Wireless Sensor Networks for search&rescue mission-critical applications: from low-level challenges to multi-sensors/multi-robots perspectives

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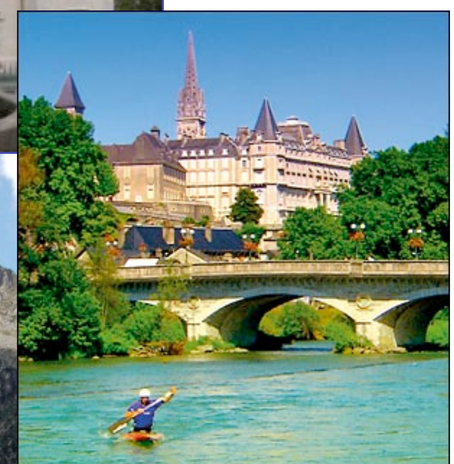
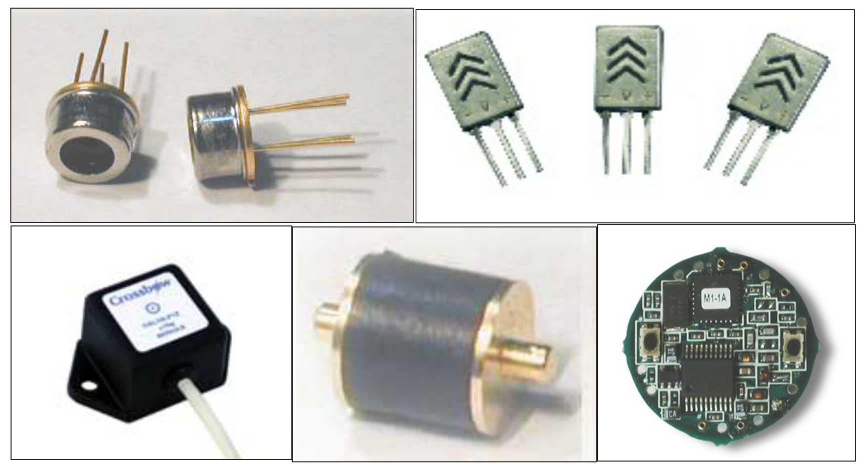


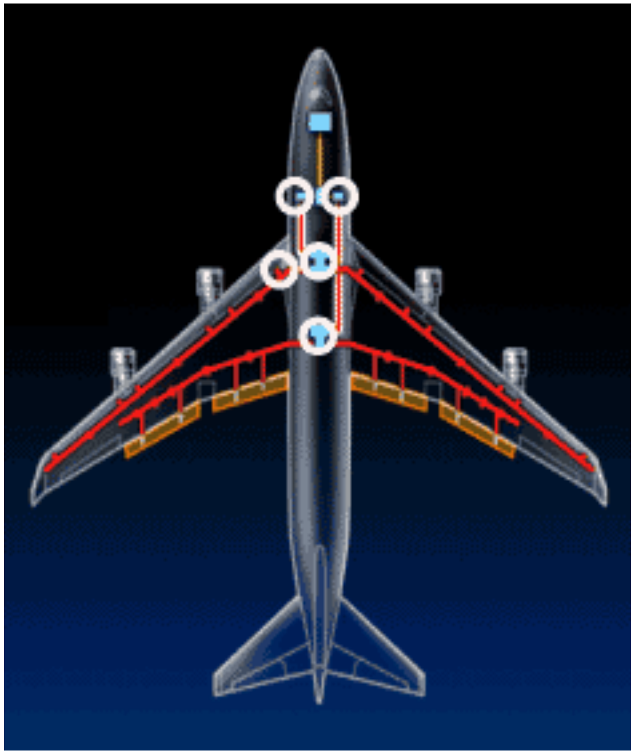
What Is A Sensor?

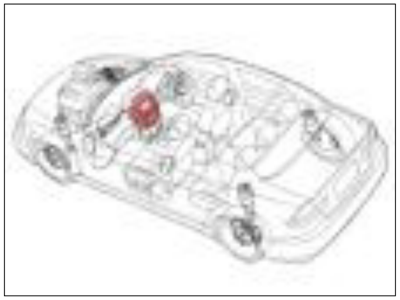
- Sensors could monitor a wide variety of ambient conditions that include the following:
  - temperature,
  - humidity,
  - vehicular movement,
  - lightning condition,
  - pressure,
  - soil makeup,
  - noise levels,
  - ...



- Sensors can be used for continuous sensing, event detection, event ID, location sensing, etc.

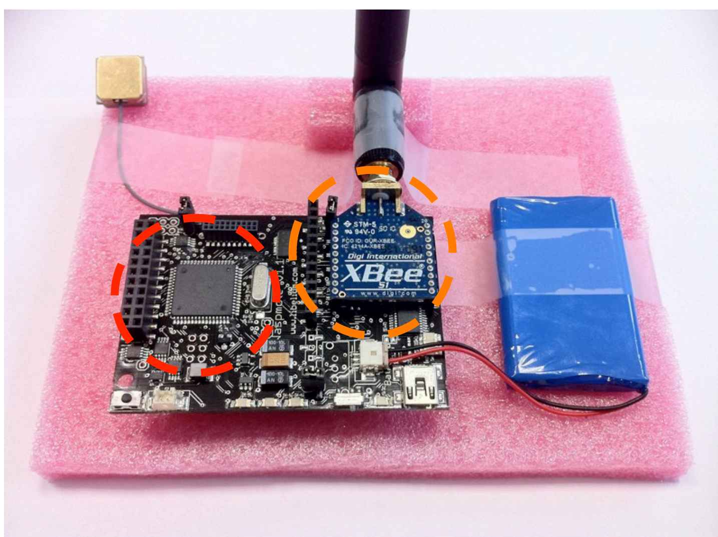
Traditional sensing applications

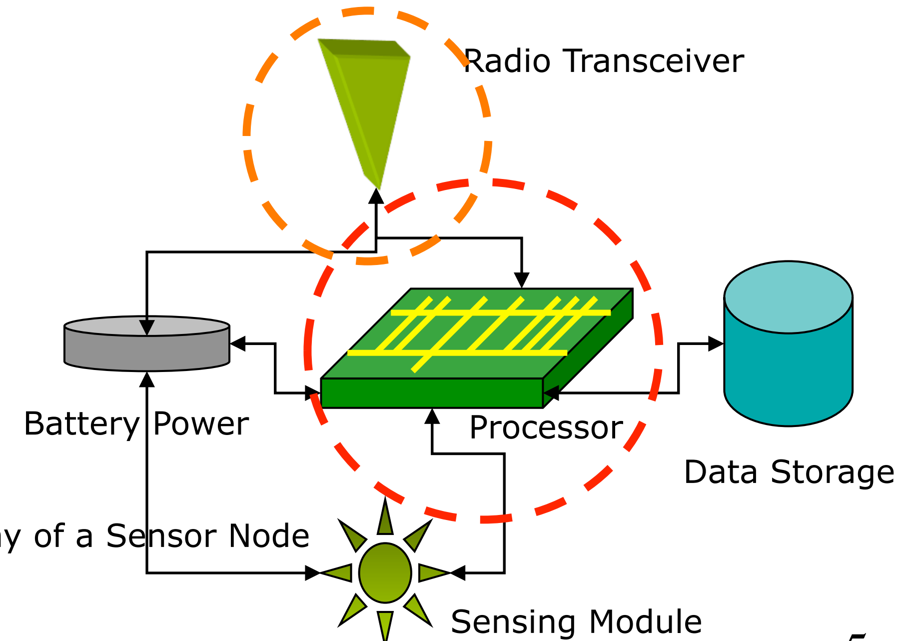




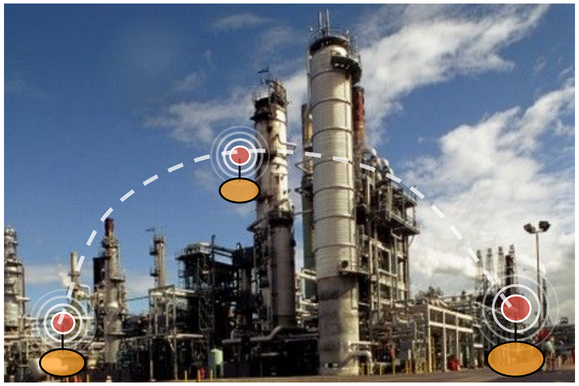
Wireless autonomous sensor

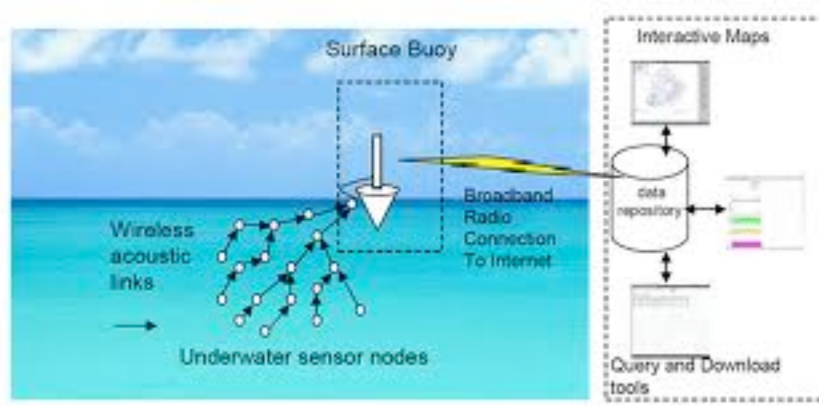
- In general: low cost, low power (the battery may not be replaceable), small size, prone to failure, possibly disposable
- Role: sensing, **data processing**, communication



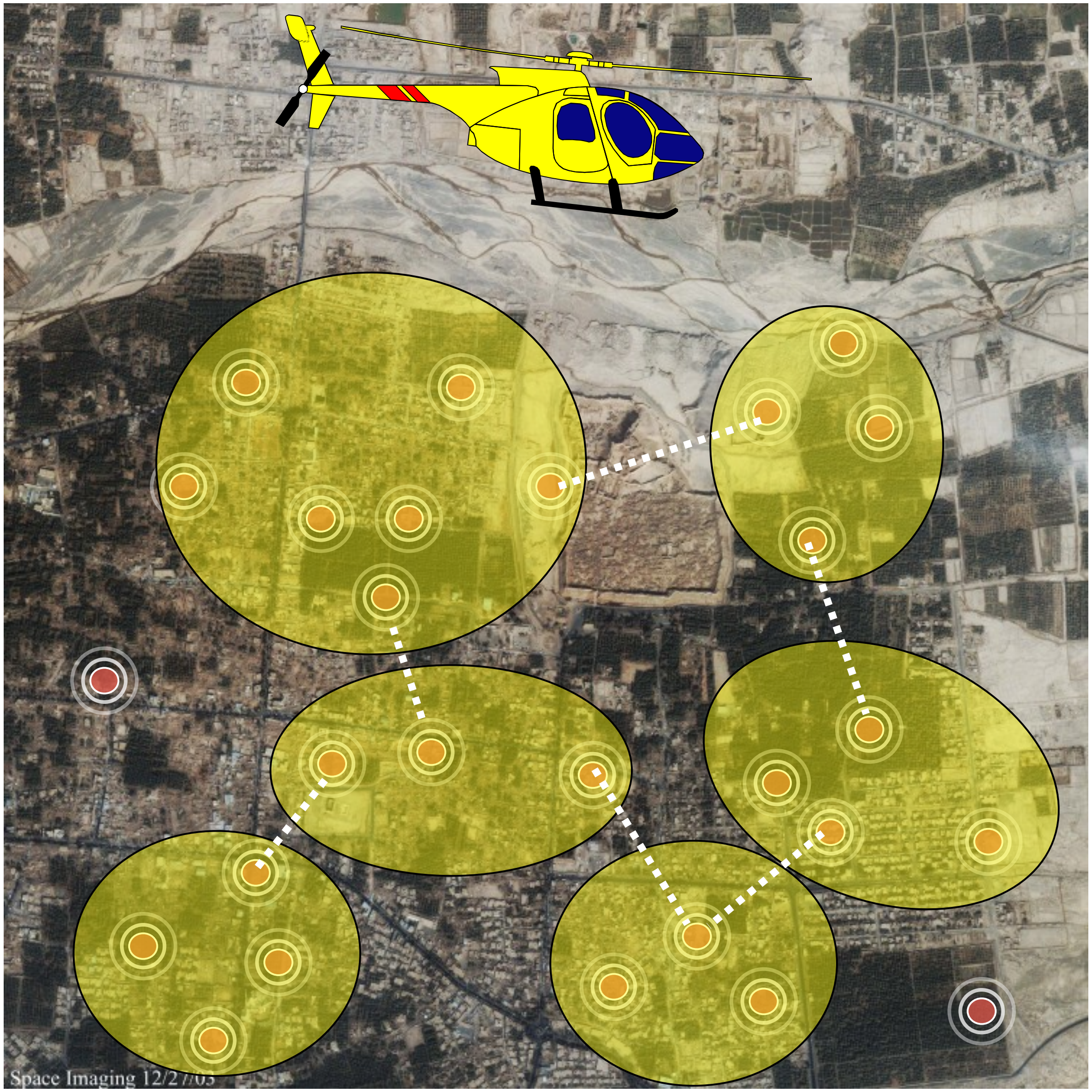


Monitoring/Surveillance





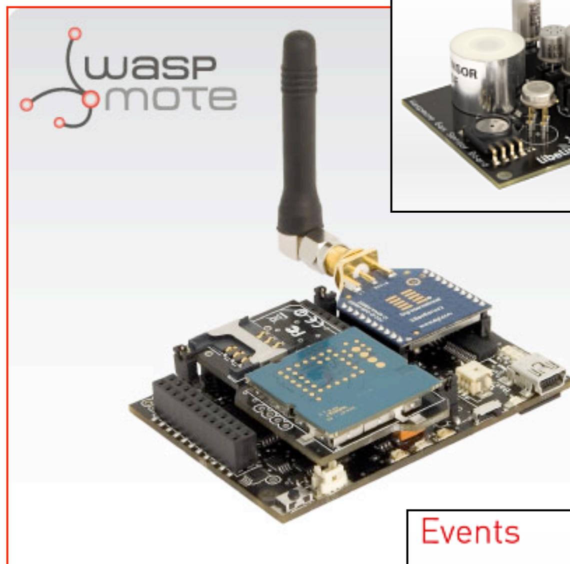
Large scale deployment



libelium

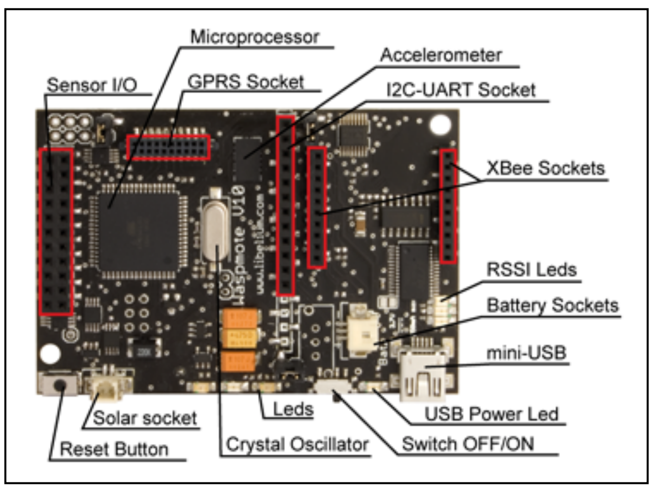
comunicaciones inalámbricas distribuidas

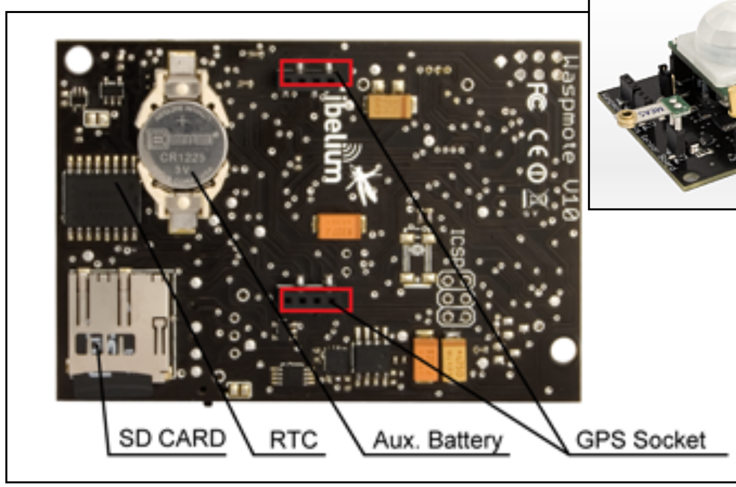
- ATMEGA1281 MICROCONTROLLER
- 8K RAM & 1G SD CARD.
- 2.4GHz IEEE 802.15.4 COMPATIBLE. RF AND GSM/GPRS



Gases

- Carbon Monoxide – CO
- Carbon Dioxide – CO2
- Oxygen – O2
- Methane – CH4
- Hydrogen – H2
- Ammonia – NH3
- Isobutane – C4H10
- Ethanol – CH3CH2OH
- Toluene – C6H5CH3
- Hydrogen Sulfide – H2S
- Nitrogen Dioxide – NO2
- Temperature
- Humidity

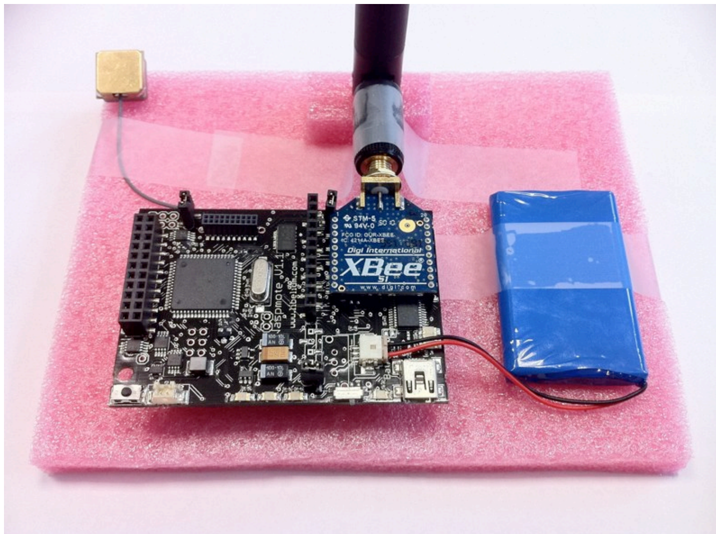


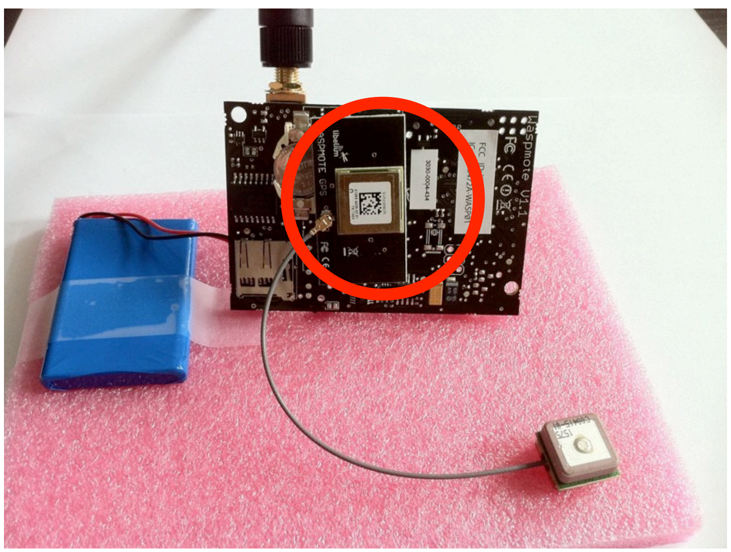


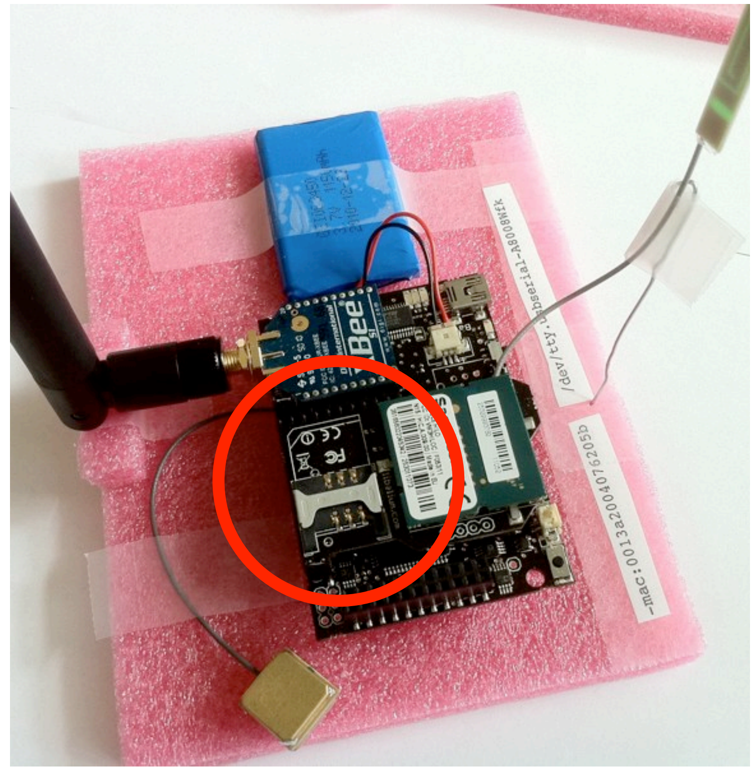
Events

- Pressure/Weight
- Bend
- Vibration
- Impact
- Hall Effect
- Tilt
- Temperature (+/-)
- Liquid Presence
- Liquid Level
- Luminosity
- Presence (PIR)
- Stretch

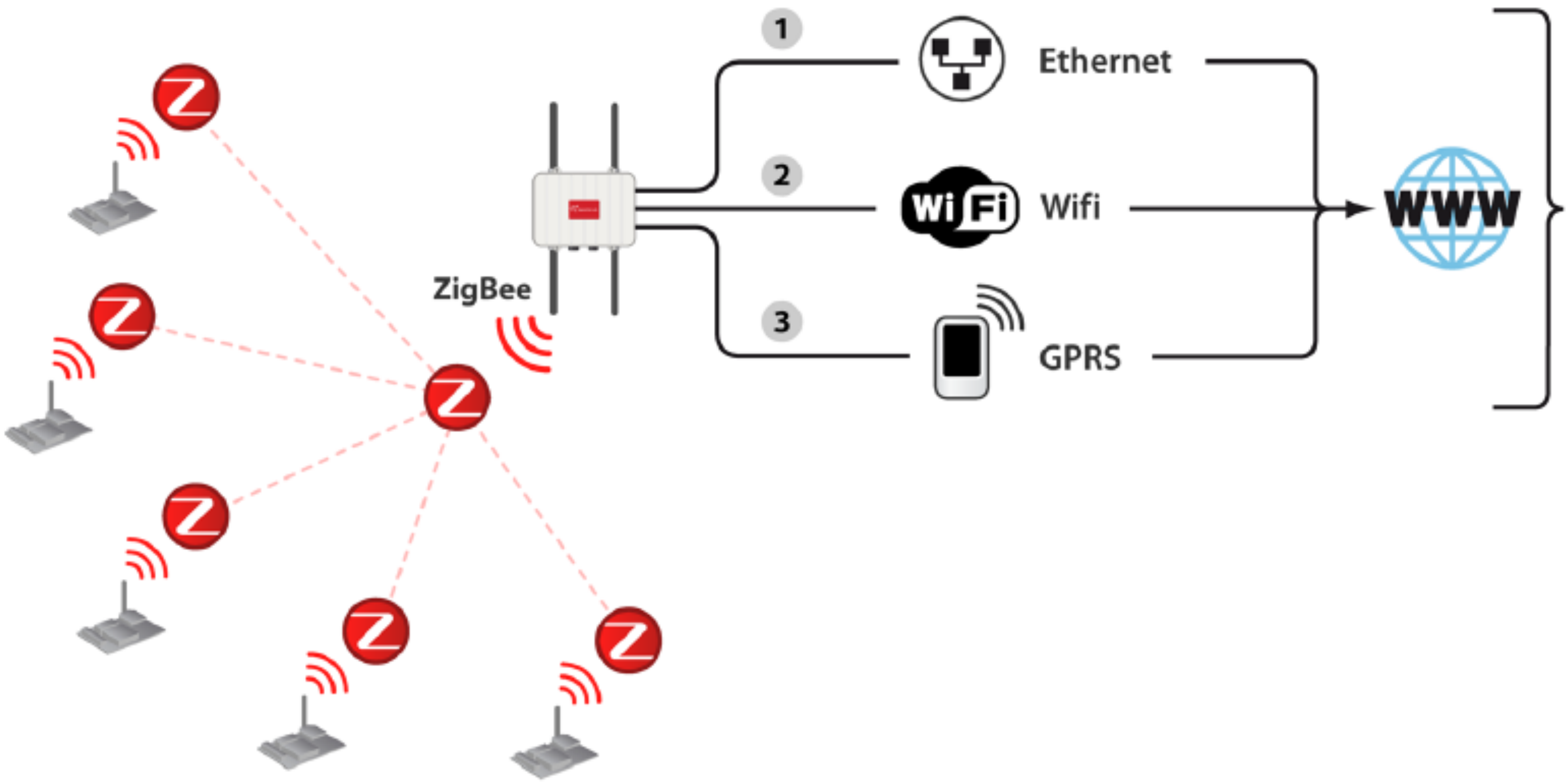
Libelium WaspMote (1)





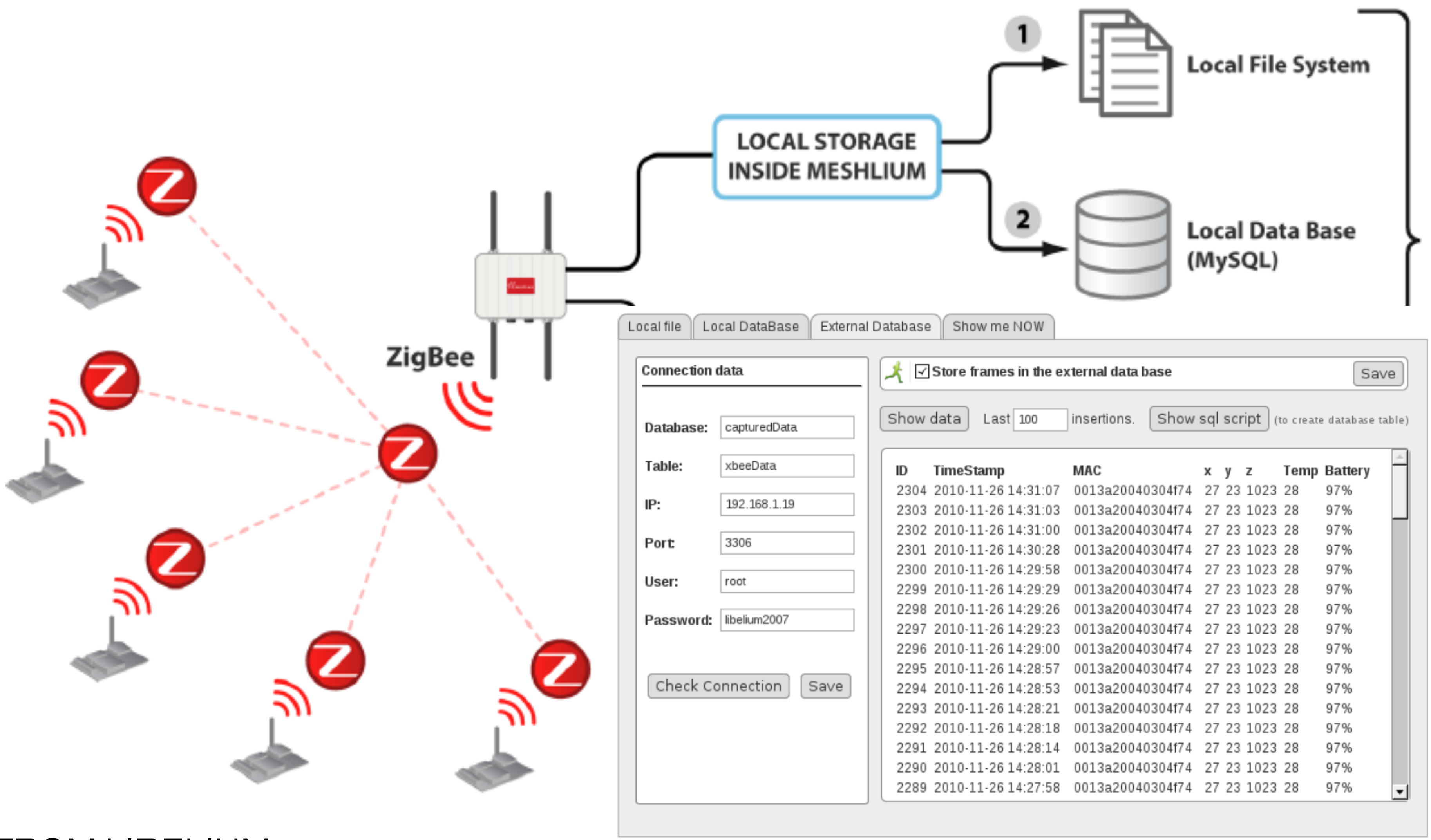


Advanced connectivity



FROM LIBELIUM

Advanced database features

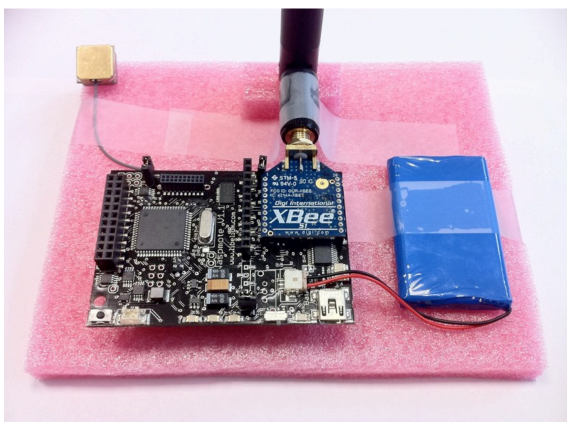


FROM LIBELIUM

The full testbed

Custom behavior

```
void setup()
{
  ACC.ON();
  USB.begin(); // starts u
}
```




```
void loop()
{

  //----------Check Register---------------------
  // should always answer 0x3A, it is used to check
  // the proper functionality of the accelerometer
  byte check = ACC.check();

  //----------X Values-----------------------
  int x_acc = ACC.getX();

  //----------Y Values-----------------------
  int y_acc = ACC.getY();

  //----------Z Values-----------------------
  int z_acc = ACC.getZ();

  //-------------------------------
```

