Challenges & Design Space in Wireless Video Sensor Networks

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Tuesday, March 17th, 2009

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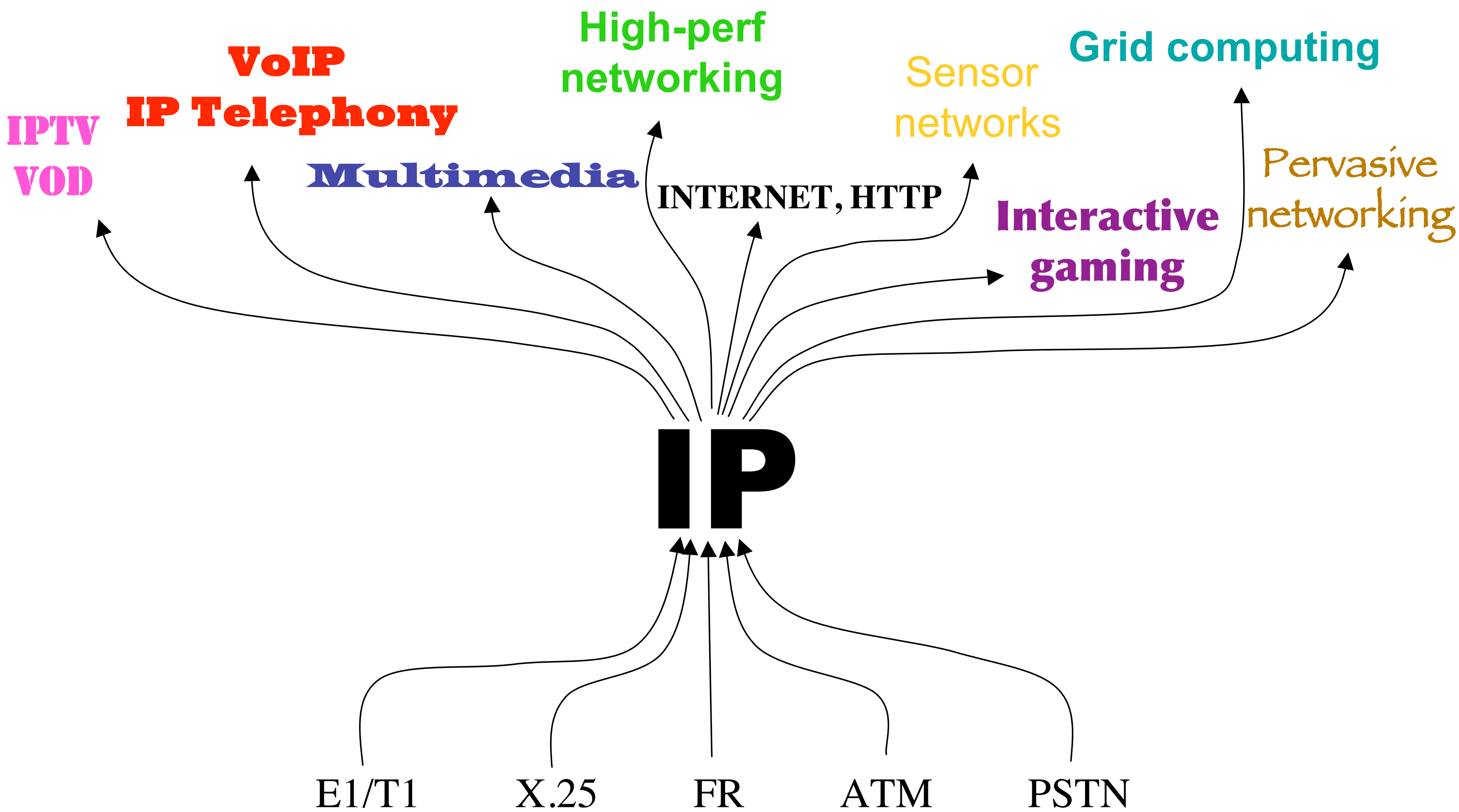
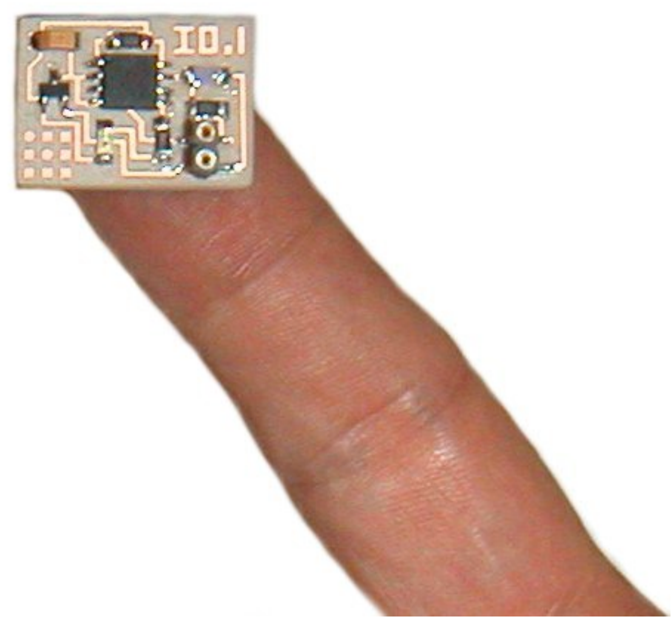
University of Pau, France

Towards all IP



Internet Hosts

1974

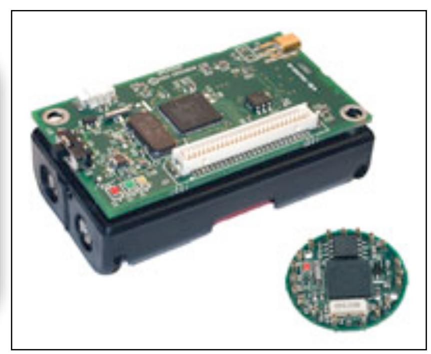


2004

Borrowed from N. Gershenfeld

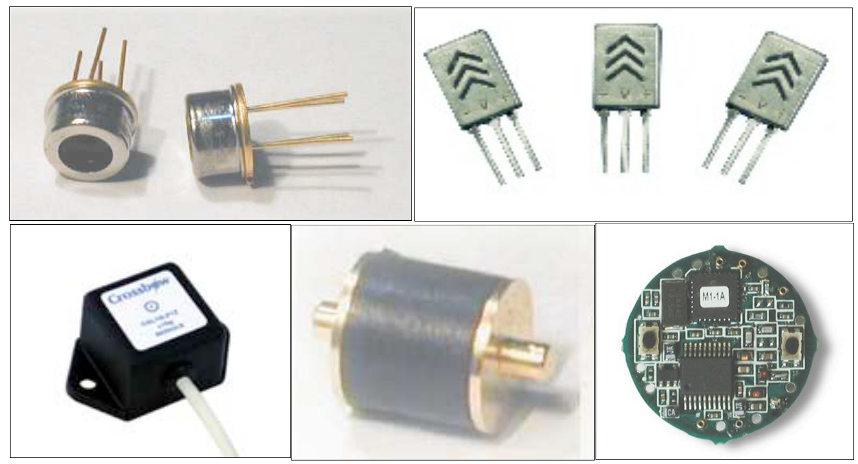
What's missing?

Between the PDA and the RFID tag of Internet-0, is the wireless autonomous sensor



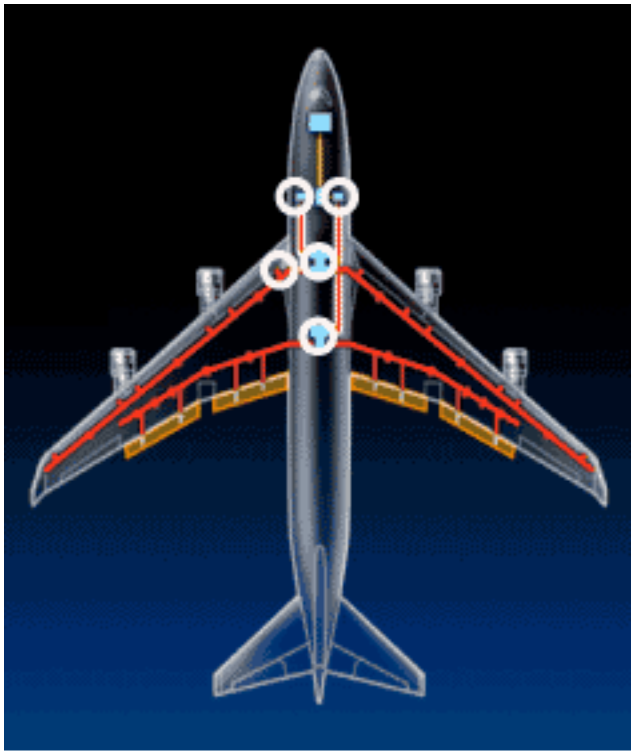
What Is A Sensor Node?

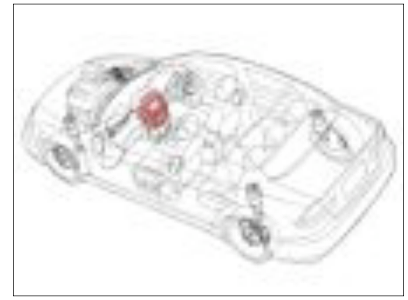
- Sensor nodes could monitor a wide variety of ambient conditions that include the following:
  - temperature,
  - humidity,
  - vehicular movement,
  - lightning condition,
  - pressure,
  - soil makeup,
  - noise levels,



  - the presence or absence of certain kinds of objects,
  - mechanical stress levels on attached objects, and
  - the current characteristics such as speed, direction, and size of an object.
- Sensor nodes can be used for continuous sensing, event detection, event ID, location sensing, etc.

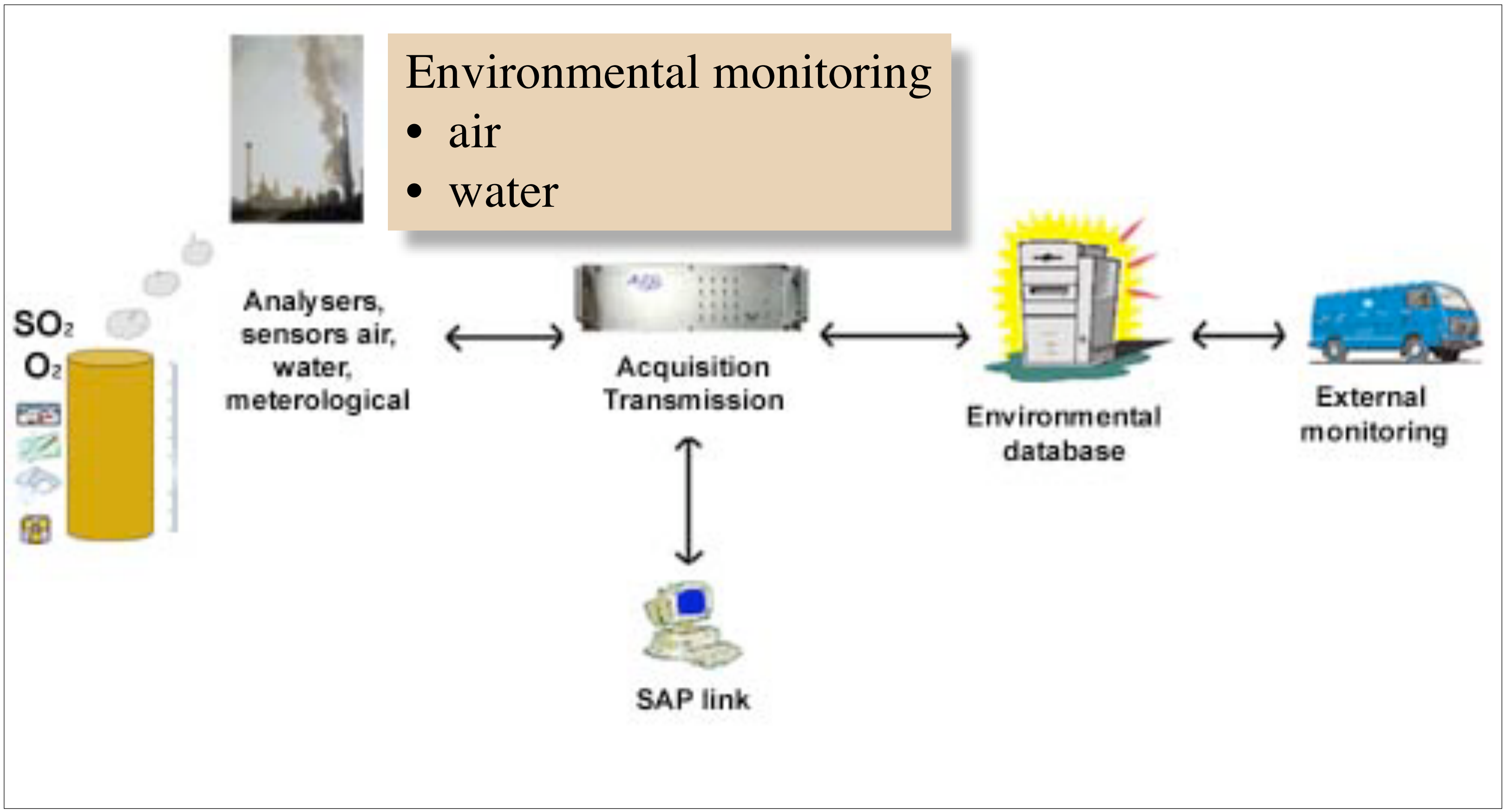
Traditional sensing applications





Traditional sensing applications (contd.)

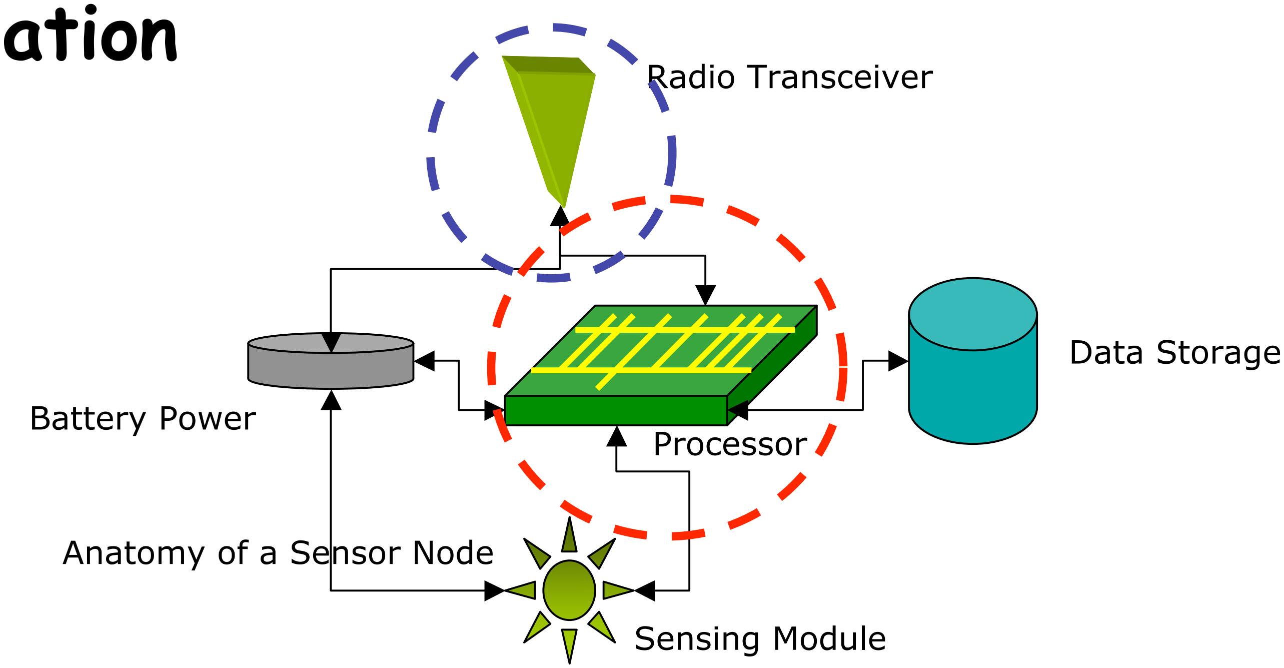
Environmental monitoring
- air
- water



Borrowed from www.iseo.fr

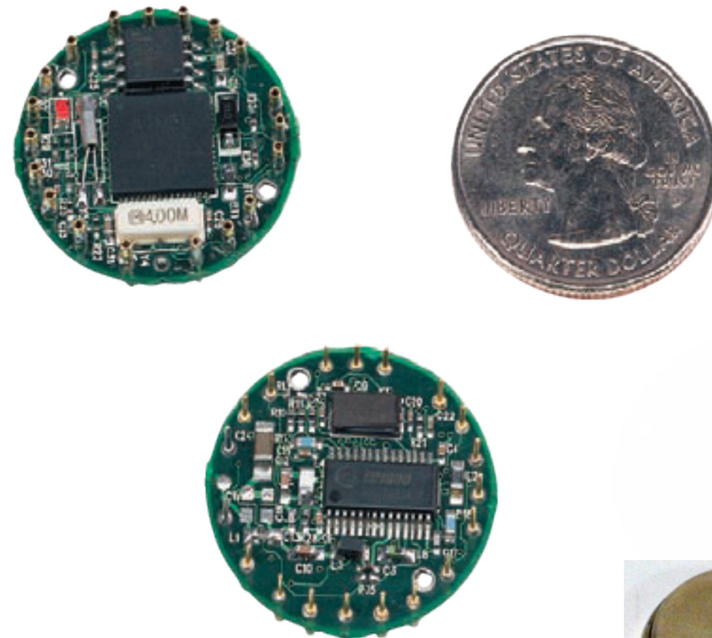
Wireless autonomous sensor

- 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

- Size: 4cm×4cm
- CPU: 4 MHz, 8bit
- 512 Bytes RAM, 8KB ROM
- Radio: 900 MHz, 19.2 Kbps, ½ duplex
- Serial communication
- Range: 10-100 ft.
- Sensors: Acceleration, temperature, magnetic field, pressure, humidity, light, and RF signal strength



MICA2DOT

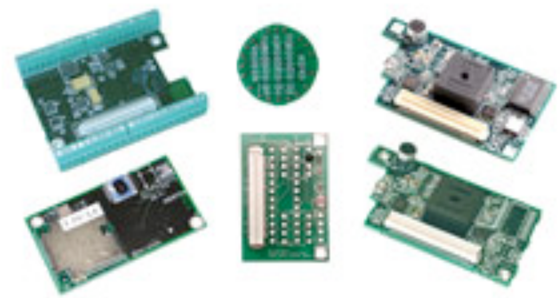
Battery
Panasonic
CR2354
560 mAh

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

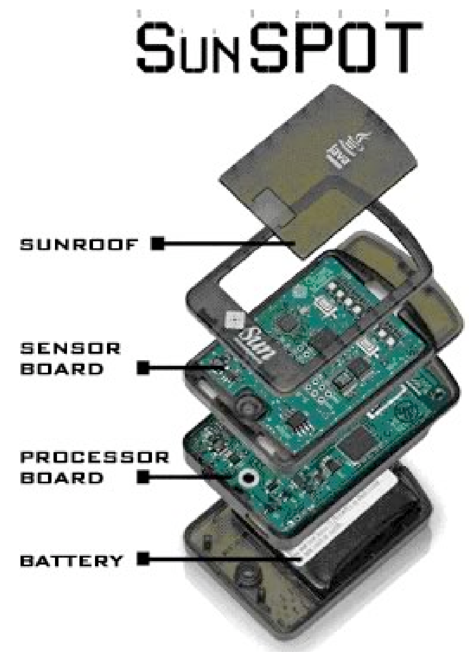
MICAz

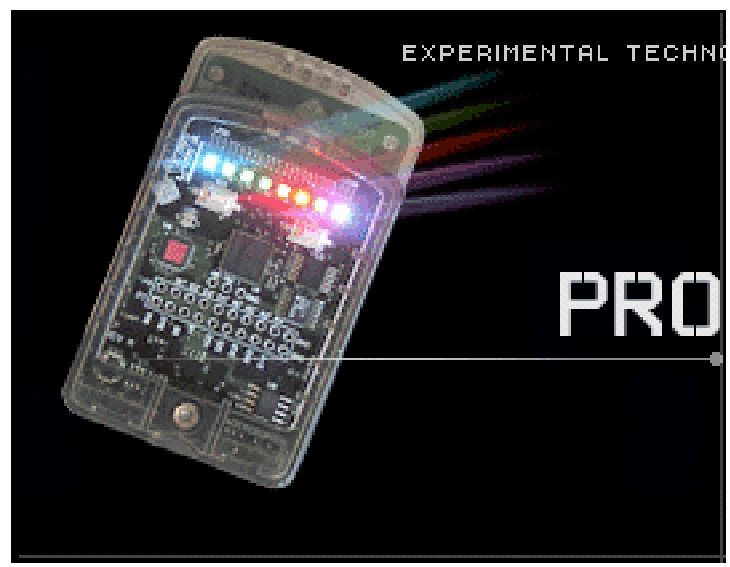


Sensing boards

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

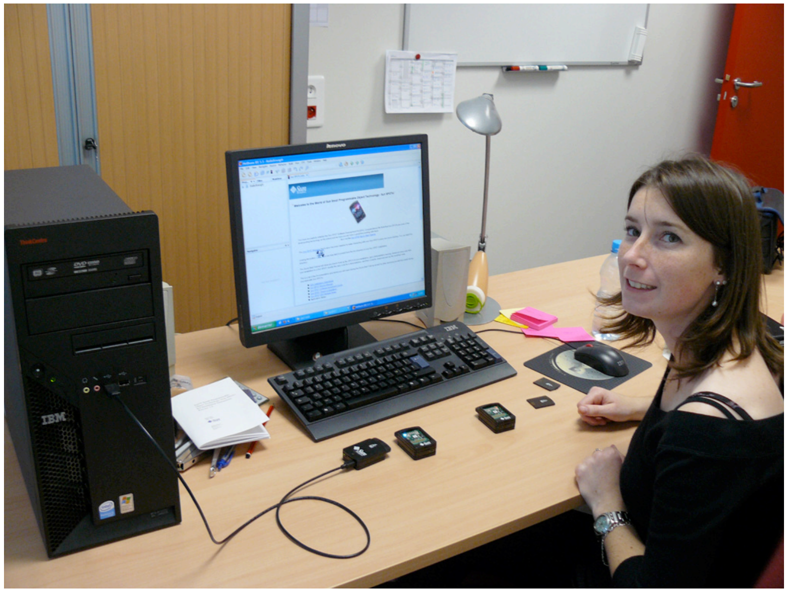


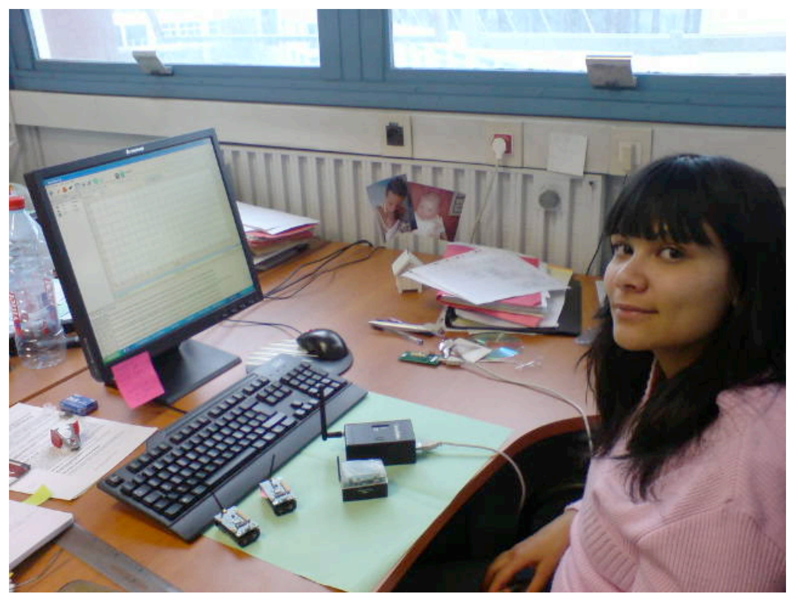


Wireless Sensors Networks

- 1 wireless sensor is better than none!
- 2 wire
- 3 wire
- 4 wire ter!!!!
- …
- 10000 better!!!!!
- 10001 incredibly bette
- …

