Control Data Systems
Industrial Wireless Communications
Use case 1 – **Industrial Remote Controls**

- End User is **IKUSI VELATIA SPAIN**, Remote Controls Division
- Remote Controls operate Industrial Cranes and Lifts
- Main requirements for the wireless network are:
  1. **Reliability.** Missed packets can result in potentially hazardous operation of industrial lifting equipment, followed by automatic equipment shutdown
  2. **Low latency.** Round trip for a control message needs to be less than 100 ms, otherwise the message is useless and discarded
  3. **Security.** All communication needs to be securely encrypted in order to ensure integrity and safety of the equipment’s operation
  4. **Fast startup.** The network needs to be fully functional in less than 1s from power on

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ISA100 Remote Control – the **Wireless Solution**

- **ISA100 Wireless** was selected for solving the problem
- The network consists of 4 devices: **one remote control** and **3 actuators** on the crane or lift equipment
- The network topology is **star**
- One node has the role of **System Manager**
- **Any** node can be selected as System Manager
- The System Manager node is **line powered**
- Each node follows the ISA100 standard **join process**
- The join process takes **less than 1s**
- There are 2 types of **ISA100 messages** used:
  - **Unicast** messages are used for management
  - **Broadcast** messages are used for process control

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ISA100 Remote Control - **Reliability**

- **ISA100 TDMA** mechanism is used to avoid message collisions
  - Time is divided in **10 ms** timeslots
  - Time slot sequence repeats after **12 slots**
  - 3,000 time slots make a **superframe**
  - Each time slot has a **dedicated role**:
    - Advertisement
    - Shared transmission
    - Reception

- **ISA100 Channel hopping** mechanism is used to avoid interference
  - **16 channels** available
  - **Blacklisting** mechanism

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<tr>
<th>Superframe Offset</th>
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<td>Device_1(SM)</td>
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</tbody>
</table>

- Advertisement Tx
- Shared Tx for Join Response or unicast DPDU for each FD
- Shared Tx for Join Request
- Generic Rx
- Broadcast Shared Tx and Generic Rx (lower priority)
ISA100 Remote Control – the **Lite System Manager**

- The ISA100 Network is controlled by a **System Manager**
- Traditionally the System Manager is running on a **large computer system**
- **ISA100 Wireless** can be optimized for a particular application
- A light version (**Lite SM**) of the System Manager was developed specifically for this project
- The Lite SM can run on an **embedded platform**
  - 32 bit **ARM Cortex M3** processor
  - **91 KB** Flash (code)
  - **72 KB** RAM
- **Any node** in the network can become the Lite SM
- The Lite SM communicates via a **Lite API** interface over **UART, SPI and I2C** with an external Application Processor.
ISA100 Remote Control – the **Persistent Model**

- The collection of all configuration parameters of the network is organized logically into a **Persistent Model**
- The Persistent Model is distributed to **all devices** in the network
- The configuration of **each device** is extracted and loaded from the common Persistent Model
- The Persistent Model is distributed in **binary format** for efficiency
- A **PC application** was developed for this project to edit the Persistent Model
- The Persistent Model concept offers great **configuration flexibility**
- The Persistent Model can be **optimized** depending on the application performance requirements (size vs speed, etc.)
- All configuration parameters stored in **external ROM** memory

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ISA100 Remote Control – the **Broadcast Mechanism**

- ISA100 is **flexible** enough to allow for implementation extensions to the standard
- To meet the latency requirements, an **extension to the ISA100 standard** was developed
- The ISA100 standard defines the **broadcast mechanism** at DLL level (e.g. advertisements)
- The broadcast mechanism was extended to **Network, Transport and Application** layers
- The ISA100 standard allows for **tunneling of application packets** through the wireless network
- In this project the **control packets** are tunneled through the ISA100 network
- Control packets are generated by the transmitter application and **encapsulated in broadcast messages**
- The Application on the receiver **de-capsulates the control packets** and retains only the relevant ones
- All parameters needed for broadcast (IPv6 address, short address, etc.) are **stored in the Persistent Model**
ISA100 Remote Control – the Results

