Routing in sensor networks (industrial): choices and technical issues

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ENG Labs
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JCSA 2014
The Industrial Internet of (Every)thing

Challenge: harness innovation
More efficient operations
New and/or improved experience
Beyond Control and Automation
Optimize processes (by 1%?)
Leveraging IT, Live big data and Analytics
Without adequate analytics clout available, and the right practices to take advantage of it, the companies rolling out M2M solutions will be destined to be stuck in the lower realms of applications: monitoring, reporting, and simple rules-based actions.” *
Technologies for the Industrial Internet

- ISA100.11a
- WirelessHART
- TSN / 6TISCH
- 6TISCH large scale monitoring
- WiFi
- CG-Mesh

Process Criticality

Nb of Devices (order of magnitude)

Control Data
Business Data
Office Data
Analytics vs. Overall M2M connection ratio *

15M to 115M Analytics related connections*

Classical Monitoring only doubles

Analytics related M2M connections surge

* Source: ABI Research
ive Big Data
The Future of Industrial Networks

Operational technology (OT) is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise.

Next % point of optimization:

...requires collecting and processing of live “big data”, huge amounts of missing measurements by widely distributed sensing and analytics capabilities.

...achievable by combination of the best of IT and OT technologies together, forming the IT/OT convergence, aka Industrial Internet.

Deterministic Wireless Industrial Networking technologies must be extended to reach higher scales at lower costs (but then, guarantees as well).

Architectural approach, standards, Industry adoption needed to embrace radical changes happening in IT networking technologies.

Secured-by-default model required throughout network lifecycle.
Not Process Control but “Missing Measurements”

Reliability and availability are important, which implies Scheduling and admission control

Scalability
10’s of thousands of new devices

Deployment cost factor is key

For Emerson this is the second layer of automation:

Typically missing are the measurements you need to monitor the condition of the equipment—temperature, pressure, flow and vibration readings you can use to improve site safety, prevent outages and product losses, and reduce maintenance costs of equipment such as pumps, heat exchangers, cooling towers, steam traps and relief valves.
Maintenance and operation represent 75% of the Total equipment cost.

Deployment of Wireless sensors is seen as an efficient solution.
IKW model for Industrial Internet

Data: Large Scale monitoring for data integration regardless of source type

Information: Descriptive meta-tags, enables compression and correlation

Knowledge: Prediction from self-learned models and Knowledge Diffusion

Wisdom: self-acquired Expertise, Actionable recommendations
A network for large scale monitoring
Wireless Connectivity

New level of cost effectiveness
Deploying wire is slow and costly
Low incremental cost per device

Reaching farther out
New types of devices (Internet Of Things)
New usages (widespread monitoring, IoE)
Global Coverage from Near Field to Satellite via 3/4G

BUT
Issues with IPv6 for scalability and Mobility
Wireless Process Control

Control loops
- global optimization of routes for jitter and latency – thus computed by a PCE –
- low (over) provisioning, duocast for 1 hop (1Hz and 4Hz, no routing) with static multipath hard slot allocation

Control loop plan B
- self-healing -thus distributed- routing, RPL
- supervisory flows
- no goal: requires determinism up into the backbone
- management
- a separate topology – a RPL instance - that does not break.
- OF?, root selection?

Alerts
- bursty, unexpected, on-demand slot allocation, prioritization
Wireless Process Control (cont)

Monitoring of lots of lesser importance
  stuff like corrosion? low cost scalability – this distributed routing, soft slots?

Cranes spanning area (ship)
  with linear and circular motion that are mobile within a range
  no goal some will need deterministic for coordination between cranes

Mobile worker
  additionally provision slots ready for mobile workers) does not need deterministic since human

Large plants
  thousands of devices– thus a backbone, multiple BBRs for 1 LLN –
  within a subnet – to avoid renumbering though not always the case, sometimes isolation is wanted

Non-production episodes
  fast and autonomic behavior – again distributed routing

Coexistence with legacy devices
  a common management above, coarse level makes sense (channels backlisting but no more…single admin is good)
Wireless scales but power constraints and fuzzy topology
⇒ Different risks, value in diversity

TDMA requires timesync, CSMA-CA needs idle time
⇒ Different usages, deterministic vs. best effort

Spatial reuse
⇒ Wired backhaul a good idea in any case

Centralized optimizes, Distributed scales economically
⇒ Different usages, deterministic vs. best effort

Reactive mixes routing and forwarding (e.g., IPv6 ND)

Link State requires full & constant topology awareness
⇒ 6TiSCH / RPL chose Distance Vector
- Ethernet
- Wired
  - CSMA-CD
  - Single Hop ?
  - WiFi
  - Mesh
- CSMA-CA
  - Single Hop ?
  - LTE
  - Reactive
  - Centralized ?
- ISA100.11a
- 6TiSCH
- Complexity
CDMA?

