A Platform for Distributed Event Detection in Wireless Sensor Networks

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Goals of WIP

(a) Shake (b) Kick (c) Lean (d) Climb

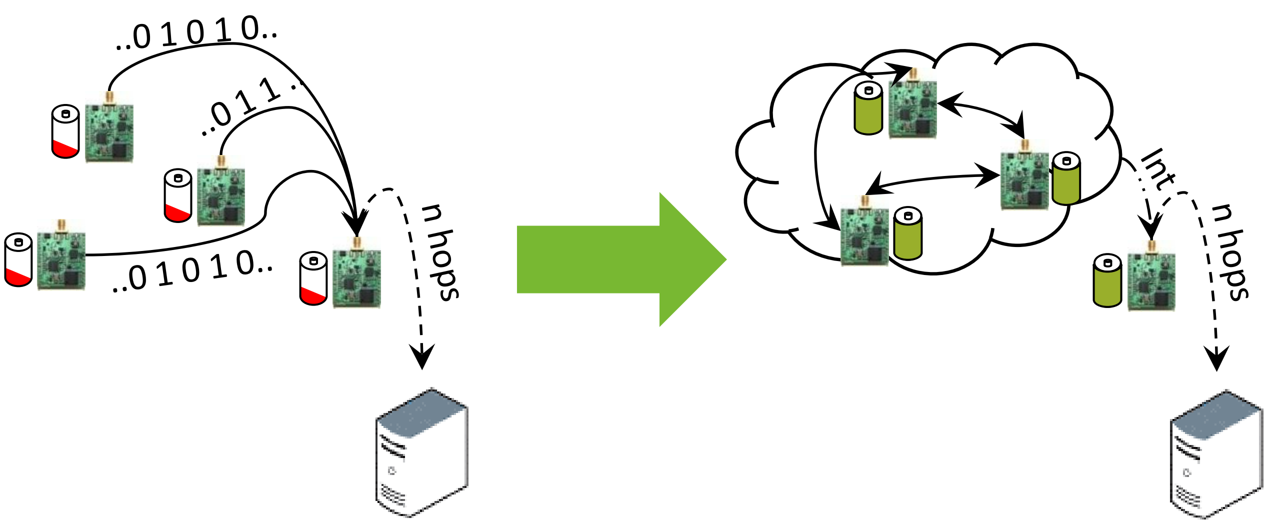
- Distributed event detection in WSNs with high accuracy

  (e.g. at a fence of construction sites based on ACC values)
- Design a new platform, based on experiences of previous fence monitoring system
- Fulfill real world requirements like secure communication and energy management
- Improve ability to use enhanced algorithms/features to detect events distributively
- Leverage pre- and post-processing of raw data, with self-calibration sensors and data quality estimation

Previous System

- **Decentralized** in-network Evaluation
- Existing **redundancy** in WSNs is leveraged to improve accuracy
- Reducing energy consumption due to **in-network data fusion**
- **Intrusion detection** on fences

