Internet Connectivity for Wireless Sensor Networks

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Outline

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- Challenges
- Internet of Things
- Related research efforts
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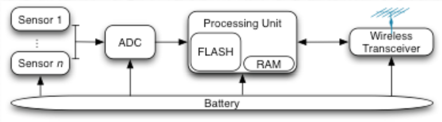
Introduction

- Wireless sensor networks
  - Smart sensors with processing core, memory, sensors, wireless transceiver and battery
  - Energy concerns/constraints
- Need for Internet connection
  - Make sensing services widely available
  - Power ubiquitous computing
- **IP** - Internet Protocol
  - Protocol used on the Internet (network layer)
  - Heterogeneous network interconnection
  - Map WSNs into public subnet, provide global connectivity



Typical block diagram of a sensor note.

Background - Architectural Perspective

- Two main approaches
  - ***Proxy-based***
  - ***IP integration***
- **Proxy-based**
  - Adaptable to almost any WSN
  - Needs protocol conversion - e.g. sink (uses dedicated WSNs protocols)
- **IP integration**
  - IP inside the smart sensor node
  - Enables technology homogeneity
  - Takes advantage of years of research on IP

Challenges

- Proxy-based approach preferred
  - IP not suited for WSNs
- Large header overhead
  - IPv4 - minimum of 20 bytes
  - IPv6 - 40 bytes
- Global addressing scheme
  - WSNs are typically data-centric
  - IP is address centric, needs global addressing scheme at the network level

Challenges *(cont.)*

- Limited bandwidth
  - Very limited bandwidth of WSN wireless communication - up to 250kbps
  - More bits -> more MAC delays and transmission times
- Limited node energy
  - Very important on many WSN scenarios
  - Bits cost energy
- Implementation
  - IP complex for 8/16 bits micro-architectures and very low memory devices
  - IEEE 802.15.4 has 102bytes payload, IP can reach 1280bytes or more
- Transport protocol
  - TCP - even more communication overhead
  - UDP - no reliability guarantees

Motivation

- ***Why IP support on all LoWPAN nodes?***
  (Low-power wireless personal area networks)
- IP-based technologies already exist, are well known and proven to be working
- The pervasive nature of IP networks allows use of existing infrastructure
- Take advantage of existing tools for network management
- Technology homogeneity with the Internet
  - Seamless connection
  - "**Internet of Things**"
- Individual smart sensor node addressing
  - Adequate for some scenarios - e.g. BSNs

Internet of things approaches

It is foreseeable that any object in the near future will have an Internet connection – this is the **Internet of Things vision**. All these objects will be able to exchange and process information, most of them characterized by small size, power constrained, small computing and storage resources. In fact, connecting embedded low-power devices to the Internet is considered the biggest challenge and opportunity for the Internet. There is a strong trend of convergence towards an Internet based solution and the 6LoWPAN may be the convergence solution to achieve the Internet of things vision.

- ZigBee
- Machine-to-machine communications
- The Future Internet
- Web of things
- Wireless sensor networks

Internet of things approaches

- There are a strong trend of convergence towards a Internet-based solution to connect all Internet of things solutions.
- The 6LoWPAN may be the convergence solution

Related Research Efforts on IP-over-WSNs

- Challenges exist to be tackled
- IP is widely used and known
- Several published papers
- Operating systems support
  - TinyOS
  - ContikiOS
- IPv6 advantages
  - Larger addressing space
  - Stateless auto-configuration

The beginning…

- Breaking the implementation myths
  - Header compression
  - Link-layer addresses (IPv6)
  - Stateless auto-configuration (IPv6)
  - Fragmentation support
- A. Dunkels, "Full TCP/IP for 8-bit Microarchitectures," in First international Conference on Mobile Systems, Applications and Services, San Francisco, CA, USA, 2003.
  - uIP - IP for 8-bit micro-architectures
  - lwIP - IP for 16-bit architectures

Takeoff

- Some networks
  - Intrusion detection - A. Dunkels, T. Voigt, N. Bergman, and M. Jonsson, "The Design and Implementation of an IP-based Sensor Network for Intrusion Monitoring," in Swedish National Computer Networking Workshop, Karlstad, Sweden, 2004.
  - Motion capture through BSNs - A. Christian and J. Healey, "Gathering Motion Data Using Featherweight Sensors and TCP/IP over 802.15.4," HPL-2005-188, 2005.
  - among others…

