Performance study of multiple cover-set strategies for mission-critical video surveillance with wireless video sensors

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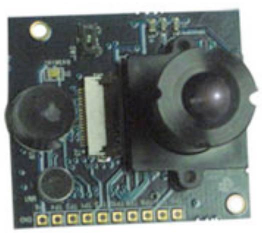
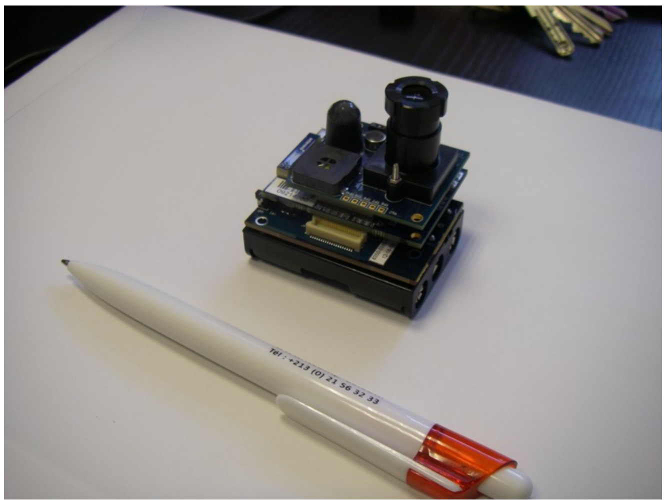
Wireless Video Sensors (1)

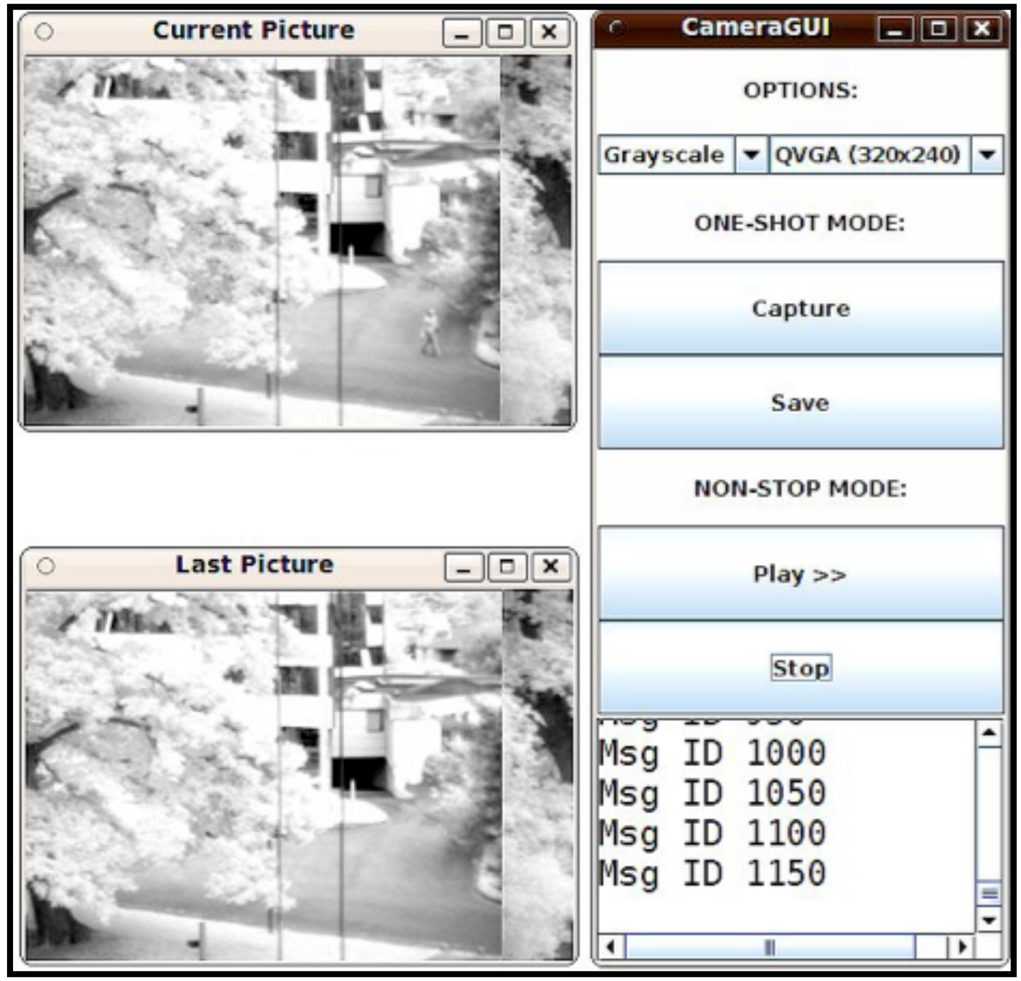
Imote2



Multimedia board

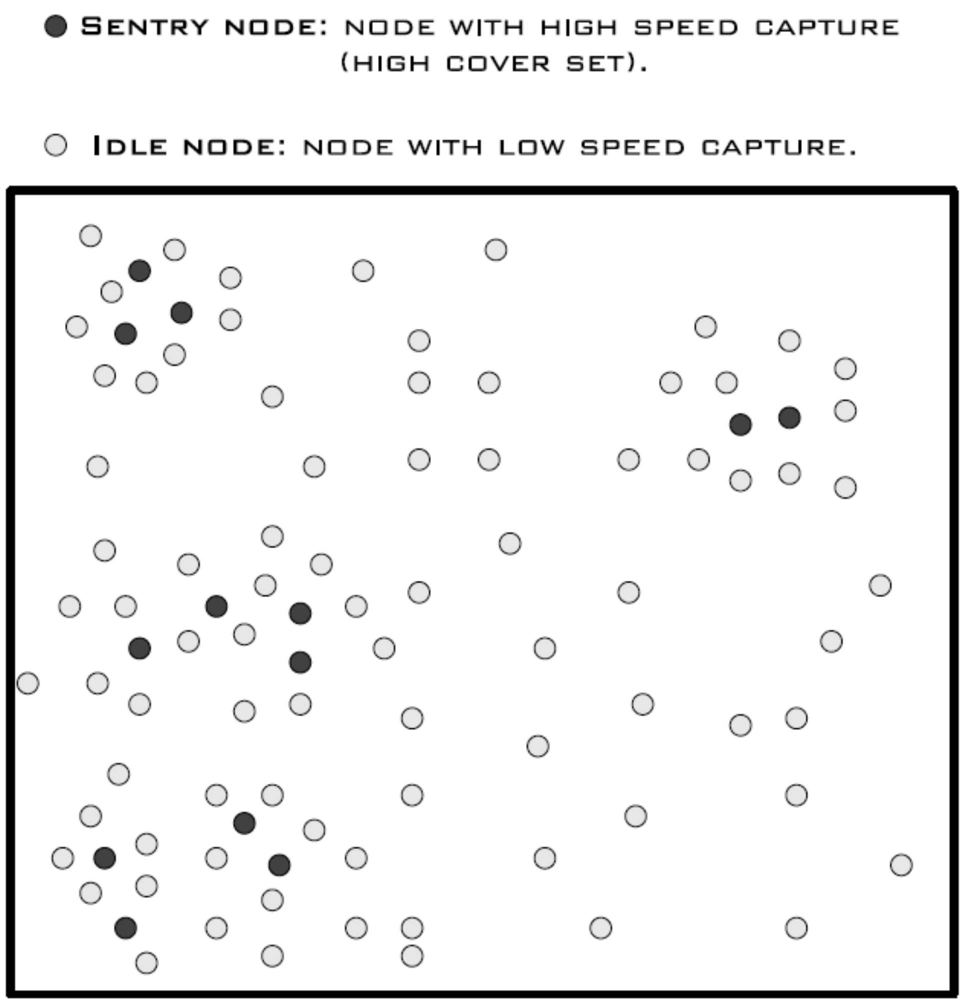
Wireless Video Sensors (2)





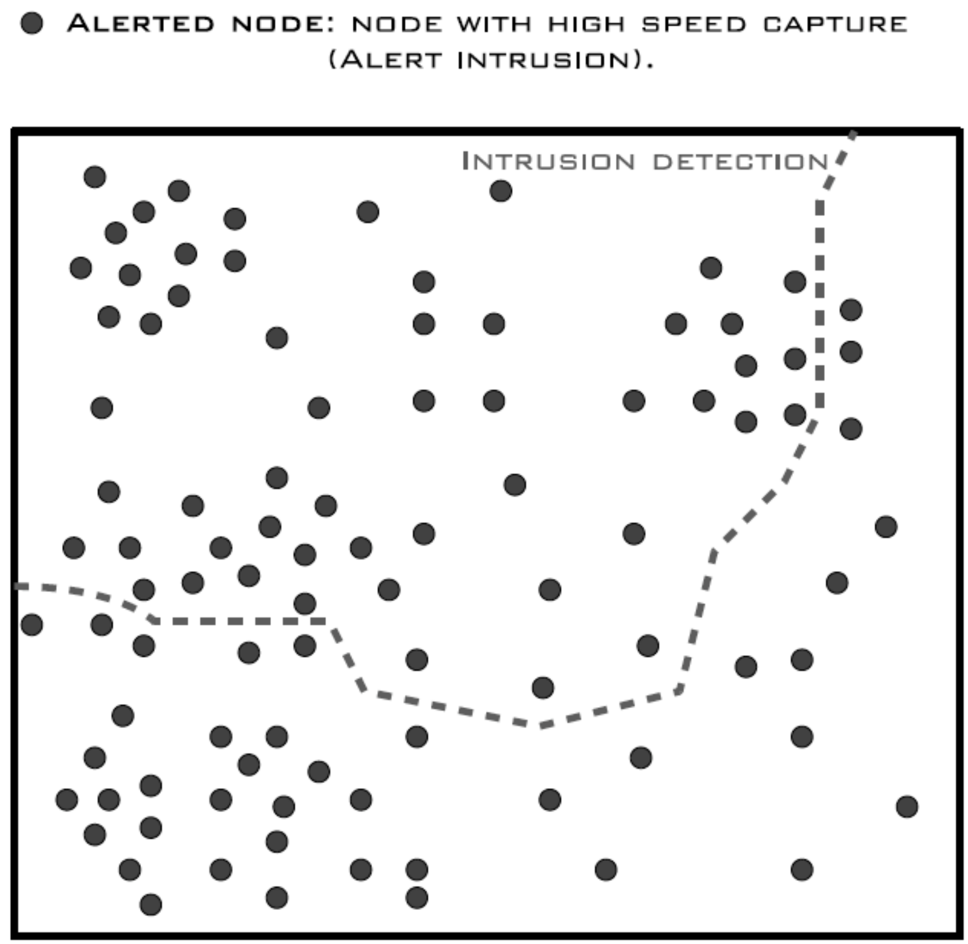
Surveillance scenario (1)

