# Fence Monitoring – Experimental Evaluation of a Use Case for Wireless Sensor Networks

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# Fence Monitoring – The Basic Idea


# Outline

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- **Motivation / Goals**
- Problem Statement / Conceptual Approach
- Experiments / Results
- Future Work / Conclusion

# Motivation

- In-network data processing is a key feature of Wireless Sensor Networks (WSNs)
  - Reduce communication with base station
  - Extend network lifetime
- Example: Distributed event detection
  - Decide locally, within the n-hop neighborhood, whether an event occurred
  - Send only confirmed events to the base station, not raw data
- Use case: Fence monitoring
  - Realistic use case in field of area/border security
  - Challenging task for event detection algorithm
  - Interesting properties:
    - User not interested in raw data
    - Aggregation / multi-hop routing inherent to application

# Goals

1. Prove feasibility of fence monitoring with current WSN technology
   - Set up working system

2. Quantify impact of event detection algorithm
   - Focus on differences between node-local and distributed event detection

3. Develop systematic approach to building a light-weight event detection and reporting architecture

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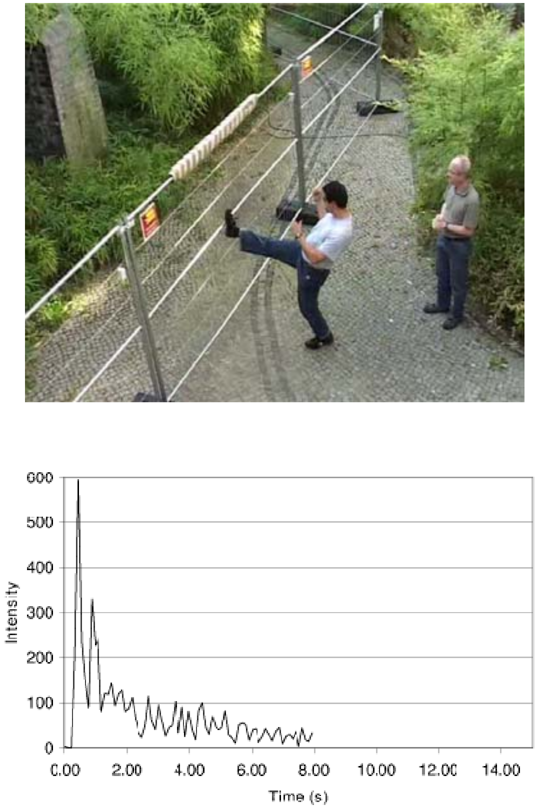
# Experimental Setup

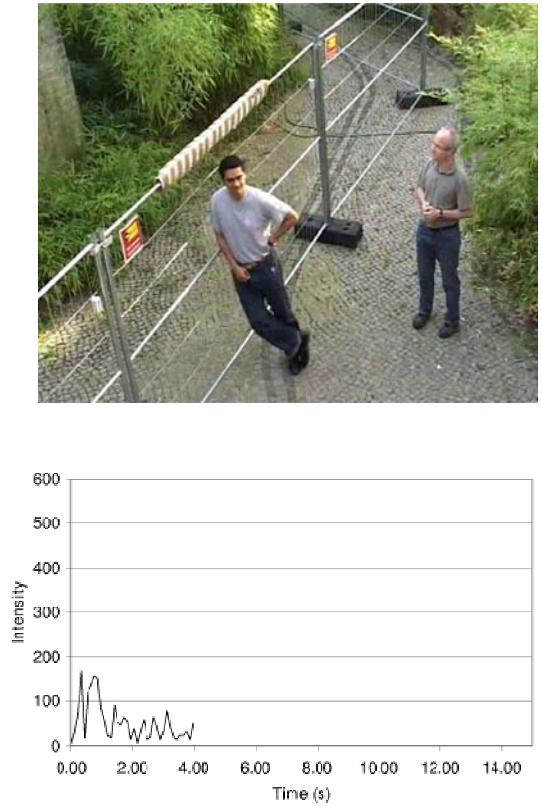

- Ten-element construction fence, each element 3.5m x 2m
- One ScatterWeb MSB sensor node per fence element
- Weather-proof junction boxes (80mm × 40mm) as casing