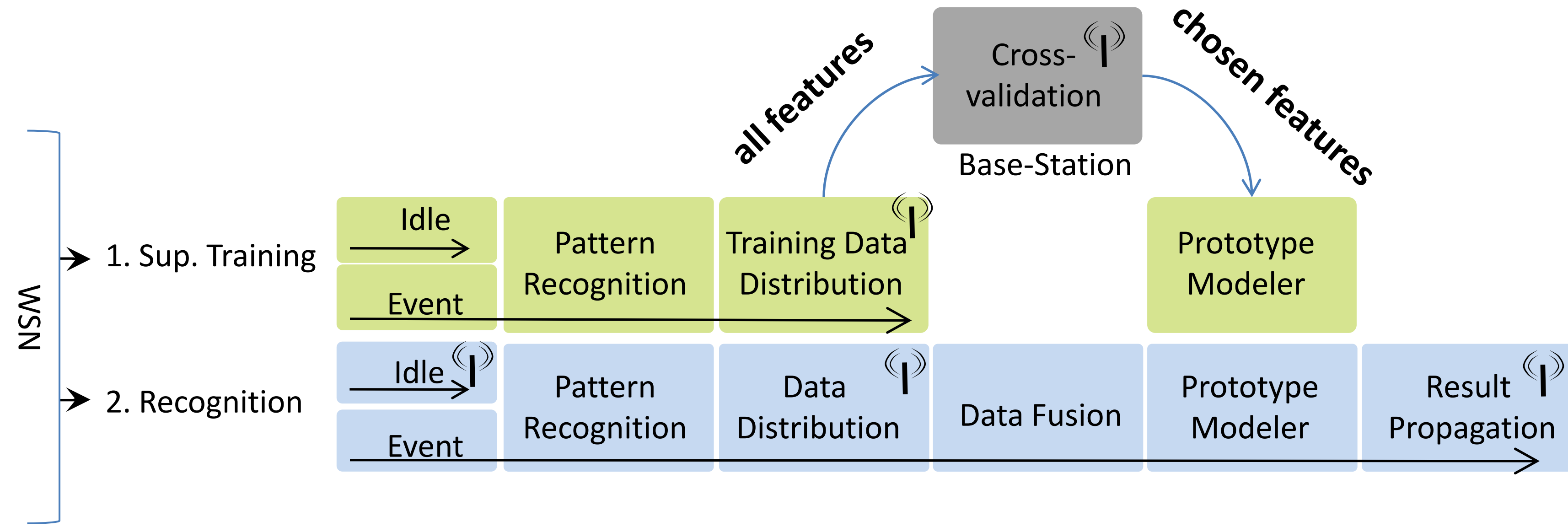
Use Case: Fence Monitoring

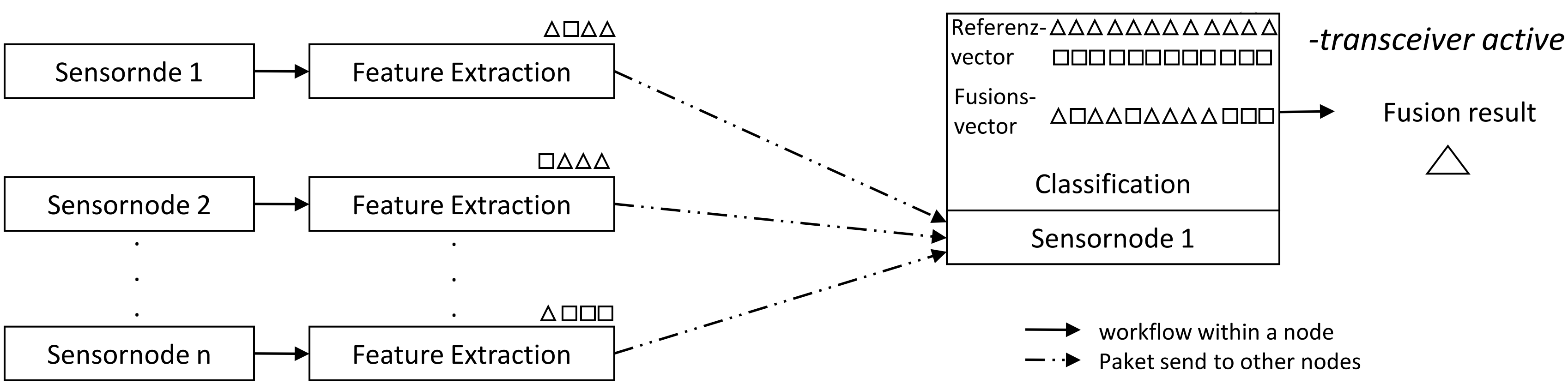


Centralized Evaluation

Decentralized in-network Evaluation

Distributed Event Detection





New Platform for Distributed Event Detection

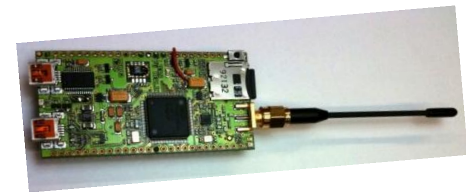
OLD : MSP430 based

Application Layer

- Distributed Event Detection System
  - Feature Extraction

System Layer

- OS: Scatterweb
  - Flooding
- HW: MSB-430-Sensor-Board
  - Acc- Sensor
  - MCU: MSP430



NEW : ARM7 based

Application Layer

- Distributed Event Detection System
  - Feature Extraction
- Data Quality Estimator

System Layer

- Energy-Management
- OS: Fire Kernel
  - Micro-Mesh-Routing
  - Security
- HW: MSBA2 - Sensor-Board
  - Self-Calibrating Acc- Sensor
  - MCU: ARM7

Energy-Management

Switch from MSB-430 to MSB-A2 => Increased energy consumption is expected.
Usage of the ARM7 requires a customized energy management system!

Problem: Scatterweb-OS sequentially polled for active tasks.
This principle weakenes the effectiveness of possible power saving modes.

Two concurrent approaches:

- integration of a multithreaded kernel (Fire-Kernel)
  - support of automatic activation of power saving modes
  - suspension of active threads => Idle Task

- Interrupt Wake-Up to reactivate the MCU (enabling wake up on any incoming tasks)
  -acceleration sensors deliver independent surveillance of defined thresholds by integrated primitive logic functions.
  -transceiver (Chipcon CC1101) enables usage of Wake-On-Radio mode

Routing

Previous system used simple flooding algorithm.
But ONLY sent notifications when events occurred.

Intuitively, proactive routing may arise as an alternative.

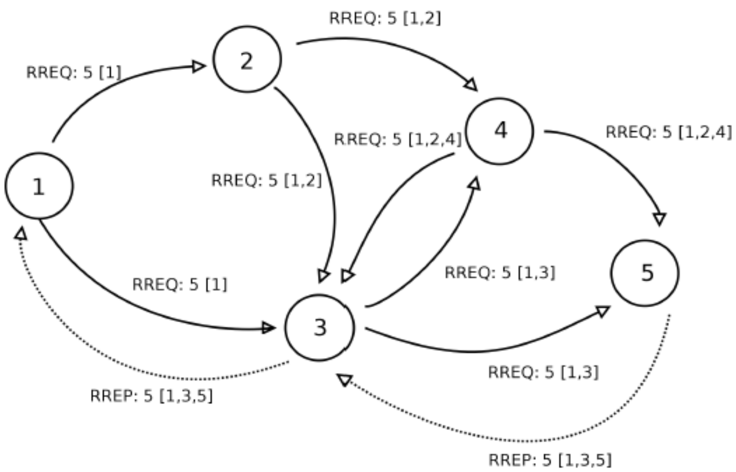
- IF proactive routing causes less maintenance traffic than sending of events does
- Otherwise: flooding is more efficient!