- 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



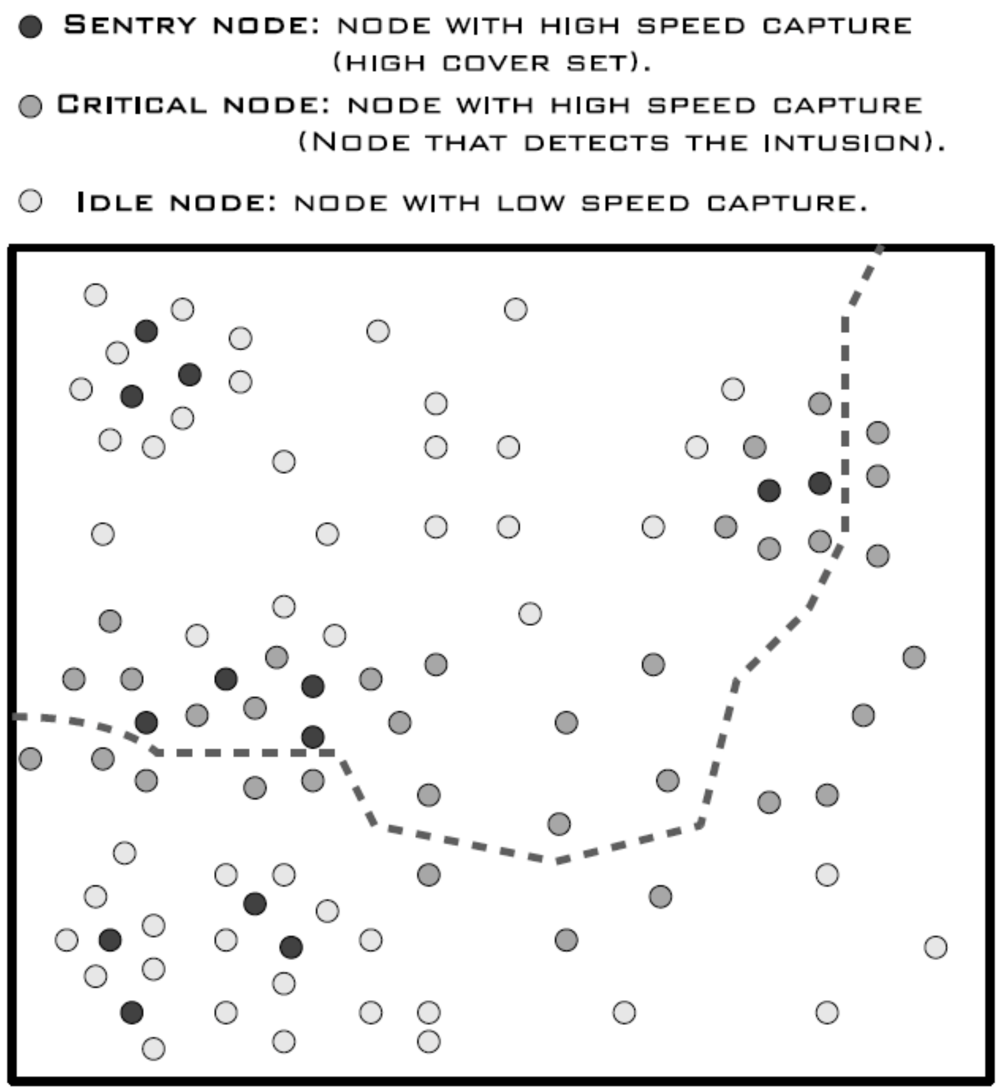
Surveillance scenario (2)

- 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



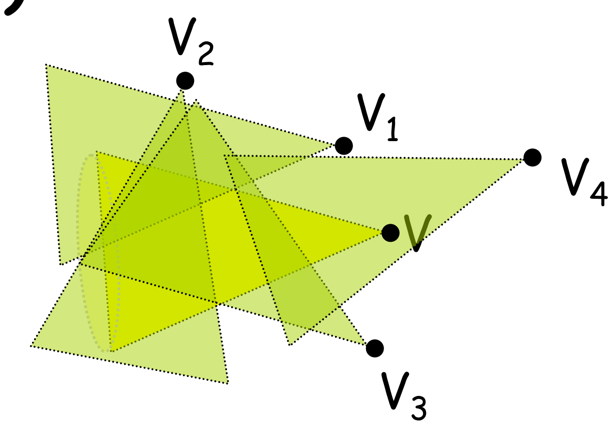
Surveillance scenario (3)

- 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 $\bigcup_{v' \in Coi(v)} FoV_{v'}$ covers FoV_v
- $Co(v)$= set of $Co_i(v)$



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

Don't miss important events!

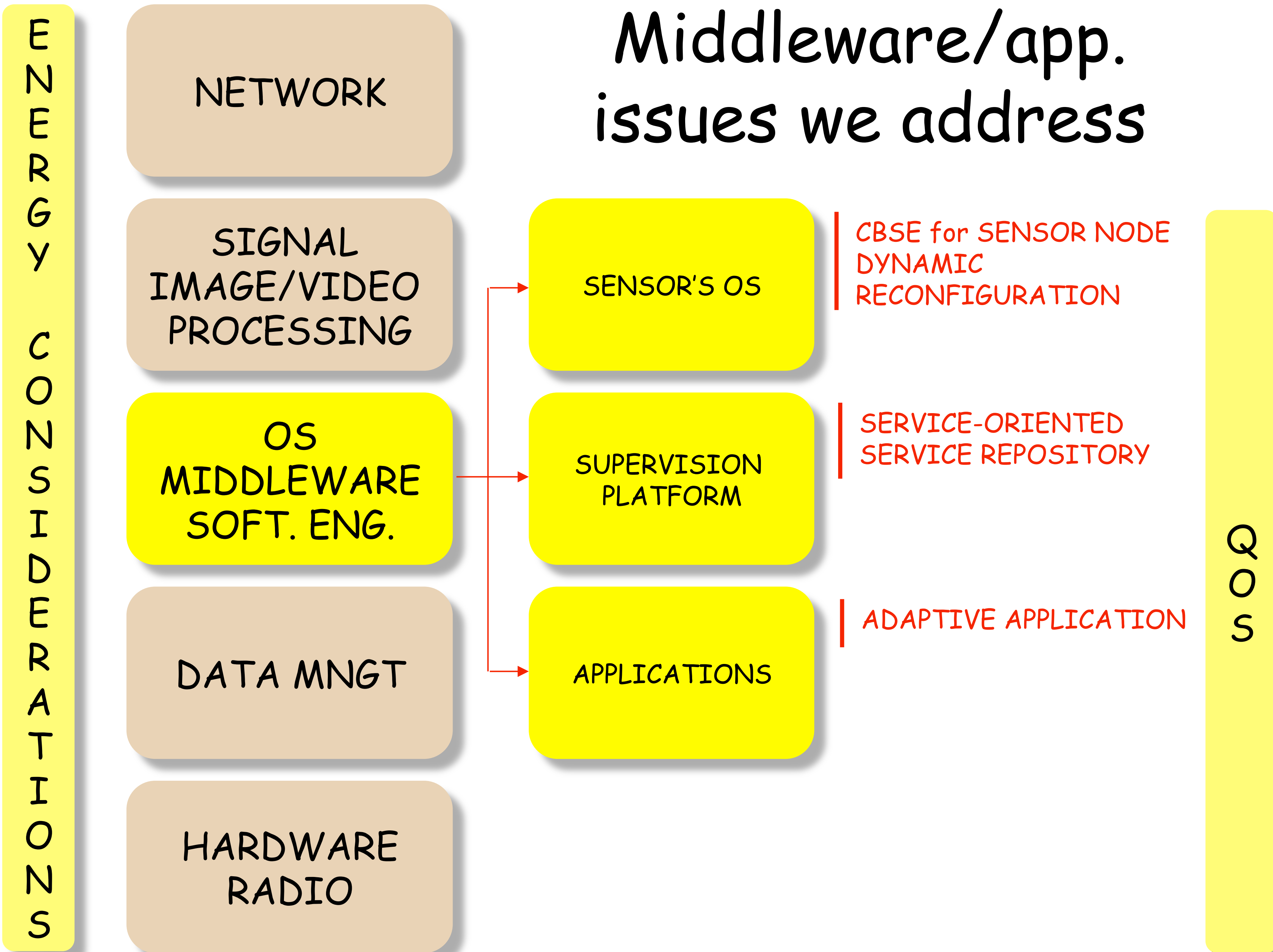
What is captured

Whole understanding of the scene is wrong!!!