Jennic sensor kits

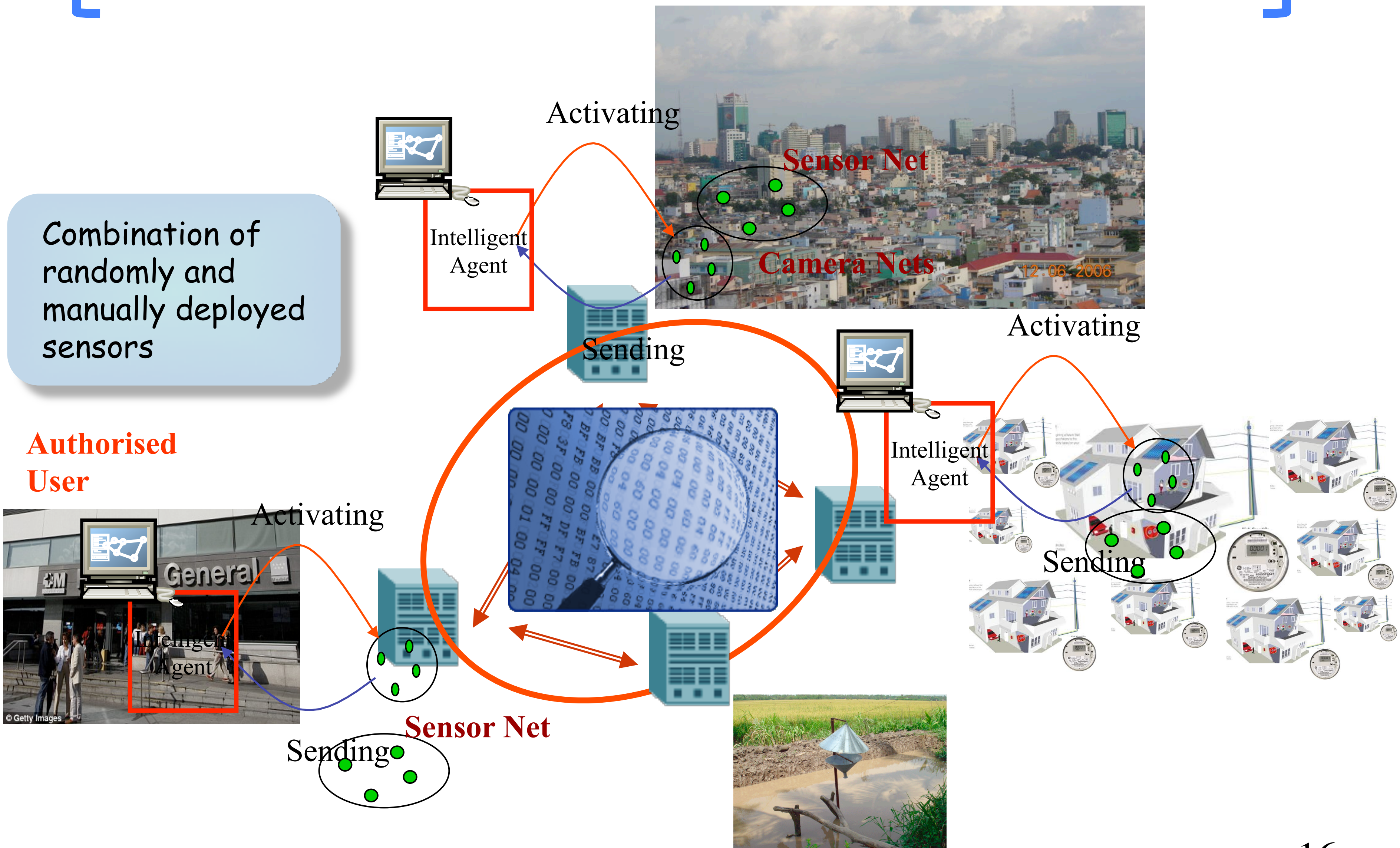
http://www.jennic.com/

Specific applications

Source JEAI DREAM, U. Can Tho

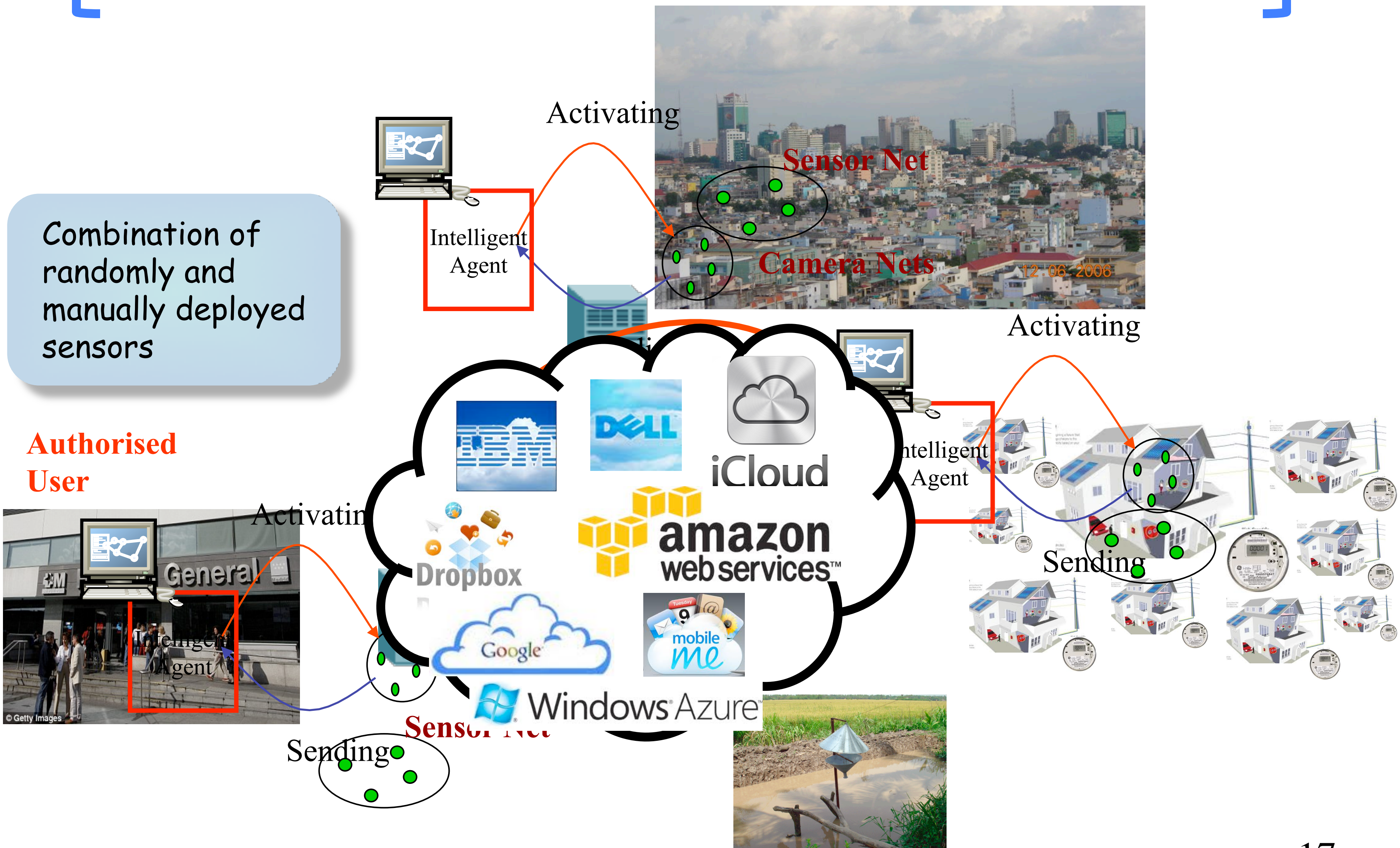
Towards global sensing

Combination of randomly and manually deployed sensors



Where Clouds come in!

Combination of randomly and manually deployed sensors



Smart cities, controlled systems

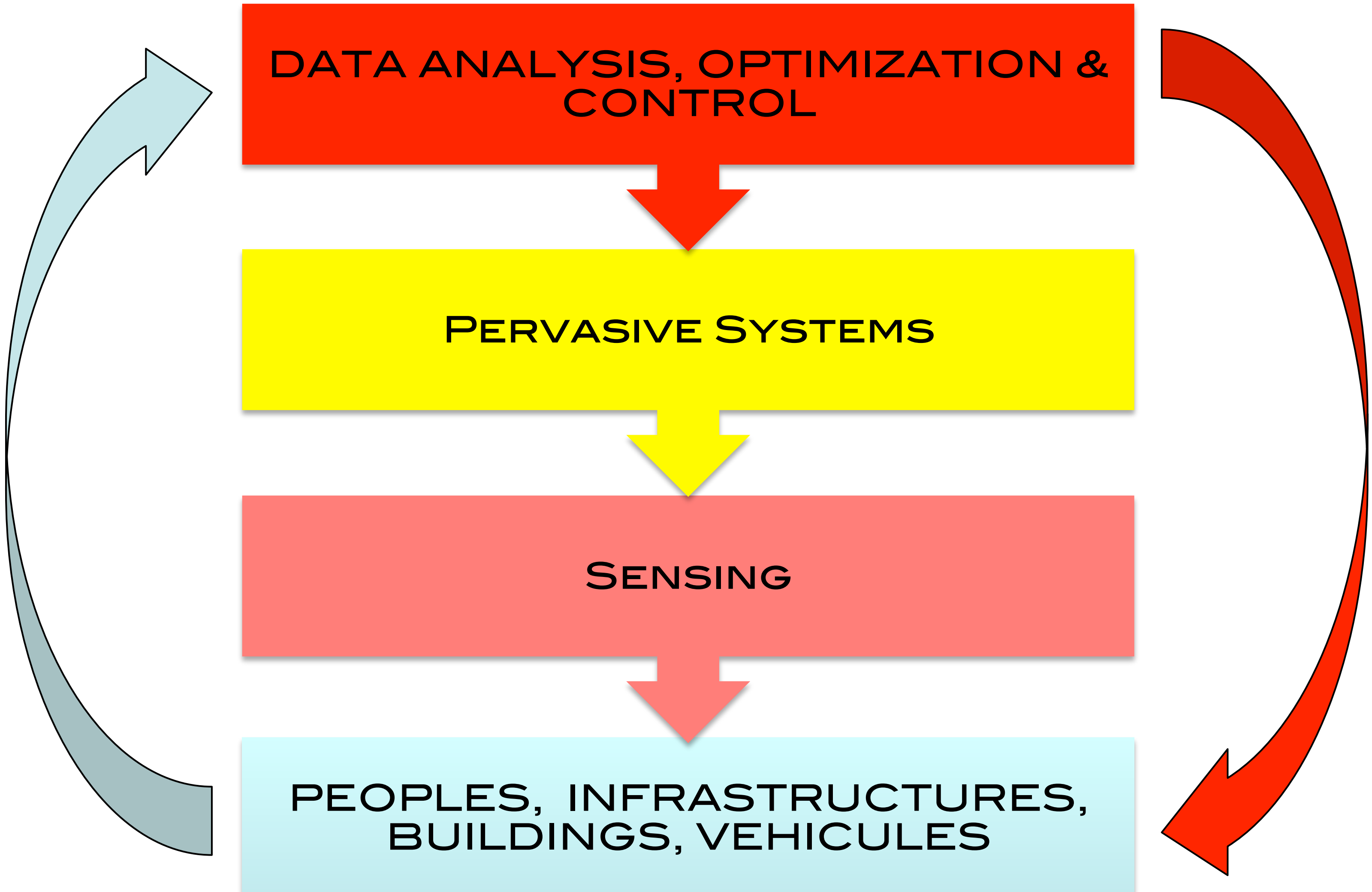
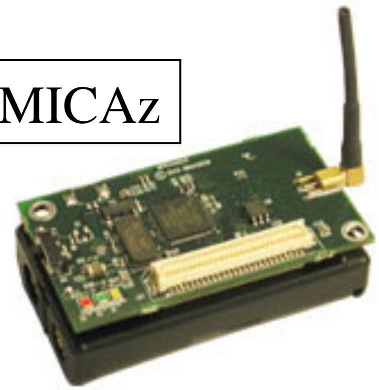
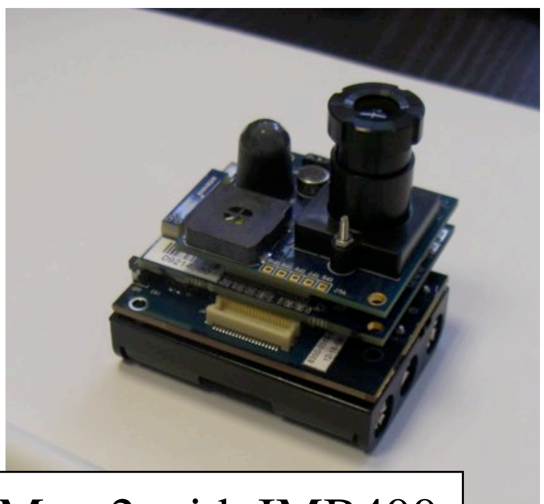


Image sensor motes

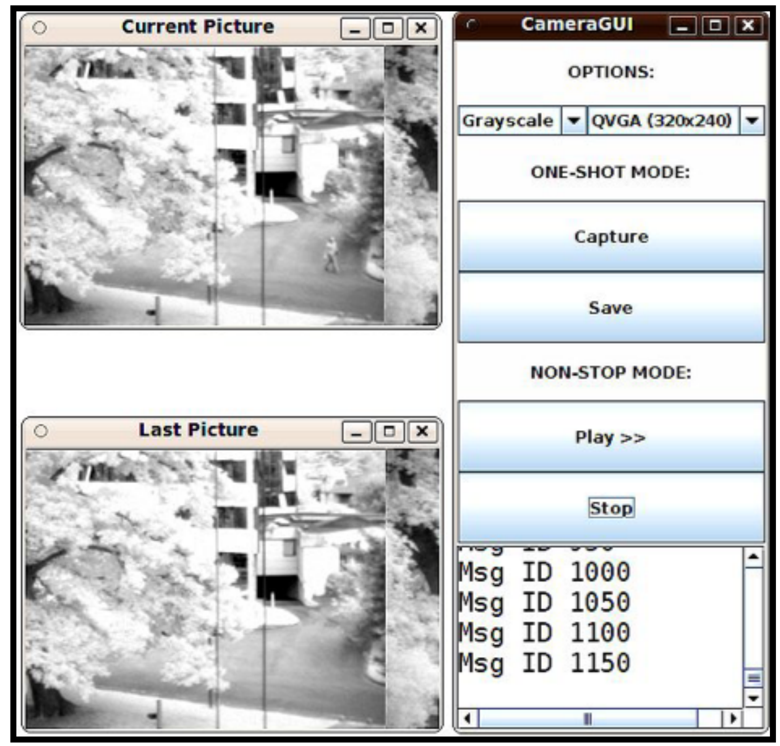
iMote2

MICAz



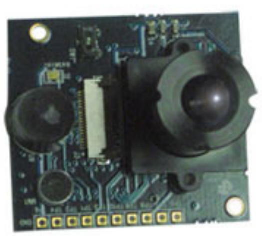


iMote2 with IMB400 multimedia board

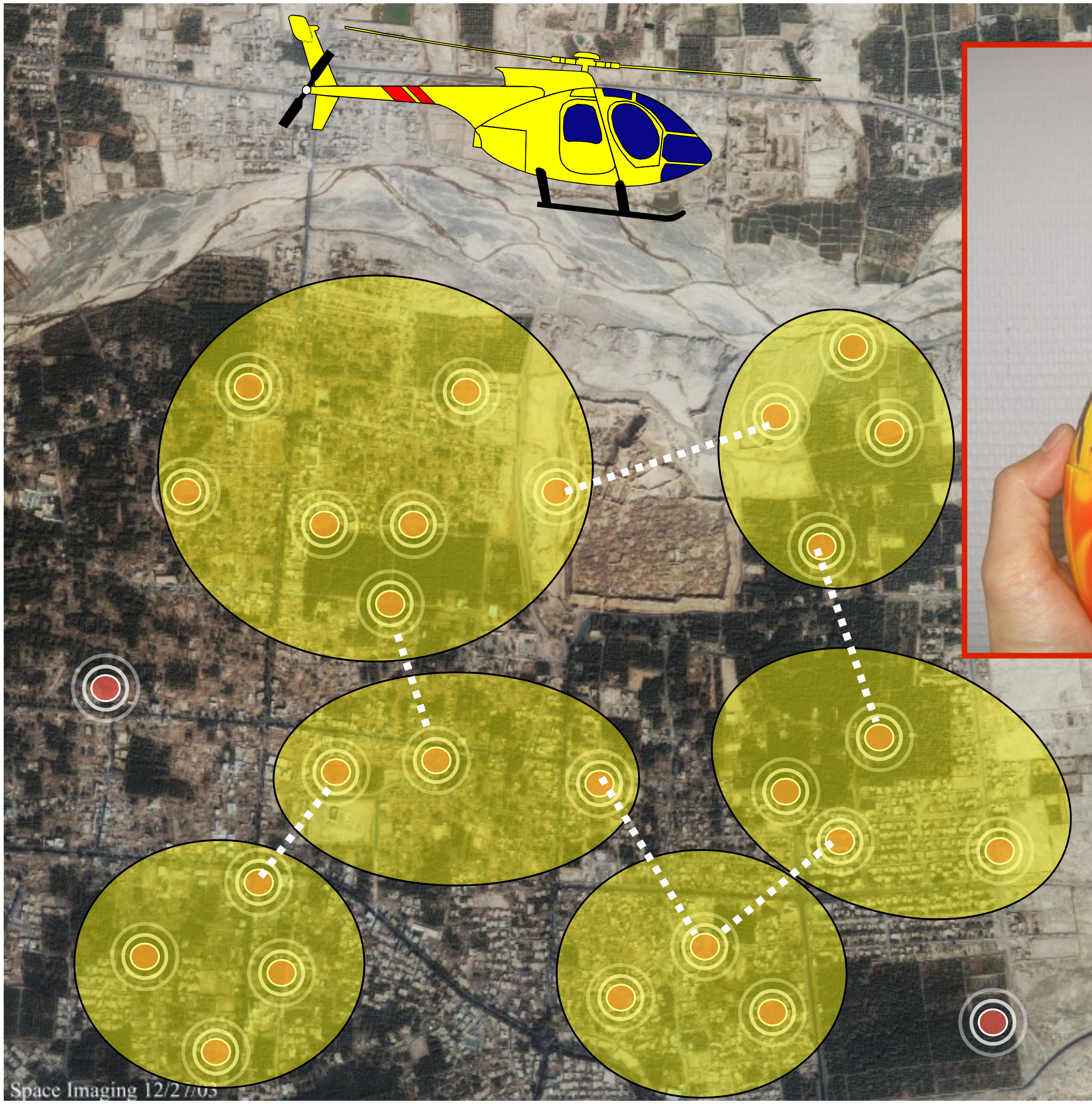


Search & Rescue

Imote2



Multimedia board

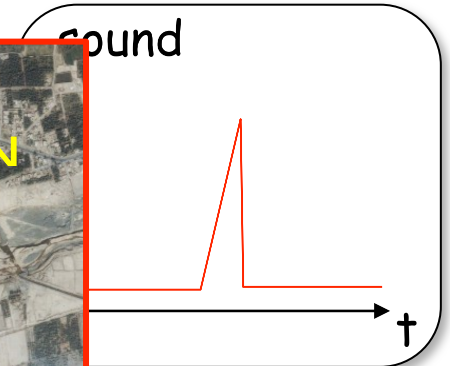


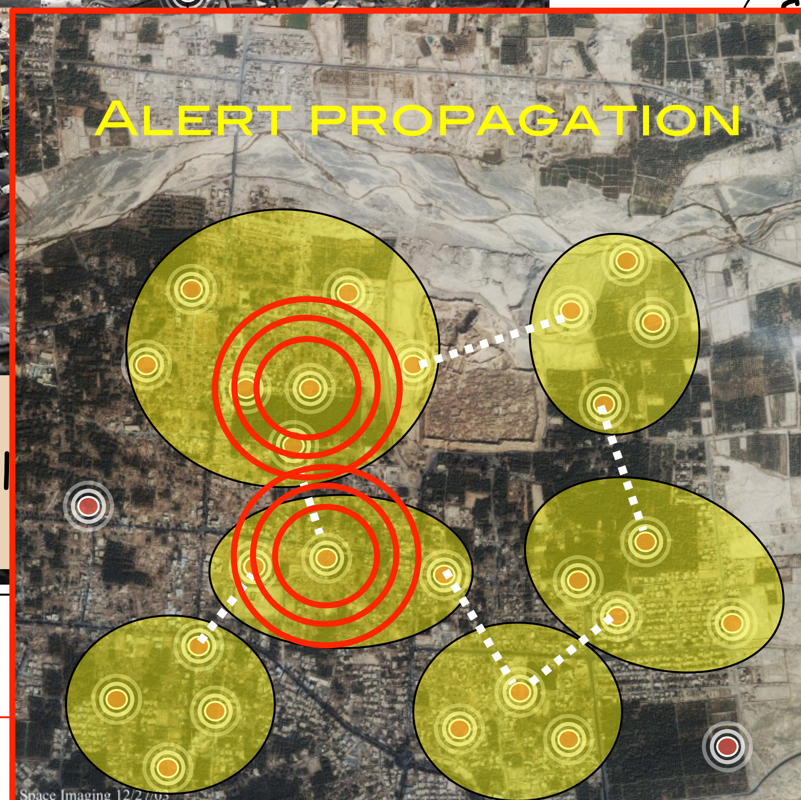
Activity detection

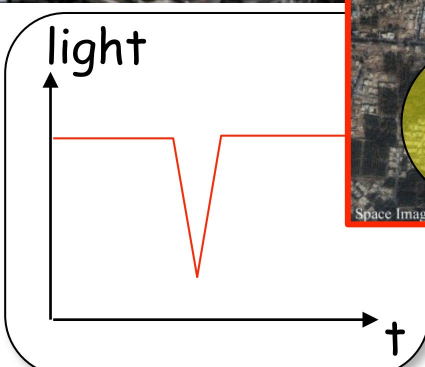
Sound could serve as detector if the person manifest itself

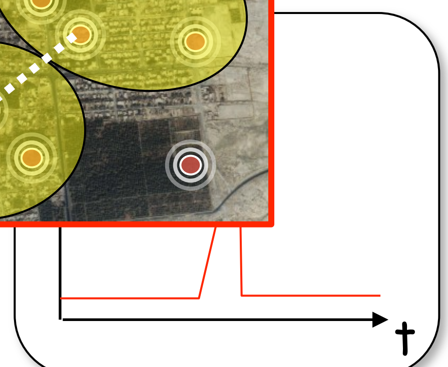
Light sensor could serve as detector if the person rapidl occult the sensor

ve as shaked

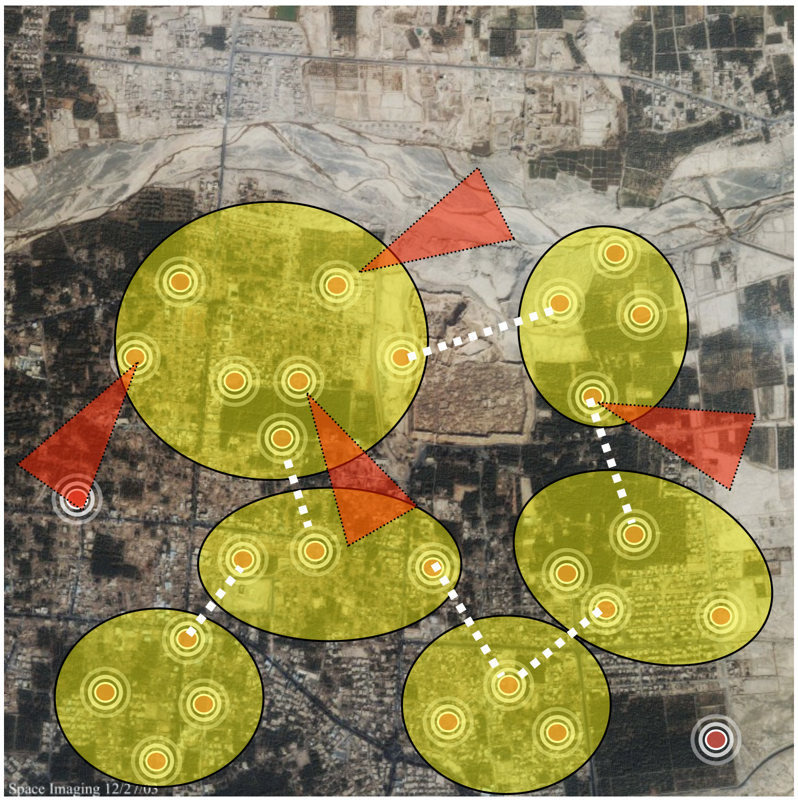




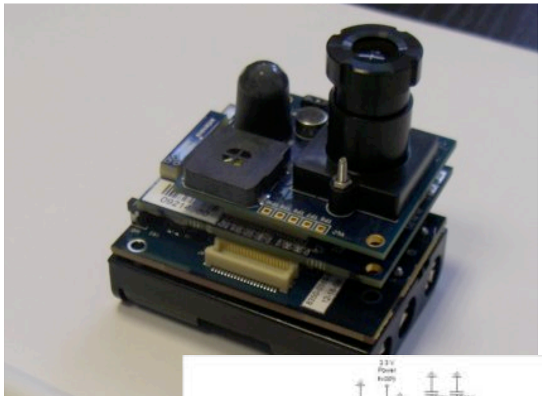




Get images from deployed sensors



Energy consideration



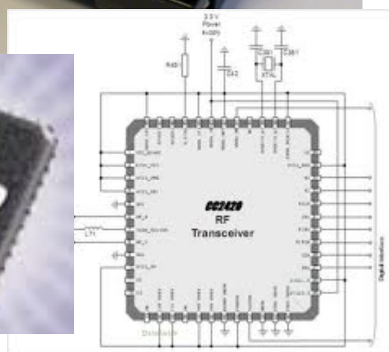
18720 Joules

TX power 0dbm: 17.4mA

P = I x V = 17.4 x 3.3 = 57.42mW

E = P x t -> t = E/P

326018s or 90.5h



Haven't considered:

- Baseline power consumption of the sensor board
- RX consumption: 18.8mA!
- Image capture consumption
- Image processing consumption

Chipcon Products from Texas Instruments

CC2420

Parameter	Min.	Typ.	Max.	Unit	Condition / Note
Current Consumption, transmit mode:					
P = -25 dBm		8.5		mA	The output power is delivered differentially to a 50 Ω singled ended load through a balun, see also page 55.
P = -15 dBm		9.9		mA	
P = -10 dBm		11		mA	
P = −5 dBm		14		mA	
P = 0 dBm		17.4		mA	

MIDDLEWARE/APP. ISSUES WE ADDRESSED

ENERGY CONSIDERATIONS

NETWORK

SIGNAL IMAGE/VIDEO PROCESSING

OS MIDDLEWARE SOFT. ENG.

DATA MNGT

HARDWARE RADIO

SENSOR'S OS

CBSE for SENSOR NODE
DYNAMIC RECONFIGURATION

SUPERVISION PLATFORM

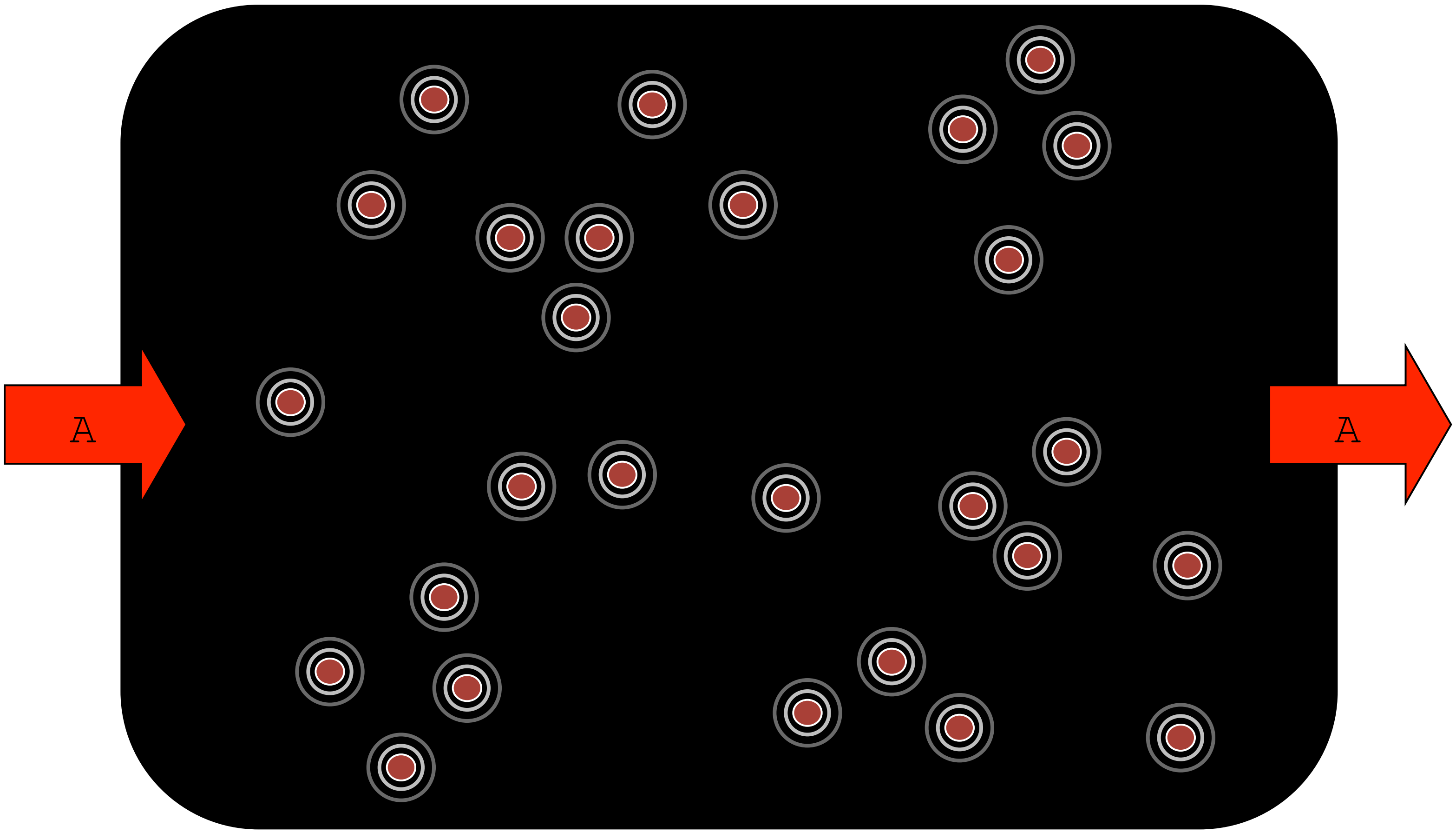
SERVICE-ORIENTED
SERVICE REPOSITORY

APPLICATIONS

ADAPTIVE APPLICATION

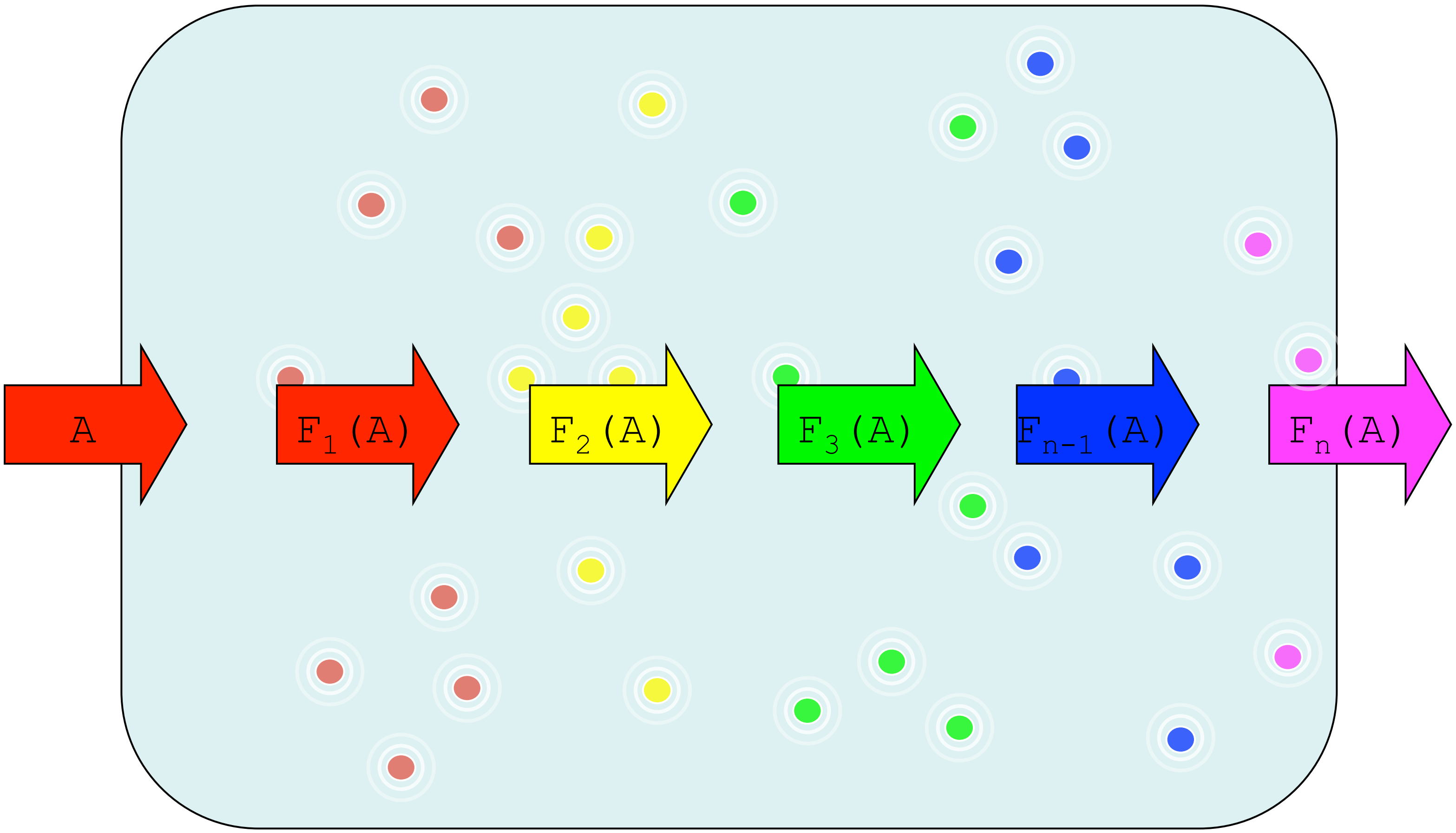
QOS

Active Sensor Nets (1)