Dedicated Stacks

- Research around dedicated IP stacks for sensor nodes
- Using 6LoWPAN
  - blip - TinyOS
  - sicslowpan - ContikiOS
  - Atmel, Jennic and Sensinode, Arch Rock implementations
  - K. Mayer and W. Fritsche, "IP-enabled Wireless Sensor Networks and Their Integration Into the Internet", in First International Conference on Integrated ad-hoc and Sensor Networks, ISBN: 1-59593-427-8, Nice, France, 2006
- Other approaches
  - LWIPv6 - H. J. Kim, W. J. Song, and S. H. Kim, "Light-weighted Internet protocol version 6 for low-power wireless personal area networks", in IEEE International Symposium on Consumer Electronics (ISCE 2008), Vilamoura, Portugal, April 14-16, 2008.
  - G. Han and M. Ma, "Connecting Sensor Networks With IP Using a Configurable Tiny TCP/IP Protocol Stack", in 6th International Conference on Information, Communications & Signal Processing, ISBN: 978-1-4244-0983-9 Singapore, 2007.

IPv6 vs IPv4

- IPv6
  - Low impact on bits transmitted
  - Added addressing space
  - New features
- IPv6 wins!

J. S. Silva, R. Ruivo, T. Camilo, and G. Pereira, "IP in Wireless Sensor Networks - Issues and Lessons Learnt," in Third International Conference on Communication Systems, Software and Middleware (COSMWARE 2008) Bangalore, India: IEEE Communication Society, 2008.

6LoWPAN

- IETF working group
- Bring IPv6 to WSNs powered by IEEE 802.15.4 radios
- Specification of an intermediate layer
  - Between IPv6 (network) and IEEE 802.15.4 (MAC)
- Features
  - Header compression
  - Fragmentation support
- Mailing list presents great activity

G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler, Transmission of IPv6 Packets over IEEE 802.15.4 Networks, RFC number 4944, IETF, 2007

- Information on header compression, frame format, IPv6 local-link addresses

Resources - Software

- Main operating systems
  - TinyOS
  - ContikiOS
- Both support IP
  - blip - TinyOS
  - uIP(v6) - ContikiOS
- Both support 6LoWPAN
- Several hardware available

TinyOS

- Open source
- Berkley university - http://www.tinyos.net
- nesC programming language
  - Component-based
  - Learning curve for C programmers
- TOSIM simulator
- One of the most used operating systems for embedded devices worldwide
- blip - Berkley IP
  - IP over WSNs, with or without 6LoWPAN
  - Formerly b6lowpan
- Linux virtual machine

blip

- Performs IP over WSNs on TinyOS
- With 6LoWPAN support
- Features
  - IPv6 neighbor discovery
  - Default route selection
  - Point-to-point routing
- Support for
  - ping6, tracert6, and nc6
  - TCP still experimental
- BSD sockets API
- Tested on Micaz, Telos and epic platforms

ContikiOS

- Open source
- Swedish Institute of Computer Science – http://www.sics.se/contiki
- C programming language
- Protothreads
  - Thread-like approach with shared stack
  - Memory efficient
  - Auto-start, start on request
- Events
  - System and programmer-defined
  - Wait for an event
- Timers
  - Event timers

ContikiOS (*cont.*)

- Two communication stacks
  - Rime and uIP(v6) (the world's smallest open source compliant IPv6 stack, for Contiki)
- COOJA Java simulator
  - recently updated with dramatic performance increase
- MSPSim standalone MSP430-based simulation
  - suitable for one node firmware testing
  - several resources namely memory usage, stack view and
- Linux virtual machine - over Ubuntu 8.04LTS - more flexible

uIP6

- IPv6 over WSN
  - More than IEEE 802.15.4 - interface independent architecture
- With 6LoWPAN support - sicslowpan
  - IPv6 over IEEE 802.15.4
  - Fragmentation and header compression support
- Features
  - TCP, UDP
  - IPv6 addressing
  - ICMPv6
  - Neighbor Discovery
- Tested on Atmel Raven, sky/Telos, Micaz, Sensinode and others
- From ContikiOS 2.2.3 (currently 2.3)

Resources - Hardware

- Crossbow as a “core” manufacturer
- Other manufacturers
  - Sensinode
  - Jennic
  - Sentilla
- Two main processor platforms
  - TI MSP430
  - Atmel ATMega
- IEEE 802.15.4 radios dominate

Resources - Hardware (some motes)

Table I. Some examples of wireless sensor hardware (motes).