# Problem Statement (Video)

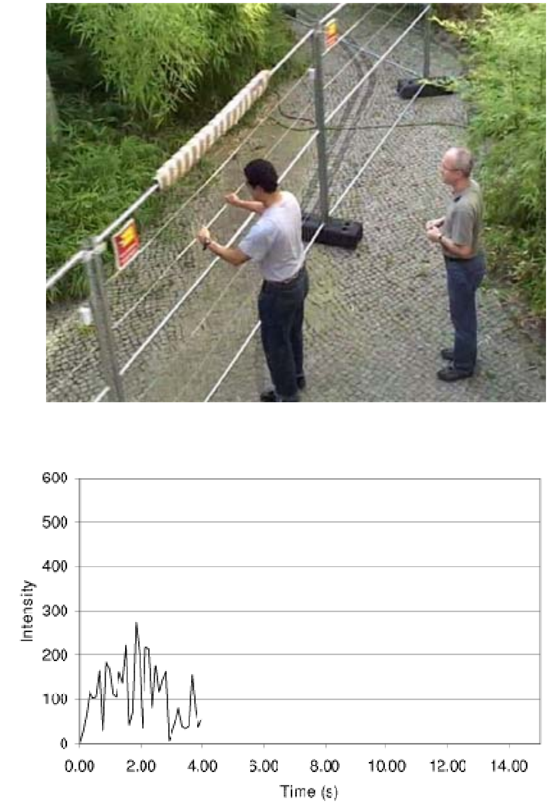
# Raw Data of Different Event Types




Kick event



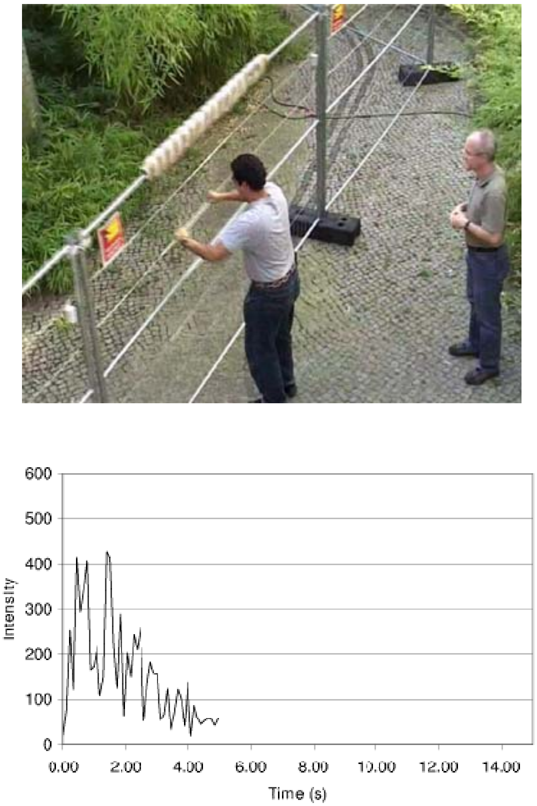

Lean event



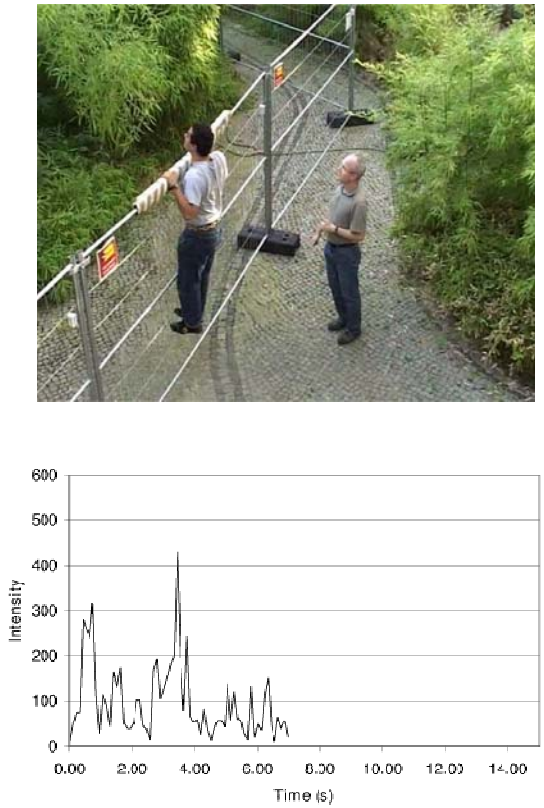

Shake (short) event

# Raw Data of Different Event Types

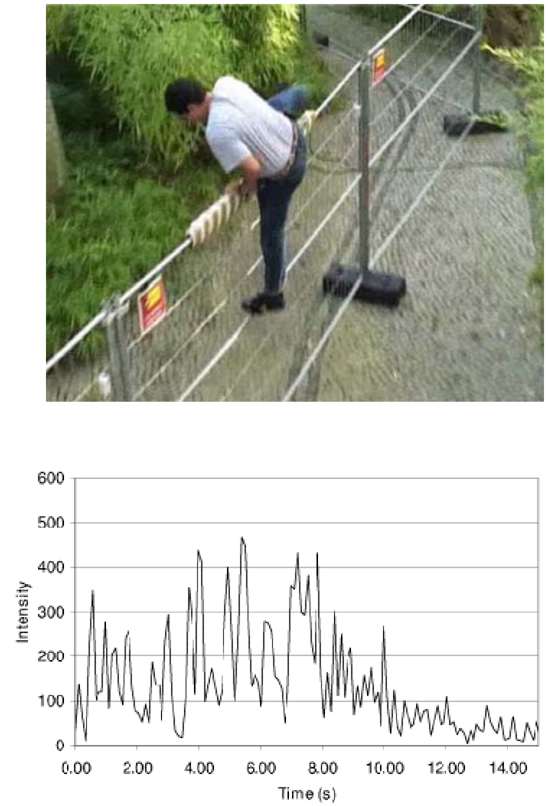





Shake (long) event

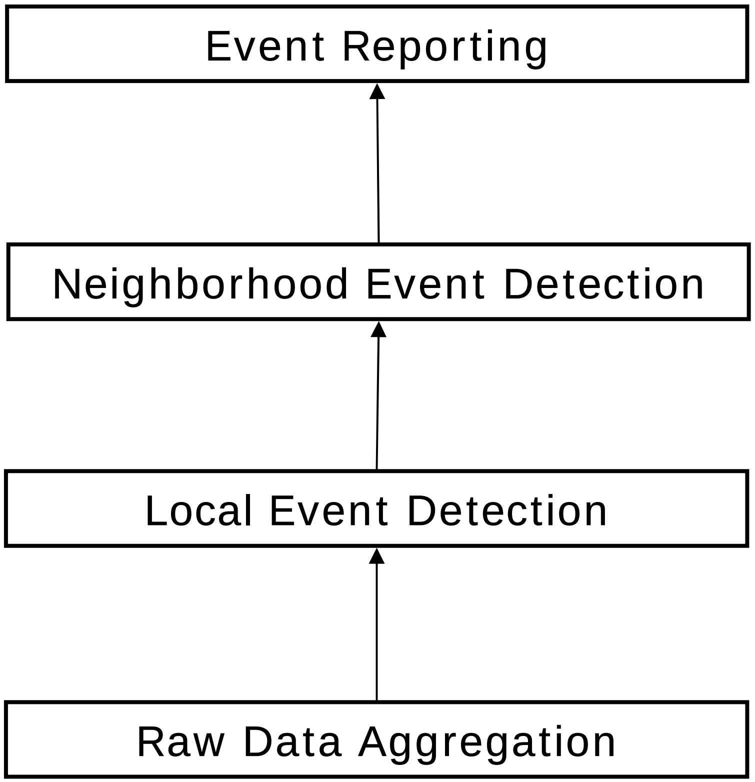



Peek event




Climb event

# Layered Event Detection Architecture




**Event Reporting**
- Route confirmed events to base station

**Neighborhood Event Detection**
- Communicate with other nodes to confirm/disconfirm event candidate
- ➢ Generate ***confirmed events***

**Local Event Detection**
- Classify event based on properties of basic events
- ➢ Generate ***event candidates***

**Raw Data Aggregation**
- Extract key features from raw data
- Adjust sampling rate of sensor
- ➢ Generate ***basic events***

# Raw Data Aggregation

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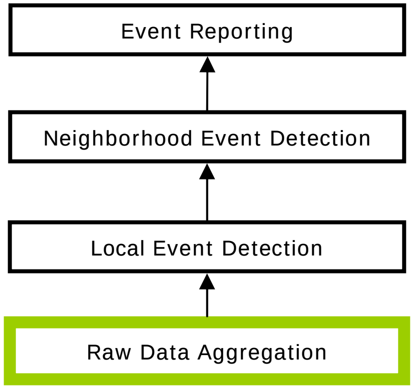
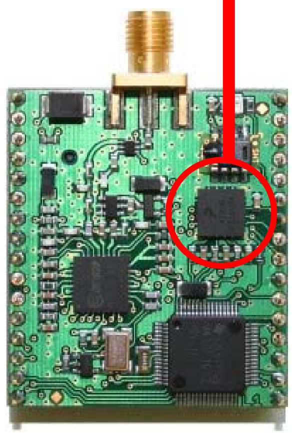
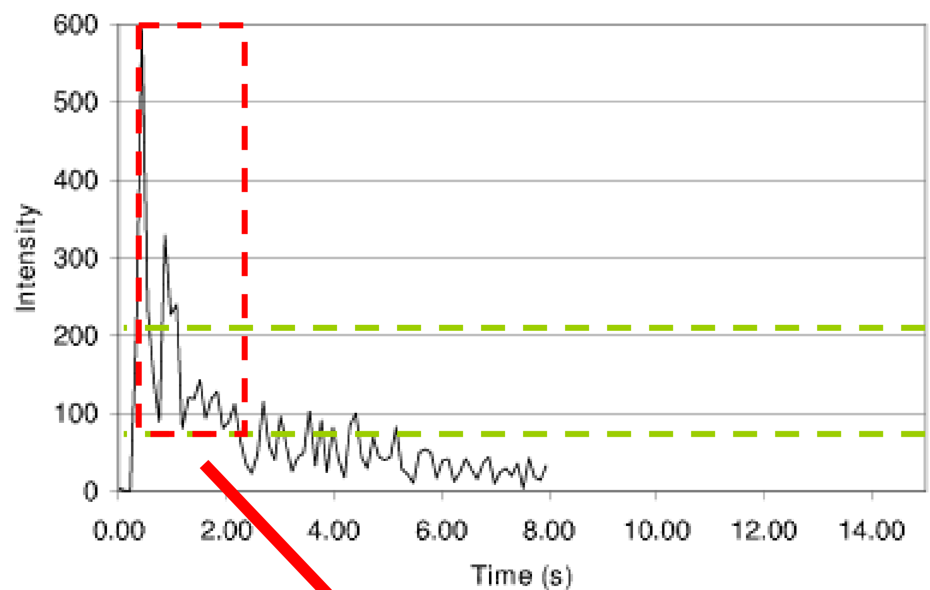



