Deployment of mission-critical surveillance applications on wireless sensor networks

Seminar at IRD/UMMISCO/MSI
IFI, Hanoi, Vietnam
October, 27th, 2010

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

Déploiement d'applications critiques de surveillance sur réseaux de capteurs sans-fils

Séminaire IRD/UMMISCO/MSI
IFI, Hanoi, Vietnam
Mercredi 27 october, 2010

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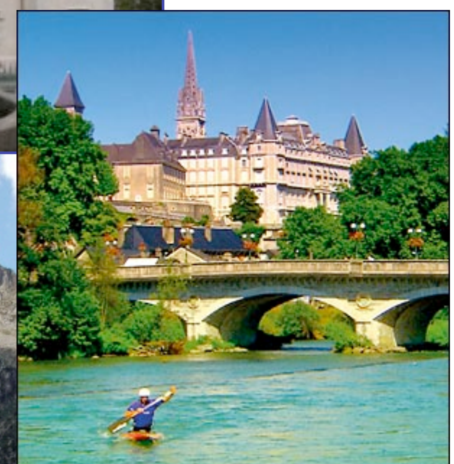
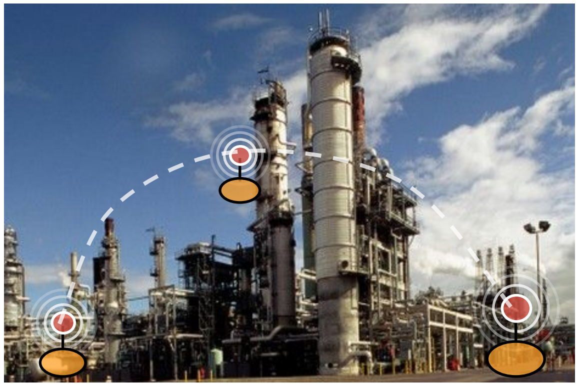
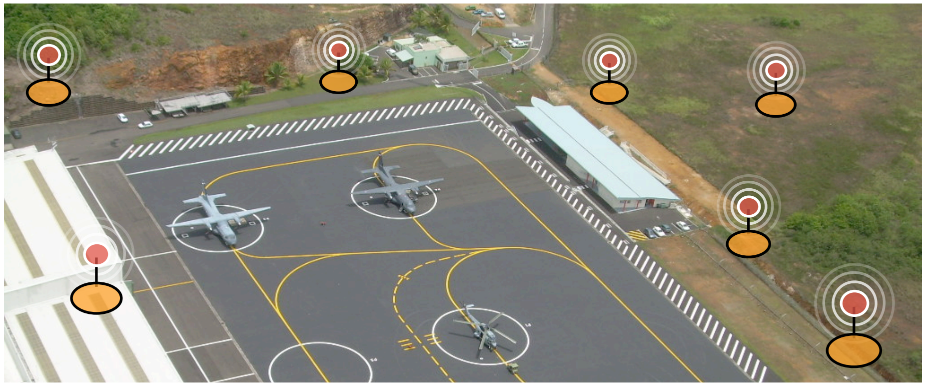
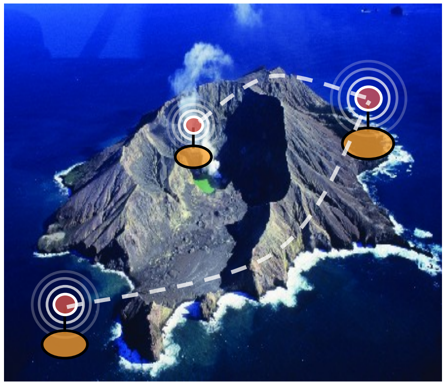


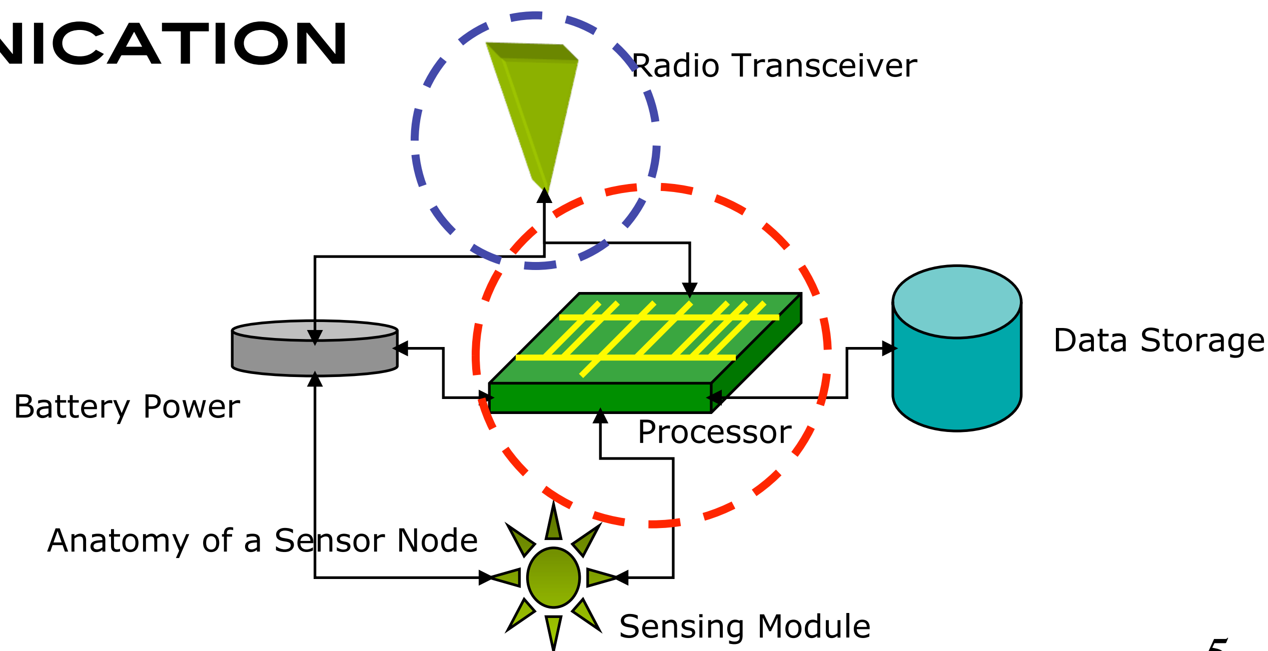
Wireless Sensor Network

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

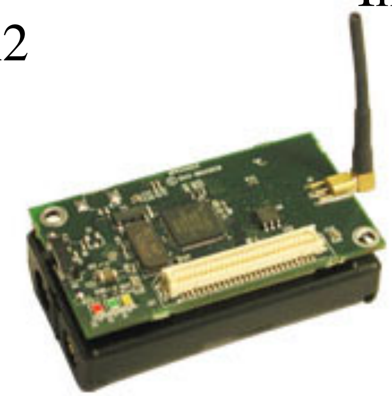


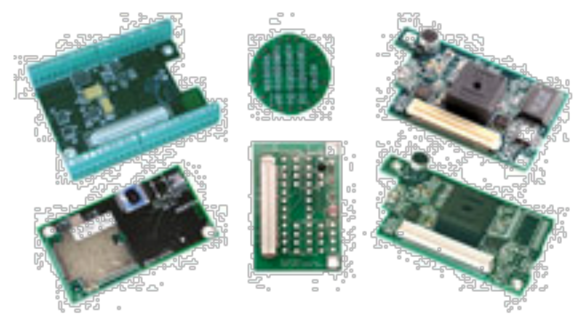
Berkeley Motes (contd.)

- Each Mote has two separate boards
  - A main CPU board with radio communication circuitry
  - A secondary board with sensing circuitry
- Decouples sensing hardware from communication hardware
- Allows for customization since application specific sensor hardware can be plugged-on to the main board


MICA2

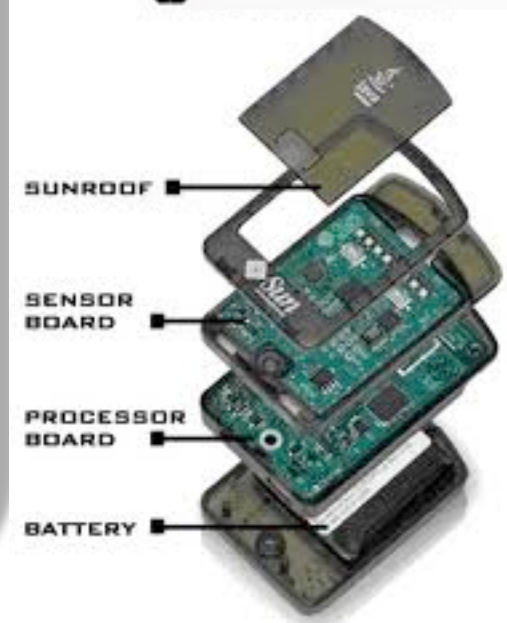

Imote2


MICAz

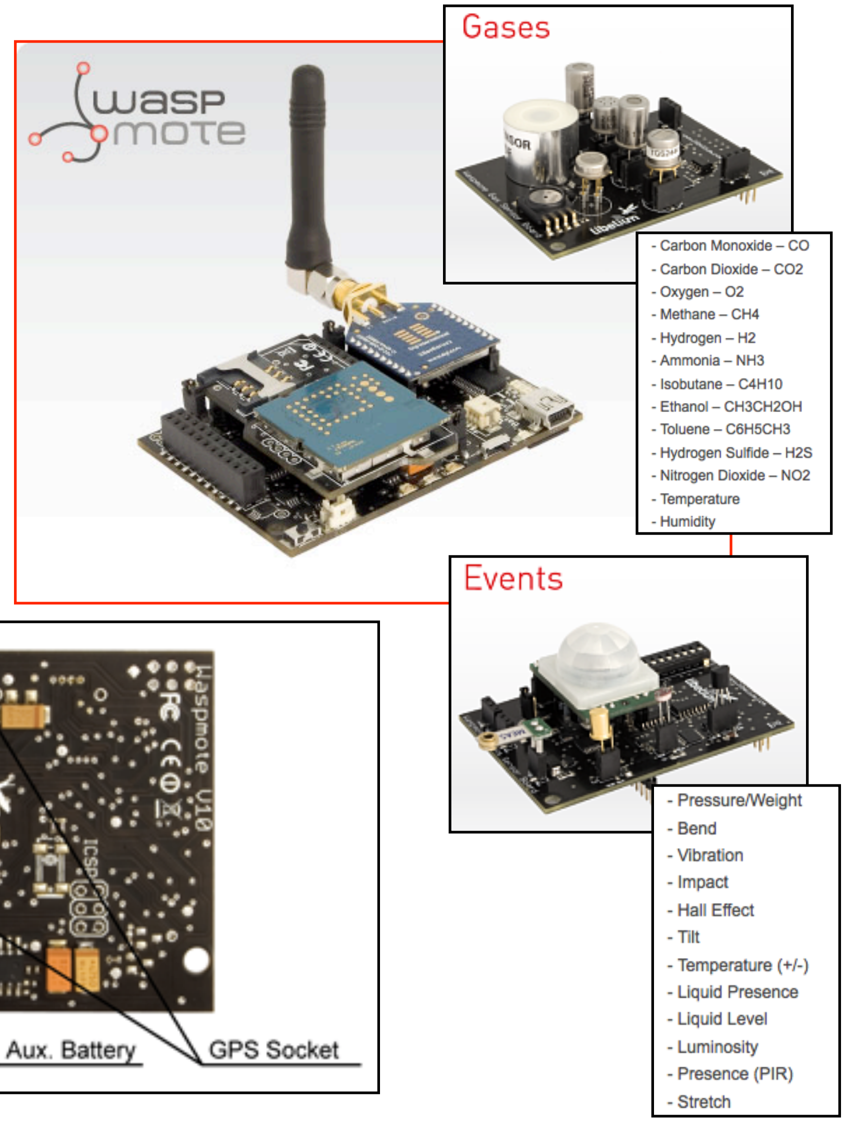

Sensing boards

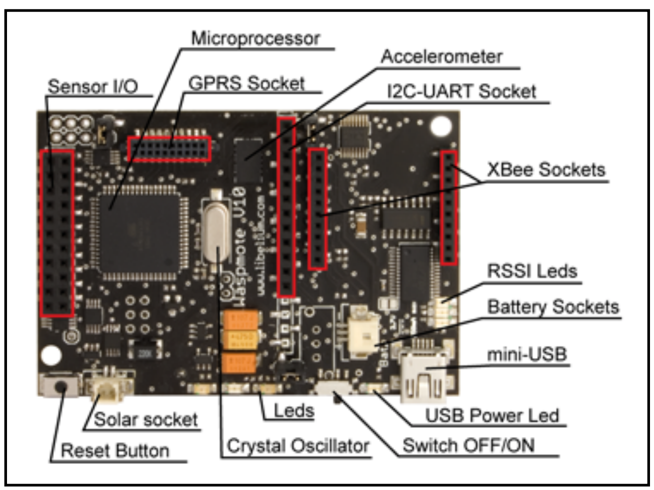
SUN SPOT

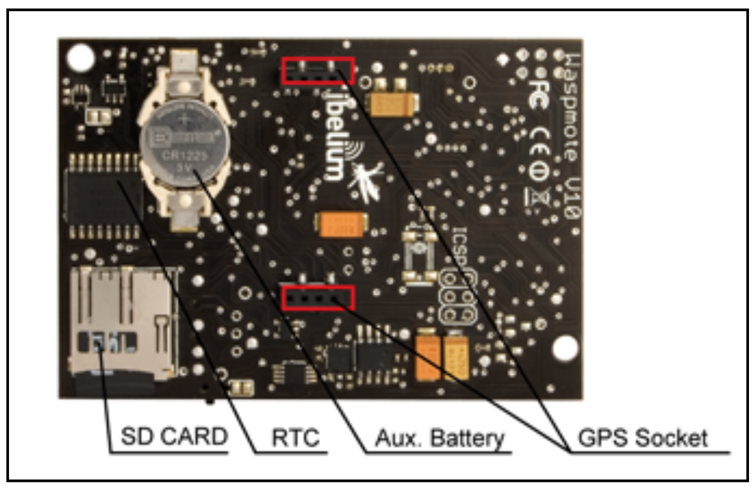
- Processor : ARM920T 180MHz 32-bit
- 512K RAM & 4M Flash.
- Communication : 2.4GHz, radio chipset: TI CC2420 (ChipCon) – IEEE 802.15.4 compatible
- Java Virtual Machine (Squawk)
- LIUPPA is official partner



- ATMEGA1281 MICROCONTROLLER
- 8K RAM & 1G SD CARD.
- 2.4GHz IEEE 802.15.4 COMPATIBLE. RF AND GSM/GPRS



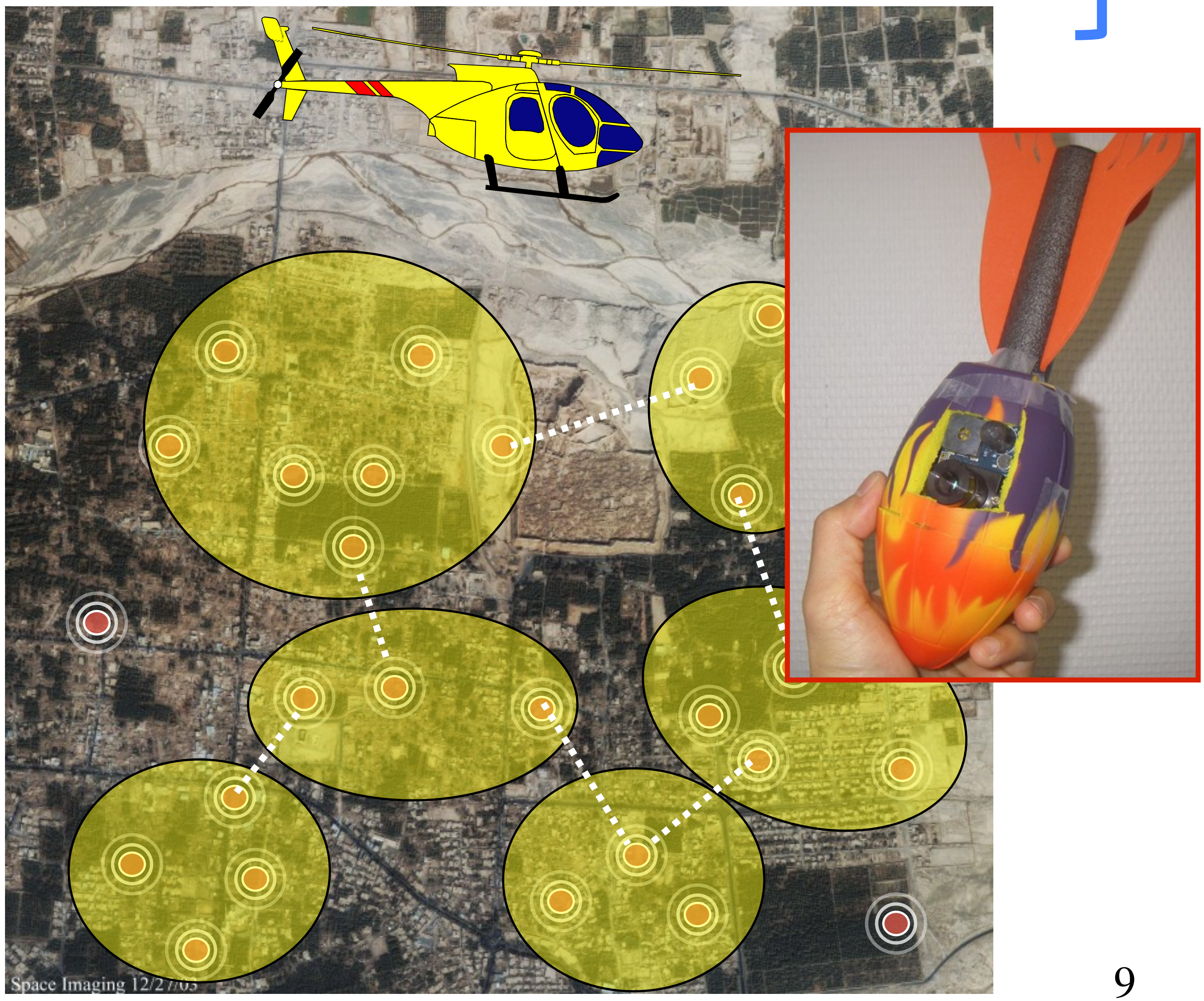




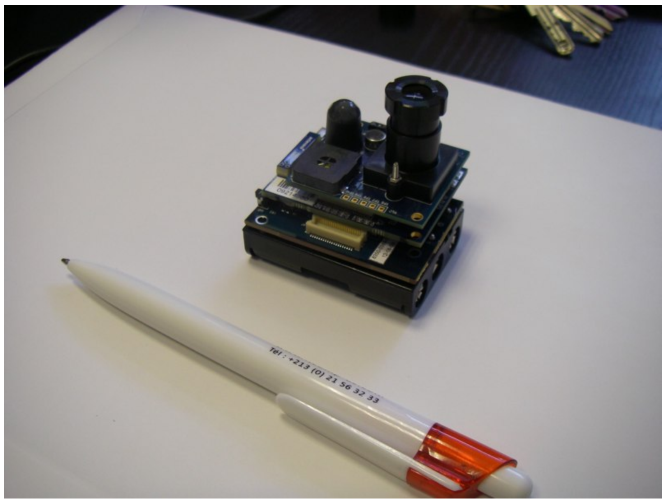
Wireless Video Sensors (1)