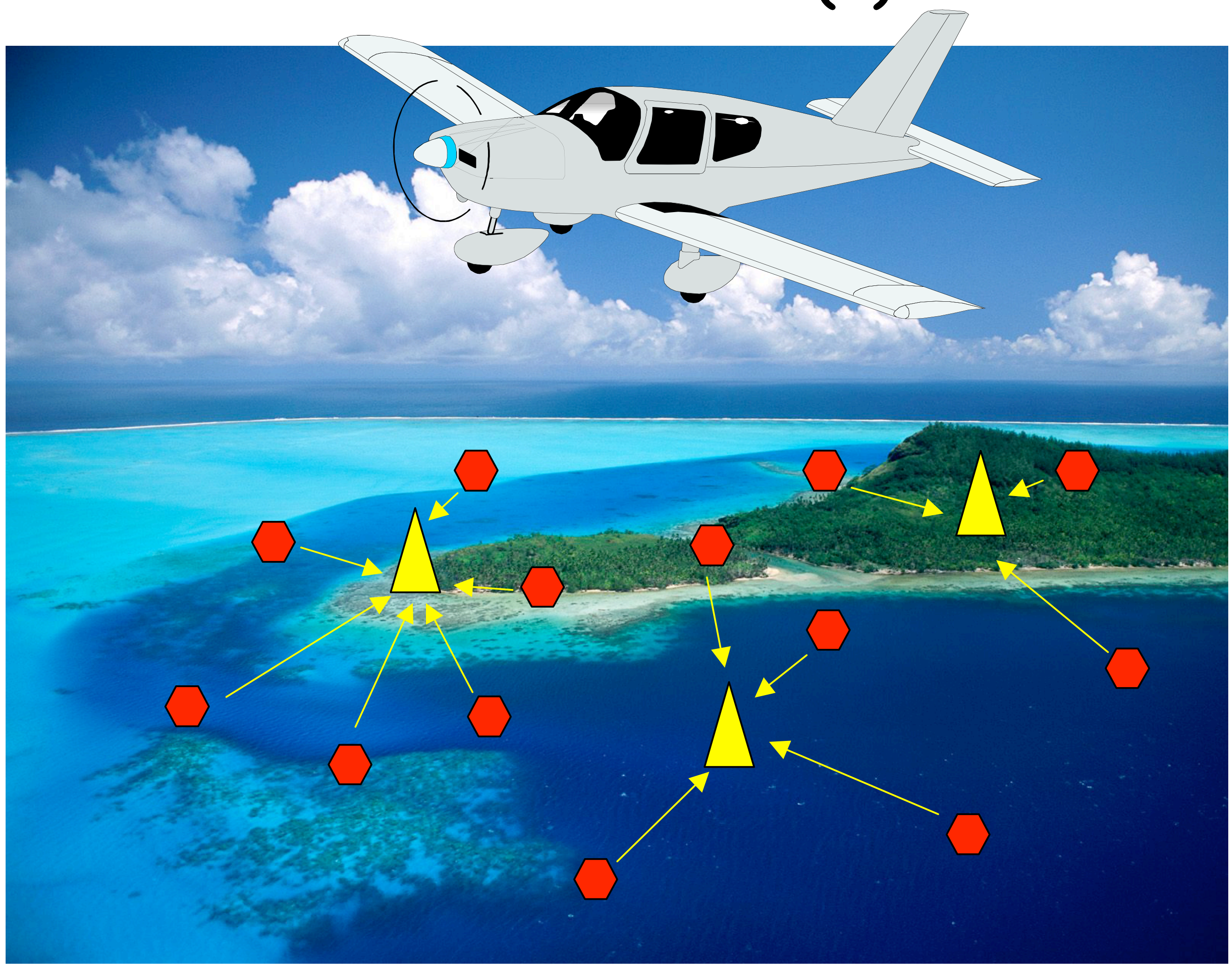
WSN at LIUPPA

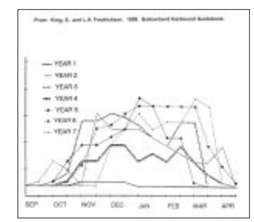




New sensor applications

environmental (1)





On-the-fly deployment of environmental monitoring's network

New sensor applications
environmental (2)

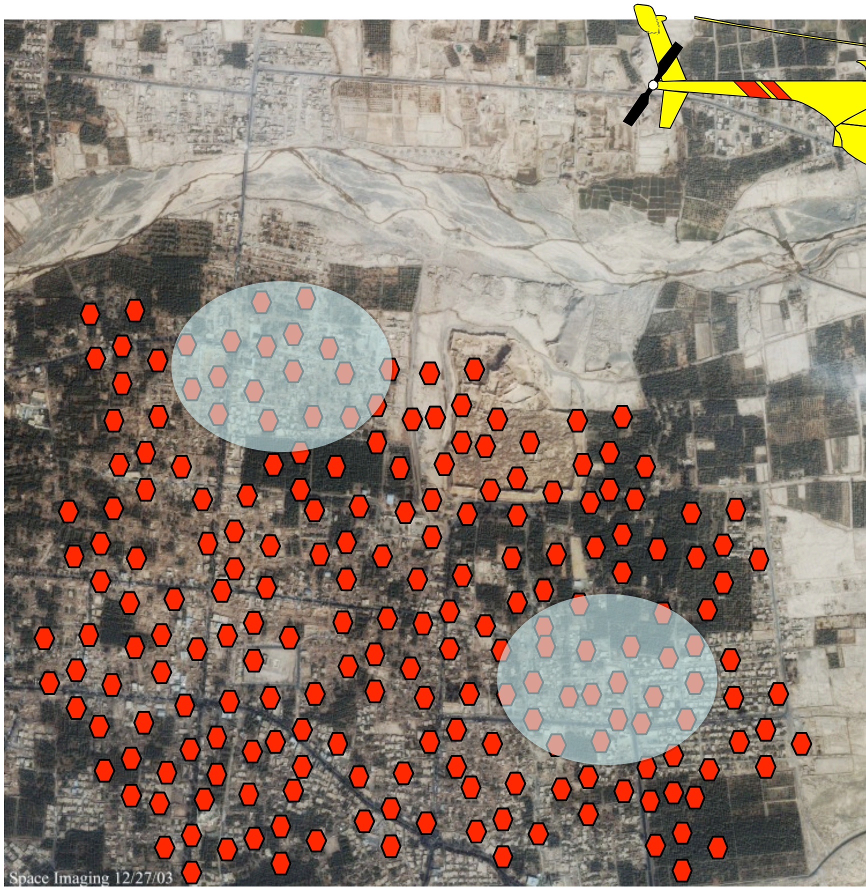
Environmental monitoring
- air
- water

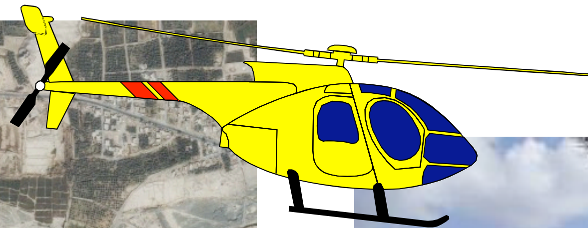
Cell-phones with embedded CO sensor

- most ubiquitous device (millions)
- not deployment cost
- high replacement rate
- no energy constraints

New sensor applications

disaster relief - security

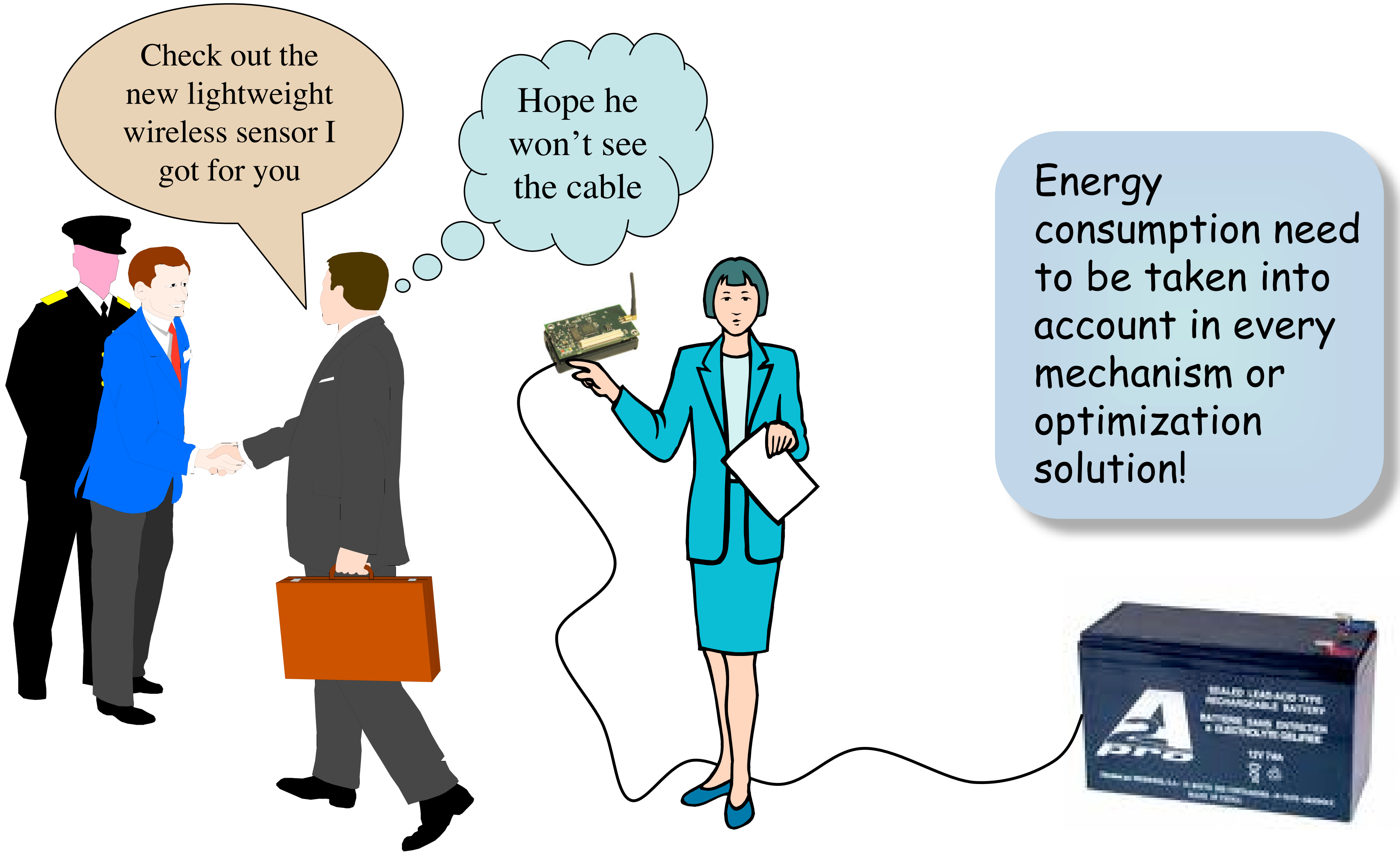




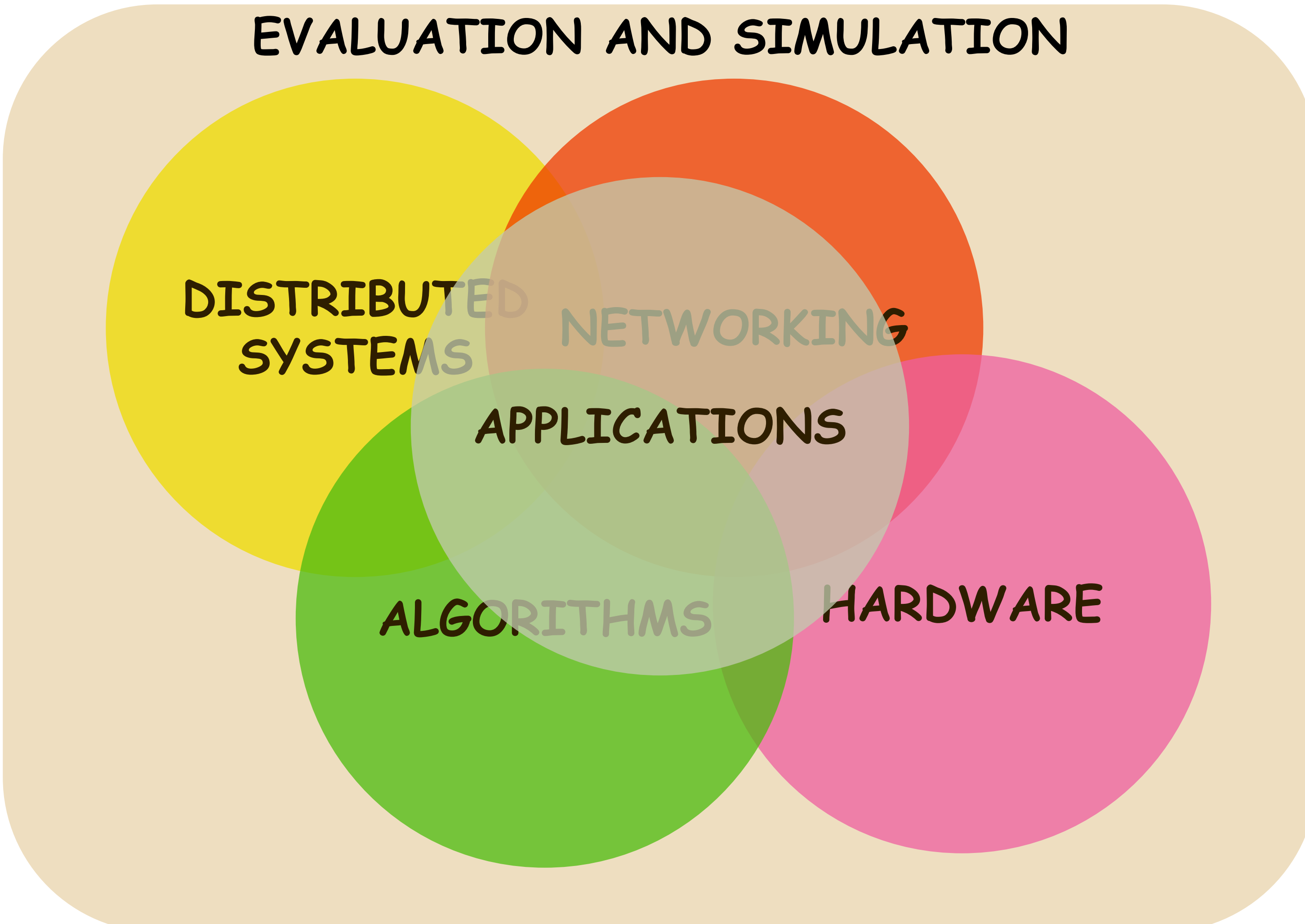
Real-time organization and optimization of rescue in large scale disasters

Rapid deployment of fire detection systems in high-risk places

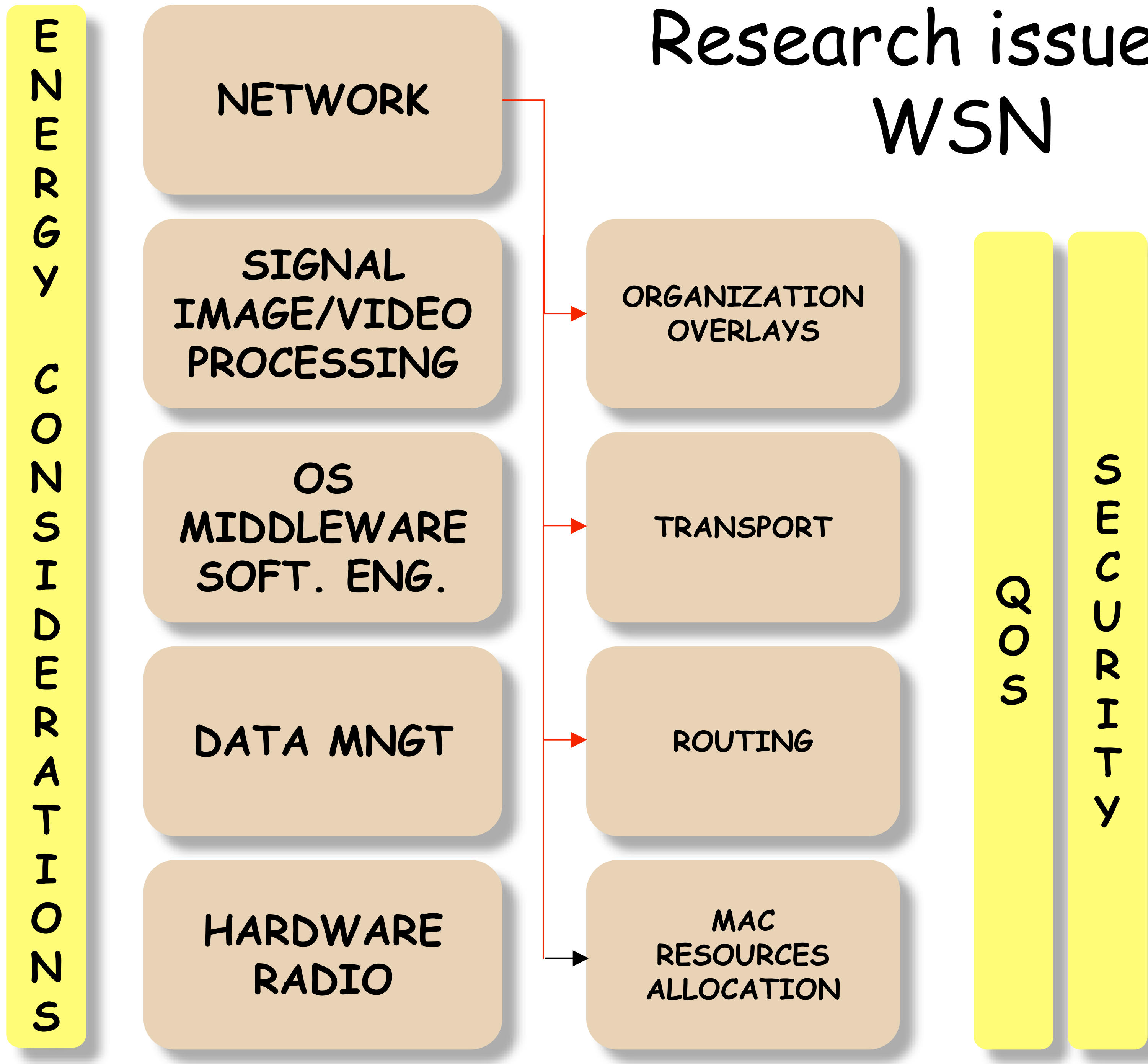
« The weakest link »



Multidisciplinary research



Research issues in WSN

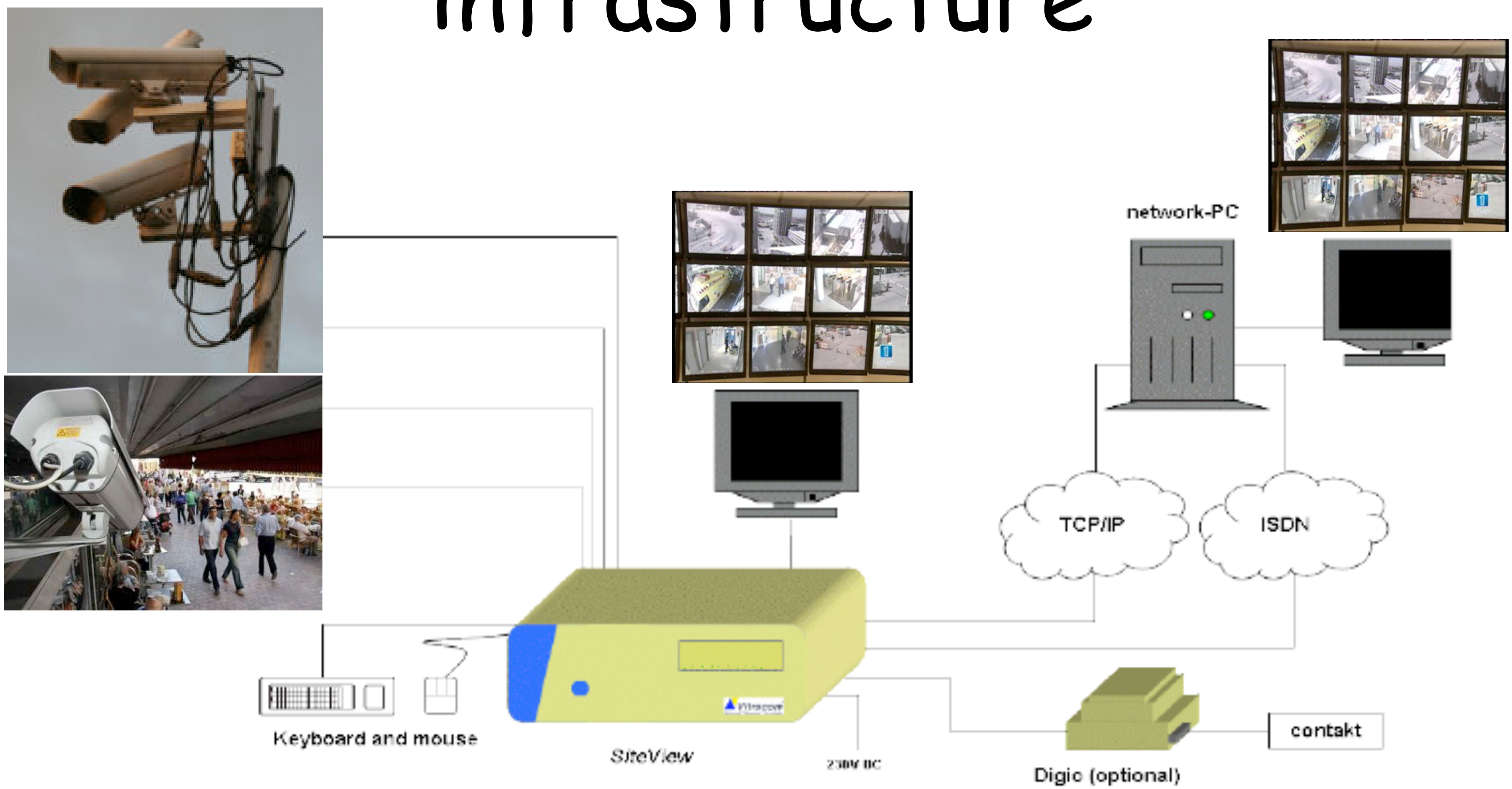


TCAP project (2006-2009)