Freescale Semi-conductor MMA7260Q Accelerometer



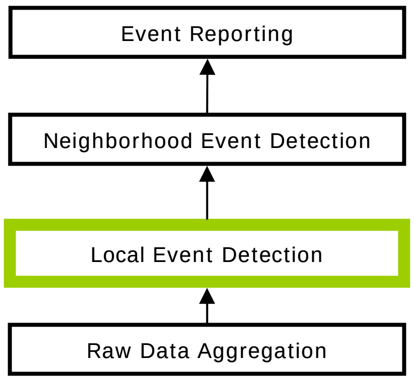
ScatterWeb MSB Sensor Node

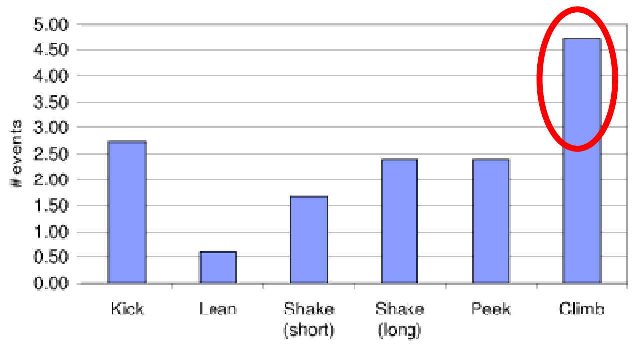
Intensity I = $|(vx\_last - vx\_cur)|$
$+ |(vy\_last - vy\_cur)|$
$+ |(vz\_last - vz\_cur)|$



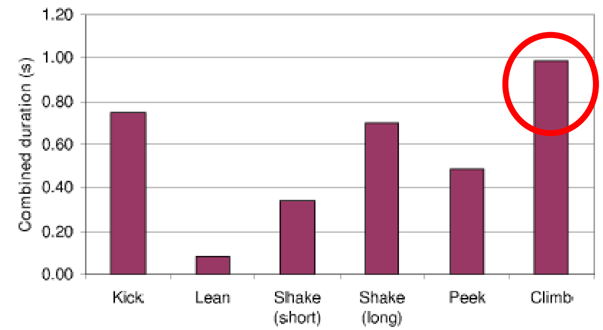

Basic Event

# Local Event Detection




Number of events

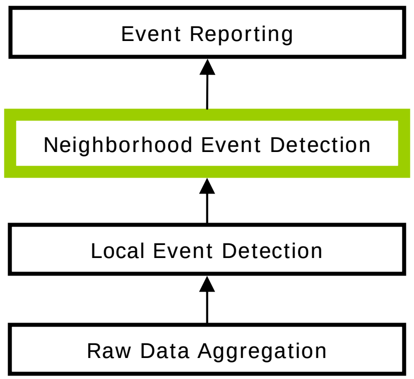


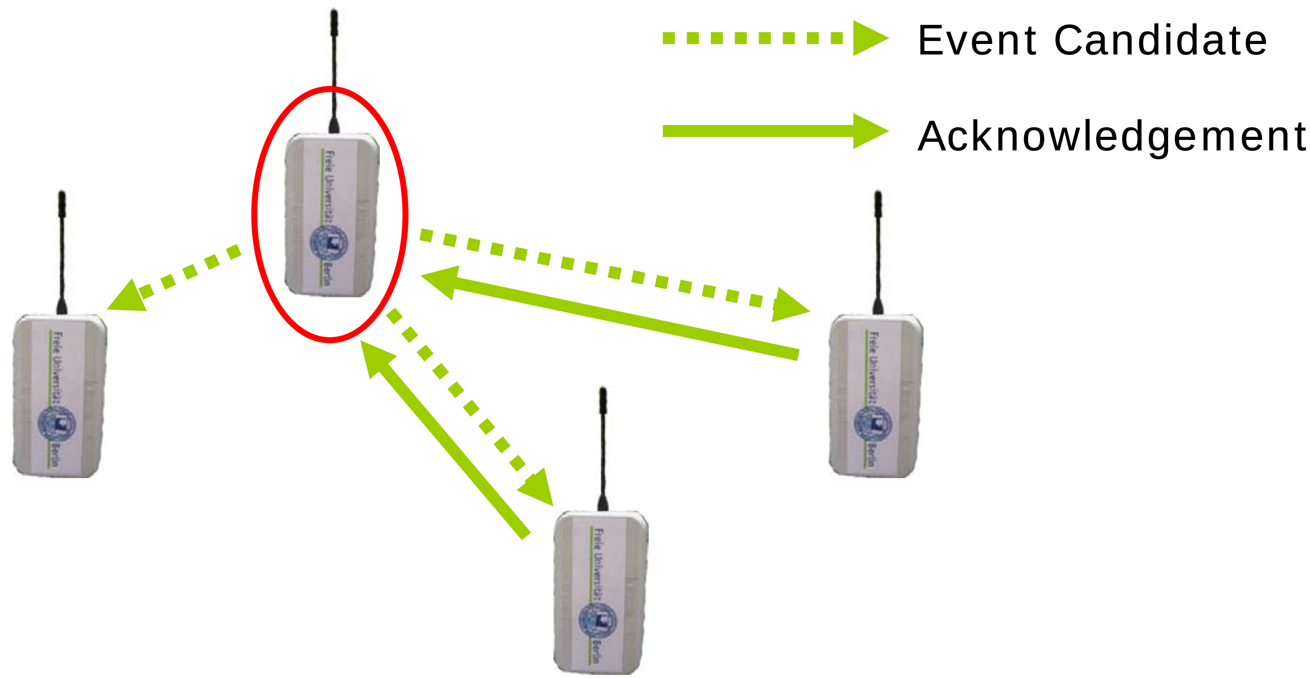

Combined duration

```
rule aggregateBasicEvents 100
<- eval ((count {basicEvent}) >= minBasicEventCount)
<- eval ((sum {basicEvent duration}) >= minDuration)
<- eval ((sum {basicEvent duration}) <= maxDuration)
-> define eventCandidate
        [intensity = (max {basicEvent intensity})]
-> retract {basicEvent}
```