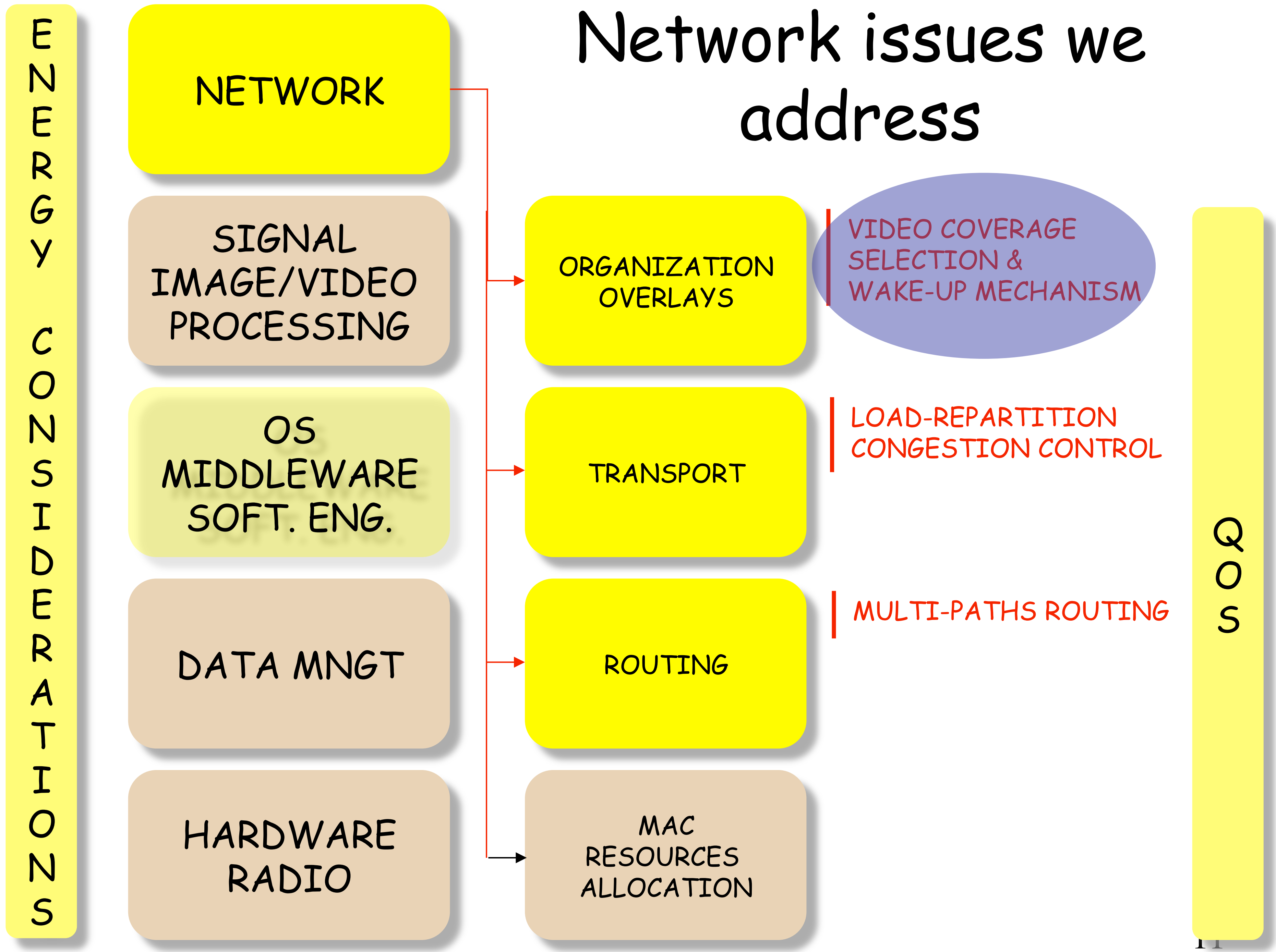
How to meet surveillance app's criticality

- 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

Middleware/app. issues we address

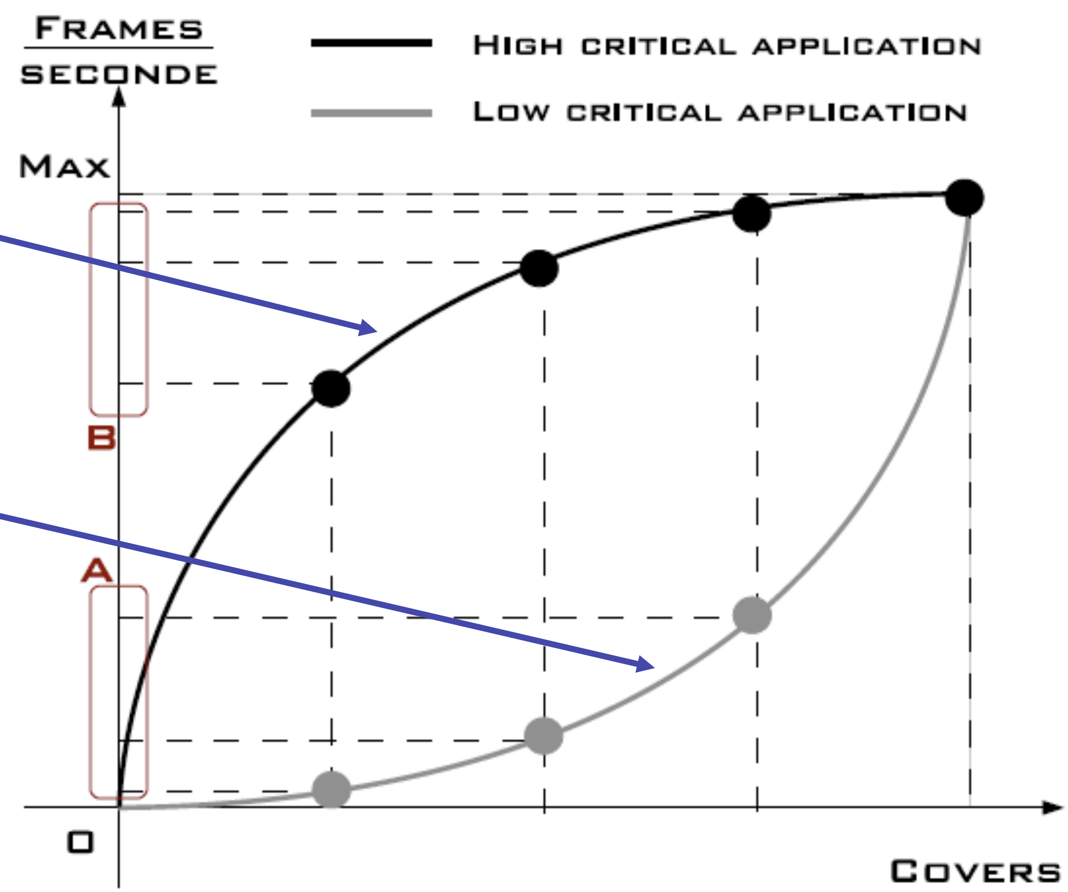


Network issues we address



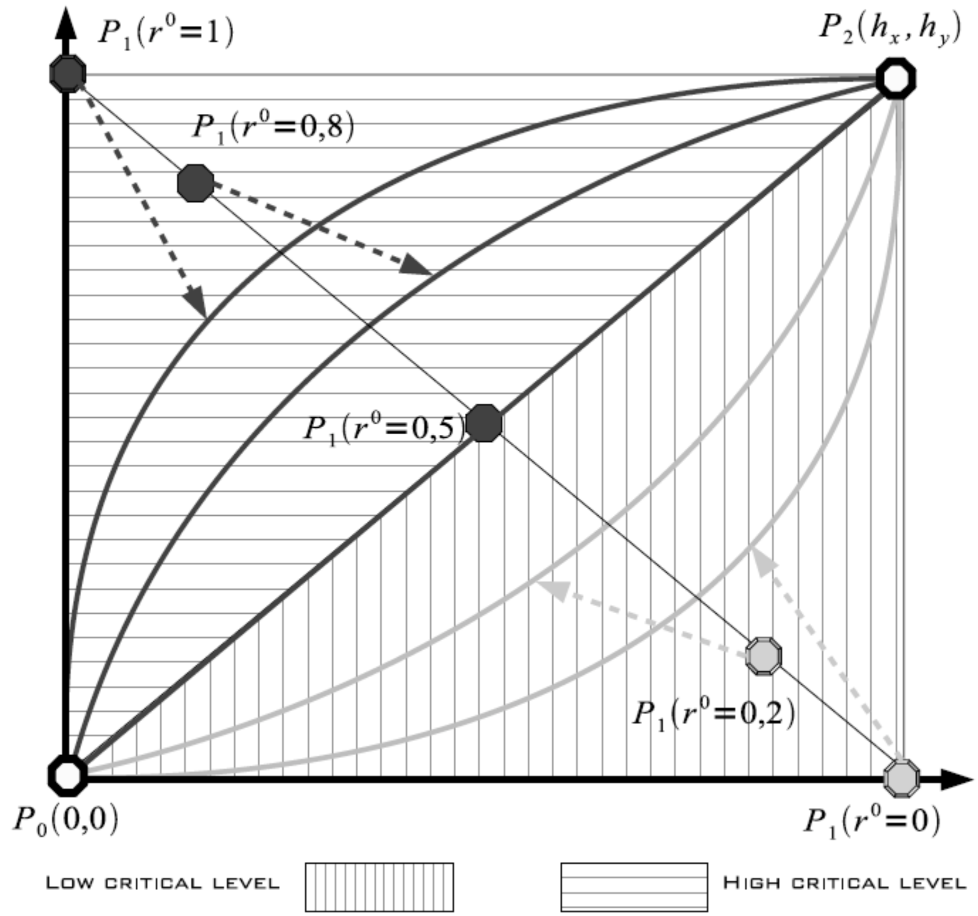
Criticality model (1)

- 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



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

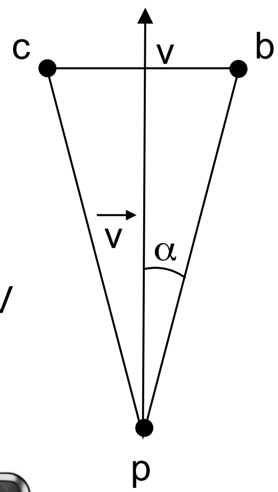
N=6
$P_2(6,6)$

r^0 \ $\lvert Co(v)\rvert$	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
$P_2(12,3)$

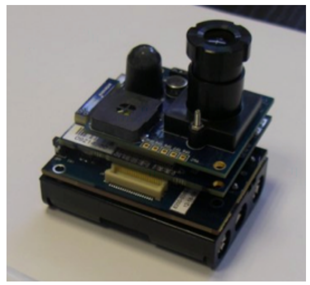
r^0	1	2	3	4	5	6	7	8	9	10	11	12
0	.01	.02	.05	0.1	.17	.26	.38	.54	.75	1.1	1.5	3
.2	.07	.15	.25	.37	.51	.67	.86	1.1	1.4	1.7	2.2	3
.4	.17	.35	.55	.75	.97	1.2	1.4	1.7	2.0	2.3	2.6	3
.6	.36	.69	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3
.8	.75	1.2	1.6	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3
1	1.5	1.9	2.2	2.4	2.6	2.7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

