Deployment of mission-critical surveillance applications on wireless sensor networks

NETCOM research group, IMDEA
University Carlos III of Madrid
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Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France
LIUPPA

COMPUTER SCIENCE LAB

32 FACULTY MEMBERS

25 PHD STUDENTS

2 RESEARCH TEAMS

MODELING, VISUALIZATION, EXECUTION & SIMULATION

INFORMATION PROCESSING, INTERACTIONS AND ADAPTATION
Deployment of mission-critical surveillance applications on wireless sensor networks
Deployment of mission-critical surveillance applications on wireless sensor networks
Surveillance applications (1)

Lesson 1: don't miss important events

What is captured

Whole understanding of the scene is wrong!!!
Surveillance applications (2)

Lesson 2: high-quality not necessarily good

333x358 16M colors, no light

167x180 16 colors, light

167x180 BW (2 colors), light

Keep in mind the goal of the application!
Lesson 3: don't put all your eggs in one basket

Several sources provide multi-view for disambiguation
Traditionnal surveillance infrastructure
Small, Autonomous Sensors

disaster relief - security

Organization of rescue in large scale disasters relief operations

Rapid deployment of fire detection systems in high-risk places
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
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
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

Cyclops video board on Mica motes

Multimedia board

128x128 140x140 240x240
Sensor as common object
toward very large scale deployment

Environmental monitoring
- air
- water

Cell-phones with embedded CO sensor
- most ubiquitous device (millions)
- not deployment cost
- high replacement rate
- no energy constraints
Wireless Sensor Network (1)
Wireless Sensor Network (2)

- Distributed system
- Ad-hoc network
Mission-critical surveillance applications

- **Availability**: 24/24 surveillance
  - Hardware: failures, energy depletion
  - Data

- **Quality**
  - Enhance/validate/disambiguate information with several sources of information
  - Adaptation to local conditions

- **Reliability/integrity**
  - Hardware
  - Network
  - Data

**QoS**

- Internet
- Ad-hoc networks
- Embedded systems
- multimédia

WSN
Surveillance as a Service

Similar to Service Level Agreement

ACCOUNTABILITY

SURVEILLANCE AT ANY PRICE

no discontinuity of service against node’s failures
data availability and reliability
Surveillance as a service: Accountability

Software architecture, middleware, supervision&control, adaptative components, optimization, heuristic…
Ex: intrusion detection (1)

Surveillance as a service: adaptivity and reconfiguration

Accelerometer could serve as detector if the sensor is kicked by the intruder

Light sensor could serve as detector if the intruder rapidly occult the sensor

Sleep mode

Internet
Ex: intrusion detection (2)

Cooperation, training, knowledge transmission

Internet

Wake up!
Towards smart sensor grids

- The ultimate goal is to define a customizable sensor grid that could be dynamically programmed according to the application’s objectives and needs
- Similar to the so-called active networking concept for the Internet...
- ...but much easier to achieve!!
The Internet we wanted, the one we have...

<table>
<thead>
<tr>
<th>End-to-end Quality of Service</th>
<th>No Quality of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed processing</td>
<td>Very centralized architecture</td>
</tr>
<tr>
<td>Internet-wide, uniform control and policies</td>
<td>Heterogeneous and domain/ISP specific policies</td>
</tr>
<tr>
<td>Fast integration of new needs, new applications, new technologies</td>
<td>Upgrades and incremental deployments are slow</td>
</tr>
</tbody>
</table>
Net Neutrality or Not?

- The Internet’s success is in a large part debtful to what’s called Net Neutrality (IP neutrality).

- But, Net Neutrality is the main brake for achieving large scale QoS: IP routers only forward packets!

- Some services can be best supported or enhanced using information that is only available inside the network!