We add Micro-Mesh-Protocol (MMP)

- MMP minimizes radio communication by establishing routes only when required
- Caches routes until they become invalid.
- MMP updates routing table by analyzing packets to be forwarded

We are still investigating:

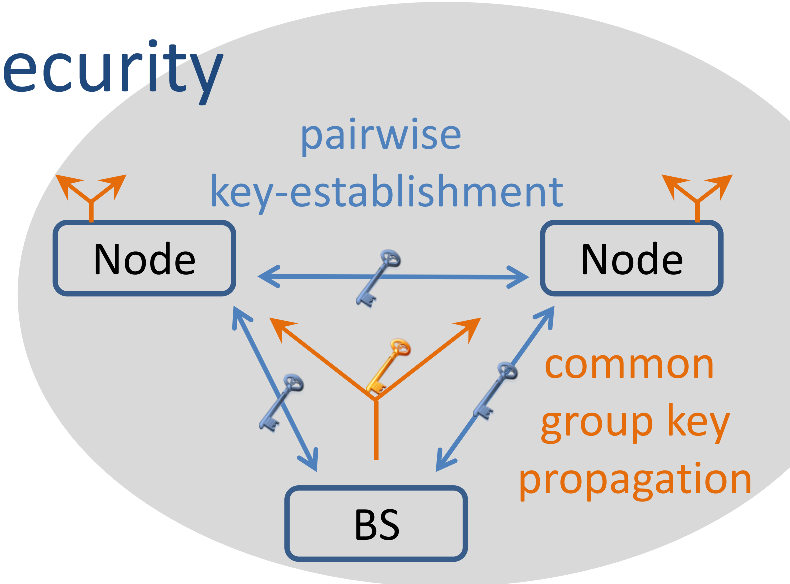
- whether the micro-mesh-protocol is superior to flooding approaches in an event detection environment.

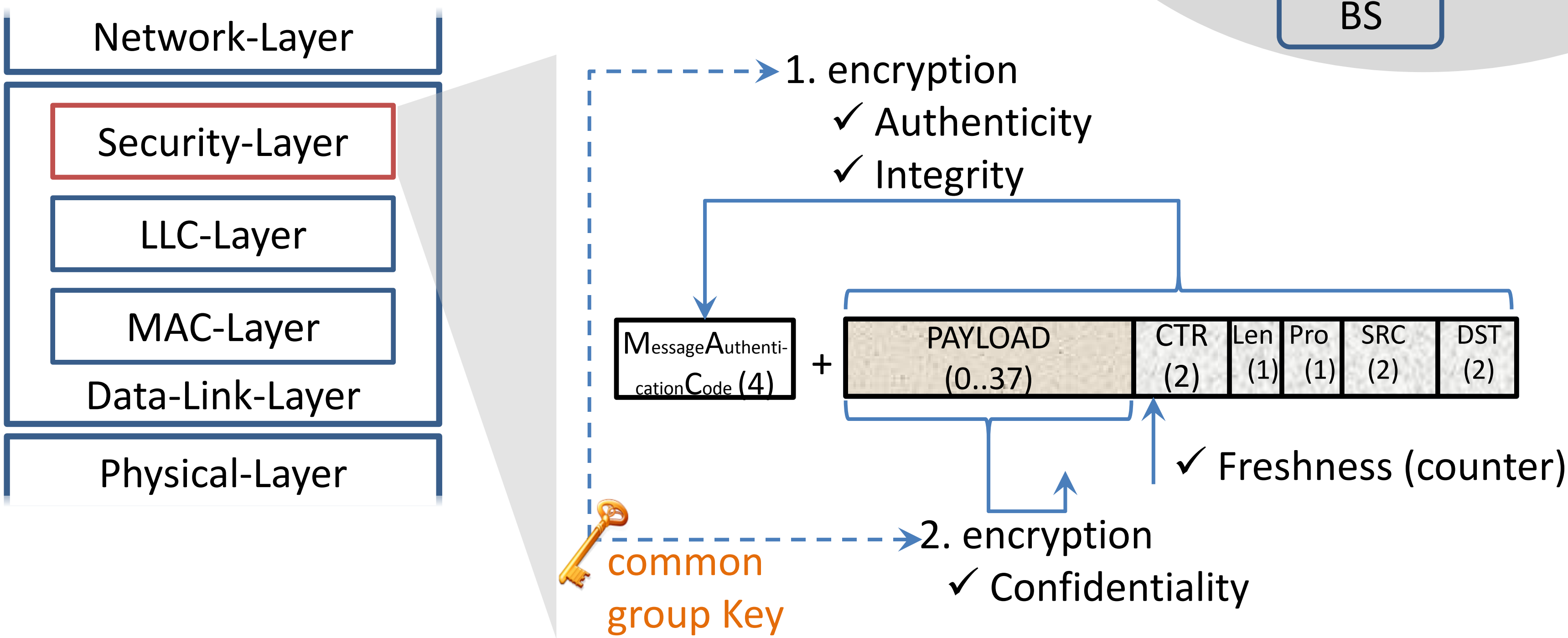


establishing route request
from node 1 to node 5 with MMP

Communication-Security

- Adding Security in Data-Link-Layer
- Group Key propagation
- Symmetric encryption in CBC mode using SkipJack





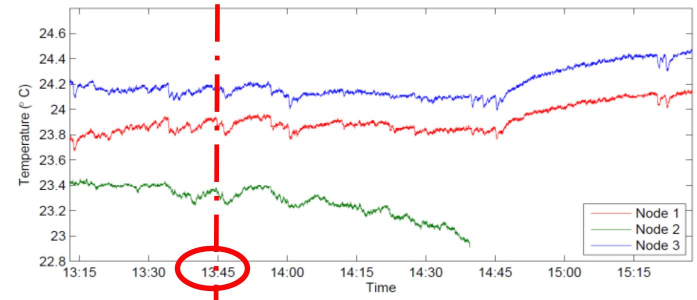
Data Quality Estimator

Sensors are **imprecise**, **unreliable** have **malfunctions.**

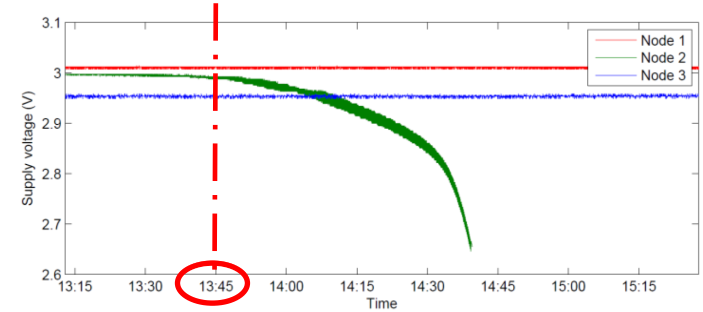
Quality depends on battery depletion, calibration, environment