AVOIDS THE BLACK-BOX VISION

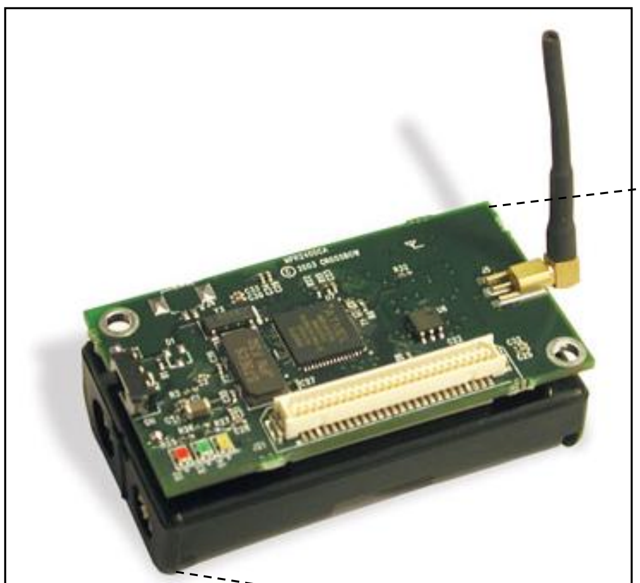
Active Sensor Nets (2)

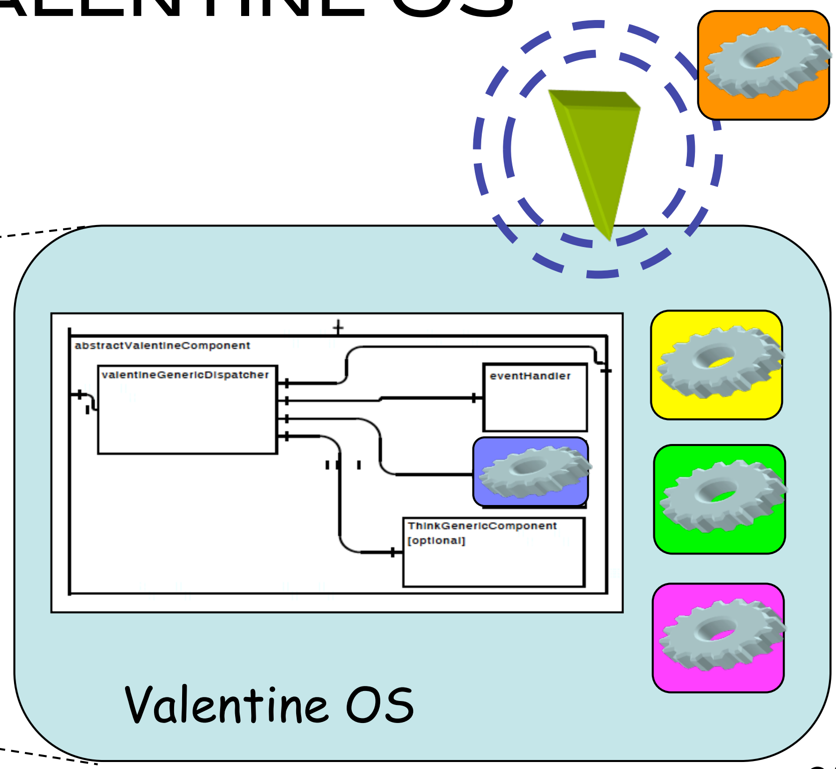


AVOIDS THE BLACK-BOX VISION

Dynamic reconfiguration

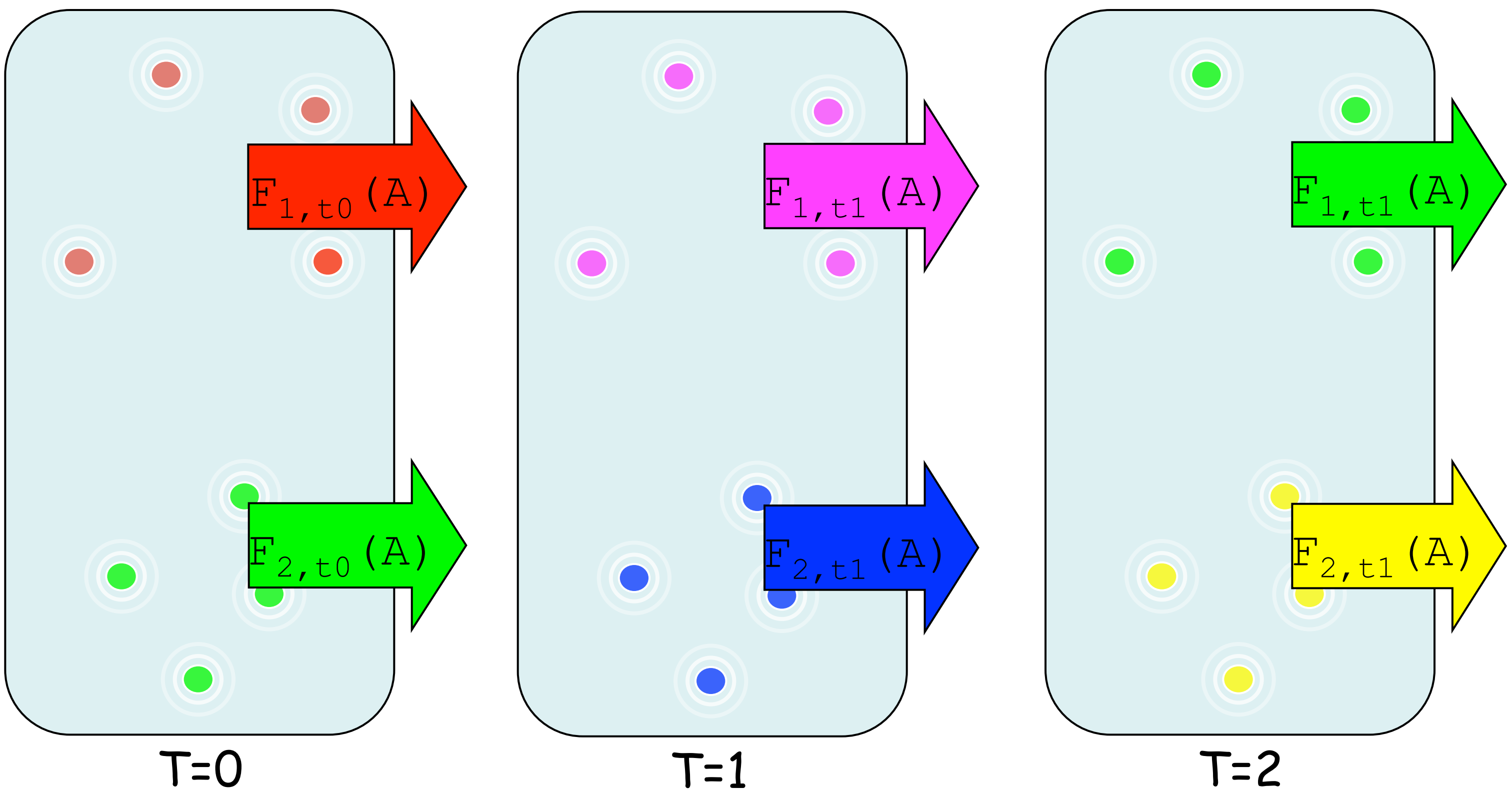
- Target platform: MicaZ
- Extension of the Think generic components →Valentine OS

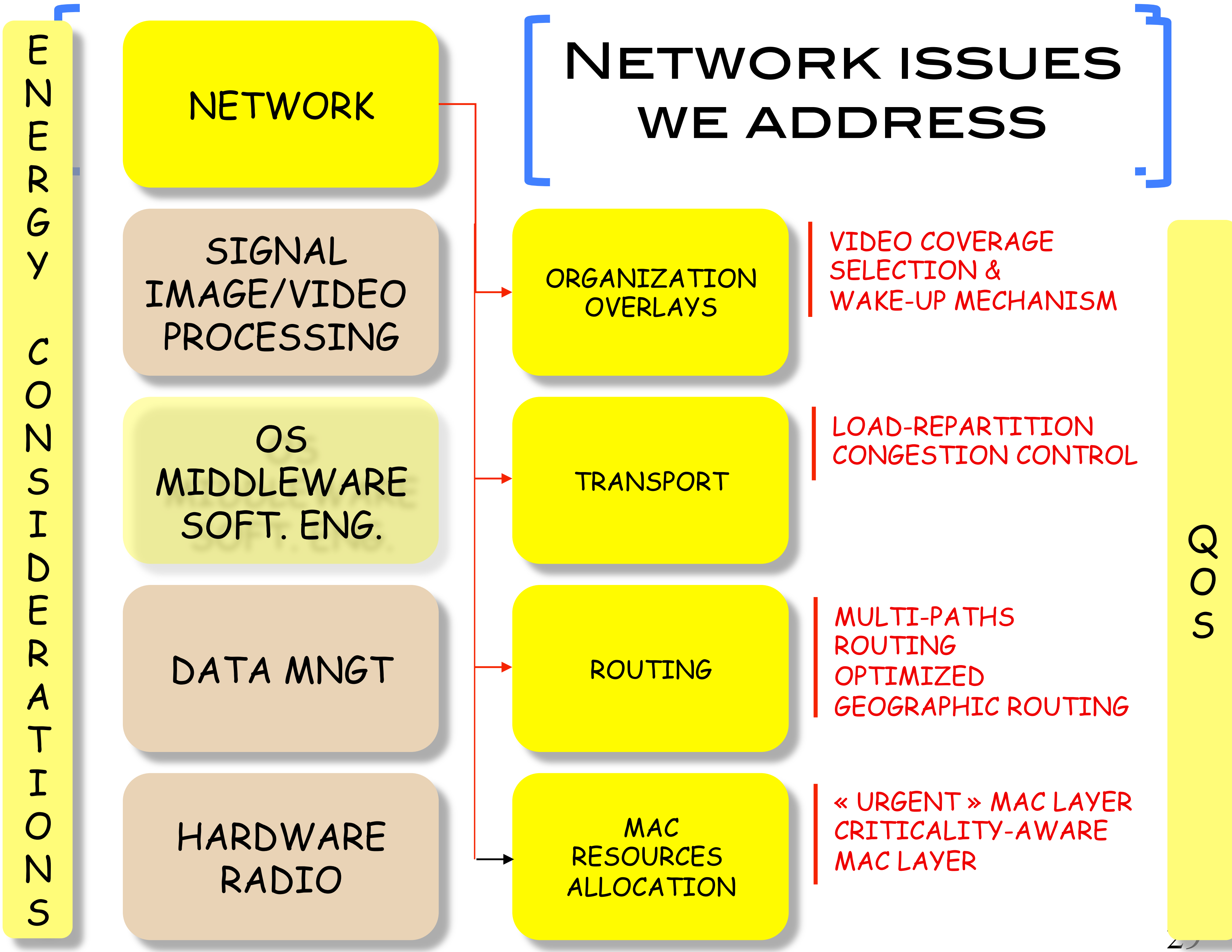




Towards Service Oriented Architecture

- Fast reconfiguration enables dynamic and on-the-fly new services deployment




ENERGY CONSIDERATIONS
NETWORK
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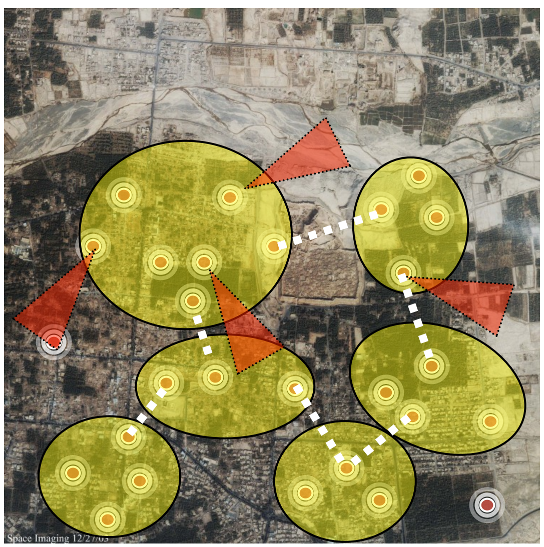
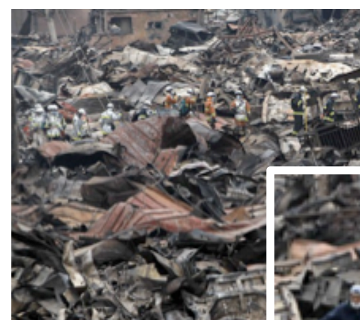
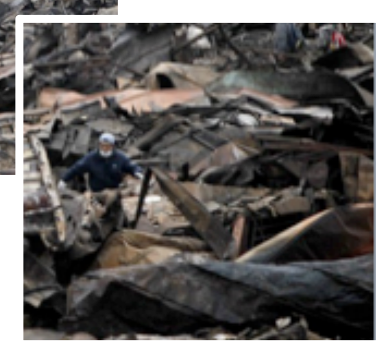
OS MIDDLEWARE SOFT. ENG.
DATA MNGT
HARDWARE RADIO
NETWORK ISSUES WE ADDRESS
ORGANIZATION OVERLAYS
VIDEO COVERAGE SELECTION & WAKE-UP MECHANISM
TRANSPORT
LOAD-REPARTITION CONGESTION CONTROL
ROUTING
MULTI-PATHS ROUTING OPTIMIZED GEOGRAPHIC ROUTING
MAC RESOURCES ALLOCATION
« URGENT » MAC LAYER CRITICALITY-AWARE MAC LAYER
QOS

Scheduling image sensors







First of all: Don't miss important events!

Whole understanding of the scene is wrong!!!

What is captured

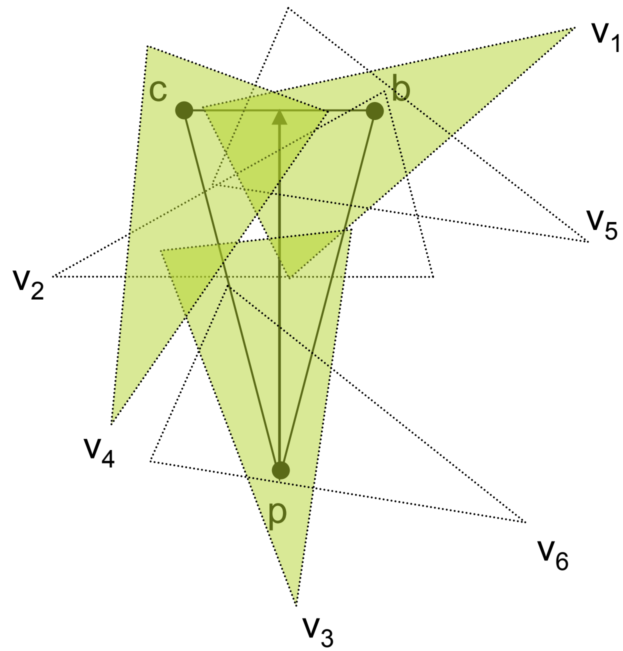
How to meet surveillance app's criticality

- 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

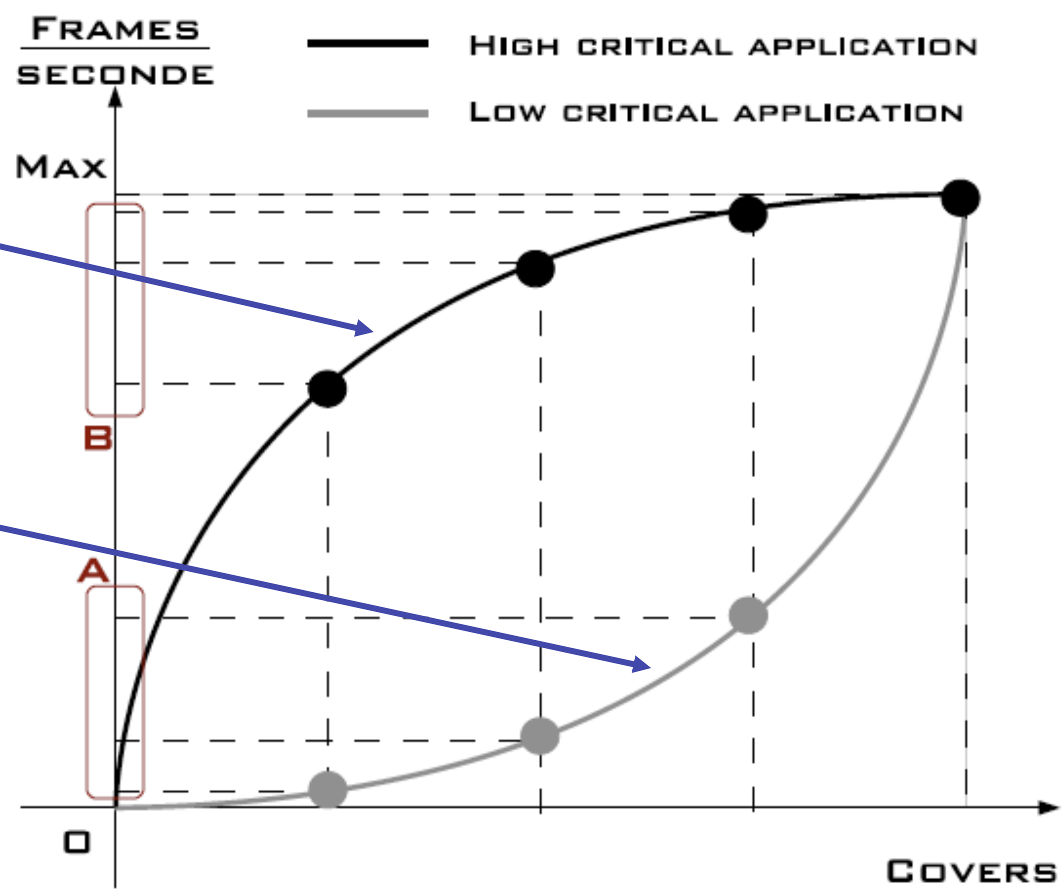
$Co(V) = \{$
$\{V\}$,
$\{V_1, V_3, V_4\}$,
$\{V_2, V_3, V_4\}$,
$\{V_3, V_4, V_5\}$,
$\{V_1, V_4, V_6\}$,
$\{V_2, V_4, V_6\}$,
$\{V_4, V_5, V_6\}$
$\}$

$|Co(V)| = 7$



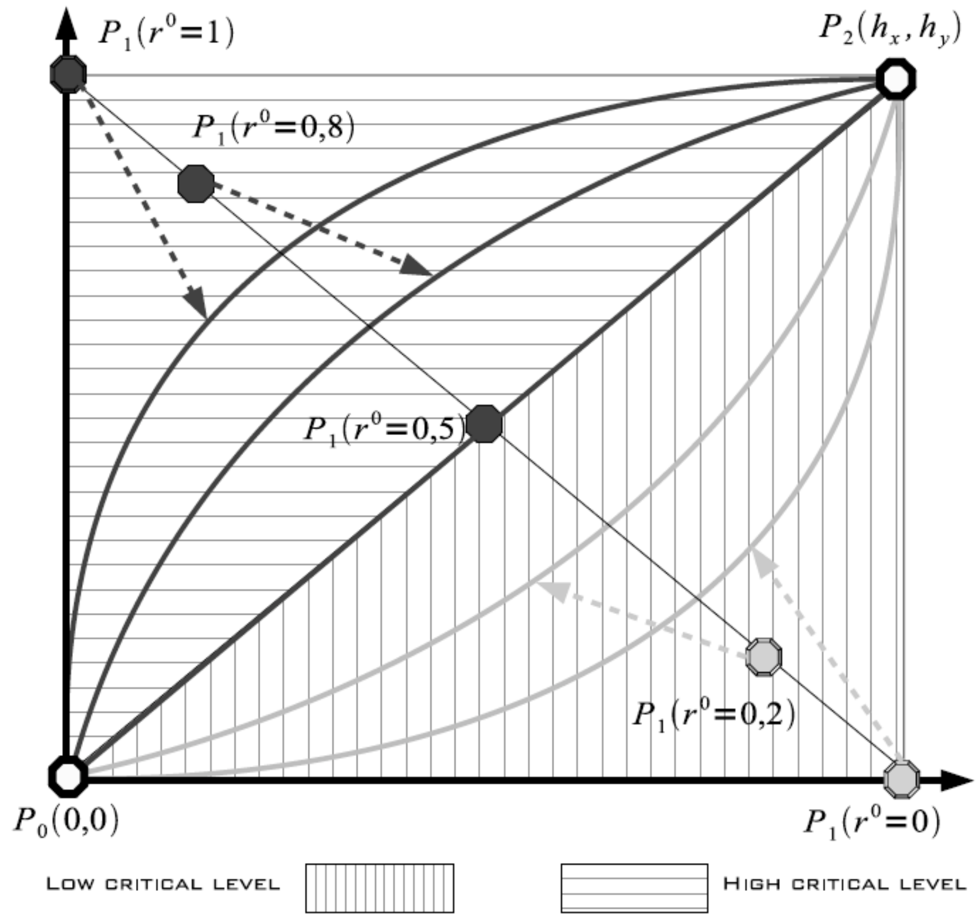
Criticality model (1)

- 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



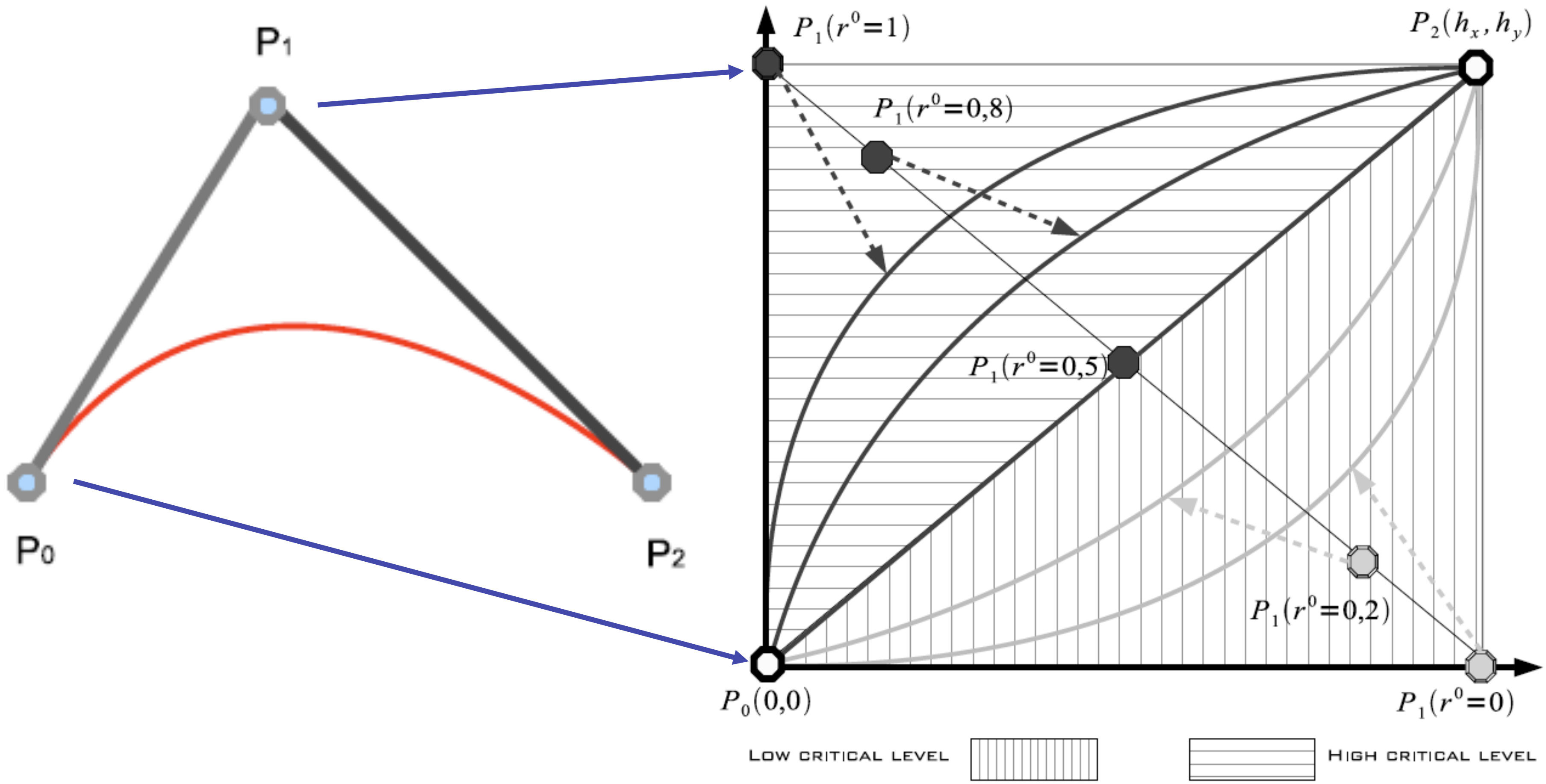
Criticality model (2)

- r^O can vary in [0,1]
- Behavior functions (BV) defines the capture speed according to r^O
- $r^O < 0.5$
  - Concave shape BV
- $r^O > 0.5$
  - Convex shape BV
- We propose to use Bezier curves to model BV functions



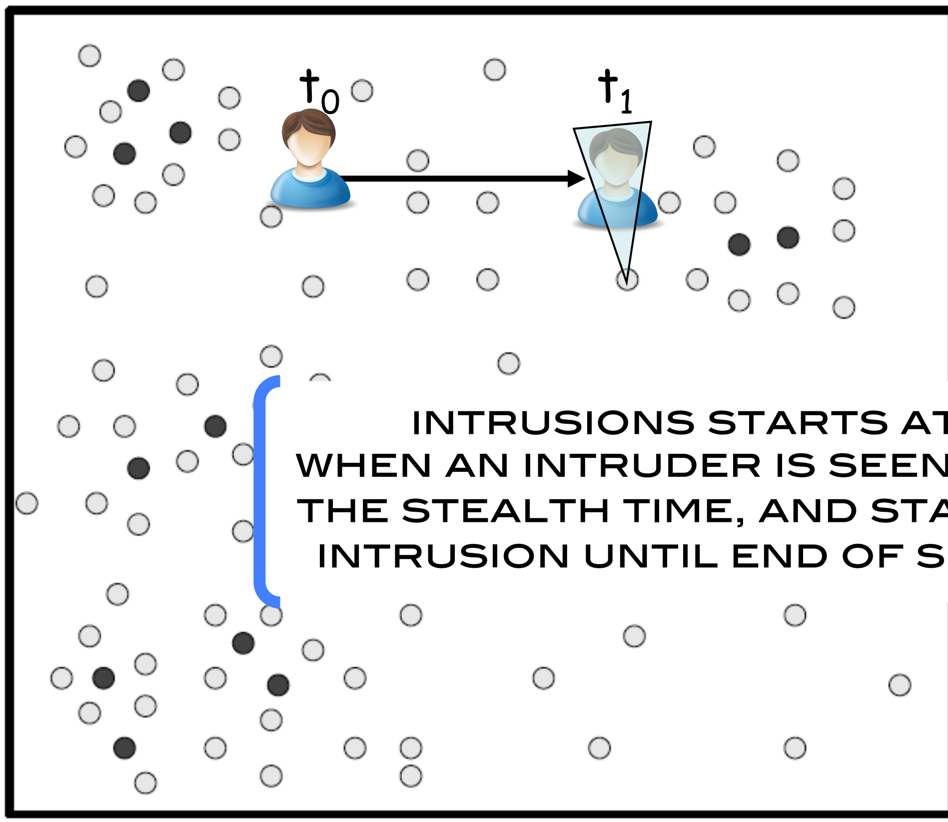
Behavior function

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



MEAN STEALTH TIME

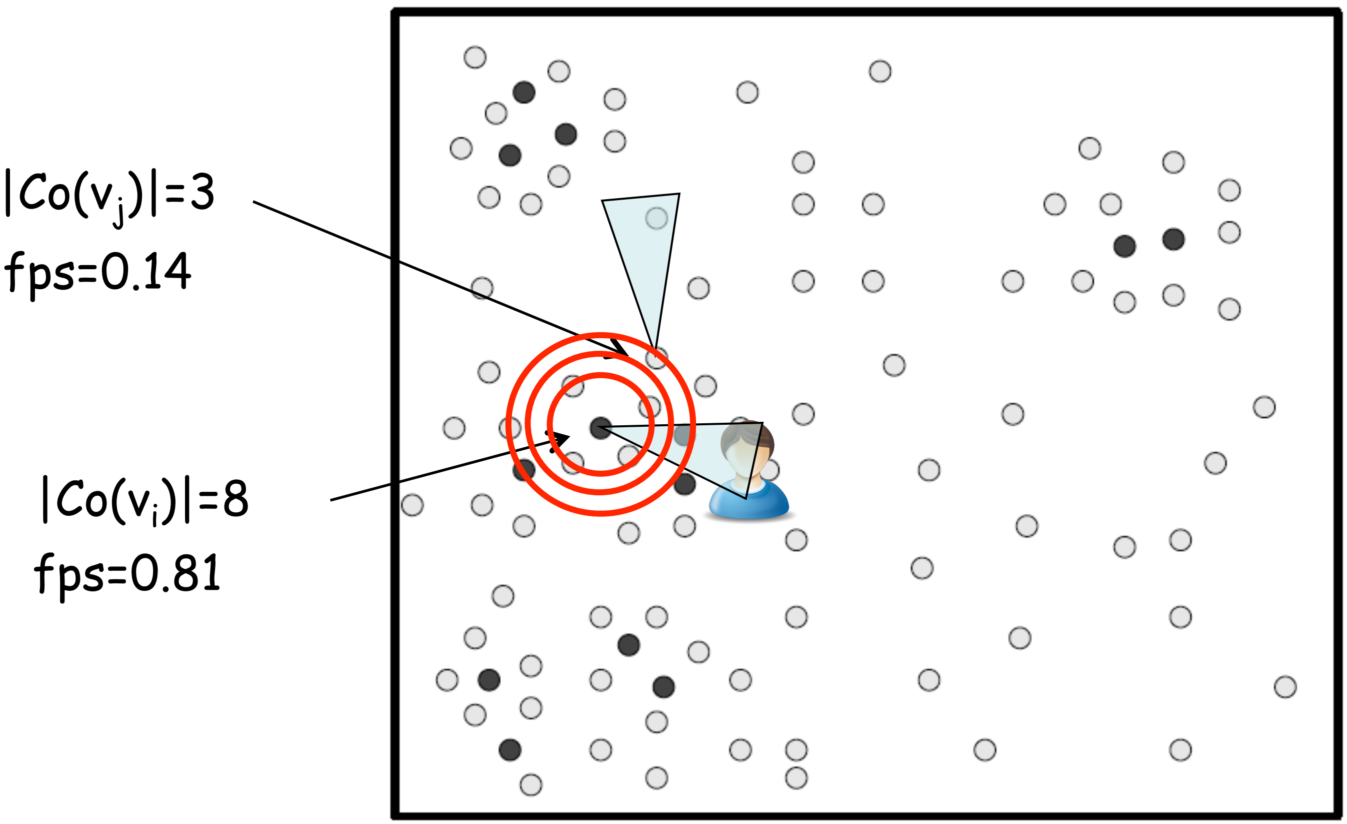
T_1-T_0 IS THE INTRUDER'S STEALTH TIME
VELOCITY IS SET TO 5M/S