Imote2

Multimedia board

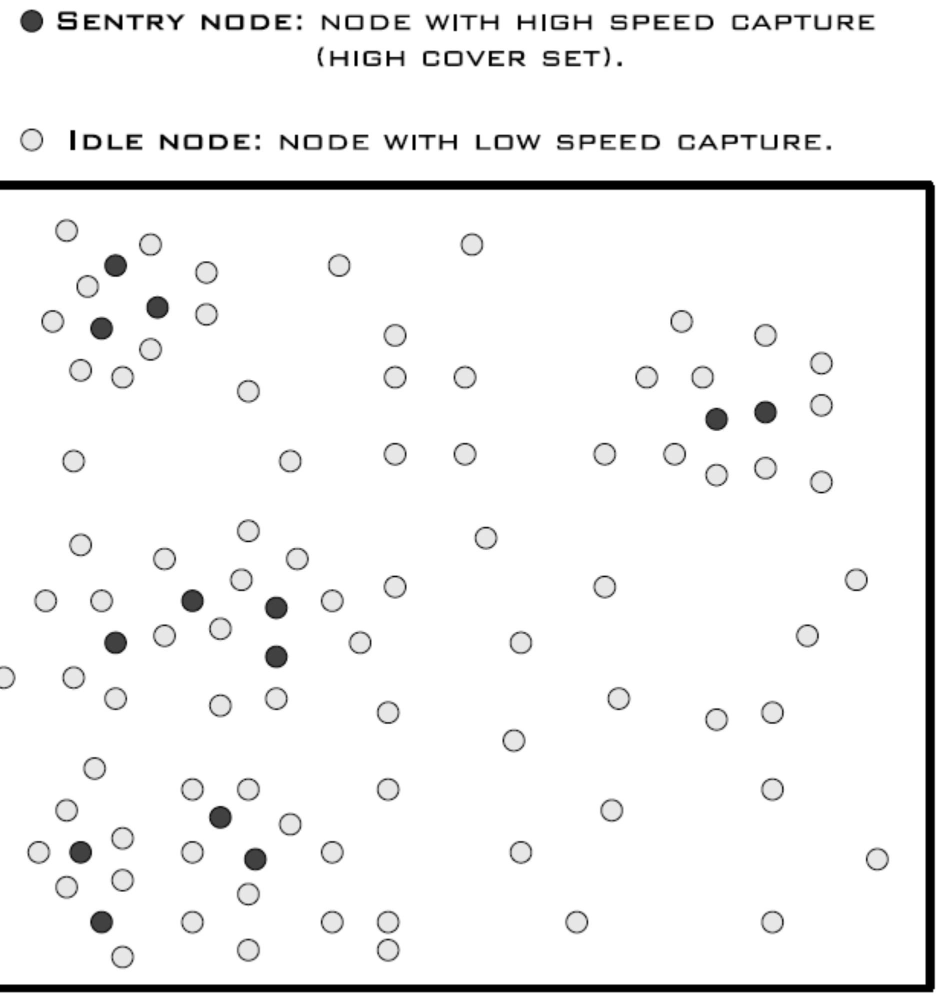


Wireless Video Sensors (2)



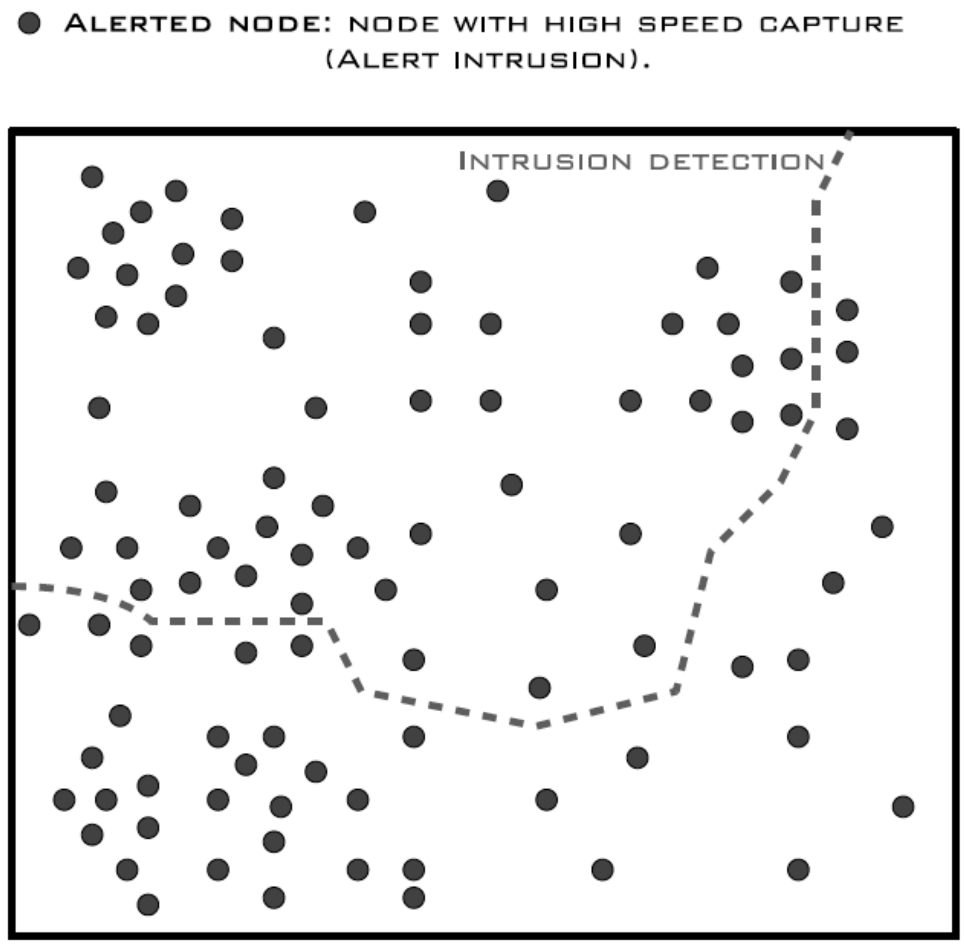
Surveillance scenario (1)

- Randomly deployed video sensors
- Not only barrier coverage but general intrusion detection
- Most of the time, network in so-called *hibernate mode*
- Most of active sensor nodes in *idle mode* with low capture speed
- Sentry nodes with higher capture speed to quickly detect intrusions



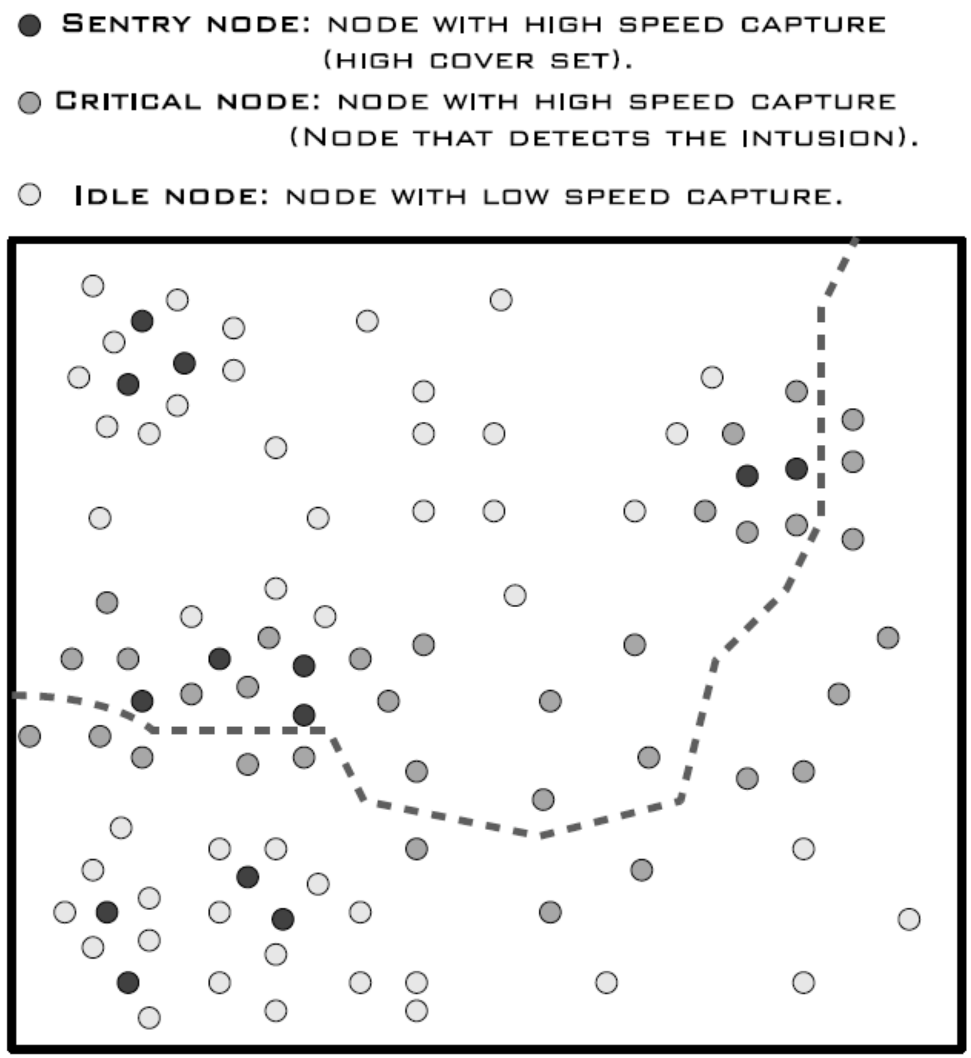
Surveillance scenario (2)

- Nodes detecting intrusion must alert the rest of the network
- 1-hop to k-hop alert
- Network in so-called *alerted mode*
- Capture speed must be increased
- Ressources should be focused on making tracking of intruders easier



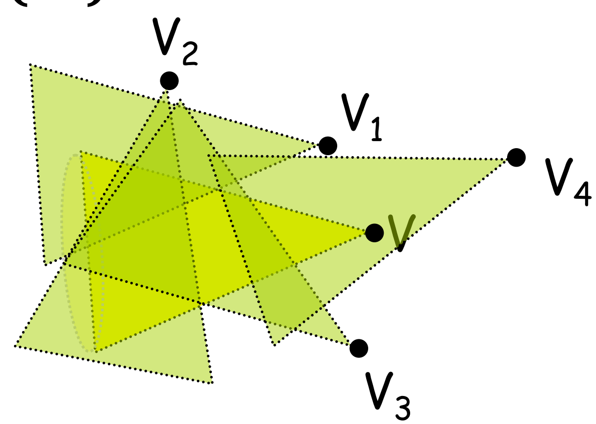
Surveillance scenario (3)

- Network should go back to *hibernate mode*
- Nodes on the intrusion path must keep a high capture speed
- Sentry nodes with higher capture speed to quickly detect intrusions

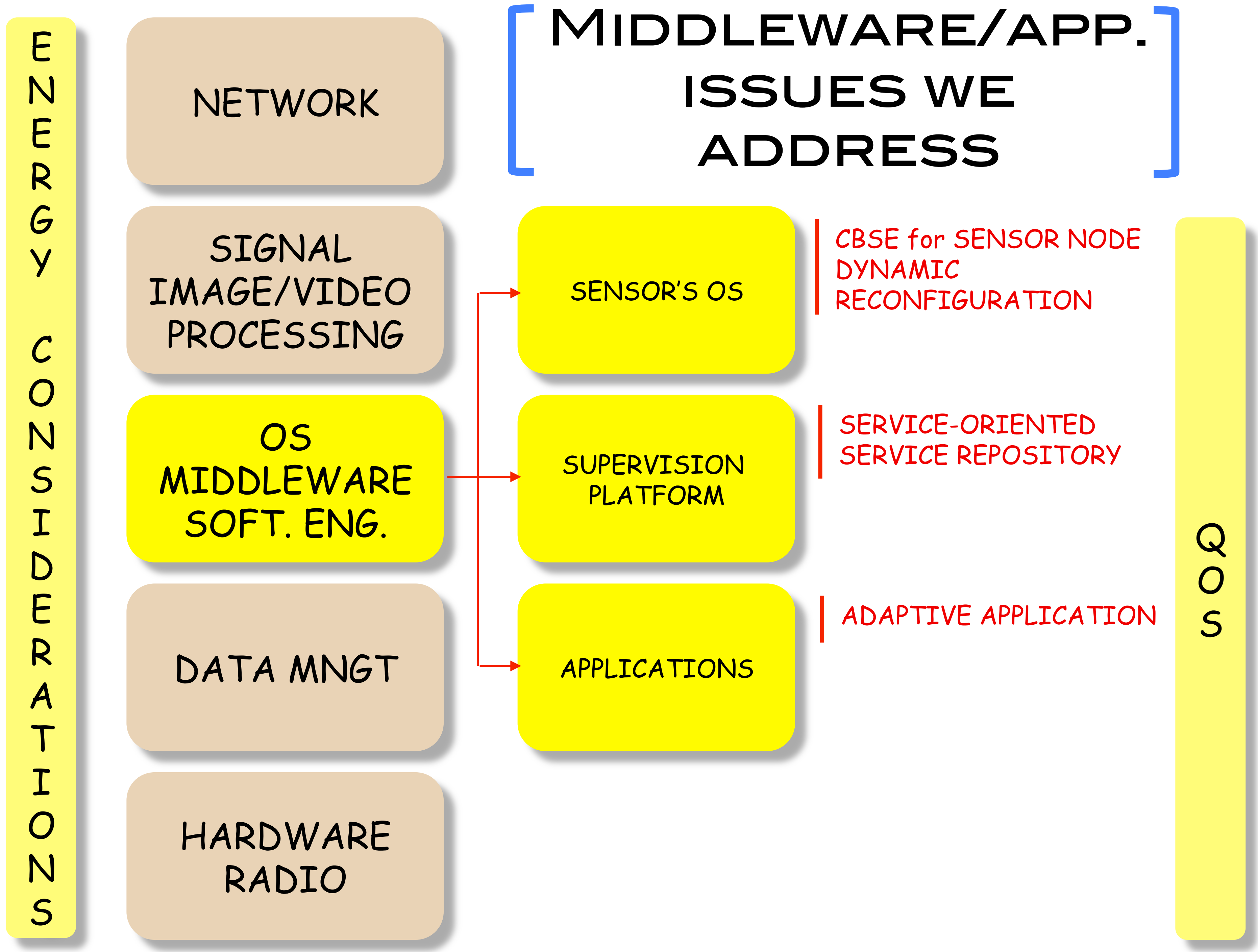


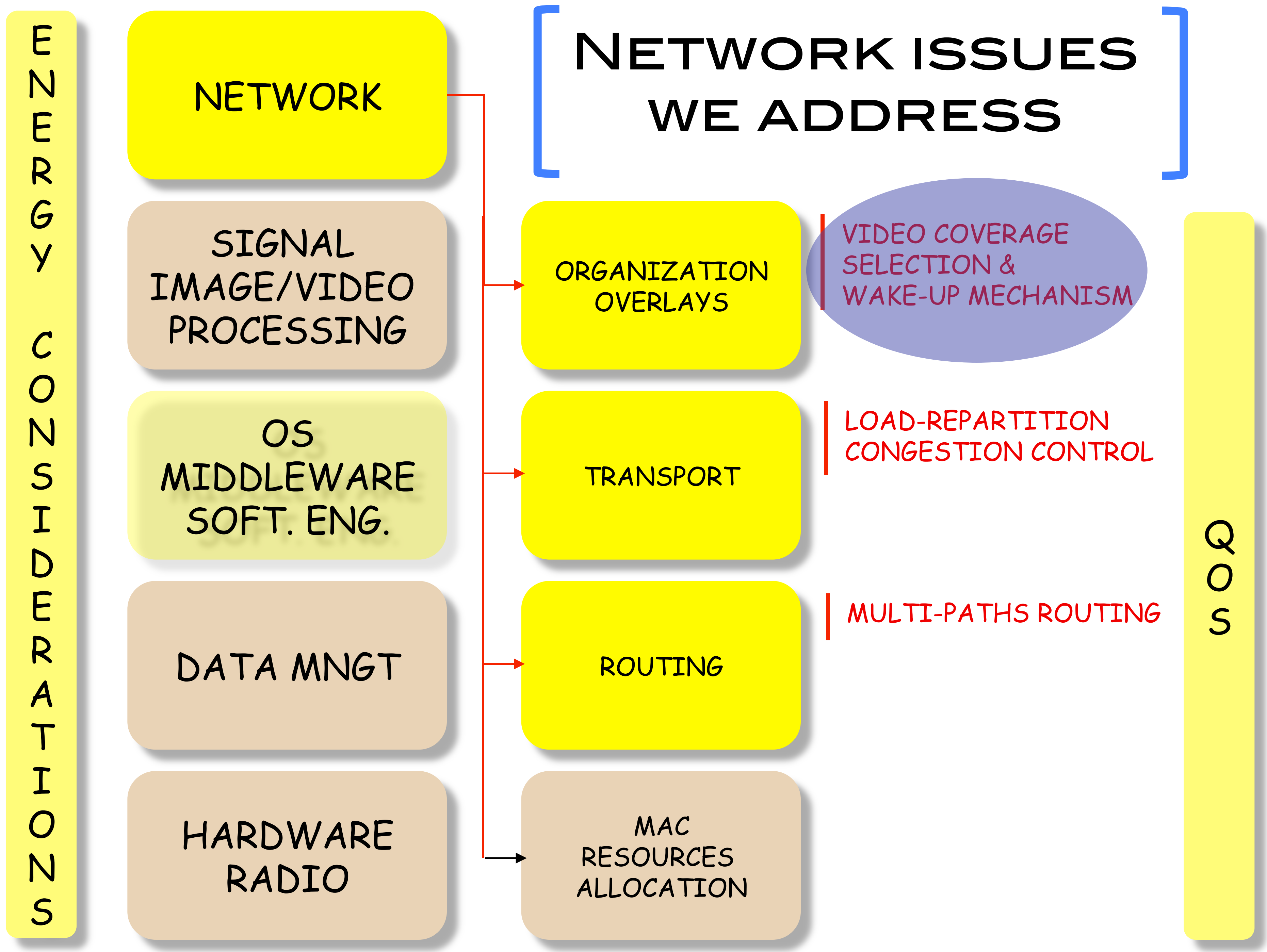
Node's cover set

- Each node v has a Field of View, FoV_v
- $Co_i(v)$ = set of nodes v' such as $\bigcup_{v' \in Co_i(v)} FoV_{v'}$ covers FoV_v
- $Co(v)$= set of $Co_i(v)$