Finding v's cover set

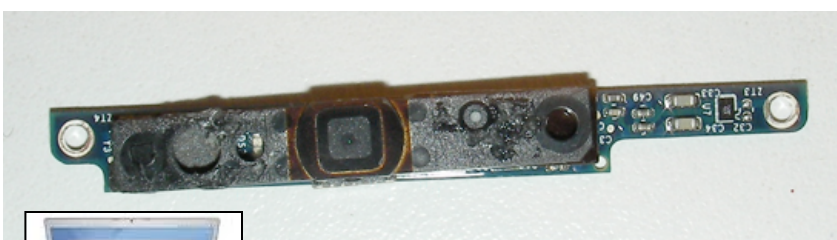


2α=AoV

AoV=20°

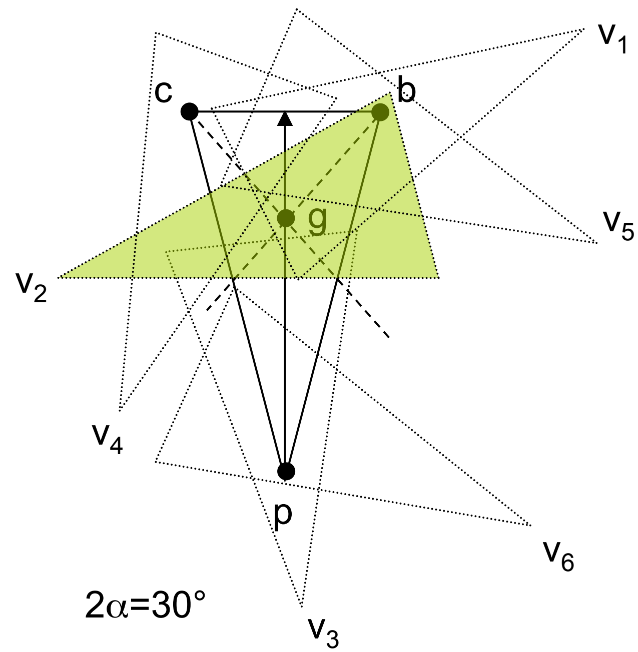


AoV=38°



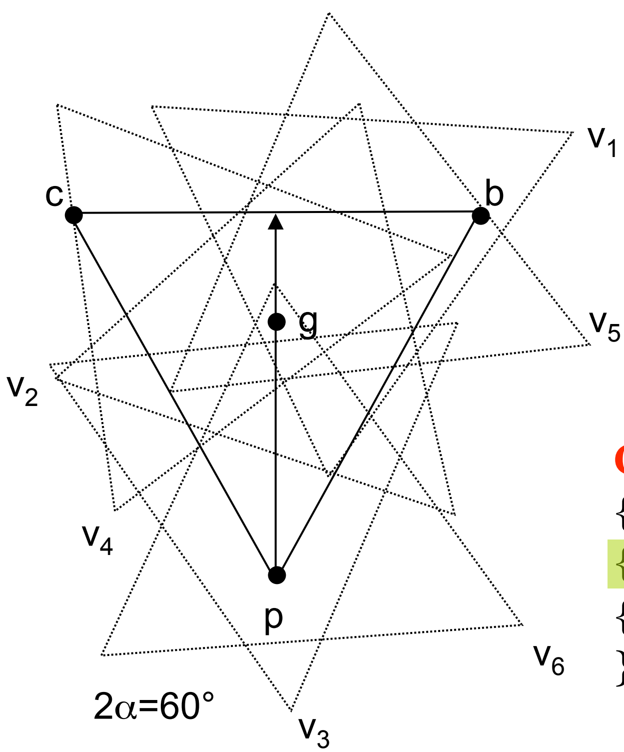
AoV=31°

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}

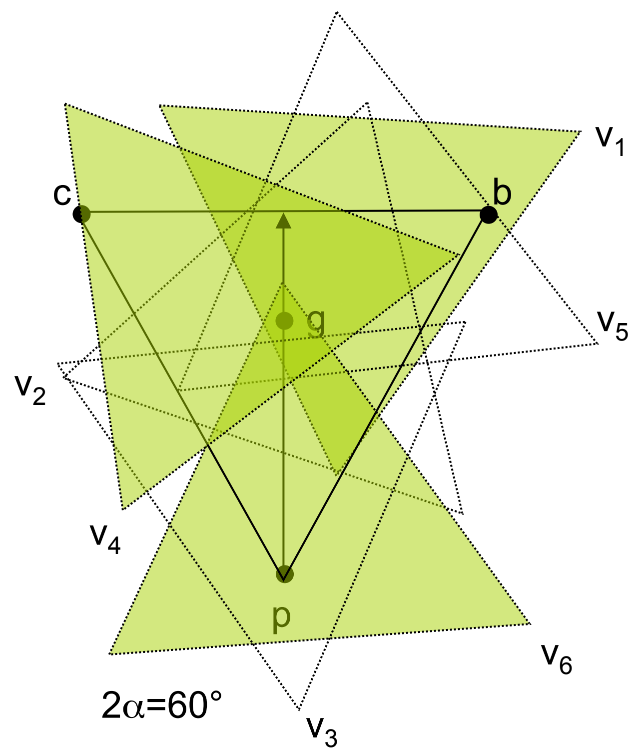


PG={P∩G}
BG={B∩G}
CG={C∩G}
Co(v)=PG×BG×CG

Large Angle of View

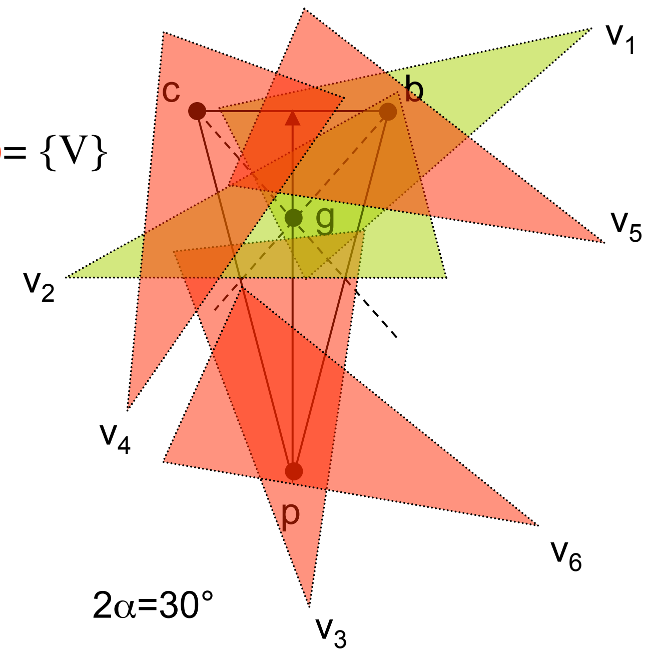


Co(V)= {
{V },
$\{V_1, V_4, V_6\}$,
$\{V_4, V_5, V_6\}$
}

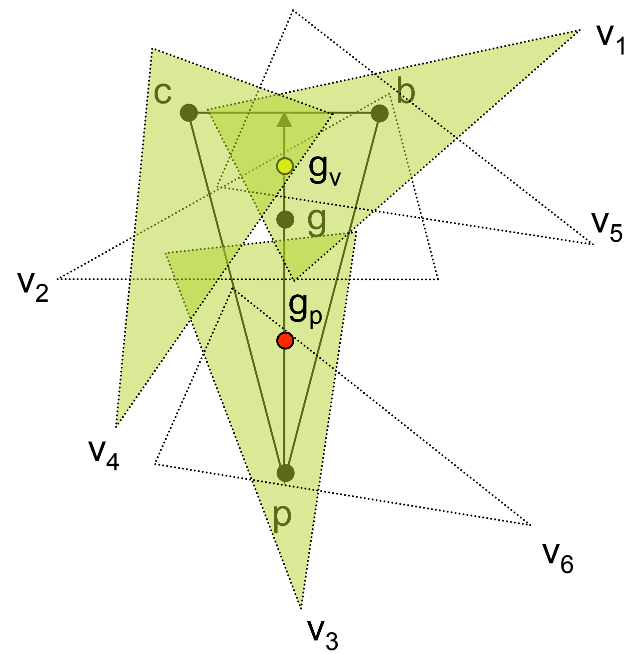


Small Angle of View

Co(V)= {V}

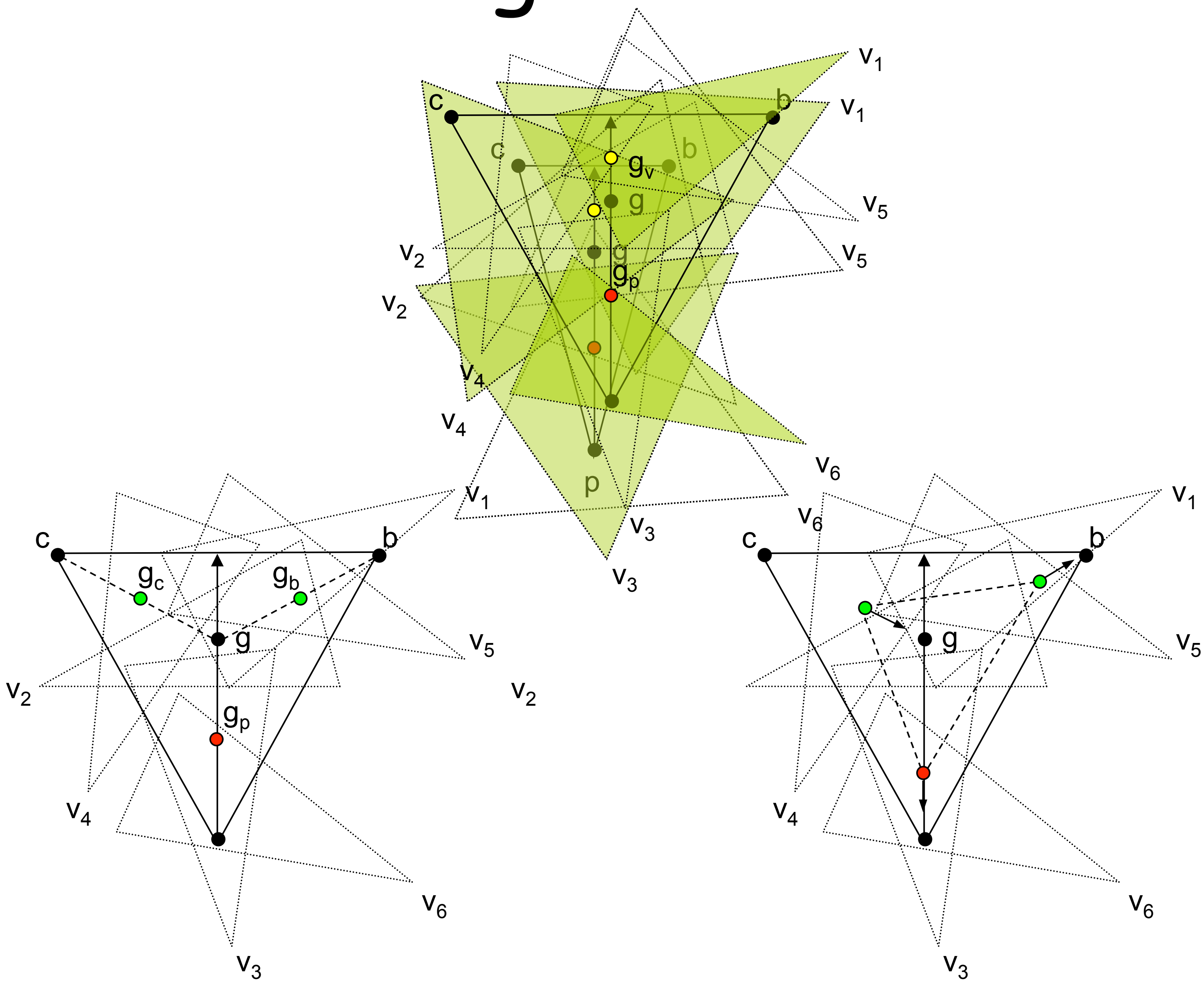


Co(V)= {
{V },
$\{V_1, V_3, V_4\}$,
$\{V_2, V_3, V_4\}$,
$\{V_3, V_4, V_5\}$,
$\{V_1, V_4, V_6\}$,
$\{V_2, V_4, V_6\}$,
$\{V_4, V_5, V_6\}$
}

