Performance Control in Wireless Sensor Networks

Prof. Cormac J. Sreenan

University College Cork, Ireland

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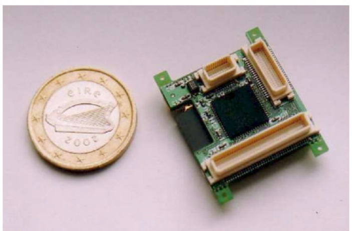
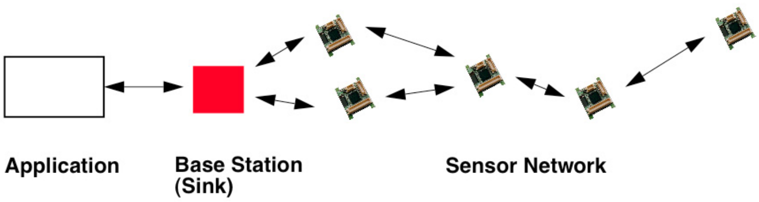
Technology Background





Sensor node

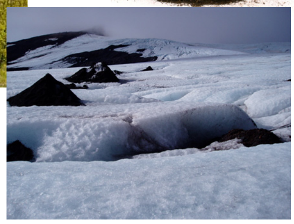
- CPU, storage unit, communication unit, sensing/acting unit, power unit
- Battery powered, short range communication, miniaturization

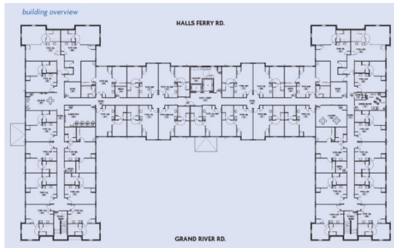
Sensor field

- Sensors and actuators
- Multi hop communication
- Large scale network
- Multiple applications

Context

- Practical experience with deployment of wireless sensor networks (WSNs) has been very limited
- Focus of research has been
  - fundamental design issues, especially energy optimisation
  - unplanned (sometimes random) deployments
  - applications that are not demanding in terms of performance or reliability





Motivation

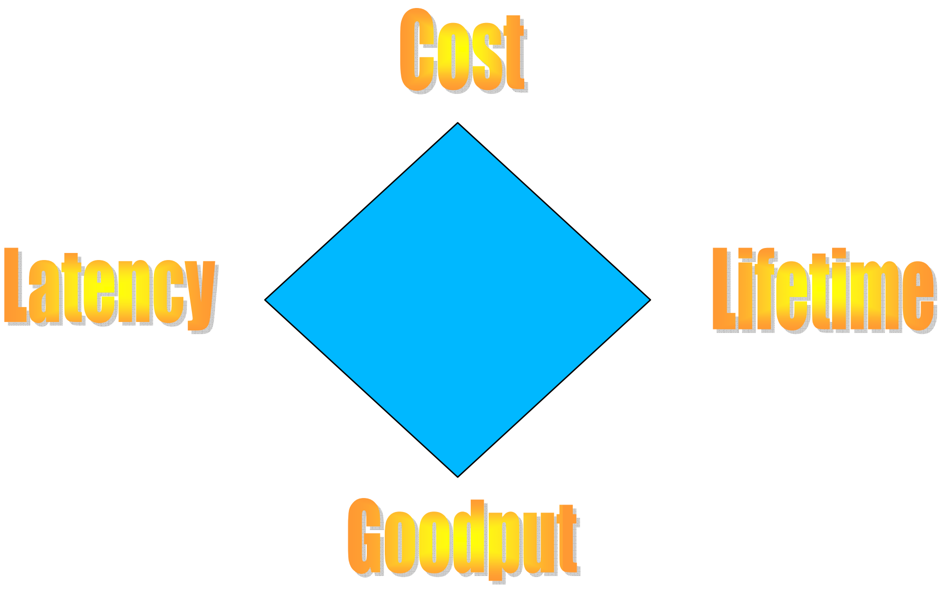
- Many applications areas require performance assurances
  - range from small-scale (e.g. patient monitoring) to large-scale (industrial plants)
- But common assumptions make this difficult
  - Deployments that are unplanned in unknown environments
  - Networks that are entirely self-configuring
  - Robustness achieved primarily by virtue of high redundancy
  - Dominant focus on maximising system lifetime
- Need for a fresh look at sensor network assumptions, design and operations