$Co(v)=\{V_1,V_2,V_3,V_4\}$


MIDDLEWARE/APP.
ISSUES WE
ADDRESS
ENERGY CONSIDERATIONS
NETWORK
SIGNAL
IMAGE/VIDEO
PROCESSING
OS
MIDDLEWARE
SOFT. ENG.
DATA MNGT
HARDWARE
RADIO
SENSOR'S OS
SUPERVISION
PLATFORM
APPLICATIONS
CBSE for SENSOR NODE
DYNAMIC
RECONFIGURATION
SERVICE-ORIENTED
SERVICE REPOSITORY
ADAPTIVE APPLICATION
QOS



NETWORK ISSUES WE ADDRESS
ENERGY CONSIDERATIONS
NETWORK
SIGNAL IMAGE/VIDEO PROCESSING
OS MIDDLEWARE SOFT. ENG.
DATA MNGT
HARDWARE RADIO
ORGANIZATION OVERLAYS
TRANSPORT
ROUTING
MAC RESOURCES ALLOCATION
VIDEO COVERAGE SELECTION & WAKE-UP MECHANISM
LOAD-REPARTITION CONGESTION CONTROL
MULTI-PATHS ROUTING
QOS

Criticality and risk-based scheduling

Basic approach: PM2HW2N/ACM MSWIN 2009
Current approach: IEEE WCNC2010
With intrusion detection results: IEEE RIVF2010
With re-inforcement: IEEE ICDCN2011
Journal paper in JNCA, Elsevier

Don't miss important events!

Whole understanding of the scene is wrong!!!

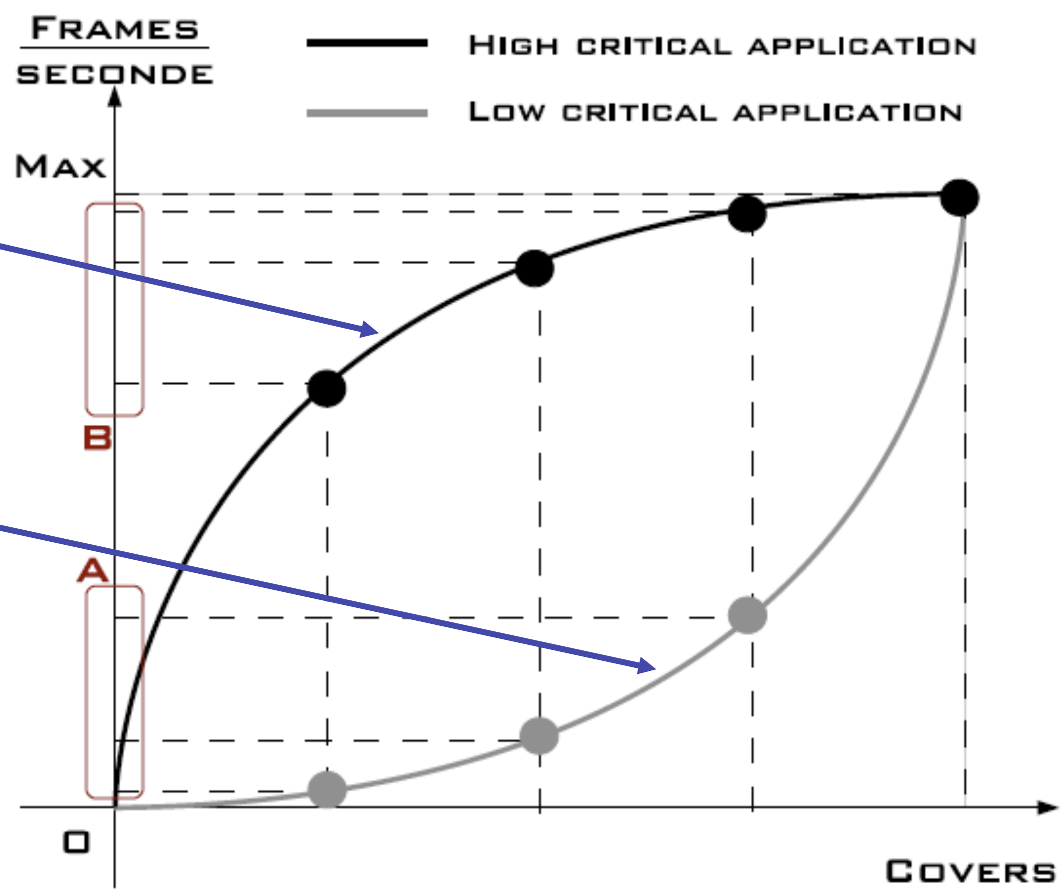
What is captured

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

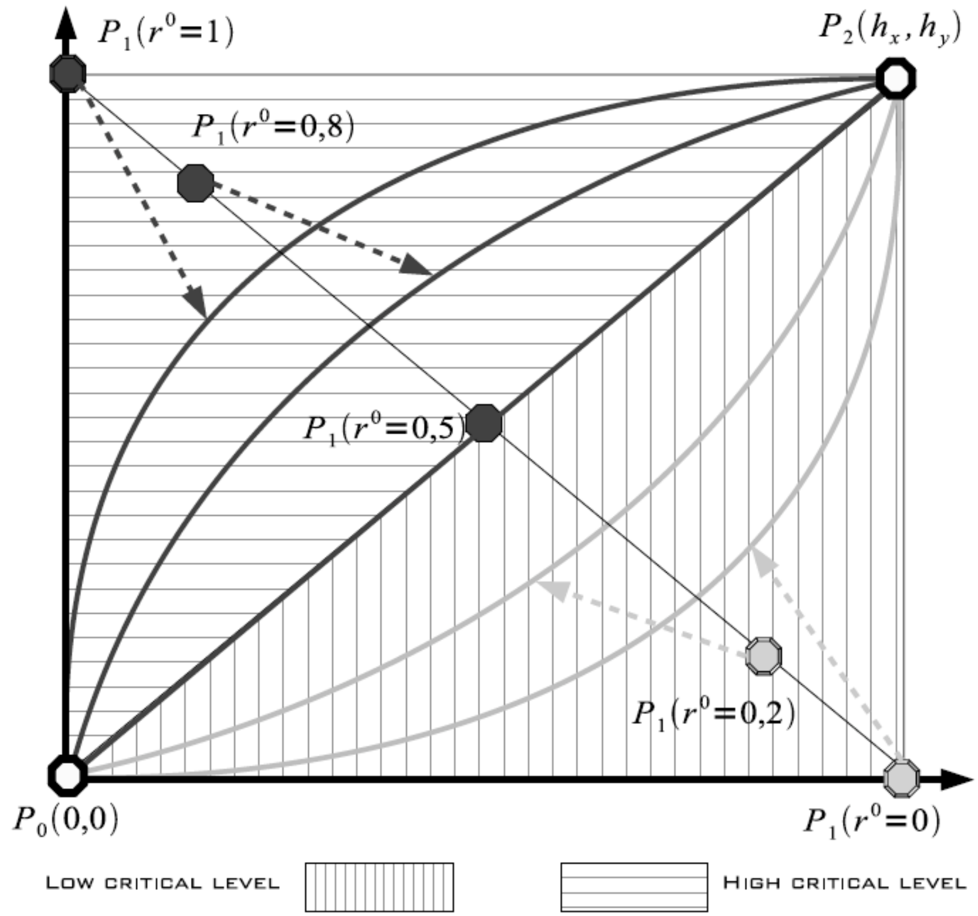
Criticality model (1)

- 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



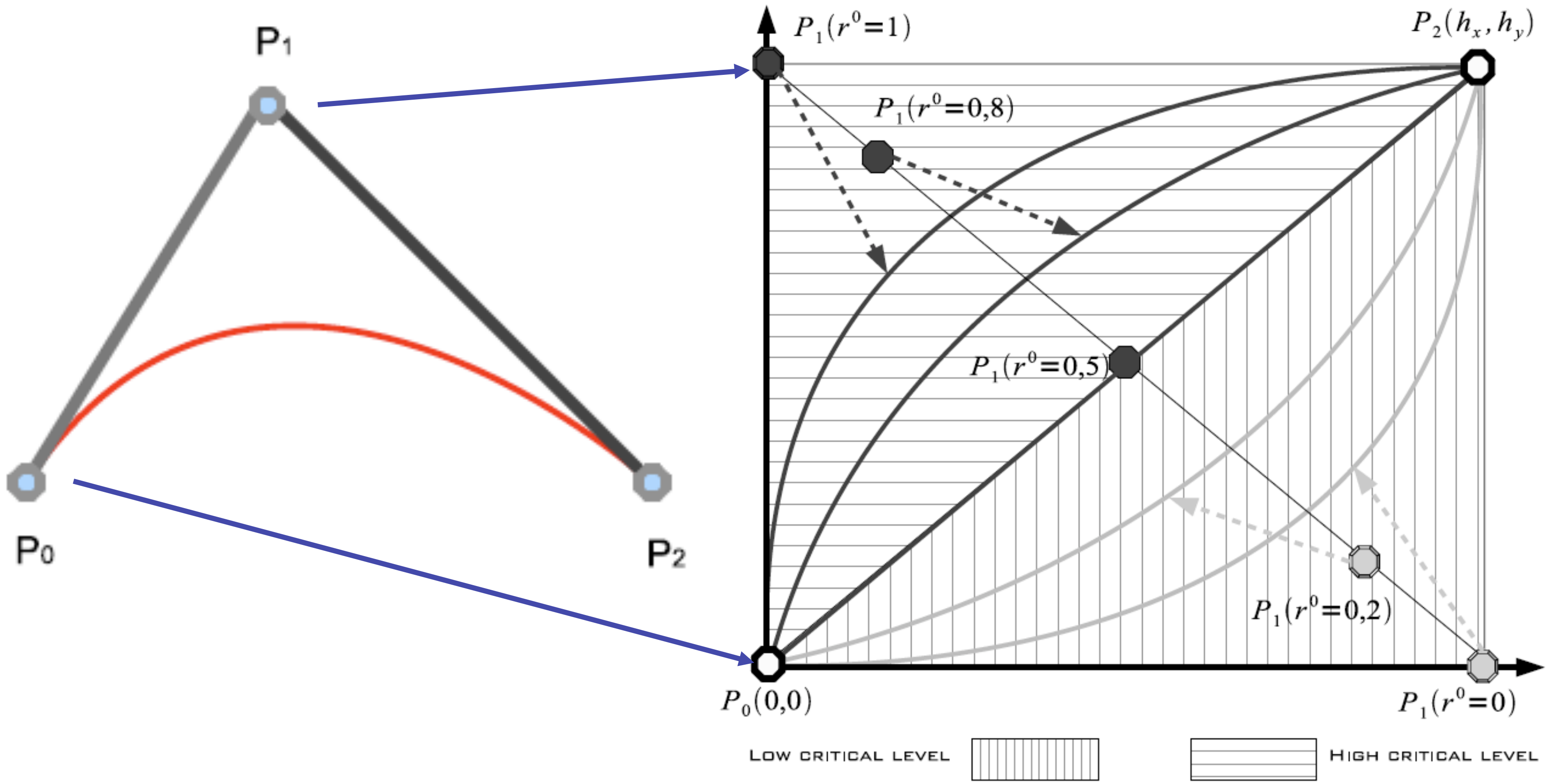
Criticality model (2)

- 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

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



Some typical capture speed

- Maximum capture speed is 6fps or 12fps
- Nodes with size of cover set greater than N capture at the maximum speed

N=6
$P_2(6,6)$

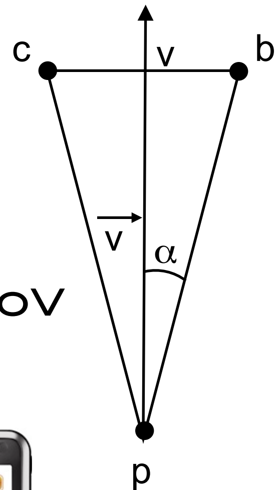
r^0 \ $\|Co(v)\|$	1	2	3	4	5	6
0.0	0.05	0.20	0.51	1.07	2.10	6.00
0.2	0.30	0.73	1.34	2.20	3.52	6.00
0.5	1.00	2.00	3.00	4.00	5.00	6.00
0.8	2.48	3.80	4.66	5.27	5.70	6.00
1.0	3.90	4.93	5.49	5.80	5.95	6.00

N=12
$P_2(12,3)$

r^0	1	2	3	4	5	6	7	8	9	10	11	12
0	.01	.02	.05	0.1	.17	.26	.38	.54	.75	1.1	1.5	3
.2	.07	.15	.25	.37	.51	.67	.86	1.1	1.4	1.7	2.2	3
.4	.17	.35	.55	.75	.97	1.2	1.4	1.7	2.0	2.3	2.6	3
.6	.36	.69	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3
.8	.75	1.2	1.6	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3
1	1.5	1.9	2.2	2.4	2.6	2.7	2.8	2.9	2.9	2.9	2	3

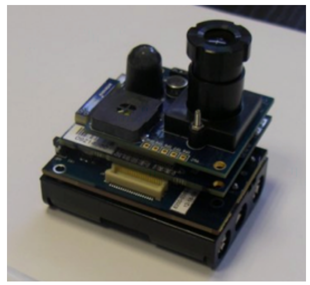
Finding v's cover set

Basic approach: IFIP WD2009
Improved version: IEEE WiMob 2010
With adaptive scheduling: IEEE ICUMT 2009

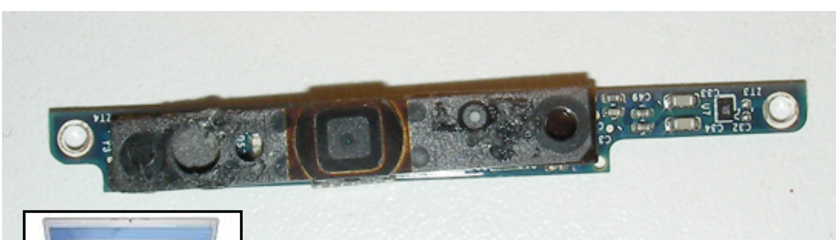


2α=AoV

AoV=20°

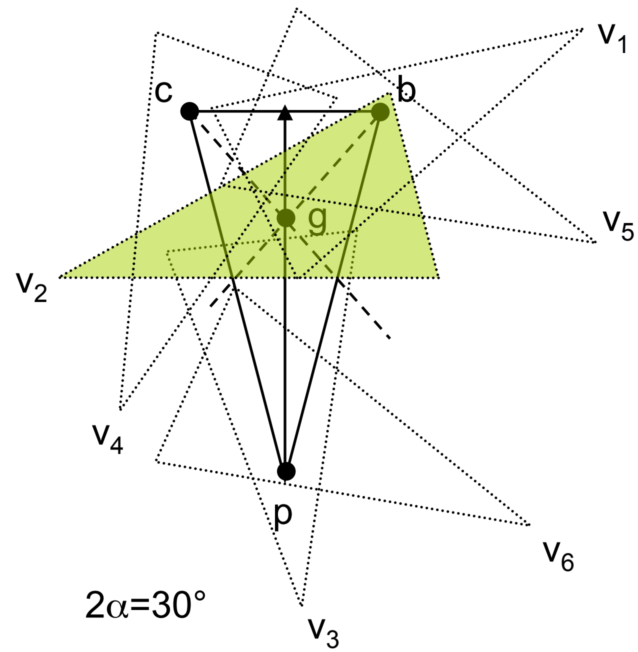


AoV=38°



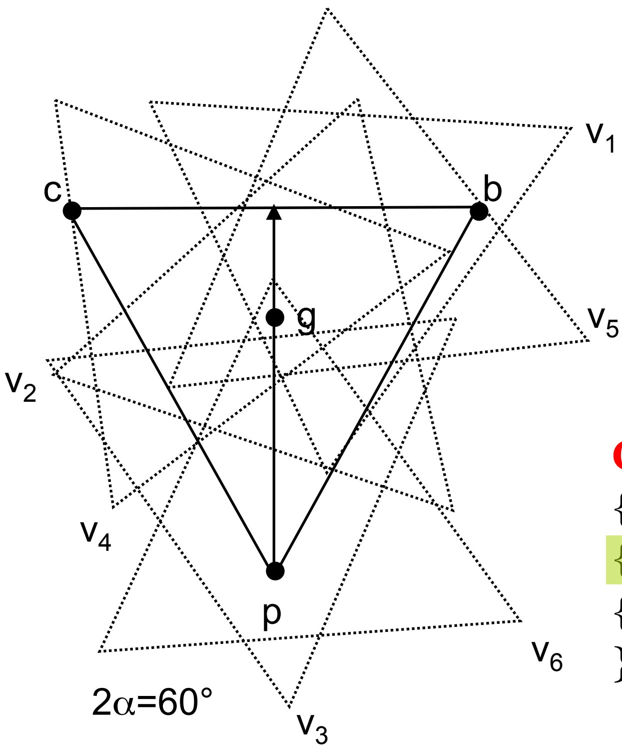
AoV=31°

P = {v ∈ N(v) : v covers the point "p" of the FoV}
B = {v ∈ N(v) : v covers the point "b" of the FoV}
C = {v ∈ N(v) : v covers the point "c" of the FoV}
G = {v ∈ N(v) : v covers the point "g" of the FoV}