Mote	Processor platform	RAM/program/measure	Transceiver	Operating systems	Price (USD)
Crossbow IRIS	Atmel ATmega 1281	8 KB/128 KB/512 KB	Atmel RF230	TinyOS	115/75
Crossbow MICAz	Atmel ATmega 128L	4 KB/128 KB/512 KB	TI CC1000	TinyOS	99/75
Crossbow MICA2	Atmel ATmega 128L	4 KB/128 KB/512 KB	TI CC1000	TinyOS/ nano-RK	115–125/75
Crossbow Imote2	Marvel PXA271	32 MB/32 MB/–	TI CC2420 (IEEE 802.15.4)	TinyOS	299/150
Crossbow TelosB	TI MSP430	10 KB/48 KB/1 MB	TI CC2420 (IEEE 802.15.4)	TinyOS/ ContikiOS	99–139
Atmel AVR Raven	Atmel ATmega 1284P+3290P		Atmel RF320	ContikiOS	85 (kit)
Scatternode	Centering TI MSP430	5 KB/55 KB/–	ISM band/19.2 kbps	Proprietary/ ContikiOS	
Shimmer	TI MSP430	10 KB/48 KB/2 GB	TI CC2420 (IEEE 802.15.4)	TinyOS 1.x	220
Coalesenses ISense	Jennic JN5139	96 KB/128 KB/–	Integrated in JN5139	Proprietary	
Sun SPOT	ARM920T	512 KB/4 MB/–	IEEE 802.15.4 radio	Java programming	299 (edu. kit)

Resources - TelosB

- All-in-one platform
  - micro-controller (MSP430)
  - IEEE 802.15.4 compliant radio (CC2420)
  - USB port - FTDI chip
  - 10KB RAM/48KB program/1MB general purpose
  - autonomous power supply - 2AA batteries
  - 3LEDs - red, green and blue
  - sensors - temperature, humidity and light
- Previous versions
  - sky
  - Telos
- Supported by both TinyOS and ContikiOS

Resources - Summary

- RAM
  - 4KB-10KB (typically)
- Flash ROM
  - 48KB-128KB (typically)
- Several combinations of software/hardware
  - TelosB supports both OS's
- ContikiOS gaining popularity
  - uIP(v6) contribution
  - Works very well with TelosB

Deploying IPv6-enabled WSNs

- Choose an operating system
  - TinyOS, ContikiOS or other
  - Examples available to start playing with
- Choose an hardware platform
  - Many platforms available
- Develop solution
  - Linux OS preferred for development - virtual machines available
- Use suitable simulation tools
  - COOJA/MSPSim/TOSIM
- Test/deploy on target hardware

Conclusions

- IP on WSNs is a reality!
- Internet of Things has emerged
- Crossbow TelosB hardware
  - Support from both TinyOS and ContikiOS
  - All-in-one platform
  - A good platform to start with
- Other platforms emerge (Raaven Atmel, ...)
- New platforms
  - Sometimes, port is not mature enough

Conclusions (*cont.*)

- Deployment of IP-based WSN possible today
  - With off-the-shelf components and open source OS
- What's the best approach?
  - Available WSNs - proxy-based
  - New deployments - depends on the network scenario
- IPv6 over WSN
  - ContikiOS takes the lead
  - But TinyOS also supports it

Some more references

- Joel J. P. C. Rodrigues and Paulo A. C. S. Neves, “A Survey on IP-based Wireless Sensor Networks Solutions”, in *International Journal of Communication Systems*, Wiley, ISSN: 1074-5351, Vol. 23, No. 8, pp. 963-981, August 2010.
- Paulo Neves, André Esteves, Rui Cunha, and Joel J. P. C. Rodrigues, “User-Centric Data Gathering Multi-Channel System for IPv6-enabled Wireless Sensor Networks”, in *International Journal of Sensor Networks* (IJSNet), InderScience Publishers, ISSN (Online): 1748-1287 - ISSN (Print): 1748-1279, Vol. 9, No. 1, 2011.
- Paulo A. C. S. Neves and Joel J. P. C. Rodrigues, “Internet Protocol over Wireless Sensor Networks, from Myth to Reality”, in *Journal of Communications* (JCM), Special Issue on High-performance Routing and Switching in Wireless Networks, Min Song, Yang Yang, and Sheng Fang (Eds.), Academy Publisher, ISSN 1796-2021, Vol.5, No. 3, pp. 189.196, March 2010.
- Paulo A. C. S. Neves, Binod Vaidya, and Joel J. P. C. Rodrigues, "User-Centric Plug-and-Play Functionality for IPv6-enabled Wireless Sensor Networks", *IEEE International Conference on Communications* (IEEE ICC 2010), Cape Town, South Africa, May 23-27, 2010.

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Thanks for your attention!

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