- Fortunately, in a sensor network, each node has de-facto specific processing capabilities.
One vision for enabling QoS in Sensor Nets (1)

AVOIDS THE BLACK-BOX VISION
One vision for enabling QoS in Sensor Nets (2)

AVOIDS THE BLACK-BOX VISION
Research issues in WSN

- ENERGY CONSIDERATIONS
  - NETWORK
  - SIGNAL IMAGE/VIDEO PROCESSING
  - OS MIDDLEWARE SOFT. ENG.
  - DATA MNGT
  - HARDWARE RADIO

- QoS
  - ORGANIZATION OVERLAYS
  - TRANSPORT
  - ROUTING
  - MAC RESOURCES ALLOCATION

- SECURITY
Middleware/app. issues we address

- ENERGY CONSIDERATIONS
  - NETWORK
  - SIGNAL IMAGE/VIDEO PROCESSING
  - OS MIDDLEWARE SOFT. ENG.
  - DATA MNGT
  - HARDWARE RADIO

- QoS
  - CBSE for SENSOR NODE DYNAMIC RECONFIGURATION
  - SERVICE-ORIENTED SERVICE REPOSITORY
  - ADAPTIVE APPLICATION

- SENSOR'S OS
- SUPERVISION PLATFORM
- APPLICATIONS

issues we address
Supervision platform
M. Dalmau & P. Roose

- 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
Dynamic reconfiguration (1)
N. Hoang (PhD student)

- Avoids monolithic OS (à la TinyOS)
- We use the Think framework, which is an implementation of the Fractal component model to generate dynamic and reconfigurable OS and services
- First step towards the « active and programmable networking » concept applied to Wireless Sensor Networks
Dynamic reconfiguration (2)

- 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

\[ F_{1,t0}(A) \]  
\[ F_{1,t1}(A) \]  
\[ F_{2,t0}(A) \]  
\[ F_{2,t1}(A) \]

T=0  
T=1  
T=2
Network issues we address

ENERGY CONSIDERATIONS

NETWORK

SIGNAL IMAGE/VIDEO PROCESSING

OS MIDDLEWARE SOFT. ENG.

DATA MNGT

HARDWARE RADIO

NETWORK OVERLAYS

TRANSPORT

ROUTING

MAC RESOURCES ALLOCATION

QoS

VIDEO COVERAGE SELECTION & WAKE-UP MECHANISM

LOAD-REPARTITION CONGESTION CONTROL

MULTI-PATHS ROUTING

NETWORK issues we address
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
- Resources 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.

Diagram:

- **Sentry node**: node with high speed capture (high cover set).
- **Critical node**: node with high speed capture (node that detects the intrusion).
- **Idle node**: node with low speed capture.

Take into account the application’s criticality level.
All surveillance applications may not have the same criticality level, $r^0 \in [0,1]$

- Environmental, security, healthcare,…

Capture speed should decrease when $r^0$ decreases

Sensor nodes could be initialized with a given $r^0$ prior to deployment
How to meet 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
Video Sensor Nodes

Imote2

Multimedia board
Node’s cover set

- Each node \( v \) has a Field of View, \( \text{FoV}_v \)
- \( \text{Co}_i(v) = \) set of nodes \( v' \) such as \( \bigcup_{v' \in \text{Co}_i(v)} \text{FoV}_{v'} \) covers \( \text{FoV}_v \)
- \( \text{Co}(v) = \) set of \( \text{Co}_i(v) \)

\[
\text{Co}(v) = \{V_1, V_2, V_3, V_4\}
\]
Finding v’s cover set

\[ P = \{ v \in N(V) : v \text{ covers the point ”} p \text{” of the FoV} \} \]
\[ B = \{ v \in N(V) : v \text{ covers the point ”} b \text{” of the FoV} \} \]
\[ C = \{ v \in N(V) : v \text{ covers the point ”} c \text{” of the FoV} \} \]
\[ G = \{ v \in N(V) : v \text{ covers the point ”} g \text{” of the FoV} \} \]

\[ PG = \{ P \cap G \} \]
\[ BG = \{ B \cap G \} \]
\[ CG = \{ C \cap G \} \]
\[ Co(v) = AG \times BG \times CG \]
Small Angle of View