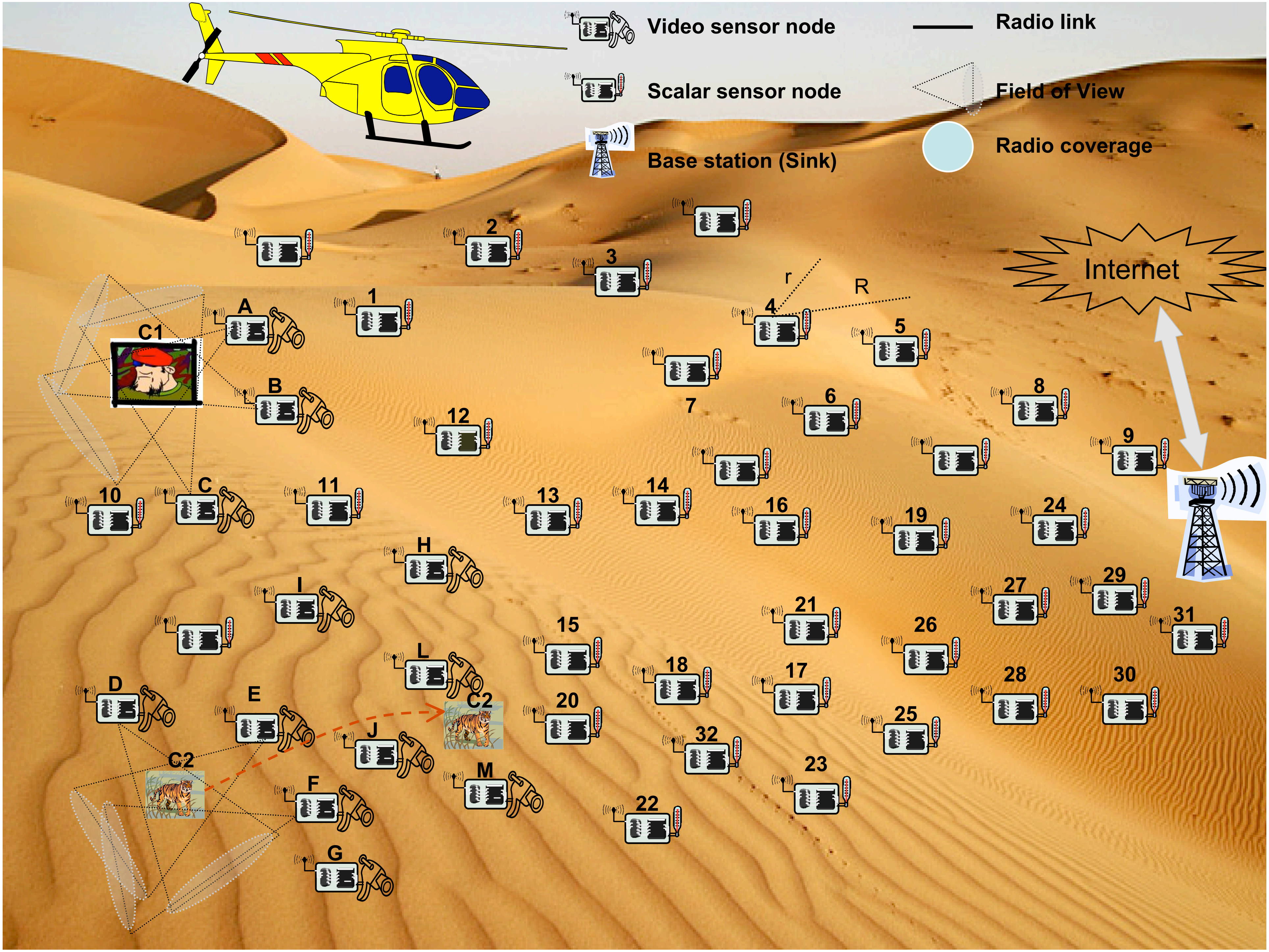
Agence Nationale de la Recherche ANR

- « Video Flows Transport for Surveillance Application »
- LIUPPA
  - Software architecture for multimedia integration, supervision plateform, transport protocols & congestion control
- CRAN (Nancy)
  - Video coding techniques, multi-path routing, interference-free routing

Traditionnal surveillance infrastructure



Vitracom®
Advanced Videosensor Technologies


Video sensor node
Scalar sensor node
Base station (Sink)
Radio link
Field of View
Radio coverage
Internet
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R
A
B
C
D
E
F
G
H
I
J
L
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C1
C2
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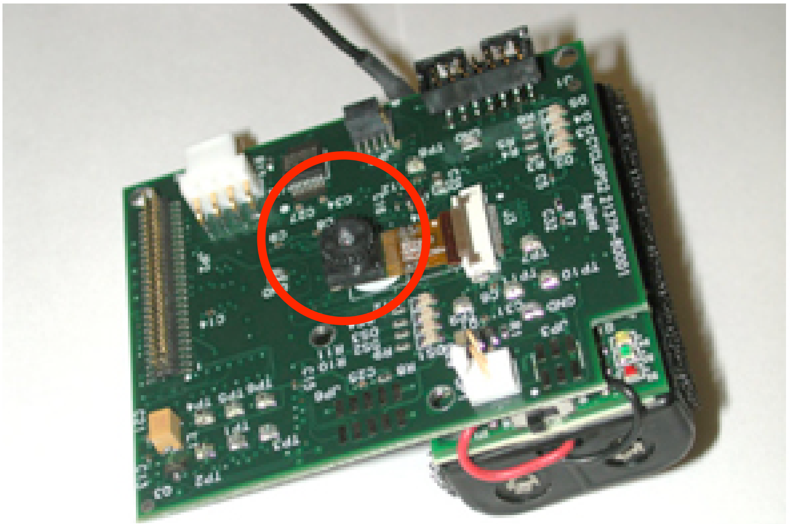
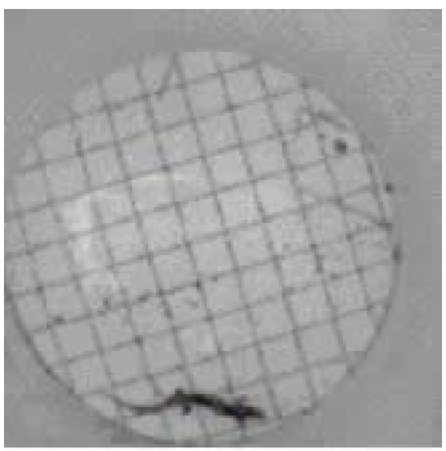
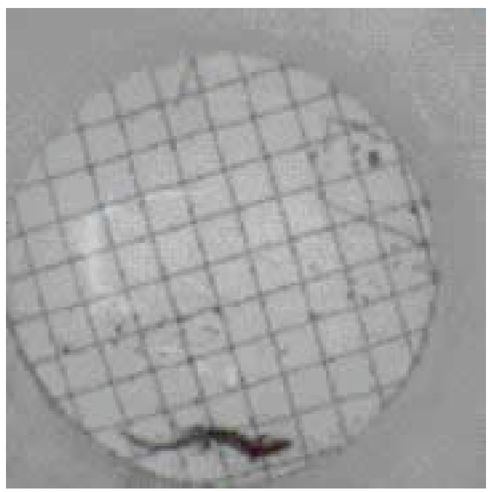
Wireless Video Sensors



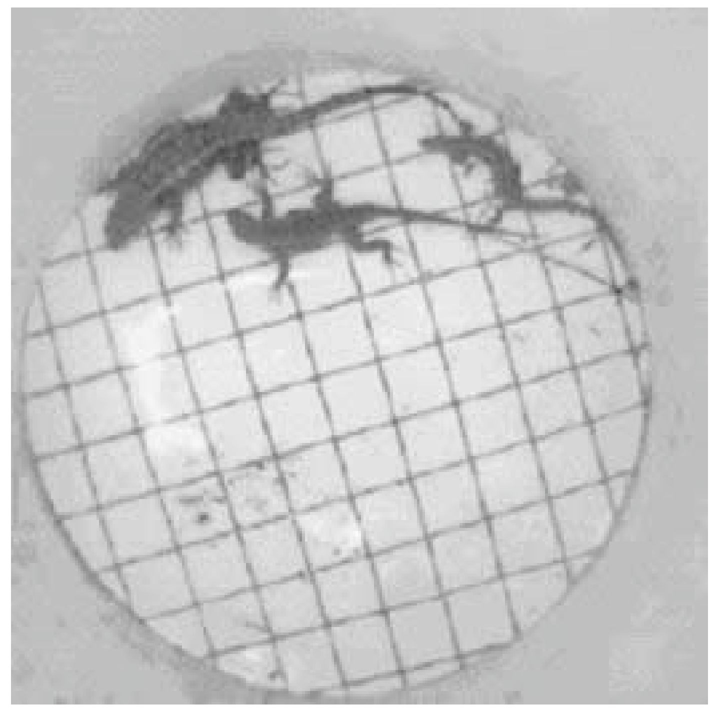
Cyclops video board on Mica motes



128x128



140x140



240x240

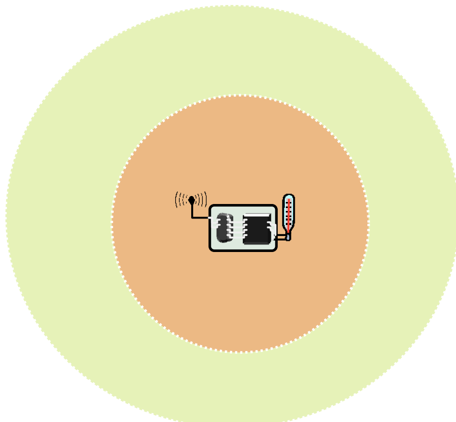
Challenges?

- Wireless Scalar Sensor Networks
  - Small size of events (°C, pressure,…)
  - Usually no mobility
  - Data fusion, localization, routing, congestion control
- Wireless Video Sensor Networks
  - What's new?
  - Video needs much higher data rate
- WVSN for Surveillance
  - What's new?
  - Where are the challenges?

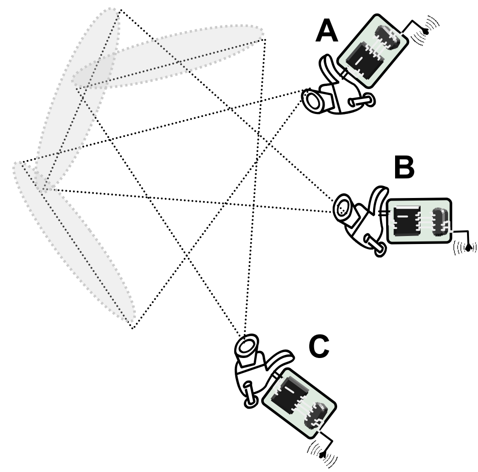
Research in WVSN

- Much works derive from scalar sensors works with video coding specificities
  - High data rate needs high compression ratio
  - Specific image/data fusion algorithms
  - Real-time flows are loss-tolerant ➔ spacial redondancy codes (FEC) rather than temporal redondancy (ARQ)
- Very little contribution on what is specific to sensors with embedded cameras
- No real settlement of the design space

Sensing range & coverage



vs

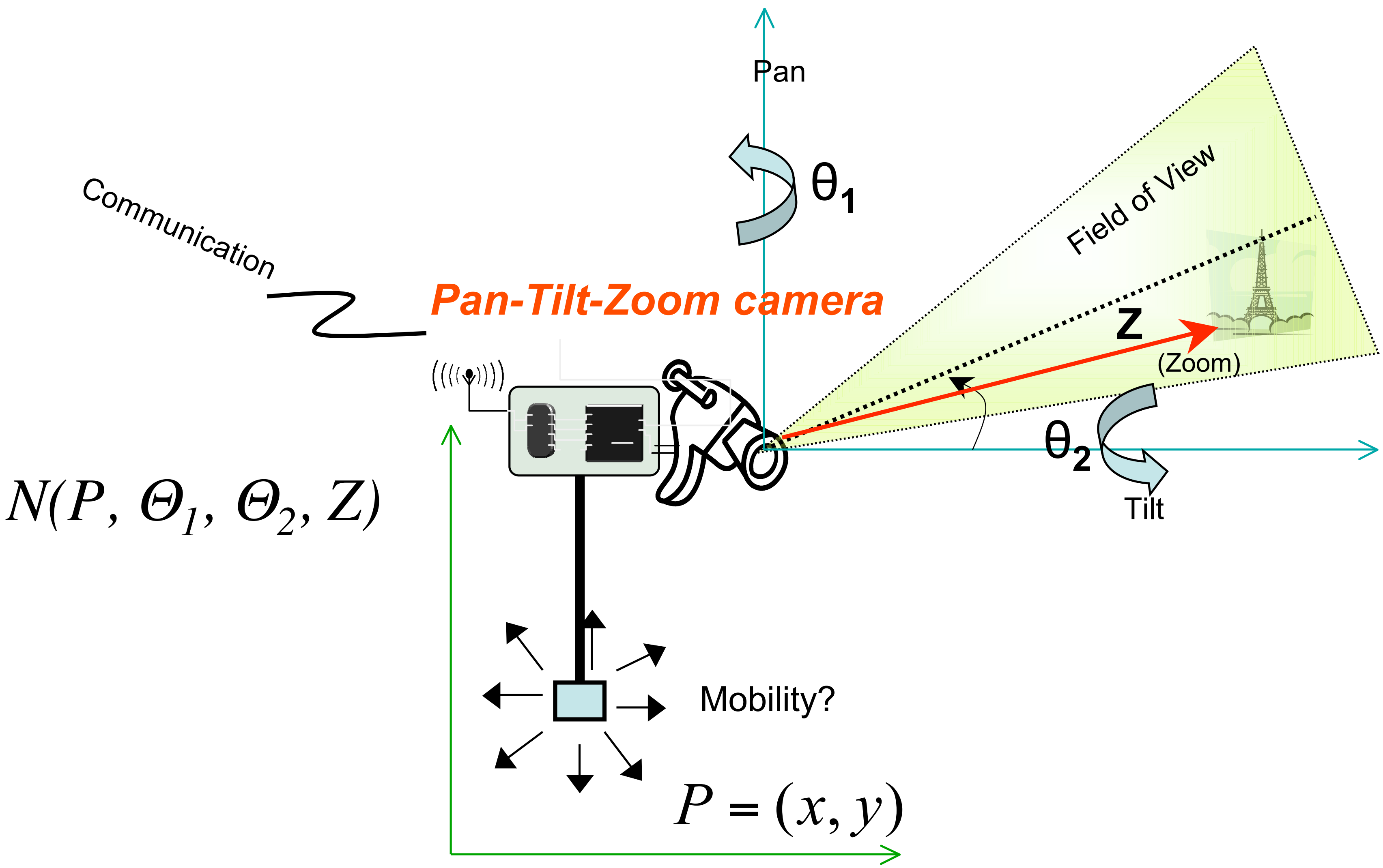


Video sensors capture scene with a Field of View ~ a cone

Zoom feature = Depth of View

Image resolution

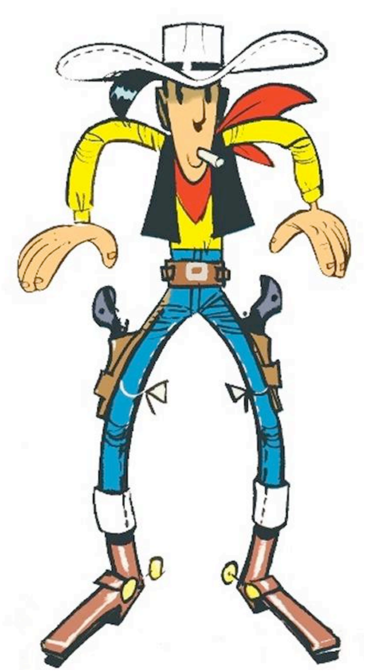
A model of video sensor



Note: P is on a plane, it could be in 3D space: P=(x,y,z)

Surveillance applications (1)

- Lesson 1: don't miss important events



Whole understanding of the scene is wrong!!!

What is captured

Surveillance applications (2)

- Lesson 2: high-quality not necessarily good

333x358 16M colors, no light

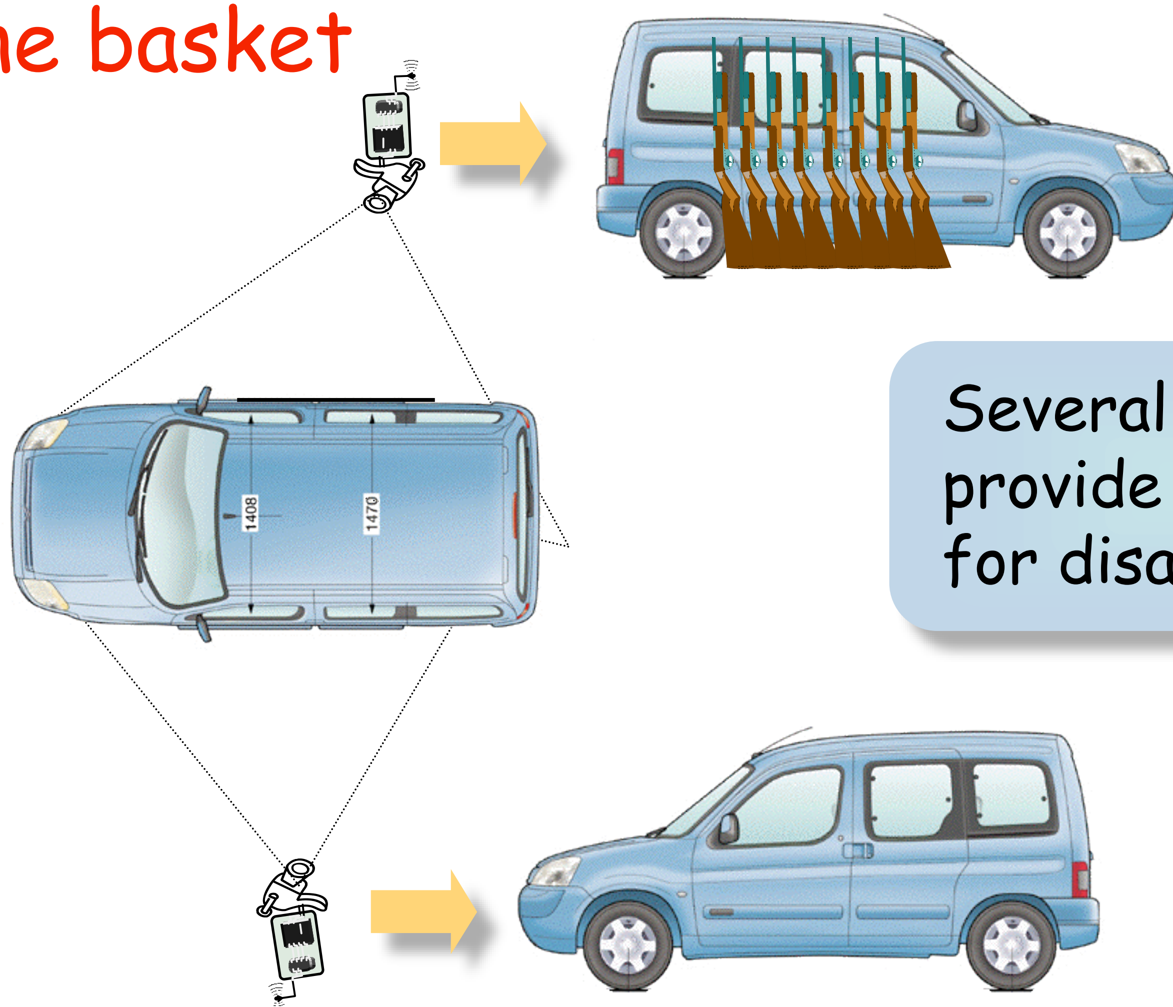
167x180 16 colors, light

Keep in mind the goal of the application!

167x180 BW (2 colors), light

Surveillance applications (3)

- Lesson 3: don't put all your eggs in one basket

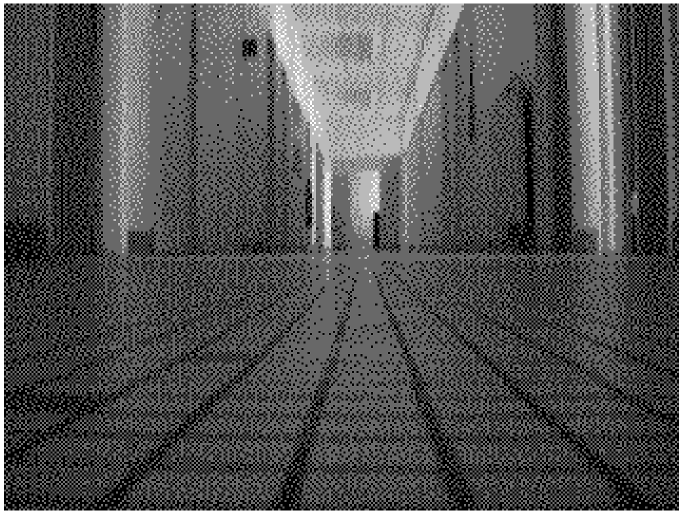


Several camera provide multi-view for disambiguation

Examples

- 320x200
- 30 fps
- 256 gray scale
- 15Mbps raw

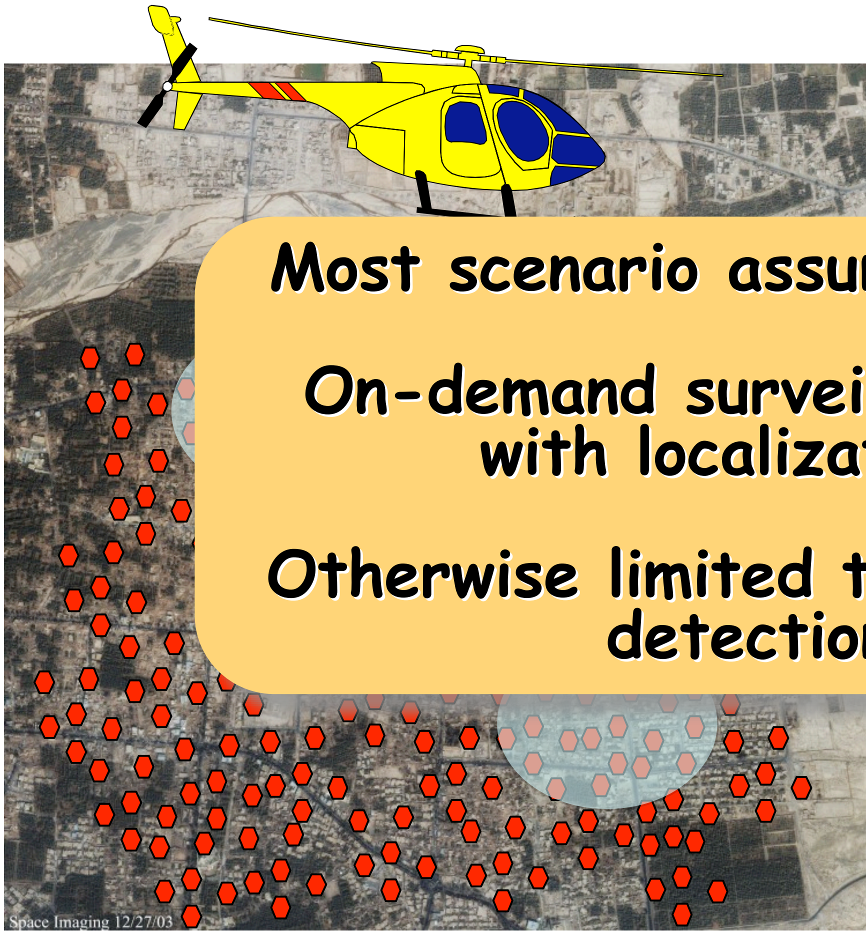
- 320x200
- 2 fps
- 4 gray scale
- 256kbps raw



Design space

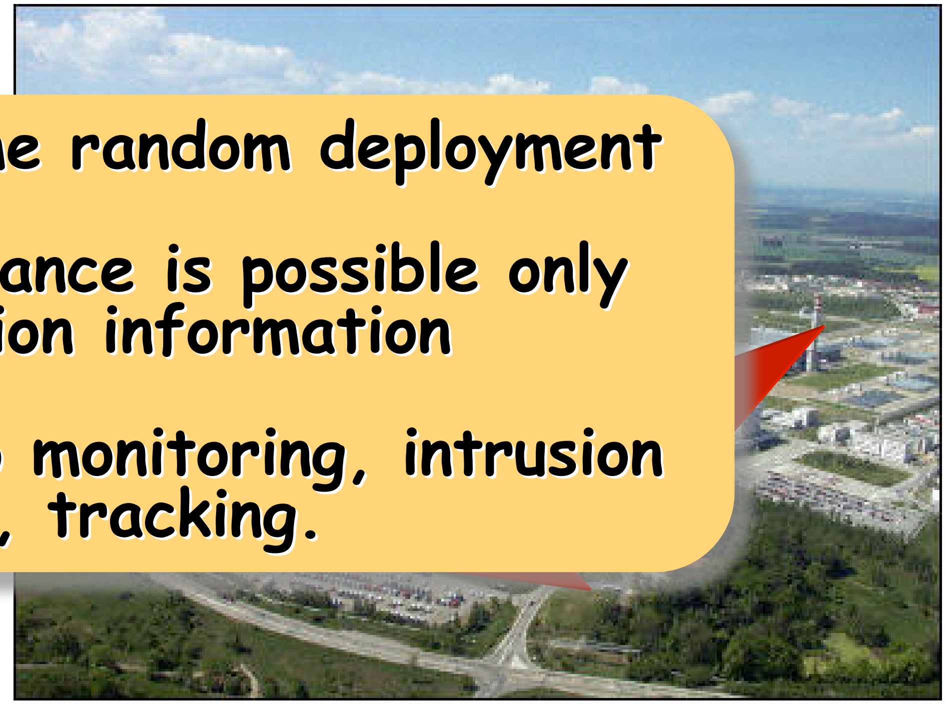
- Deployment scenario?
- Surveillance models?
- Homogeneous or heterogeneous?
- Stationary or mobility?
- Coverage?
- Energy consumption?
- Quality of Service?
- Synchronization?
- Intelligent vs non intelligent?