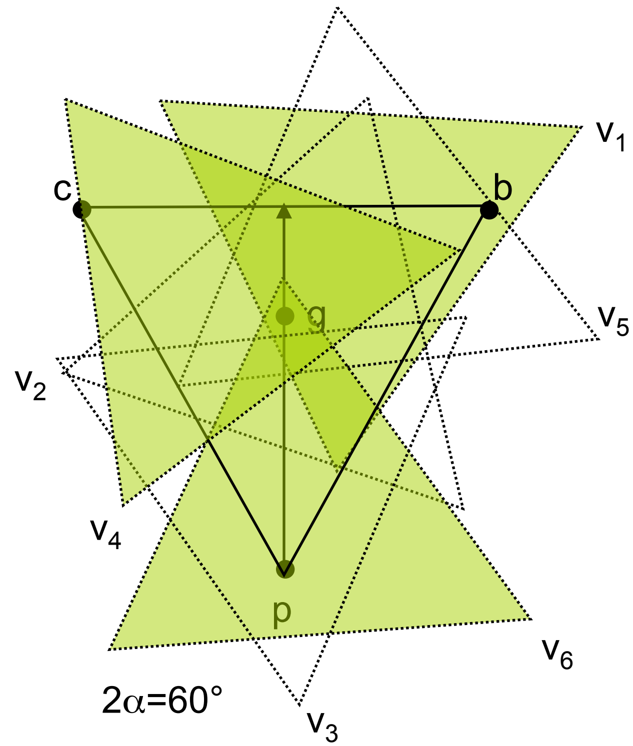


PG={P∩G}
BG={B∩G}
CG={C∩G}
Co(v)=PG×BG×CG

Large Angle of View

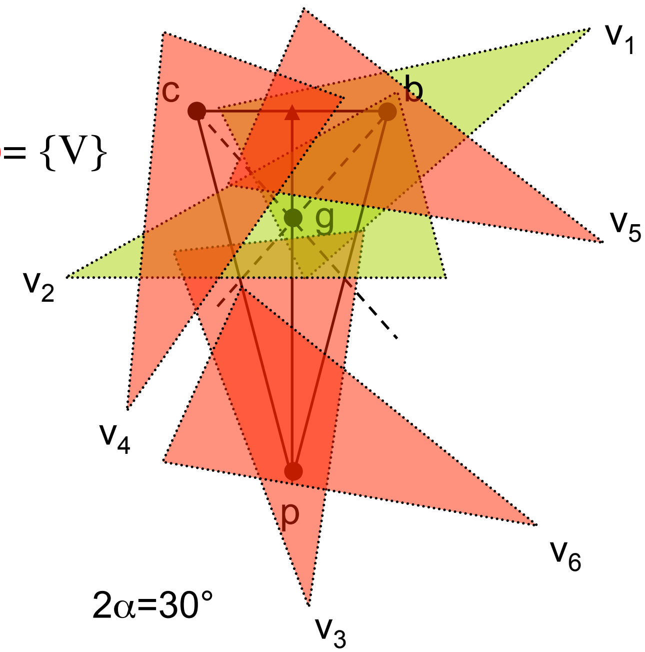


Co(V)= {
{V },
{V_1, V_4, V_6},
{V_4, V_5, V_6}
}

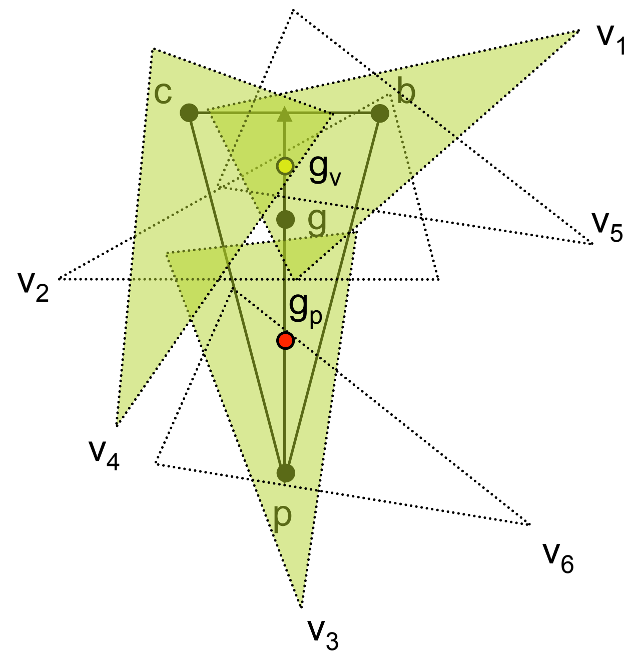


Small Angle of View

Co(V)= {V}

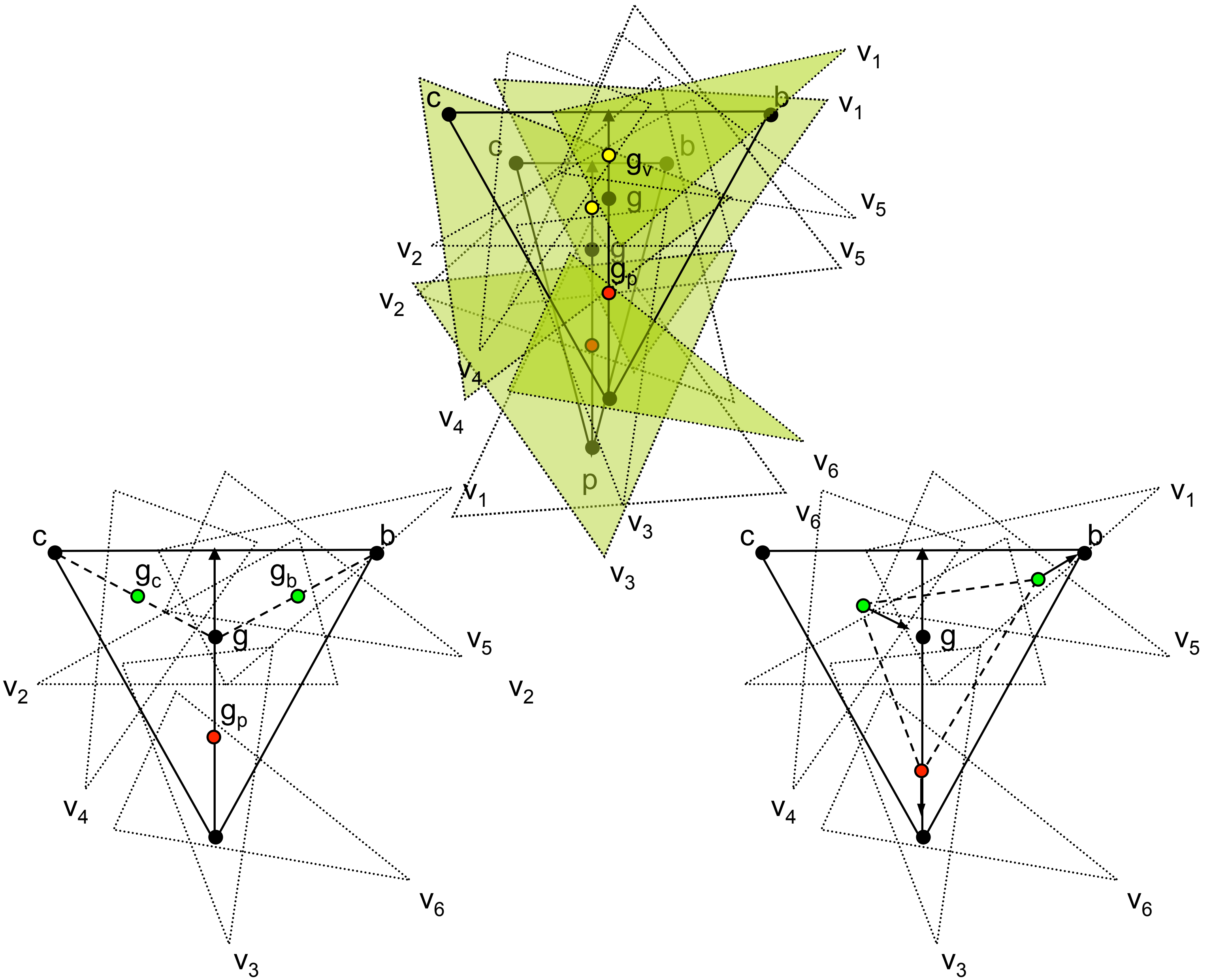


Co(V)= {
{V },
{V_1, V_3, V_4},
{V_2, V_3, V_4},
{V_3, V_4, V_5},
{V_1, V_4, V_6},
{V_2, V_4, V_6},
{V_4, V_5, V_6}
}



$PG=\{P \cap G_P\}$
$BG=\{B \cap G_V\}$
$CG=\{C \cap G_V\}$
$Co(V)=PG \times BG \times CG$

Heterogeneous AoV



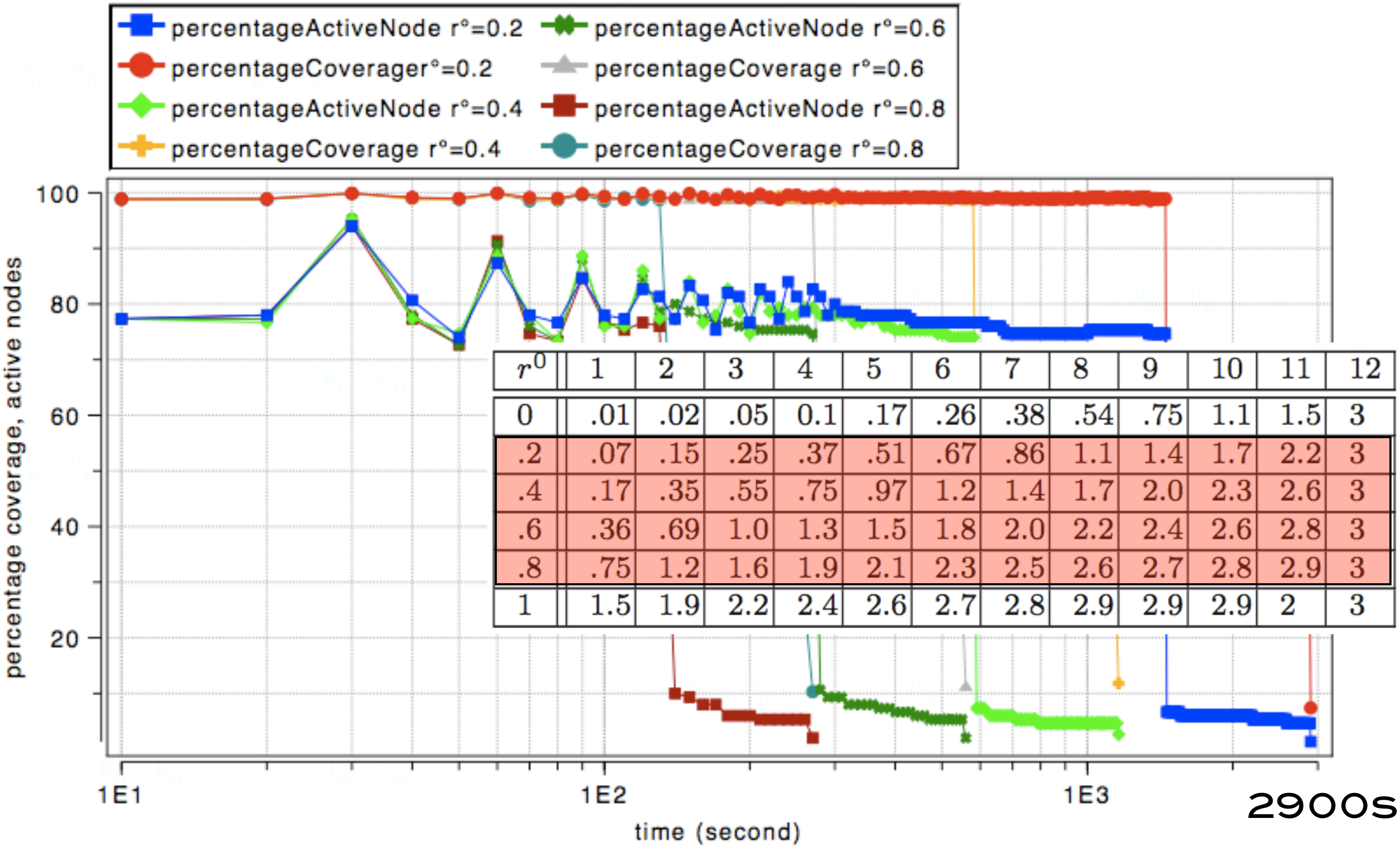
Simulation settings

- OMNET++ simulation model
- Video nodes have communication range of 30m and depth of view of 25m, AoV is 36°. 175 sensors in an 75m.75m area.
- Battery has 100 units, 1 image = 1 unit of battery consumed.
- Max capture rate is 3fps. 12 levels of cover set.
- Full coverage is defined as the region initially covered when all nodes are active

Risk-based scheduling

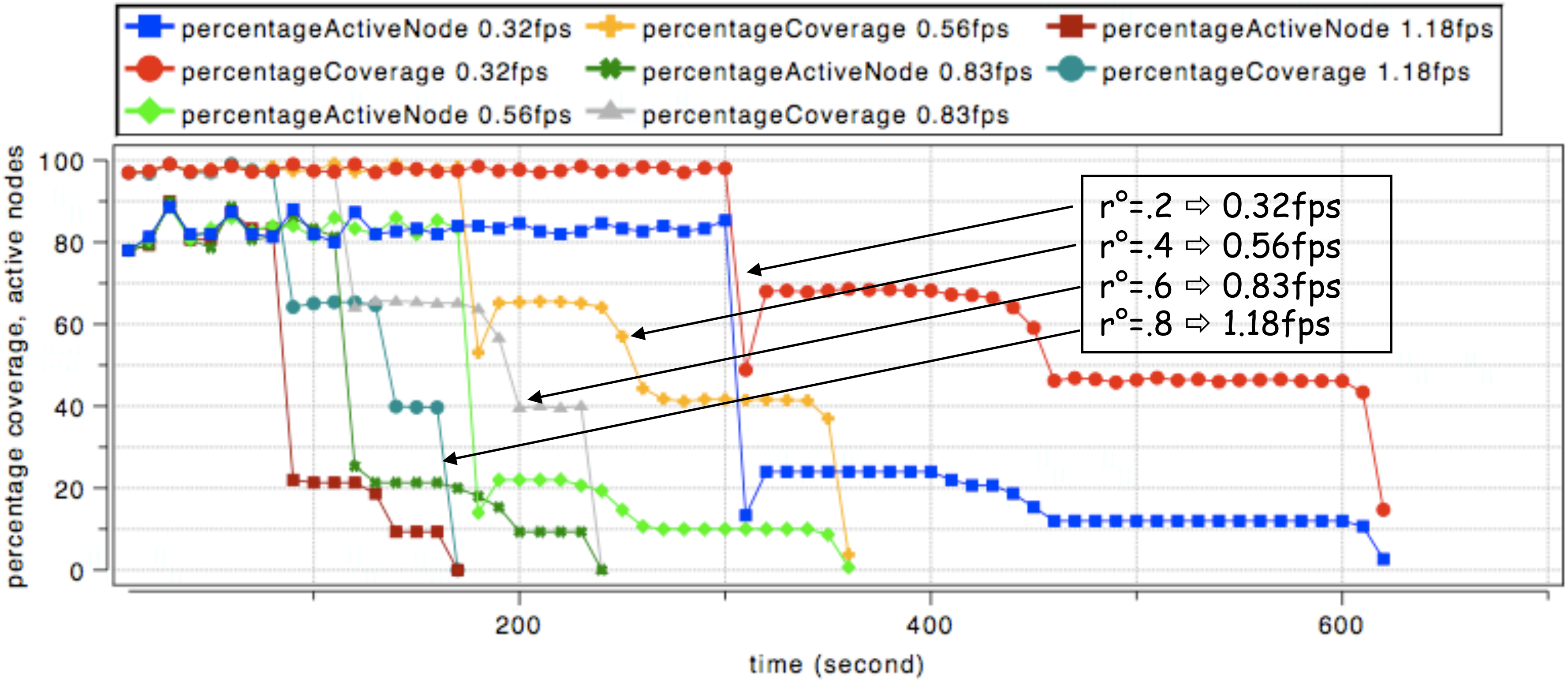
- Static risk-based scheduling
  - r°=Cte in [0,1]
- Dynamic risk-based scheduling
  - Starts with a low value for r° (0.1)
  - On intrusion, alert neighborhood and increases r° to a r_{max} value (0.9)
  - Stays at r_{max} for T_a seconds before going back to r°
- Dynamic with reinforcement
  - Same as dynamic but several alerts are needed to get to r°= r_{max}
  - Going back to r° is done in one step