Motivating Examples

- Petrochemical Industry - Pipe monitoring
  - Constant monitoring of pipes (e.g. pressure)
  - Close valves before critical condition is reached
  - Reduces maintenance effort and production cost
  - Improve safety and reduce environment hazards

- Aircraft Industry - Active flow control systems
  - Constant airflow monitoring
  - Actuators to modify wing configuration
  - Reduces drag, fuel consumption and emissions
  - Might help to meet EU aviation emission targets

Performance Dimensions



Network Taxonomy

CRITERIA	CLOSED	OPEN
Application	Single application	Multiple applications
Performance requirements	Fixed	Specified per application
Scale	Small/medium	Large
Lifetime	Long, e.g years	Short/medium
Topology	Static	May be dynamic, e.g. mobile nodes
Data handling	Delivery only	Also in-network processing

What might be needed?

- Performance specified per application
- Notion of end-to-end quality of service
- Possible metrics
  - Latency of sensor report being delivered or acted upon
  - Probability of reliable delivery / loss rate
  - Variability in report delivery (jitter)
  - Goodput over longer durations
  - Accuracy of periodic report generation
  - Latency of event detection
  - Accuracy of event detection / tracking
- Various general categories
  - Critical/safety, closed-loop control, open-loop control, alerting, monitoring, tracking, logging

What might go wrong?

- Missed events or inaccurate detection due to power-saving at source nodes(s)
- Delays in reporting and forwarding due to
  - duty-cycling of radio
  - contention for medium access
  - retransmission due to packet loss/error
  - queuing caused by congestion at forwarding nodes
  - waiting associated with in-network aggregation, filtering or processing
  - delay due to operating system non-preemption
- Node failures or movement affecting report origination and forwarding

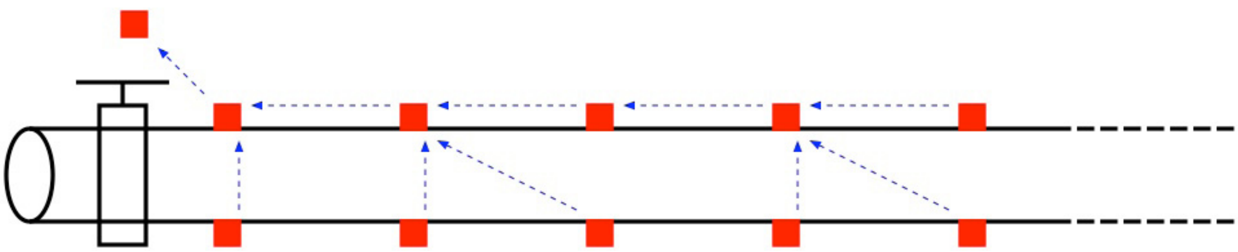
What methodologies might be useful?

- Survey of operating environment to characterise radio noise levels and variability, mobility bounds, communication ranges, sensors
- Network planning and dimensioning – topology control, redundancy degree, traffic profiles, worst case delays (e.g. using network calculus)
- Design of communication and processing components to be deterministic (cross-layer considered harmful?)
- Network simulation to verify operational bounds
- Inference-based (energy-conserving) online models to identify reasons for performance exceptions

Key Requirements

- Performance assured based on selected metrics
- Application gets to specify performance envelope/bounds
- Network to support multiple applications
- Applications may be relatively complex, certainly beyond conventional process instrumentation
- Actuation and sensing
- Peer to peer communication, not always via sinks
- Possibility of mobile nodes
- Network sizes varying from small to very large

Simple Example – A Pipe



- Require
  - bound for the sensor-to-sink message transfer delay D and message transfer reliability R.
  - to close the valve in time
- Provide (at least!)
  - Individual nodes must offer deterministic forwarding delay
  - Routing must select suitable path
  - Topology and traffic control to avoid congestion