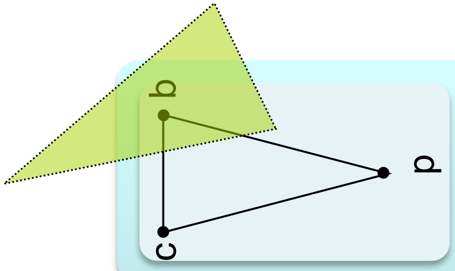


$PG=\{P\cap g_p\}$
$BG=\{B\cap g_v\}$
$CG=\{C\cap g_v\}$
$Co(v)=PG\times BG\times CG$

Heterogeneous AoV

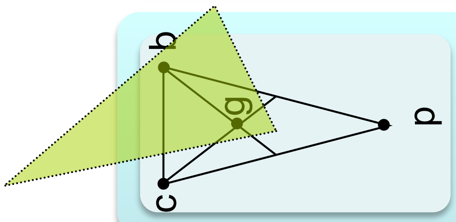


Comparison of cover-set strategies



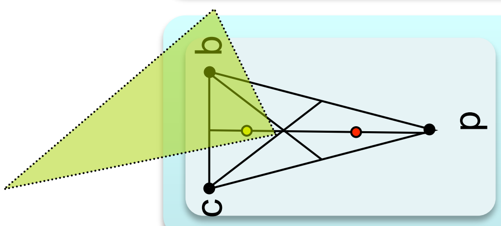
COV_{woG}

- Only triangle's points, without point G



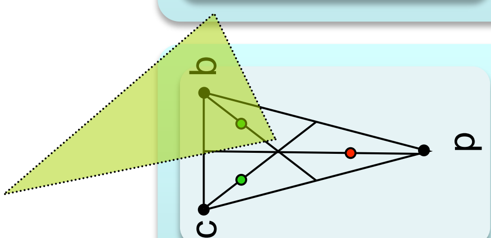
COV_{wG}

- Triangle points, with point G



COV_{waGpv}

- Triangle points, with alternate gp & gv



COV_{waGbc}

- Triangle points, with alternate gp, gb & gc

Implementation issues

1
- Needs the coordinates of sensor nodes (GPS, …)

2
- Needs the camera directions (compass)

3
- Coordinates of significant points can easily be determined given p, b & c

4
- Determining whether a point x is inside a triangle (p,b,c) is done geometrically

Testing for Point Inclusion in a Triangle

Testing for Point Inclusion in a Triangle

Given a triangle (v1,v2,v3) and a point *p*, the test for *p*'s
inclusion ... traverse
the po... ays see
the po... ng. If
v1,v2,... e points
inside ... oint is
outsid... be at
the rig... a
clockw... a point
that is... he
segme...

Thus, ...
(v1,v2,... tion
along the triplets (v1,v2,p), (v2,v3,p) and (v3,v1,p). The
point is inside if and only if the three directions are equal.

These operations « are based exclusively on the orientation of triplets of points » which requires « only three real number multiplications and five additions ». « No trigonometric function calculations are involved. »

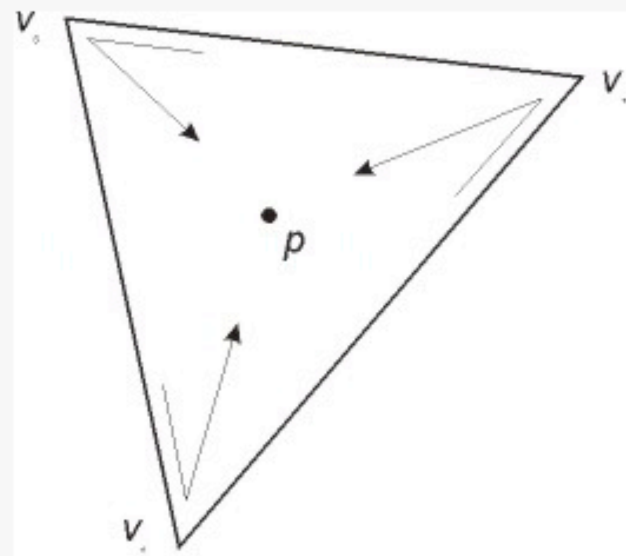


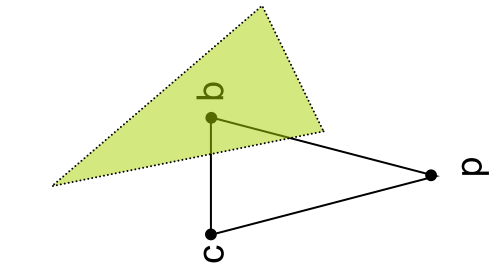
Figure 3

« Efficient 2-D Geometric Operations » by Carlos Moreno, http://www.mochima.com

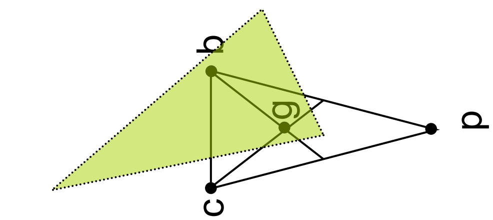
Simulation settings (1)

- OMNET++ simulation model
- Video nodes have communication range of 30m and depth of view of 25m, AoV are 36° & 60°.
- Deployment field is an 75m.75m area.
- Full coverage is defined as the region initially covered when all nodes are active

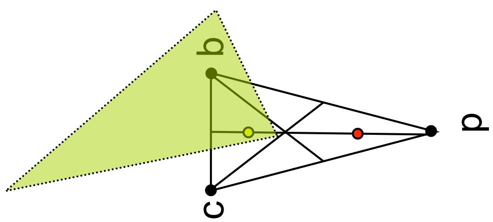
Accuracy of cover set (1)



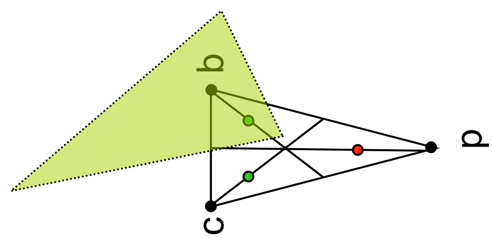
COV_{woG} 60^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	60.89	56.15	18.95,90.79	16.52	2,130	26.42
100	65.33	55.21	19.87,86.46	14.55	2,396	61.46
125	72	55.83	25.95,90.01	13.66	3.66,473.66	104.79
150	78.00	55.68	29.15,91.62	11.77	4,846.33	184.01
175	80.38	56.27	24.64,89.78	11.77	8.33,872	217.17



COV_{wG} 60^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	4.89	94.04	90.36,98.15	3.67	1,5.66	2.20
100	7.33	94.63	86.99,98.49	4.40	1,6	2.99
125	11.73	95.06	85.20,99.52	4.12	1,13	3.53
150	17.11	95.44	84,99.82	3.98	1,16.33	4.15
175	26.29	94.64	83.57,99.89	4.01	1,35.66	6.40

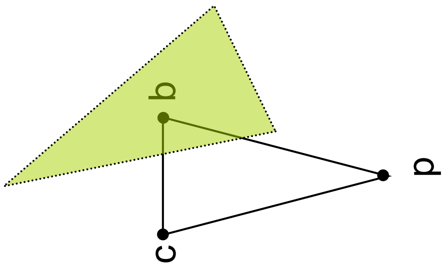


COV_{waGpv} 60^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	12.44	88.18	73.2,99.13	9.47	1,5	2.51
100	14.33	90.52	74.25,98.87	7.15	1,34.66	7.93
125	24.53	90.23	72.60,99.40	6.70	1,48	12.52
150	29.78	89.53	65.14,99.04	7.11	1.33,80	12.03
175	34.48	89.46	67.40,99.72	7.31	1.66,58	12.37

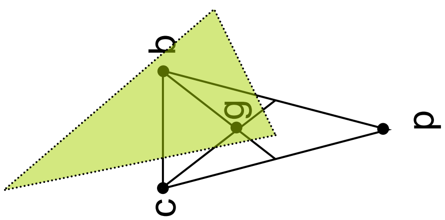


COV_{waGbc} 60^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	35.56	77.91	58.98,94.93	10.07	1,18.66	6.68
100	50	79.18	56.00,98.57	10.38	1,59	11.40
125	58.13	80.42	57.68,98.77	8.61	1.33,130.66	27.38
150	66.89	81.32	53.9,96.46	8.34	1.33,164.66	37.63
175	73.33	81.93	53.79,98.39	8.15	1.33,260	52.45

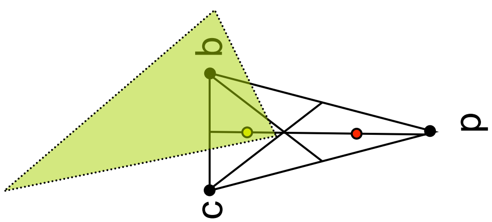
Accuracy of cover set (2)



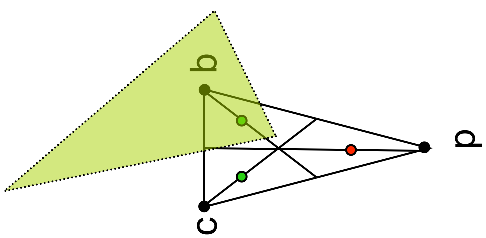
COV_{woG} 36^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	38.22	46.96	14.40,86.27	18.08	1,45.33	9.59
100	49.67	47.67	16.58,83.05	15.53	1.33,110.66	20.31
125	64.80	48.67	15.48,89.40	15.67	1,150	29.98
150	67.78	48.81	12.77,90.88	15.67	1.66,170.33	35.93
175	75.24	47.83	18.50,89.56	13.31	1.66,412	82.24



COV_{wG} 36^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	0	0	0,0	nan	0,0	0
100	1	92,03	89.78,98.64	0	1,1	1
125	1.87	91.45	88.83,93.15	2.97	1.33,2	1.56
150	1.78	95.06	91.47,98.29	4.06	1,3	1.94
175	3.43	94.42	87.60,99.03	4.40	1.33,2.66	1.92

