The Intelligent Container - Wireless Sensor Networks in Logistics

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19. ComNets-Workshop

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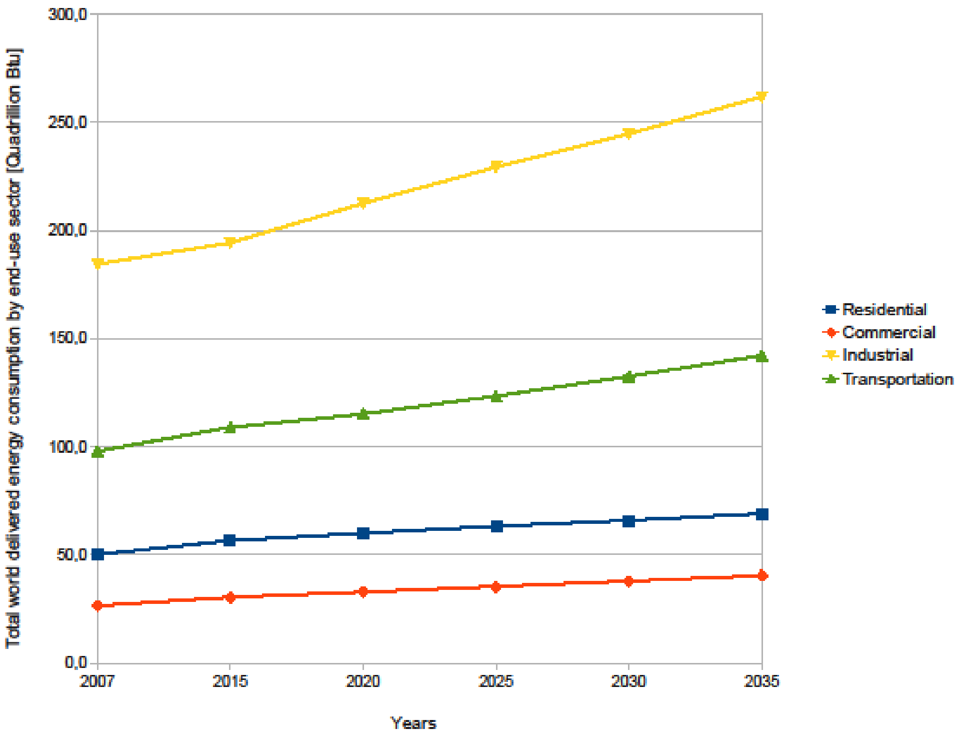
Agenda

- Intelligent Container
  - The big picture
  - Research Projects
- Wireless Sensor Networks
  - (Open) Standards
  - Service Discovery
- Modelling and Simulating a Service Discovery Algorithm
  - Distribution Algorithm ‚Trickle'

Intelligent Container?

- Autonomous transport monitoring system for perishable and sensitive goods
- Technologies: RFID, sensor networks and software agents
- Permanent and freight-specific supervision of each transport package along the supply chain
- Local pre-processing of sensor information reduces costs for external mobile communication
- Quality prediction model @ the container, truck or semi-trailer

The Big Picture



[Data Source: International Energy Outlook 2010, Report #: DOE/EIA-0484(2010), U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy]

- Economical & Ecological Impact

- Transport of food (perishable)
- Dynamic FEFO
  (First Expire, First Out)

- Reduce Food-Scrap
- Reduce Over-Provisioning of Cooling
- Improve Logistical Risk-Awareness
- Create new Logistical Handling Options

Intelligent Container Project(s)

- DFG Collaborative Research Centre 637 Sub-projects B3, B6 among others
  - 2004 – 2008
  - Demonstrator

- DFG Collaborative Research Centre 637 Sub-project T4
  - 2008 – 2009
  - Fieldtests