Deployment scenario



Random, thrown in mass

*



Fixed, semi-fixed, by hand

Most scenario assume random deployment

On-demand surveillance is possible only with localization information

Otherwise limited to monitoring, intrusion detection, tracking.

* No nuclear plant in particular

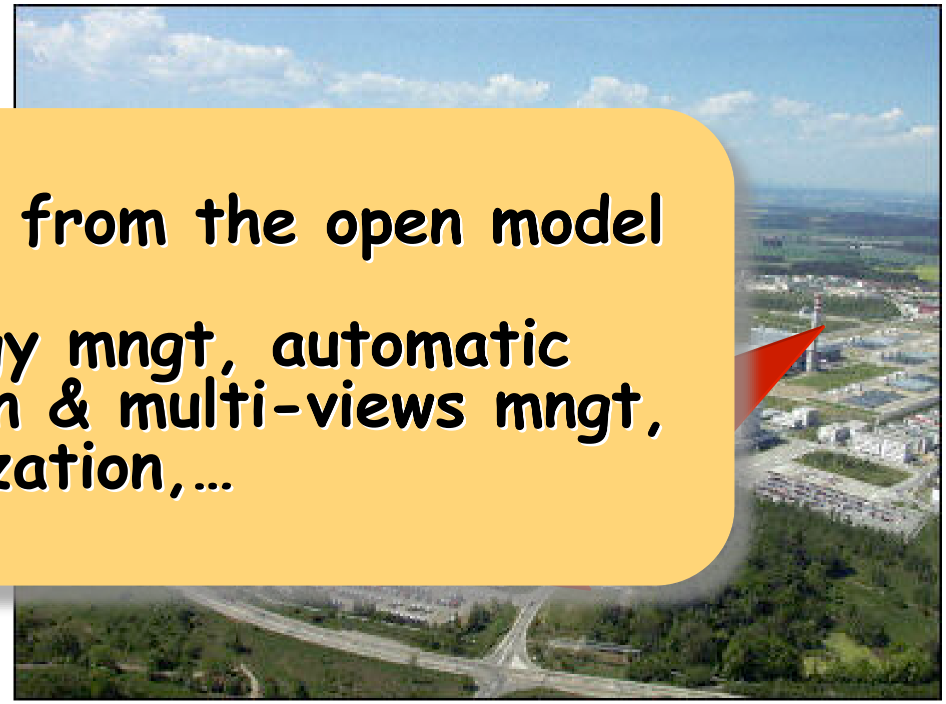
Surveillance models

Most problems come from the open model

Coverage & energy mngt, automatic redundancy detection & multi-views mngt, organization,…

Open model, no well-defined surveillance area

*



Infrastructure-oriented model, usually, we know what we are monitoring

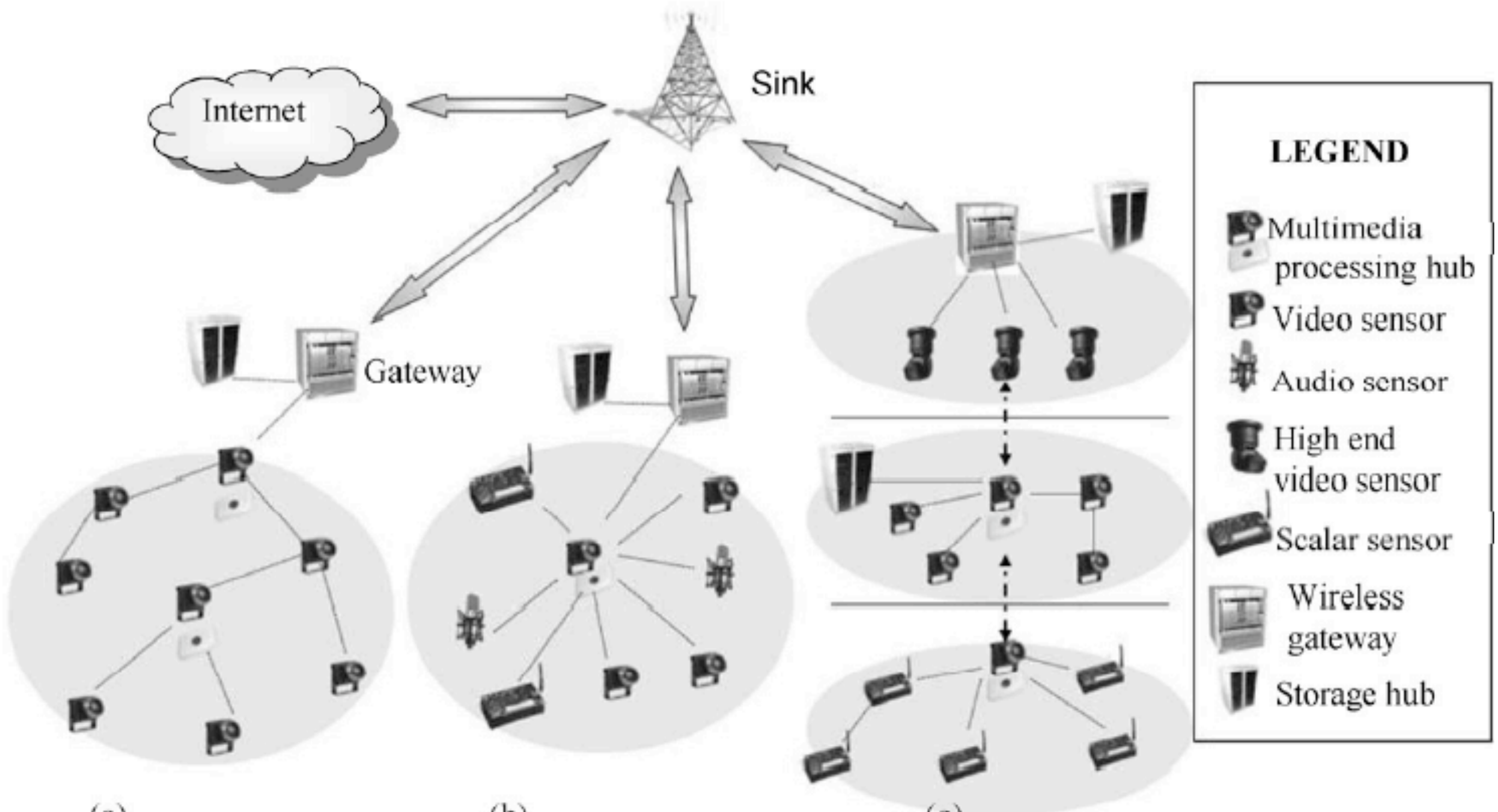
* No nuclear plant in particular

Homogeneity or not?

- Video nodes are more expensive
- Large scale WVSN WILL BE heterogeneous!

- Multi-tiers is a common approach
  - Hardware characteristics
  - Functionalities
- Energy management is the prime goal

Reference architecture

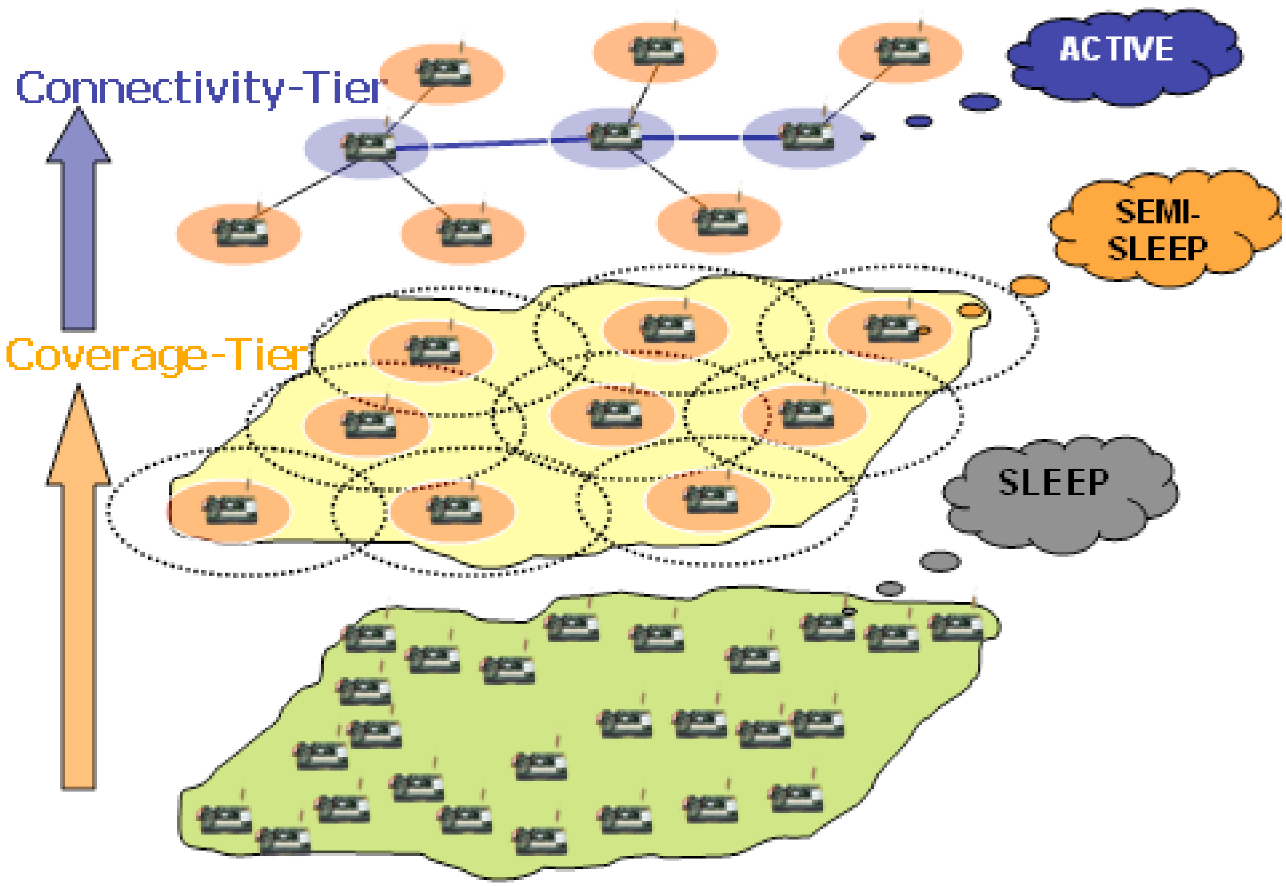


(a)
Single-tier flat,
homogeneous sensors,
distributed processing,
centralized storage

(b)
Single-tier clustered,
heterogeneous sensors,
centralized processing,
centralized storage

(c)
Multi-tier,
heterogeneous sensors,
distributed processing,
distributed storage

Multi-tiers for multi-purposes



TTS: A Two-Tiered Scheduling Mechanism for Energy Conservation in Wireless Sensor Networks. See Nurcan Tezcan's Research Projects

Advanced heterogeneity

- Reliability in surveillance
  - Enhance/validate/disambiguate video information with other sources of information
- 24/24 surveillance
  - Replace video by infrared when it's dark
  - If critical, why not « kamikaze » flash-sensor?

➔SURVEILLANCE SERVICE🡐

Surveillance at any price!

Surveillance Service

Buzzword!

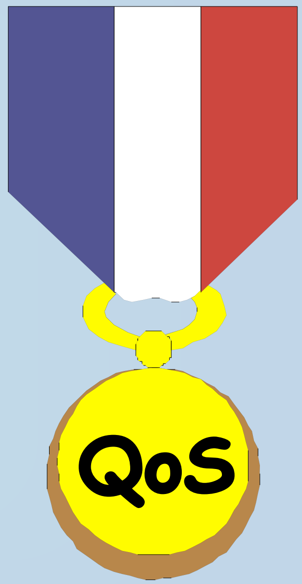
- Similar to Service Level Agreement

➔ SURVEILLANCE AT ANY PRICE ⬅

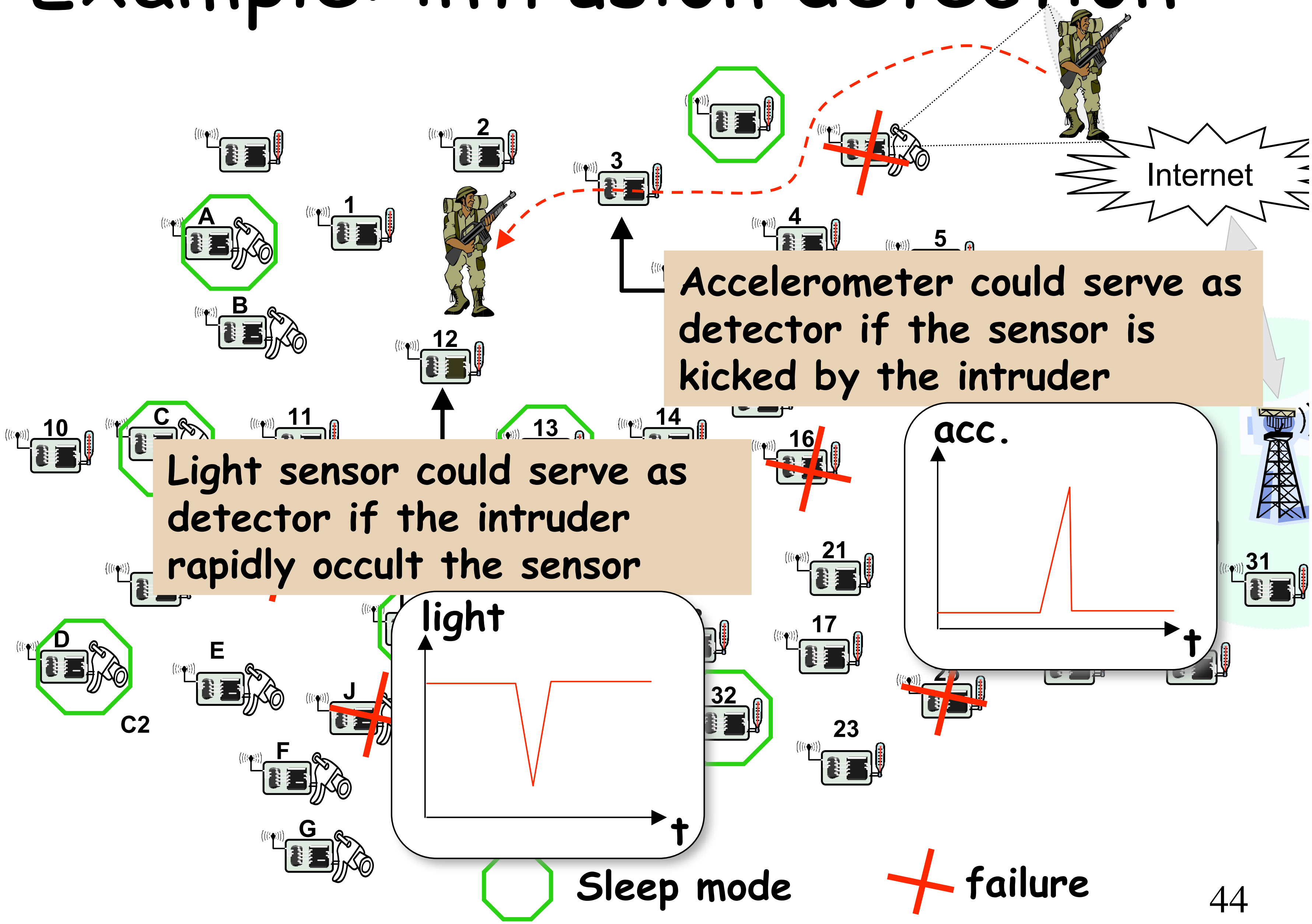
no discontinuity of service against node's failures

collaborative sensors

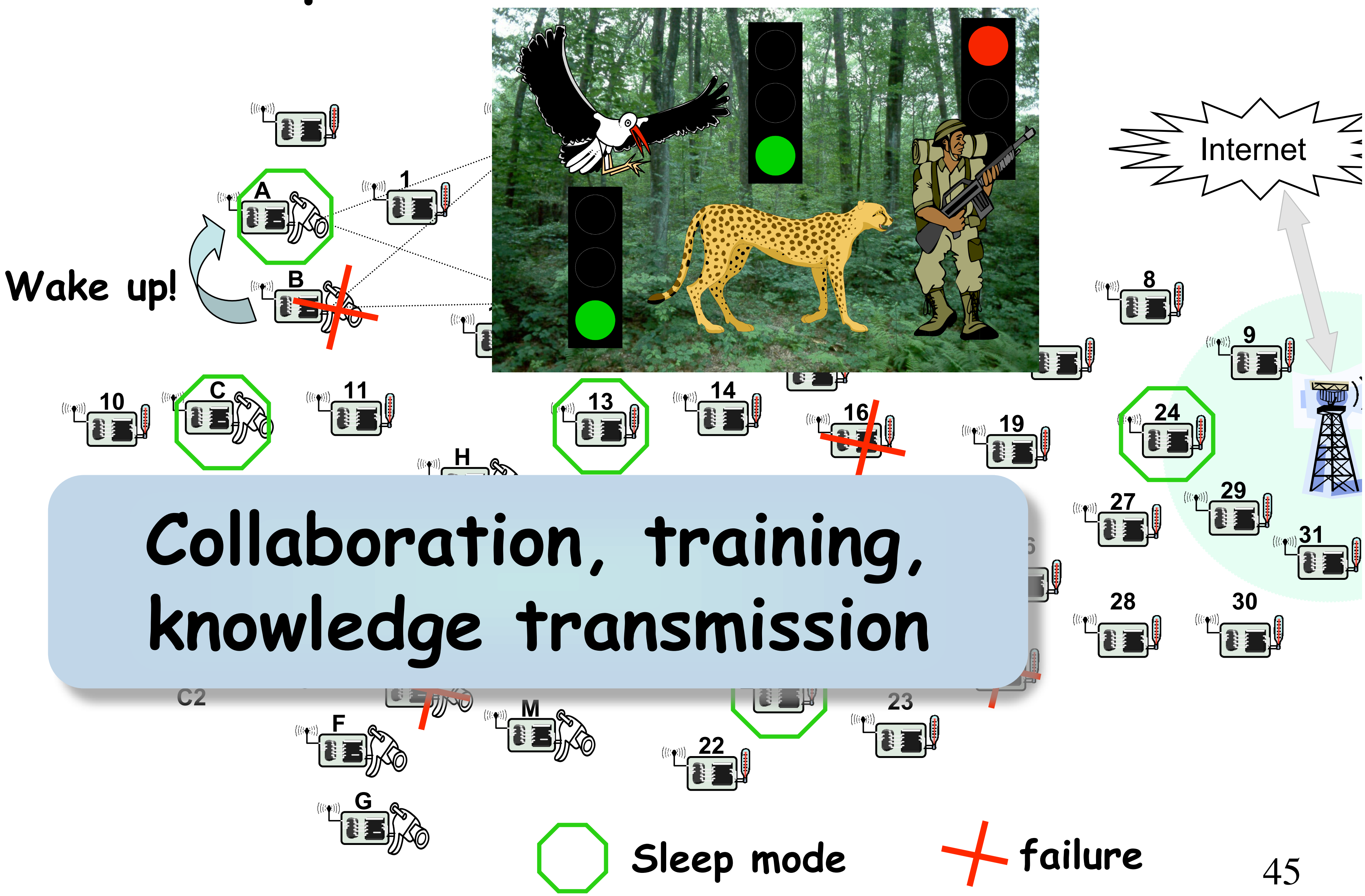
service independant of its implementation