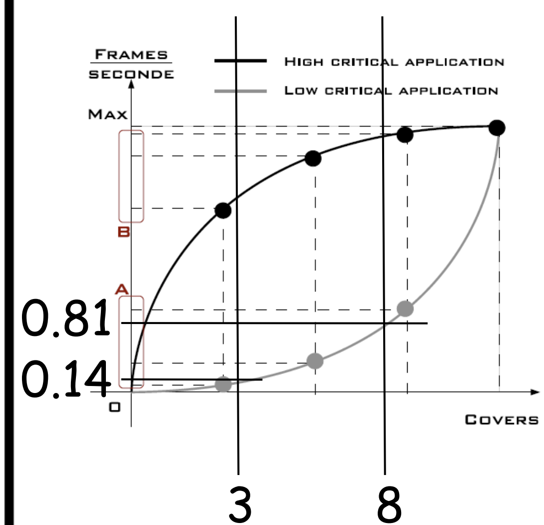


INTRUSIONS STARTS AT T=10S
WHEN AN INTRUDER IS SEEN, COMPUTE THE STEALTH TIME, AND STARTS A NEW INTRUSION UNTIL END OF SIMULATION

Risk-based scheduling in images (1)

- $R^o = R^o_{MIN} = 0.1$, $R^o_{MAX} = 0.9$, no alert



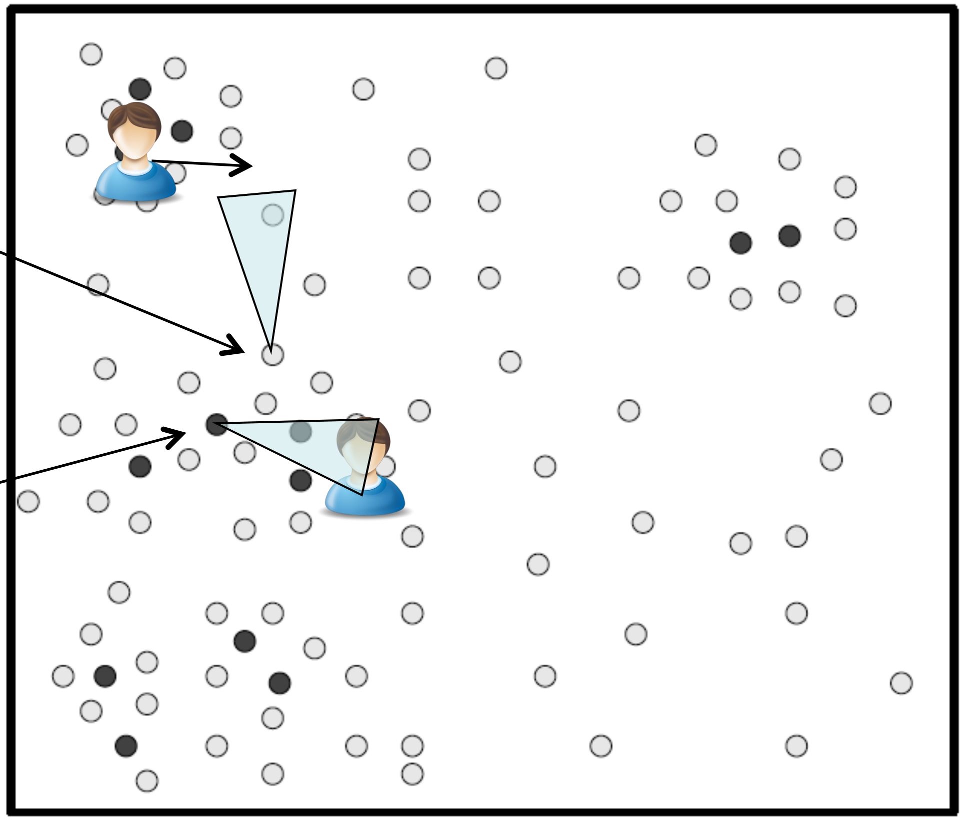


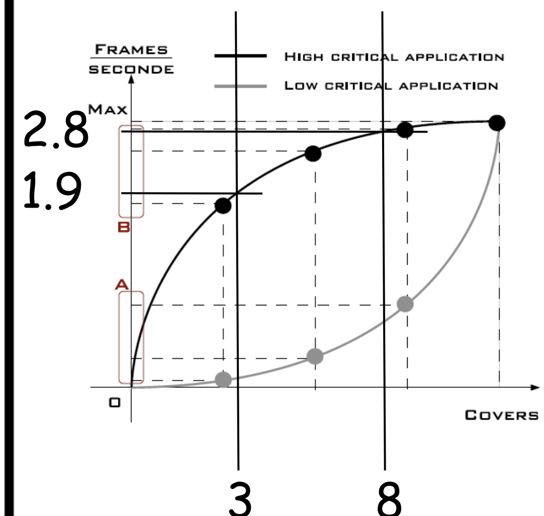
Risk-based scheduling in images (2)

- $R^\circ \rightarrow R^\circ = R^\circ_{MAX} = 0.9$

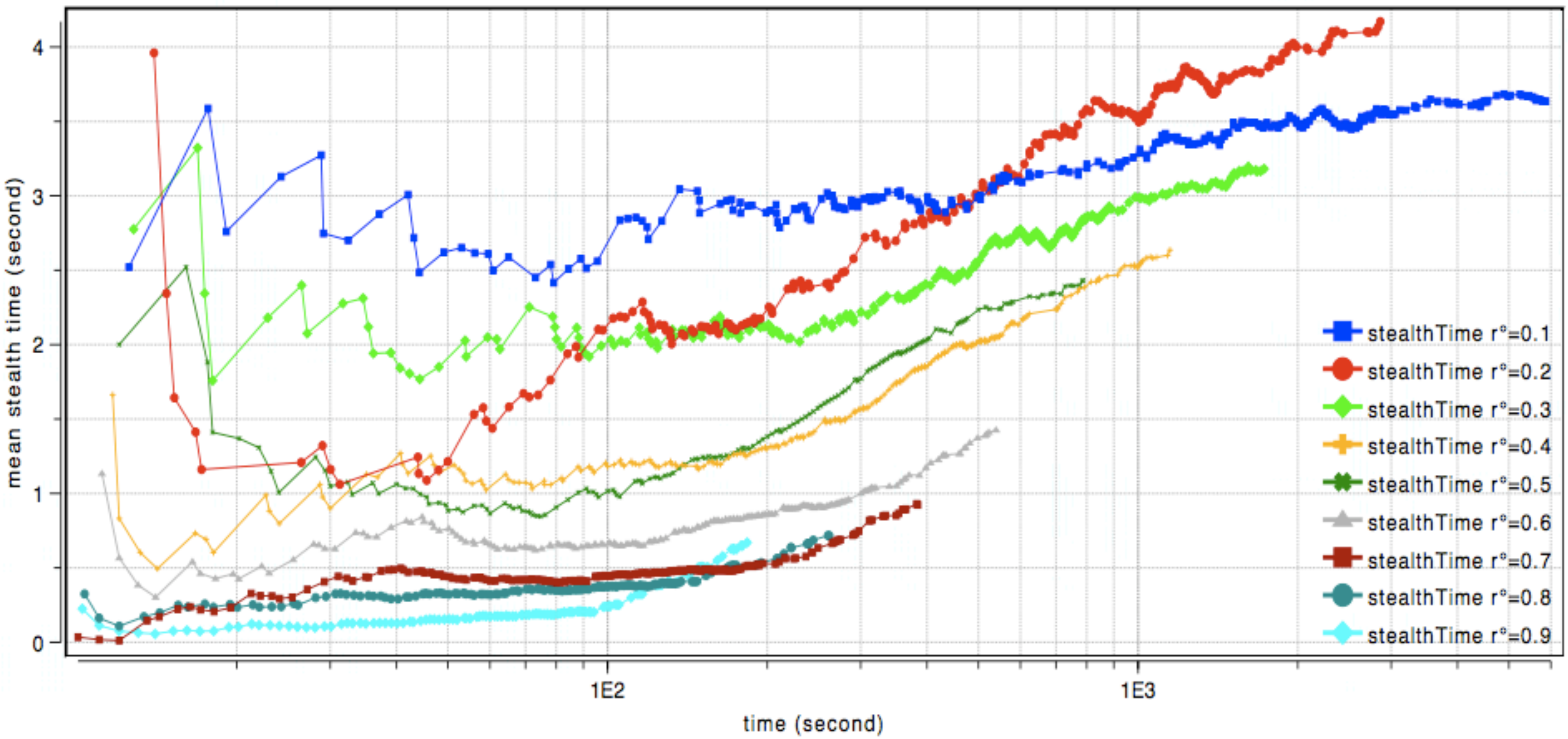
$|Co(v_j)|=3$
Fps=1.9

$|Co(v_i)|=8$
Fps=2.8

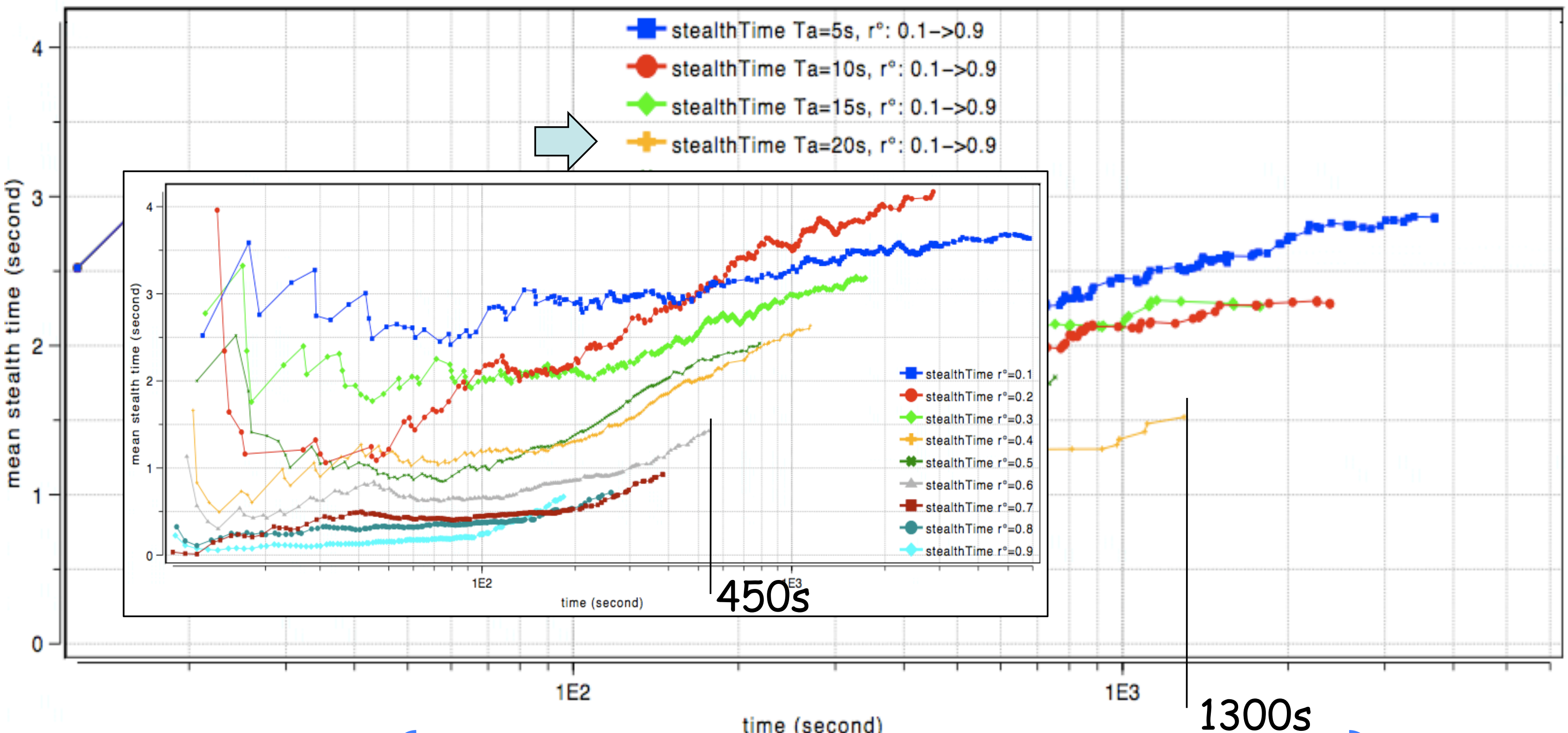




MEAN STEALTH TIME
STATIC SCHEDULING

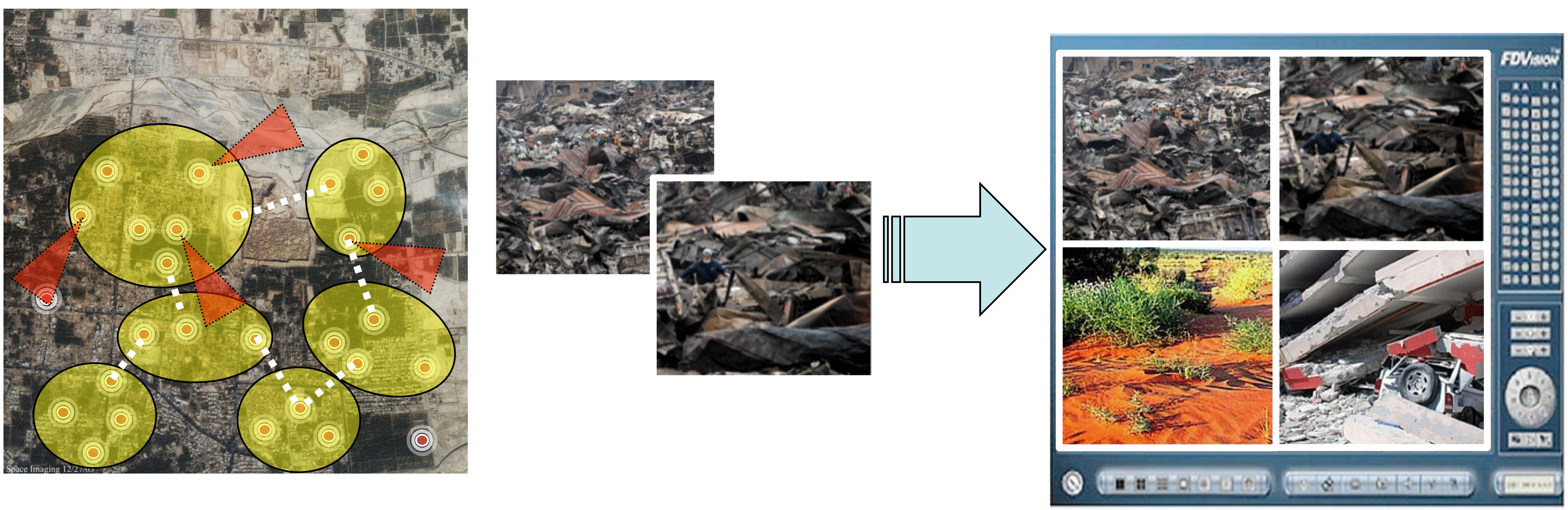


MEAN STEALTH TIME RISK-BASED SCHEDULING

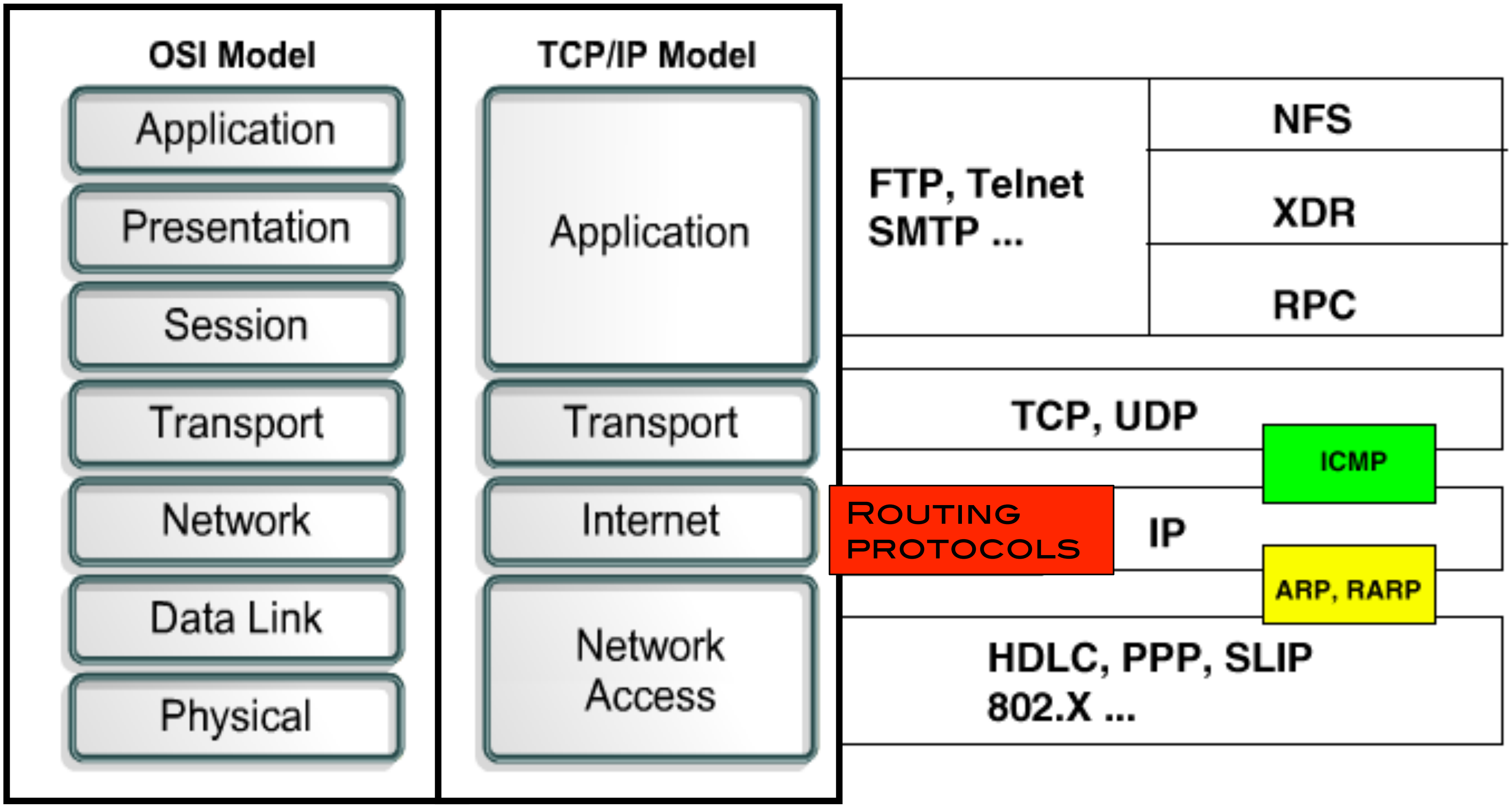


Sensor nodes start at 0.1 then increase to 0.9 if alerted (by intruders or neighbors) and stay alerted for Ta seconds

Communication issues

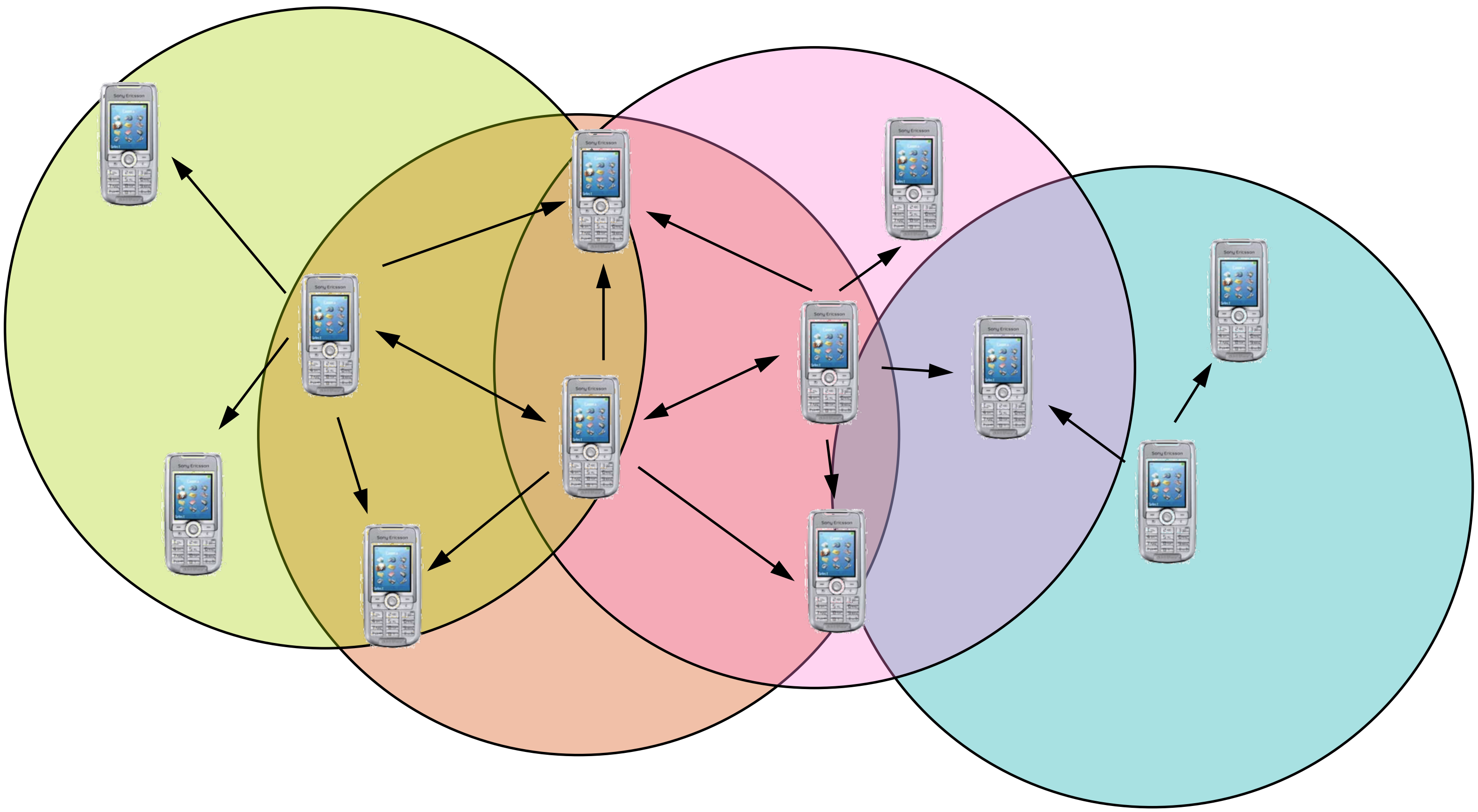


Review of Communication Architecture

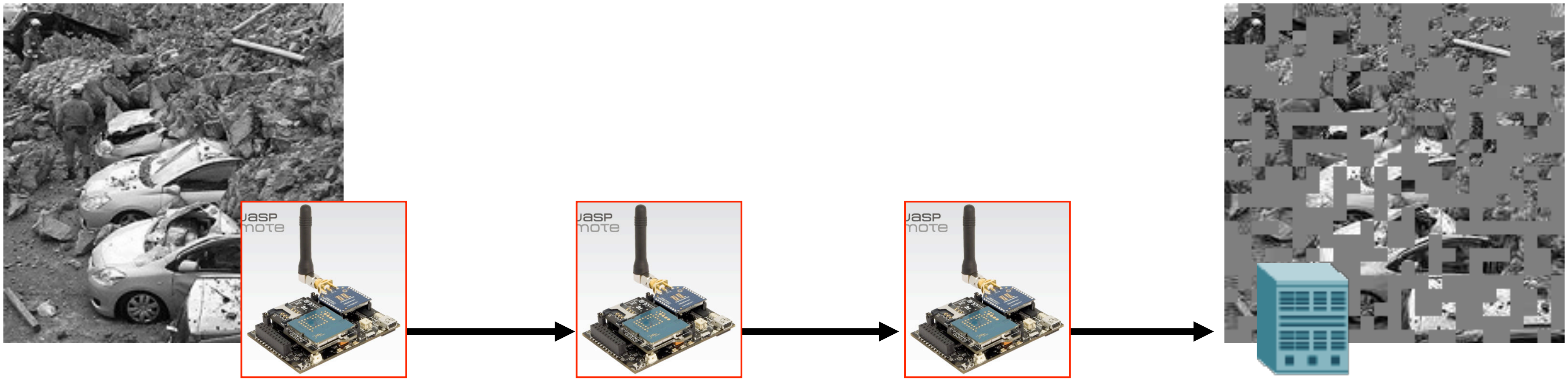


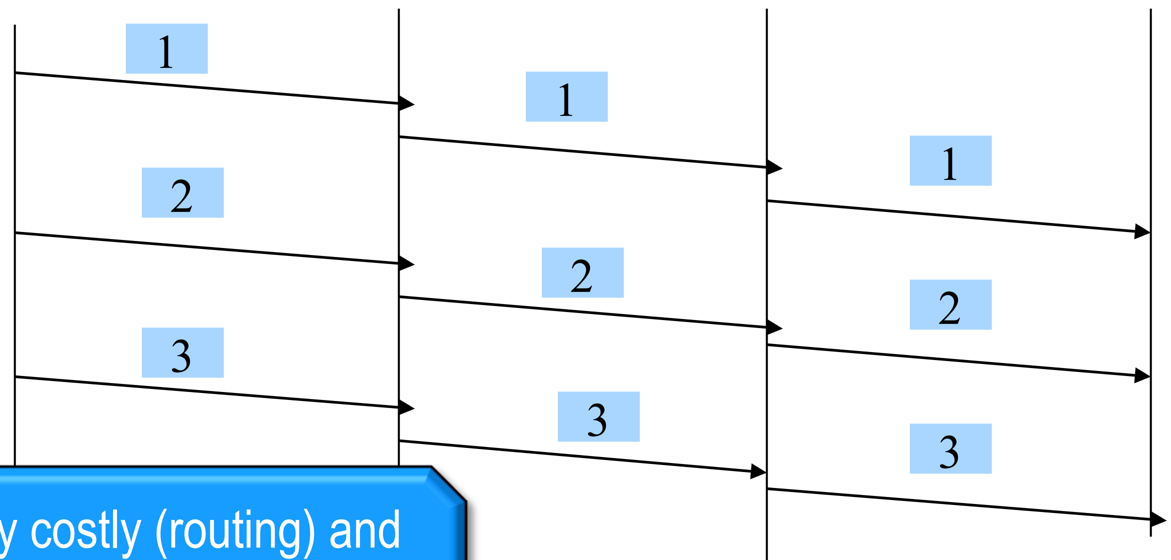
Ad-hoc networks

- Infrastructure-less networks
- MANET (Mobile Adhoc NETworks)



Multi-Hop Packet Forwarding



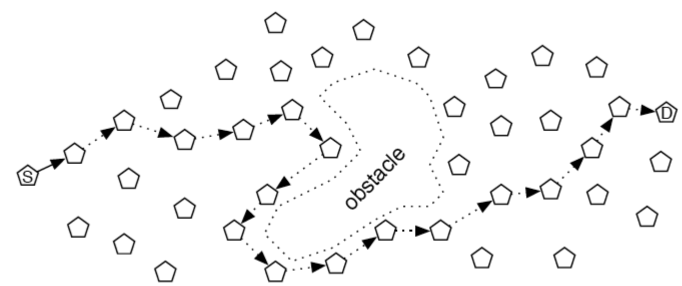


Multi-hop is very costly (routing) and generates lot's of packet losses!