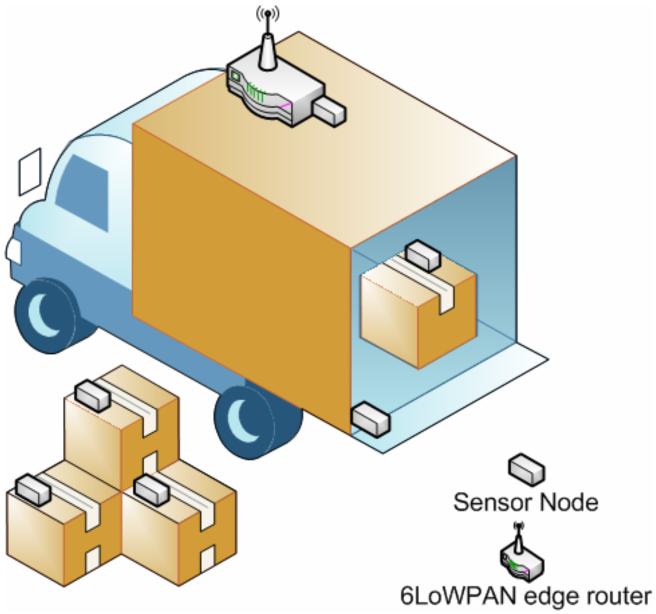
- BMBF/DLR Alliance for Innovation
  - 2010 – 2013
  - Pre-prototyping

- Partners:

WETRALOG FOOD-LOGISTIK
KÜHN Transporte Lagerung
CARGOBULL TELEMATICS
universität bonn
RUNGIS express
ProSyst
Microsoft Innovation Center Europe
aicas realtime
SEEBURGER BUSINESS INTEGRATION
BIBA Bremer Institut für Produktion und Logistik an der Universität Bremen
IMSAS
ATB
ComNets Kommunikationsnetze
Dole
CHS
The Mobility Manager OHB TELEDATA
TEXAS INSTRUMENTS
ITEM
ELBAU Elektronik Bauelemente GmbH Berlin