Redundant nodes assess the **trust** of their own measurements

- Fuses measurements based on heuristics delivering trust
- Use of Dempster-Shafer Theory of Evidence to handle uncertainty in sensor data regarding correctness
  - Goal: find most credible proposition
  - set of propositions and associated evidences express believe, plausibility and doubt.
  - Rule for combining evidences to derive degree of bel.

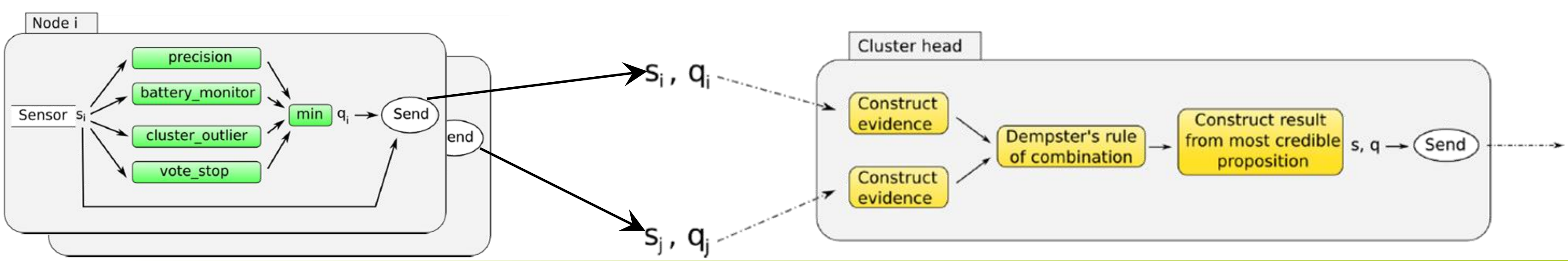


Three sensor nodes measure temperature



Supply voltage of the nodes.

Battery of Node 2 declines/oscilates at 13:45



Acceleration Sensors

Acquire movement events with acceleration sensors

We investigate, the SMB380 and the MMA7455L (triaxial sensors)

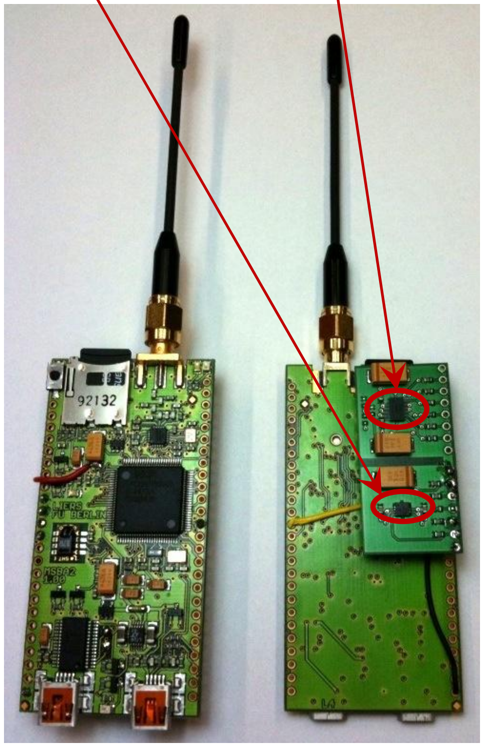
SMB380 samples with 3 kHz
lower sampling rates can be emulated via integrated filter routine

MMA7455L supports two possible sampling settings, 125 Hz and 250 Hz.

SMB380	MMA7455L
1 µA in standby mode	10 µA in standby mode
200 µA in operation mode	490 µA in operation mode

We mounted both acceleration sensors on a common board extension, to achieve ideal comparability.

SMB380 MMA7455L



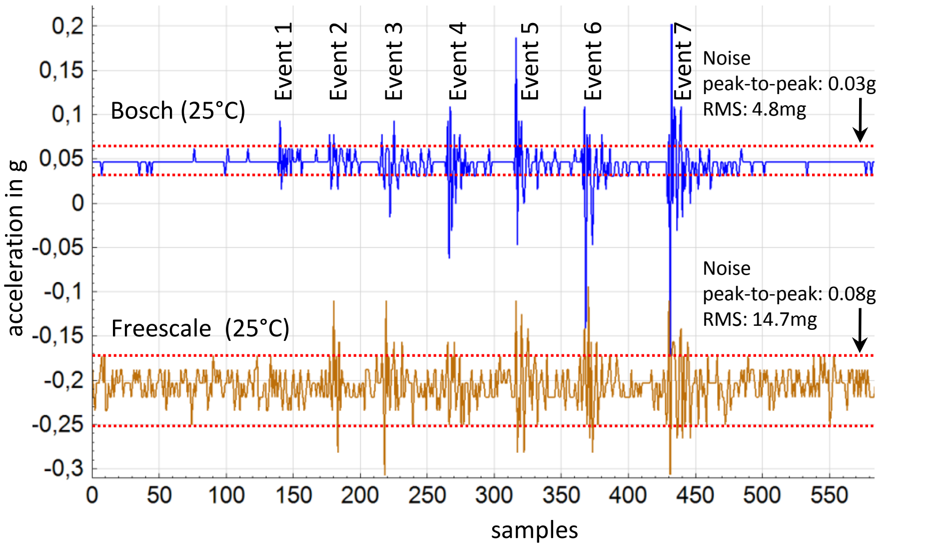
MSB-A2 with two ACC-Sensors
Left: foreside Right: backside

Comparison of Acceleration Sensors

Exposing ACC sensors to shock events of increasing intensity .