Example: intrusion detection

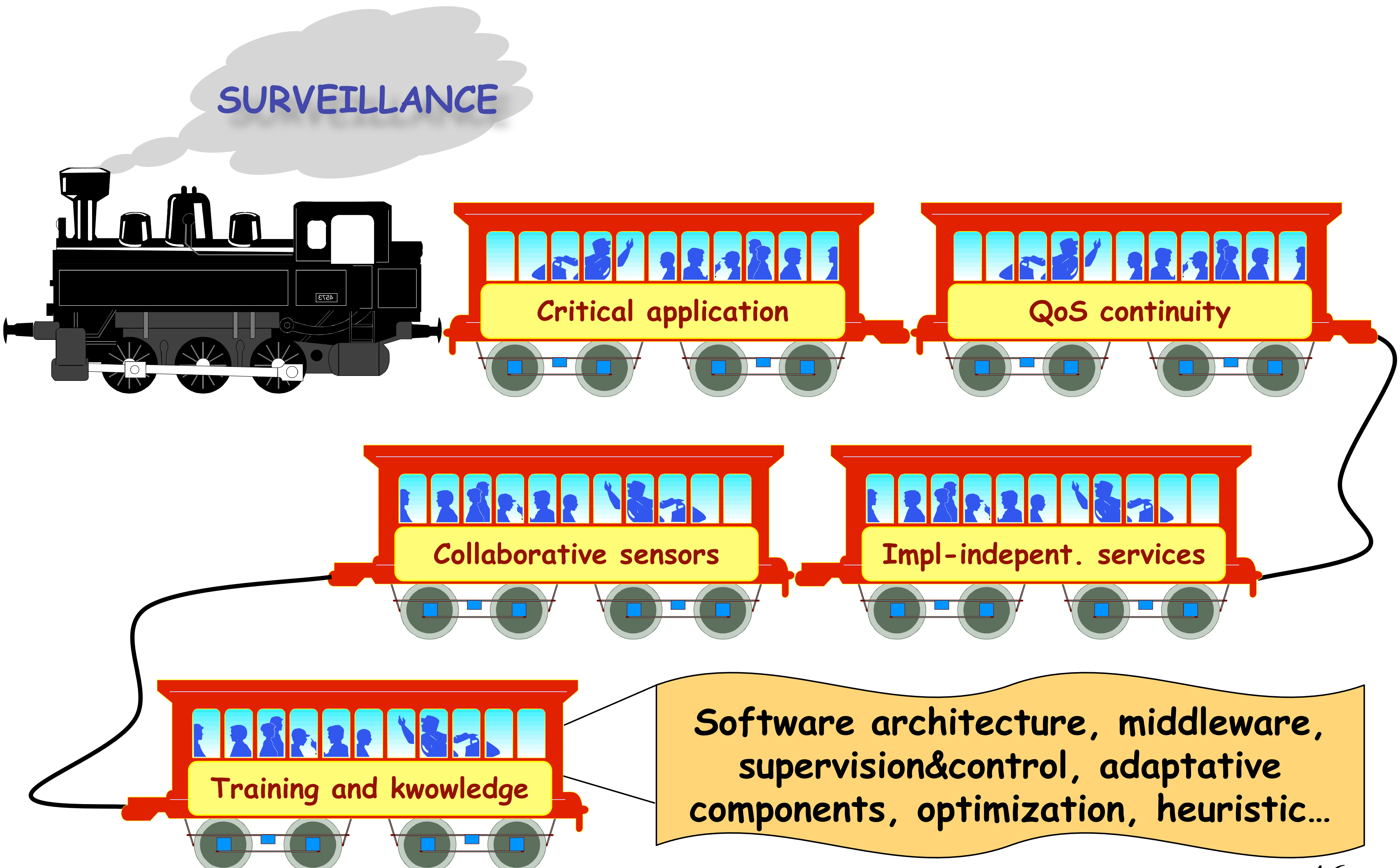


Example: intrusion detection



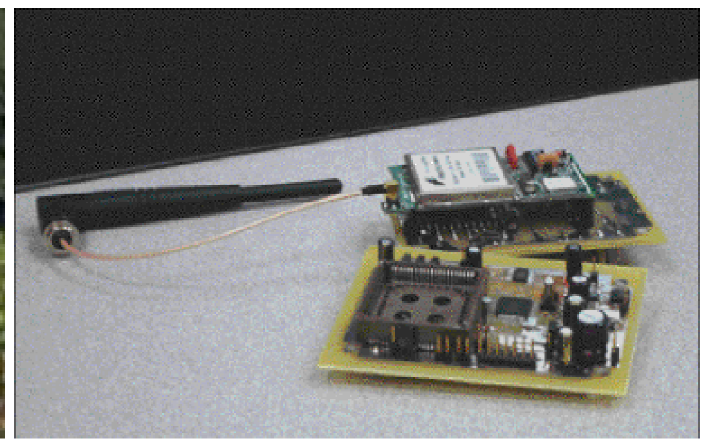
Collaboration, training, knowledge transmission

Impacts of QoS



Mobility

- Mobility for wireless sensor is expensive
  - Size constraints, terrain constraints
  - Energy constraints
- Most WSN have no mobility→ monitoring, intrusion detection applications
- Non-controllable mobility has limited applications: mostly exploration (ZebraNet) & communication is the main scientific problem

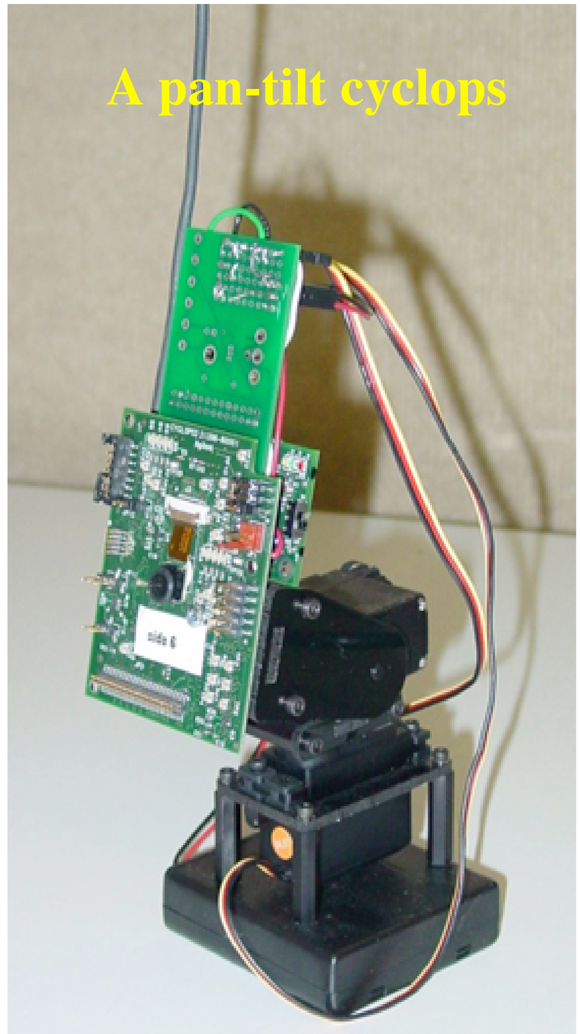



ZebraNet project, university of Princeton: exploring wildlife

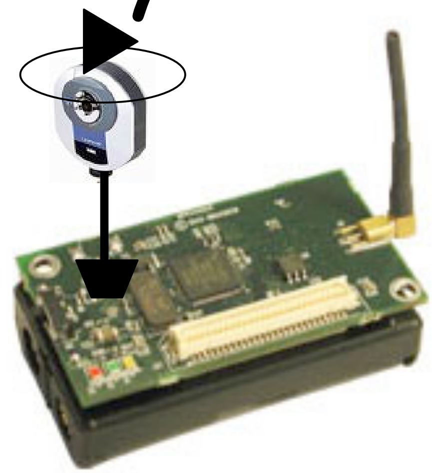
We see cheap mobility!

- Video sensors have a cheap mobility feature

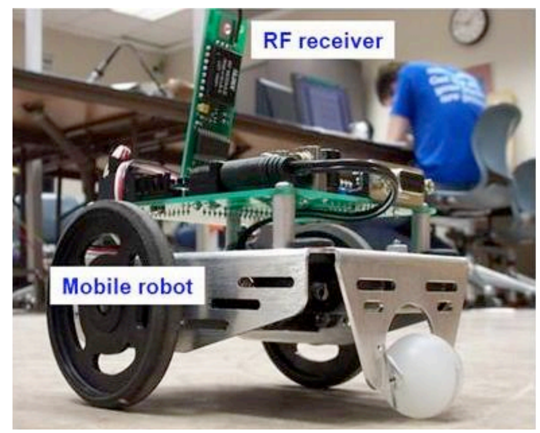
- Pan-tilt camera provide multiple views possibility, large variety of app.: monitoring, on-demand exploration, tracking.



NOW

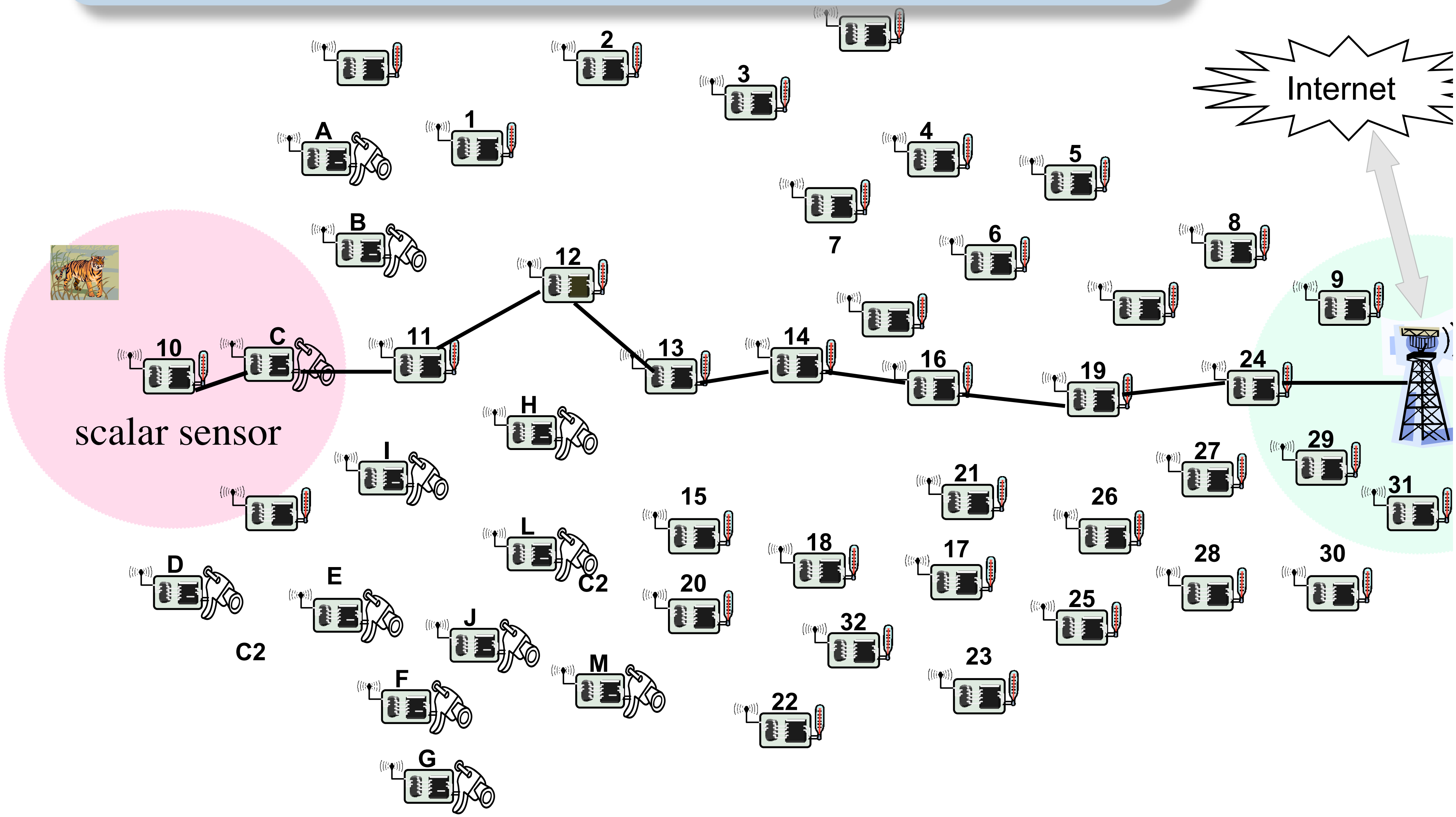


SOON

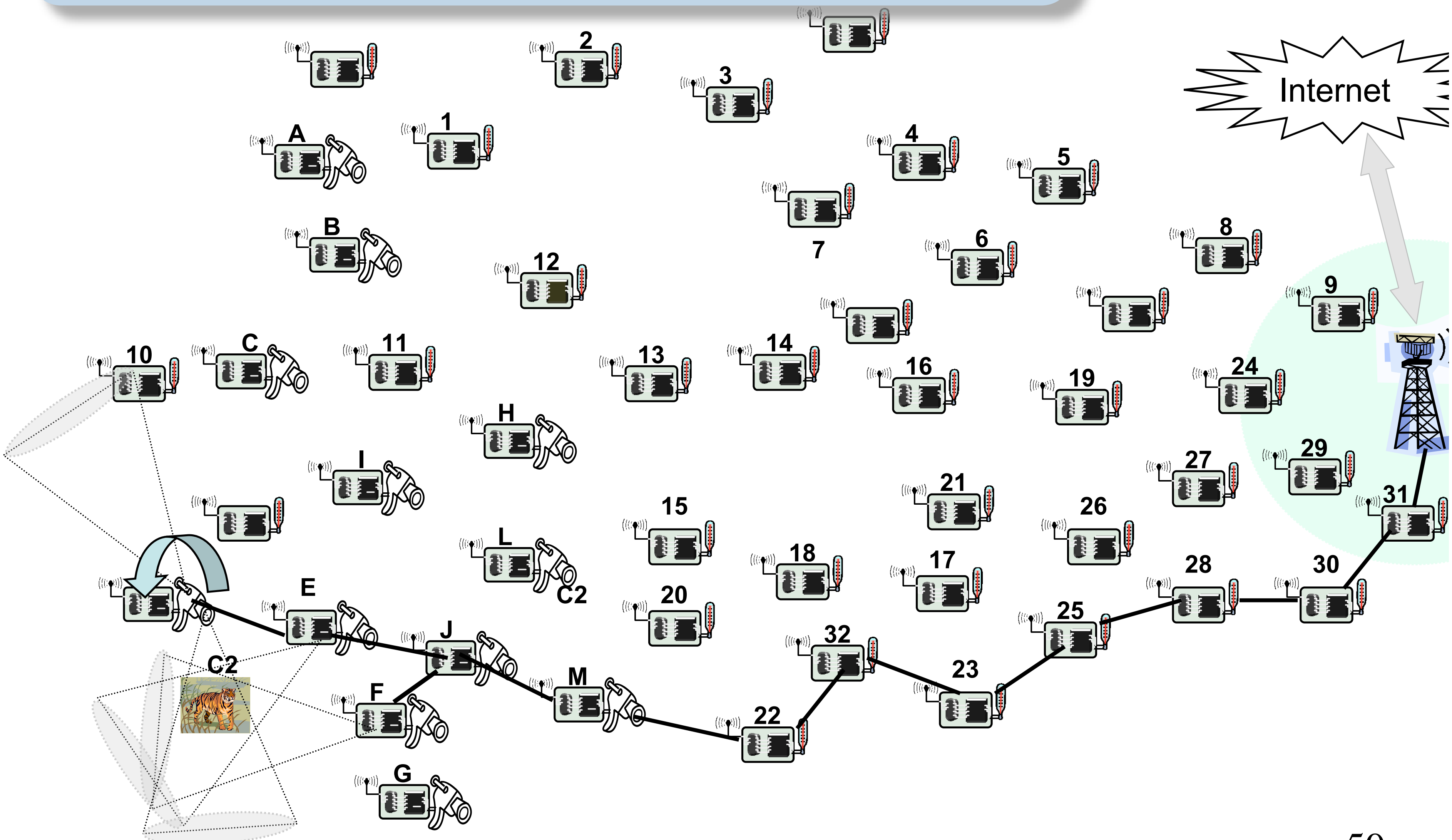


Simpler & less expensive than above

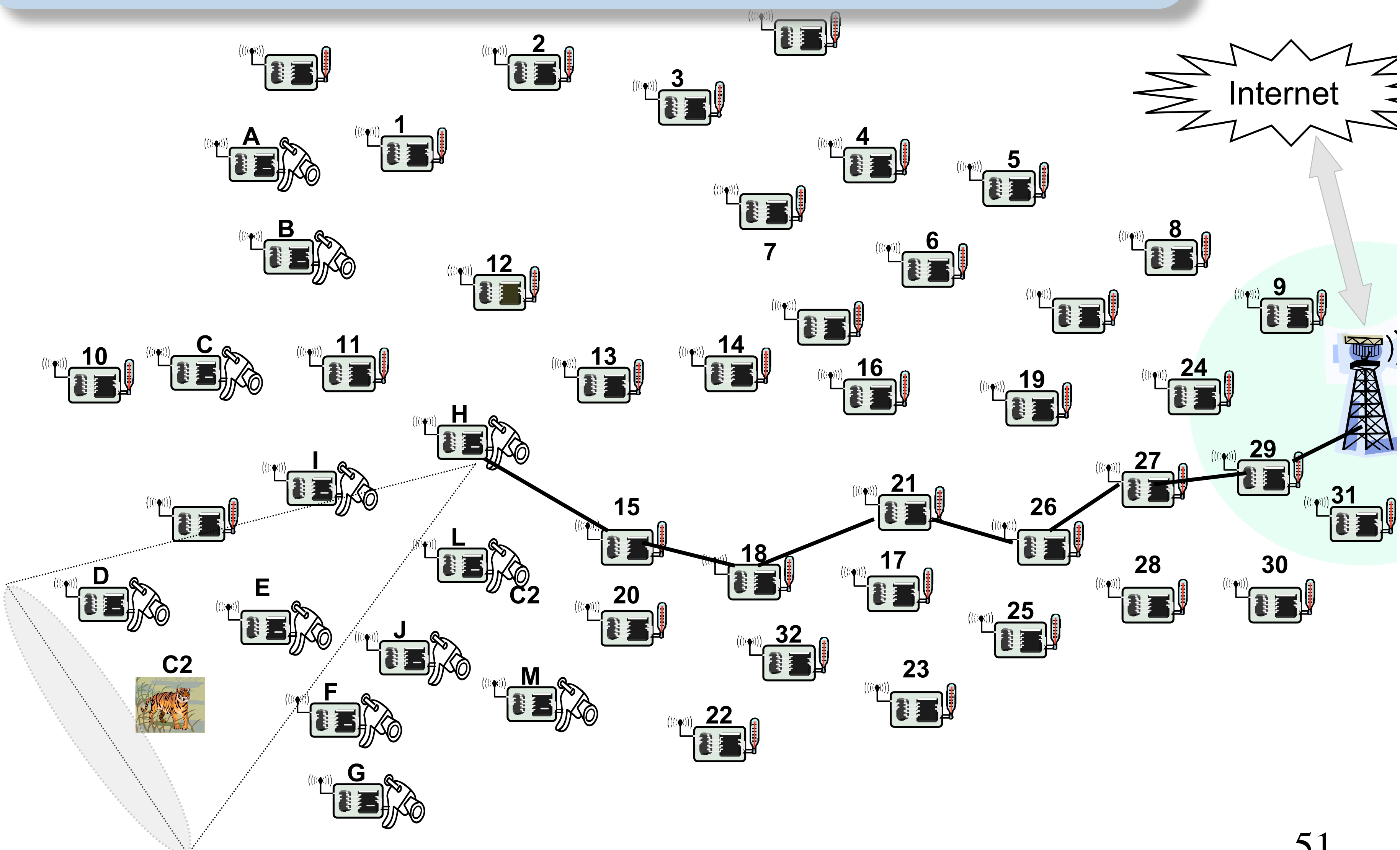
Event's position determines sensors



Mobility (pan-tilt) complexifies coverage problem

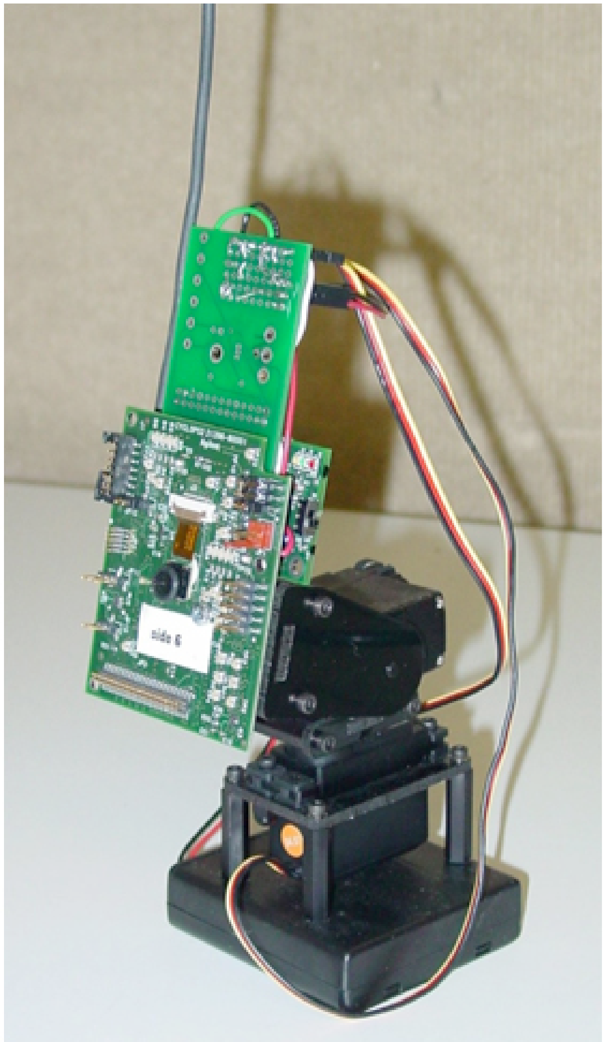


Far sensors can potentially capture the global scene better (weather conditions)!