Event Candidate

# Neighborhood Event Detection

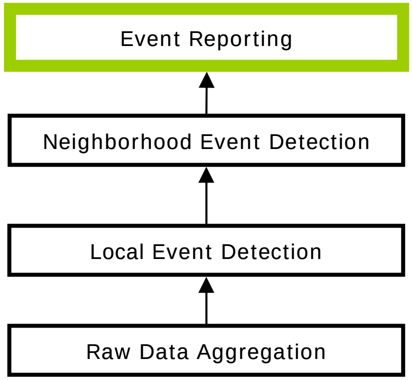


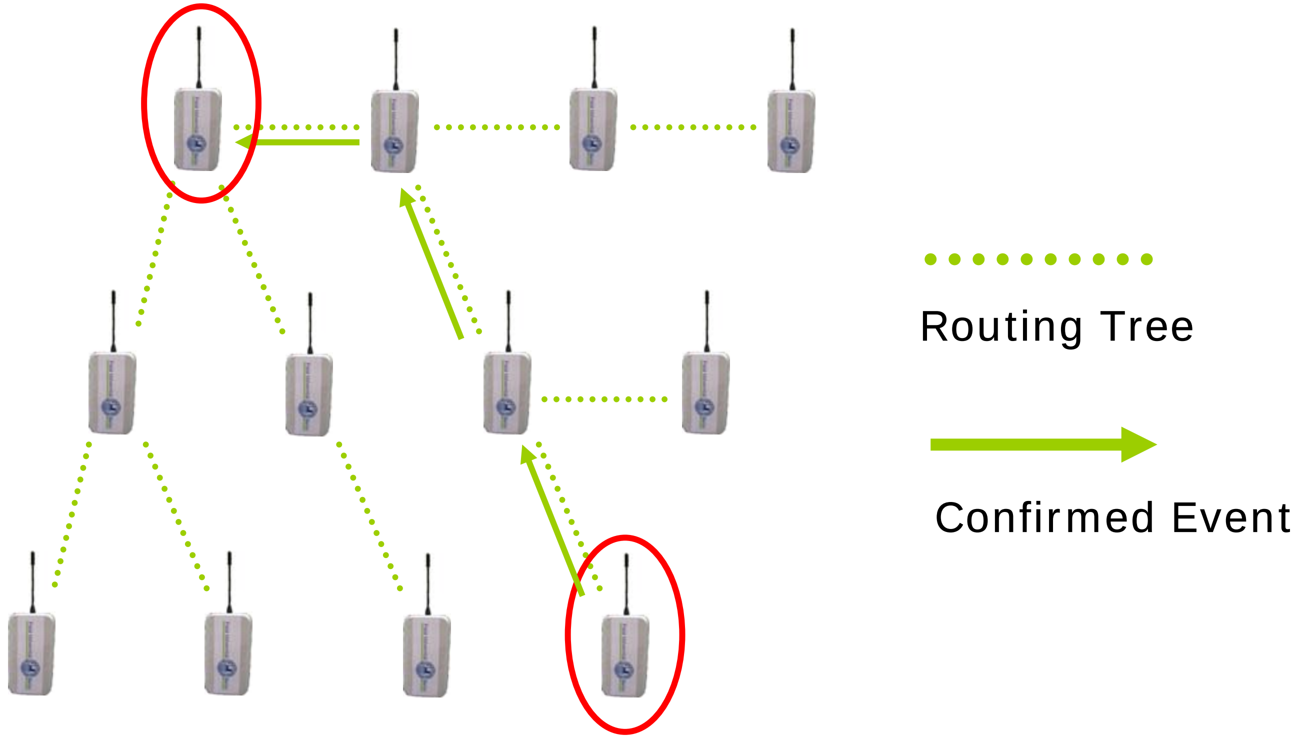




```
rule evalAcksOnTimeout 110
<- exists {timerExpired}
<- eval ((count {ack}) >= minAckCount)
-> define confirmedEvent
         [intensity = {eventCandidate intensity}]
```

Confirmed Event

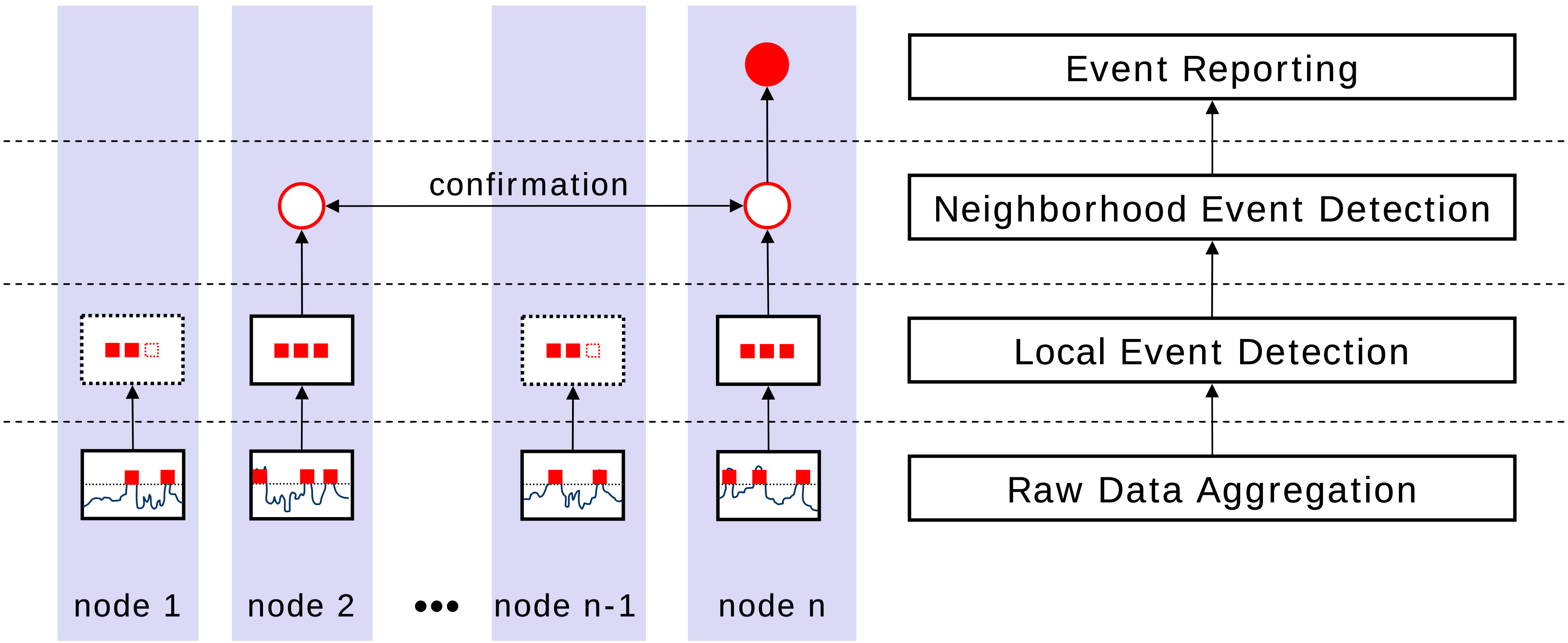
# Event Reporting




```
rule routeAlertsToSink 225
<- exists {confirmedEvent}
-> send {route nextHop} systemTxRange {confirmedEvent}
-> retract {confirmedEvent}
```