Measurements have slight offset,
=>due to minimal differences of the sensor position on the board.
=> noise is not affected by orientation

SMB380 shows lower noise RMS: 4.8 mg
MMA7455L RMS: 17.7 mg



- For small bandwidth values, events are easier to detect for the SMB380
- The SMB380 allows to save more energy and delivers a higher detection resolution.
- We expect to get more descriptive features using the Bosch in our platform.

Conclusion and Outlook

- We presented a new platform for event detection in WSNs in the state of WIP.
- Enables high standards in minimizing energy consumption and maximizing event detection accuracy with a secured communication.
- The platform itself, consisting out of a high performance MSB-A2 hardware and an extensible kernel, enables us to evaluate event detection accuracy in WSNs with serious environmental effects.
- Higher computational power enables the use of Fast Fourier Transform for feature extraction.

- We plan to set up a deployment for about 100 sensor nodes at the construction site of the Berlin Brandenburg International Airport (BBI).
- Current research funded by German Federal Ministry of Education and Research (BMBF) since fall 2009.

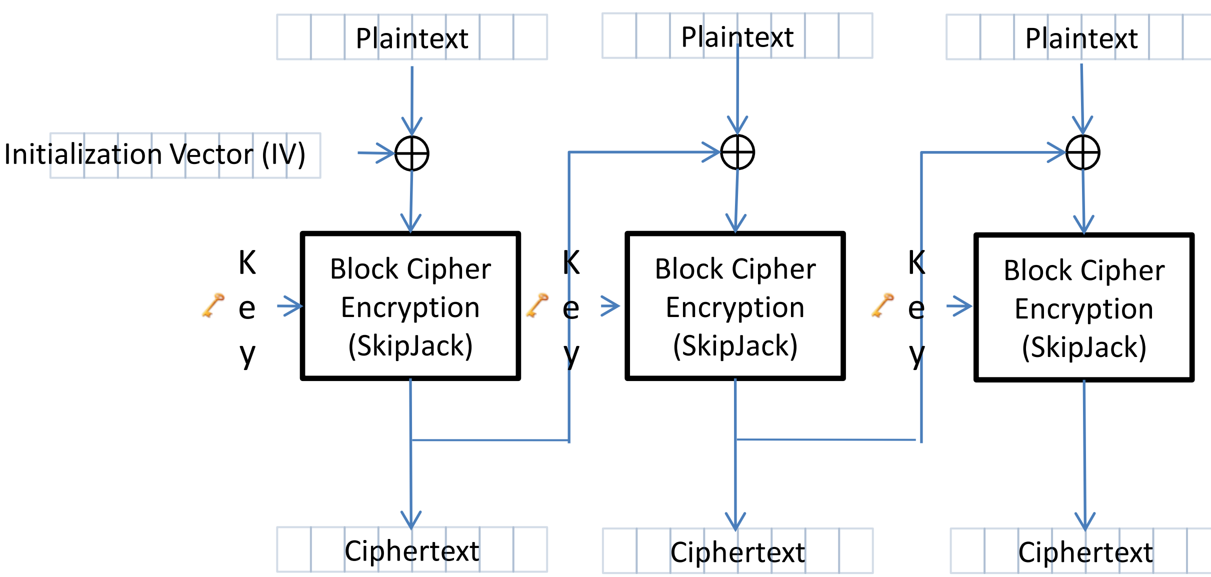
Thank you! Question?

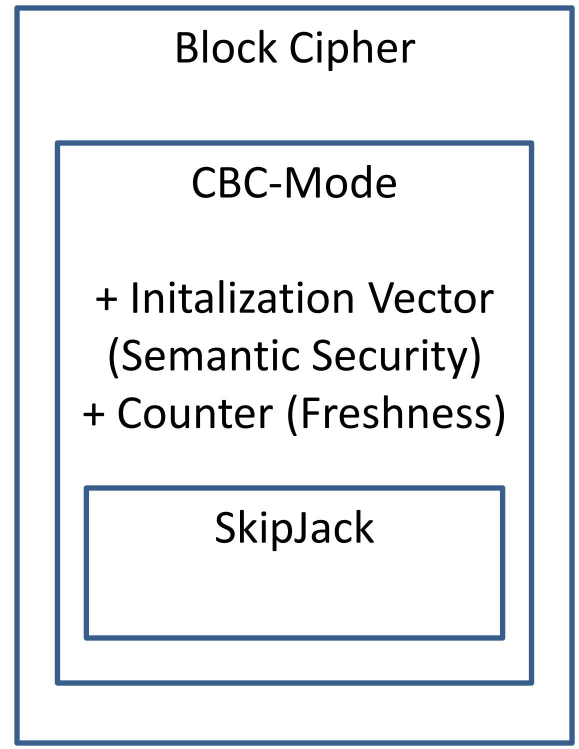
Security - CBC

Preconditions:

- usage of symmetric key alg.
- every node owns the same encryption key
- none of the nodes are compromised during deployment
- every node trusts itself

Encryption in Cipher Block Chaining mode (CBC)





