WIRELESS PROCESS MONITORING AND CONTROL:
A Brief Overview

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Contents

- Motivation
  - Why use Wireless?
  - Opportunities for Wireless

- Communication Technologies and Process Automation
  - Automation Pyramid
  - Control Systems Advancements
  - Key Wireless Technologies
  - Competing Industrial Wireless Standards

- Wireless Monitoring & Control: A New Regime!
  - Application Classification
  - Wireless Control: Next step up the ladder!

- Ongoing Activities

- Conclusion
Aims and Objectives

- Understand the wireless applications in Process Industry
- Examine the suitability of commercial wireless networking solutions for Process Automation
- Identify the challenges of moving from open-loop to closed-loop control
- Motivate the use of wireless for control
- Setup a HIL test-bed for studying wireless networked control systems
- Develop strategies suitable for control over a resource-constraint wireless network
Advent of Wireless Technology in Process Automation

- The pursuit to improve:
  - Process Operations,
  - Compliance with Regulations,
  - Operability,
  - Resource Management &
  - Safety at reduced investment cost has paved the way for wireless technology

- The bottom-line is:
  To increase the process transparency and to utilise up-to-date knowledge of a process/plant

- Significant part of the solution is:
  Wireless technology which can help enhance this knowledge by offering access to regions considered inaccessible in past due to economical or physical barriers

Made possible by advancements in performance of wireless networking and a reduction in price of networking

*DoE
Why use Wireless?

<table>
<thead>
<tr>
<th>Feature</th>
<th>Wired Technology</th>
<th>Wireless Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear-and-tear free data transfer</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Pre-planning Requirement</td>
<td>VERY IMPORTANT</td>
<td>LESS IMPORTANT</td>
</tr>
<tr>
<td>Installation &amp; maintenance cost *</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
<tr>
<td>Problem trouble-shooting connectors **</td>
<td>HIGH</td>
<td>–</td>
</tr>
<tr>
<td>Infrastructure flexibility and mobility</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Spare capacity requirement *** [e.g. cards, marshalling cabinets]</td>
<td>VERY IMPORTANT</td>
<td>LESS IMPORTANT</td>
</tr>
<tr>
<td>Suitability for deployment in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mobile &amp; rotating equipments</td>
<td>LESS SUITABLE</td>
<td>SUITABLE</td>
</tr>
<tr>
<td>hostile &amp; remote locations</td>
<td>LESS SUITABLE</td>
<td>SUITABLE</td>
</tr>
</tbody>
</table>

* ARC Advisory, 2008  ** Hartebrodt et al., 2004  *** Ferris, 2010

and less mechanical design limitations…

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Opportunities for Wireless:

Industrial Measurements

Environmental Monitoring

Management
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The cost-effective operation of a plant is highly dependent on automation systems, of which communication networks are a **life-line** to the process operations.
Control Systems Advancements [Architecture and Communication Technologies]:

3-15 psi Pneumatic → 4-20 mA Analog → 4-20 mA Smart → Fieldbuses → Wireless Technology

after (Georgiev, B [2003]) & Binsai

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Key Wireless Communication Technologies:

License-exempt, Low-power and Globally Available *

IEEE802.11x (Issues) according to Irwin et al.,
-- Channel Contention linked to Scalability
-- Retransmission of data leading to delays
-- Insufficient bandwidth can lead to longer delays
-- FIFO etc.

* Restriction on channels and emission levels apply
### Wireless Standards:

- Limitations of commercial solutions

<table>
<thead>
<tr>
<th></th>
<th>Bluetooth</th>
<th>Wi-Fi [IEEE802.11b]</th>
<th>ZigBee</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Applications</strong></td>
<td>Cable replacement e.g. hands-free &amp; mouse</td>
<td>Computer networking</td>
<td>Monitoring and control</td>
</tr>
<tr>
<td><strong>Battery Life</strong></td>
<td>Low (days)</td>
<td>Very Low (hours)</td>
<td>Long (years)</td>
</tr>
<tr>
<td><strong>Scalability</strong></td>
<td>Low</td>
<td>Medium</td>
<td>Very High</td>
</tr>
<tr>
<td><strong>Real-time support and Reliability</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Channel Access</strong></td>
<td>Contention-free</td>
<td>Contention-based</td>
<td>Contention-based</td>
</tr>
<tr>
<td><strong>Topology (flexibility)</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td>Good</td>
<td>Very Good</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Hence are not suitable for Process Automation**
Industrial Requirement:

Network which is:
- Secure
- Safe
- Reliable
- Energy-efficient
- Supports Real-time
- Operates in licence-exempt band
- Ensures Co-existence
- and offers QoS

Resulted in: Four standards...