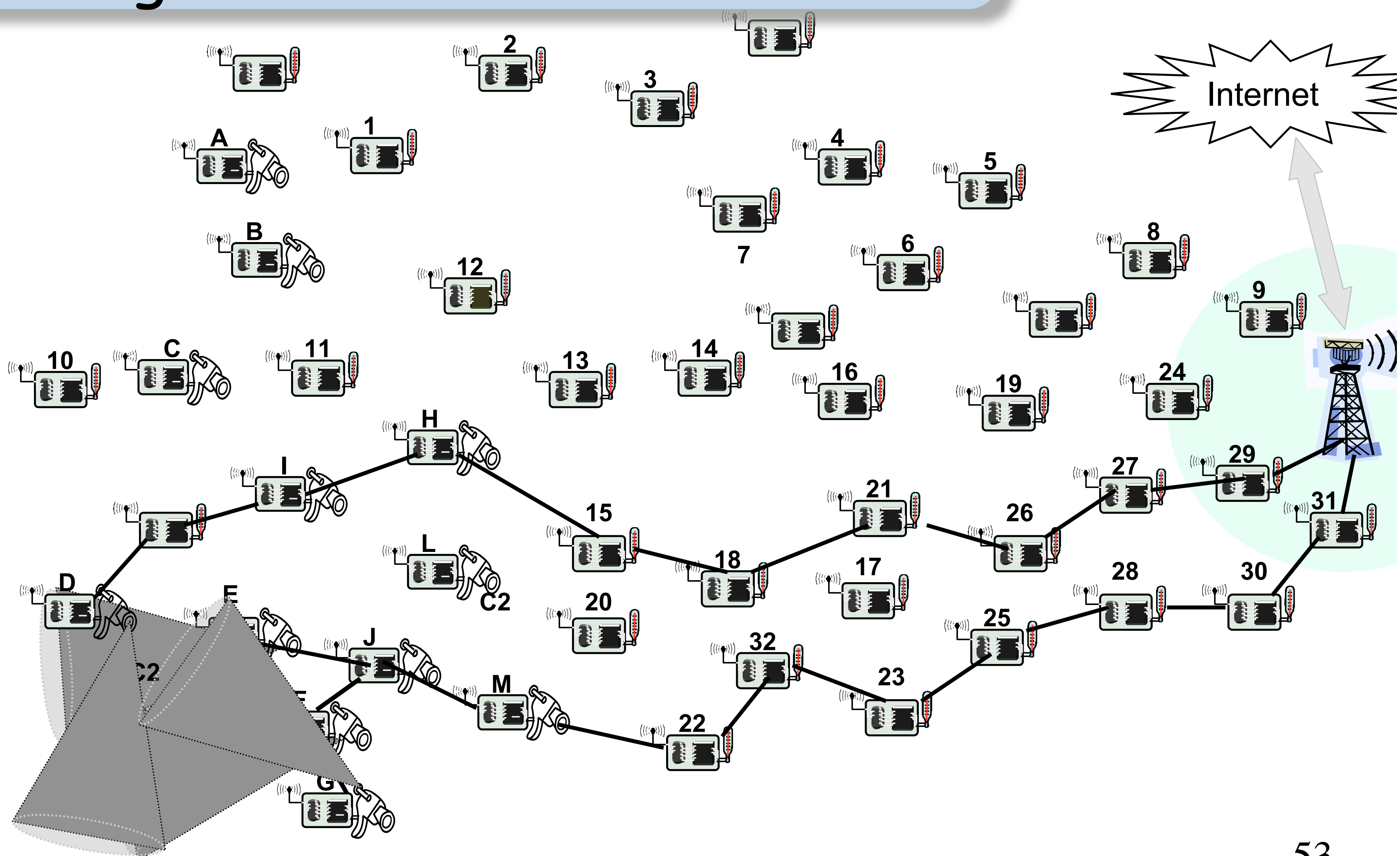
Impact of pan-tilt-zoom mobility

- More parameters, more optimization possibilities
  - Coverage determination and sensor selection procedures
  - Energy-efficient initial configuration settings
  - Quality of service

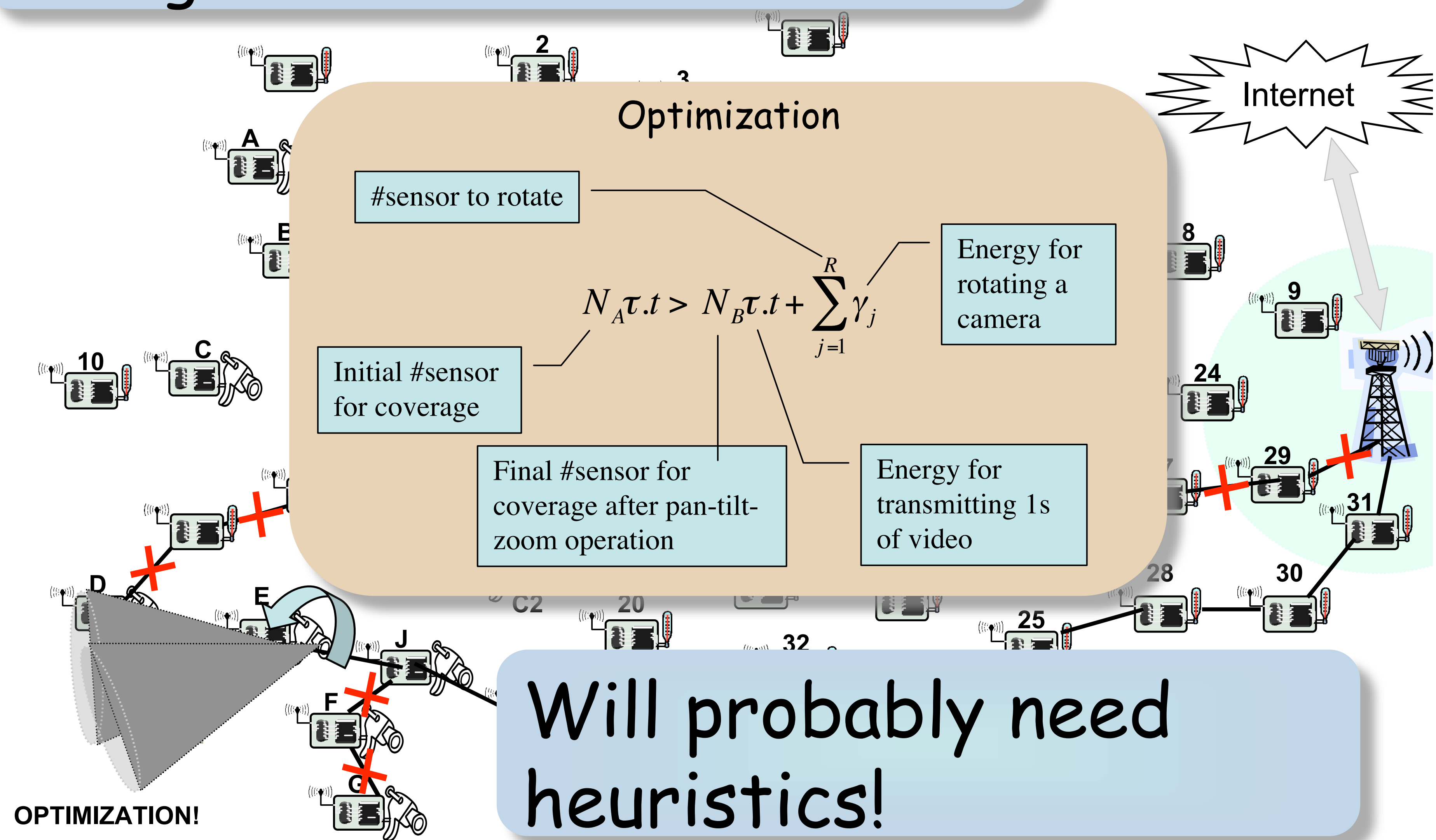


A pan-tilt cyclops

Ex: Energy-efficient initial configuration



Ex: Energy-efficient initial configuration



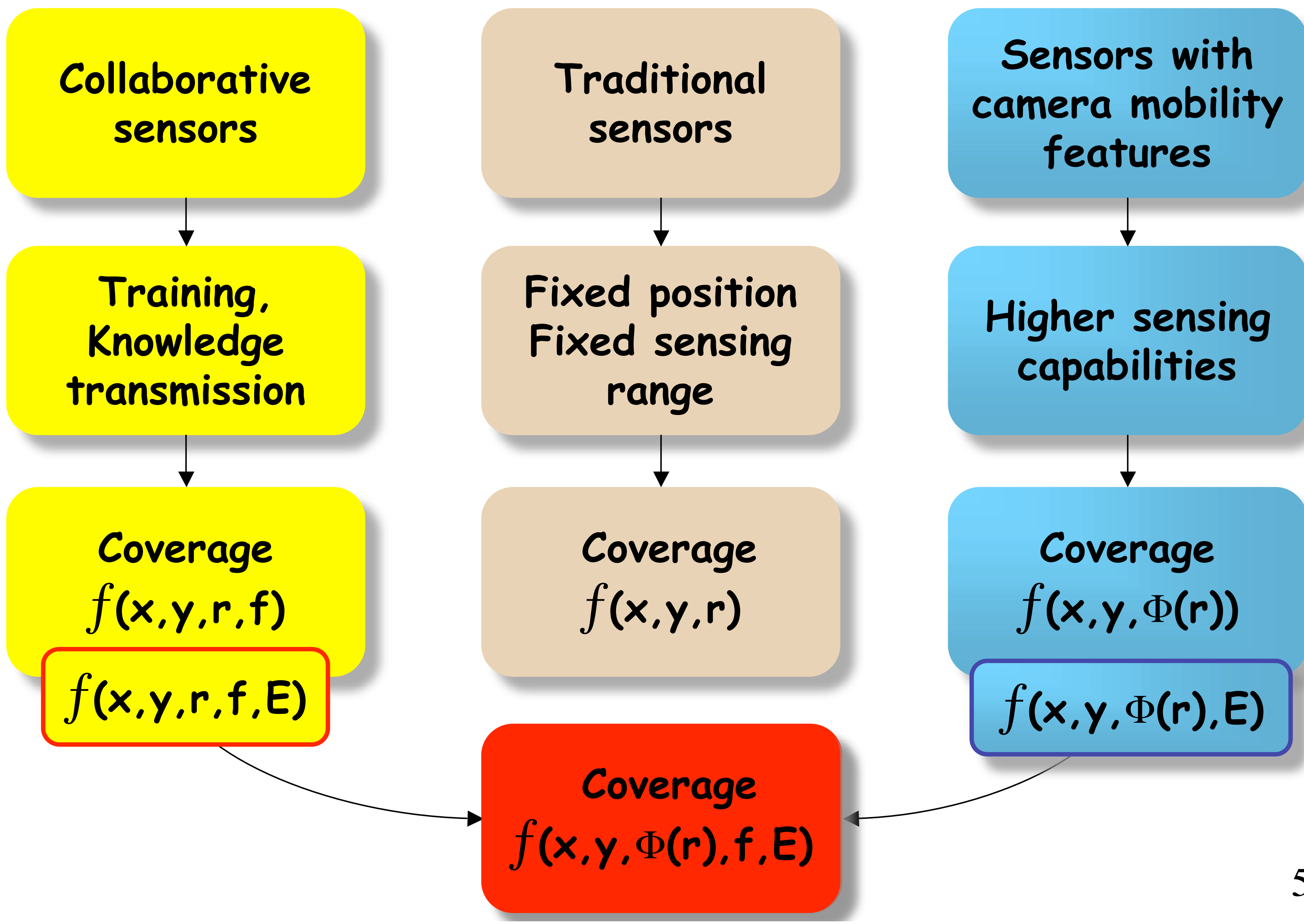
Optimization

$$N_A \tau . t > N_B \tau . t + \sum_{j=1}^{R} \gamma_j$$

- #sensor to rotate
- Initial #sensor for coverage
- Final #sensor for coverage after pan-tilt-zoom operation
- Energy for rotating a camera
- Energy for transmitting 1s of video

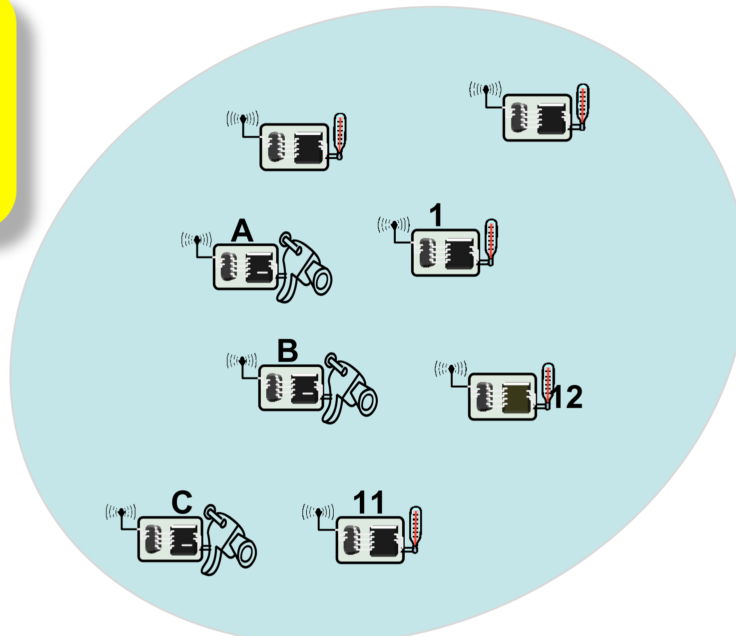
Will probably need heuristics!

On the coverage problem



The overall surveillance system: the wishes

Heterogeneous sensor hardware



Best coverage
Highest net. lifetime

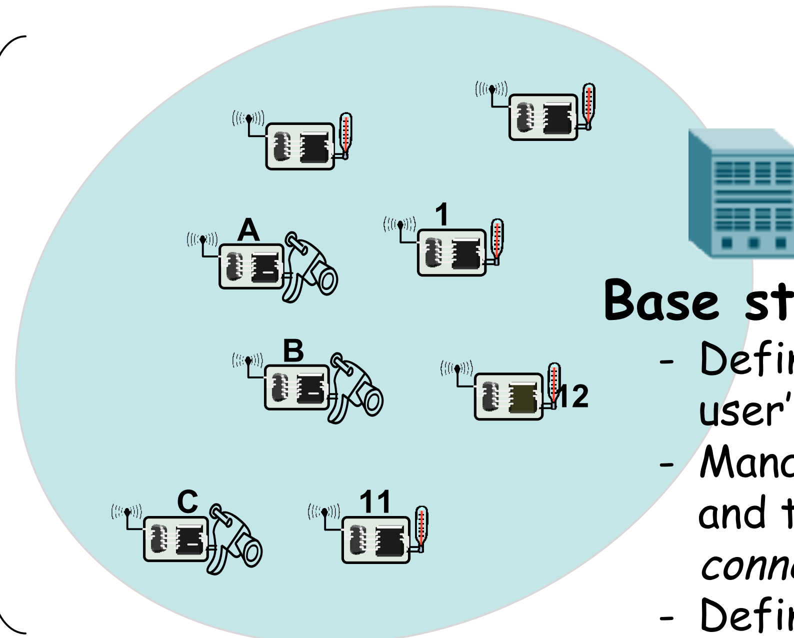
Operate 24/24

SLA for surveillance service

The overall surveillance system: the answers

Sensors must be able to

- Define best way to insure coverage
- Schedule themself to increase network lifetime
- Able to reconfigure themselves
- Communicate to collaborate

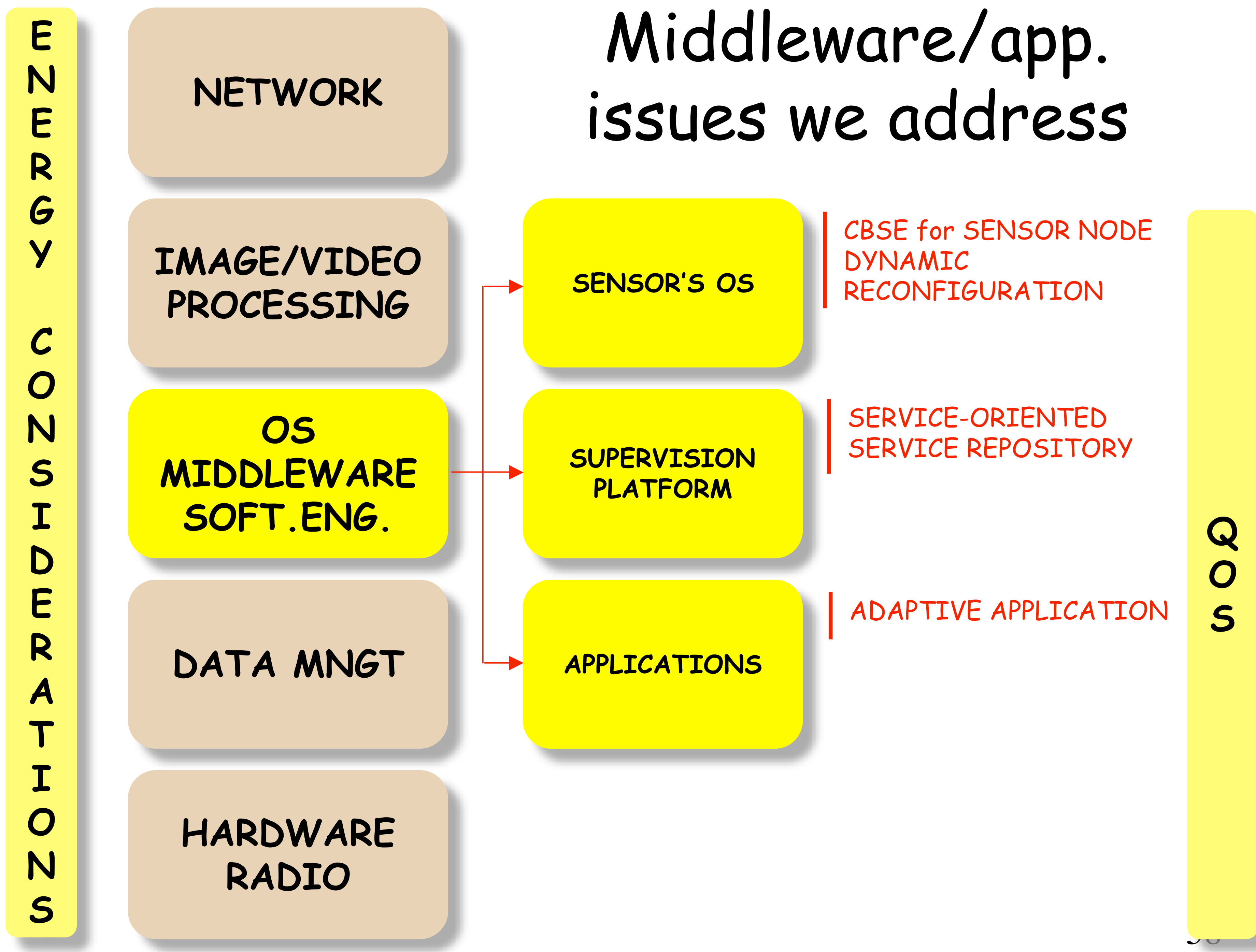


Base station

- Define & monitor user's QoS
- Manage soft. Components and traffic flows through *connectors*
- Define best configuration according to context
- Supervise the set of sensors, manage failures

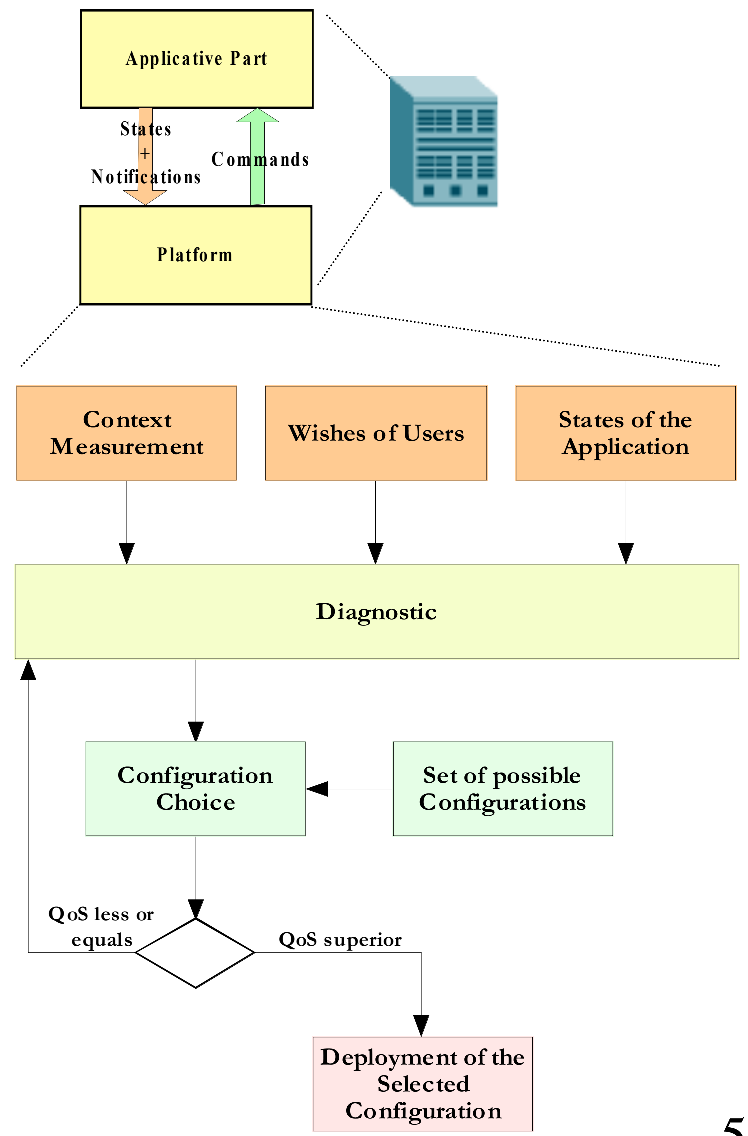
Communication protocols must

- Provide efficient connectivity, multi-hop, multi-path routing
- Handle information-intensive traffic


Middleware/app. issues we address
ENERGY CONSIDERATIONS
NETWORK
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

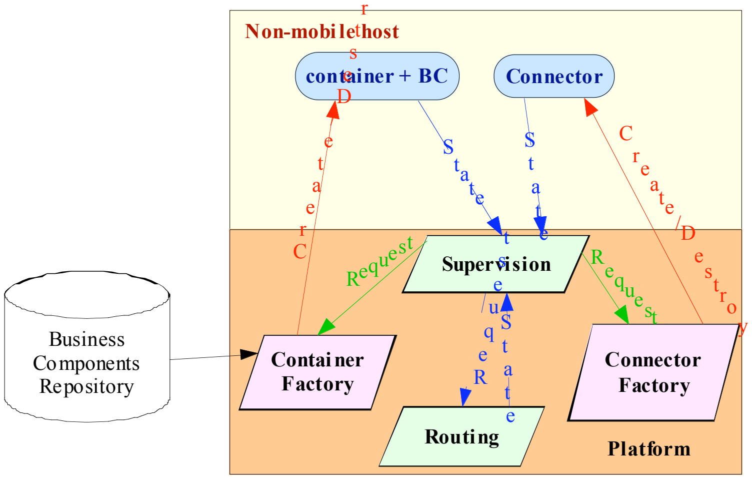
Supervision platform

- Take care of user's QoS and QoS continuity
- Allows for a service-oriented surveillance system
- Discovery and publish mechanisms
- In charge of determining which configuration is better