One To One Comparison ARM7 vs. MSP

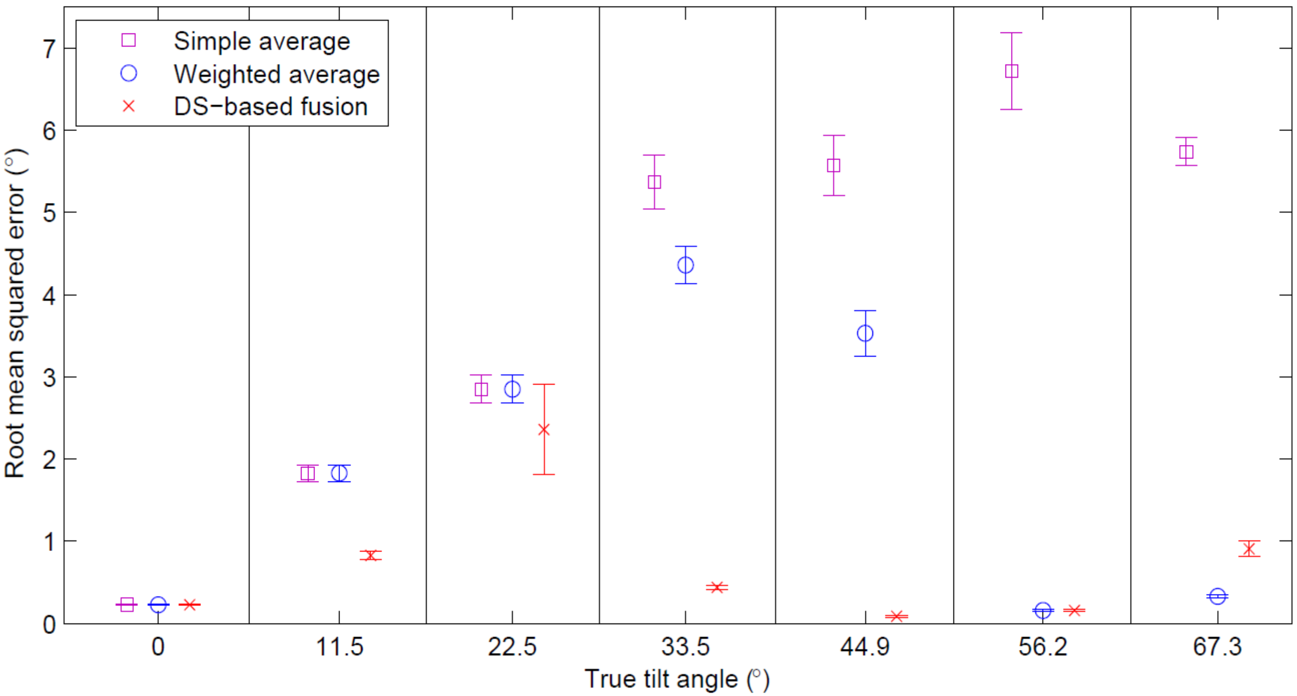
LPC2387	**MSP430F1612**
ARM7TDMI-S CPU, running at up 72 MHz	running at 8 MHz
Based on 16-bit/32-bit ARM7TDMI-S CPU	16-Bit RISC Architecture
512 KB on-chip flash memory	55KB Flash Memory
96 KB SRAM	5 KB SRAM
Advanced Vectored Interrupt Controller (VIC): 32 Vectored Interrupts	None
General Purpose DMA (GPDMA): for SSP, I2S port, (SD/MMC) card and memory-to-memory transfers.	Three-Channel Internal DMA
Real-Time Clock (RTC)	None
4 timers	2 timers

One To One Comparison Bosch vs. Freescale

	SMB380	MMA7455L
Acceleration range	±2g/±4g/±8g	±2g/±4g/±8g
Filter bandwidh (Hz)	25, 50, 100, 190, 375, 750	62.5, 125
Acceleration data refresh rate	3000 Hz	125 Hz, 250 Hz
Operating temperature (°C)	from -40 to +85	from -40 to +85
Level detection	yes	yes
Pulse detection	no	yes
Cross axis sensitivity	2 % (Max)	from -5% to +5%
Current consumption	Operational mode: 200 µA Sleep mode: 1 µA Wake-up mode: (1.5-6) µA	Operational mode: 490 µA Standby Mode: 10 µA
Output noise	0.5 mg/Hz	-
Wake-up-time	1 – 1.5 ms	-
Start-up-time	3 ms	-