DSSS offers throughput and resilience but CDMA consumes energy in DSPs.

LTE going OFDM
Energy budget: Power vs. Time

Higher speed does not necessarily mean more energy
LP WiFi a contender to 802.15.4
802.11ah designing for 2 hops

Interesting developments in sub gig for LP-WideArea
ultra narrow band (e.g. SigFox 100KHz)
802.15.4K (e.g. OnRamp Wireless)
DM and Scheduling

Schedule => direct **trade-off** between throughput, latency and power consumption. A **collision-free** communication schedule is typical in industrial applications. But requires network synchronization, and de-sync means long isolation.

e.g. 31 time slots (310ms)
Which diversity?

Code diversity
- Code Division Multiplex Access
- Network Coding (WIP)

Frequency diversity
- Channel hopping
- B/W listing

Time Diversity
- ARQ + FEC (HARQ)

Spatial diversity
- Dynamic Power Control
- DAG routing topology + ARCs
- Duo/Bi-casting (live-live)
Routing for Spatial Reuse

Hidden terminal
Interference domains grows faster that range
Density => low power => multihop => routing
Centralized vs. Distributed routing

Centralized
- God’s view optimization
- Multipath redundancy
- Deterministic (optimized)
- Virtualization

Distributed
- Autonomic & Mobile
- Highly available (DARPA)
- Deterministic
- Scalability
Proactive vs. Reactive

Aka stateful vs. On-demand routing

Note: on-demand breaks control vs. Data plane separation
Link State vs. Distance Vector

Aka SPF vs. Bellman-Ford
LS requires full state and convergence
LS can be very quiet on stable topologies
DV hides topological complexities and changes
Routing With RPL

How Power Lossy Nets

Dynamic topologies
Peer selection
Constrained Objects
Fuzzy Links
Routing, local Mobility
Global Mobility

Addressed in RPL ?

- Distance Vector + stretch
- Peer only with parents
- DV + Non-storing mode
- Lazy Update & datapath valid
- Constrained instances, TID
- Req coupling with LISP/NEMO
6TiSCH in a nutshell
Requirement for a new standard

- Industrial requires standard-based products
- Must support equivalent features as incumbent protocols
- Must provide added value to justify migration

6TiSCH value proposition

  Design for same time-sensitive MAC / PHY (802.15.4e TSCH)
  Direct IPv6 access to the device (common network mgt)
  Distributed routing for scalability (for monitoring)
  Large scale IPv6 subnet for mobility (50K +)
6TiSCH Charter

Deterministic IPv6 over IEEE802.15.4e TimeSlotted Channel Hopping (6TiSCH)

The Working Group will focus on enabling IPv6 over the TSCH mode of the IEEE802.15.4e standard. The scope of the WG includes one or more LLNs, each one connected to a backbone through one or more LLN Border Routers (LBRs).

Active drafts

http://tools.ietf.org/html/draft-ietf-6tisch-minimal
http://tools.ietf.org/html/draft-ietf-6tisch-6top-interface
**TSCH Properties**

**Channel Hopping:**
- retry around interference,
- round robin strategy

**Time Slotted (or Synchronized):**
- Deterministic: through TDM, Synchronized + Time formatted in SlotFrame(s)
- Tracks: below IP, can be orchestrated by a third party like virtual circuits
- Slotted: benefits of slotted aloha vs. aloha => reduce chances of collisions
- Battery operation: when traffic profile is known, devices only wake upon need
Active IETF WG, 4 WG docs being adopted
Define an Architecture that links it all together
Align existing standards
   (RPL, 6LoWPAN, PANA, RSVP, PCEP, MPLS) over 802.15.4e TSCH
Support Mix of centralized and distributed deterministic routing
Design 6top sublayer for L3 interactions
Open source implementations (openWSN…)
Multiple companies and universities participating
Centralized route and track computation and installation