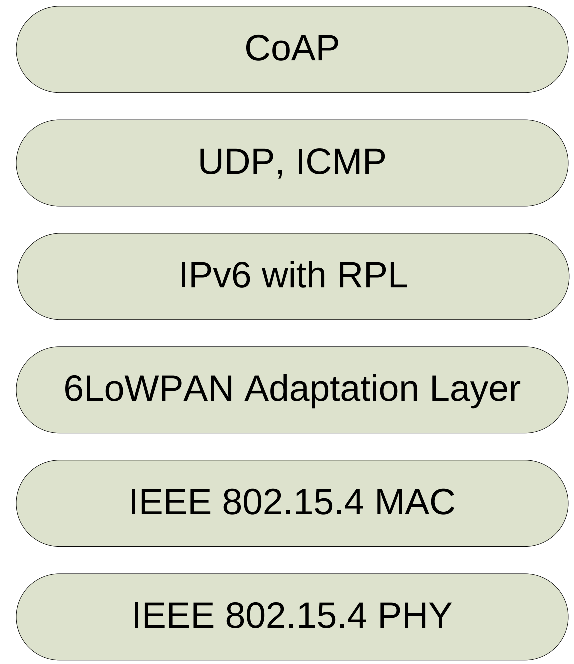
Wireless Sensor Networks

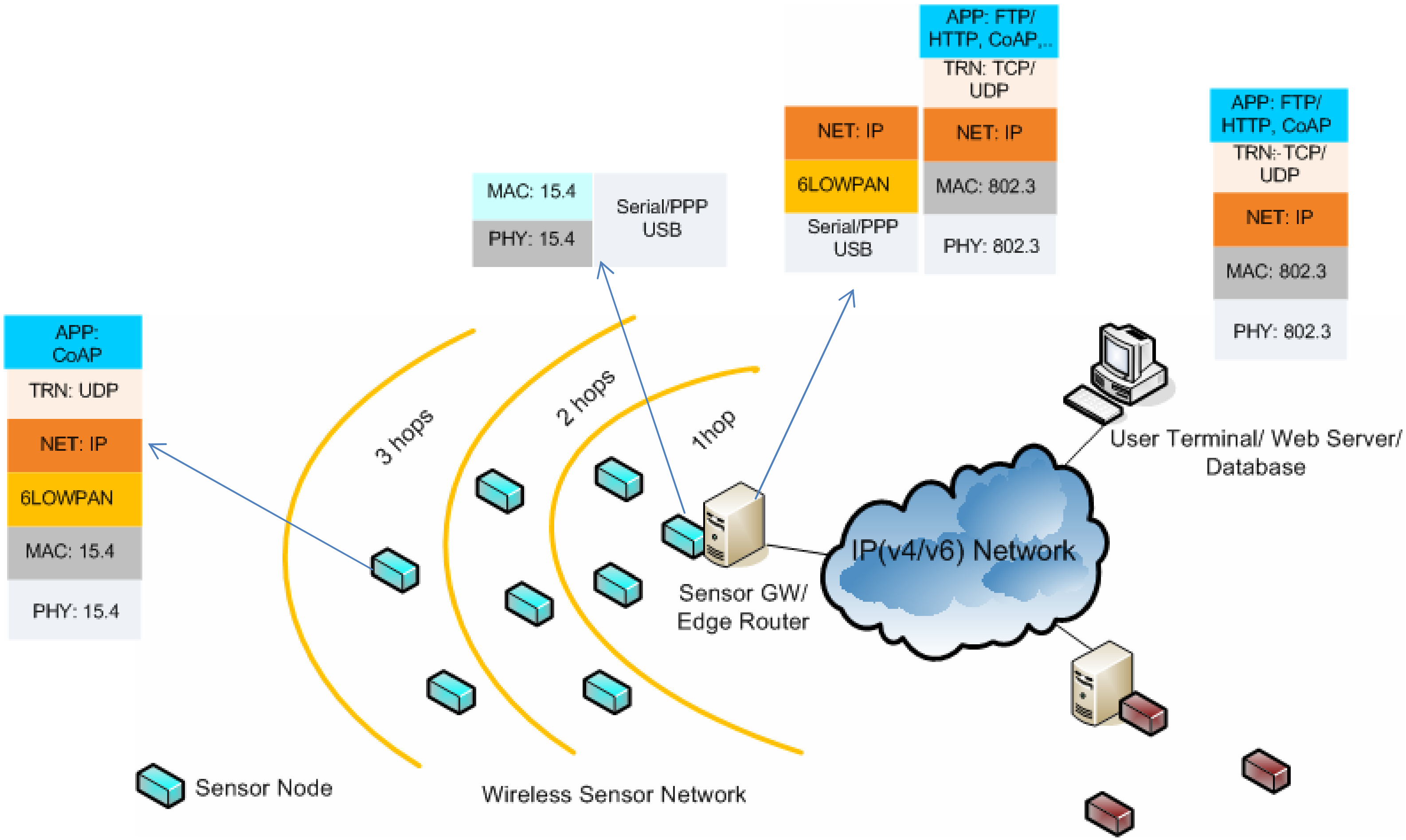
- Sensor Node
  - Constrained in energy, computational power, storage capacity, transmission range & data rate
  - Typically
    - MSP430 microcontroller with 10kB RAM
    - 16-bit RISC with 48K Program Flash
    - IEEE 802.15.4 compliant radio (< 250 kbps)
    - 1MB external data flash ROM
    - Two AA batteries/USB
    - 1.8 mA (active); 5.1uA (sleep)
- Wireless Sensor Networks
  - A collection of embedded tiny devices (sensors) with networking capabilities
- Challenges on WSNs in Logistics
  - Multi-player business
  - Generic WSNs required
  - Mobility



(Open) Standards in the WSN Domain

- IEEE 802.15.4
  - 127 byte packets
  - max. 250 kbit/s
- IETF 6LoWPAN (IPv6 over Low power WPAN)
  - IPv6 Adaptation Layer for IEEE 802.15.4:
    header compression, fragmentation, reduced use of multicast
  - RFC 4944, draft-ietf-6lowpan-hc, draft-ietf-6lowpan-nd
- IETF RPL (IPv6 Routing Protocol for Low power and Lossy Networks)
  - ROLL Working Group
  - draft-ietf-roll-rpl
- IETF CoAP (Constrained Application Protocol)
  - CoRE Working Group
  - draft-ietf-core-coap





APP: FTP/ HTTP, CoAP,..
TRN: TCP/ UDP
NET: IP
NET: IP
6LOWPAN
MAC: 802.3
Serial/PPP USB
PHY: 802.3
MAC: 15.4
PHY: 15.4
Serial/PPP USB
APP: FTP/ HTTP, CoAP
TRN:-TCP/ UDP
NET: IP
MAC: 802.3
PHY: 802.3
APP: CoAP
TRN: UDP
NET: IP
6LOWPAN
MAC: 15.4
PHY: 15.4
3 hops
2 hops
1hop
User Terminal/ Web Server/ Database
IP(v4/v6) Network
Sensor GW/ Edge Router
Sensor Node
Wireless Sensor Network