Data Quality Estimator – First results in tilt angle scenario

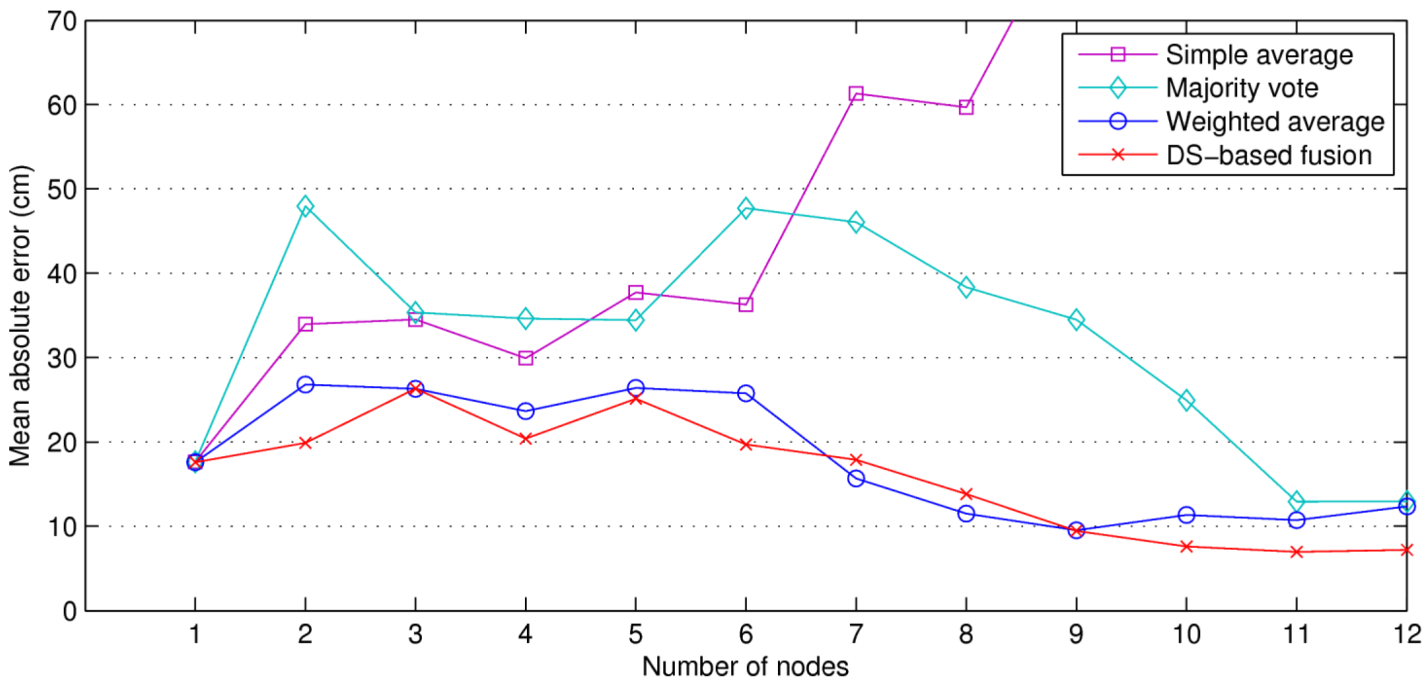
- seven different angles
- evaluated with four sensor nodes
- using different fusing approaches in a tilt angle scenario.



Root mean squared error of the respective fusion approaches

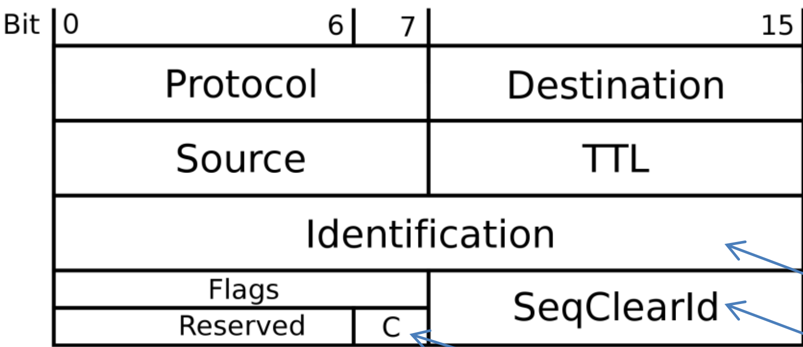
Water level-Szenario: tilt angle approx. with 4 nodes

Data Quality Estimator – First results on more nodes



- Simple Avg.: more nodes => more errors
- Utilizing quality information, by using heuristics that improve accuracy
- Fusing based on quality estimator are able to increase accuracy by increasing #nodes

Header of Micro Mesh Routing



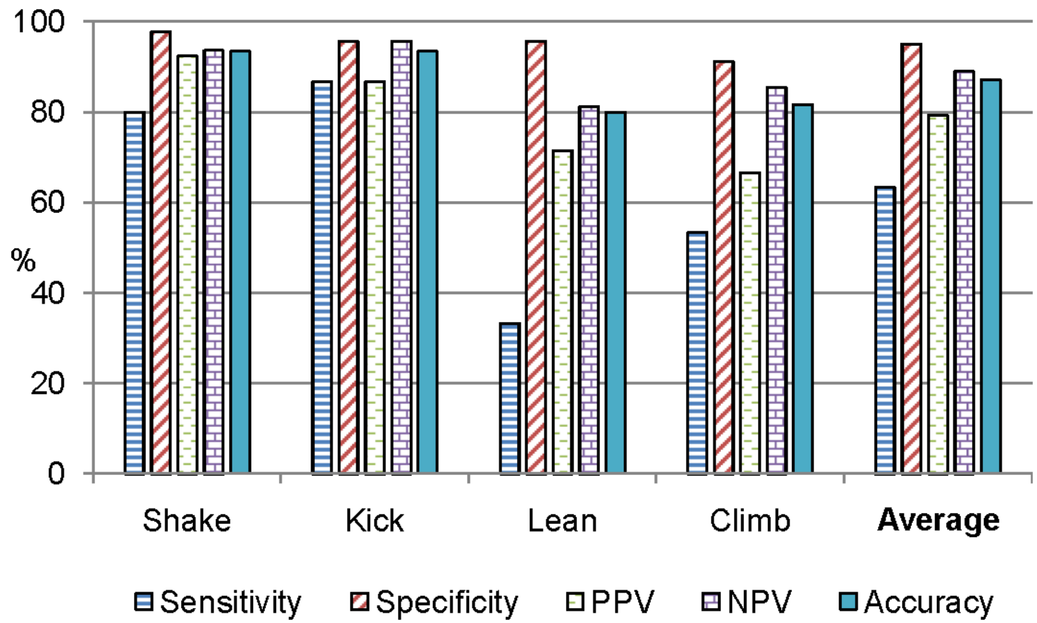
Header of MM-Routing

packet doublication protection: Identification-field

If (overflow==TRUE)
    fill SeqClearID with new random number
    AND
    set C-Flag

getting c-flagged packet:
If (SeqClearID!= SeqClearID_old)
    receiver resets Identification in Routing Table

