Middleware for Wireless Sensor Networks: An Outlook

Gian Pietro Picco
disi.unitn.it/~picco
d3s.disi.unitn.it
Department of Information Engineering & Computer Science
University of Trento, Italy

joint work with Luca Mottola, SICS, Sweden
Wireless Sensor Networks

- Enabled by miniaturization of processing, communication, sensing and actuating devices
- Distinctive feature: *self-organizing* topology with *multi-hop* communication
  - transmit power $\approx \text{distance}^2$
  - many cheap devices with short-range communication
  - more coverage with less energy (and no wires!)
- Challenges: *reliability, lifetime*
WSN Hardware and Software

- **Example: Tmote Sky (TelosB)**
  - TI MSP430 (16 bit RISC)
    - 8 MHz, 10 KB RAM, 48 KB code, 1MB flash
  - Chipcon CC2420 radio
    - IEEE 802.15.4 compliant, 250 kbits/s
  - On-board antenna
  - Temperature, light, and humidity sensors built-in

- **Software development is also stuck in the ’70**
  - Applications developed directly on the OS layer
  - code-and-fix approach
The Role of Software in WSNs

Application
Middleware?
Transport
Routing
MAC
Hardware

Application-agnostic vs Application-specific

Conventional distributed systems
Wireless sensor networks
OS Libraries & Components

- **Operating system libraries**
  - OSes for WSNs provide only very basic functionality
  - System services are effectively provided as an intermediate layer between the OS and the application
    - E.g., data collection and dissemination, time synchronization, localization, …
  - Example: in TinyOS these are built on top of Active Messages, which play a role similar to sockets

- **Component-based middleware**
  - Focus on dynamic reconfiguration and deployment of application functionality
  - Example: RUNES middleware
Many approaches, covering a broad feature spectrum: A “solved problem”?

In our survey:
- 28 systems
- 13 actually implemented on WSN hardware
- Only 1 used in a real-world, long-term deployment
TeenyLIME
... and the Real-World

- Replaces 1-hop message broadcast with 1-hop data sharing
- Targets both application- and system-level functionality

“Programming Wireless Sensor Networks with the TeenyLIME Middleware”
P. Costa, L. Mottola, A. Murphy, and G.P. Picco. In Proc. of the 8th Int. Conf. on Middleware, 2007
Active Messages vs. TeenyLime
Or Why Abstractions are Useful…

bool pendingMsg;
TOS_Msg sendMsg;
event TOS_MsgPtr ReceiveInterestMsg.receive(TOS_MsgPtr m) {
    struct InterestMsg* payload = (struct InterestMsg*) m->data;
    if (isRecipient(payload, TOS_LOCAL_ADDRESS))
        insertInterest(payload->sender, payload->type, payload->threshold, payload->timestamp);
    return m;
}
event result_t TemperatureSensor.dataReady(uint16_t reading){
    if (!pendingMsg && matchesInterest(reading)) {
        atomic {
            pendingMsg = TRUE;
            struct DataMsg* payload = (struct DataMsg*) sendMsg->data;
            msg->sender = TOS_LOCAL_ADDRESS;
            msg->type = TEMPERATURE_READING;
            msg->value = reading;
            if (call SendDataMsg.send(TOS_BCAST_ADDR,sizeof(struct AppMsg),&sendMsg)!= SUCCESS)
                pendingMsg = FALSE;
        }
    }
    return SUCCESS;
}
event result_t SendDataMsg.sendDone(TOS_MsgPtr msg, result_t success) {
    if (msg == sendMsg)
        pendingMsg = FALSE;
    return SUCCESS;
}

event result_t TemperatureSensor.dataReady(uint16_t reading){
    tuple<uint16_t, uint16_t> temperatureValue = newTuple(
        actualField(TEMPERATURE_READING),
        actualField(reading));
    call TupleSpace.out(FALSE,TL_LOCAL,&temperatureValue);
    return SUCCESS;
}
Open Research Challenges
Finding the Right Abstraction... 
... for the right application

Today’s focus:
- many-to-one interactions
- sense-only applications in fixed-node WSNs

Tomorrow:
- many-to-many interactions
- in-network intelligence
  - Cyber-Physical Systems
- opportunistic interactions
  - mobile WSNs, Internet of Things
Finding the Right Abstraction…
… for the right developer

- Wants “good” data!
- Sees the network as a whole
- Knows (more than you’d expect) about basic IT

- Wants “good” yield!
- Sees the behavior of the individual nodes
- Can deal with complex languages/systems and their interaction

We need to support both!
(and probably someone in between)
The “right” architecture is likely to depend on the intended developer.
Joining the Flow
Integrating WSNs into the Mainstream

- At best, WSNs are seen as a monolithic “service”
- CPS and IoT scenarios are pushing WSNs to become part of mainstream business processes
- How to reconcile (and integrate) business process technology with the peculiarities of WSNs?

>makeSense
Easy Programming of Integrated Wireless Sensor Networks
Other Research Challenges

- **Cross-layering**
  - Advocated as a must in WSNs, to guarantee performance in spite of scarce resources
  - In practice, no WSN middleware fully supports it

- **Supporting multiple concurrent applications**
  - Will become more and more important as the Internet of Things becomes commonplace

- **Enabling reliable, predictable implementations**
  - Provide well-defined failure modes
  - Middleware is the right level of abstraction for verification

- **“How good is my middleware?”**
  - Often answered only in terms of performance
  - Impact on programming practice overlooked
Tactics vs. Strategy

... Hardware and OS: Cozy or Adventurous?

- Experiment with more resource-rich platforms
  - Anticipating future hardware developments
  - "System" challenges vs. "abstraction" challenges
- Beware: unlike with PCs, it’s not just a hw upgrade
  - The software must be (heavily?) adapted, too
Tactics vs. Strategy
“Have You Ever Heard of ZigBee?”

- Conflicting goals
- Clean-slate research vs. standard compliance
- In which playground do you want to play?
Tactics vs. Strategy

Is Interoperability an Issue?

- No middleware provides support for multiple OS
- Interoperability is not an issue ... today
Let’s Not Forget the Final Goal …

- To make an impact, middleware must sustain the challenges of real-world deployments
  - Just like networking protocols did…
- In-field validation is not enough:
  - tradeoffs between research speculation and practical issues must be resolved early on
A Different Mindset

- Designers of WSN middleware must “get their hands dirty” with the networking stack.
- A broad blend of competences is required, currently scattered across different research communities…
  - … sometimes not speaking to each other.
- A concerted effort is ultimately needed.