# Distributed Event Detection




Layers of the Distributed Event Detection Algorithm

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# Accuracy Metrics

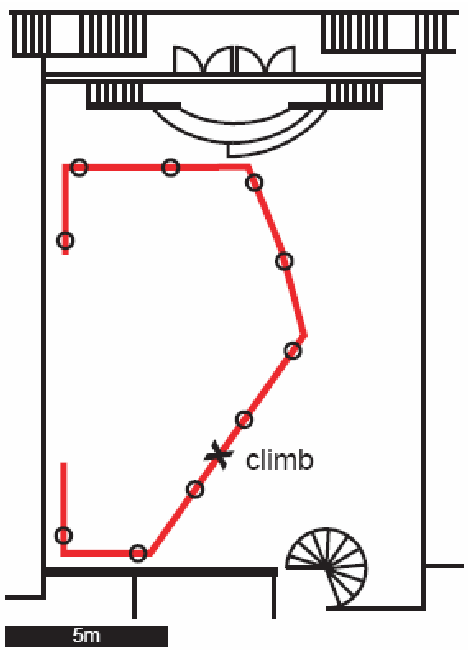


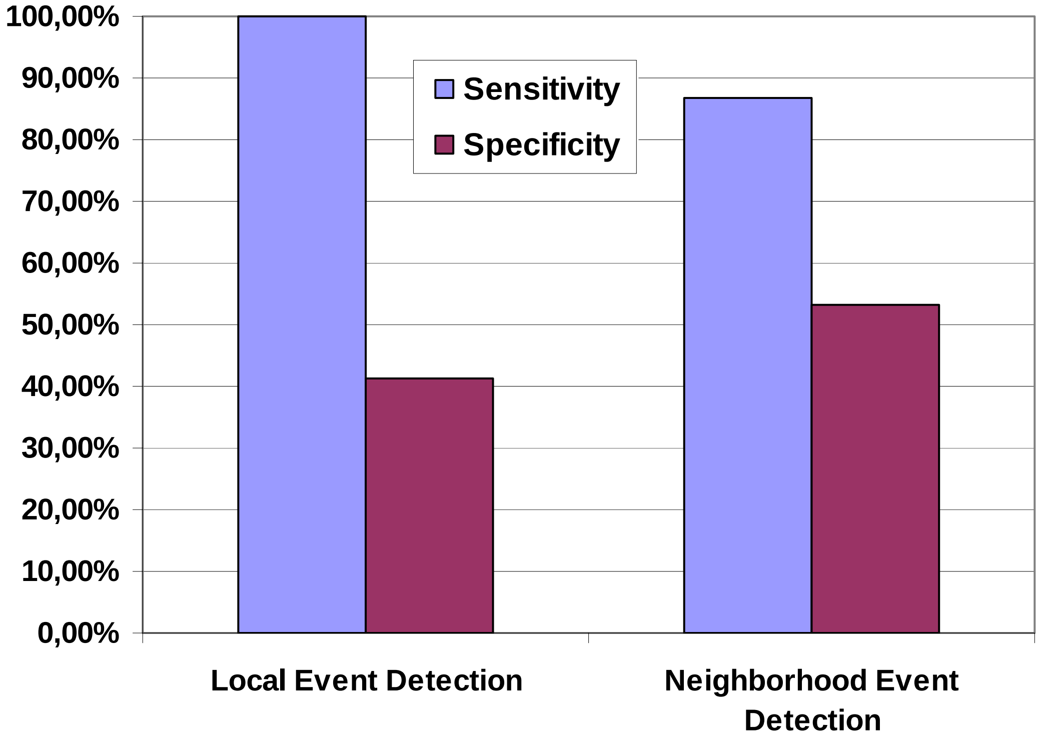
- Sensitivity
  - Ratio of correctly identified target events and all target events that occurred
  - Sensitivity = **#true positives** / (**#true positives** + **#false negatives**)

- Specificity
  - Ratio of correctly neglected other events and all other events
  - Specificity = **#true negatives** / (**#true negatives** + **#false positives**)

➢ Ideally, specificity = sensitivity = 100%

# Results – Experiment




- 40+ test runs comprising all six event types
  - 10 runs to calibrate raw data aggregation
  - 15 runs to calibrate local event detection