Percentage of coverage, active nodes (1)



r^0	1	2	3	4	5	6	7	8	9	10	11	12
0	.01	.02	.05	0.1	.17	.26	.38	.54	.75	1.1	1.5	3
.2	.07	.15	.25	.37	.51	.67	.86	1.1	1.4	1.7	2.2	3
.4	.17	.35	.55	.75	.97	1.2	1.4	1.7	2.0	2.3	2.6	3
.6	.36	.69	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3
.8	.75	1.2	1.6	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3
1	1.5	1.9	2.2	2.4	2.6	2.7	2.8	2.9	2.9	2.9	2	3

Percentage of coverage, active nodes (2)

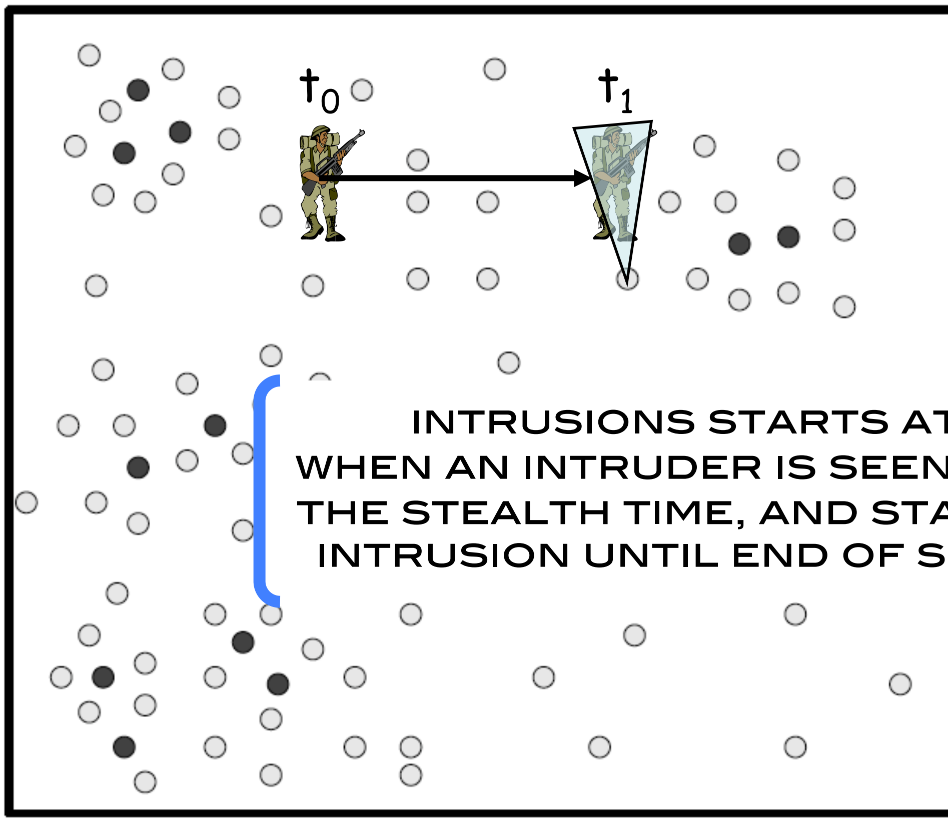


In comparison, using a dynamic risk-based scheduling gives a network lifetime of nearly 2900s for r°=0.2

MEAN STEALTH TIME

T_1-T_O IS THE INTRUDER'S STEALTH TIME

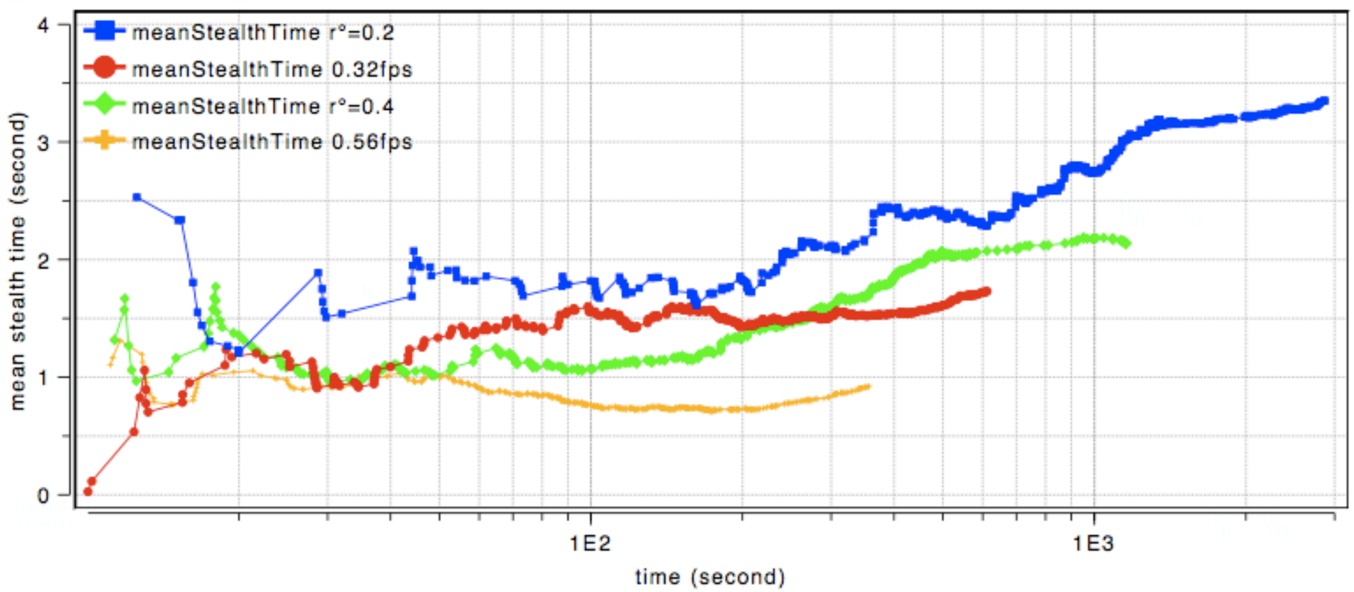
VELOCITY IS SET TO 5M/S

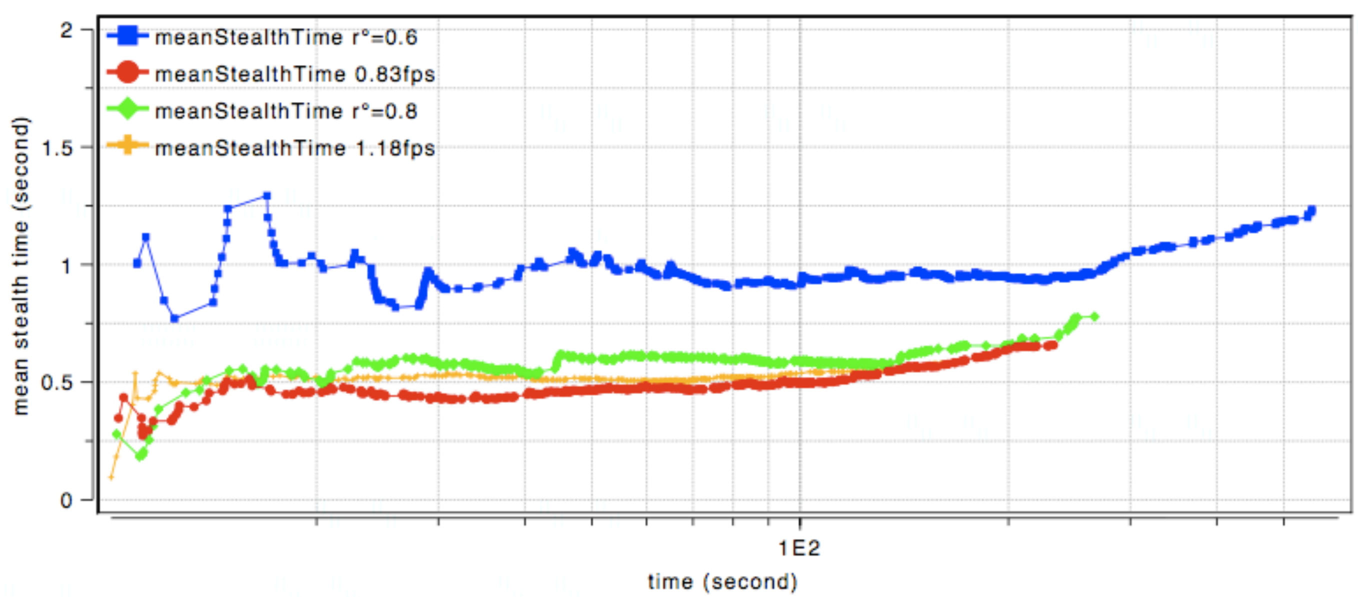


INTRUSIONS STARTS AT T=10S

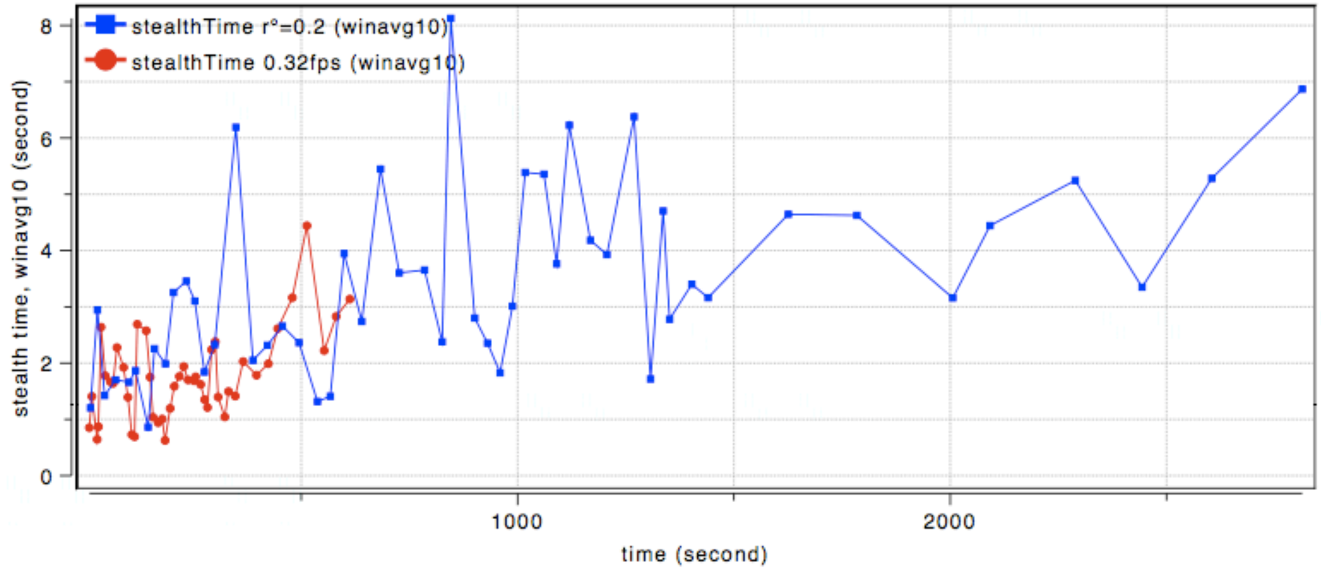
WHEN AN INTRUDER IS SEEN, COMPUTE THE STEALTH TIME, AND STARTS A NEW INTRUSION UNTIL END OF SIMULATION

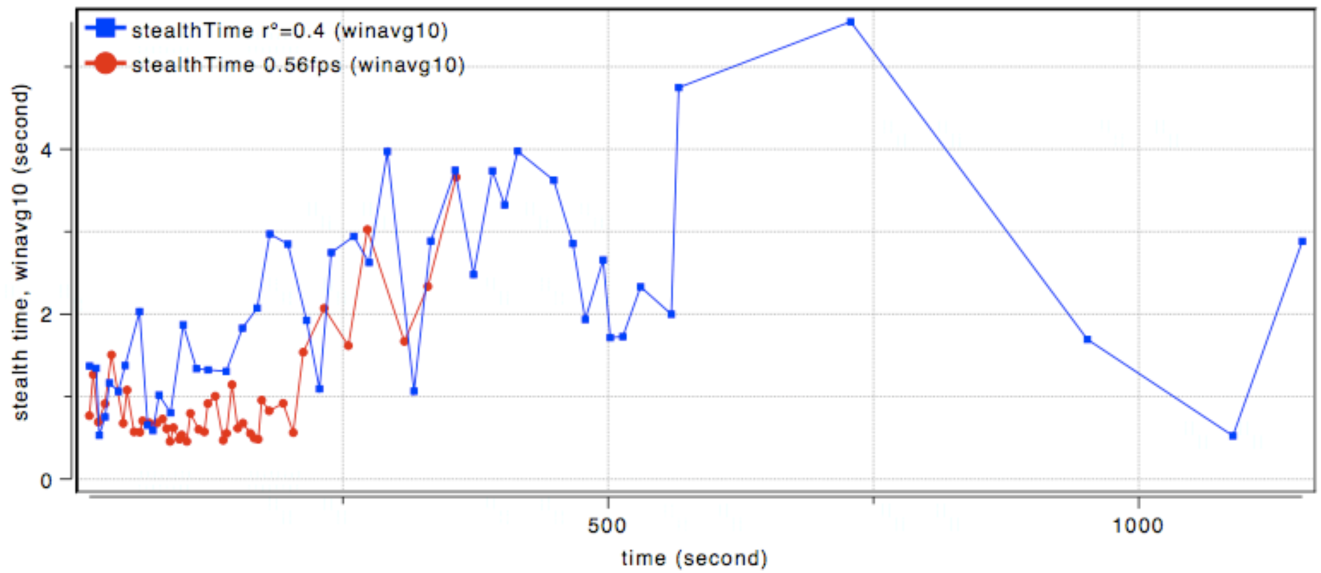
MEAN STEALTH TIME



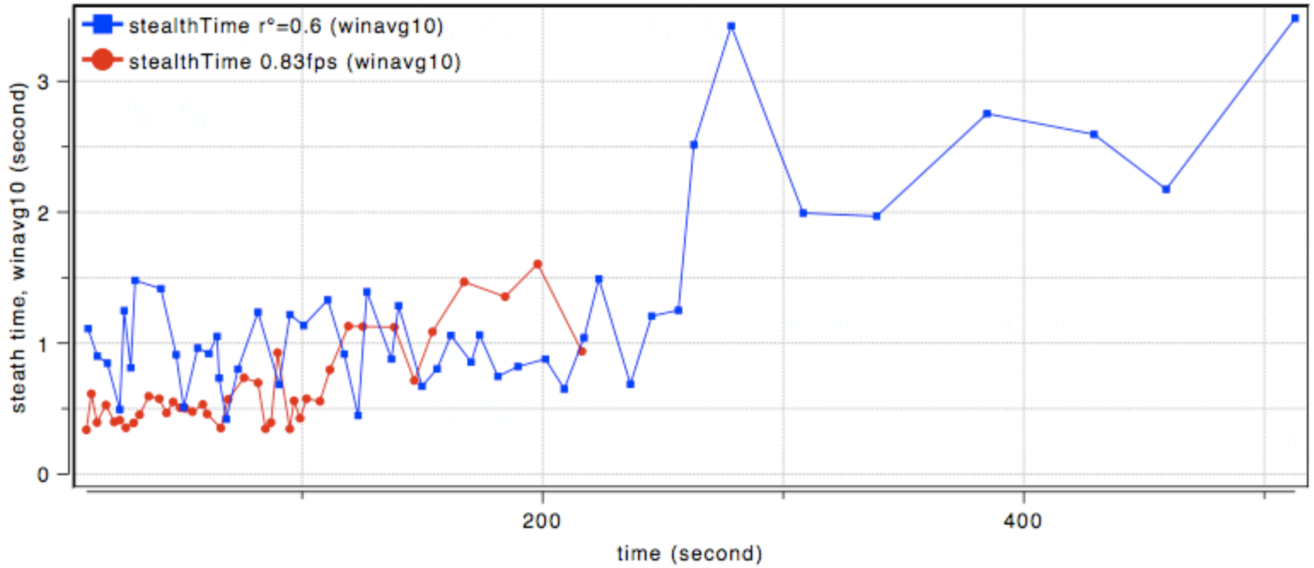


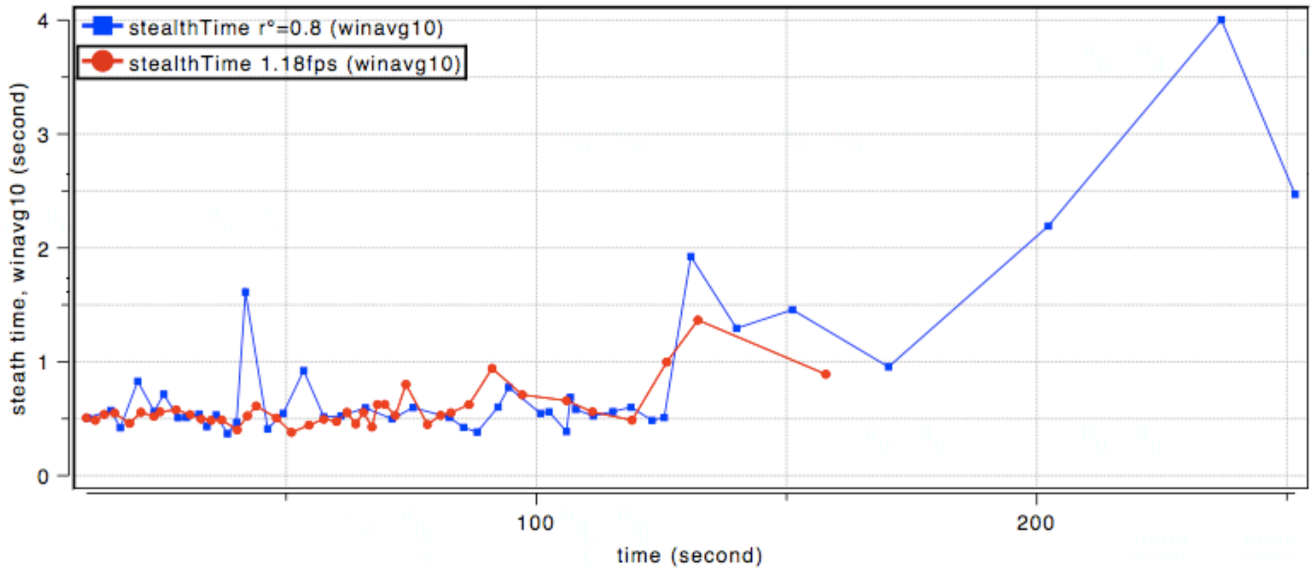
STEALTH TIME, WINAVG[10]