Challenges & Some Related Research

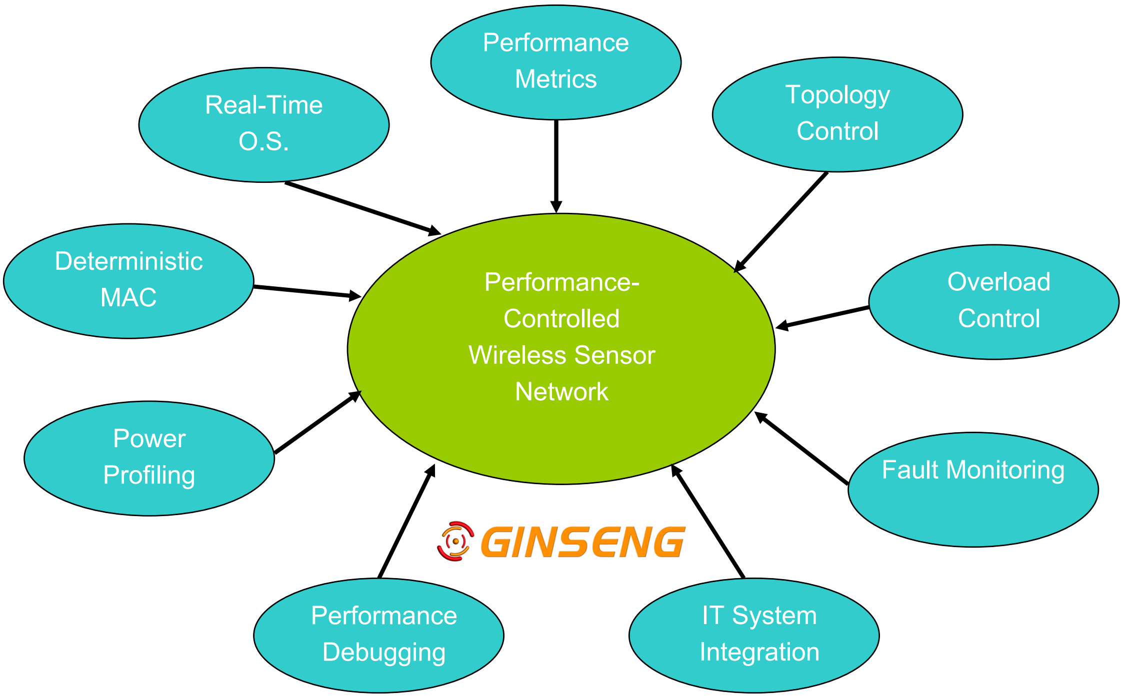
- Performance metrics
  - identification, definition, measurement, estimation
  - Mapping to component behaviour and performance bounds/envelope
- Software components with deterministic behaviour (“building blocks”)
  - Deterministic medium access control
    - Collision avoidance (e.g f-mac by Roedig et. al. EWSN’06 and BitMAC by Ringwald et. al. EWSN’05)
    - TDMA for scheduling with network calculus for worst-case dimensioning (Suriyachai et. al. EWSN’08)
  - Operating system scheduling

    Preemptable TinyOS (Duffy et. al. EmNets’07)
- Predicting performance failures
  - Power profiling for nodes (Dunkels et. al. SenSys’07)

Challenges & Some Related Research

- Middleware to provide real-time responses
  - Peer-to-peer within the network
  - On backend systems e.g. based on stream processing
- Adaptive algorithms - topology control, traffic management
  - Routing
    - RPAR by Chipara et. al. IWQoS’06
    - RAP by Lu et. al. RTAS’02
  - Time-bounded data aggregation (Roedig et. al. EUROMICRO’06)
- Deployment and management tools
  - Network planning/simulation, dimensioning and reconfiguration
  - Performance debugging
  - fault identification and isolation

FP7 GINSENG Approach



Related Activity

- First Workshop on Performance Control at IFIP Networking 2006
- Wireless HART
  - Extension to wired HART system for instrumentation. Multi-hop, based on IEEE 802.15.4. Specification approved Sept. 2008.
- ISA systems for instrumentation in process industries
  - ISA100.11a – wireless periodic monitoring. Draft standard, approval expected Dec. 2008.
  - ISA100.12 – convergence between ISA100.11a and WirelessHart. Early stage.
- IEEE 802.15.4
- 6lowPAN & IETF RFC 4944
- Proprietary systems include
  - Emerson Smart Wireless, Honeywell OneWireless, Apprion/Invensys