# Results – Simulation (1)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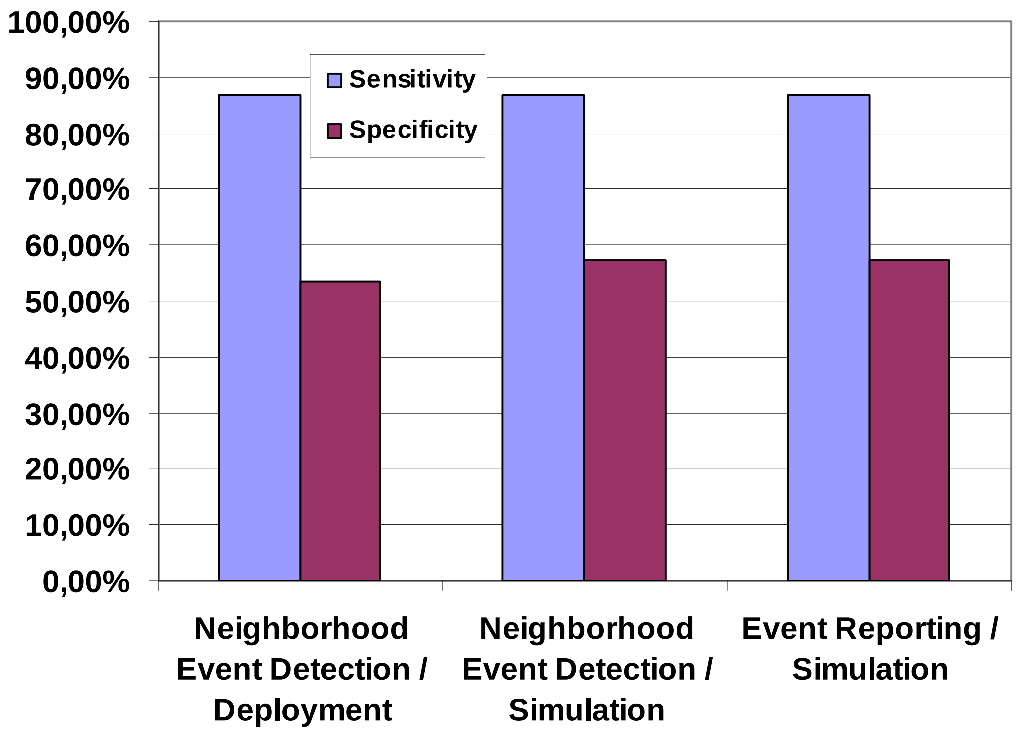
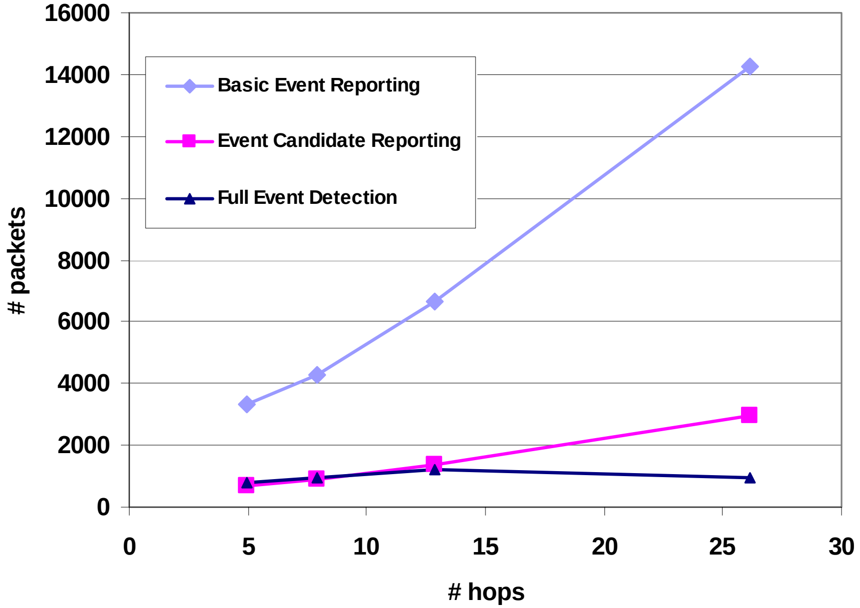



- U.S. embassy construction site in Berlin
- **ns-2** simulation with 105 sensor nodes placed 3.5m apart along fence line, two-ray ground radio propagation

# Results – Simulation (2)




Number of packets against hops between event source and base station

- Traffic reduction attributed to event detection increases with distance between event source and base station
- Neighborhood event detection incurs small overhead, only pays off in large deployments
- Local event detection reduces traffic by 75.6% even for small deployments

# Results – Beyond the Numbers

Technical Issues:

- Two node failures due to physical stress
- Even simple routing scheme performed surprisingly well
- Manual calibration weakest link in architecture

Non-technical Issue:

- Patterns in raw data changed as test subjects got more proficient at climbing over fence

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# Future Work

- Event detection

Event Reporting → Reliable delivery

↑

Neighborhood Event Detection → Topology adaptation

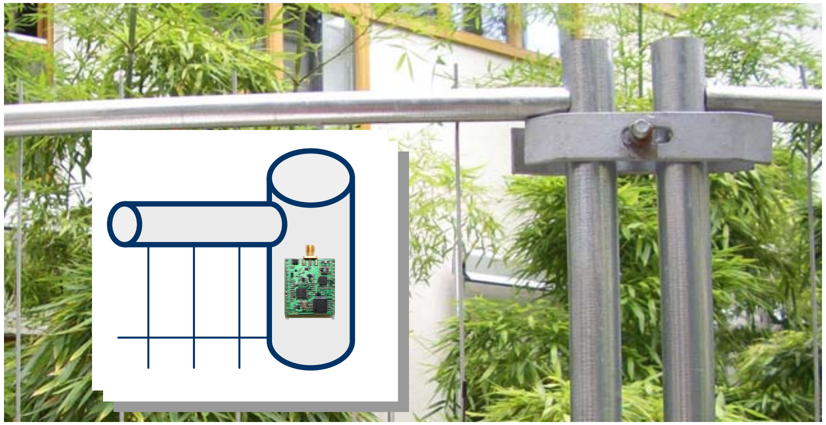
↑

Local Event Detection → Automatic calibration

↑

Raw Data Aggregation → Pattern matching algorithms

- Industry-scale deployment



# Conclusion

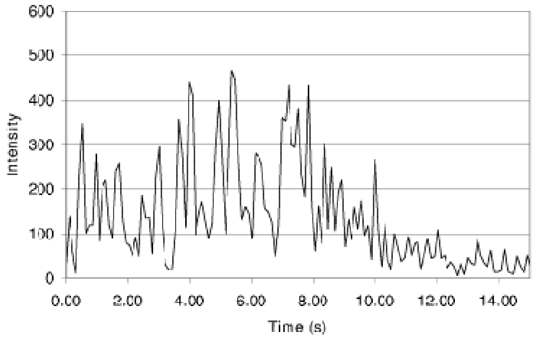
- Distributed event detection prime example for in-network data processing in WSNs
  - Fence monitoring realistic use case

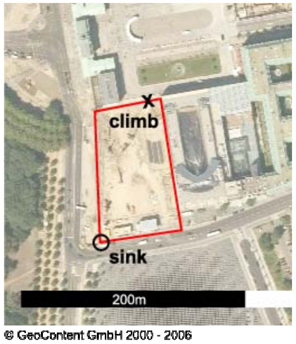
- Proof-of-concept and evaluation with both real-world and simulated experiments
  - Acceptable accuracy in comparison with other deployments
  - Considerable reduction in network traffic even for small deployments

- Layered event detection architecture allows for iterative refinements
  - Work towards production-level accuracy and robustness