CoAP Architecture

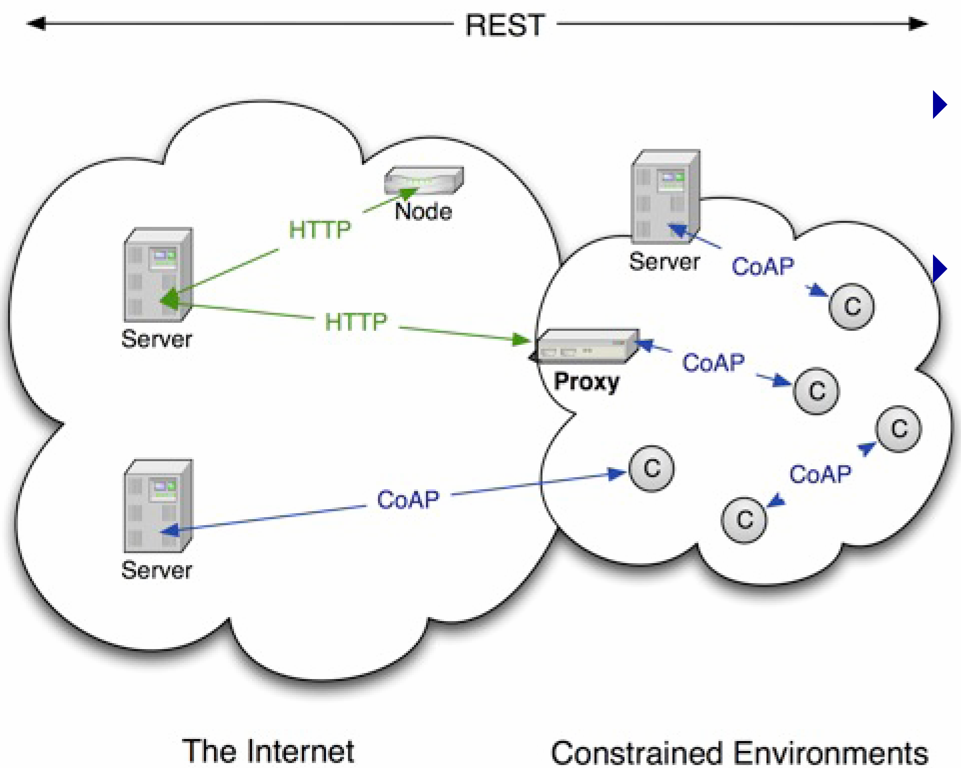


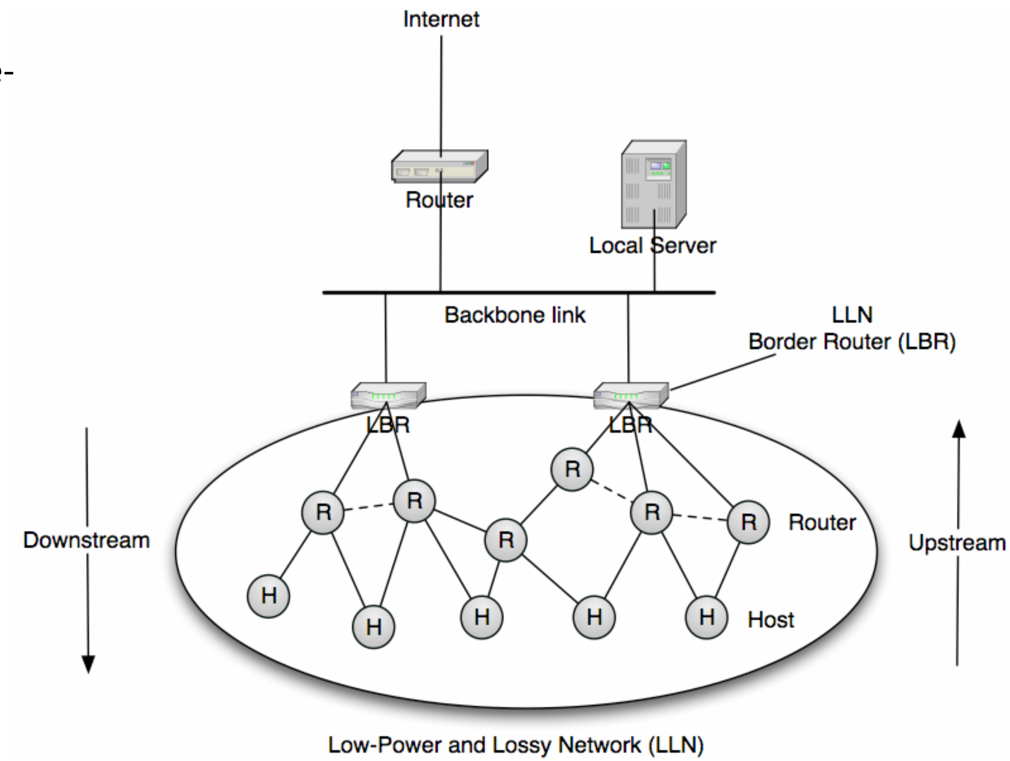
*Image Source: **77th IETF core WG presentations***