Experimental Evaluation - Metrics



Sensitivity (recall) = TP / (TP+FN)

Proportion of correctly detected events

Specificity = TN / (TN+FP)

Proportion of correctly ignored events

Positive Predictive Value (PPV, precision) = TP / (TP+FP)

Probability that correctly detecting an event reflects the fact that the system was exposed to a matching event

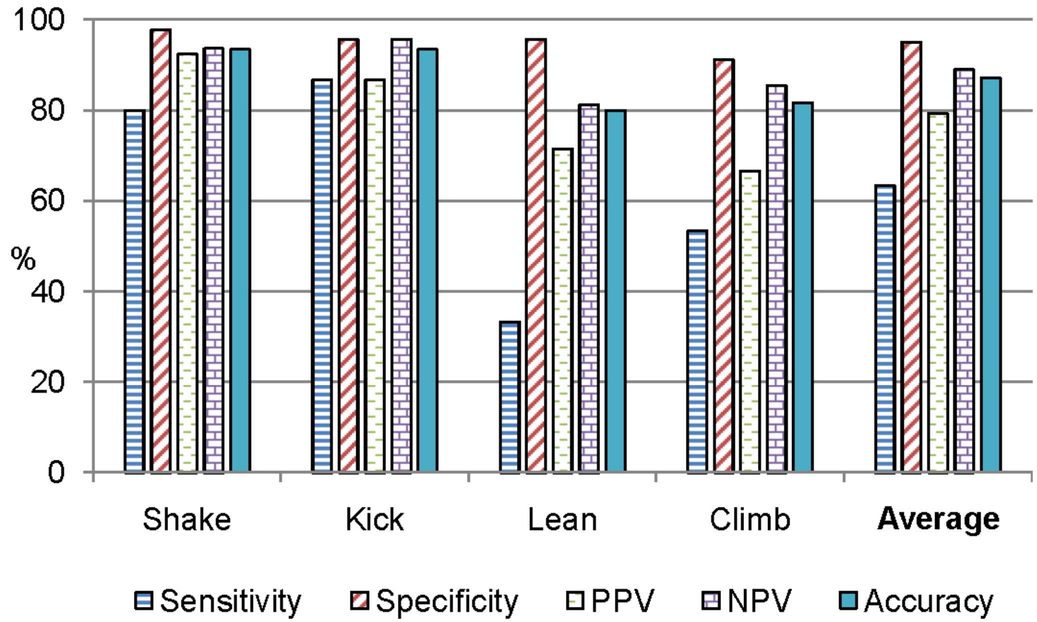
Negative Predictive Value (NPV) = TN / (TN+FN)

Probability that correctly ignoring an event reflects the fact that the system was not exposed to a matching event

Accuracy = (TP+TN) / (TP+TN+FP+FN)

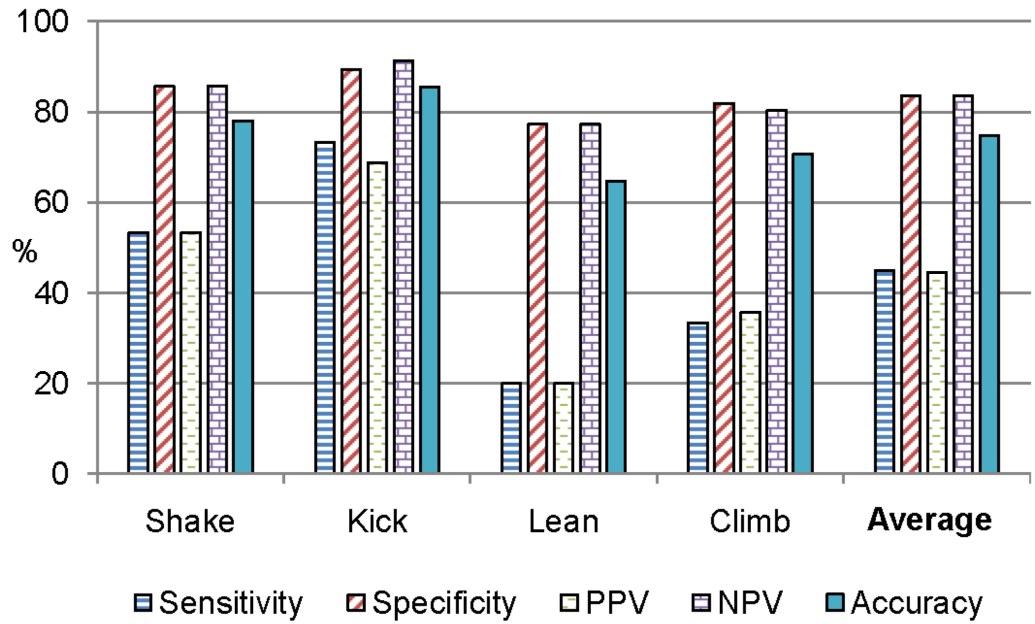
Proportion of true results in the population, i.e., the sum of all correctly detected and all correctly ignored events.

Results – Feature Fusion



- Shake and kick events detected reliably
  - All metrics above 80%, accuracies of 93.3%
- Detection of lean or climb events not as accurate
  - Sensitivity is comparatively low, while specificity remains high
  - Too many events are falsely rejected due to prototype regions being too small
  - Training runs were too similar to each other, prototype regions only enclose part of required space
- Overall accuracy of 87.1% after feature fusion

Results - Classification Fusion



- NPV and accuracy remain stable, but sensitivity and PPV decrease considerably
- Base station counts incorrect classification from other nodes, if
  a) correct classification is falsely rejected on the node #7, while incorrect classification is reported from another node
  b) node reports incorrect classification with classification metric smaller than that of correct classification
- Overall accuracy of 74.8%