# Thank you for your time!

# Any questions?

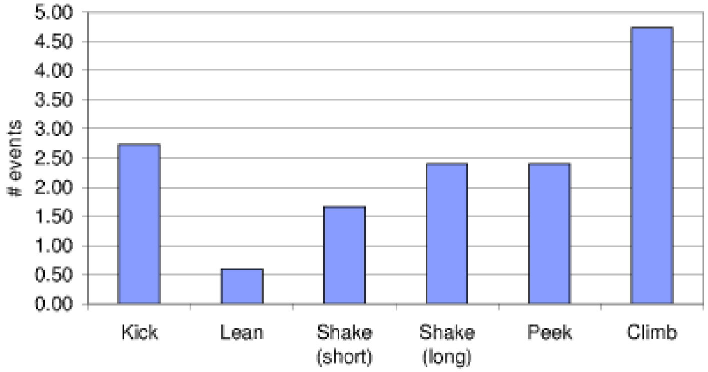


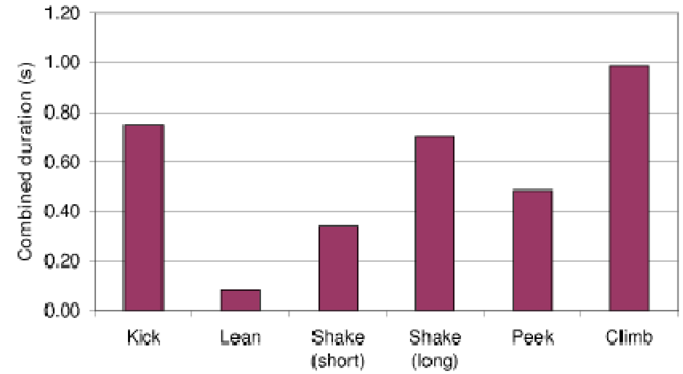

http://www.inf.fu-berlin.de/inst/ag-tech/projects/FenceMonitoring/

# Local Event Detection

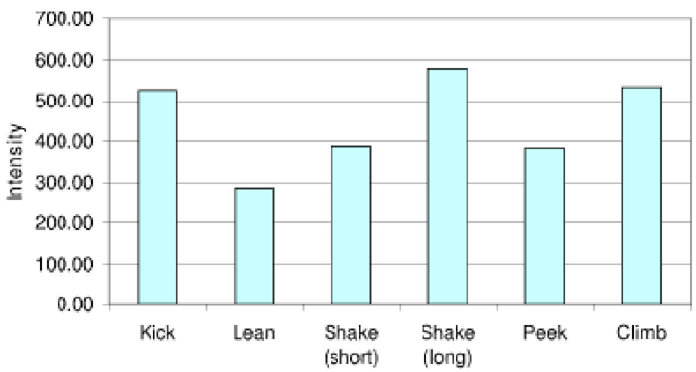




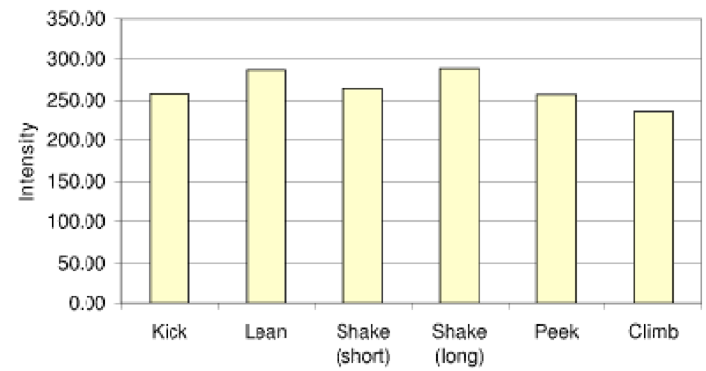

Number of events




Combined duration



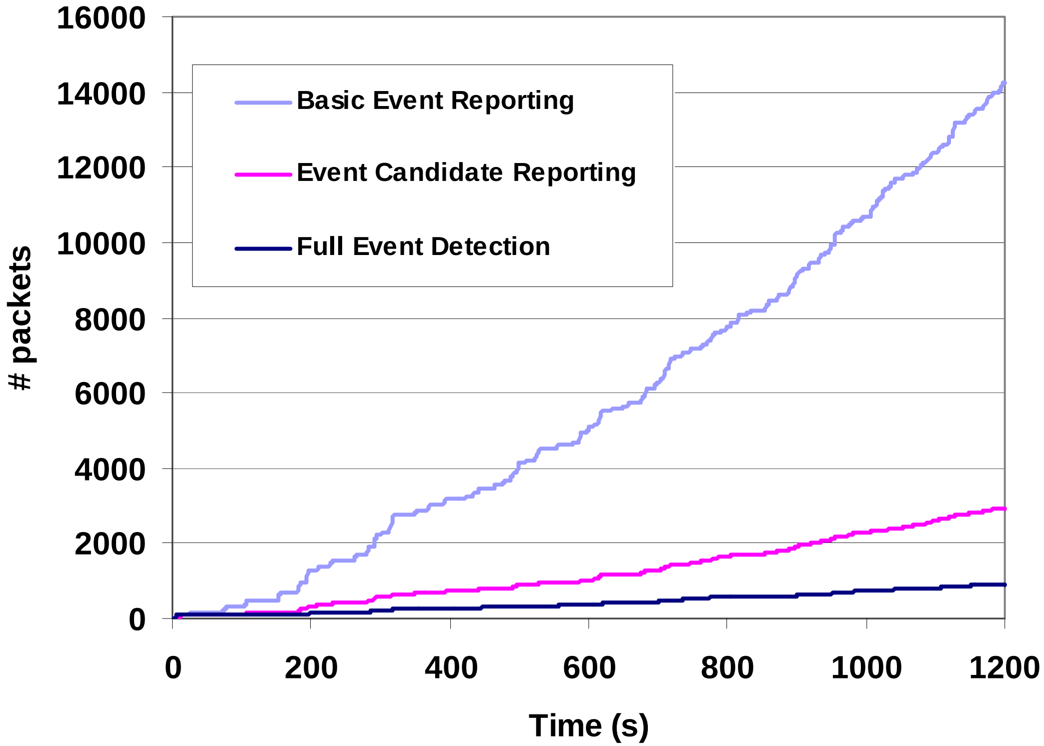

Maximal intensity




Minimal intensity

Aggregated Data of Different Event Types

# Results – Simulation (3)

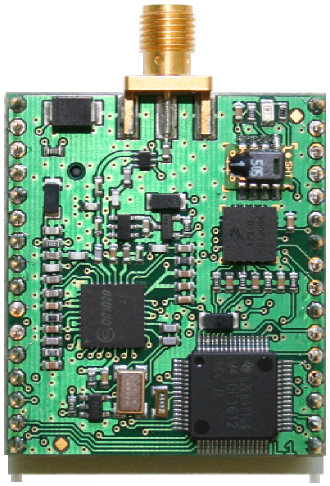


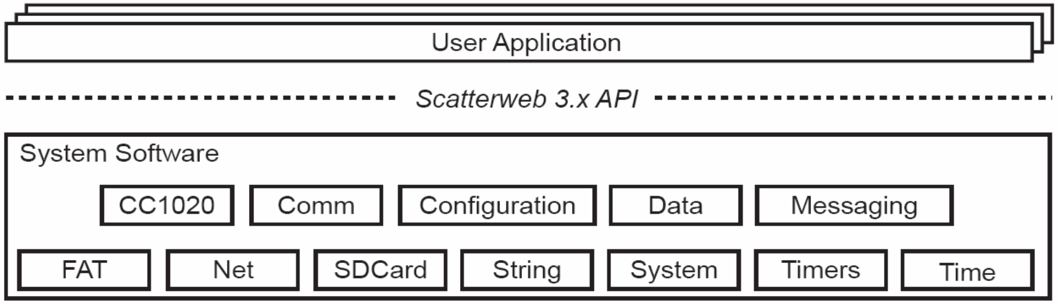

Number of packets transmitted over time
with 10m transmission range

# ScatterWeb Sensor Nodes

- ScatterWeb WSN Platform:
  - Developed by AG CST at FU Berlin.
  - Project started in 2002.
  - Components commercially available.