<u>C: Constrained node</u> - sensor nodes
<u>Non-constrained nodes</u> - server, proxy, node, etc

- Use of web services on the Internet depends on the **Representational State Transfer (REST)** architecture
- **RESTful** protocol to cater the special requirements of a constrained environment
  - Simple RESTful protocol transport
  - Create, Read, Update, Delete, Notify
    - Small, simple header
    - 4 byte base header
    - TLV options, typically 3-4 bytes per option
  - URI support: e.g. coap://
  - Subset of content types
  - Subset of HTTP-compatible response codes
  - UDP and TCP bindings
  - default port = 61616

IETF ROLL RPL Routing

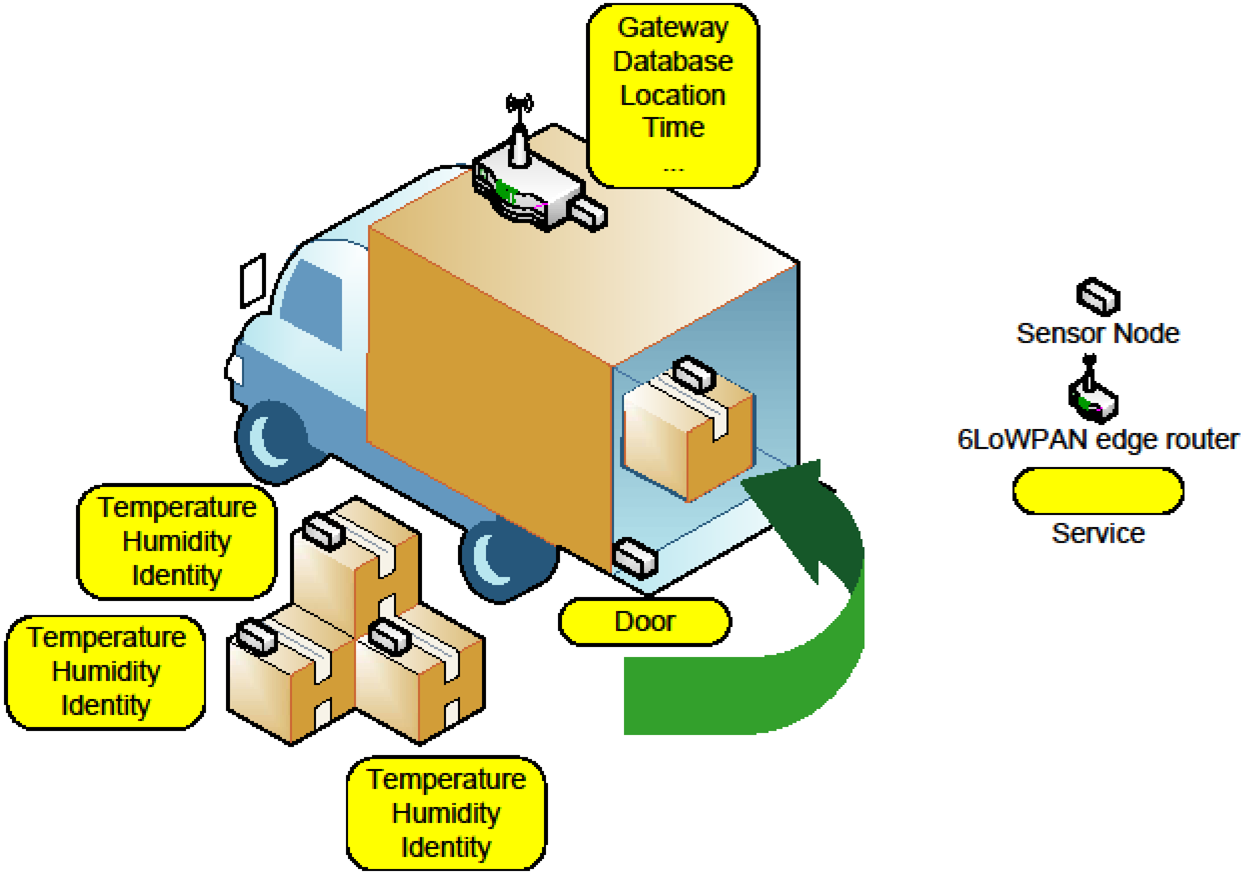
- RPL routing
  - draft-ietf-roll-rpl-15: Proactive distance-vector approach, uses graph structure (objective: topology needs to be discovered and maintained using a minimal amount of signaling)
- Routing Metric
  - draft-ietf-roll-routing-metrics-12: path calculations (node energy, hop count, throughput, latency, etc)
- The Trickle Algorithm
  - draft-ietf-roll-trickle-05: to exchange information in a highly robust, energy efficient, simple, and scalable manner



