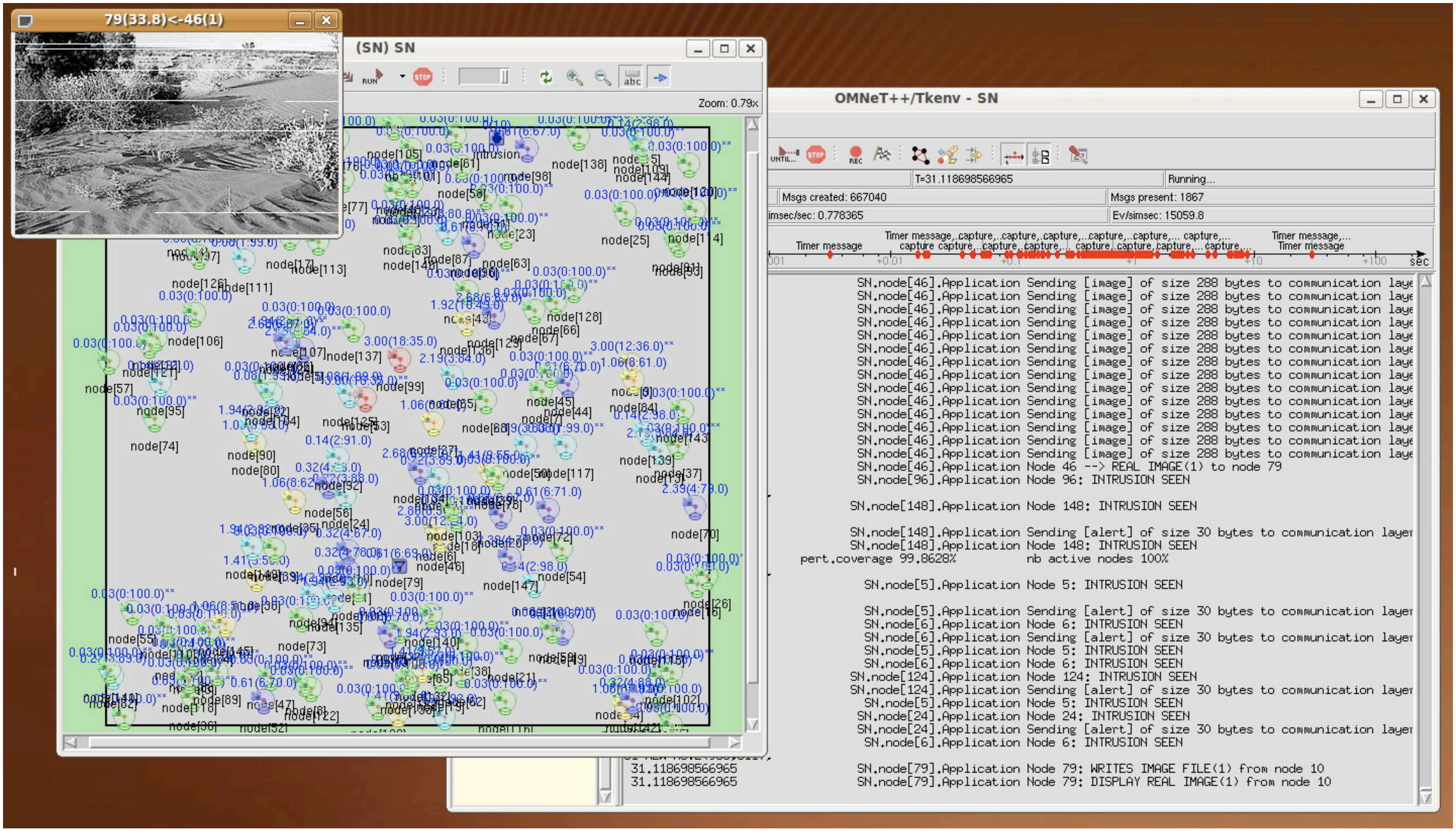


Image sensor simulation model under OMNET++

- Communication layers are very important for WSN
- Use specific simulator



Study the impact of communication layer on surveillance quality



Robot simulators

- Mobility, exploration, navigation, tracking, control and design are very important for robots
- Use specific robot simulators