- Modular Sensor Board (MSB):
  - TI MSP430 16-bit microcontroller
  - Chipcon CC1020 radio transciever
  - 2 KB RAM, SD Card support



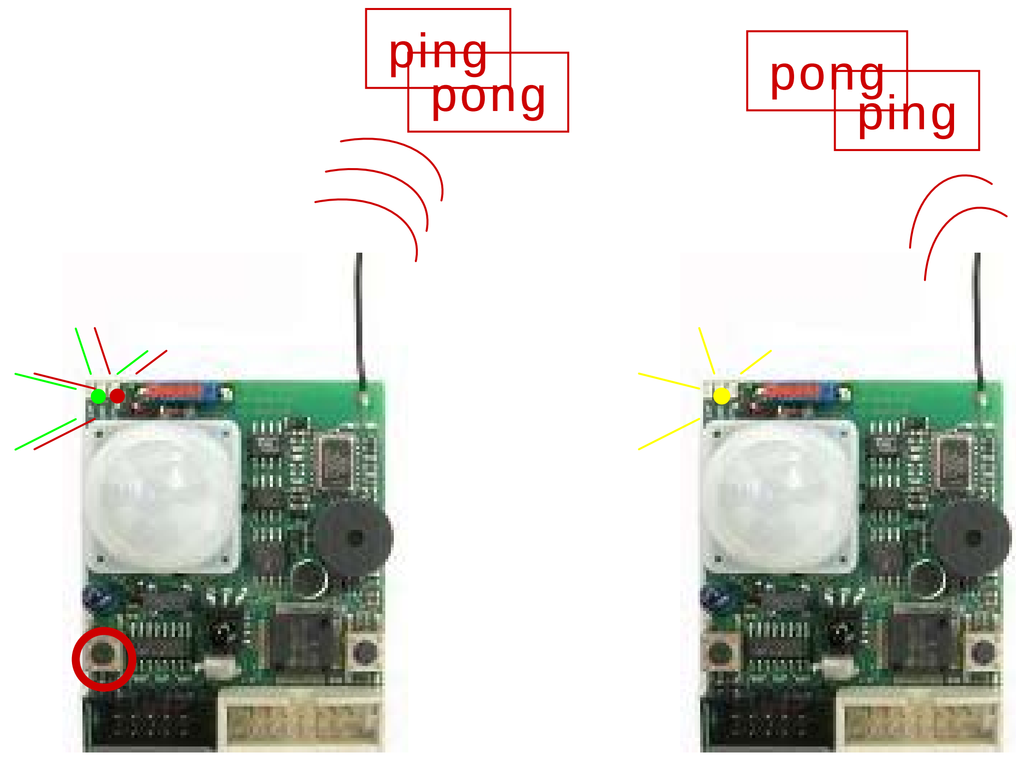


# FACTS Middleware

```
rule button 150
<- exists {button}
-> retract {button}
-> define ping
-> send 0 15 {ping}
-> retract {ping}
-> call toggleGreenLED

rule ping 100
<- exists {ping}
-> retract {ping}
-> define pong
-> send 0 15 {pong}
-> retract {pong}
-> call toggleYellowLED

rule pong 100
<- exists {pong}
-> retract {pong}
-> call toggleRedLed
```




Condition: push
pong

Condition: ping

# Related Work (1)

- Theoretical approaches to event detection:
  - Petri nets by Jiao et al., 2005 [1]
  - Boolean expressions by Kumar et al., 2005 [2]
  - Probabilistic Context Free Grammars (PCFGs) by Lymberopoulos et al., 2006 [3]

➢ No deployment or experimental evaluation

- High-profile deployments of WSNs:
  - Great Duck Island by Szewczyk et al., 2004 [4]
  - Wildfire monitoring by Doolin et al., 2005 [5]
  - Glacier monitoring by Martinez et al., 2005 [6]

➢ Focus on raw data, no in-network processing or event detection

# Related Work (2)

Evaluations of accuracy and in-network data processing:

- VigilNet by He et al., 2006 [7]:
  - Surveillance system, e.g. support for vehicle tracking
  - Evaluates required number of node-local event detections for correct global detection (“degree of aggregation”)
  - Describes false alarm reduction and software calibration
- Volcano monitoring by Werner-Allen et al., 2006 [8]:
  - WSN deployment to monitor eruptions on active volcano
  - Partial in-network processing, triggered by base station
  - Accuracy suffers from calibration problems

# References


(1) Jiao, B., Son, S.H., Stankovic, J.A.: GEM: Generic Event Middleware for Wireless Sensor Networks. In: Proceedings of the Second International Workshop on Networked Sensing Systems (INSS'05), San Diego, U.S.A. (2005)

(2) Kumar, A.V.U.P., Reddy, A.M., Janakiram, D.: Distributed Collaboration for Event Detection in Wireless Sensor Networks. In: Proceedings of the Third International Workshop on Middleware for Pervasive and Ad-hoc Computing, Grenoble, France (2005) 1–8

(3) Lymberopoulos, D., Ogale, A.S., Savvides, A., Aloimonos, Y.: A Sensory Grammar for Inferring Behaviors in Sensor Networks. In: Proceedings of the Fifth International Conference on Information Processing in Sensor Networks (IPSN'06), Nashville, U.S.A. (2006)

(4) Szewczyk, R., Polastre, J., Mainwaring, A., Culler, D.: Lessons From a Sensor Network Expedition. In: Proceedings of the First European Workshop on Sensor Networks (EWSN'04), Berlin, Germany (2004)

(5) Doolin, D.M., Sitar, N.: Wireless Sensors for Wildfire Monitoring. In: Proceedings of SPIE Symposium on Smart Structures & Materials / NDE'05, San Diego, California, U.S.A. (2005)

(6) Martinez, K., Padhy, P., Riddoch, A., Ong, R., Hart, J.: Glacial Environment Monitoring using Sensor Networks. In: Proceedings of the Workshop on Real-World Wireless Sensor Networks (REALWSN'05), Stockholm, Sweden (2005)

(7) He, T., Krishnamurthy, S., Stankovic, J.A., Abdelzaher, T., Luo, L., Stoleru, R., Yan, T., Gu, L., Zhou, G., Hui, J., Krogh, B.: VigilNet: An Integrated Sensor Network System for Energy-Efficient Surveillance. ACM Transactions on Sensor Networks (TOSN) 2(1) (2006) 1–38

(8) Werner-Allen, G., Lorincz, K., Johnson, J., Lees, J., Welsh, M.: Fidelity and Yield in a Volcano Monitoring Sensor Network. In: Proceedings of the Seventh USENIX Symposium on Operating Systems Design and Implementation (OSDI'06), Seattle, U.S.A (2006)