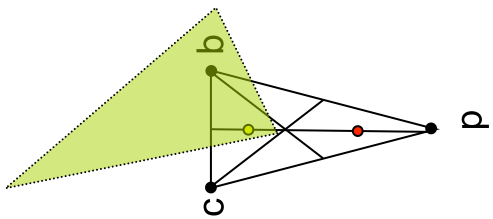


COV_{waGpv} 36^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	6.22	82.07	74.78,89.98	6.24	1.33,4	2.23
100	11	79.22	55.47,96.68	13.16	1,5.33	2.05
125	18.93	79.86	49.99,98.90	12.14	1,11.33	3.23
150	18.89	82.22	54.56,99.07	11.67	1,8.66	2.97
175	26.67	82.07	59.26,99.26	10.17	1,22.66	5.32

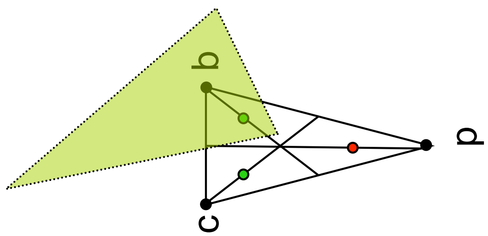


COV_{waGbc} 36^o #nodes	% nodes with coverset	mean % coverage	min,max % coverage/coverset	stddev of % coverage	min,max #coverset/node	mean #coverset/node
75	12.44	77.48	56.46,91.81	13.33	1.33,9.33	3.62
100	20.33	79.62	53.65,98.98	12.05	1,10.66	3.94
125	30.67	76.89	50.53,97.92	11.58	1,34	5.40
150	35.11	78.47	52.07,96.09	10.60	1,31.33	6.90
175	48.57	77.76	49.97,98.20	10.54	1,50.33	11.57

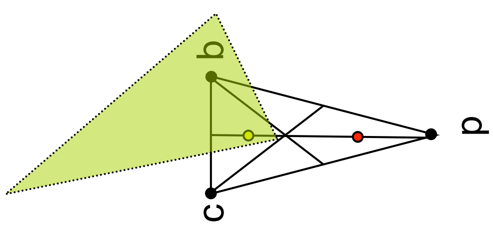
Accuracy of cover set (3)



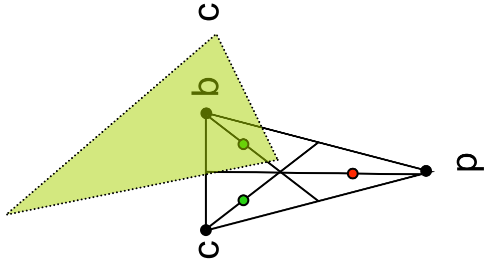
COV_{waGpv} $36^o(50\%)$ $60^o(50\%)$ #nodes	% nodes with coverset	mean % coverage	min,max % coverage per coverset	stddev of % coverage	min,max #coverset per node	mean #coverset per node
75	11.56	83.36	70.20,93.99	9.12	1,8	2.70
100	16.33	86.88	61.52,99.50	11.21	1,13.33	3.62
125	29.07	89.07	63.14,100	9.20	1,24.66	6.66
150	33.56	88.01	56.18,99.99	10.06	1,40	8.23
175	43.81	88.52	58.76,99.97	9.02	1,45.33	10.47



COV_{waGbc} $36^o(50\%)$ $60^o(50\%)$ #nodes	% nodes with coverset	mean % coverage	min,max % coverage per coverset	stddev of % coverage	min,max #coverset per node	mean #coverset per node
75	8.44	85.81	71.60,96.59	10.22	1,5.66	2.53
100	12.33	79.34	56.33,94.49	12.08	1.33,14	4.92
125	13.87	80.88	61.50,94.87	9.63	1.33,35.33	10.27
150	18.22	76.04	54.17,97.23	11.81	1,34	9.58
175	24.95	75.21	55,92.26	9.33	1.66,99.33	18.93



COV_{waGpv} $36^o(80\%)$ $60^o(20\%)$ #nodes	% nodes with coverset	mean % coverage	min,max % coverage per coverset	stddev of % coverage	min,max #coverset per node	mean #coverset per node
75	16	81.97	60.34,100	11.84	1,9	2.83
100	15	88.34	69.60,100	9.00	1,12	3.13
125	14.40	85.16	55.43,100	14.14	1,12	4.17
150	28.67	85.95	57.58,100	10.88	1,16	3.77
175	33.14	85.94	54.34,100	11.85	1,32	6.21



COV_{waGbc} $36^o(80\%)$ $60^o(20\%)$ #nodes	% nodes with coverset	mean % coverage	min,max % coverage per coverset	stddev of % coverage	min,max #coverset per node	mean #coverset per node
75	10.67	83.39	57.20,97.34	14.34	2,12	5.38
100	17	86.29	62.58,99.78	12.44	1,12	3.06
125	41.60	81.41	56.86,95.58	8.36	1,48	11.25
150	47.33	81.92	55.51,100	11.18	1,48	9.39
175	54.86	80.18	51.84,98.24	10.41	1,120	17.20

The advantage of having more cover-set (1)

N=6
$P_2(6,6)$

r^0 \ $\lvert Co(v) \rvert$	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
$P_2(12,3)$

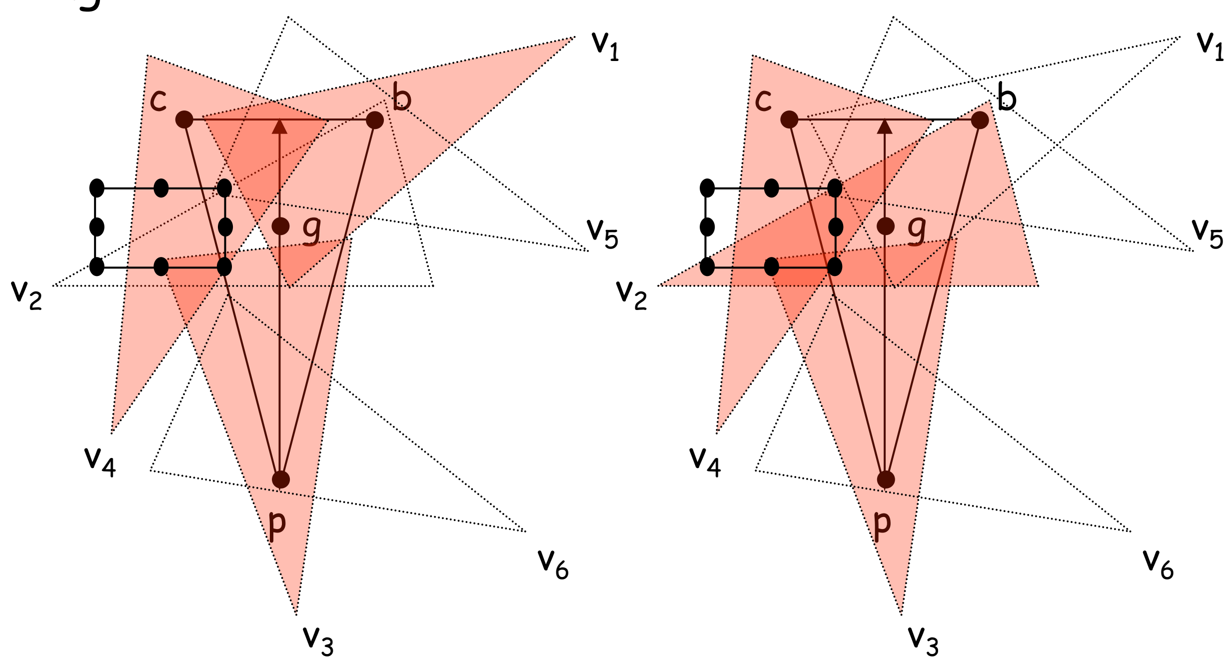
r^0	1	2	3	4	5	6	7	8	9	10	11	12
0	.01	.02	.05	0.1	.17	.26	.38	.54	.75	1.1	1.5	3
.2	.07	.15	.25	.37	.51	.67	.86	1.1	1.4	1.7	2.2	3
.4	.17	.35	.55	.75	.97	1.2	1.4	1.7	2.0	2.3	2.6	3
.6	.36	.69	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.8	3
.8	.75	1.2	1.6	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3
1	1.5	1.9	2.2	2.4	2.6	2.7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

Simulation settings (2)

- 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. Criticality level r^0=0.8.
- Full coverage is defined as the region initially covered when all nodes are active