- ZigBee PRO
- WirelessHART
- ISA100.11a
- WIA-PA
Key features which makes them Industrial Strength:

- **Reliability:**
  - Mesh Networking
  - Channel Hopping
  - Time-Synchronized Communications

- **Security:**
  - Encryption, Verification, Authentication and Session Keys

- **Power Efficiency:**
  - Smart Publishing (publish data when it changes)
  - Time Synchronized Communication

- **Topology:**
  - Flexible (e.g. star, mesh), hence spatial diversity

- **Determinism:**
  - Time Division Multiple Access (TDMA)

- **Channel Management:**
  - Channel Assessment and blacklisting features
<table>
<thead>
<tr>
<th>Comparison:</th>
<th>IEEE802.15.4</th>
<th>IEEE802.15.4</th>
<th>IEEE802.15.4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transceiver</strong></td>
<td>ZigBee PRO</td>
<td>WirelessHART</td>
<td>ISA100.11a</td>
</tr>
<tr>
<td><strong>Topology (Mesh Support)</strong></td>
<td>Star, Tree, Mesh (Yes)</td>
<td>Mesh (Yes)</td>
<td>Star, Tree, Mesh (Yes)</td>
</tr>
<tr>
<td><strong>Channel Hopping</strong></td>
<td>Agility</td>
<td>Time slot Hopping</td>
<td>Time slot Hopping &amp; Slow Hopping</td>
</tr>
<tr>
<td><strong>Superframe Slot Size</strong></td>
<td>N/A</td>
<td>10ms</td>
<td>Configurable</td>
</tr>
<tr>
<td><strong>Channel Access</strong></td>
<td>CSMA/CA</td>
<td>TDMA</td>
<td>TDMA</td>
</tr>
<tr>
<td><strong>Device Type</strong></td>
<td>FFD, RFD</td>
<td>FFD</td>
<td>FFD, RFD</td>
</tr>
<tr>
<td><strong>Expansion/New</strong></td>
<td>Extension of ZigBee</td>
<td>Extension of HART protocol</td>
<td>New protocol</td>
</tr>
<tr>
<td><strong>Determinism</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Channel Management Features</strong></td>
<td>Preferred Channel</td>
<td>Blacklist</td>
<td>Whitelist &amp; Blacklist</td>
</tr>
<tr>
<td>*<em>Battery Life</em></td>
<td>Best</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Reliability and Robustness against Jamming</strong></td>
<td>Low</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
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Classification of PA applications:

- **Mesh technology** is useful to increase **reliability** and **range**, however, it can lead to increase in **latency** times (concern for control).
Control applications over a wired Network – Inherent Challenges:

- NCS design challenges:
  - Time-delay
  - Packet loss
  - Limited communications (network capacity)
  - Sampling-rate constraints
  - Disturbances in communication network
Control applications over a wireless Network – Additional Challenges:

How is it different to Wired NCS?

- Packet delays and dropouts are to be expected (more profound)
- Co-existence issue due to operation in 2.45 GHz ISM band
- Power consumption constraint due to limited onboard battery
- Connection loss (Outages)
- BER and Quantization error
- Network congestion (shared utilization)

*Different from traditional wired systems*

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Approach *:

- **Network-Aware Control**
  - Communication imperfections are to be modelled.
  - System with time delays.
  - Compensation for delays/data loss.

- **Control-Aware Communication**
  - Protocol selection or modification for real-time performance.
  - Reduce delays.
  - Packet dropouts.

- **Co-Design Solution**
  - Integrated design of application and communication layers.
  - Adaptive Techniques.

* Liu, X & Goldsmith, A.

- **Controller Design** needs to be robust and adaptive to communications constraints AND
- **Network** needs to be optimised for end-to-end control performance
NCS Performance (Depends on):

- Network traffic
- Network devices and application requirements
- Distributed control architecture
- Communication protocol
- Controller and its implementation

*Time delays* and *packet-dropouts* degrade control system performance, and can even lead to instability.
Ongoing Activities: Time Synchronization in WSNs using Radio-Clocks

Importance: Accurate time stamping of data, data fusion, coordination etc...

Application: Process Monitoring of a spatially distributed Pipeline Network

Conference Paper [ETFA 2010]:
Ikram, W.; Stoianov, I.; Thornhill, N.F.; Centre for Process Syst. Eng., Imperial Coll. London, London, UK

Deployment sites

Mote Integrated with Radio Clock
Ongoing Activities: Closed-Loop Control over a LR-Wireless Network

HiL setup enables to quantify and examine the issues in WNCSs

Conference Paper [UKACC 2010]:


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The use of wireless technology in PA systems offer a cost-effective, modular and flexible system design.

The use of Wireless in Industry is currently focusing on monitoring applications. However, closed-loop control is its natural extension.

NCS introduces latency in packet delivery and even packet drop-outs. In WNCS these problems become more prevalent.

Conventionally control and communication systems are designed based on often different and competing tradeoffs.

Using wireless communication for closing the loop requires robustness, guaranteed real-time data delivery, integrity, security and availability under all conditions.
- WNCSs (multi-disciplinary):
  - Control Engineering
  - Communications Engineering
  - Real-time Computation and Embedded Programming
  - Systems Engineering

- Closed-loop control over a constraint wireless network requires a co-design approach for satisfactory results.

Thank you for listening