[Image Source: http://6lowpan.net/the-book/]

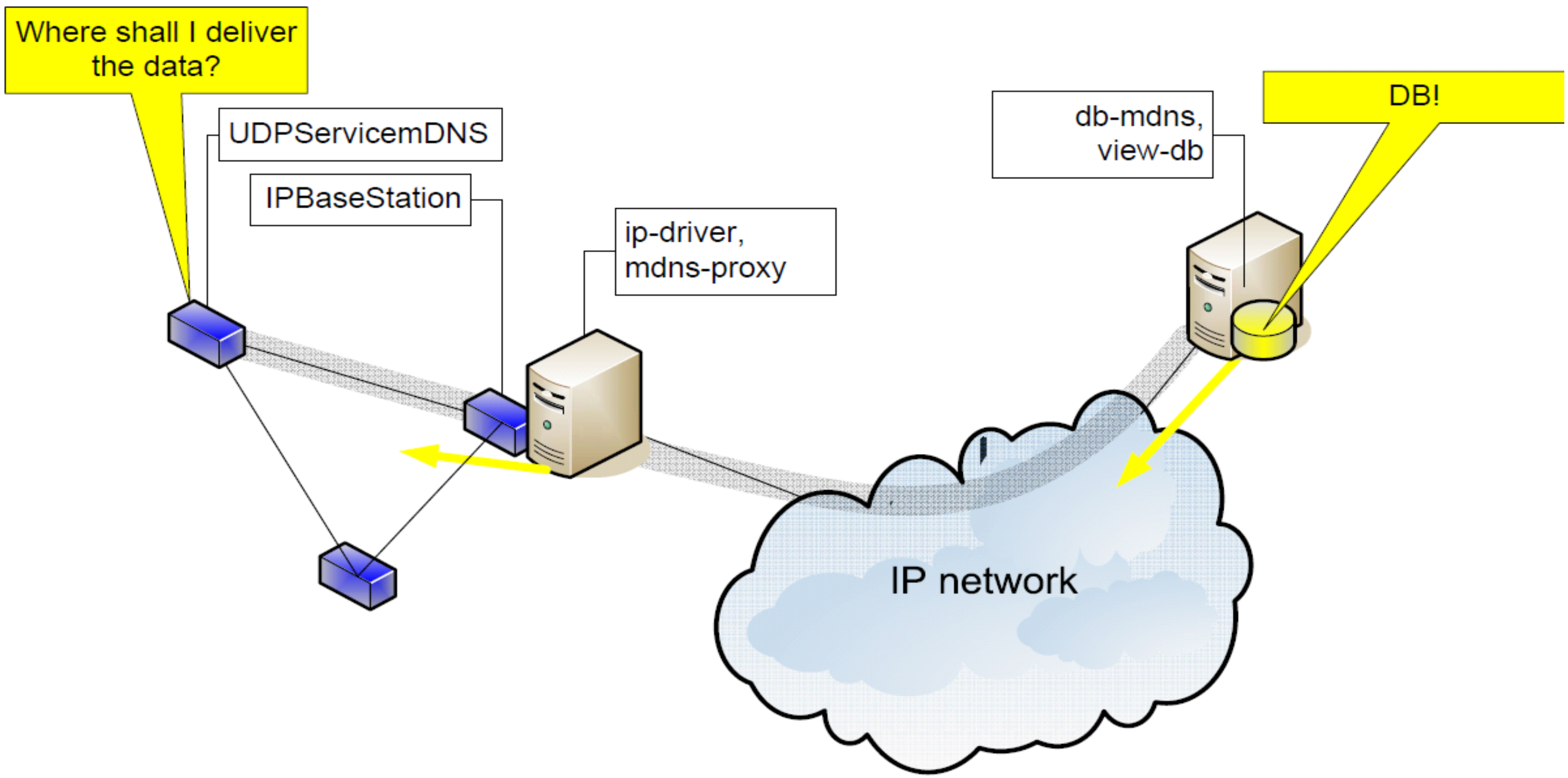
Wireless Sensor Service Networks

- Multitude of Services in Wireless Sensor Networks
- Autonomous discovery of services needed



Sample Service Discovery

- Discovery of a database service with 6LoWPAN



Distribution Algorithm for WSNs

- P. Levis, N. Patel, D. Culler, S. Shenker: ’Trickle: A Self-Regulating Algorithm for Code Propagation and Maintenance in Wireless Sensor Networks’ in NSDI’04 Proceedings.
- P. Levis, T. Clausen, J. Hui, O. Gnawali, J. Ko: ’The Trickle Algorithm’ IETF Internet Draft. draft-ietf-roll-trickle-08. State: RFC Ed queue.
- M. Becker, K. Kuladinithi, C. Görg: Modelling and Simulating the Trickle Algorithm. Submitted for IP+SN2011.

Trickle Algorithm: Rules, Variables & Constants

τ expires

- Double τ, up to τ_H, pick a new T from range $[\tau/2, \tau]$

T expires

- If $C < K$, transmit

Received consistent data

- Increment C

Received inconsistent data

- Set τ to τ_L. Reset C to 0, pick a new T from $[\tau/2, \tau]$

τ	Communication interval length
T	Timer value in range $[\tau/2, \tau]$
C	Communication counter
K	Redundancy constant
τ_L	Lowest τ
τ_H	Highest τ

- Density-aware algorithm
- Rate adaptive to inconsistency in network

Simulation Scenarios

- Line scenario
  - Only direct neighbors (’Line-Direct’)
  - Closest Pattern Matching Model (’Line-CPM’)
- Grid scenario (’Grid’)
- Random scenario (’Random’)
- MoteLab scenario (’MoteLab’)

- For Line-Direct, Line-CPM, Grid and Random scenarios:
  - Varying number of nodes
  - Varying inter-node distances / scenario size

Simulation Execution

- TinyOS application with 6LoWPAN implementation ‚blip‘
- Simulation tool TOSSIM
- ‚blip‘ extended for simulations
- Monte-Carlo iterations for each scenario instance

Analytical Models for Service Discovery

- Service Consistency Time pdf

$$p(t) = \frac{1}{N} \sum_{i=0}^{N-1} h_i(t) * p_i(t)$$

$$p_i(t) = \begin{cases} \delta(t) & , i = 0, \\ \mathcal{L}^{-1}\{\mathcal{L}\{\Theta(t - \frac{\tau_L}{2}) - \Theta(t - \frac{\tau_L}{2} - \tau_L)\}^i\} & , i \geq 1. \end{cases}$$