Co(V) = \{ \emptyset \} 

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_5 \}, 
\{ V_1, V_4, V_6 \}, 
\{ V_2, V_4, V_5 \}, 
\{ V_2, V_4, V_6 \}, 
\{ V_4, V_5, V_6 \} 
\}
Heterogeneous AoV
Accuracy of cover set (1)

\[ \text{Co}(V) = \{ \{ V \}, \{ V_1, V_3, V_4 \}, \{ V_2, V_3, V_4 \}, \{ V_3, V_4, V_5 \}, \{ V_1, V_4, V_6 \}, \{ V_2, V_4, V_6 \}, \{ V_4, V_5, V_6 \} \} \]
**Accuracy of cover set (2)**

### Table 1: Accuracy of Cover Set (2)

<table>
<thead>
<tr>
<th>COV</th>
<th>% nodes with coverset</th>
<th>mean % coverage</th>
<th>min, max % coverage per coverset</th>
<th>stddev of % coverset</th>
<th>min, max #coverset per node</th>
<th>mean #coverset per node</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV$_{360<em>60,600</em>60}$</td>
<td>75</td>
<td>11.56</td>
<td>83.36</td>
<td>70.20, 93.99</td>
<td>9.12</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>16.33</td>
<td>86.88</td>
<td>61.52, 99.50</td>
<td>11.21</td>
<td>1.13, 33</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>29.07</td>
<td>89.07</td>
<td>63.14, 100</td>
<td>9.20</td>
<td>1.24, 66</td>
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<td>150</td>
<td>33.56</td>
<td>88.01</td>
<td>56.18, 99.99</td>
<td>10.06</td>
<td>1.40</td>
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<tr>
<td></td>
<td>175</td>
<td>43.81</td>
<td>88.52</td>
<td>58.76, 99.97</td>
<td>9.02</td>
<td>1.45, 33</td>
</tr>
<tr>
<td>COV$_{360<em>60,600</em>60}$</td>
<td>75</td>
<td>8.44</td>
<td>85.81</td>
<td>71.60, 96.59</td>
<td>10.22</td>
<td>1.56</td>
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<tr>
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<td>100</td>
<td>12.33</td>
<td>79.34</td>
<td>56.33, 94.49</td>
<td>12.08</td>
<td>1.33, 14</td>
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<td>150</td>
<td>18.22</td>
<td>76.92</td>
<td>54.17, 97.23</td>
<td>11.81</td>
<td>1.34</td>
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<td></td>
<td>175</td>
<td>24.95</td>
<td>75.21</td>
<td>55.92, 26</td>
<td>9.33</td>
<td>1.66, 99, 33</td>
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<tr>
<td>COV$_{360<em>20,600</em>20}$</td>
<td>75</td>
<td>16</td>
<td>81.97</td>
<td>60.34, 100</td>
<td>11.84</td>
<td>1.9</td>
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<td>100</td>
<td>15</td>
<td>88.34</td>
<td>69.60, 100</td>
<td>9.00</td>
<td>1.12</td>
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<tr>
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<td>125</td>
<td>14.40</td>
<td>85.16</td>
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<td>1.12</td>
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<td>28.67</td>
<td>85.95</td>
<td>57.38, 100</td>
<td>10.88</td>
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<td>175</td>
<td>33.43</td>
<td>58.94</td>
<td>54.34, 100</td>
<td>11.86</td>
<td>1.32</td>
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<tr>
<td>COV$_{360<em>20,600</em>20}$</td>
<td>75</td>
<td>10.67</td>
<td>83.39</td>
<td>57.20, 97.34</td>
<td>14.34</td>
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<td>56.86, 95.58</td>
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<td>1.48</td>
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<td>47.63</td>
<td>81.92</td>
<td>55.51, 100</td>
<td>11.18</td>
<td>1.48</td>
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<tr>
<td></td>
<td>175</td>
<td>54.86</td>
<td>80.18</td>
<td>51.84, 98.24</td>
<td>10.41</td>
<td>1.12, 0</td>
</tr>
</tbody>
</table>
Node's # of cover set