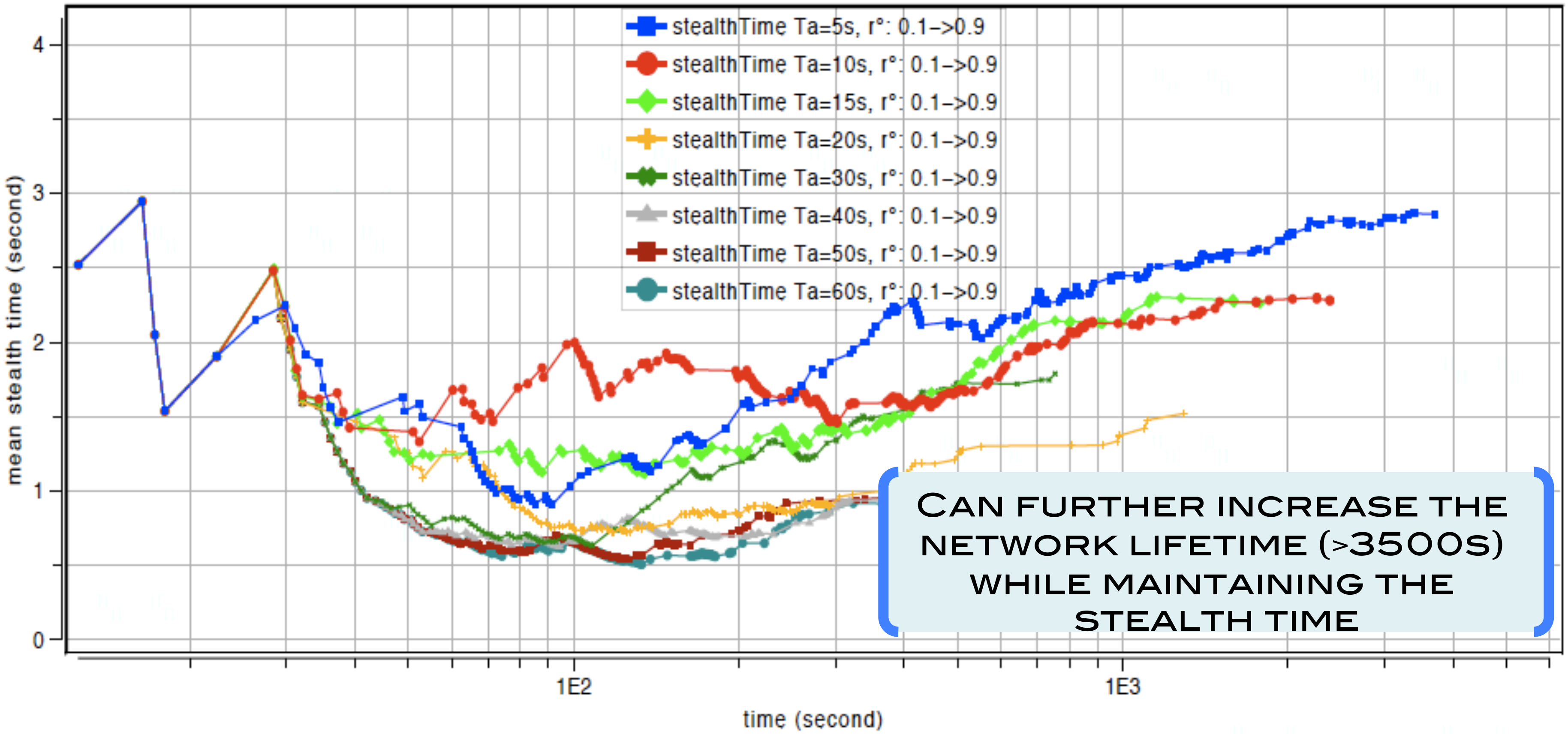
STEALTH TIME, WINAVG[10]





Dynamic scheduling

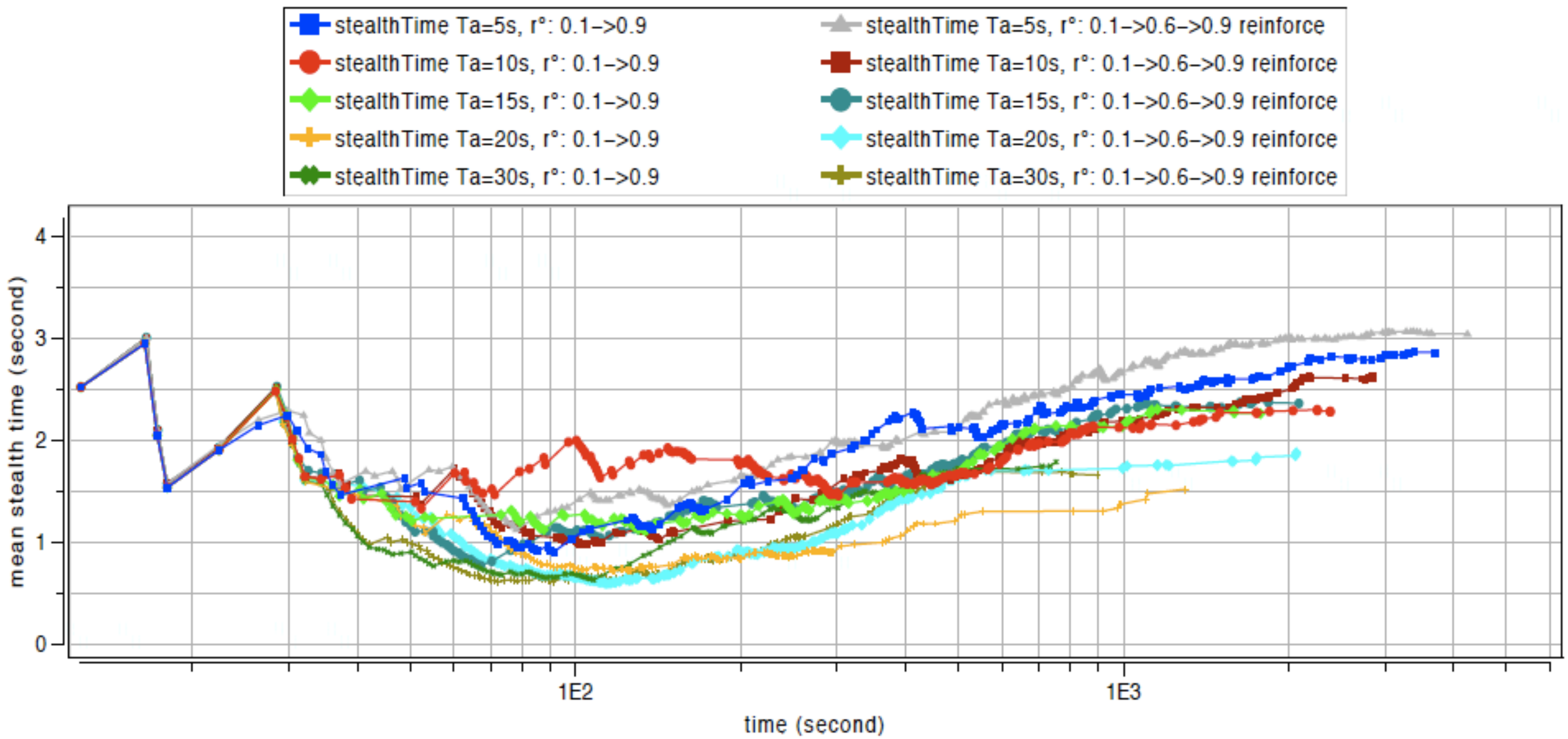
- $r° = 0.1$, $R_{MAX} = 0.9$, $T_A = 5, 10, 15, 20..60s$



Can further increase the network lifetime (>3500s) while maintaining the stealth time

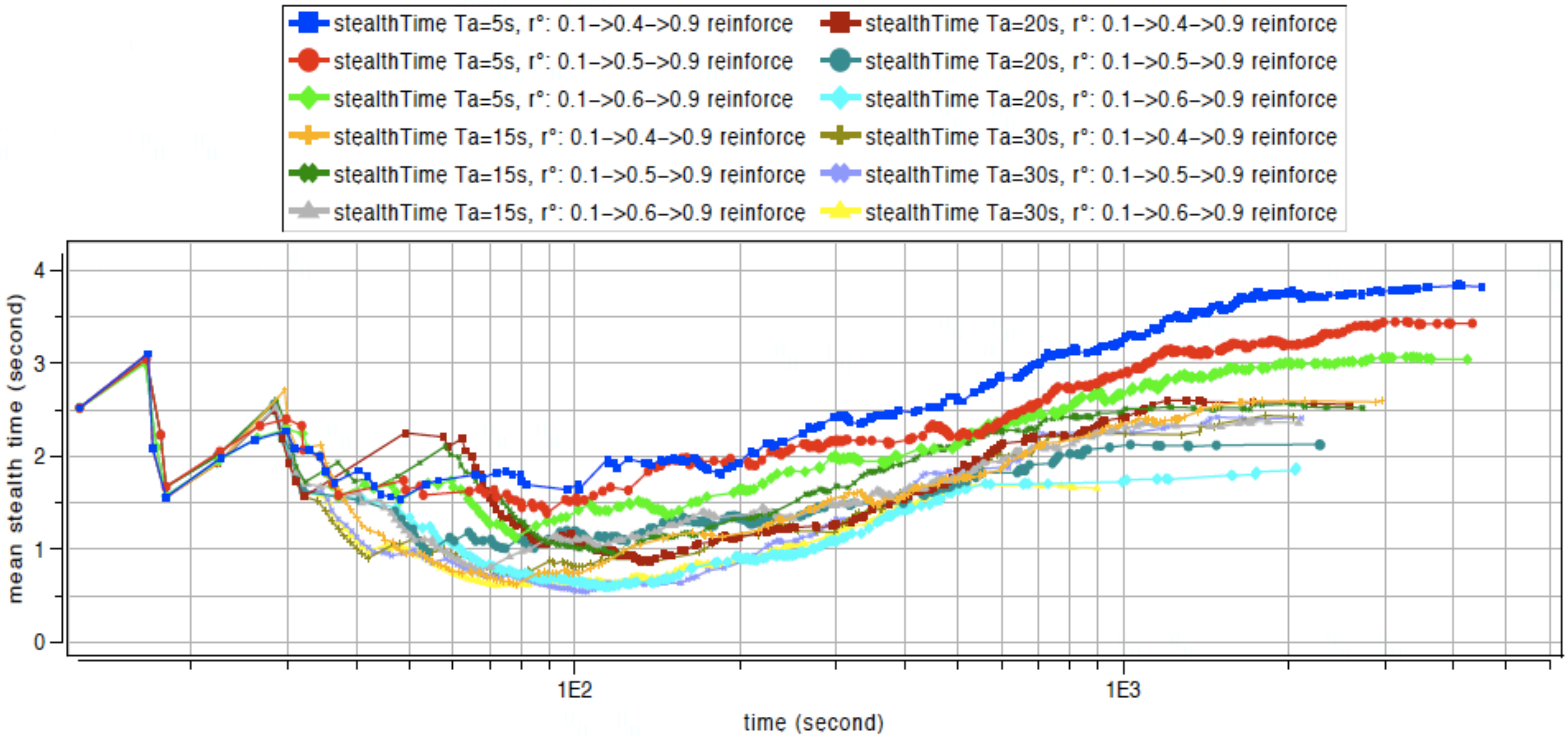
Dynamic with reinforcement (1)

- $R° = 0.1 \rightarrow I_R = 0.6 \rightarrow R_{MAX} = 0.9$
- 2 alert msg to have $I_R = I_R + 0.1$



Dynamic with reinforcement (2)

- $R° = 0.1 \rightarrow I_R = 0.4/0.5/0.6 \rightarrow R_{MAX} = 0.9$
- 2 alert msg to have $I_R = I_R + 0.1$



The advantage of having more cover-set (1)

N=6
$P_2(6,6)$

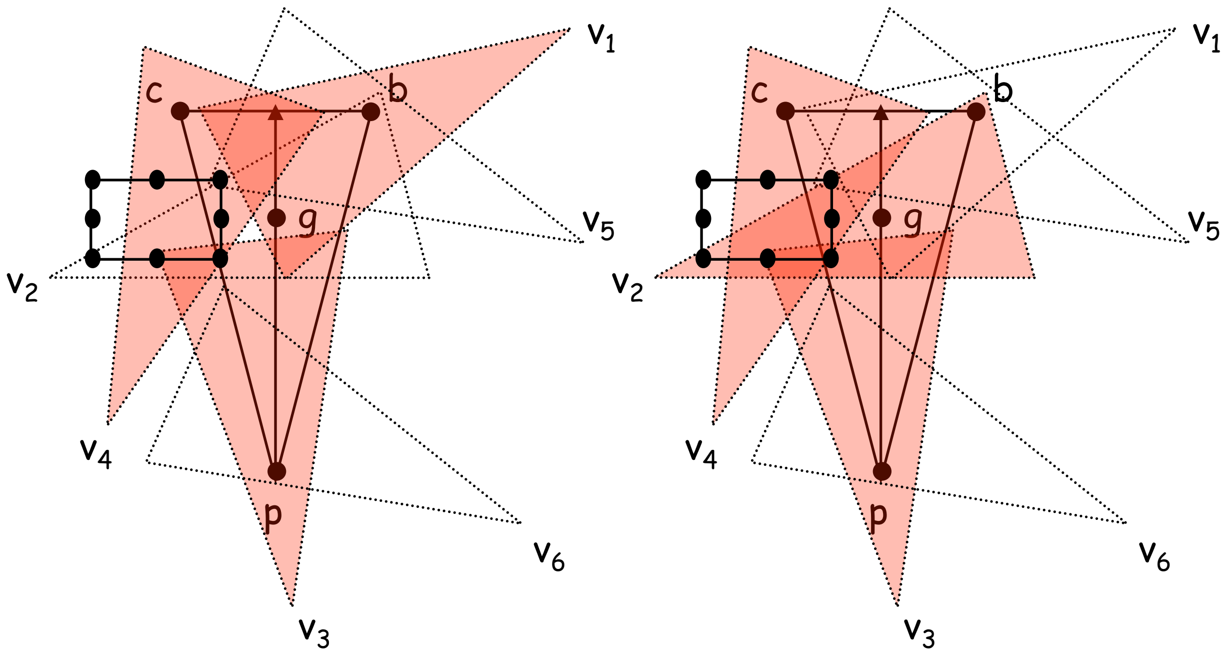
r^0 \ $\|Co(v)\|$	1	2	3	4	5	6
0.0	0.05	0.20	0.51	1.07	2.10	6.00
0.2	0.30	0.73	1.34	2.20	3.52	6.00
0.5	1.00	2.00	3.00	4.00	5.00	6.00
0.8	2.48	3.80	4.66	5.27	5.70	6.00
1.0	3.90	4.93	5.49	5.80	5.95	6.00

N=12
$P_2(12,3)$

r^0	1	2	3	4	5	6	7	8	9	10	11	12
0	.01	.02	.05	0.1	.17	.26	.38	.54	.75	1.1	1.5	3
.2	.07	.15	.25	.37	.51	.67	.86	1.1	1.4	1.7	2.2	3
.4	.17	.35	.55	.75	.97	1.2	1.4	1.7	2.0	2.3	2.6	3
.6	.36	.69	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3
.8	.75	1.2	1.6	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3
1	1.5	1.9	2.2	2.4	2.6	2.7	2.8	2.9	2.9	2.9	2	3