Routing
Energy vs latency

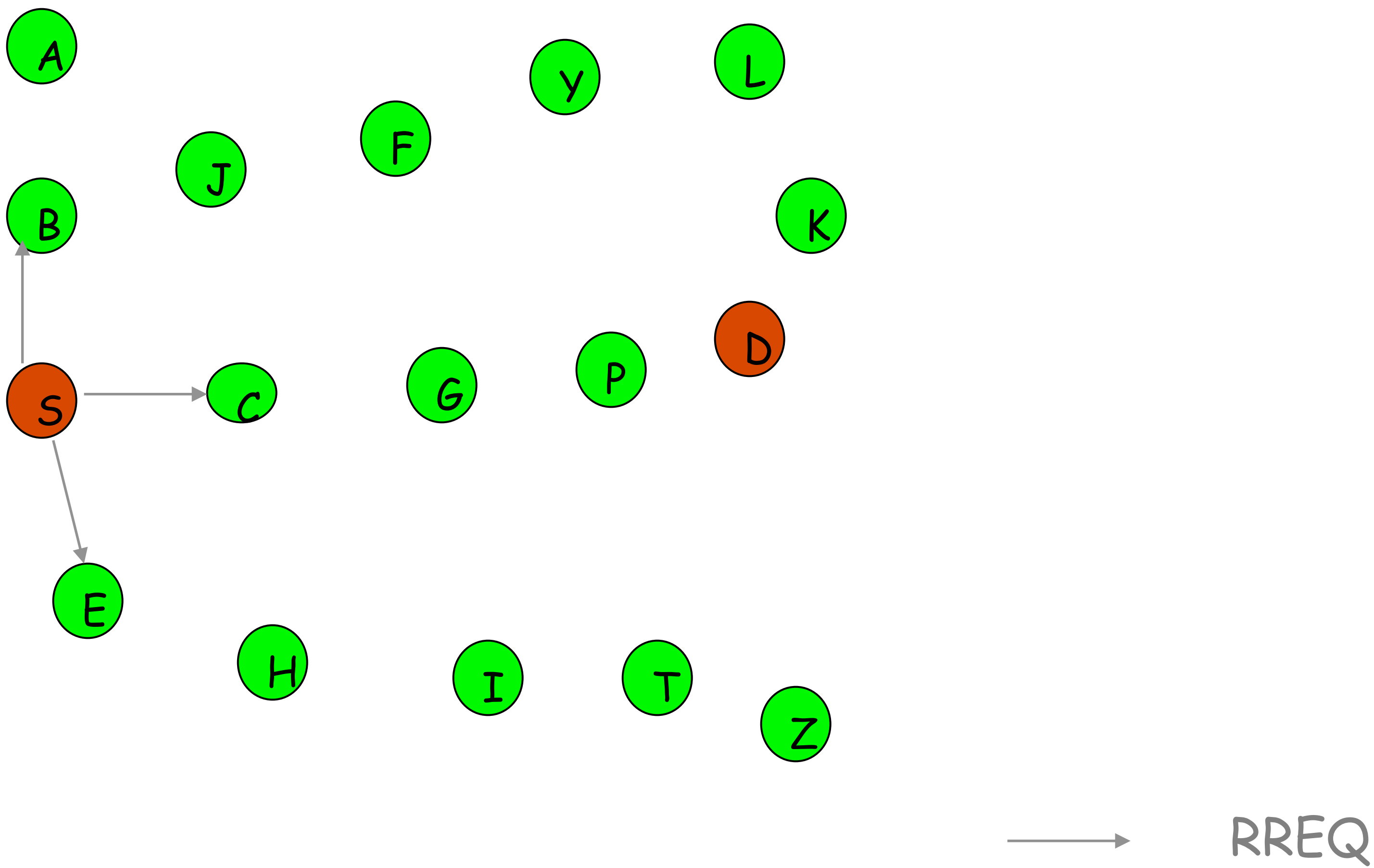
- Proactive?
  - Maintain & update routing table independently of communication needs
  - Periodical updates
  - Same philosophy than in wired-networks (RIP, OSPF)
  - Low latency
  - « Waste » bandwidth and energy
- Reactive, on-demand?
  - On-the-fly discovery of routes, when communication needs appear
  - Save bandwidth and energy
  - Higher latency
  - Generally efficient at low load
- Hybrid?
  - Proactive or reactive depending on the distance

Flat vs Hierarchical

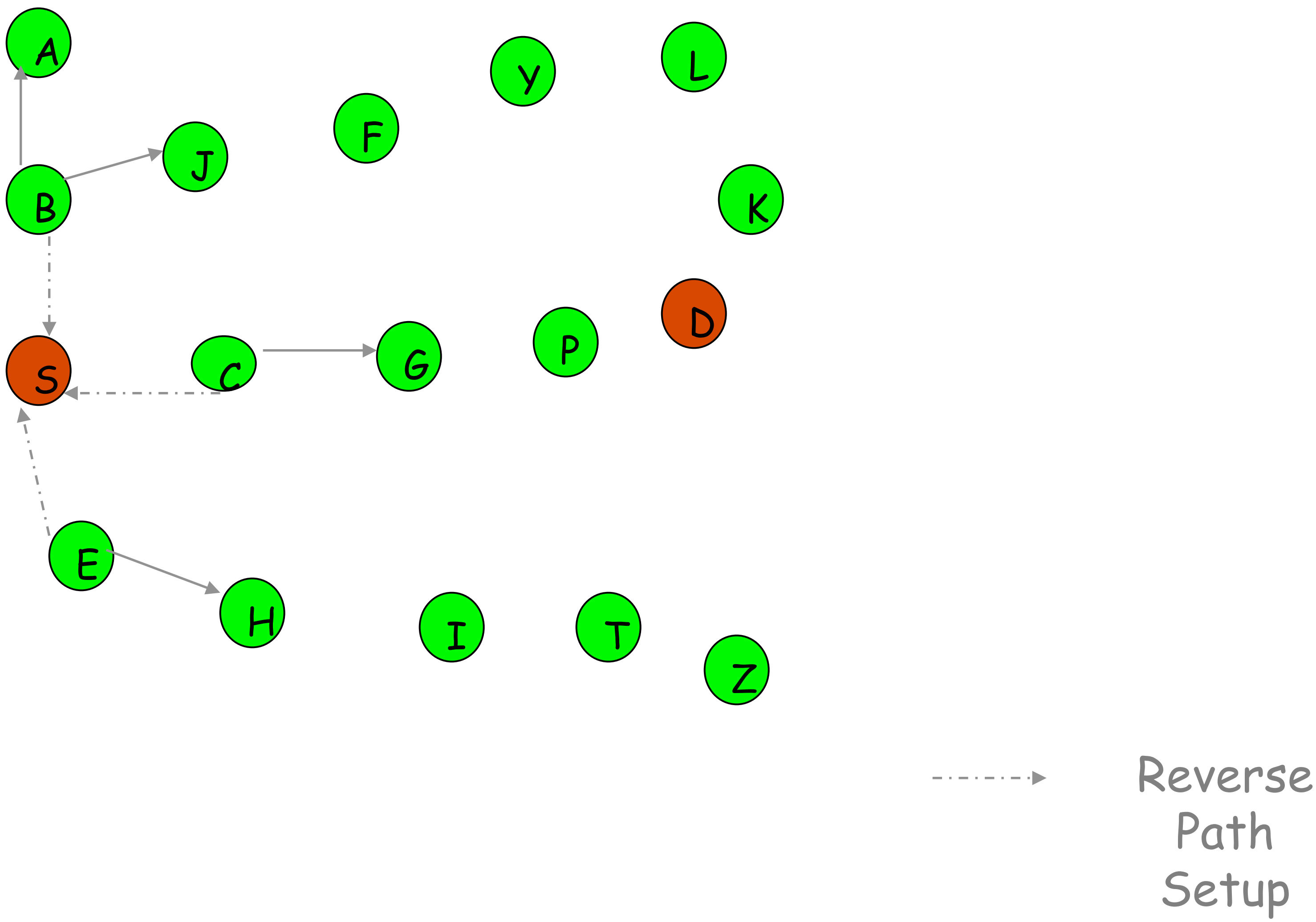


- Flat routing?
  - Simple
  - Not scalable!
- Hierarchical routing?
  - More efficient
  - « leaders » election overhead
  - Mobility cost
  - Multiple hierarchy levels are possible
- Geographical routing?
  - GPS-aided for instance
  - Efficient routing towards the destinations
  - Geographical information are propagated using flooding

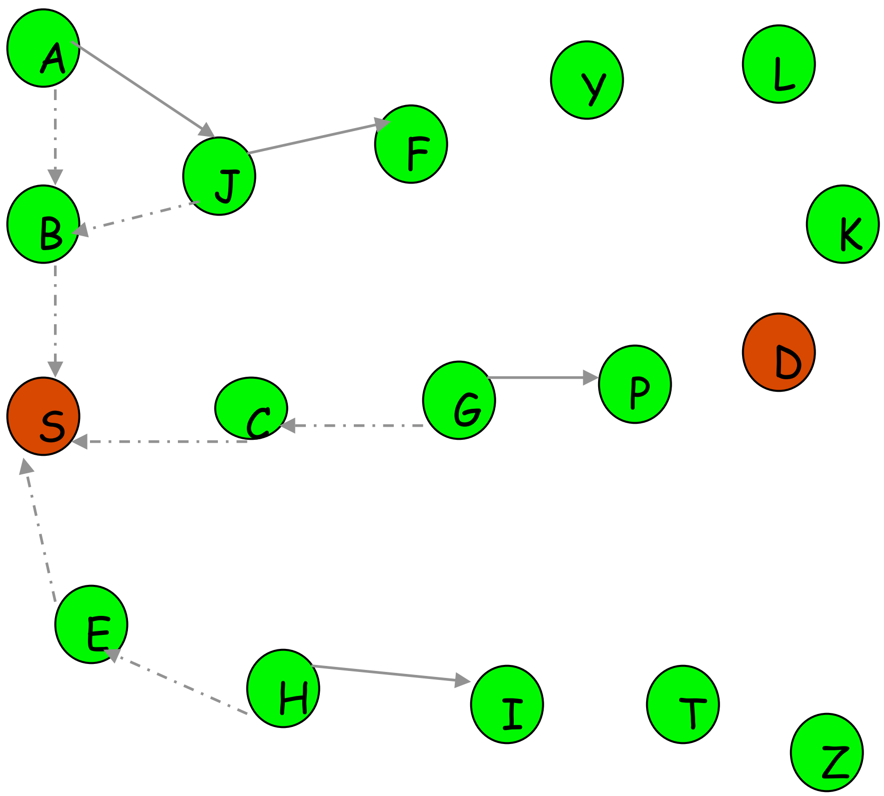
On-demand multi-hop routing illustrated: AODV example



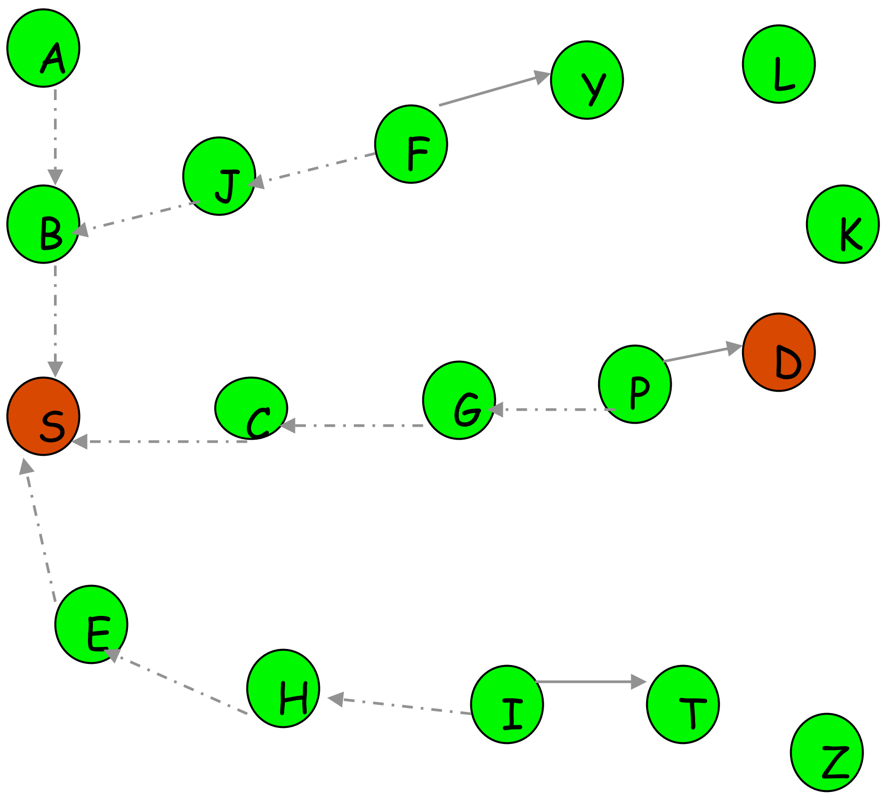
AODV (Example)



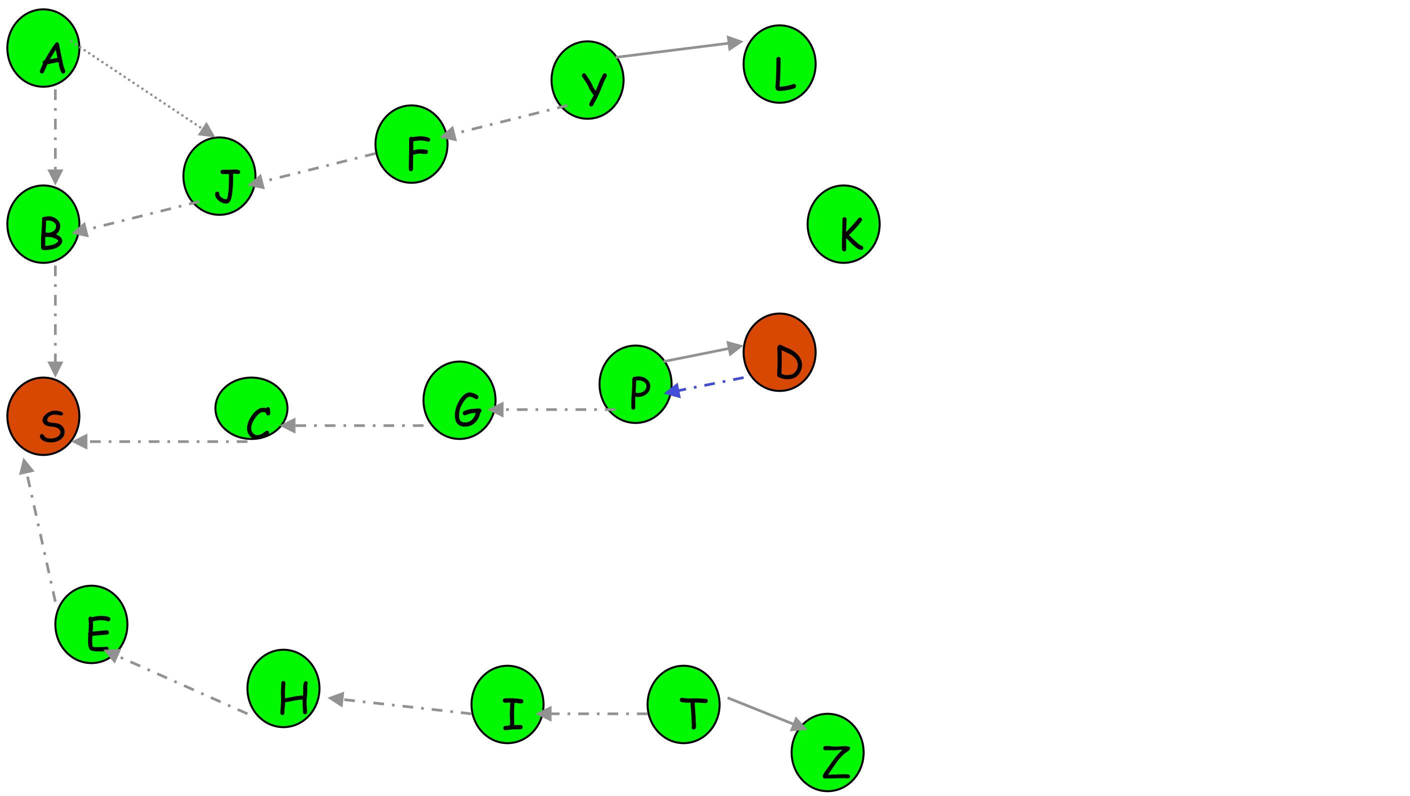
AODV (Example)



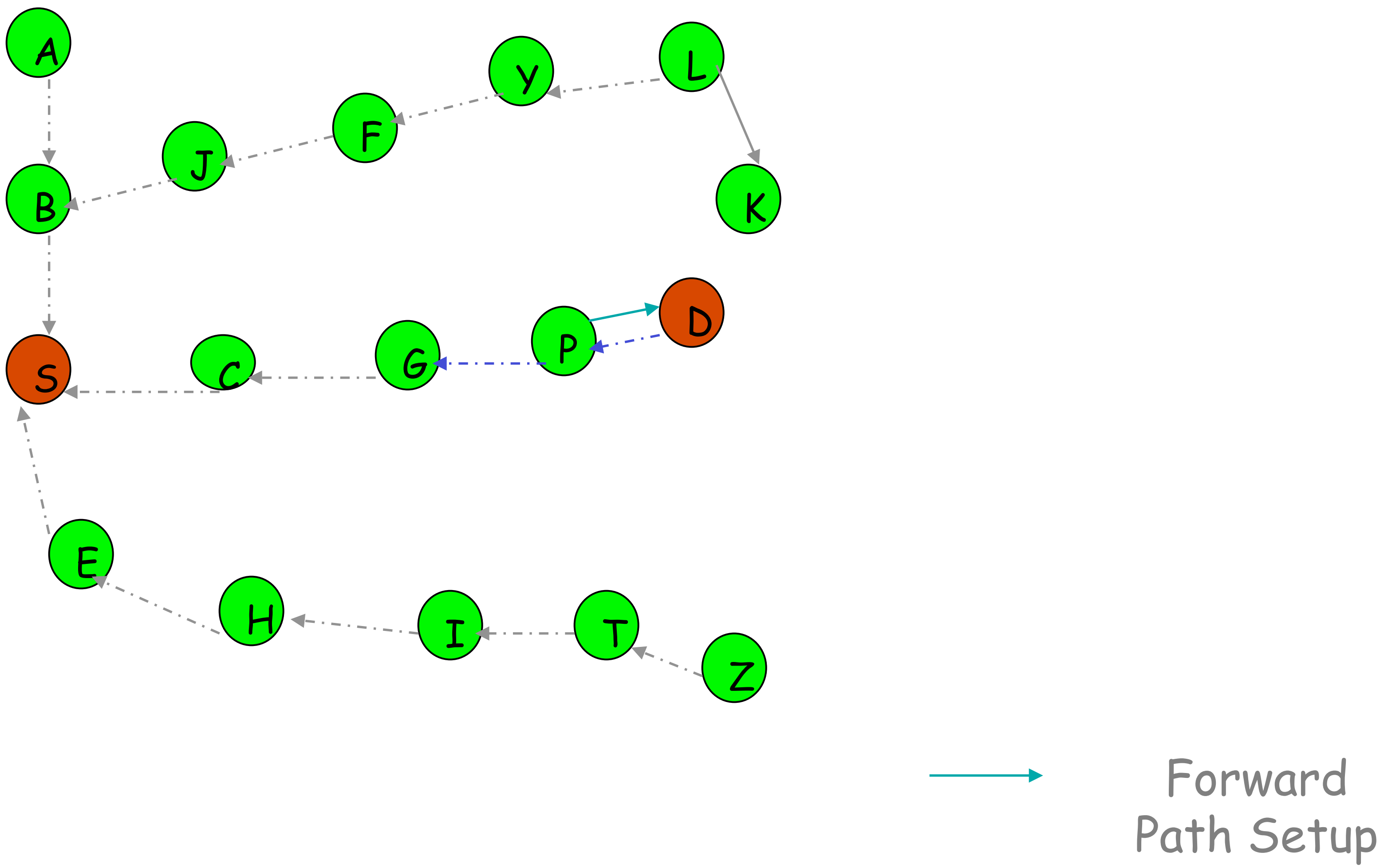
AODV (Example)



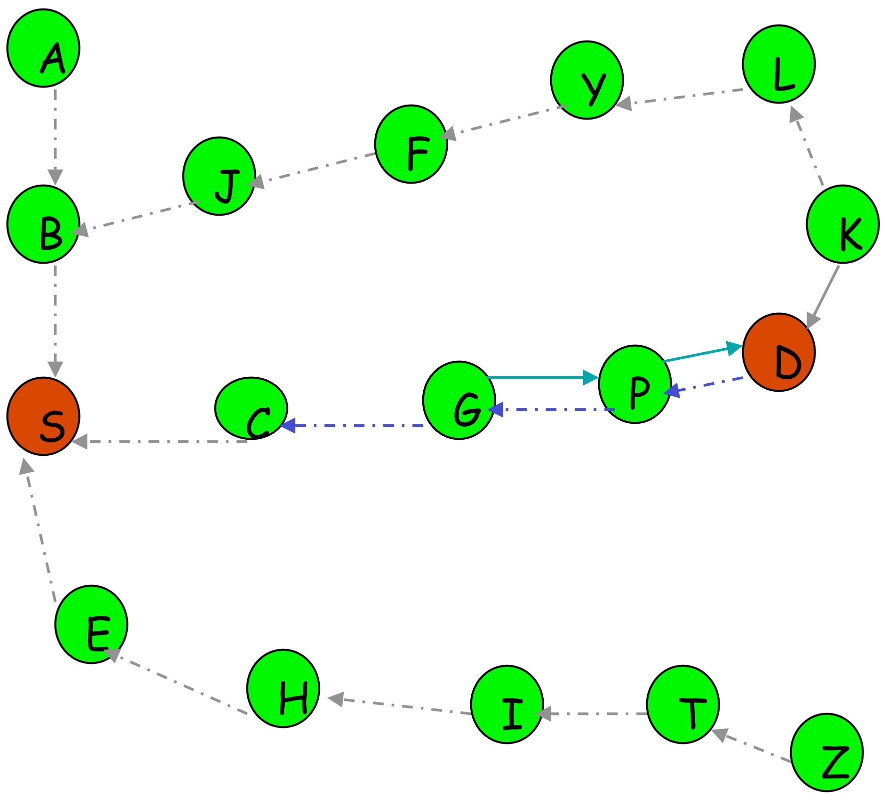
AODV (Example)



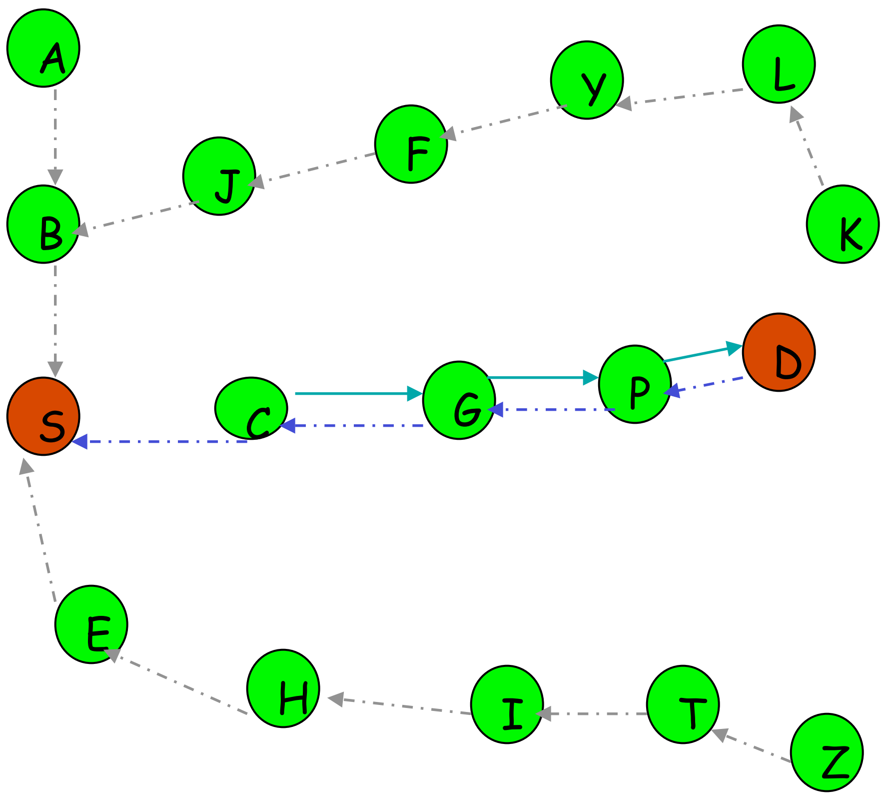
AODV (Example)



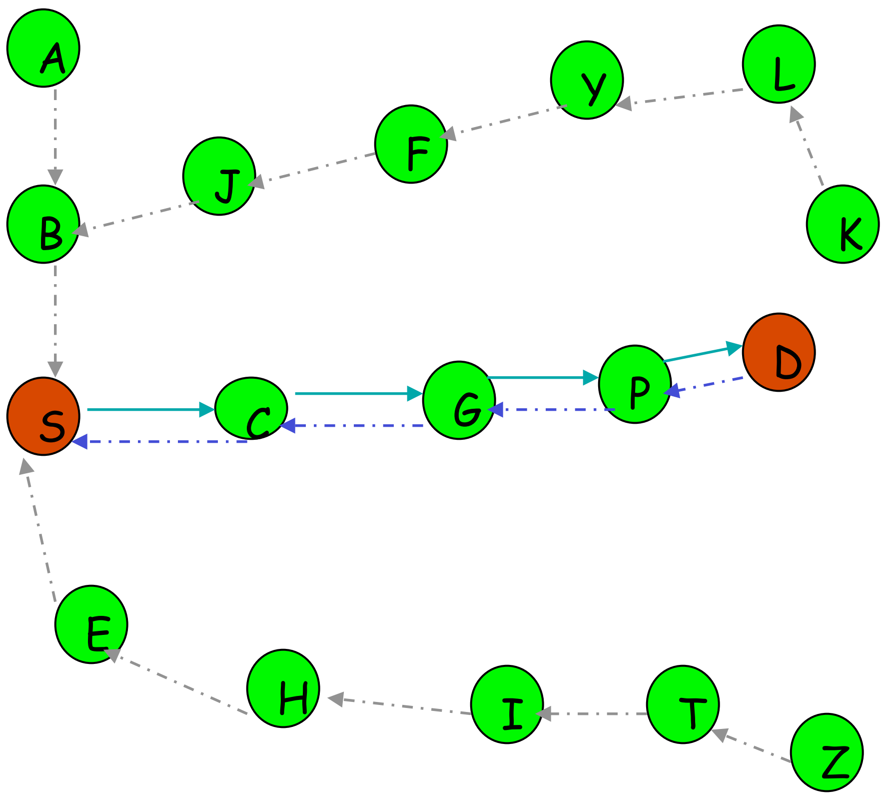
AODV (Example)



AODV (Example)

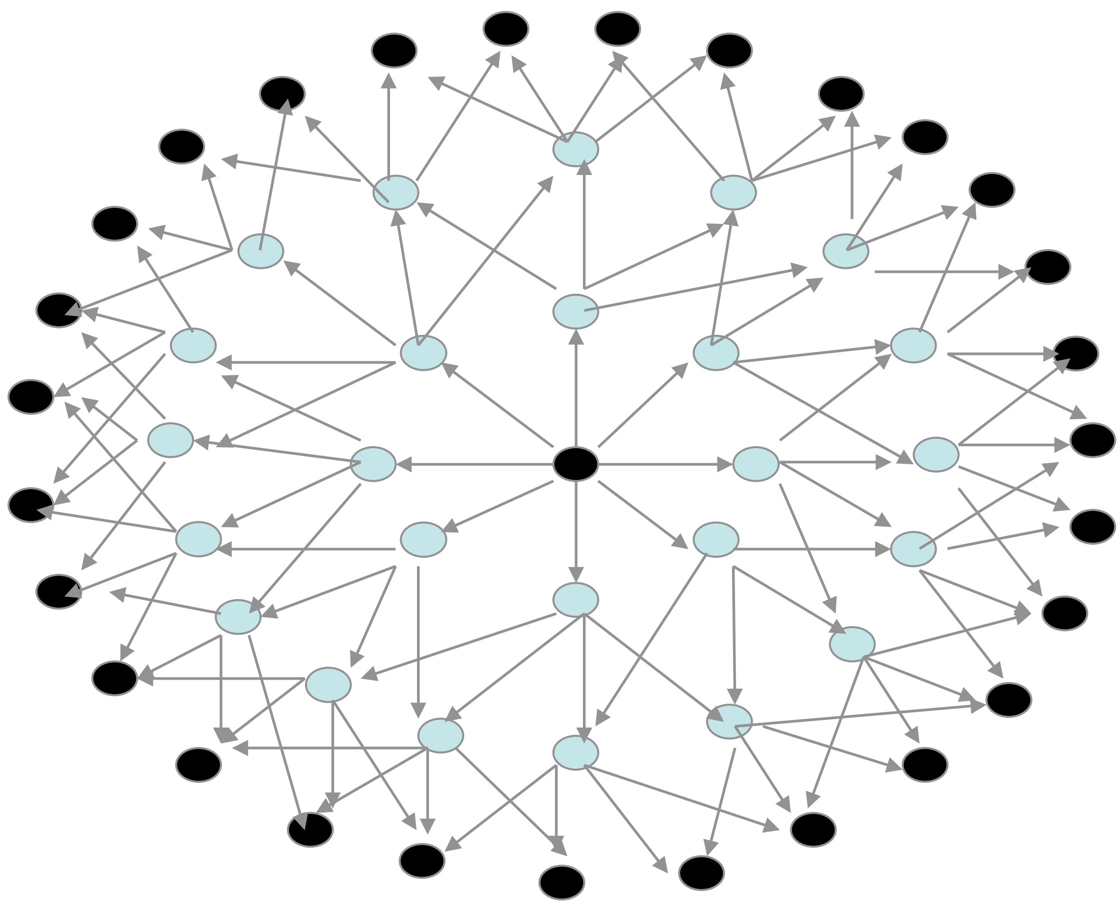


AODV (Example)

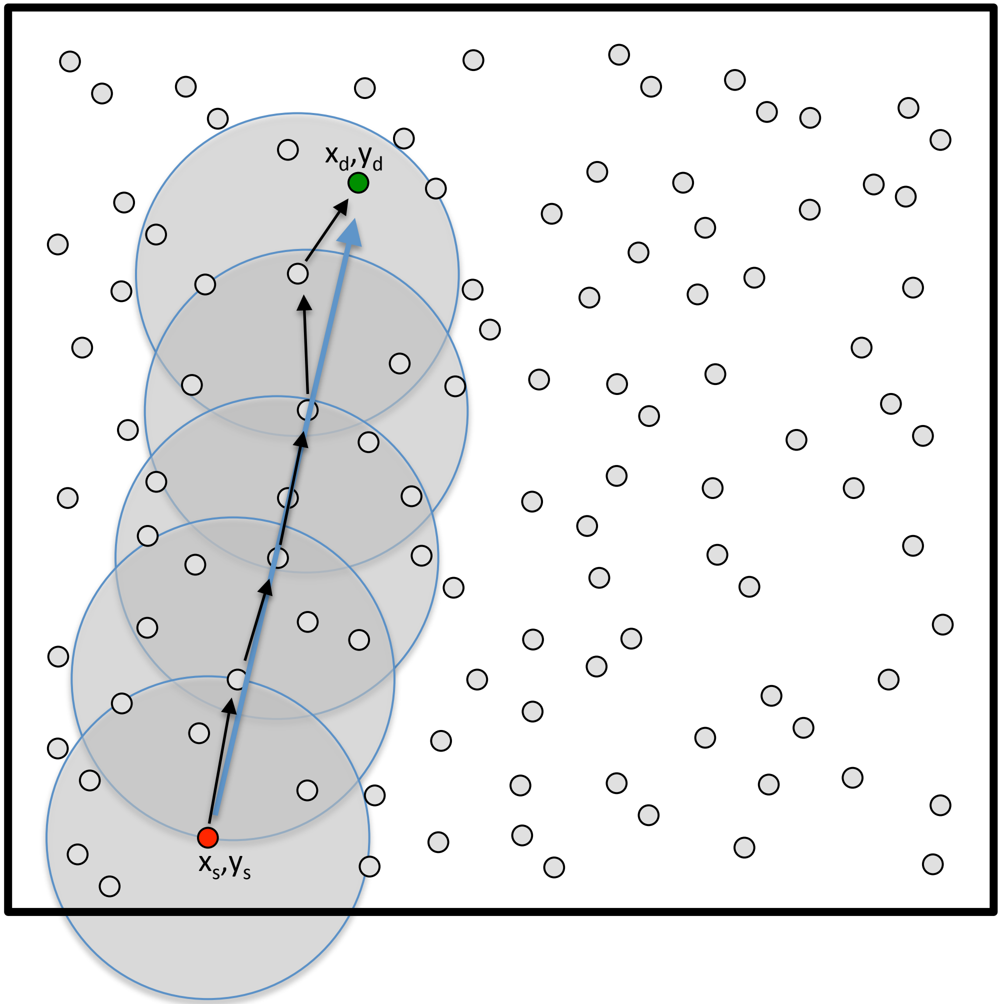


Broadcast overhead

- Quite high in large networks!