- Number of Messages

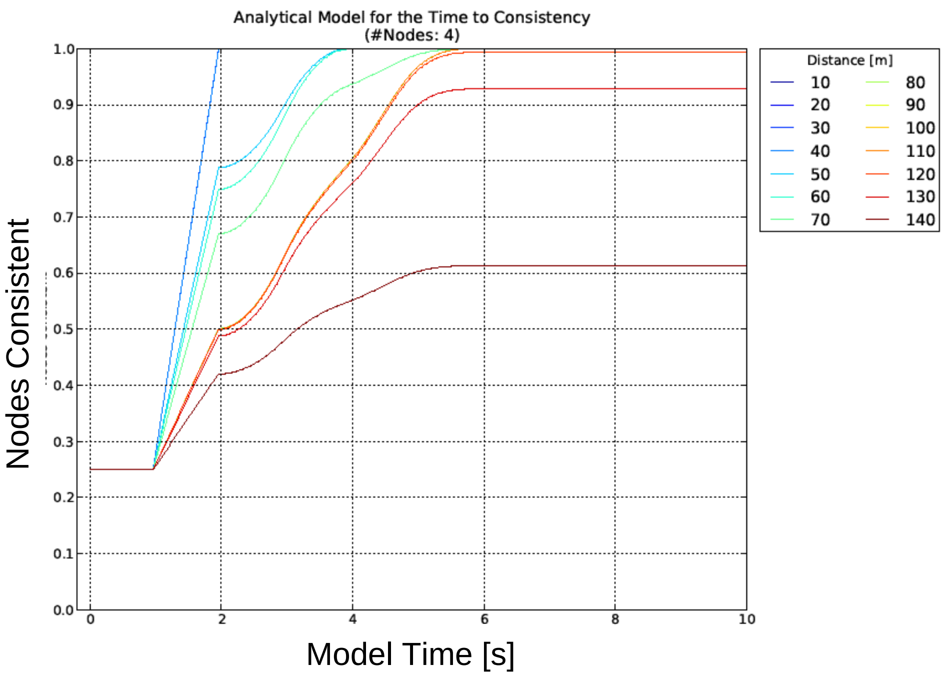
$$\texttt{\#cycles} = \begin{cases} \log_2 \tau_h - \log_2 \tau_l + 1 + \frac{T_u - (2\tau_h - 1 - log_2 \tau_l)}{\tau_h} \\ \qquad \text{if } T_u > 2\tau_h - 1 - \log_2 \tau_l, \\ \log_2 \tau_h - \log_2 \tau_l + 1 + \frac{T_u - (2T_u - 1 - log_2 \tau_l)}{2^{log_2 T_u - log_2 \tau_l + 1}} \\ \qquad \text{if } T_u \leq 2\tau_h - 1 - \log_2 \tau_l. \end{cases}$$

$$\texttt{\#packets} = K * \texttt{\#cycles} * \texttt{\#nodes} * \frac{1}{\texttt{mean(\#neighbors)}}$$

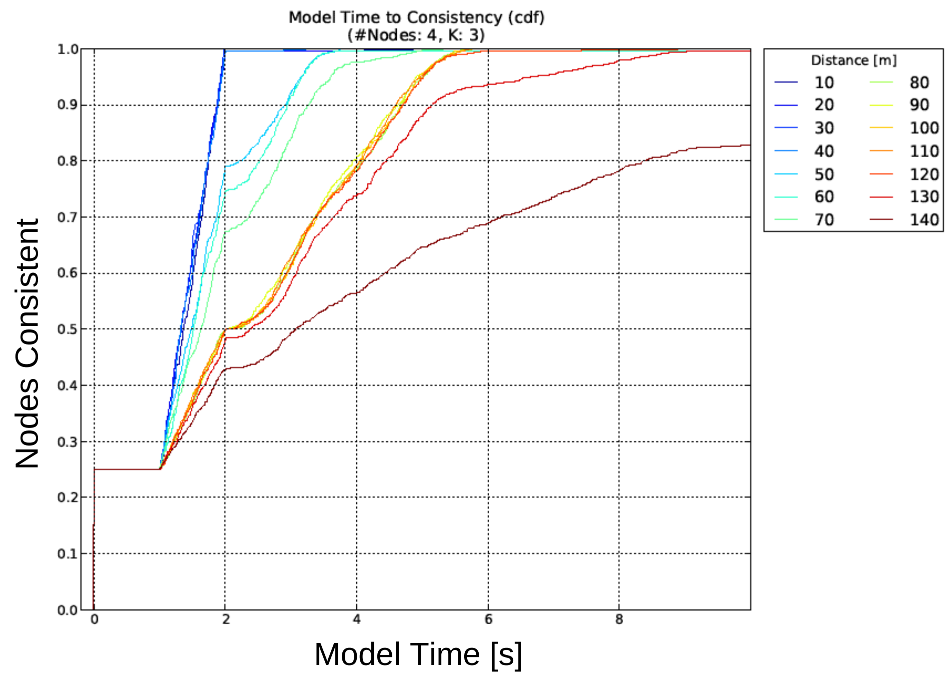
Results from Analytical Models and Simulation

- Service Consistency cdf
- Line-CPM scenario, 4 nodes

- Analytical Model



- Simulation



Conclusions & Outlook

- Trickle suitable for
  - network layer protocols
  - service discovery

- Measurement of Trickle Algorithm in a Testbed
- Comparison of Measurements, Simulation and Analytical Model