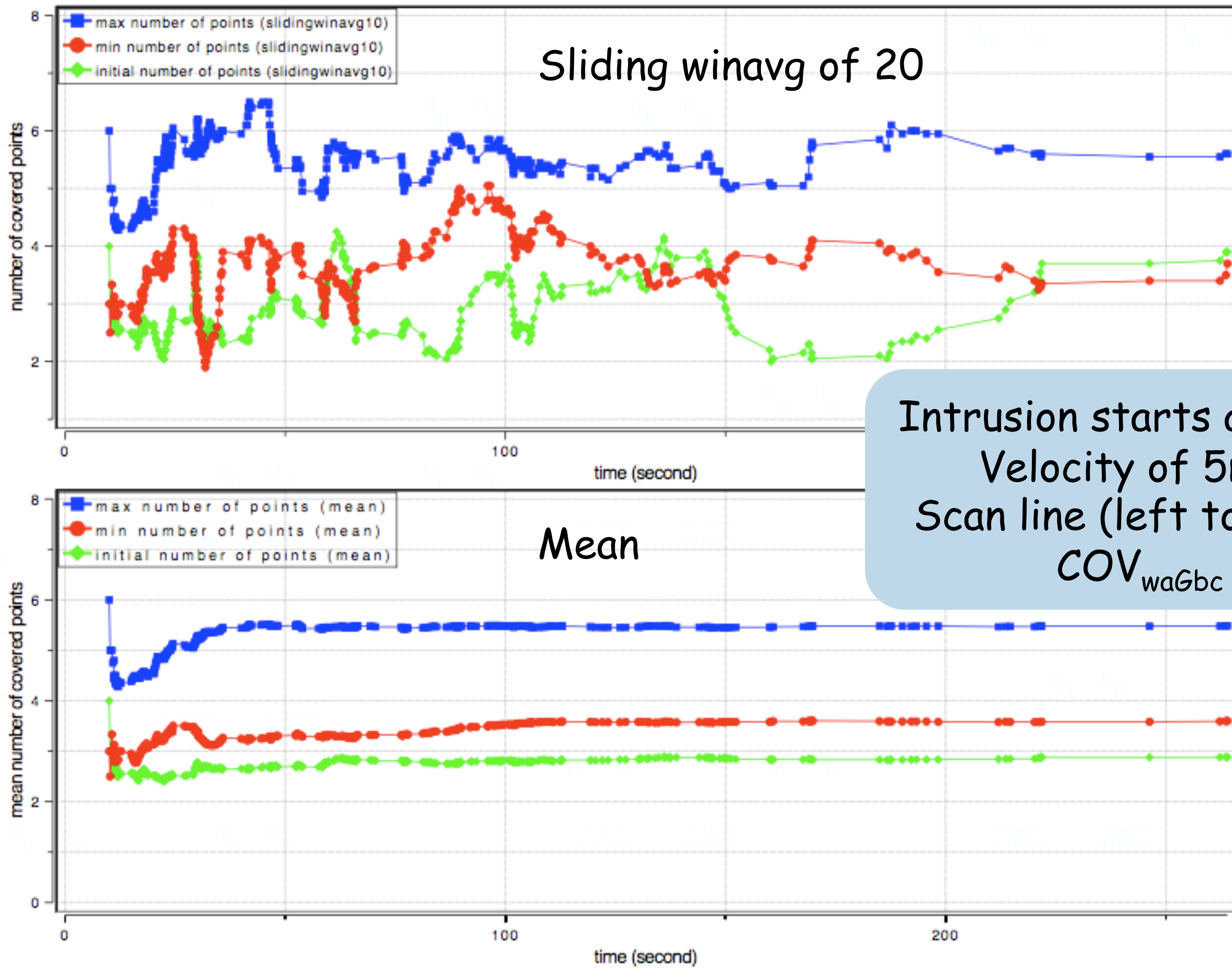
Occlusions/Disambiguation

8m.4m rectangle



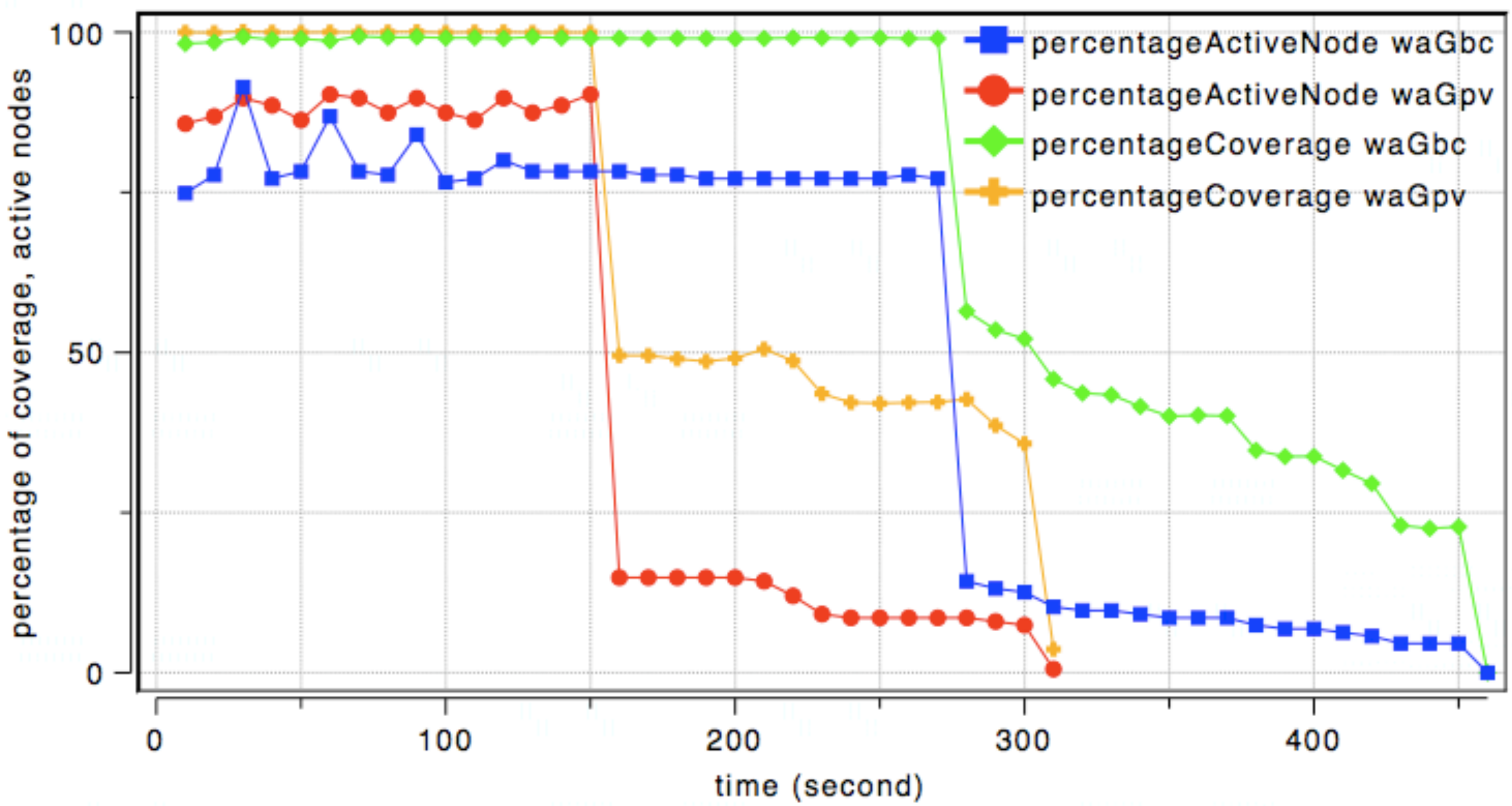
Multiple viewpoints are desirable
Some cover-sets « see » more points than other

The advantage of having more cover-set (2)



Intrusion starts at t=10s
Velocity of 5m/s
Scan line (left to right)
COV_{waGbc}

%coverage, %active nodes COV_{waGpv} vs COV_{waGbc}

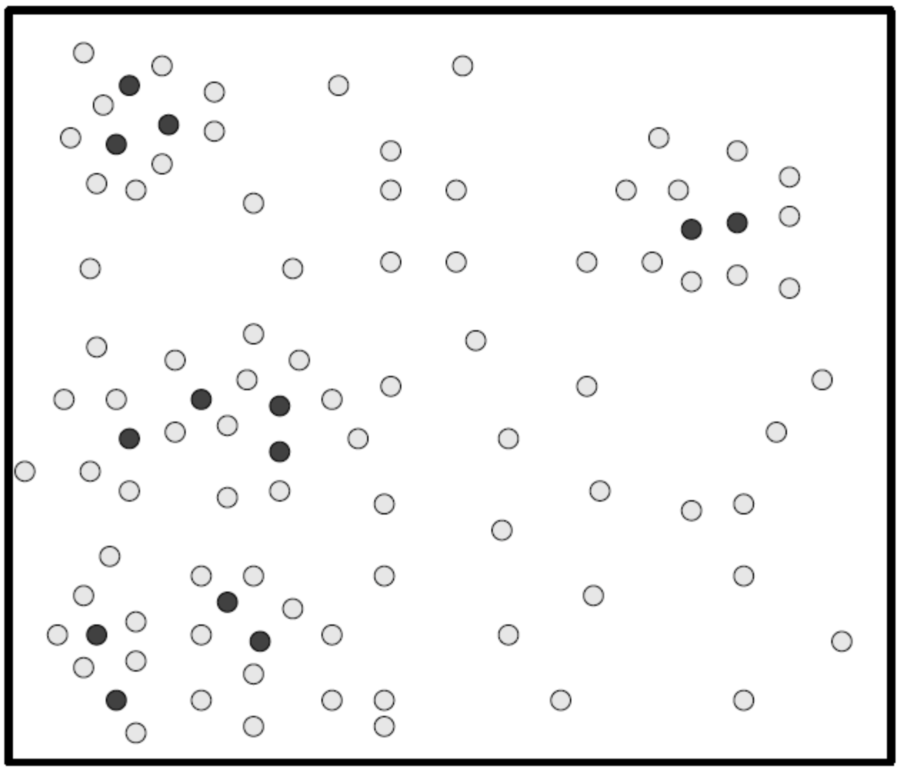


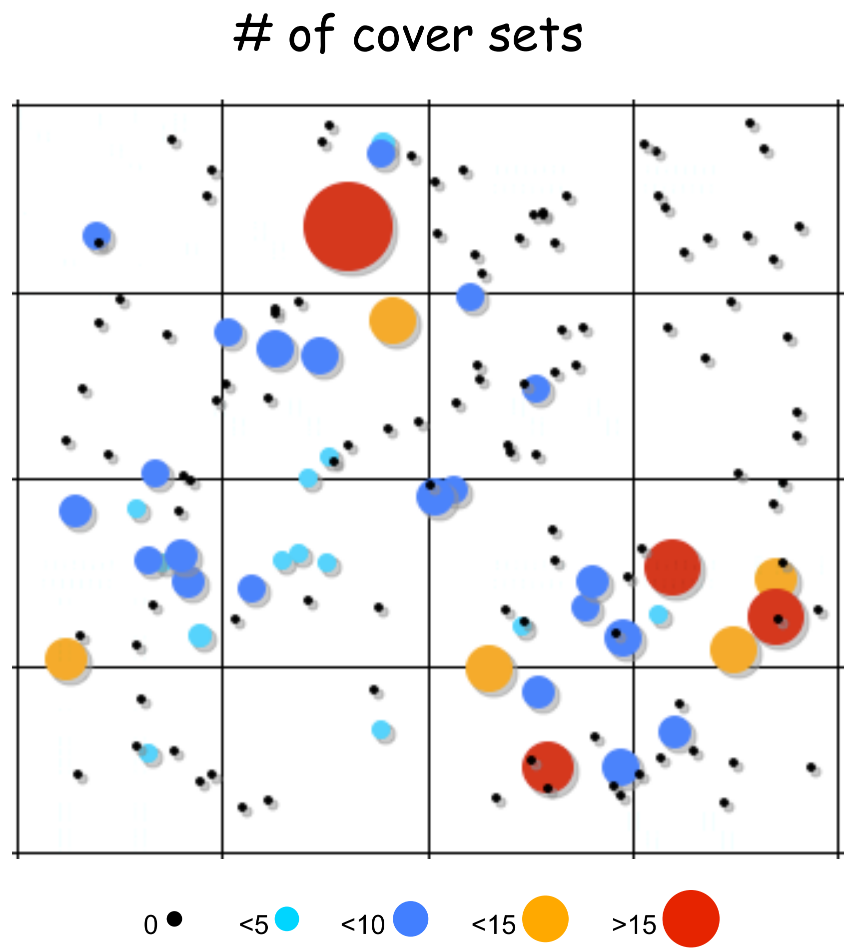
COV_{waGbc} provides a higher network lifetime while maintaining a %coverage close to the COV_{waGpv} strategy

Defining sentry nodes

● SENTRY NODE: NODE WITH HIGH SPEED CAPTURE (HIGH COVER SET).