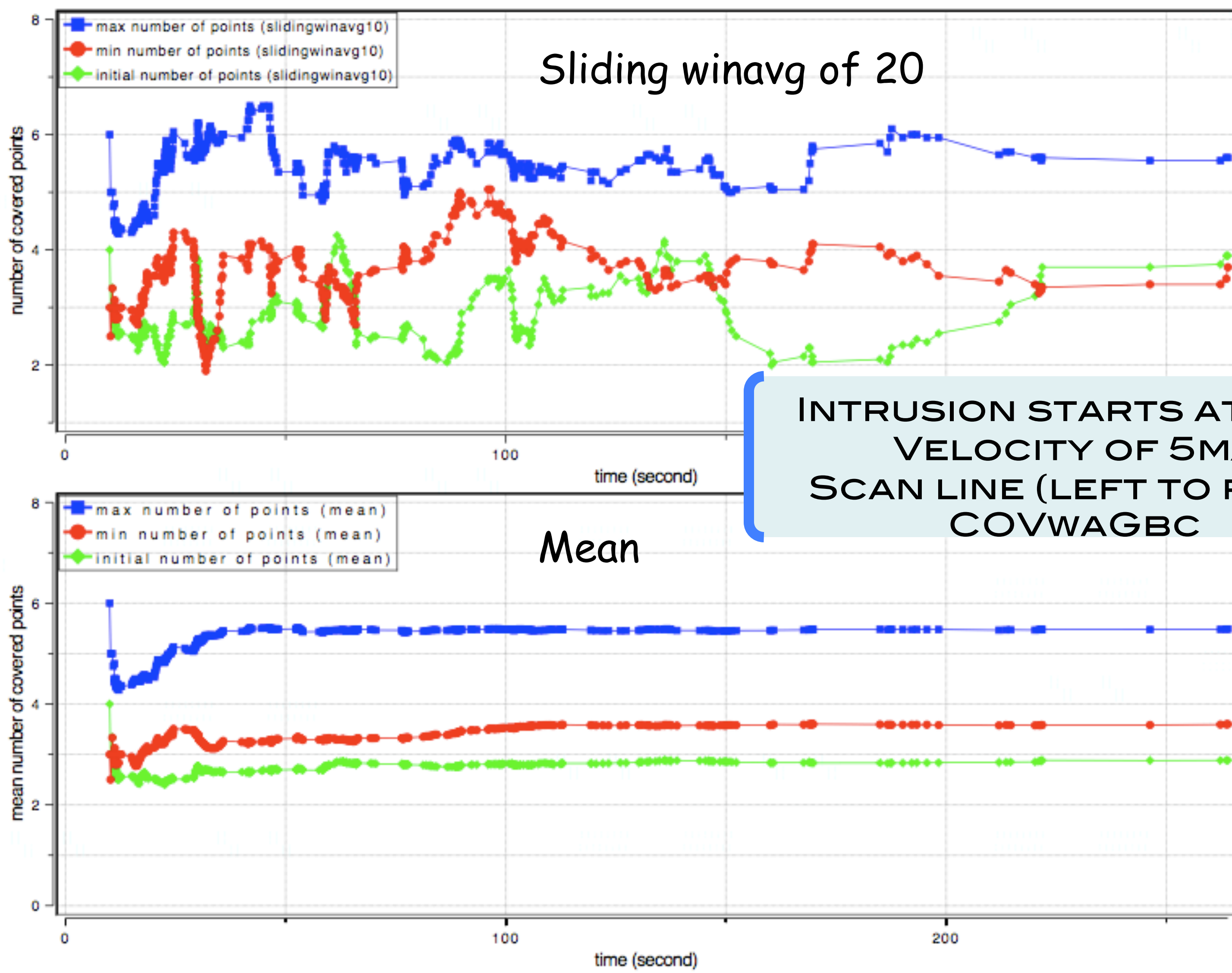
Occlusions/ Disambiguation

8m.4m rectangle→grouped intrusions



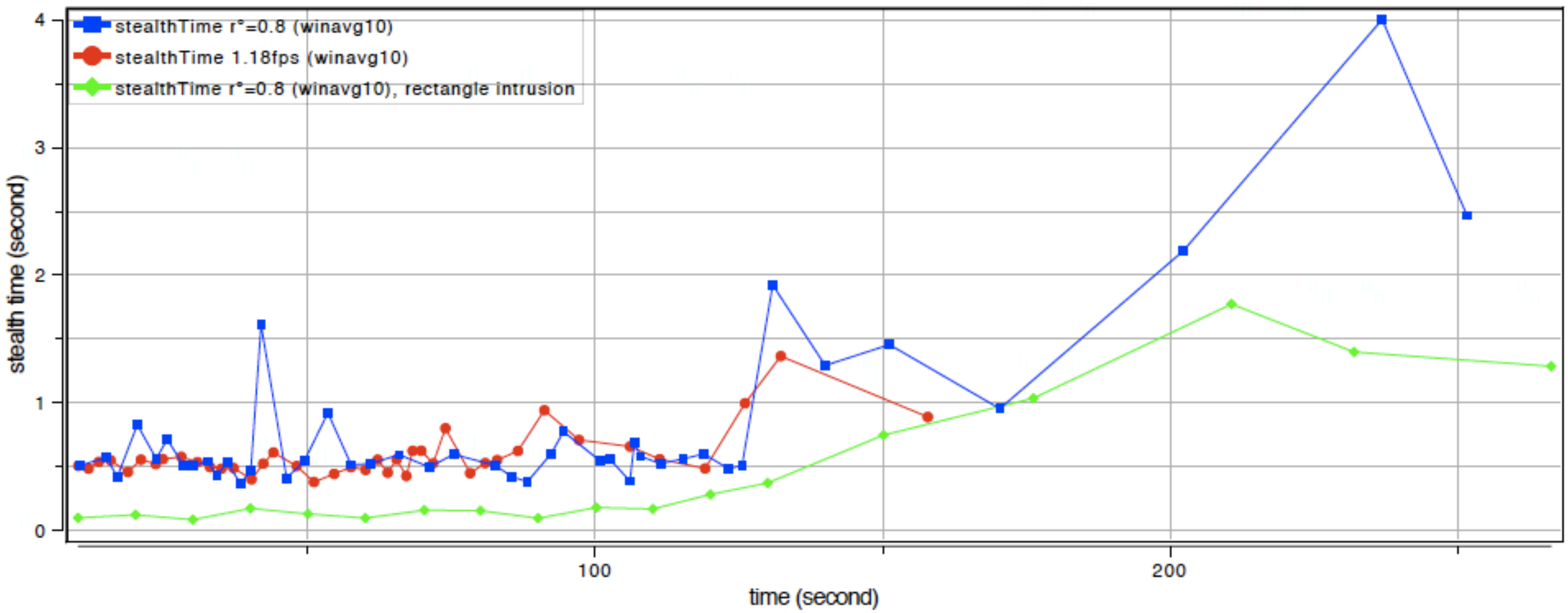
Multiple viewpoints are desirable
Some cover-sets « see » more points than other

The advantage of having more cover-set (2)



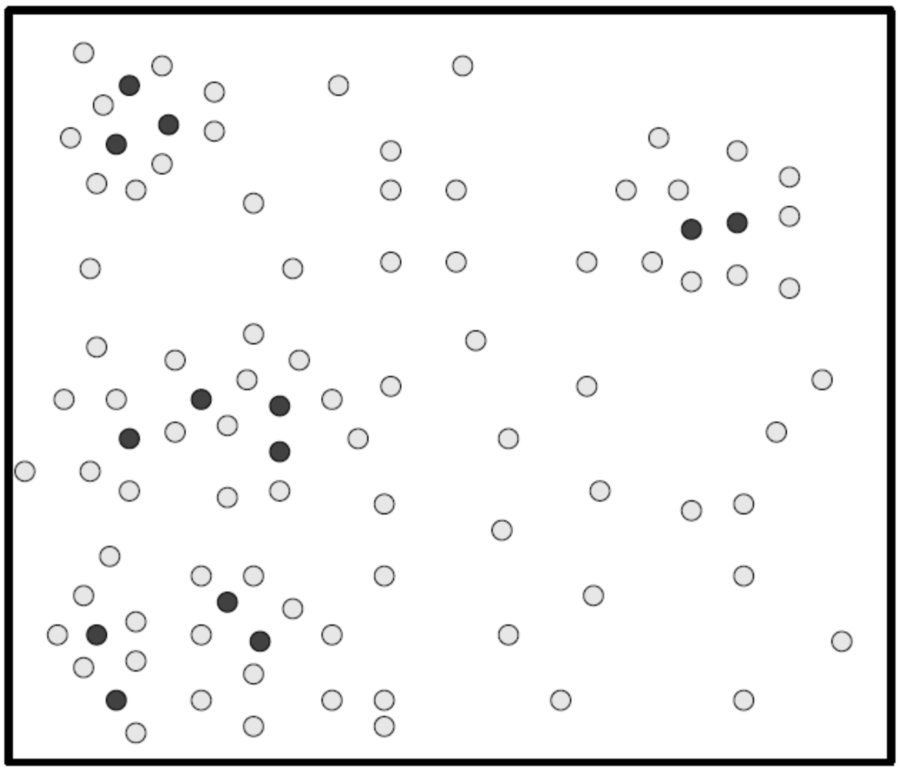
Intrusion starts at t=10s
Velocity of 5m/s
Scan line (left to right)
COVwaGBC

Stealth time with grouped intrusions

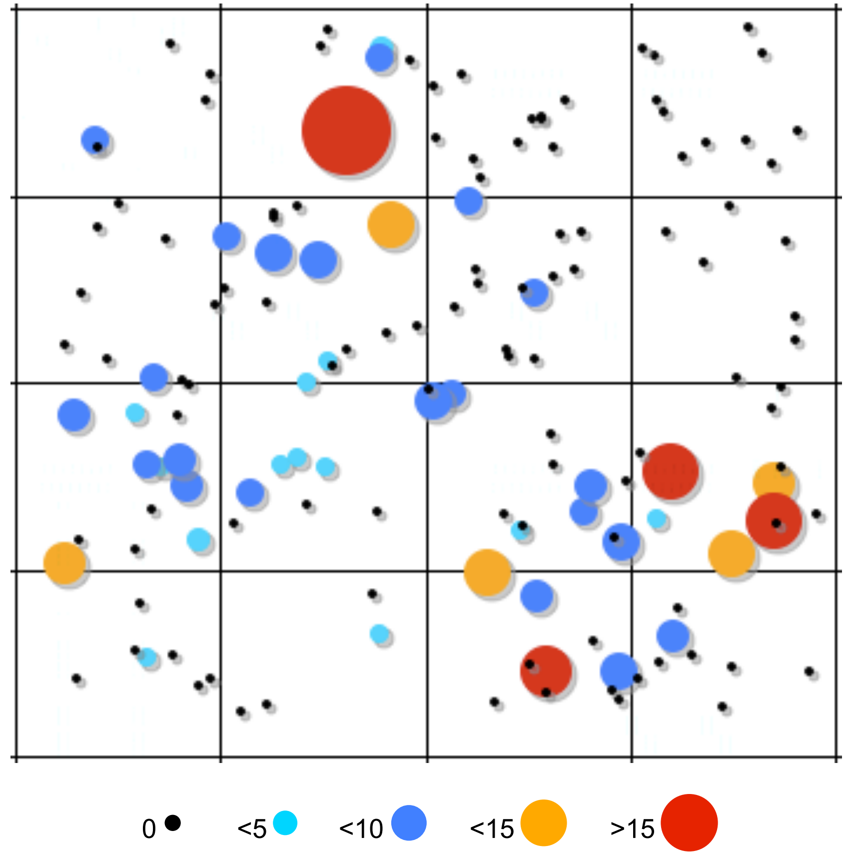


Defining sentry nodes

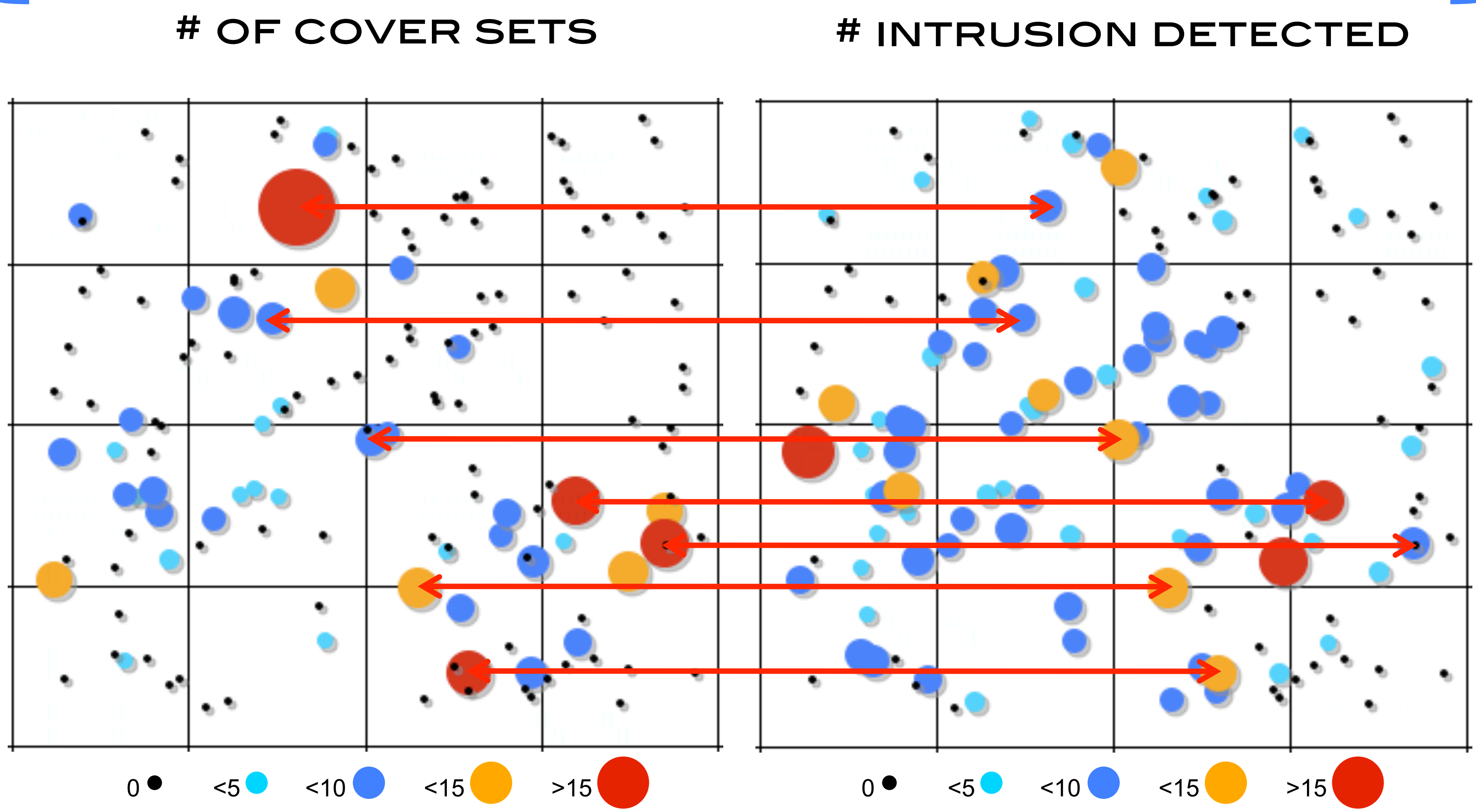
- ● Sentry node: node with high speed capture (high cover set).
- ○ Idle node: node with low speed capture.