175 nodes, AoV=36°, COVwaGpv strategy
Defining sentry nodes

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

![Diagram with sentry and idle nodes](image-url)
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

\[ B(t) = (1 - t)^2 \ast P_0 + 2t(1 - t) \ast P_1 + t^2 \ast P_2 \]
Some typical capture speed

- Maximum capture speed is 6fps
- Nodes with size of cover set greater than \( N \) capture at the maximum speed

| \( r^0 \) | \( |Co(v)| \) | 1   | 2   | 3   | 4   | 5   | 6   |
|---------|------------|-----|-----|-----|-----|-----|-----|
| 0       | 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|

<table>
<thead>
<tr>
<th>( r^0 )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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<td>0</td>
<td>.01</td>
<td>.02</td>
<td>.05</td>
<td>.17</td>
<td>.26</td>
<td>.38</td>
<td>.54</td>
<td>.75</td>
<td>1.1</td>
<td>1.5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>.2</td>
<td>.07</td>
<td>.15</td>
<td>.25</td>
<td>.37</td>
<td>.51</td>
<td>.67</td>
<td>.86</td>
<td>1.1</td>
<td>1.4</td>
<td>1.7</td>
<td>2.2</td>
<td>3</td>
</tr>
<tr>
<td>.4</td>
<td>.17</td>
<td>.35</td>
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<td>.75</td>
<td>.97</td>
<td>1.2</td>
<td>1.4</td>
<td>1.7</td>
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<td>1.5</td>
<td>1.9</td>
<td>2.2</td>
<td>2.4</td>
<td>2.6</td>
<td>2.7</td>
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<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
320x200, 30 fps, 256 gray scale, 15Mbps raw

5 fps, 4 gray scale, 640kbps raw

2 fps, 4 gray scale, 256kbps raw

1 fps, 4 gray scale, 128kbps raw
Simulation settings

- **OMNET++ simulation model**
- Video nodes have communication range of 30m and depth of view of 25m, AoV is 36°. 150 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.
Percentage of coverage, active nodes (1)
Percentage of coverage, active nodes (2)

- $r^\circ = 0.2 \Rightarrow 0.32\text{fps}$
- $r^\circ = 0.4 \Rightarrow 0.56\text{fps}$
- $r^\circ = 0.6 \Rightarrow 0.83\text{fps}$
- $r^\circ = 0.8 \Rightarrow 1.18\text{fps}$
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
mean stealth time
stealth time, winavg[10]
stealth time, winavg[10]
Conclusions

- Surveillance applications have a high level of criticity which make accountability important
- Criticality model with adaptive scheduling of nodes
- Optimize the resource usage by dynamically adjusting the provided service level
- Extension for risk-based scheduling in intrusion detection systems
Research directions

PERVASIVE AND UBIQUITOUS SYSTEMS

DATA MNGT

RESOURCE CONTROL

MONITORING INTEGRITY

SCHEDULING

ORGANIZATION
Controlled propagation (1)

- **Sentry node:** node with high speed capture (high cover set).
- **Idle node:** node with low speed capture.
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
Congestion control (1)

- Lot’s of sensor nodes = lot’s of traffic
- High probability of bottleneck, lot’s of packet drop, no useful data back to user!
- Scheduling is tightly linked to resource control to be efficient
- Scheduling is then not only find these nodes that «see» the event, but also how to select a subset of those nodes that minimizes congestion
Congestion control (2)
Congestion control (3)
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 speed (probably high speed)
  - How define different the target frame capture speed for each node of the same cover set?
Towards wide-area situation awareness

Combination of randomly and manually deployed sensors

Madrid Hospital

Smart GRID

Sensor Grid

Sending

Activating

Authorised User

Intelligent Agent

Resource Control

Data Management

Monitoring

Organization

Scheduling

Integrity

Pervasive and Ubiquitous Systems

Authorised User