Geographic routing

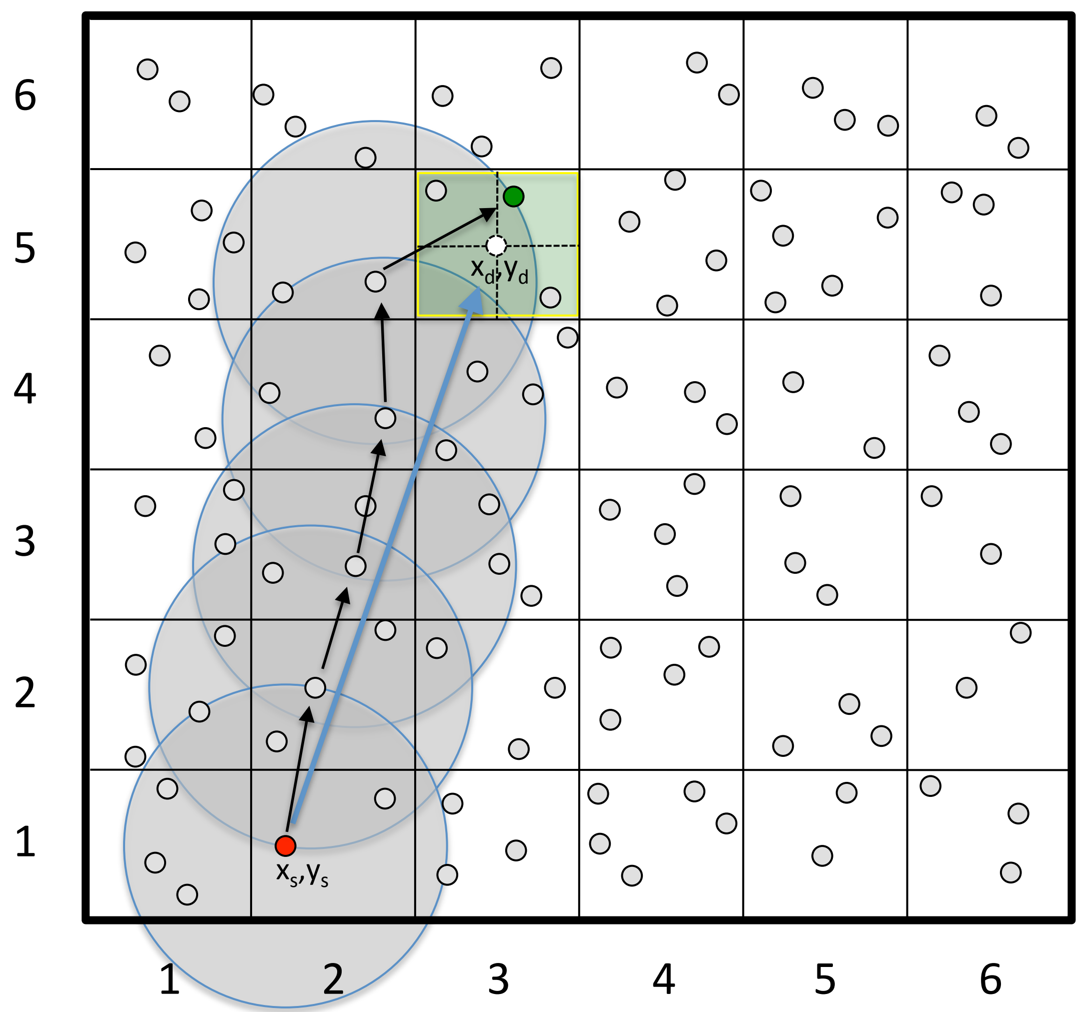


Avoids keeping routing information

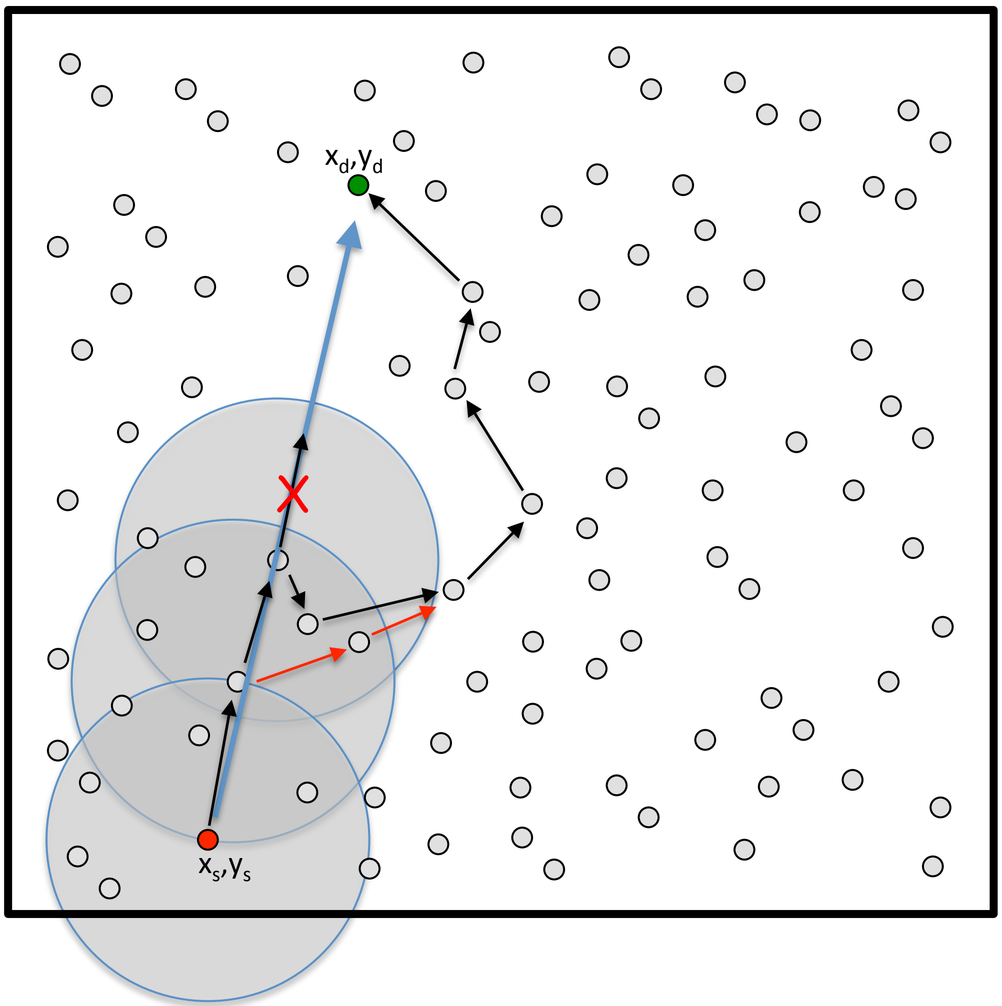
Relies on geographic (GPS) coordinates to find next-hop node

Reduces route maintenance overhead

Area-based geographic routing



Cons: holes in network increases path length



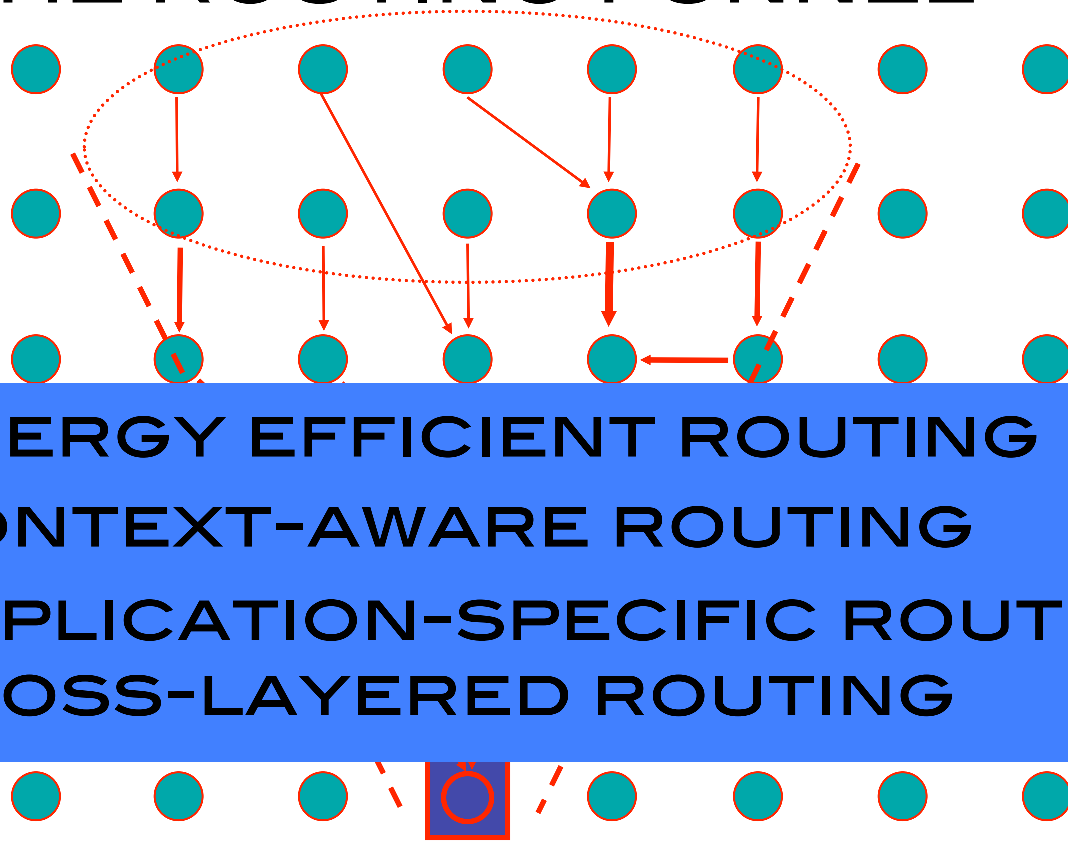
Need to detect/indicate where are the holes so that nodes at the border of a hole will not be selected

Nodes that run out of energy may create new holes!

Holes signalling overhead can become high

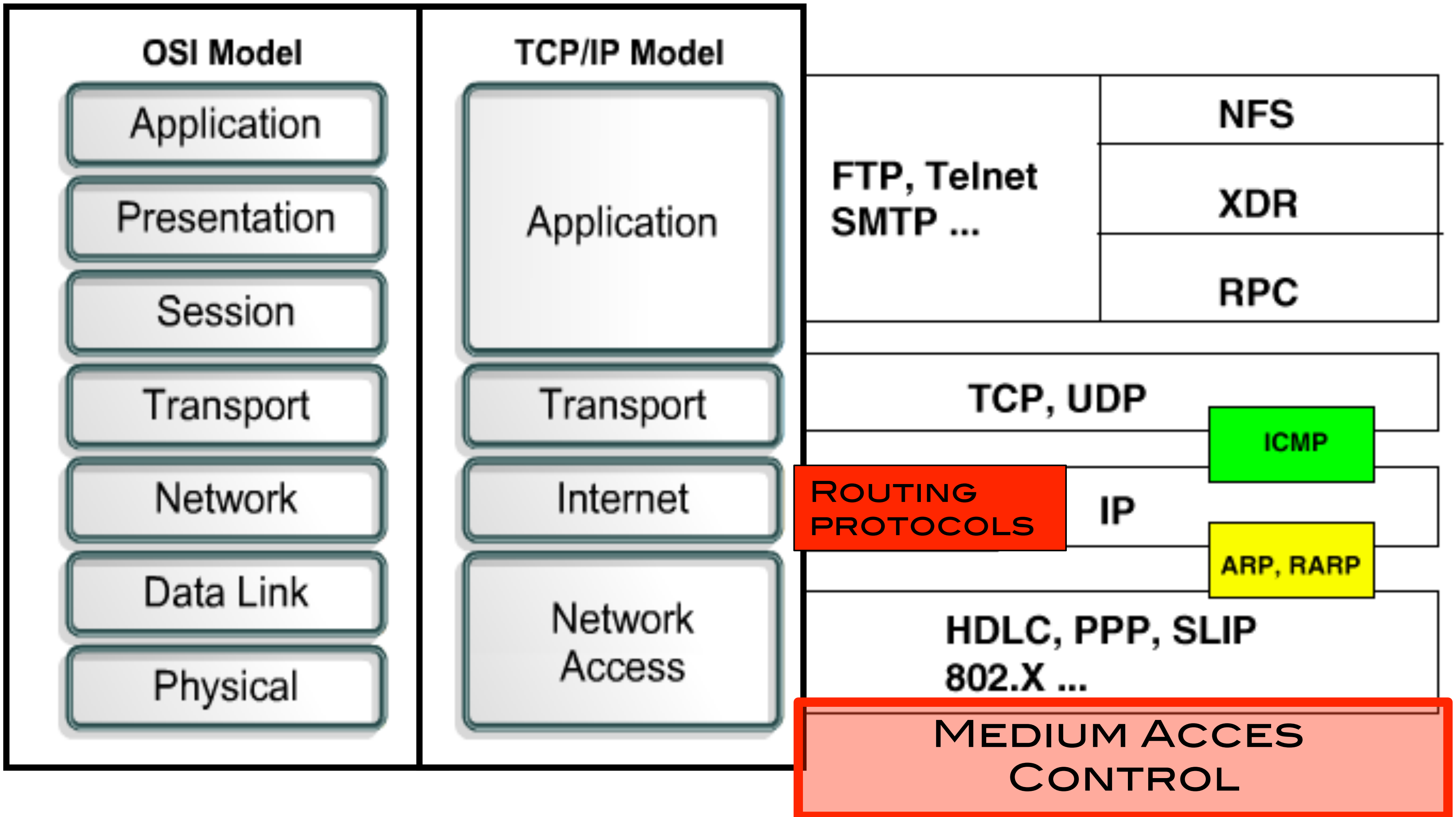
Funneling Effect

- Many-to-one traffic pattern causes congestion in the routing funnel

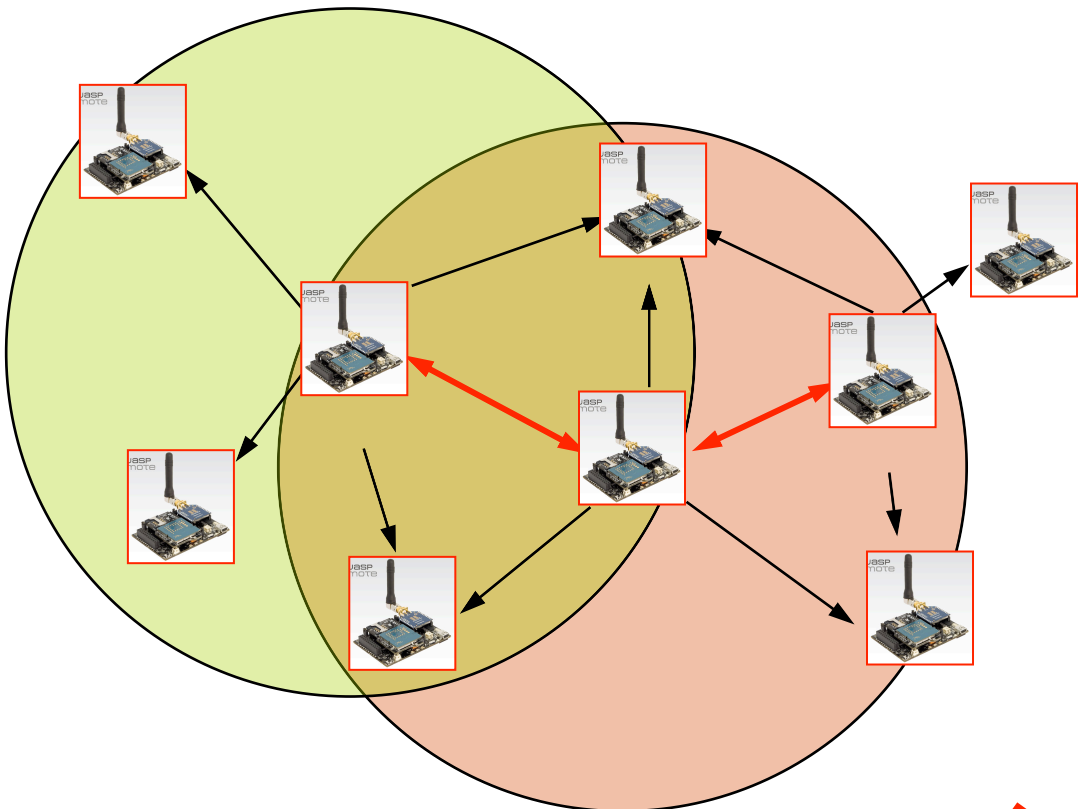


- Energy efficient routing
- Context-aware routing
- Application-specific routing, cross-layered routing

Review of Communication Architecture



Wireless Medium is a Shared Medium



Collisions when multiple transmissions (e.g. multi-hop)

Hidden terminal problem

WiFi transmission power is too energy-consuming for WSN!

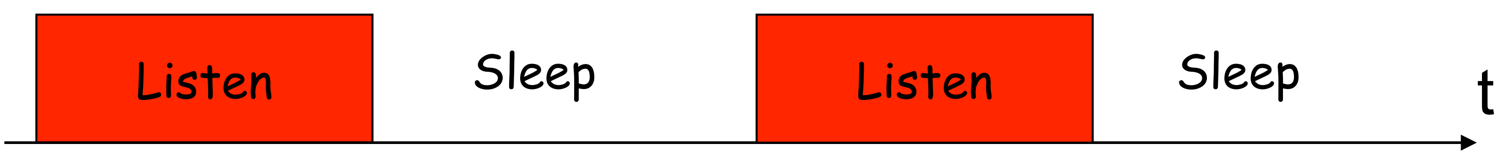
Huge cost of passive listening!

WSN can be idle for a long period!

TDMA is usually not used because of waste of resource

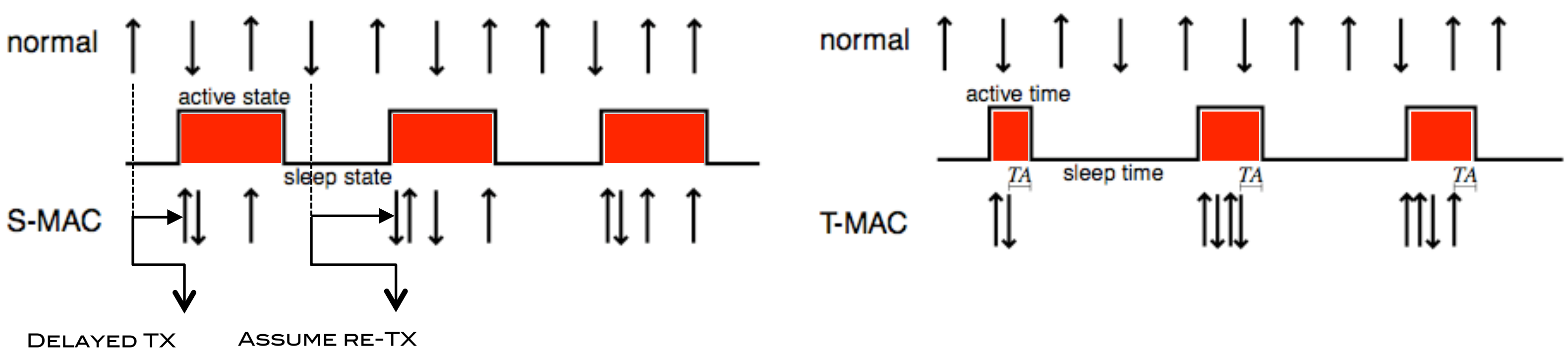
S-MAC - Sensor MAC

- Nodes periodically sleep
- Trades energy efficiency for lower throughput and higher latency
- Sleep during other nodes transmissions
- Needs complex synchronization mechanisms



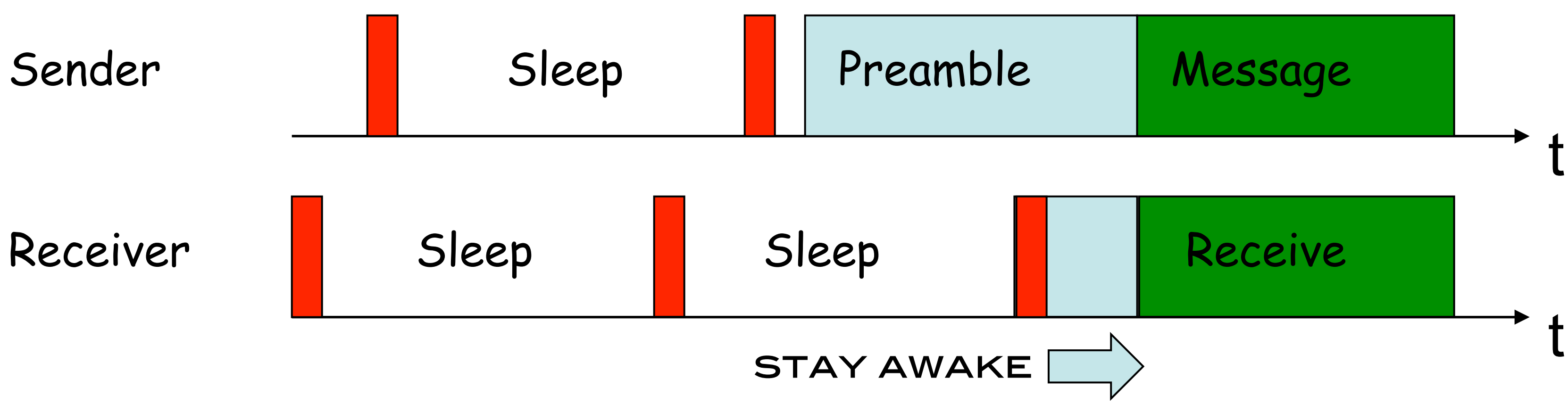
T-MAC - Timeout MAC

- Transmit all messages in bursts of variable length and sleep between bursts
- RTS / CTS / ACK Scheme
- Synchronization similar to S-MAC



B-MAC

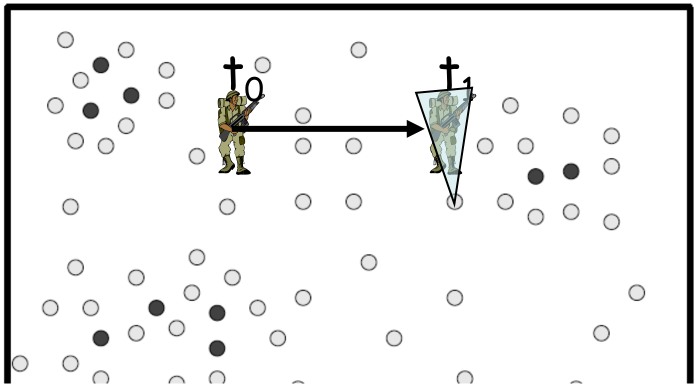
- Low Power Listening (LPL) using preamble sampling
- Avoids costly synchronization mechanisms



Challenges for MAC protocols in WSN

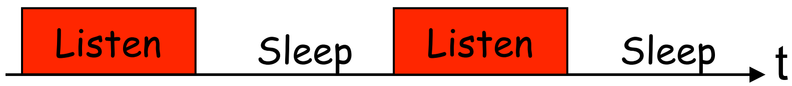
- Energy efficiency
- Low latencies
- Fairness

A CHALLENGE FOR MISSION-CRITICAL APPLICATION

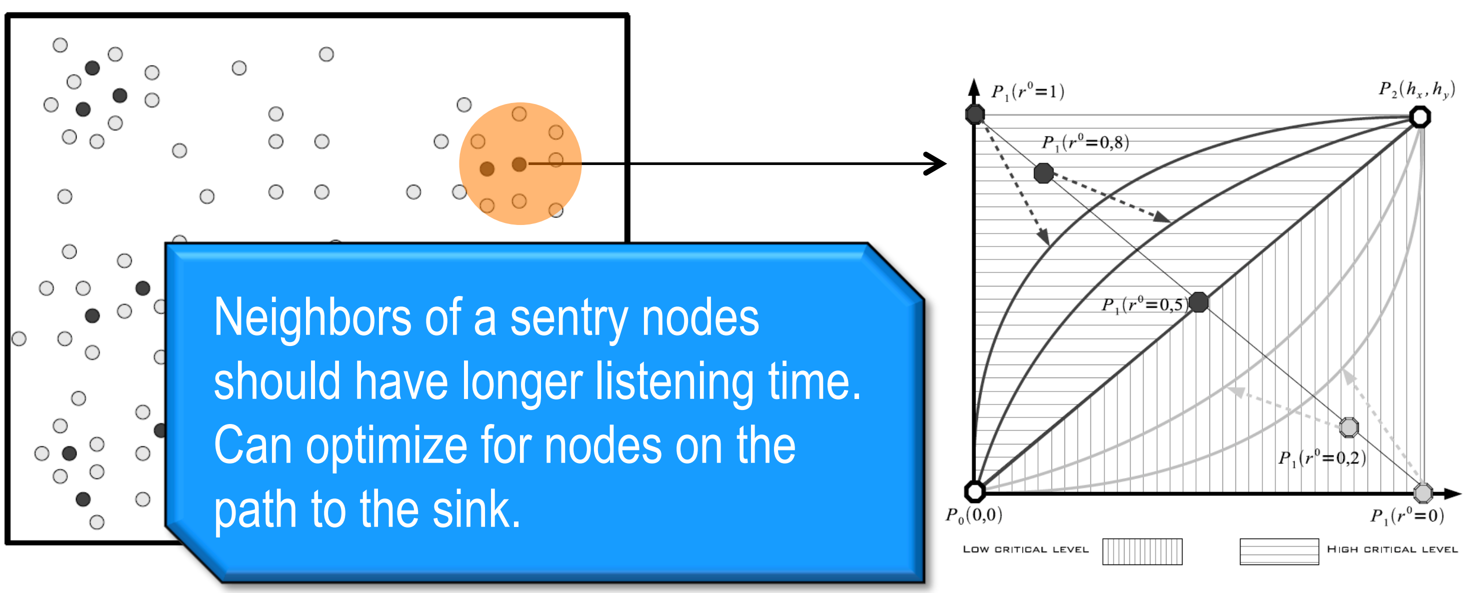


Our current research on MAC layer

- Duty-cycled MAC (e.g. SMAC)

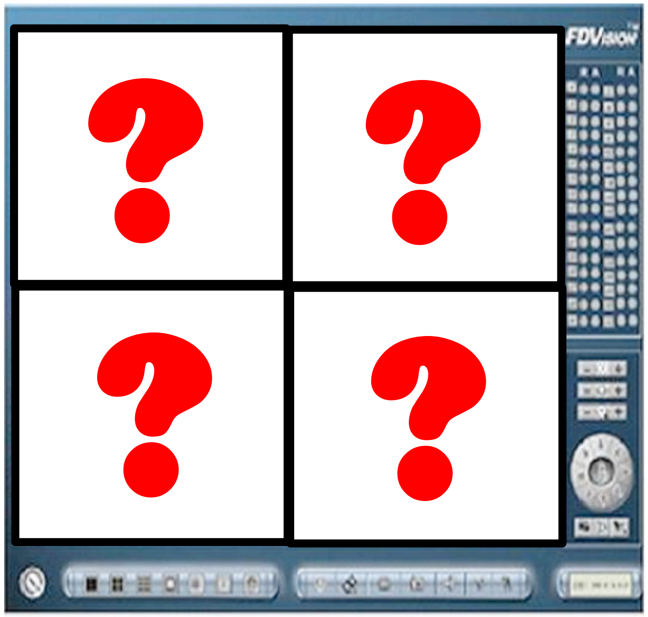


- Link the listening time to the criticality model



End-to-end performances?

Holes in deployment
Limited buffers
Multi-hop overhead
Congestion
Channel contention
Duty-cycling MAC
Physical interference
Small PDU
Nodes availability
…



END-TO-END LOSS RATE IS EXPECTED TO BE HIGH!

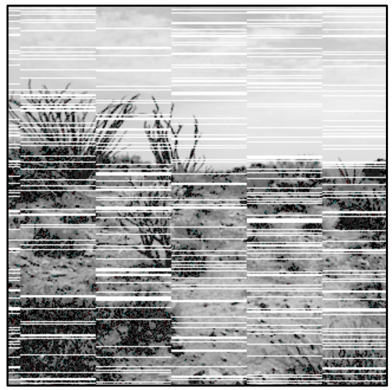
Image quality? Uncompressed BMP

1617 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling

Original 320x320
256 gray levels,
BMP 102400 bytes

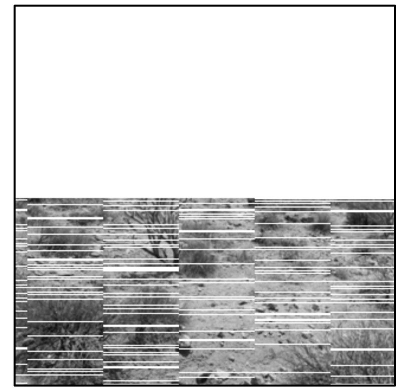
Max TX rate = 250 kps
(IEEE 802.15.4)

Minimum latency = 6.46s



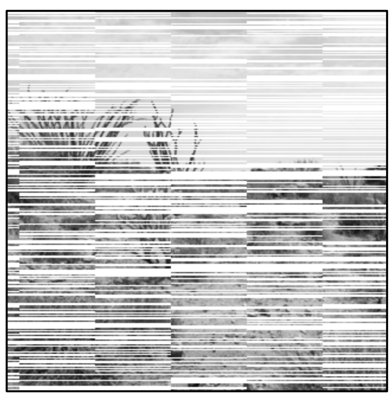
1340 out of 1617
packets received

1303 out of 1617
packets received

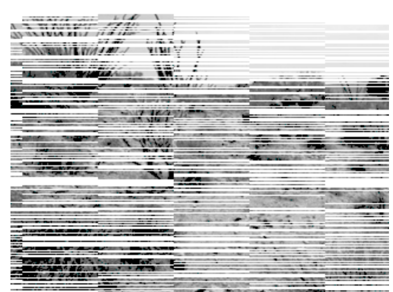


674 out of 1617
packets received

With loss bursts (radio)



921 out of 1617
packets received



689 out of 1617
packets received

913 out of 1617
packets received

Cannot really use the compressed version of BMP using RLE.

Image quality?
Standard JPG

427 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling

Original 320x320
256 gray levels,
JPG 27303 bytes

348 out of 427
packets received

351 out of 427
packets received

9 out of 12 images
could not be decoded

?