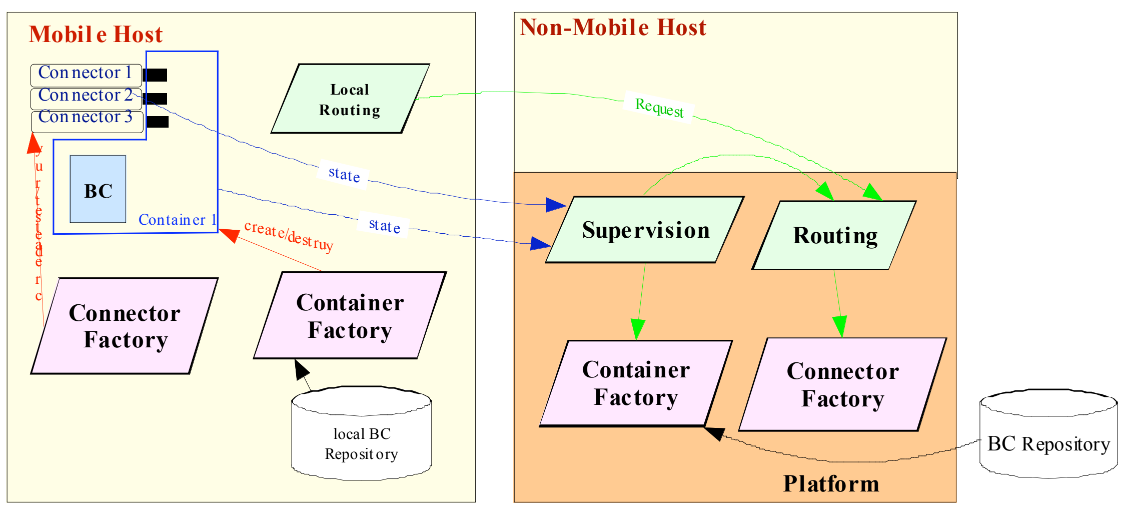


A bit of the internal design

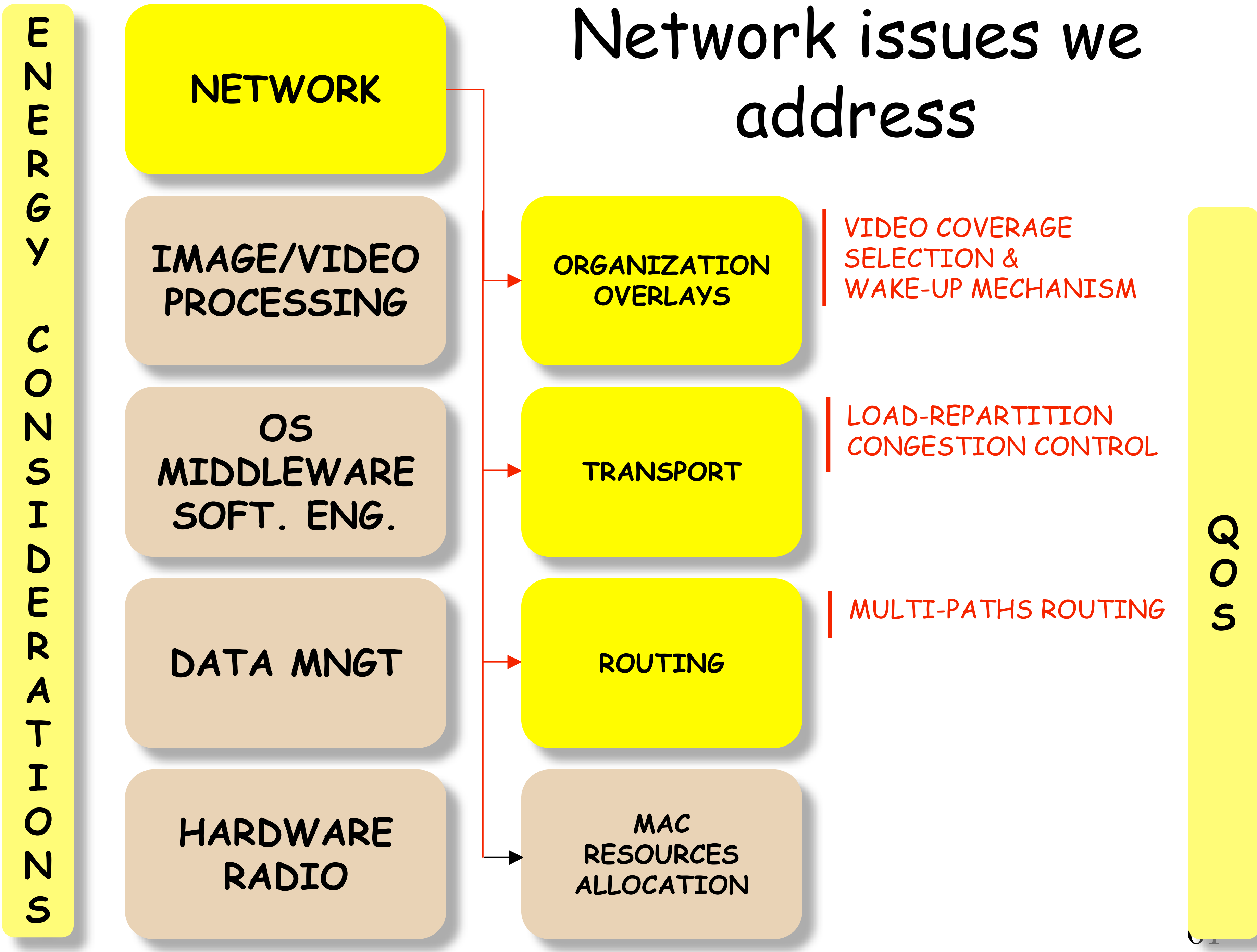
Fixed-node/base station



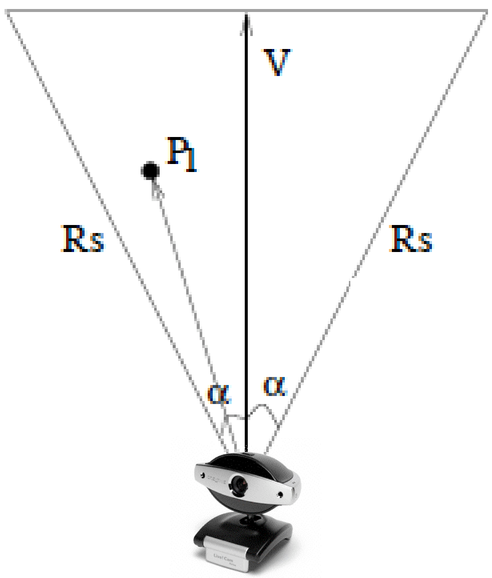
Mobile/lightweight-node

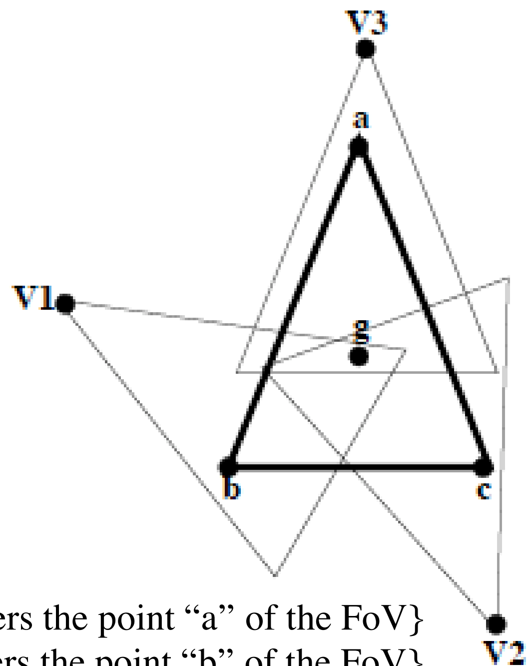


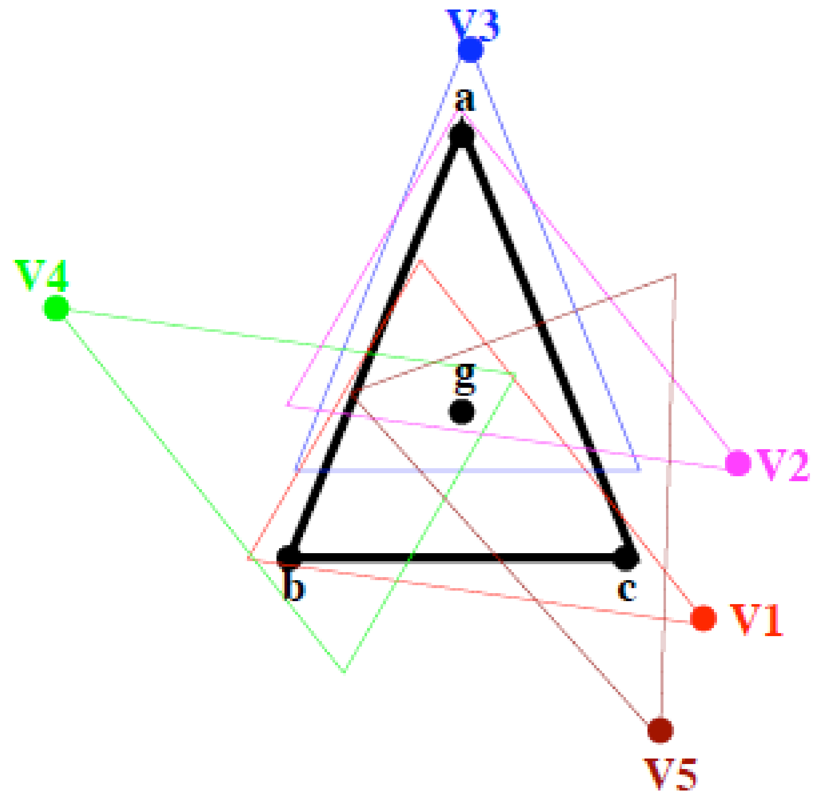
Network issues we address



Video coverage







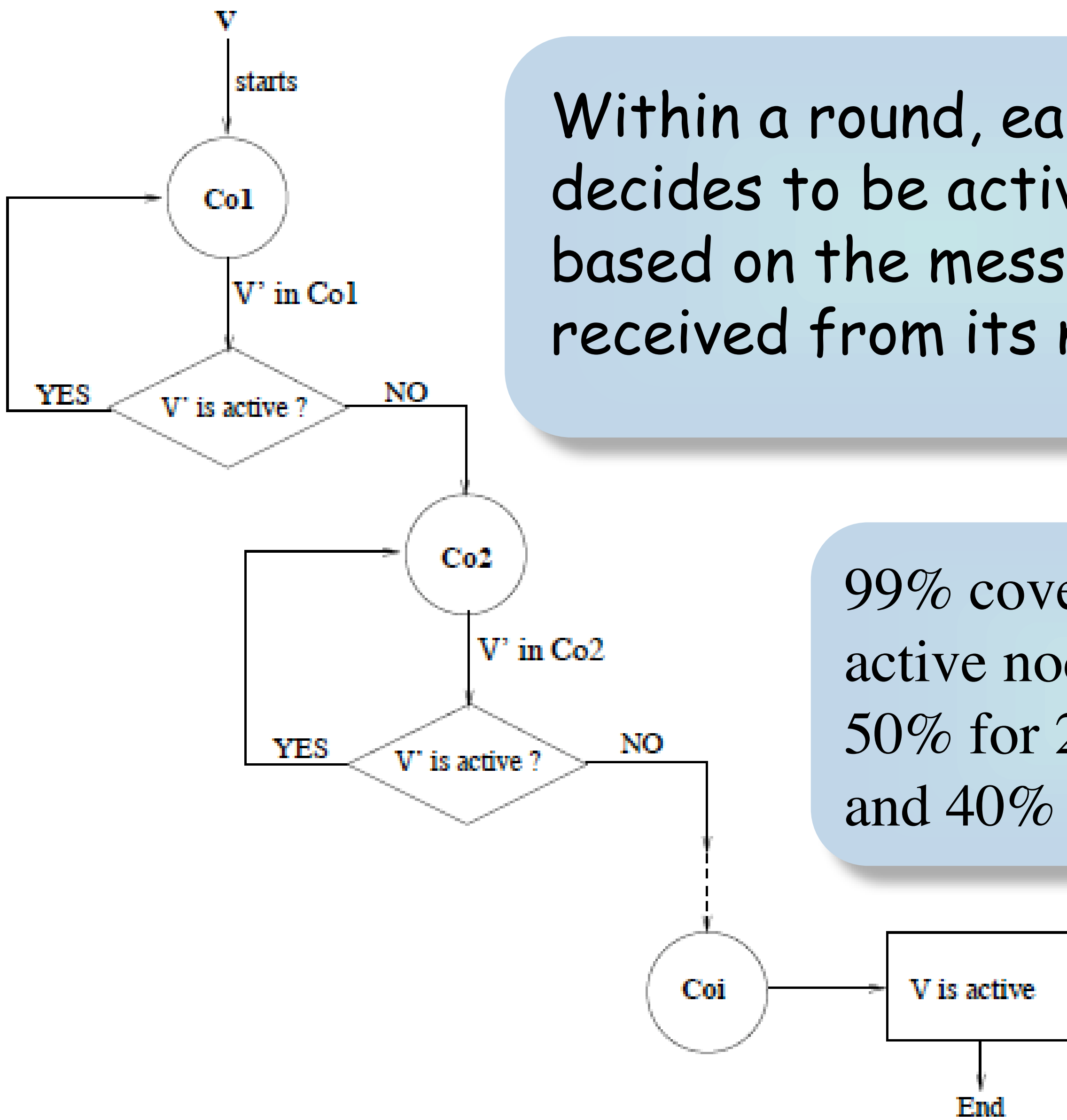
A = {v ∈ N(V) : v covers the point “a” of the FoV}
B = {v ∈ N(V) : v covers the point “b” of the FoV}
C = {v ∈ N(V) : v covers the point “c” of the FoV}
G = {v ∈ N(V) : v covers the point “g” of the FoV}

{{V },
{V 2, V 1},
{V 3, V 1},
{V 2, V 4, V 5},
{V 3, V 4, V 5}}

Sensor selection/wake-up

- The activity of video sensor nodes operates in rounds.
- Within a round, each node decides to be active or not based on the messages received from its neighbors.
- Every node orders the sets of covers in term of their cardinality,
- Gives priority to the covers which have minimum cardinality.

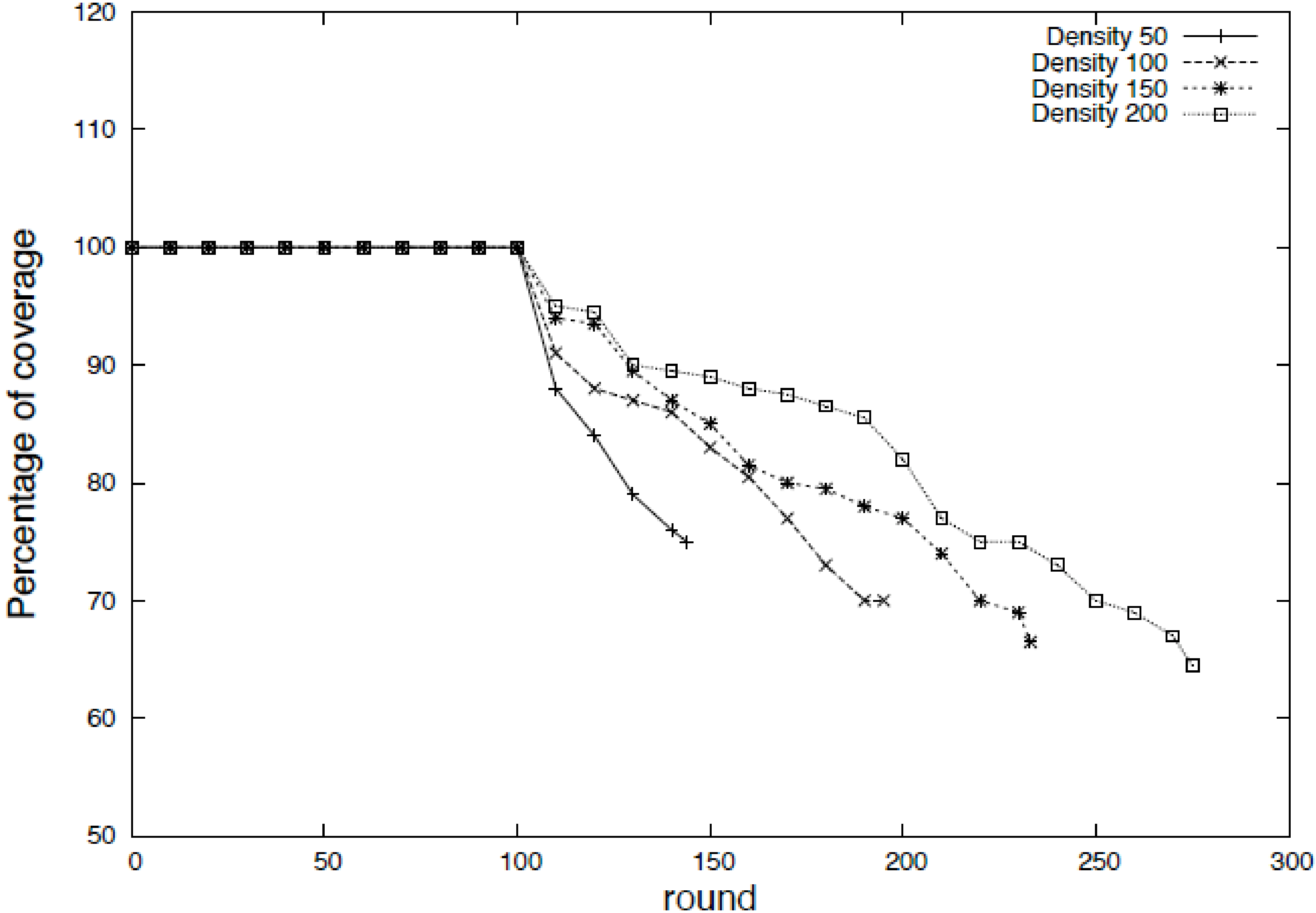
Selection procedure



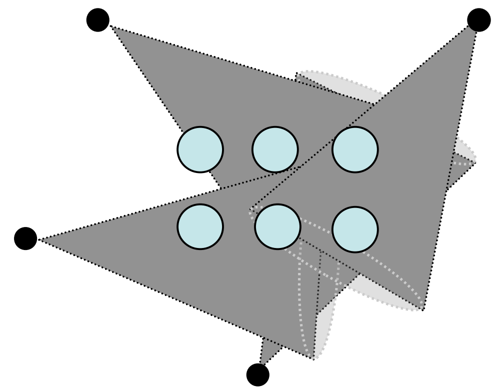
Within a round, each node decides to be active or not based on the messages received from its neighbors

99% coverage with 60% active nodes for 100 nodes, 50% for 200, 44% for 250 and 40% for 300

% of coverage (Rs=25m)

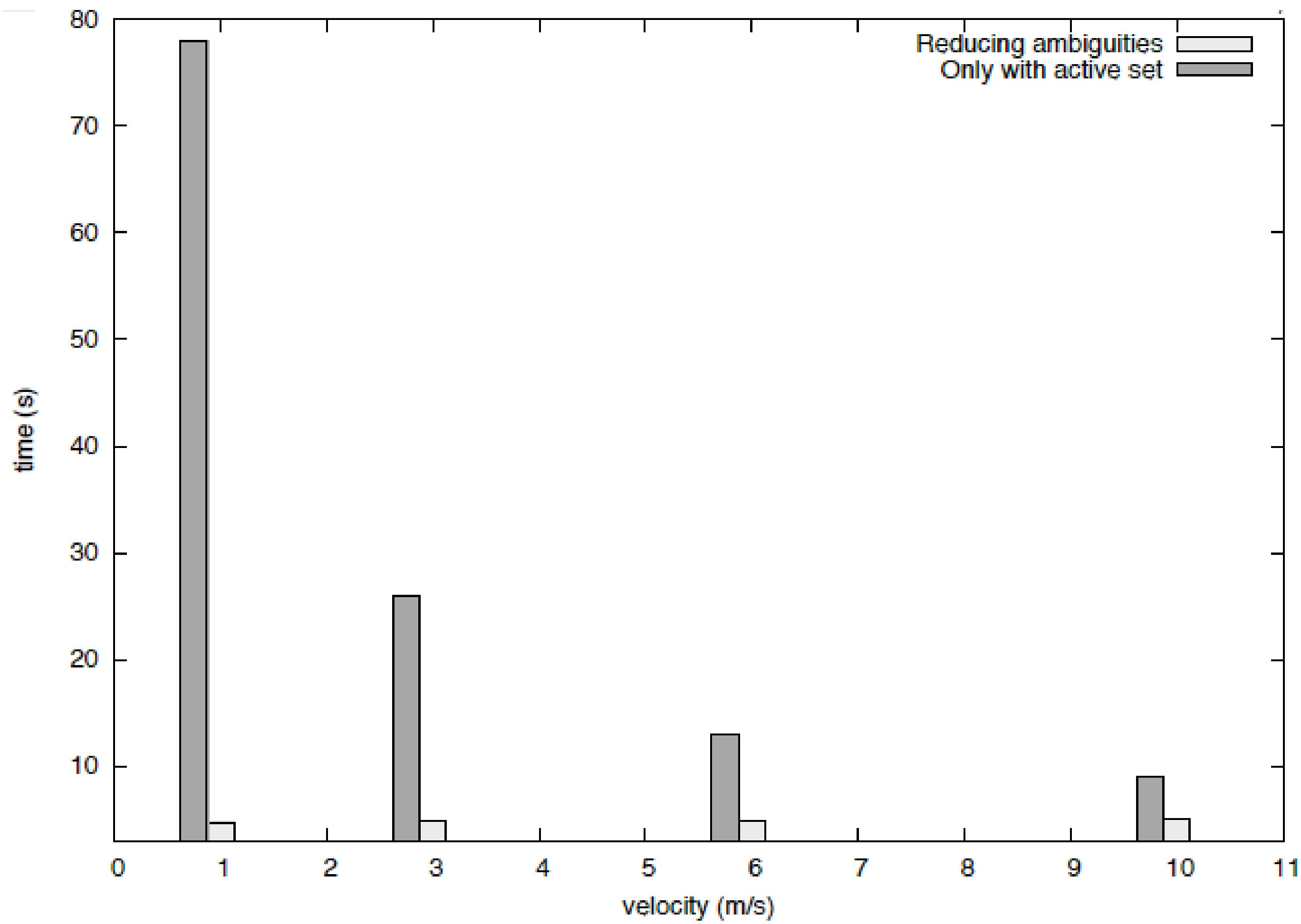


Intrusion detection (1)



- Use more camera!
  - To circumvent occlusions
  - To help for disambiguation
- On intrusion, V sends an urgent message to neighbors to end the current round
- from V's set of covers V selects the one that ensure the target's multi-coverage
- If ok, V goes to sleep mode and sends its status to its neighbors…
- …which in their turn schedule their activity, and a new round starts.

Intrusion detection (2)



The rectangular object (4×2m2) traverses a 100∗100m2 area where we have randomly dispersed 150 video nodes.

CC scenario in WSN

- Densely deployed sensors
  - Persistent hotspots
  - Congestion occur near the sources
- Sparsely deployed sensors, low rate
  - Transient hotspots
  - Congestion anywhere but likely far from the sources, towards the sink
- Sparsely deployed sensors, high rate
  - Both persistent and transient hotspots
  - Hotspot distributed throughout the network

Some ideas for CC in WSN

- Congestion detection
  - Monitor output buffer/queue size
  - Monitor channel busy time, estimate channel's load
  - Monitor the inter-packet arrival time (data, ctrl)
- Congestion notification
  - Explicit congestion notification in packet header, then broadcast (but then energy-consuming!)
- Congestion control
  - Dynamic reporting rate depending on congestion level
  - In-network data reduction techniques (agressive aggregation) on congestion

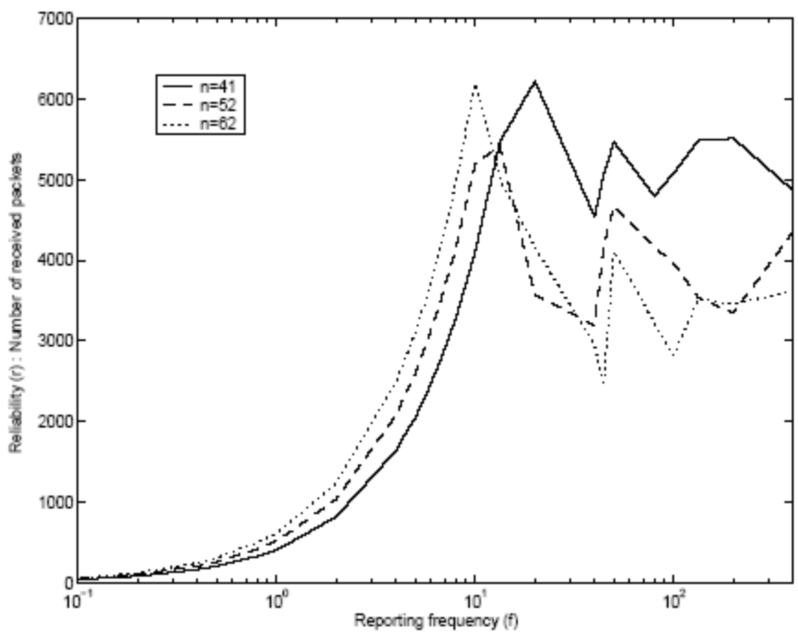
Ex: ESRT

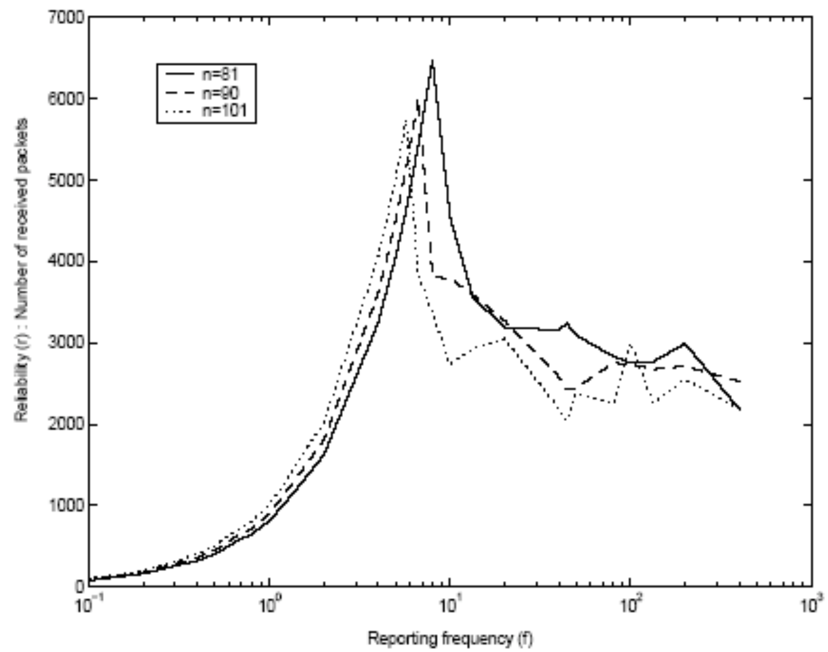
Event-to-Sink Reliable Transport

- Places interest on events, not individual pieces of data
- Application-driven: Application defines what its desired event reporting rate should be
- Runs mainly on the sink
- Main goal: Adjust reporting rate of sources to achieve optimal reliability requirements → event reliability

