Application Support Design for Wireless Sensor Networks

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Application Support Design for Wireless Sensor Networks

TIMELINE

Sep 2006
- Double Master of Science in Computer Engineering
  - Politecnico di Torino (Italy)
  - Kungliga Tekniska Högskolan (KTH)

Sep 2008
  - Saab Security and SICS (Kista, Stockholm)

Mar 2009
- Thesis extension
  - SICS

Jun 2009
- Ph.D. at the University of Lübeck (Germany)
  - Just started!

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OUTLINE

➢ Motivation
  ▪ Pervasiveness of Wireless Sensor Networks
  ▪ Limited adoption by the industry
    - Concern on robustness and reliability of sensor nodes
    - Increasing need of a faster deployment
    - Lack of application support that impacts the easiness of programming

➢ Contributions
  ▪ Design of an application support layer
  ▪ Deployment support module
  ▪ Solutions to increase robustness and reliability of WSN
  ▪ Novel mechanism for rapid radio channel quality assessment
WIRELESS SENSOR NETWORKS

- **Main characteristics**
  - Low-size, low-cost, low-power
  - Several micro-sensors vs. a single macro-sensor
    - Improved accuracy
    - Better fault tolerance
  - Equipped with wireless radio transceivers
    - Flexibility (no wired infrastructure)
    - Reliability of the wireless medium (!)
    - Cooperation
    - Self-healing and self-configuring
    - Minimal need of human interaction
  - Memory-constrained
  - Energy-constrained
    - *Extreme Low Power System Architecture (Jerker Delsing, Luleå University)*
WIRELESS SENSOR NETWORKS

- Wide range of applications
  - Industrial control and monitoring
  - Military and defense applications
  - Civil surveillance
  - Wildfire monitoring
  - Precision agriculture
  - Habitat monitoring
  - Bridges monitoring
  - Volcano monitoring
  - Home automation
  - Parking slots
  - High-confidence transport
  - Health care monitoring

- There is much more ...
**WIRELESS SENSOR NETWORKS**

- **Internet of things**
  - These devices can talk via IPv6 to another device which is thousands of miles away!
  - Thousands of applications! (Example: streetlinenetworks.com)
APPLICATION SUPPORT LAYER DESIGN

Goal:
- Simplify the programming of applications
- Deployment support
- Increasing robustness and reliability

Implemented functionality:
- Sensor data query and data logging for fault recovery
- On-line battery estimation
- Deployment support module
- Temperature control
- Robustness to the changing weather
- Rapid channel quality assessment
APPLICATION SUPPORT LAYER DESIGN

Application 1  Application 2  ...  Application n

SQDDP
(Sensor Query Language and Data Dissemination Protocol)
- Sensor data query and dissemination
- DataBase Management System (DBMS)

SMP
(Sensor Management Protocol)
- Deployment support
- Rapid channel quality assessment
- Optimization for outdoor deployments
- Battery lifetime estimation module
- Node monitoring support
- Network status log
- Keepalive protocol

Contiki

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SENSOR DATA QUERYING AND LOGGING

- Can a query language improve the application performance and robustness?
  - Example: radio channel selection

- Transparent log facility
  - Persistent data
  - Fault recovery detection
  - Fully configurable by the application

- Enabling three different types of queries
  - Snapshot
  - Continuous (periodic)
  - Historical
SENSOR DATA QUERYING AND LOGGING (DESIGN)

- **Transparent log in the secondary memory**
  - Automatic sampling and storage of sensor data

- **Logical grouping of sensor data**
  - Data is stored based on the time at which it was retrieved into two arrays
  - One array contains recent data, while the second one contains past data

- **Configurable array size**
  - Configurable by the application
  - Memory requirement is known
  - Energy control
SENSOR DATA QUERYING AND LOGGING

- Fault detection and network monitoring
  - Data is persistent to node reboot
  - Data is accessible both locally and remotely

- Snapshot, continuous, and historical queries enabled!
  - Energy consumption for writing is constant
  - Energy consumption for reading is affected by the file system internals
ON-LINE BATTERY MONITORING

- **Goal:** find the residual lifetime of the battery
  - Continuous monitoring, always available
  - Minimizing memory and computational costs
  - Exploiting only the available data (SHT11 temperature sensor, battery voltage from internal ADC of the microprocessor MSP430)
  - Give an approximate number of hours left given the current draw and current temperature

- **Batteries are hard to model**
  - Electro-chemical composition
  - Load applied on the battery
  - Status of the battery
  - Temperature
  - Recharge-ability
ON-LINE BATTERY MONITORING

- **Simplified mathematical model**
  - Gompertz function (sigmoid)
  - Only two inputs: temperature and the battery voltage from internal ADC
  - Minimizes energy consumption and computational costs
  - Limited to Ni-Mh non-rechargeable AA batteries

\[
f(v, t) = \frac{a(t)}{1 + e^{b(t) + c(t)v}}
\]

- \(a(t) = 156770t + 700000\)
- \(b(t) = 0.1496t + 26.341\)
- \(c(t) = -5E^{-5}t - 0.0099\)

\[V_{\text{MIN}} = \max(\text{threshold}_{\text{sensors}}, \text{threshold}_{\text{radio}}, \text{threshold}_{\text{cpu}}) = 2.4 \text{ V}\]
Deployment is a crucial and non-trivial phase