Management and Setup Discovery Pub/Sub

Authentication for Network Access

Wireless ND (NPD proxy)

Distributed route and track computation and installation

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<table>
<thead>
<tr>
<th>Protocol</th>
<th>CoAP/DTLS</th>
<th>PANA</th>
<th>6LoWPAN ND</th>
<th>RPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>UDP</td>
<td>ICMP</td>
<td></td>
<td>RSVP</td>
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IPv6

6LoWPAN HC

6top

IEEE 802.15.4e TSCH

Time Slot scheduling and track G-MPLS forwarding
next generation Backbone

Authoritative Registrar(s)
MIPv6 HA, 6LBR, interface to external services

Intermediate Registrars
6LR, NEAR, Optionally ND proxy

Backbone Routers
RPL root, ND proxy

Legacy IPv6 devices
Other SDOs status (as of IEEE plenary in Dallas)

Since the WG was announced, we received signs of interest from the incumbent standards and vendors to evolve to include that work.

IEEE 802.15 WNG
  Well received: an IEEE Interest Group formed to help IETF work
  802.1Qcc/AVNU codesign for consistent track reservation
ISA100 formed a Study Group to evaluate opportunity for a revision
  Large scale monitoring with 6TiSCH
Mobility
PHYs (G; M, K?)
Converged Plant Network
- High availability
- Flow Isolation
- Guaranteed Bandwidth

IP based Control Network
- Autonomic, zero touch commissioning
- Time Sensitive Networking for critical apps
- Packet Reliability

IPv6-based Wireless Field Network
- Deterministic, Autonomic, Secure
- Large Scale for Monitoring (RPL)
- Backward Compatible (with ISA100 or HART)
Thank you.
Instrumentation, Systems, and Automation Society is a non-profit technical society for engineers, technicians, businessmen, educators and students, who work, study or are interested in industrial automation.

It was originally known as the Instrument Society of America.

ISA provides leadership and education in the instrumentation and automation industries, assisting engineers, technicians, and research scientists, as well as many others, in keeping pace with the rapidly changing industry.
Wireless Systems for Industrial Automation

A100.11a Industrial WSN
Wireless systems for industrial automation
Process Control and related applications
Deterministic nature (802.15.4e TSCH)
Leverages IPv6
Link Local Join process
Global Address runtime
6LoWPAN Header Compression

Everything else proprietary
competition with Wireless HART and WIAPA
hinders global acceptance
**ISA100.11a infrastructure**

- **Gateway**: An interface between the wireless and plant. A gateway can be implemented as a single or redundant device and supports duocast.

- **Backbone router**: A field device, which has a field network interface and a backbone interface.

- **Routing device**: These devices can provide range extension for a network and path redundancy by routing ISA100.11a communication received from other ISA100.11a I/O devices.

- **Non-routing (I/O) device**: An input or output field instrument with the minimum characteristics required to participate in the network. I/O devices use CSMA.
What’s a Backbone Router?

- Provides common link abstraction over a backbone
- Scale Address Resolution and any link-operations relying on broadcast or multicast
- Allows interaction with nodes on the backbone or in other subnets running different operations
- draft-thubert-6lowpan-backbone-router
ETF RFC References in ISA100.11a

RFC 768  UDP (see also RFC 2460 and RFC 6282)

RFC 2460  IPv6

RFC 2988  Computing TCP's Retransmission Timer. Used at L5 for transactional interactions

RFC 3610  Counter with CBC-MAC (CCM) (partial, in fact CCM*, see IEEE802.15.4) at L2 and L4

RFC 5405  Unicast UDP Usage Guidelines for Application Designers (validated throughput the design)

RFC 6282  6LoWPAN Header Compression (partial, not all cases needed)
The Vision
Trillion devices in the Internet
The core technologies will not change
Leakless Autonomic Fringe
Leakless Route Projection

Million devices in a Subnet
New models for the subnet protocols
IPv6 ND, ARP, Service Discovery …
Fiber + Copper + Radio Backbone
802.11 + 802.15.4 + … Fringe

Unhindered Mobility
Location / ID Separation

10's of K

Overlays, Overlays, Overlays