349 out of 1617
packets received

Max TX rate = 250 kps
(IEEE 802.15.4)

Minimum latency = 1.61s

Encoding cost of JPEG2000 is too high for these devices.

With loss bursts (radio)

258 out of 427
packets received

270 out of 427
packets received

8 out of 12 images
could not be decoded

?

269 out of 427
packets received

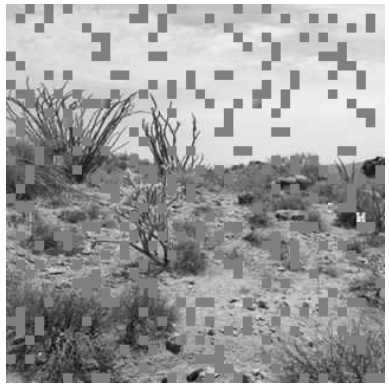
Improving image robustness

302 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling

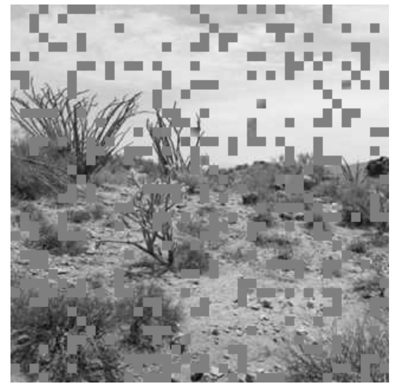
Original 320x320
256 gray levels,
WSN specific 17199 bytes

Max TX rate = 250 kps
(IEEE 802.15.4)

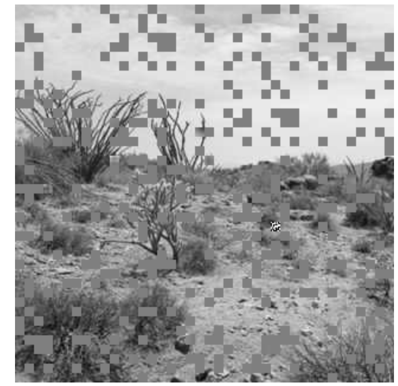
Minimum latency = 1.14s



248 out of 302
packets received

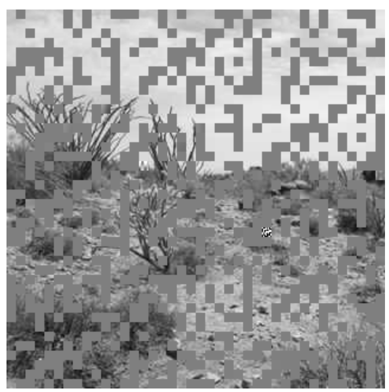


236 out of 302
packets received

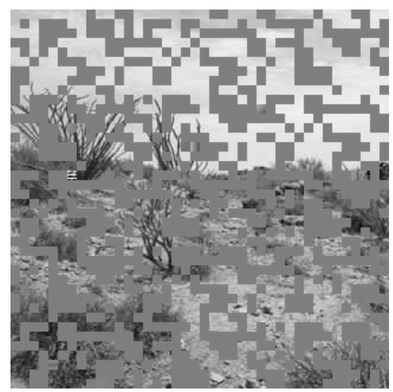


243 out of 302
packets received

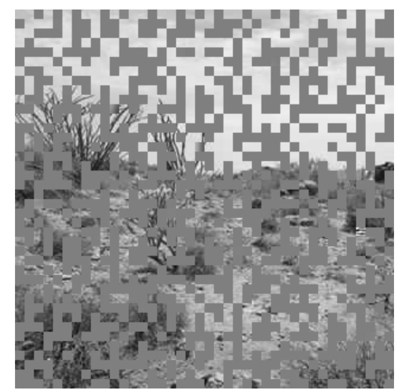
With loss bursts (radio)



188 out of 302
packets received



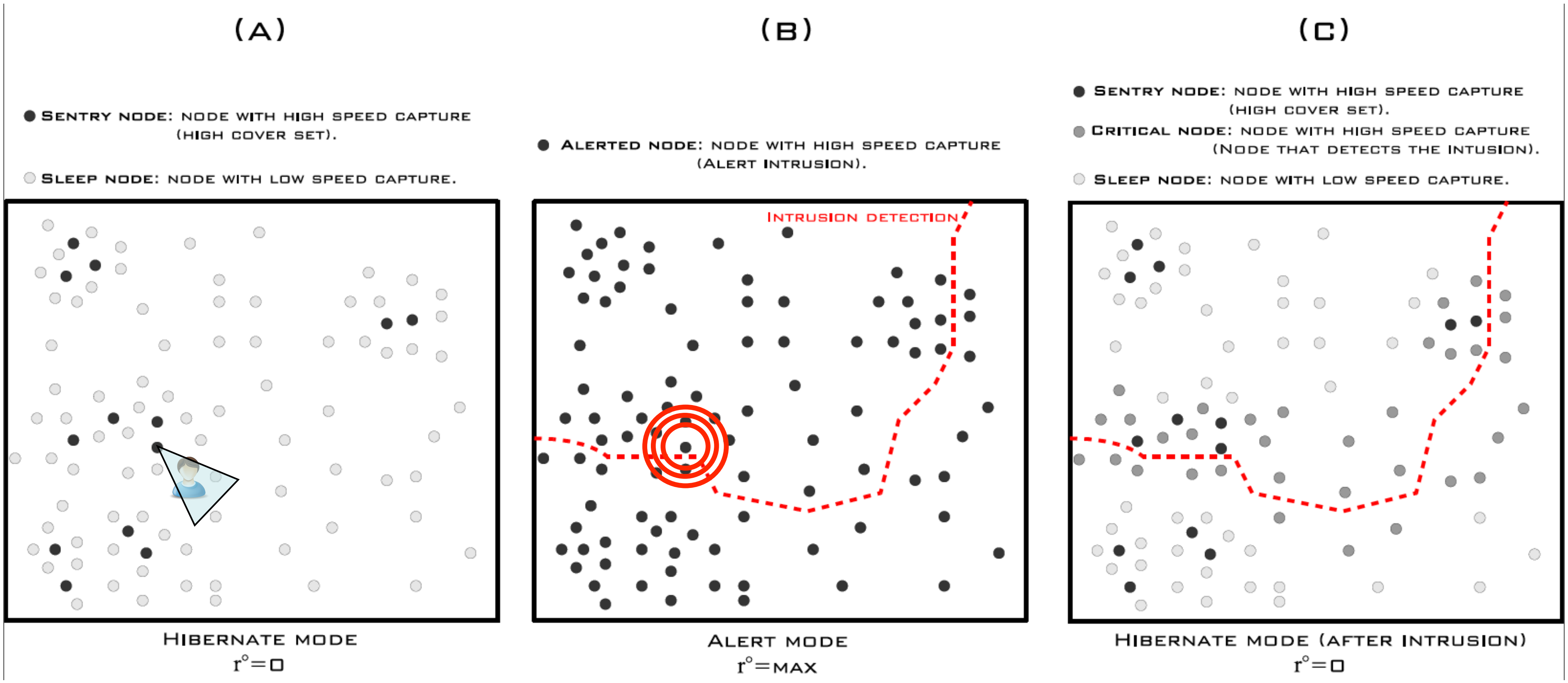
167 out of 302
packets received



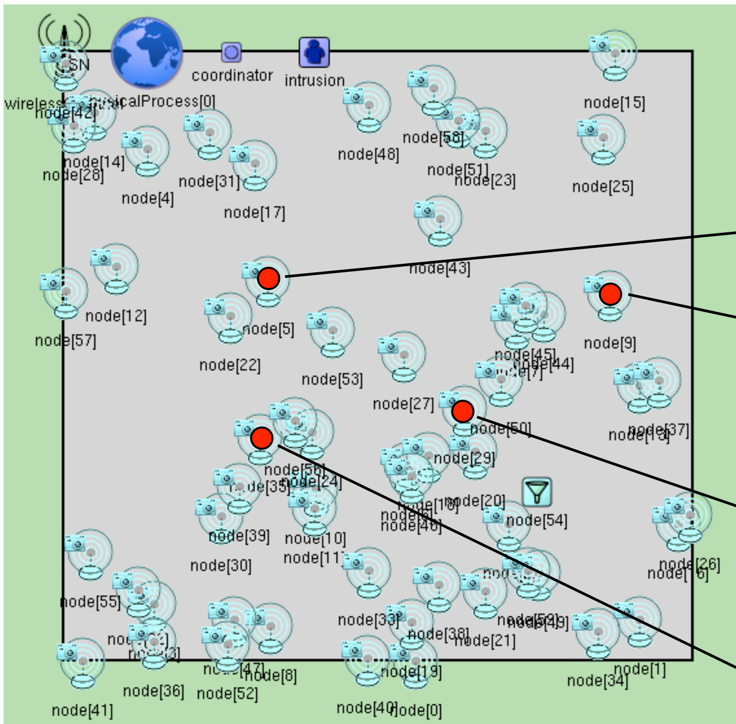
158 out of 302
packets received

Collaboration with CRAN laboratory, Nancy, France, for robust image encoding techniques for WSN.

Intrusion detection scenario



Some images displayed by the sink



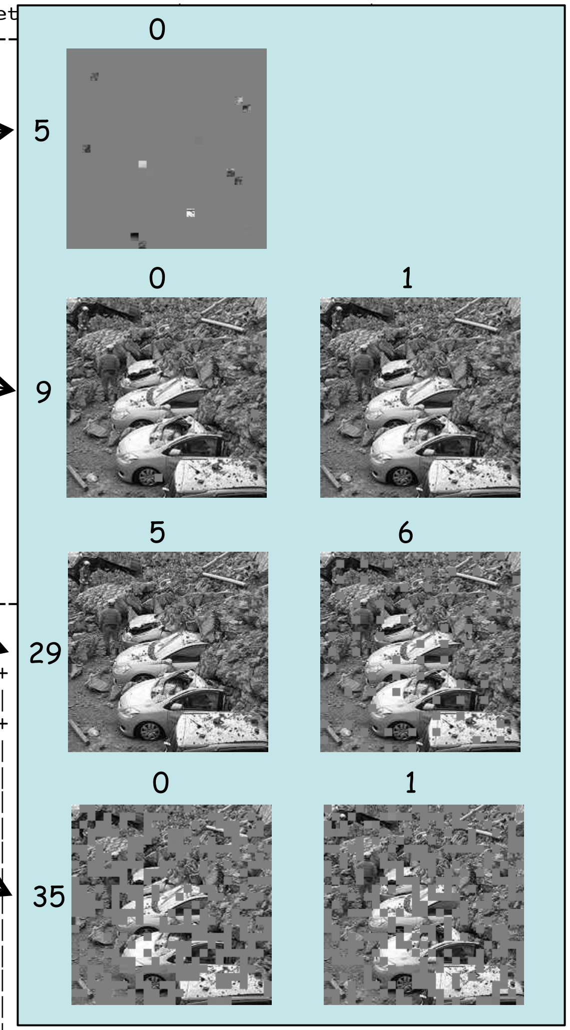
60 image sensor nodes
75mx75m
1 sink (node 54)

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

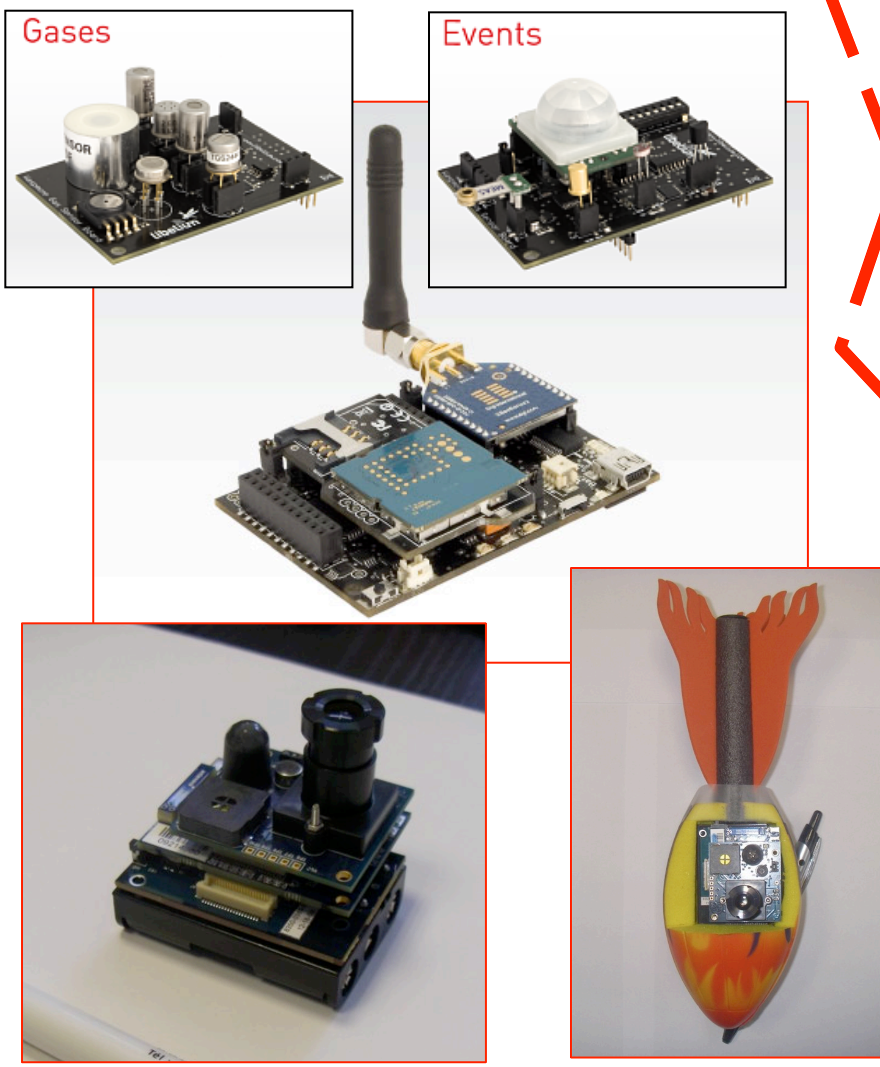


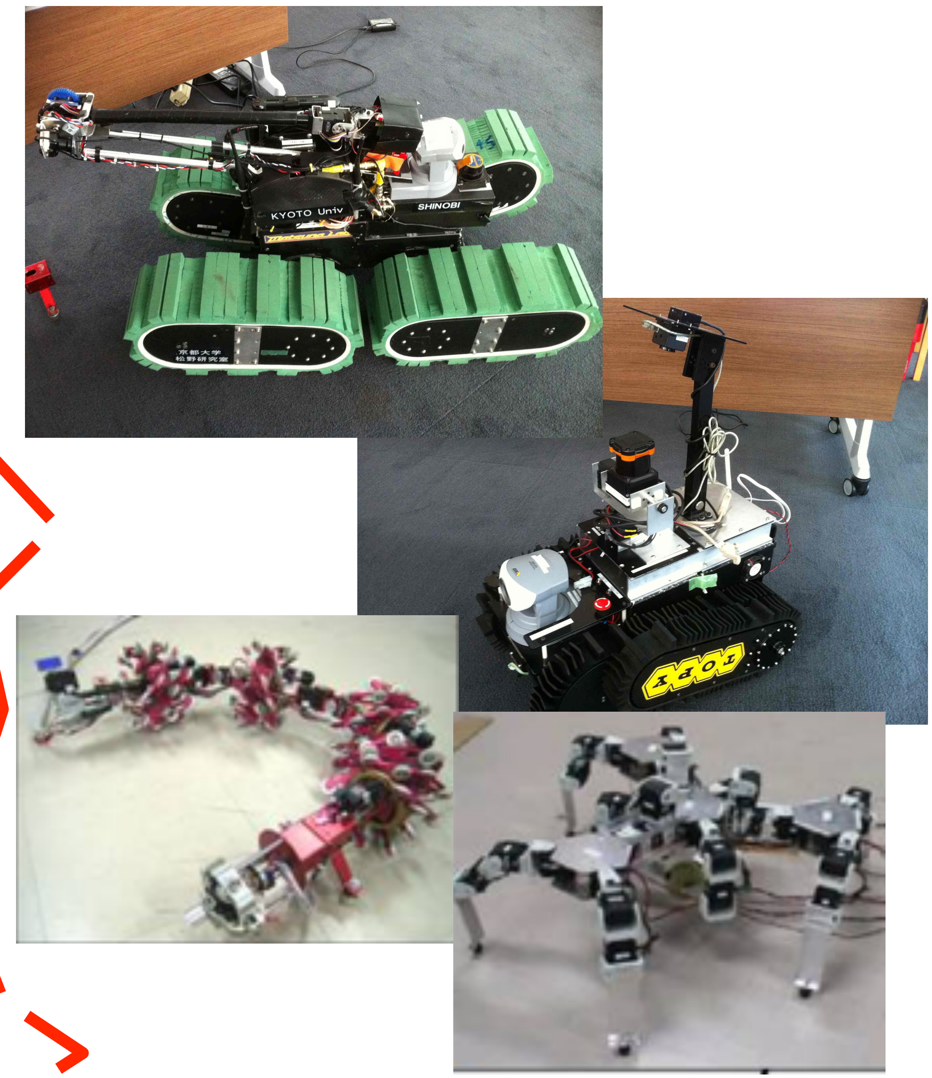
Enabling large-scale, operational search & rescue applications

Sensor & Robots

- 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
  - WSN provide sensing data to robots
  - Robots maintain connectivity
  - Sensors could help for localization when GPS data are down

Challenging cooperation implies differences!

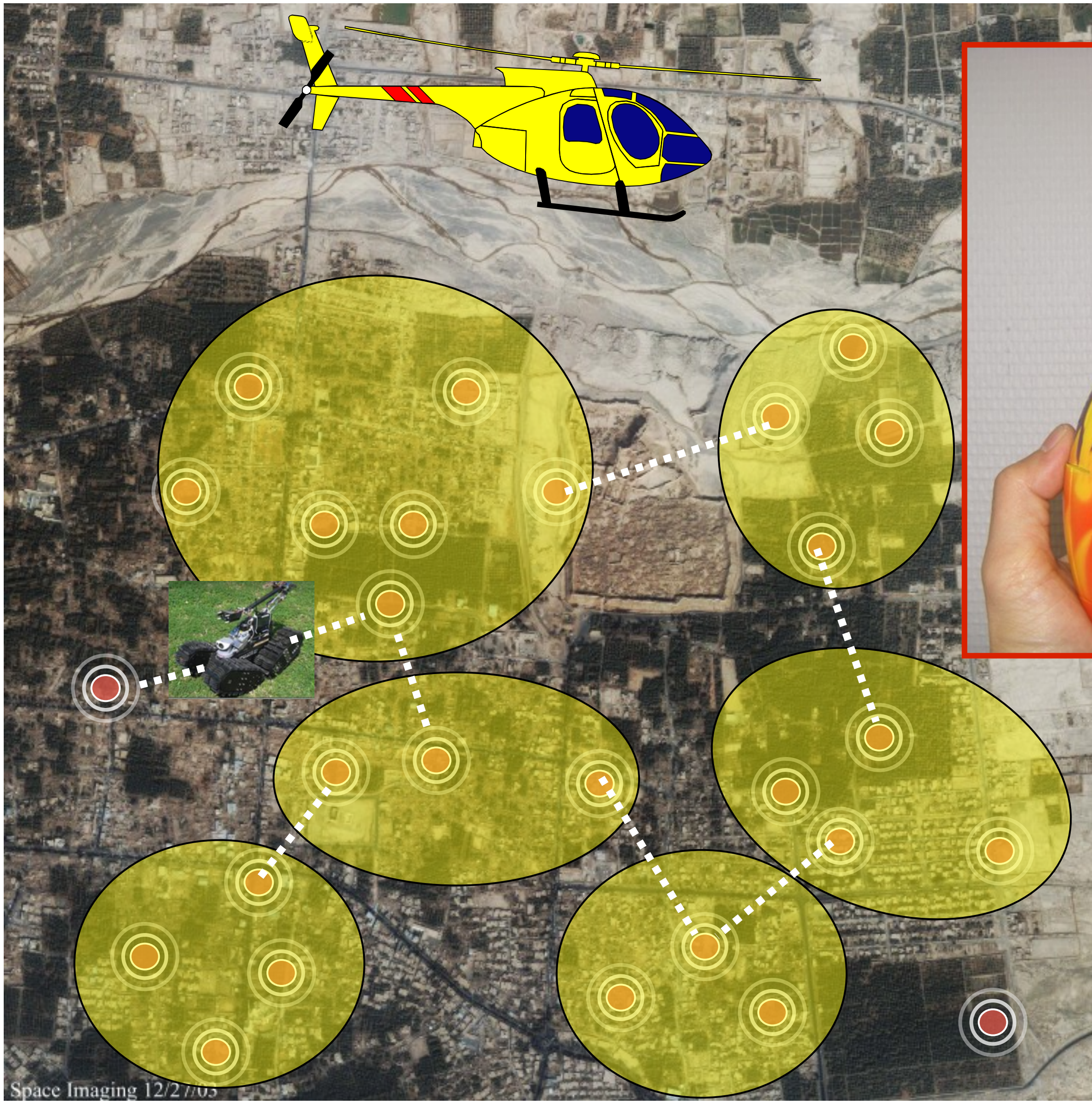




Robot's mobility to preserve connectivity

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)

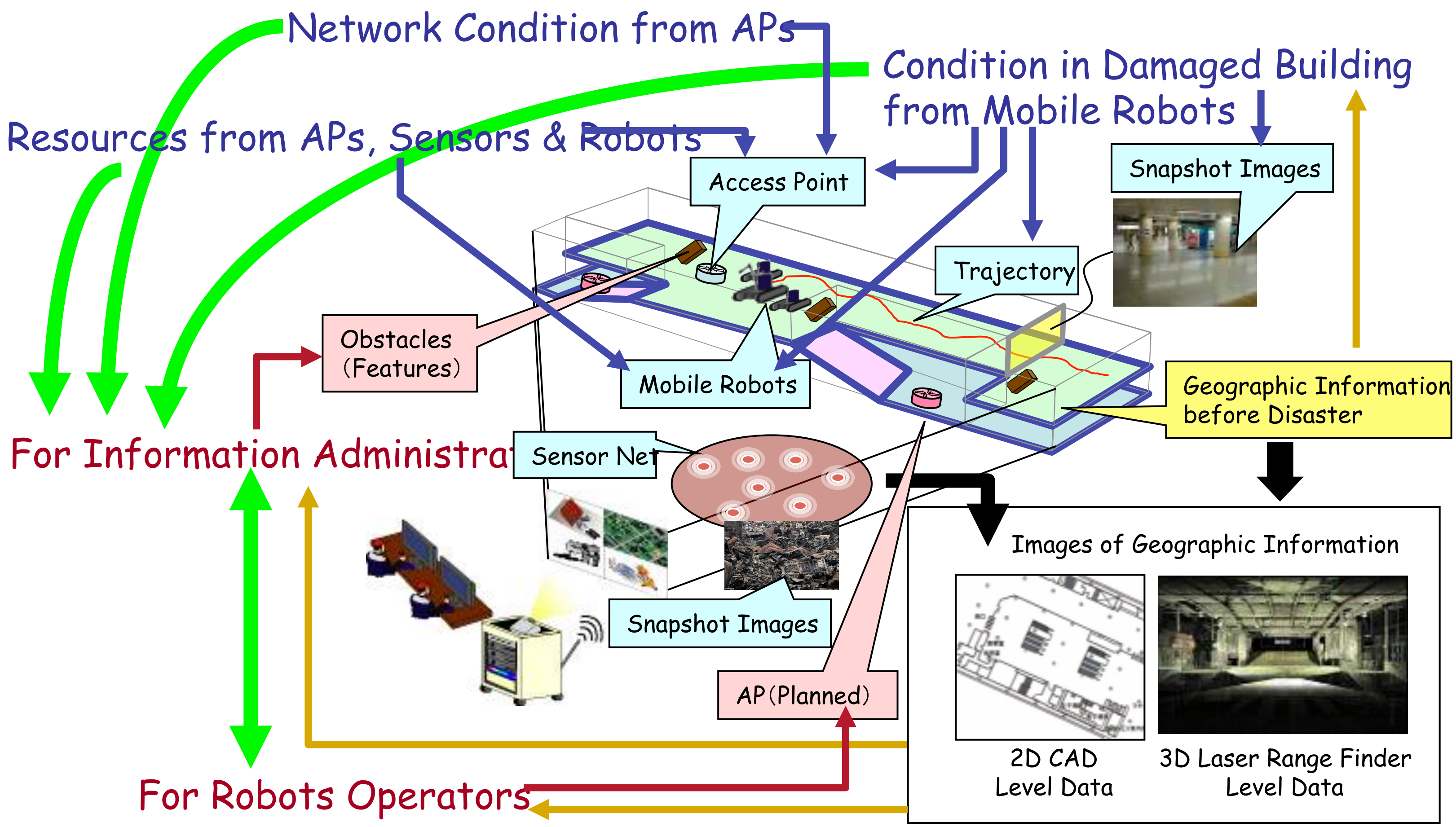
Robots could serve as relay or install communication gateways to maintain WSN connectivity and increase data storage capability

Sensor & Robots Search & Rescue

- Rescue could be operated in several phases (4)

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

Disaster Management Information Systems

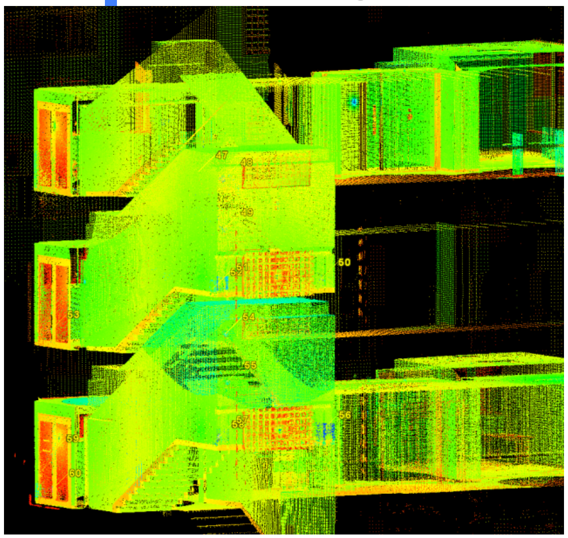


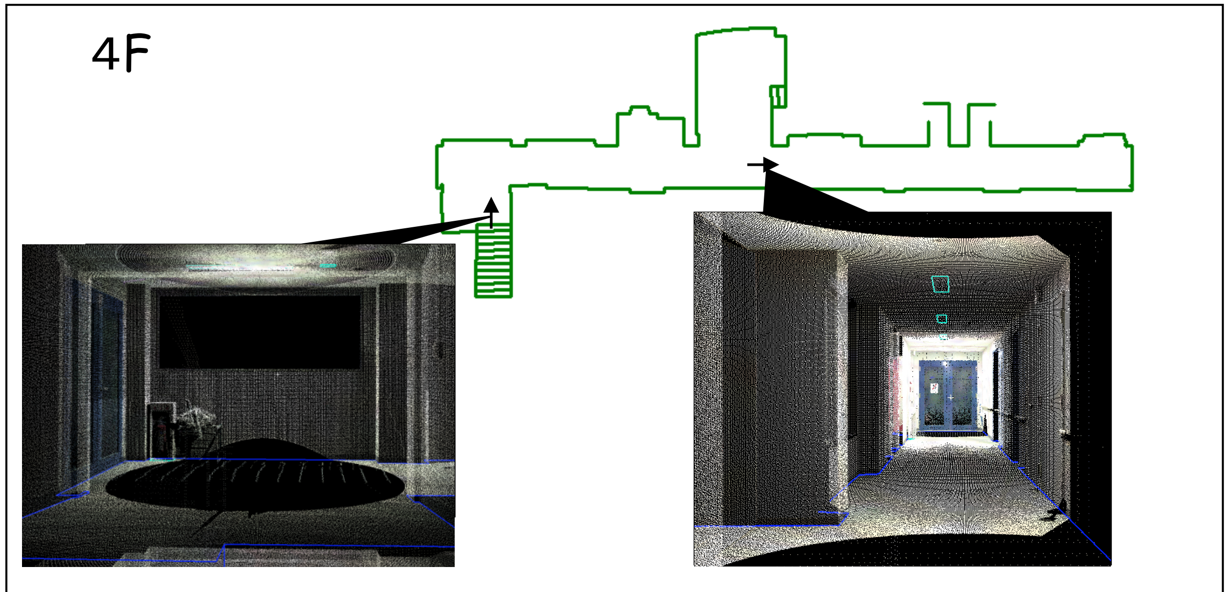
From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System", Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10. Modified by C. Pham with sensor nets.