- Resource-constrained hardware
- Difficult access to the data
- Interaction with the environment

A trade-off is needed to reduce time and costs of the deployment phase

- A too fast deployment may cause an error-prone network topology
- An accurate deployment is costly, and requires too much time and manpower
DEPLOYMENT SUPPORT FOR WSN

- **Real-time guidance mechanism**
  - Engineer is guided by the sensor node in the deployment phase
  - Basic real-time information to the engineer that satisfies energy and cost constraints
  - Decrease the deployment time
  - Decrease the manpower involved
  - No additional hardware needed

- **Real-time validation at the same time!**
  - Optimized validation process (weather and temperature, basic device check)
  - Increase the robustness of the deployment
  - Auto-configuration of the sensor node
Outdoor expeditions were carried out to investigate the common problems:

- Probability of having grey areas increases with non-flat soil
- Height from the ground impacts communication
- Hard to realize the radio range border when in the field
- RFID and electronic devices impact hard to quantify clearly
- Repeatability of outdoor experiments

Temperature affects the communication between sensor nodes:

- Strong impact when temperature increases

Rain and fog may affect the communication as well.

IMPA CT OF TEMPERATURE ON LOW-POWER COMMUNICATION

- Temperature has a strong impact on communication
  - If temperature increases, the radio signal strength decreases
  - Impact can reach 8-9 dB from -40°C to +60°C

IMPACT OF TEMPERATURE ON LOW-POWER COMMUNICATION

- **Temperature has a strong impact on communication**
  - The cause is the low-power radio chip that suffers high thermal variations (~1°C change can cause 0.1 dB difference in RSSI)
    - Output transmission power is affected by temperature
    - Receiver sensitivity is also affected by temperature
  - Temperature impacts both RSSI and LQI indicators
  - Important observation for outdoor deployments
    - Wildfire monitoring
    - Industrial applications

IMPACT OF WEATHER ON LOW-POWER COMMUNICATION

- **Weather effect on sensor motes**
  - Do fog, snow, and rain really affect the communication between motes?
  - In all the published work, different experiences led to different conclusions...

IMPACT OF WEATHER ON LOW-POWER COMMUNICATION

➢ Special experiments to discern the effects of temperature and weather
  ▪ Motes were kept indoor at fixed temperature but with free Line of Sight (LoS)
  ▪ Temperature effect was eliminated

➢ Results
  ▪ The impact of rain is non negligible with rain intensity higher than 2,5 mm/hour
  ▪ Fog seems not to affect the ongoing communications
  ▪ Snow at LoS seems not to affect the radio signal

IMPACT OF WEATHER ON LOW-POWER COMMUNICATION

- Meeting fire safety EU-regulations
  - Cheaper to enclose wireless sensor nodes in ATEX-compliant enclosures rather than building ATEX-compliant sensor nodes
  - ATEX enclosures do not affect the radio signal too much
  - They avoid the node to suffer rapid thermal variations → More predictability!

![Graph showing temperature vs. time comparison between outside and inside ATEX casing](image)

IMPACT OF TEMPERATURE ON OUTDOOR INDUSTRIAL APPLICATIONS

- Industrial oil refinery scenario (Sines, Portugal)
  - Safety-critical!
  - We cannot just have safety margin thresholds! (Batteries?)
  - Reducing the transmission power during night can save up to 20% energy

IMPACT OF TEMPERATURE ON OUTDOOR INDUSTRIAL APPLICATIONS

- Transmission power control for improved energy efficiency
  - Relationship between temperature and transmission power

From 15.1 mA (60-65 °C) …
To 11.2 mA (15-20 °C)

IMPACT OF TEMPERATURE ON OUTDOOR INDUSTRIAL APPLICATIONS

- Transmission power control for improved energy efficiency
  - Nighttime (winter time) operations are executed at lower temperatures
  - Reducing (adapting) the TX power w.r.t. temperature can save up to 26% energy

RAPID CHANNEL QUALITY ASSESSMENT

- **Indicators for the link quality**
  - Past: Packet Reception Rate
  - Today: hardware metrics

- **Hardware metrics**
  - Radio Signal Strength Indicator (RSSI)
  - Link Quality Indicator (LQI)
  - RSSI noise floor reading

- **Link Quality Indicator (LQI)**
  - Good estimation, but at least 120 packets have to be averaged due to its high variance (Srinivasan et al.)
  - I show that LQI variance can be used as a metric for a faster channel quality assessment

RAPID CHANNEL QUALITY ASSESSMENT

- Through LQI variance we can obtain a rapid estimation with only few transmissions
  - Unreliable channels have high LQI variance (in the order of thousands)
  - Reliable channels have low LQI variance (in the order of hundreds)
  - Only 10 received packets are needed to obtain a good estimation
  - Energy consumption is reduced!


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CONCLUSIONS AND FUTURE WORK

- **Application support**
  - Increases the network robustness
  - Simplifies development and programming

- **Deployment support**
  - Faster deployment with less manpower
  - Optimizations for outdoor deployments
  - Increased robustness to the environment

- **Channel quality assessment**
  - LQI variance is not necessarily a limitation
  - New approach proposed to distinguish very good links based on the LQI variance
  - Less packets are needed w.r.t. the widely used LQI mean approach

- **Future work**
  - Create a metric for a better link quality estimation
  - Temperature control in industrial settings
  - More accurate battery model
QUESTIONS & ANSWERS