- The **Lite SM capabilities** (maximum size network) have been estimated at:
  - 150 nodes
  - 200 links
  - 120 control packets in Queue

- Using a setup of **1 Transmitter** and **3 Actuators** the following performance was measured:
  - Join Duration for the entire network from power on: ~1 second
  - Minimum granted discovery duration = 380 ms
  - Control packet latency with no retry at DLL level: ~20 ms
  - Clock synchronism between any 2 nodes: < 100 us

- Future improvements
  - A **Dynamic Persistent Model** will support control applications for larger, mesh networks

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Use case 2 – Intra satellite communications

• End User is the European Space Agency (ESA)
• Satellite data handling systems are traditionally wired (Mil-1553b, CAN, SPI, I2C... or point-to-point connections such as RS422, SpaceWire, etc).
• Wired data systems (harnesses) pose a series of problems:
  • The increment of the **dry mass** of spacecraft due to harnessing is in the order of a 10%.
  • Wiring requires **complex assembly** (communication paths), integration and testing as spacecraft complexity increase.
  • **Signal leakage** requires isolation for avoiding electromagnetic compatibility issues (EMC)
  • Restriction in **physical dimensions**
  • High cost of late **design changes**
  • Possible failures of wires and connectors, risk of system malfunctioning due to EMI and risk of total failure due to any short circuit
Intra satellite communications – **ISA100 advantages**

- Advantages of an **ISA100 Wireless harness** in Satellite assembly
  - Significant **reduction of mass** (up to 10%) resulting in **lower launch cost**
  - **Reduction in AIT** (Assembly, Integration and Testing) effort, resulting in **lower assembly costs**
  - **Increased reliability**, resulting in a **lower cost** due to less redundant wires
  - **Lower cost** for **late design changes**
  - Meeting the **low latency** requirements for the satellite attitude control application
Intra Satellite Communications – the **Challenge**

- **Requirements** for Intra Satellite Wireless Communications
  - **Low number** of nodes – sensors and actuators
  - **High volume** of data (10s of KB/sec) from sensors
  - **Strict timings** for actuators control (100s of msec)
  - **Resistant to interference** with other equipment
  - Must **not generate interference** with other equipment
  - Minimal **node weight** (10s of grams)
  - Low **power consumption** (10s of mW)
Intra Satellite Communications – the **ISA100 solution**

Due to the **flexibility** of the ISA100 Wireless standard, the following solution was applied to meet the requirements:

- **Replacement of the physical layer**
  - The 802.15.4 2.4 GHz PHY layer was replaced with **802.15.4 UWB (Ultra Wide Band)**
  - The data rate was increased from 250kbps to **6.8 Mbps**
  - This **high data rate** allows the transmission of data generated by the satellite instruments and sensors

- **Increase of the packet size**
  - The packet size was increased from 128 B to **1023 B** in order to optimize the network for traffic size

- **Reduction of the time slot duration**
  - The time slot was reduced from 10 ms to aprox. **1.6 ms** to optimize the network for low latency
Intra Satellite Communications - Timings for 128 B frame

- These timings were measured for a **standard** ISA100 Wireless frame (128 B)
- The measurements were taken after replacing the 802.15.4 2.4 GHz PHY layer
- The new PHY layer was **802.15.4 UWB** in the 5 GHz band