Making Base GIS Data

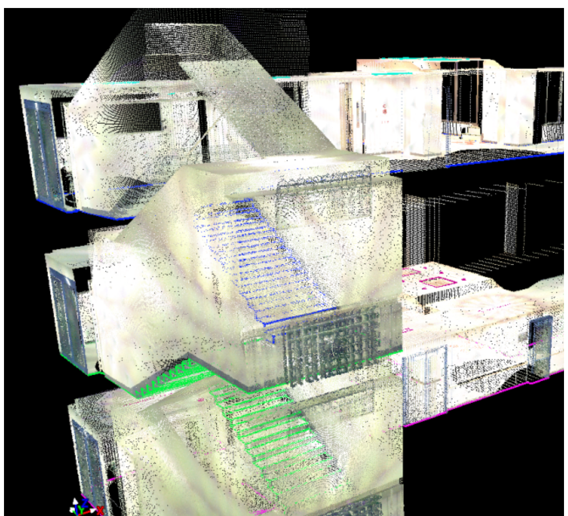
3D Laser Range Finder

accuracy : mm

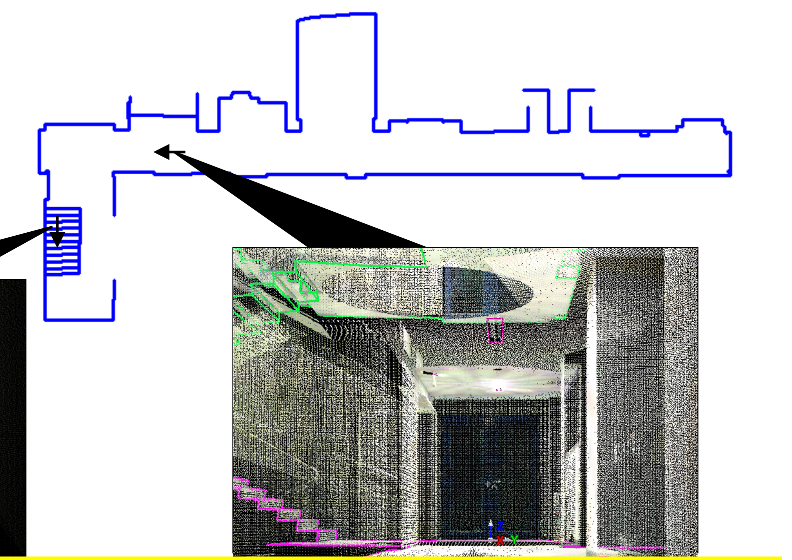




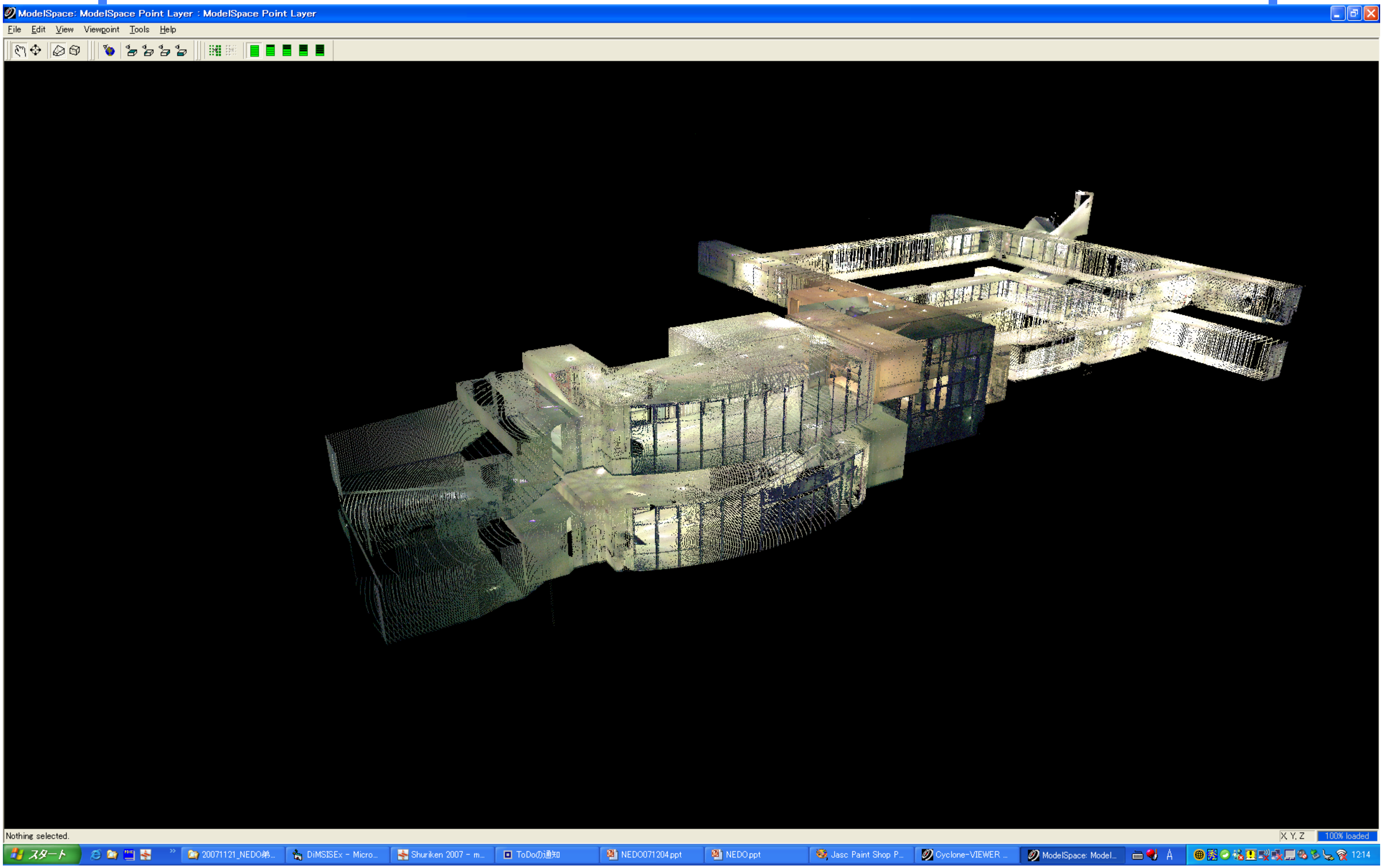
Points to Polygons



Format Translation



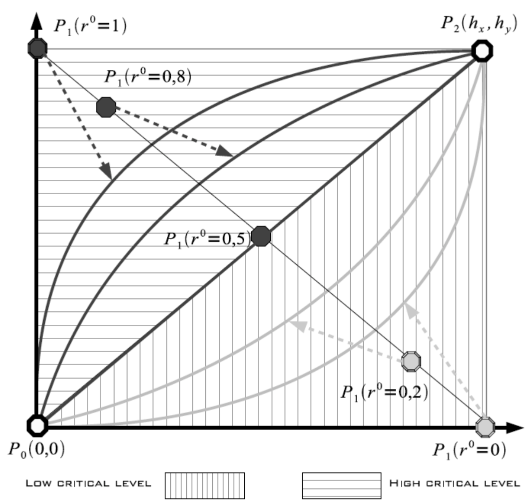
From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System", Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10

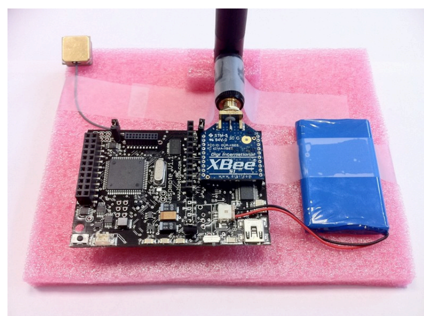


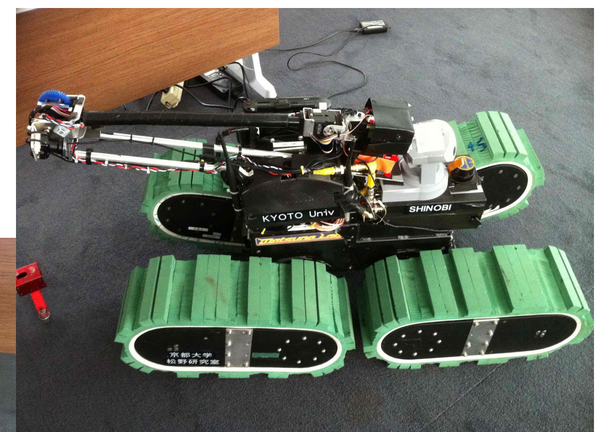
From « Development of Temporal GIS Server Unit for Grouped Rescue Robots System", Michinori HATAYAMA(DPRI, Kyoto Univ.), Hisashi Mizumoto (Kyoto University), Fumitoshi Matsuno (Kyoto University). Slides presented at ROSIN 10

Sensors & Robots Propose new interaction schemes

- Use the criticality model to control both sensors and robots
- Prototyping on real hardware



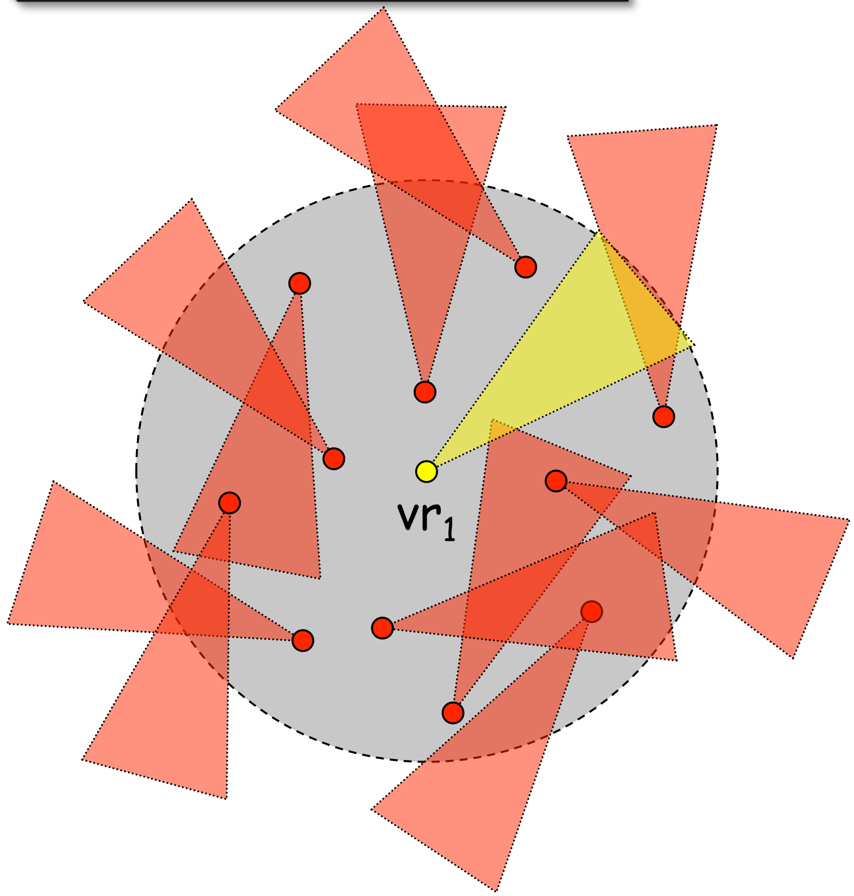


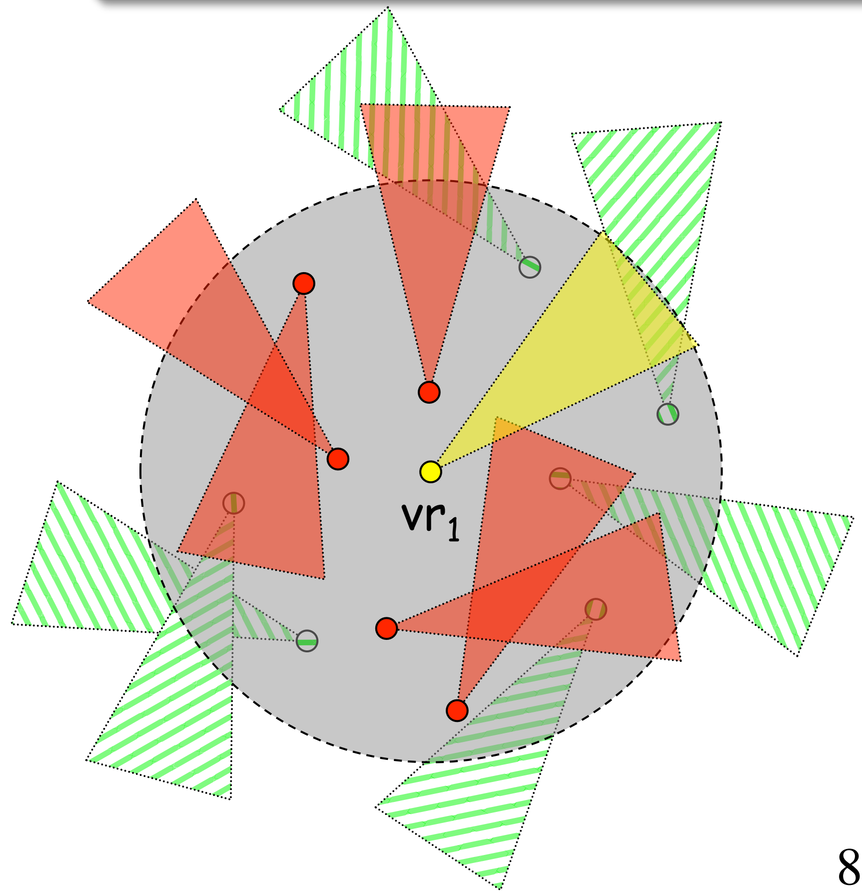


Cooperation with cameras on mobile robots

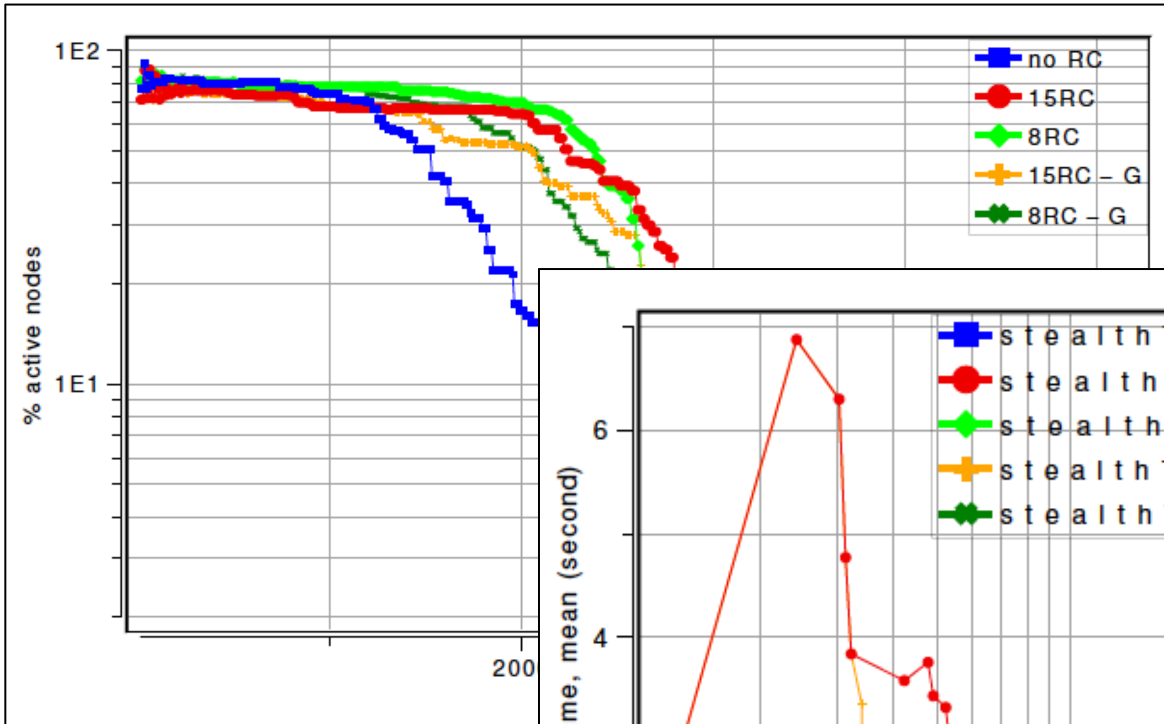
Fixed image sensors near a mobile camera can decrease their criticality level

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





Impact on lifetime & stealth time



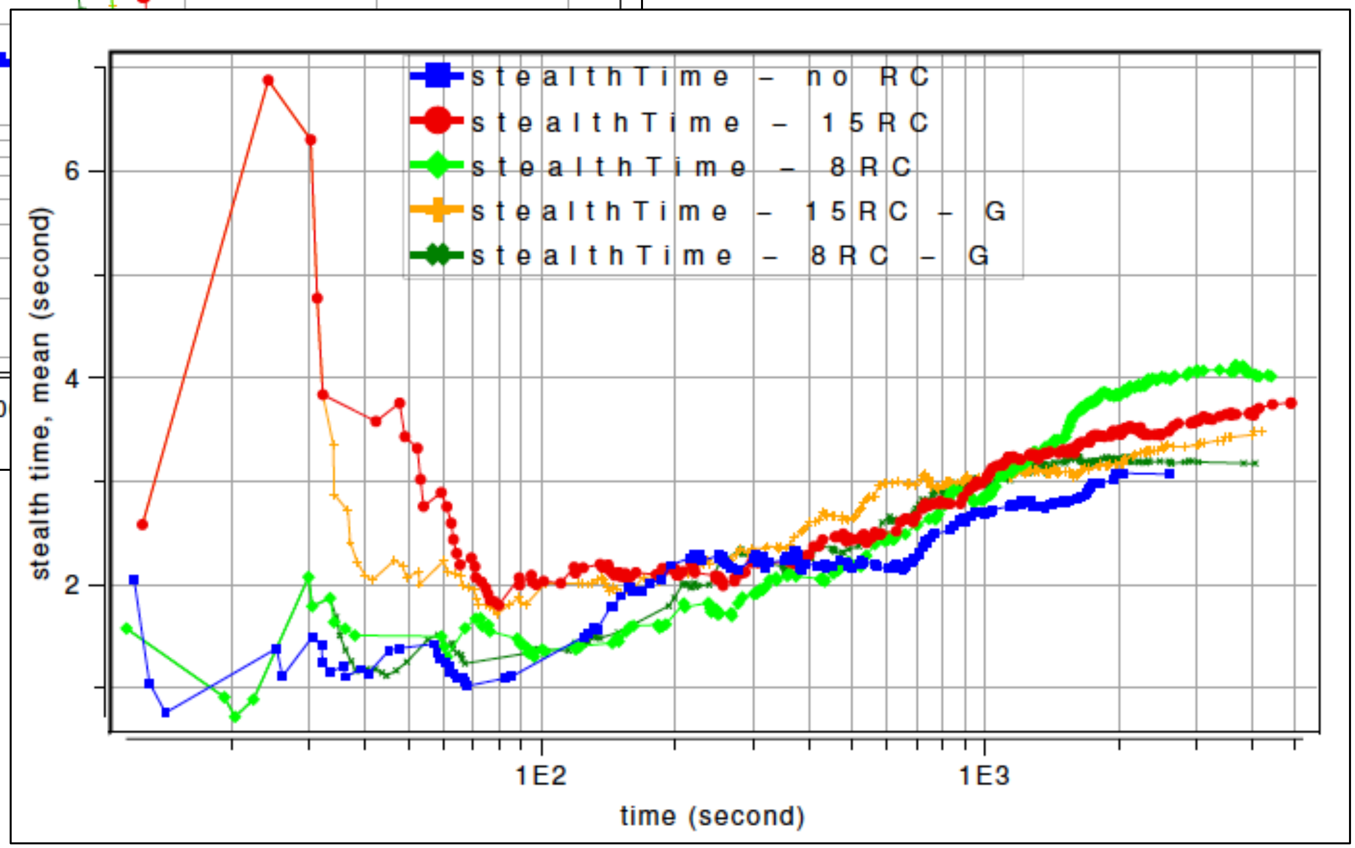
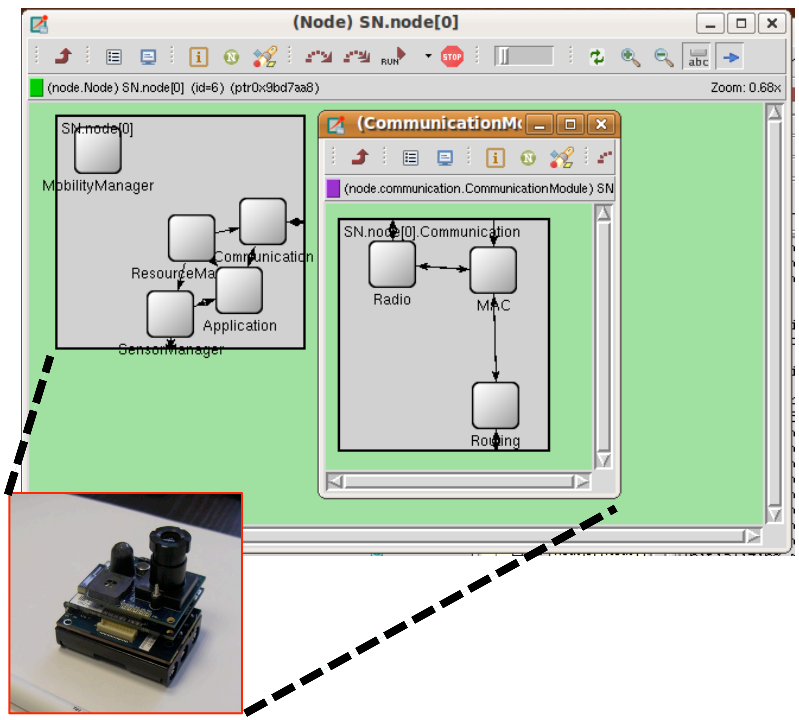
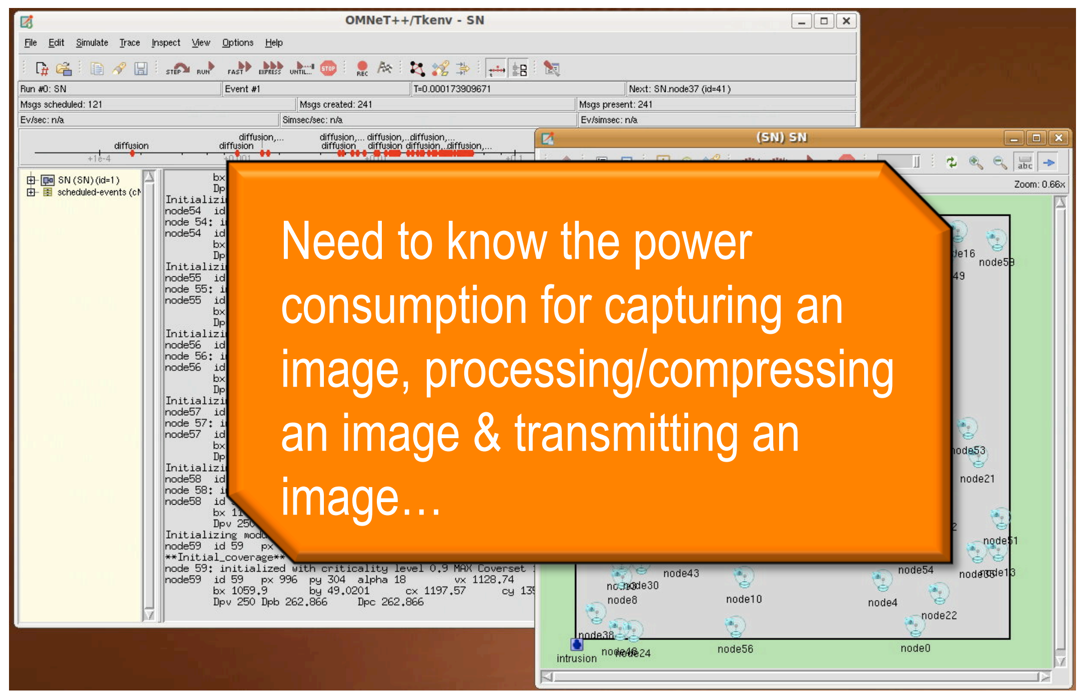


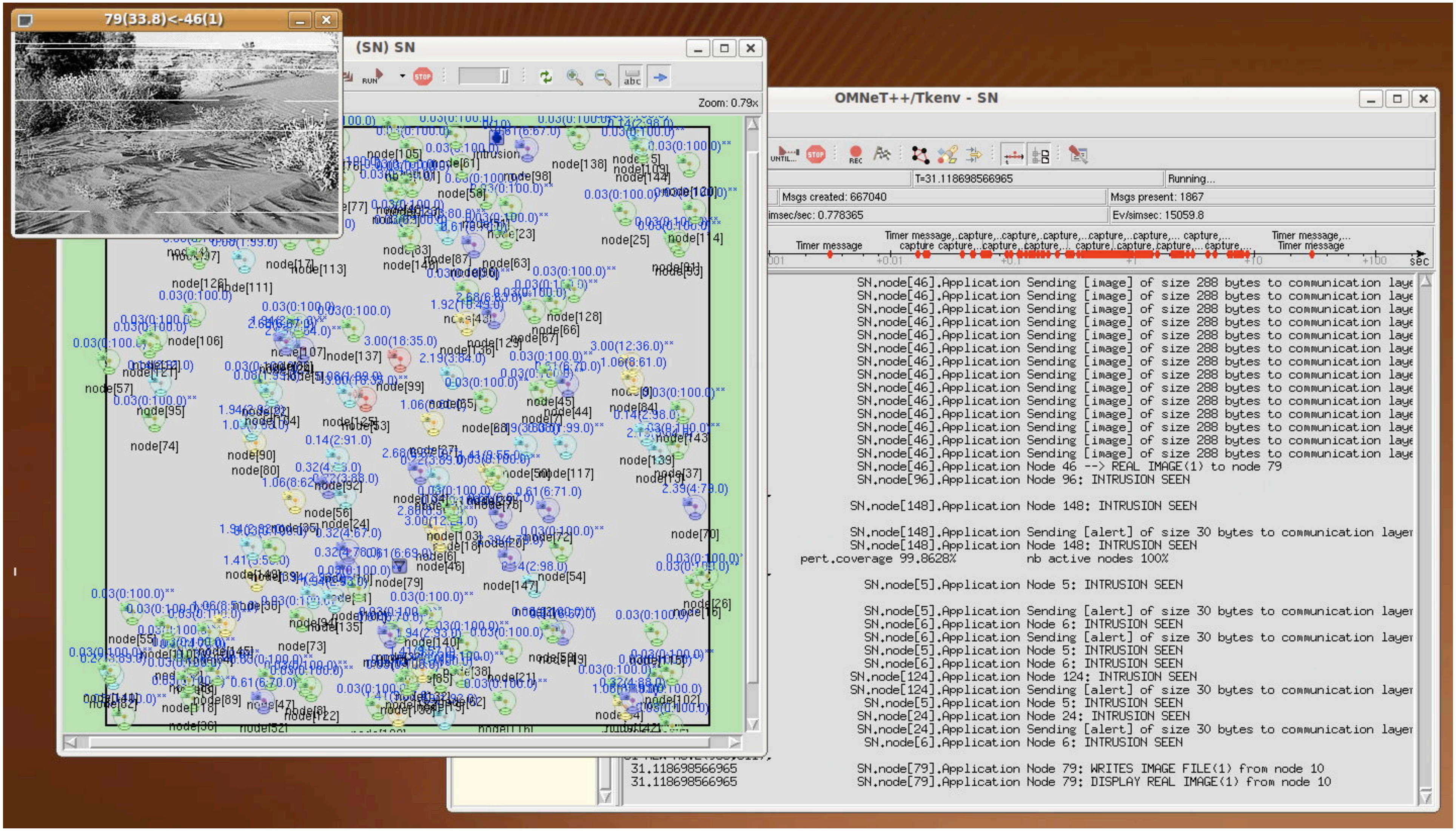
Image sensor simulation model under OMNET++

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



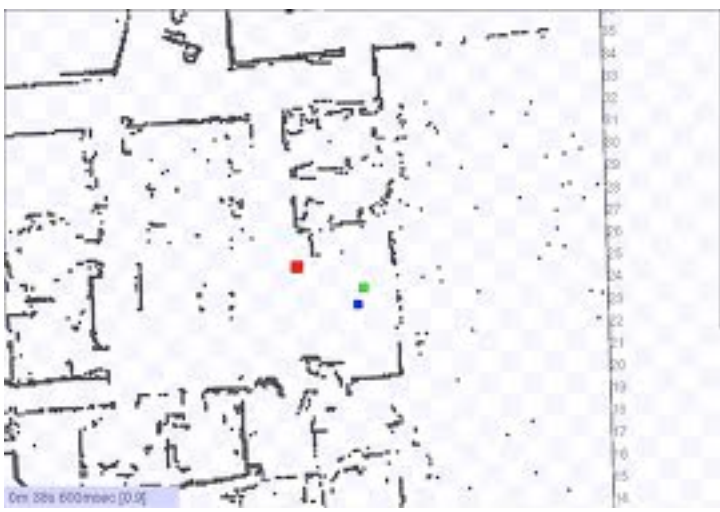


Study the impact of communication layer on surveillance quality



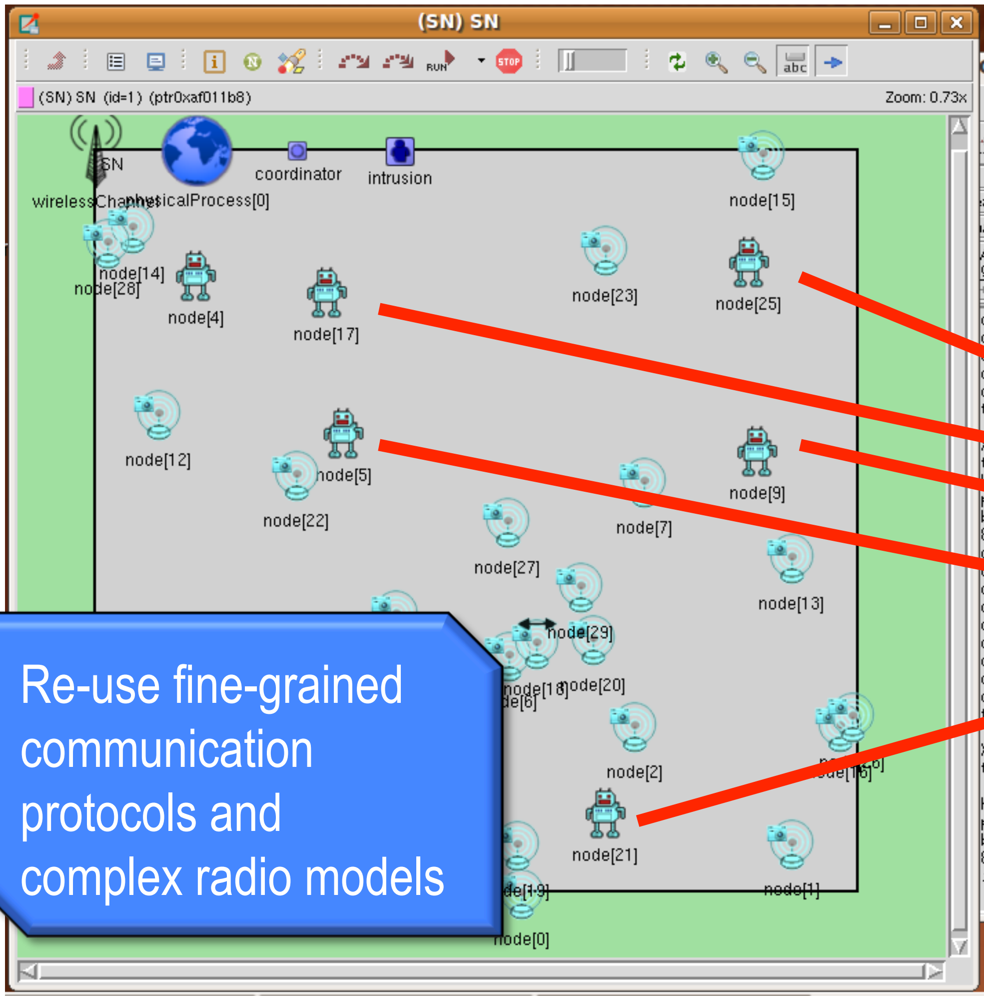
Robot simulators

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

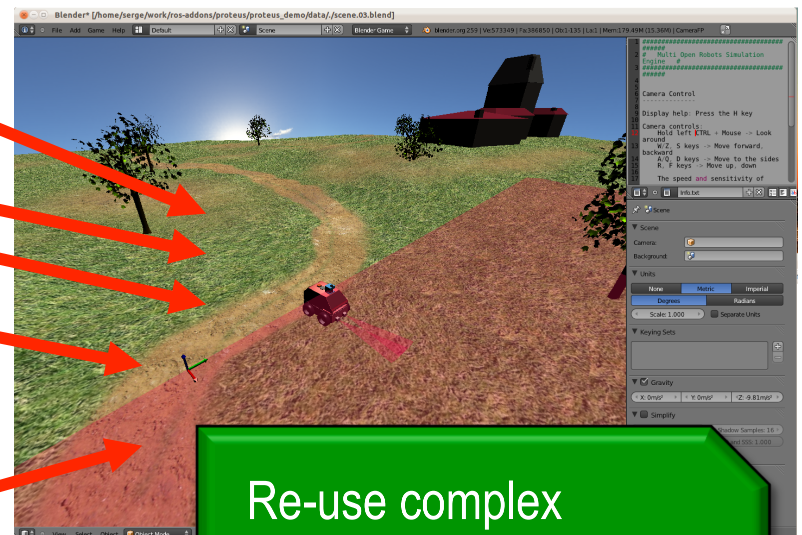


Sensors & Robots enable realistic interaction studies

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,…)

Conclusions

- WSN's natural application is surveillance but...
- ... Using WSN technology for mission-critical applications is far from being mature!
- Need to take the application's criticality into account when designing control mechanisms and protocols
- Building efficient, reliable low layers is challenging!
- Sensors & Robots are complementary technologies for mission-critical applications but...
- ...need suitable tools!