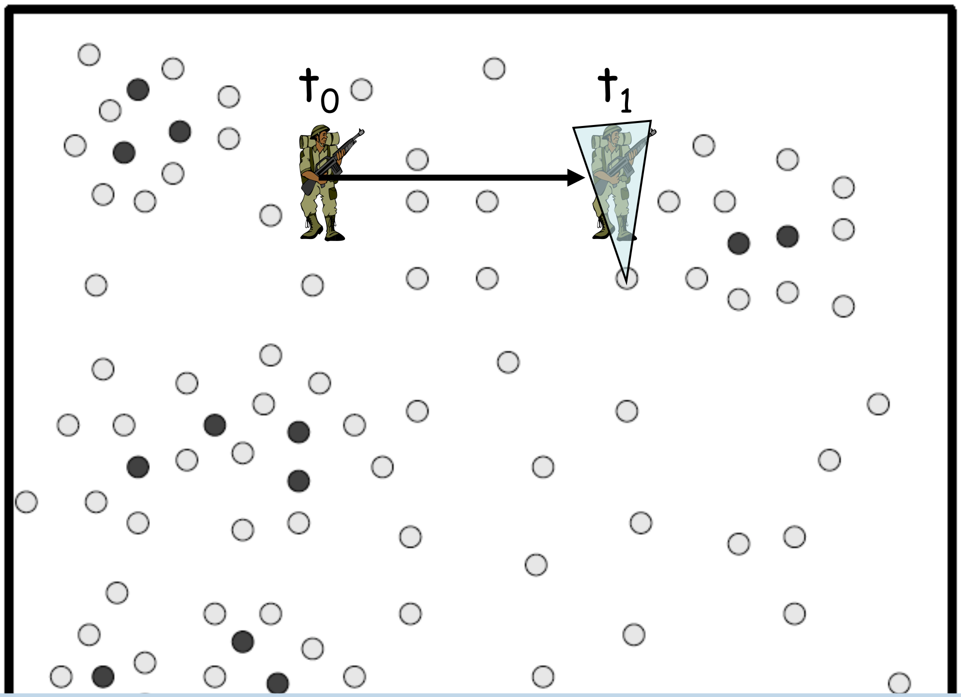
○ IDLE NODE: NODE WITH LOW SPEED CAPTURE.





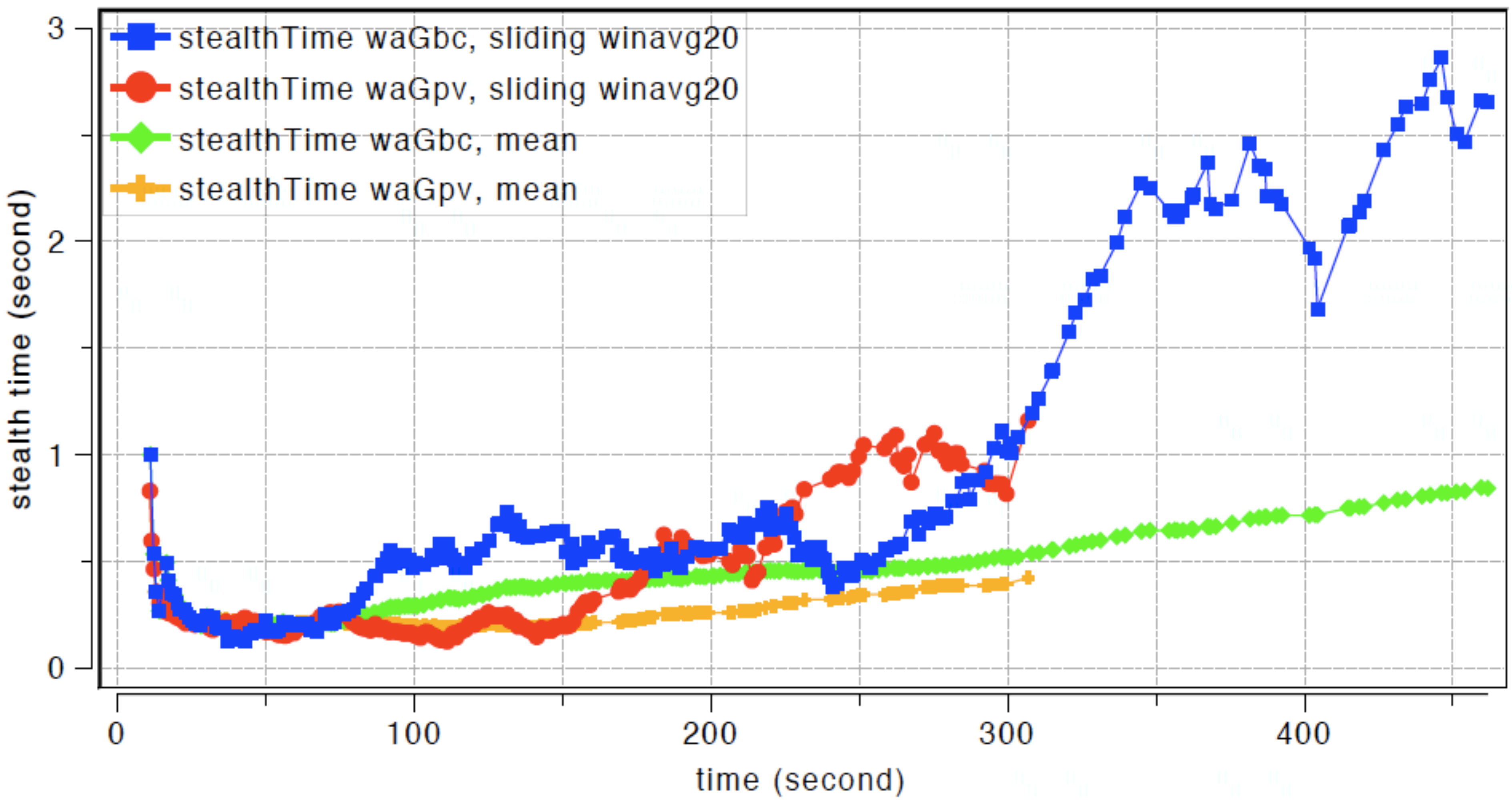
mean stealth time

t_1-t_0 is the intruder's stealth time
velocity is set to 5m/s

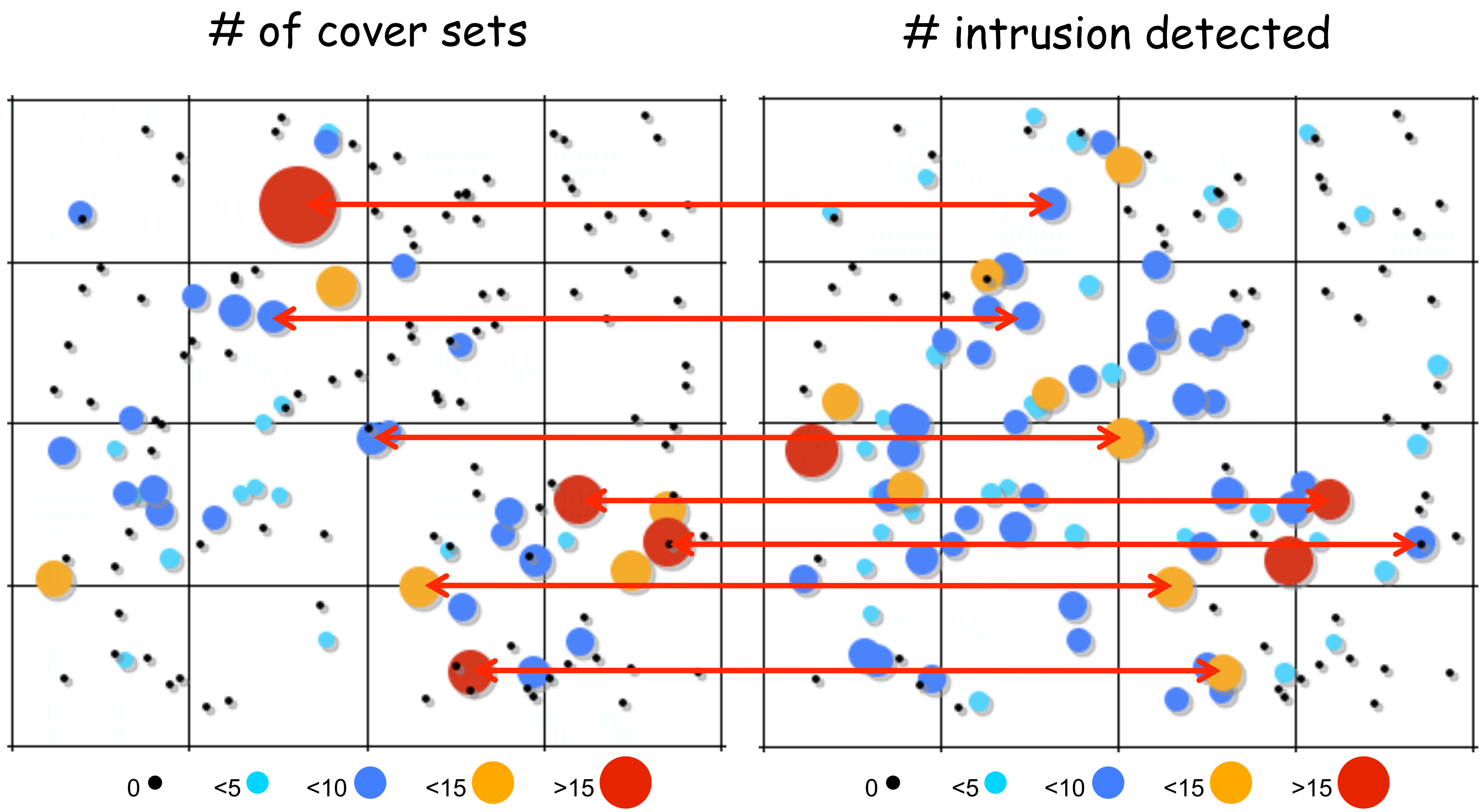


intrusions starts at t=10s
when an intruder is seen, compute the stealth time, and start a new intrusion until end of simulation

mean stealth time COV_{waGpv} vs COV_{waGbc}



Sentry nodes



Conclusions

- Simple method for cover-set computation for video sensor node
- Takes into account small AoV and AoV heterogeneity
- Used jointly with a criticality-based scheduling, can increase the network lifetime while maintaining a high level of service (mean stealth time)