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<tr>
<th>Interval</th>
<th>Measured value</th>
<th>Comments</th>
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<tr>
<td>(t_0)</td>
<td>139.28 µsec</td>
<td>Write frame over SPI to DWM1000</td>
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<tr>
<td>(t_1)</td>
<td>28.59 µsec</td>
<td>End write frame to start TX</td>
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<td>(t_2)</td>
<td>347.18 µsec</td>
<td>Frame transmission</td>
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<td>(t_3)</td>
<td>268.4 µsec</td>
<td>Read frame over SPI from DWM1000</td>
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<td>(t_4)</td>
<td>62.56 µsec</td>
<td>RX to TX mode switch</td>
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<td>(t_5)</td>
<td>846.01 µsec</td>
<td>TX to RX ((t_0+t_1+t_2+t_3+t_4)) wait</td>
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<td>(t_6)</td>
<td>1.63 msec</td>
<td><strong>Slot time</strong></td>
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</table>
Intra Satellite Communications - Timings for 1023 B frame

- These timings were measured for a **non standard** ISA100 Wireless frame (1023 B)
- The measurements were taken **after** replacing the 802.15.4 2.4 GHz PHY layer
- The new PHY layer was **802.15.4 UWB** in the 5 GHz band
- Three different data rates were measured in the test

<table>
<thead>
<tr>
<th></th>
<th>(6.8 Mbps)</th>
<th>(850 Kbps)</th>
<th>(110 Kbps)</th>
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<tr>
<td>t₀</td>
<td>0.721 msec</td>
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<td>0.716 msec</td>
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<td>t₁</td>
<td>28.83 µsec</td>
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<td>t₂</td>
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<td>1.202 msec</td>
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<td>t₄</td>
<td>62.33 µsec</td>
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<td>t₅</td>
<td>92.08 µsec</td>
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<td>29.08 µsec</td>
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<td>t₇</td>
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<td>t₈</td>
<td>0.1863 msec</td>
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<td>t₉</td>
<td>3.852 msec</td>
<td>12.74 msec</td>
<td>80.155 msec</td>
<td>Slot time</td>
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- Slot time

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ISA100 Wireless for Control Applications
UWB Test System

- 6 nodes network
  - 1 BBR/SM
  - 2 sensors
  - 1 actuator
  - 1 provisioning device
- Test performed on 2 satellite mock-ups
  - Venus Express (at ESA)
  - Sentinel 3 (at CDS)

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Legend
- Idle slot
- Receive slot
- Transmit slot
UWB Test results – Venus Express at ESA

Chart 1: Average PSR on Venus Express

<table>
<thead>
<tr>
<th>Channel</th>
<th>64b</th>
<th>128b</th>
<th>256b</th>
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<tr>
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<td>99%</td>
<td>99%</td>
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<tr>
<td>Channel 2</td>
<td>99%</td>
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<td>Channel 3</td>
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<td>Channel 5</td>
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<td>99%</td>
</tr>
<tr>
<td>Channel 7</td>
<td>99%</td>
<td>98%</td>
<td>100%</td>
</tr>
</tbody>
</table>

85% 88% 90% 93% 95% 98% 100% 103%
UWB Test Results – Sentinel 3 at CDS

- No retries used
- 3 preambles tested: 64b, 128b and 256b
- 256b preamble performed best
- Carbon fiber vs aluminum inner panels were tested
- Carbon fiber had much better results (100%)
- High power vs low power was tested
- Low power resulted in better results
Intra Satellite Communications – Conclusions

• **ISA100 Wireless** is suitable for Intra Satellite Communications
  - The ISA100 Wireless network can handle the required **data throughput** is 126,472 bps or 15,809 Bps (15.43 KBps) generated by the sensors and instruments
  - The ISA 100 Wireless network meets the **required latency** of less than 1s with actual number of **less than 100 ms**
  - The ISA100 Wireless network is **resistant** to interference and **does not interfere** with on board instruments and equipment

• The ISA100 Wireless network is **flexible** enough to allow for
  - **PHY layer change to UWB with 6.8 Mbps data rate**
  - **Data throughput optimization** by using the 1023 B frame length, in case priority is given to data acquisition from instruments
  - **Latency optimization** by using the 127 B frame length, in case priority is given to control of actuators

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