# of cover sets

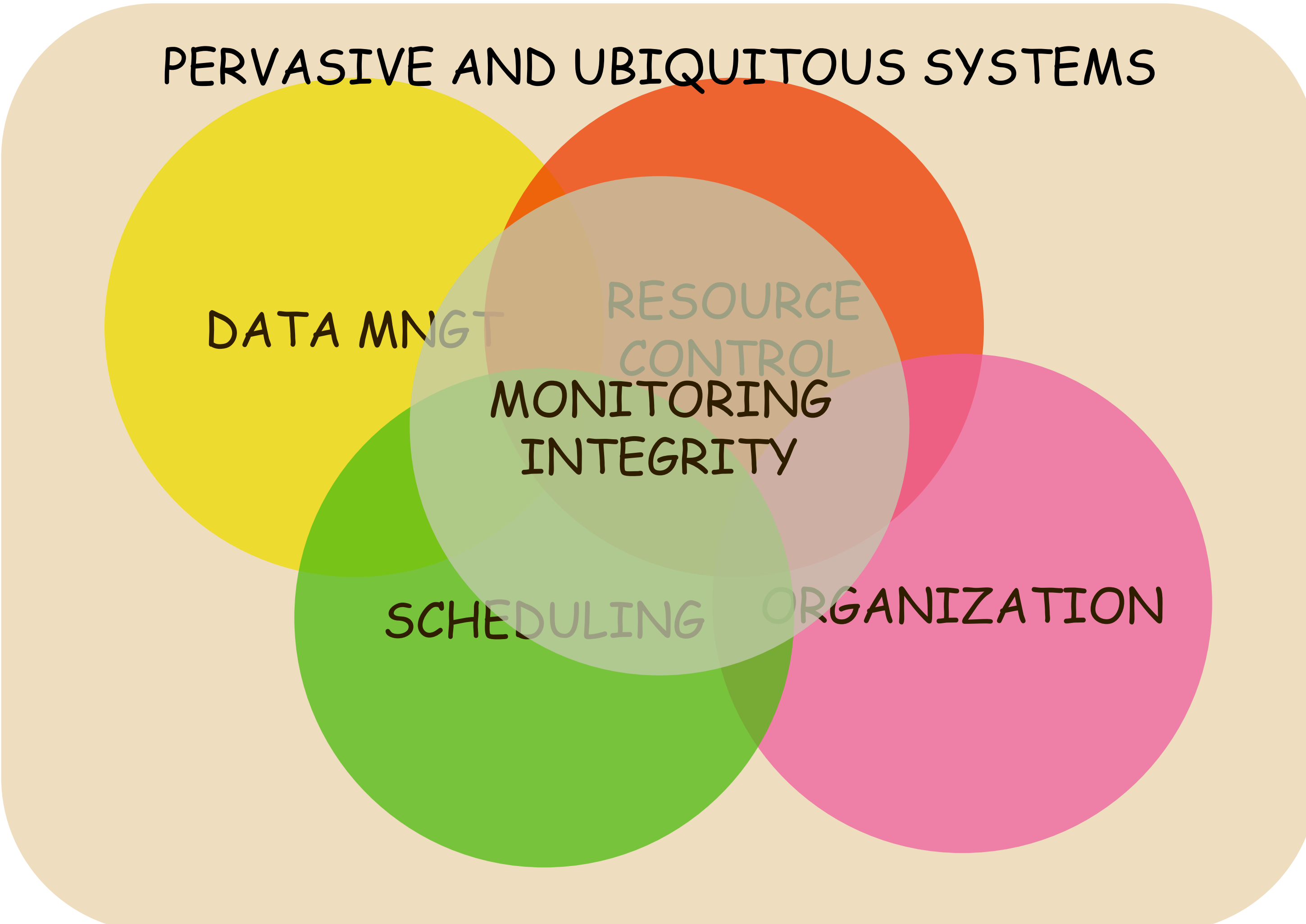


Sentry nodes

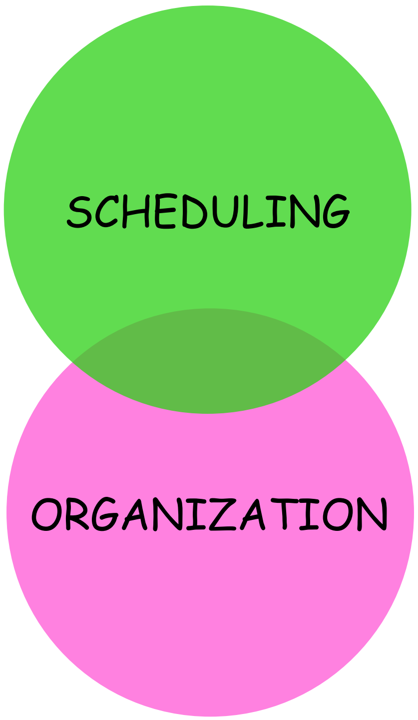


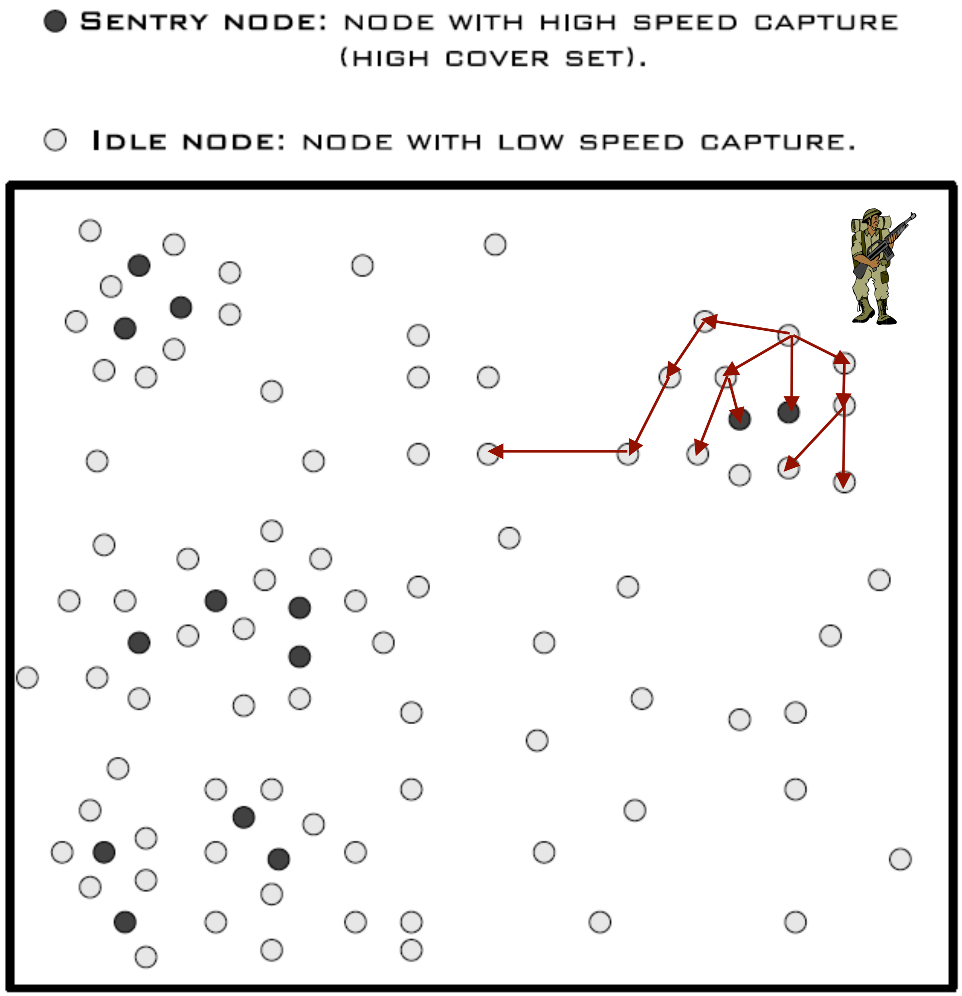
Research directions

Research directions

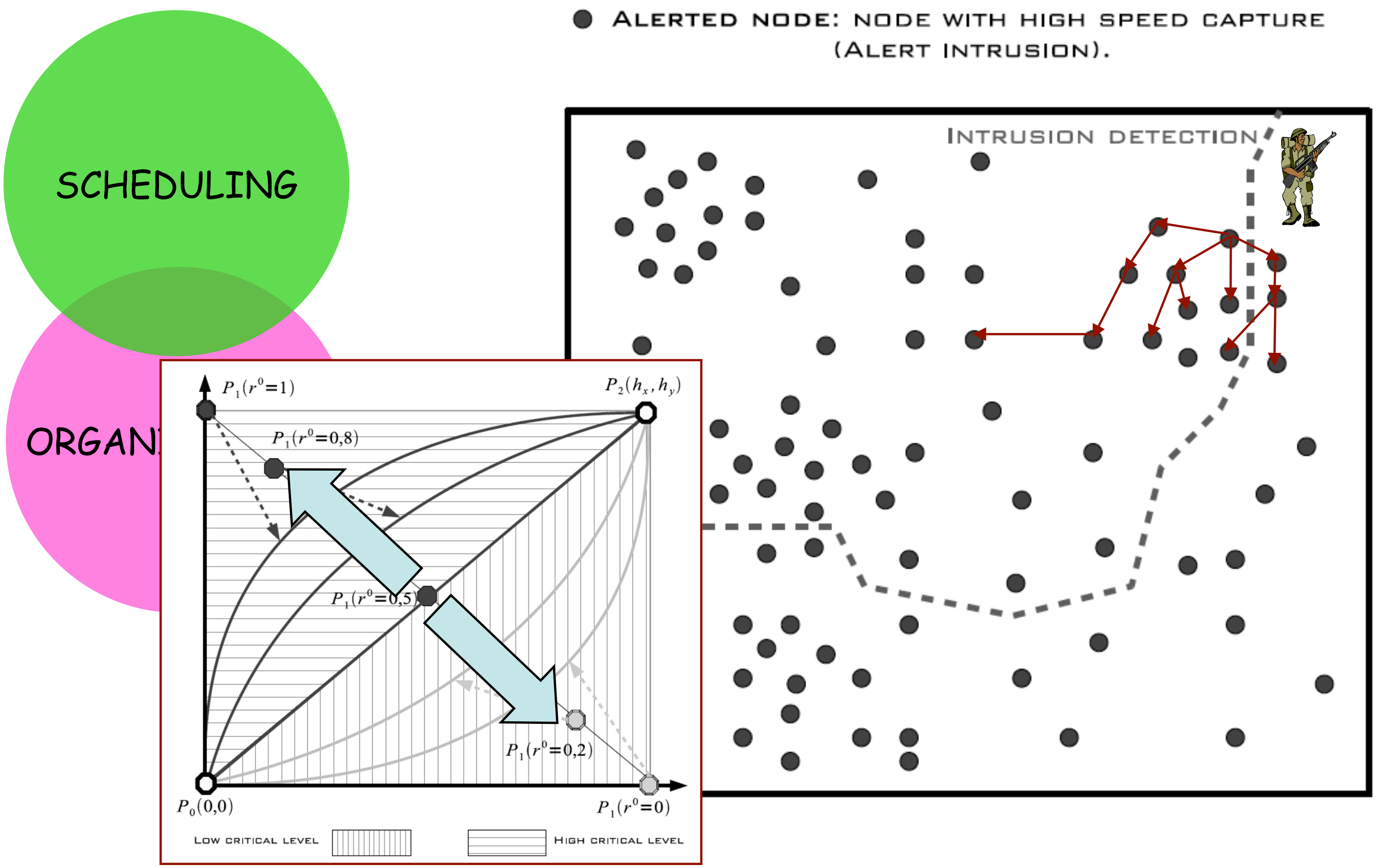


Controlled propagation (1)

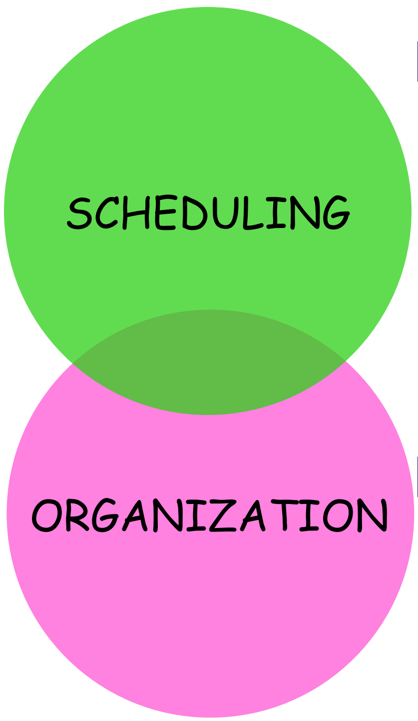




Controlled propagation (2)



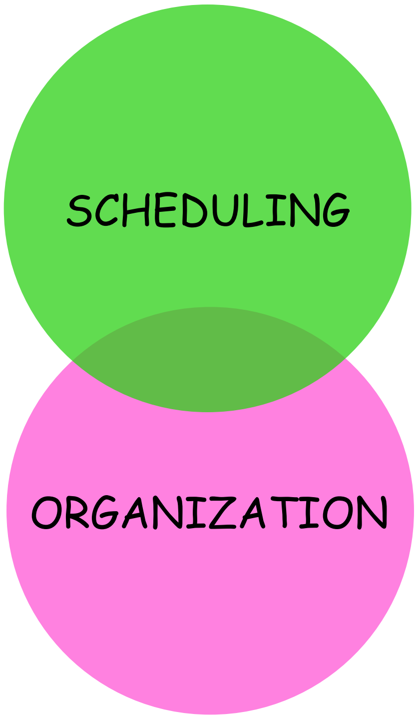
Controlled propagation (3)

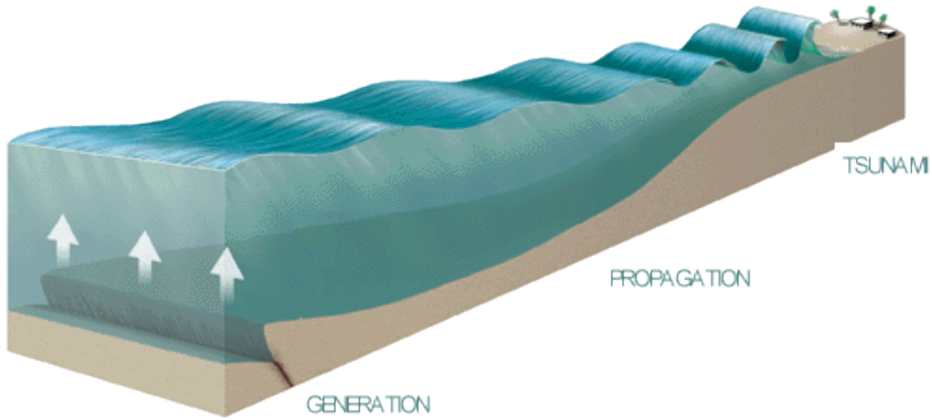


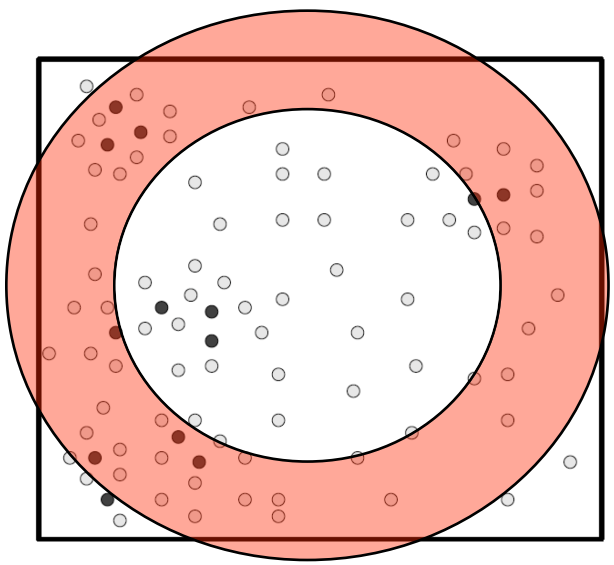
- Not a simple propagation or broadcast algorithm
  - Not all nodes need to be at the maximum (same) alert level
  - Which nodes should be more than others?
- Borrow propagation model from other disciplines
  - Epidemic propagation, percolation, wave propagation, ...
  - According to the model, map the parameter of a surveillance system to the model's parameters

Controlled propagation (4)

Ex: tsunami generation





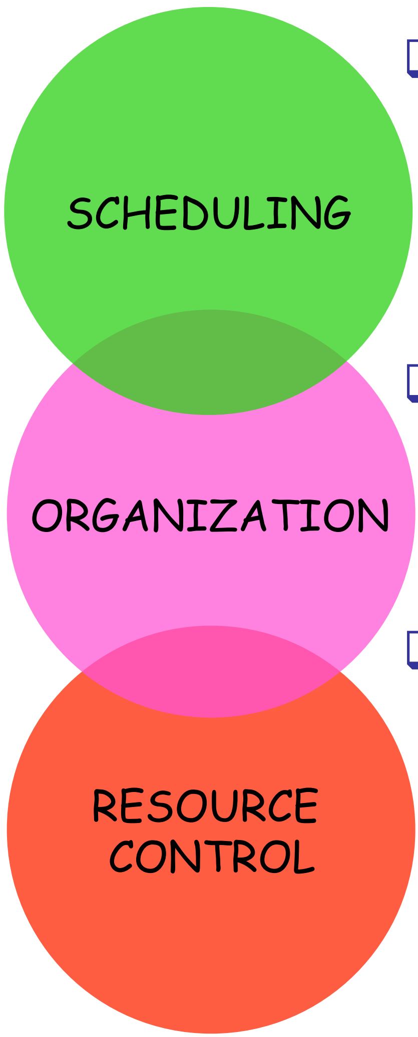


sensor nodes near the border may need to be « alerted » than others, they could have an amplification factor greater than those near the centre

Scheduling cover-set

- On intrusion, it is desirable to use more camera
  - To circumvent occlusions
  - To help for disambiguation
- It is not necessary that all activated camera capture at a same rate
  - How to define the capture rate for each node of the same cover set? Consensus?
  - Camera rotation capabilities?
  - Take into account routing of flows?

Interactions of mobile nodes and fixed nodes



- Study the interactions under the criticality management scheme
  - Fixed sensors can decrease their criticality level on proximity of a mobile node
- Some mobility can be triggered by alerts
  - Applied the criticality model for mobility degree?
- What trajectory for mobile nodes? What functionality?
  - Mobile nodes as relay
  - Mobile nodes as aggregators
  - Mobile nodes as validators

MAC level & Routing

SCHEDULING

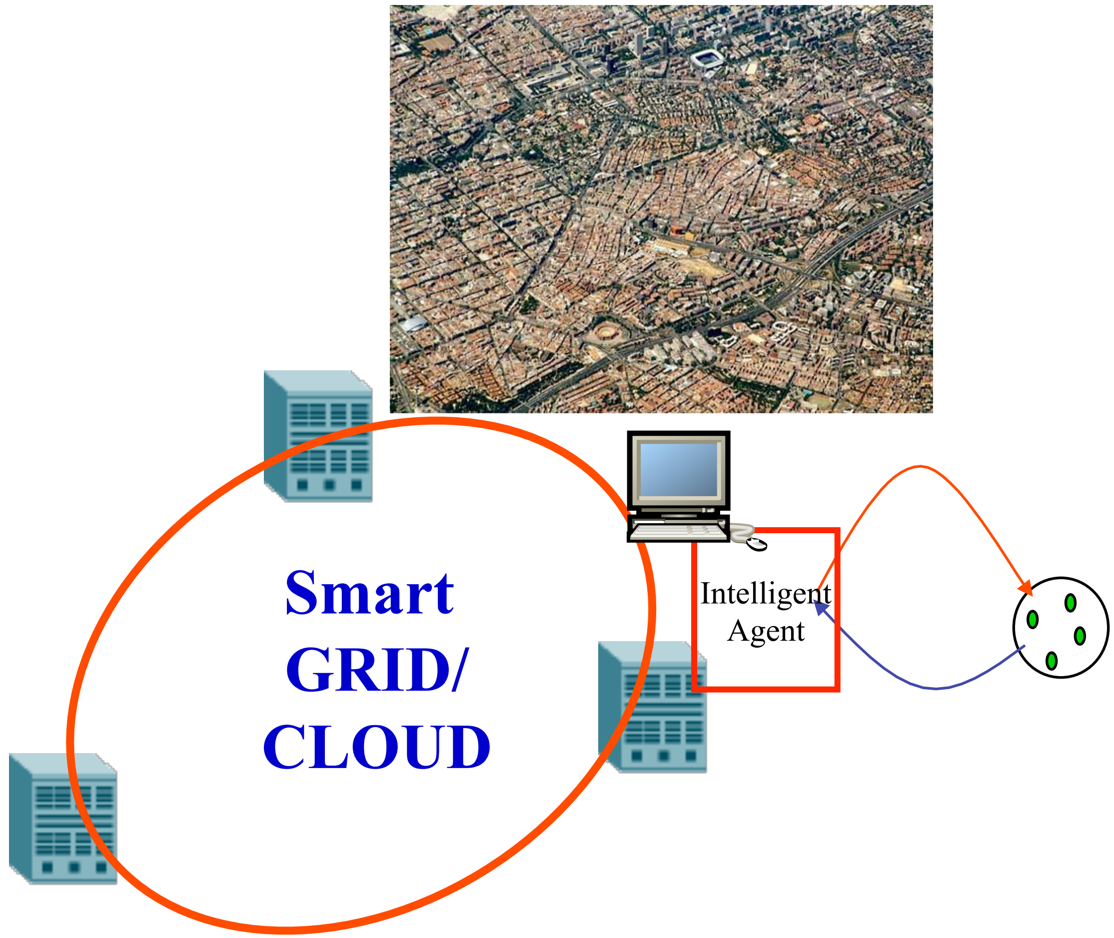
- Design MAC layer for emergency traffic
  - Cross-layer approach?
  - TASSILI Project with Algeria
- Design multi-path routing for efficient video transfer
  - Cross-layer approach?
  - Collaboration with CRAN/ Nancy

RESOURCE CONTROL

Towards wide-area situation awareness

Authorised User

Madrid Hospital



The tools

OMNET++/CASTALIA