Y. Sankarasubramanian, O. B. Akan, and I. F. Akyildiz, "ESRT: Event-to-Sink Reliable Transport," in Proceedings of ACM MobiHoc'03

Reliability vs Reporting frequency





- Initially, reliability increases linearly with reporting frequency
- There is an optimal reporting frequency (f_{max}), after which congestion occurs
- F_{max} decreases when the # of nodes increases

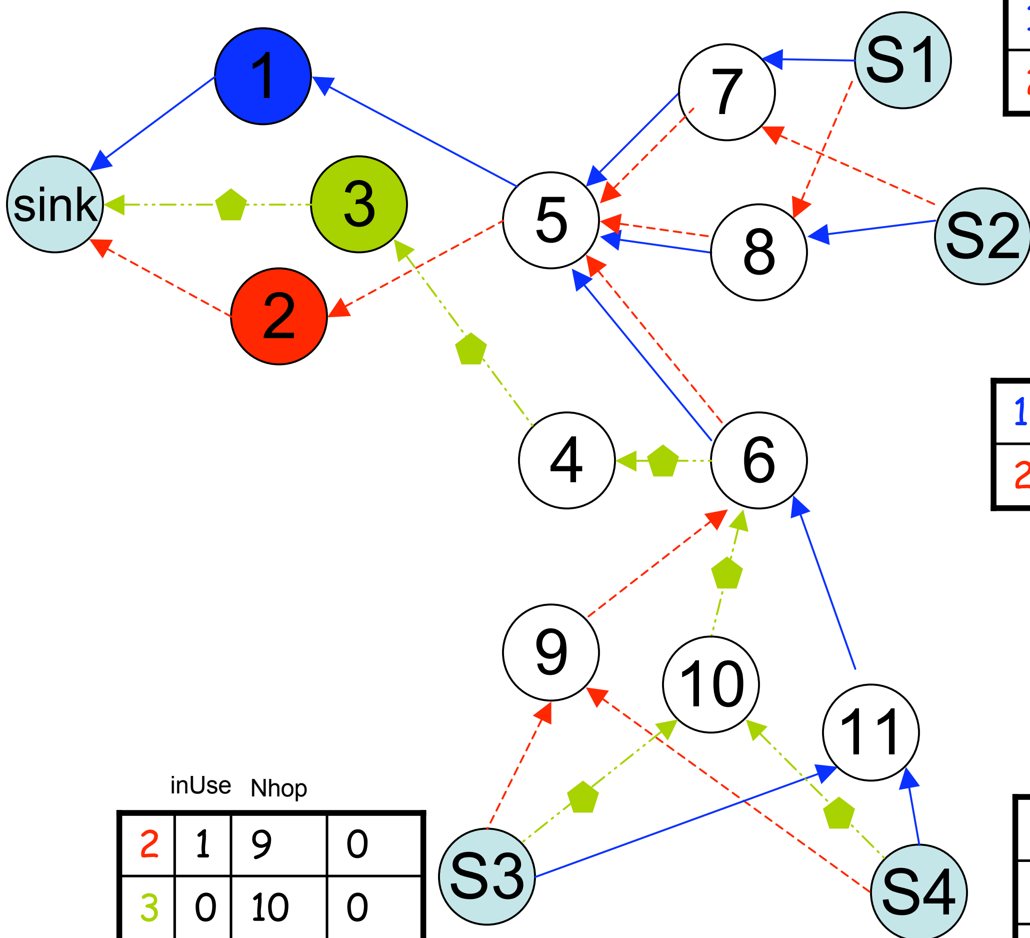
Which CC for WMSN?

- Approaches that reduce the reporting rate may impact on detection efficiency
- Some packets are more important than others in most of video coding schemes
- Collaborative in-network processing: Reduce asap the amount of (redundant) raw streams to the sink

Lightweight Load Repartition

- Keep sending rate, thus video quality, constant: surveillance & critical applications
- Suppose
  - path diversity: path-id
  - Congestion notifications from network: CN(node-id, path-id)
- Load repartition of video traffic on multiple paths

Path diversity



	inUse	Nhop	
1	1	7	0
2	0	8	0

	inUse	Nhop	
1	1	8	0
2	0	7	0

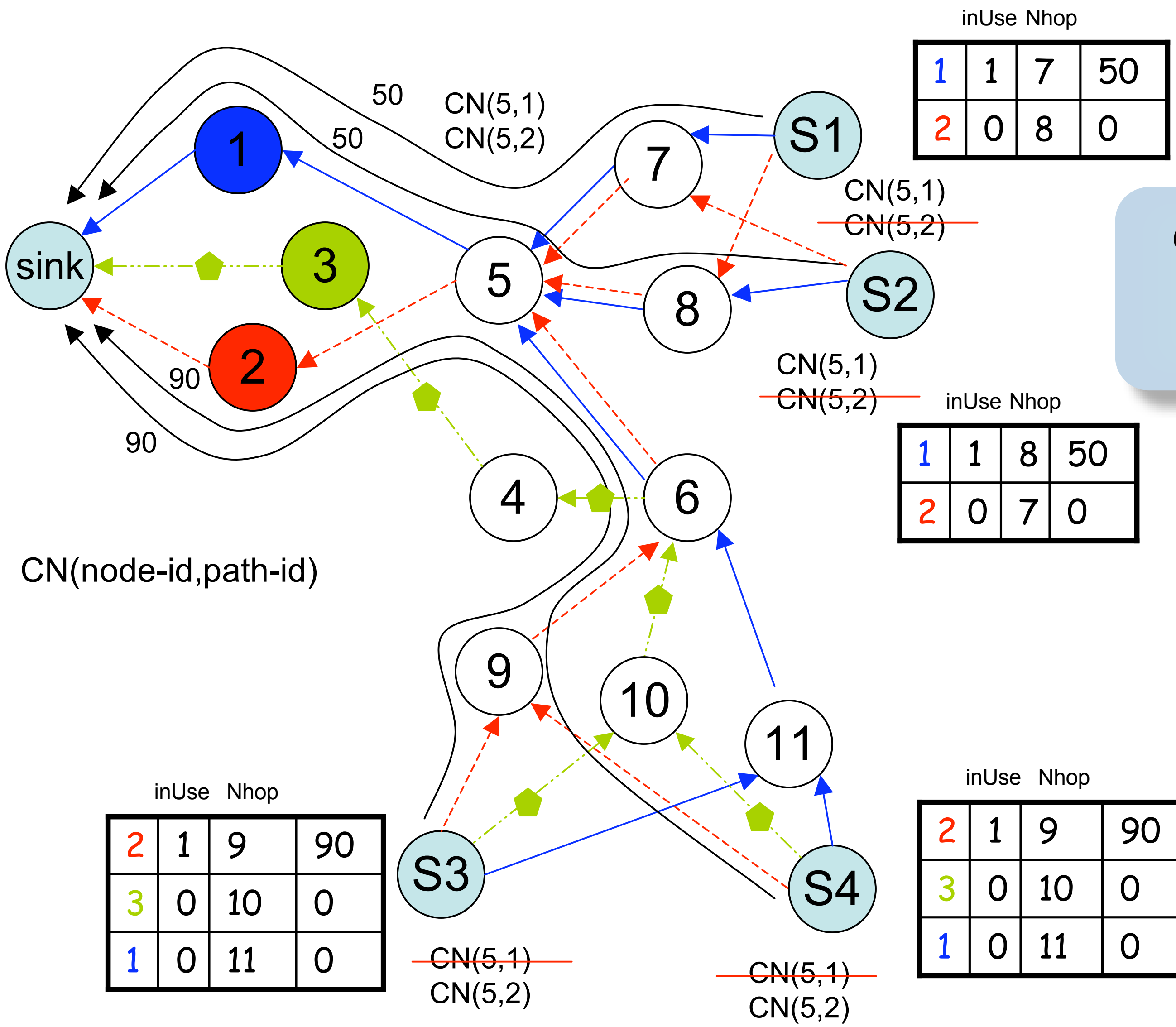
	inUse	Nhop	
2	1	9	0
3	0	10	0
1	0	11	0

	inUse	Nhop	
2	1	9	0
3	0	10	0
1	0	11	0

Load repartition modes

- Mode 0
  - no load-balancing
- Mode 1
  - uses all available paths from the beginning
- Mode 2
  - starts with 1 path, for each CN(nid,pid) adds a new path
- Mode 3
  - starts wih 1 path, for each CN(nid,pid) balance uniformly trafic load of path pid on all available paths (including path pid to avoid oscillation)

Node 5 is congested



	inUse	Nhop	
1	1	7	50
2	0	8	0

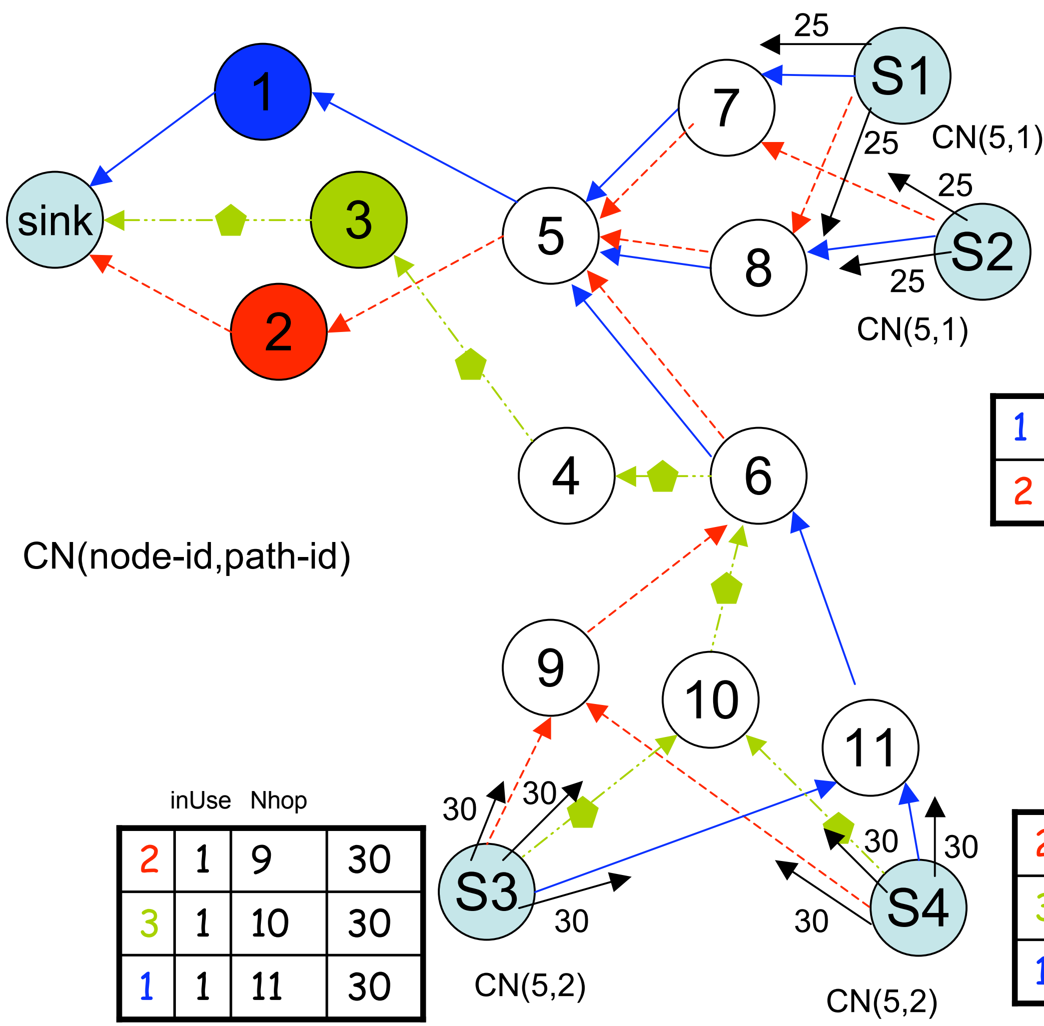
	inUse	Nhop	
1	1	8	50
2	0	7	0

	inUse	Nhop	
2	1	9	90
3	0	10	0
1	0	11	0

	inUse	Nhop	
2	1	9	90
3	0	10	0
1	0	11	0

Only active paths are concerned

Node 2 becomes congested



	inUse	Nhop	
1	1	7	25
2	1	8	25

	inUse	Nhop	
1	1	8	25
2	1	7	25

	inUse	Nhop	
2	1	9	30
3	1	10	30
1	1	11	30

	inUse	Nhop	
2	1	9	30
3	1	10	30
1	1	11	30

Load balance excess trafic of available paths

Some results (1)

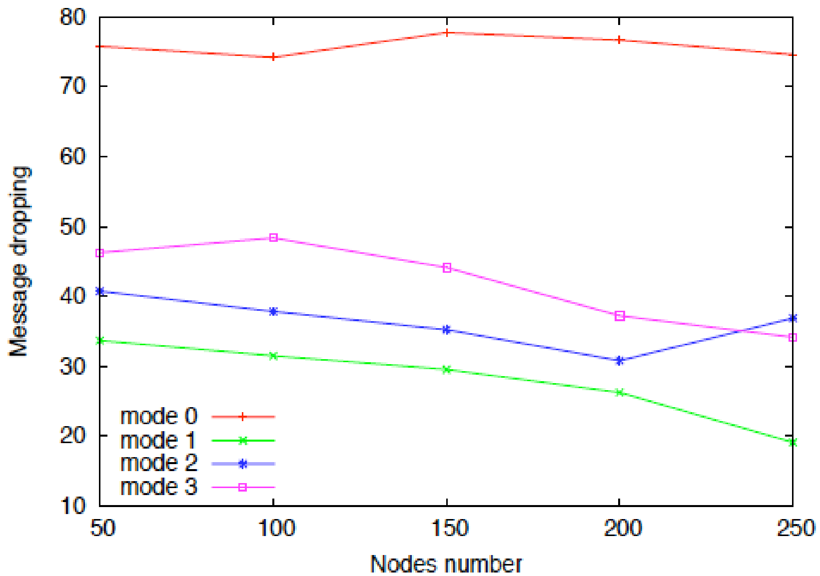


Fig. 4. Message dropping rate at sensor queues

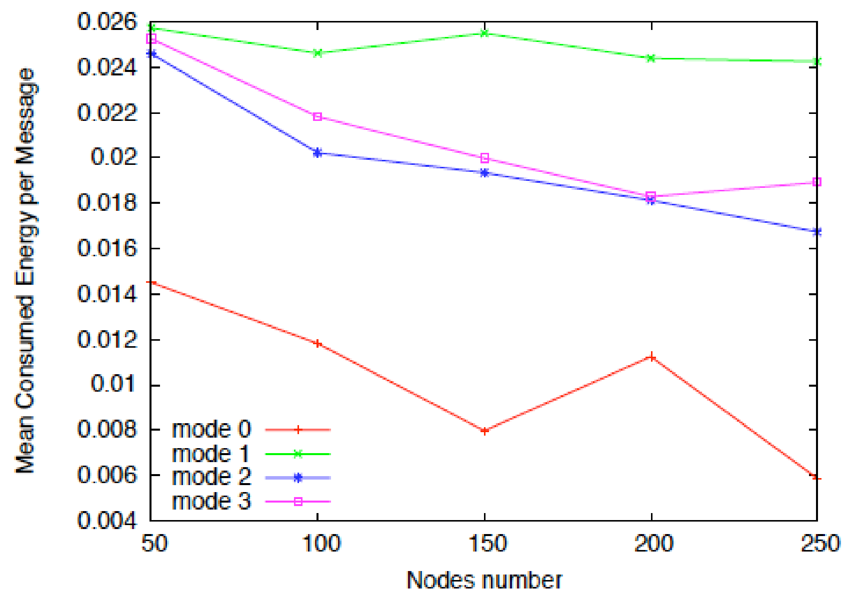


Fig. 7. Mean consumed energy per received packet

Some results (2)

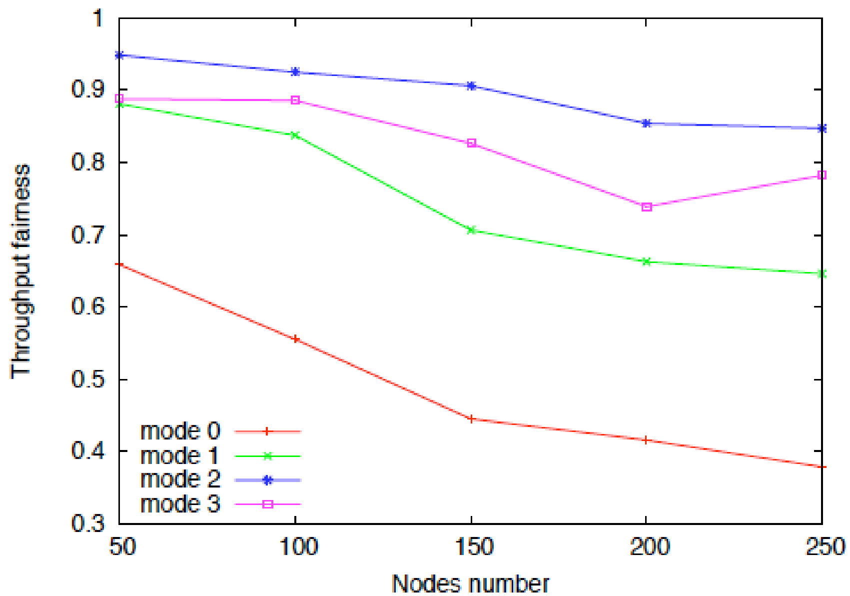


Fig. 5. Rate fairness among sources

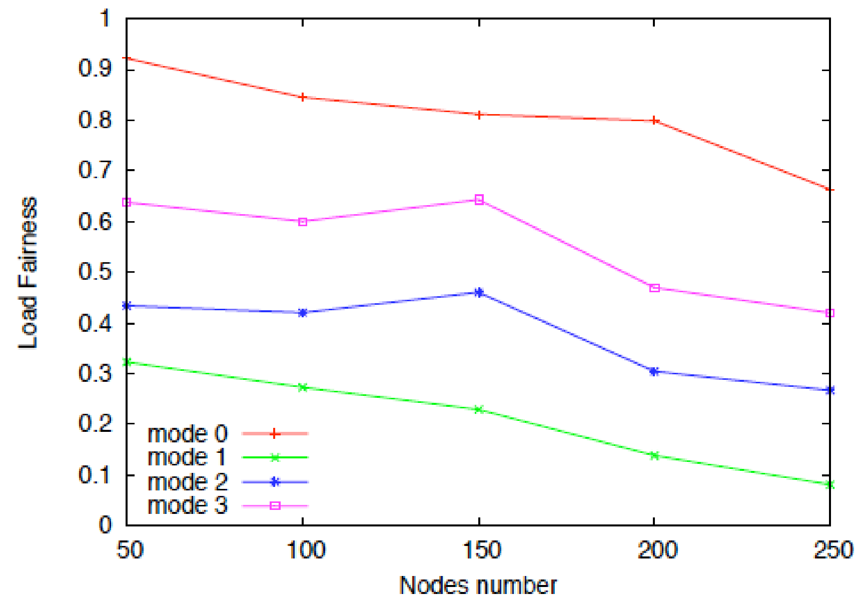
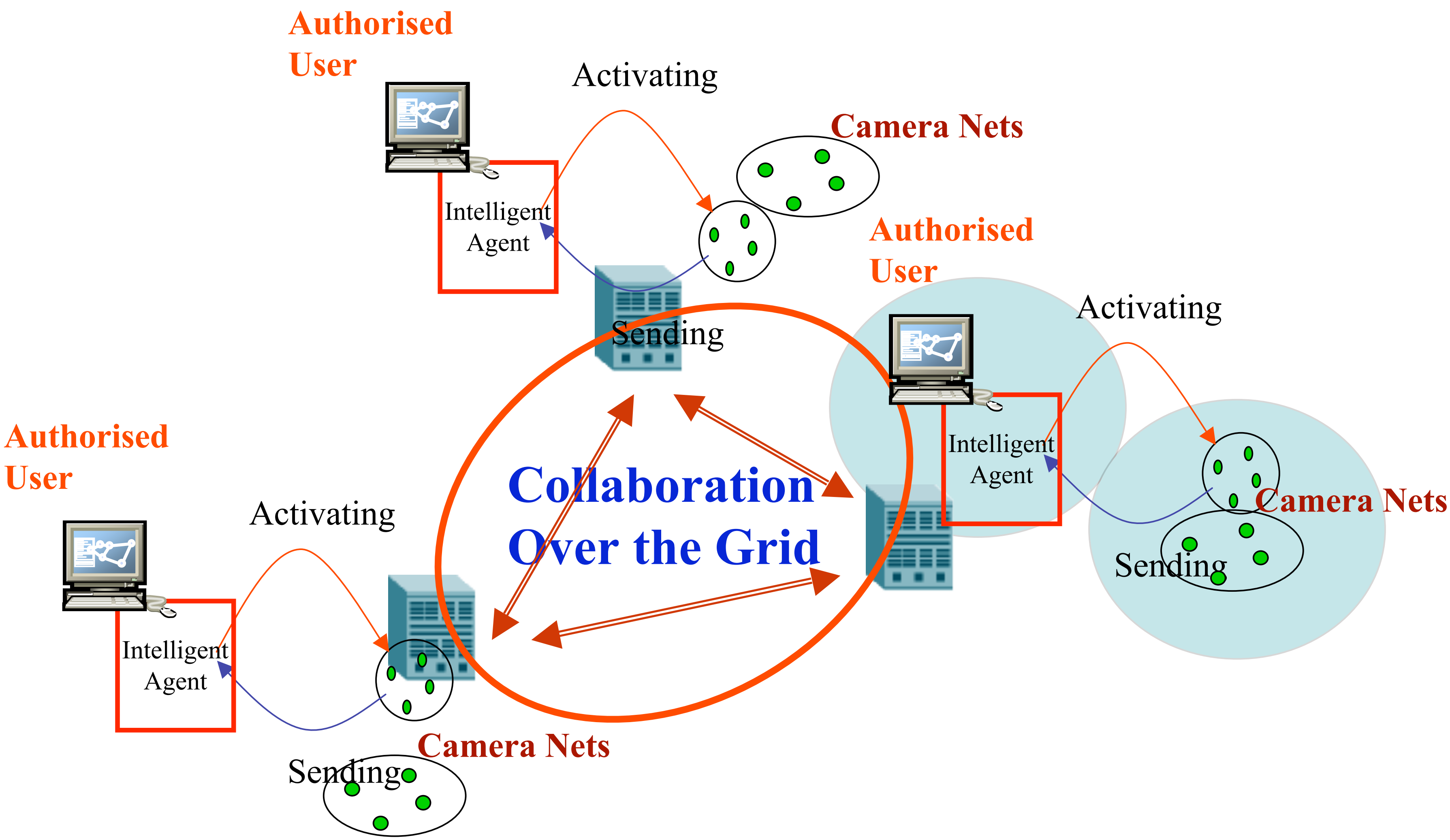


Fig. 6. Load fairness among active sensors

Towards the big picture

(with D. Hoang from UTS)



Conclusions

- New domain
- Mentioned scientific problems may be not new, but new parameters to take into account
  - Larger design space than traditional surveillance infrastructures
  - Larger design space than scalar sensors
- Lots of related domains where contributions could be done