Control Data Systems

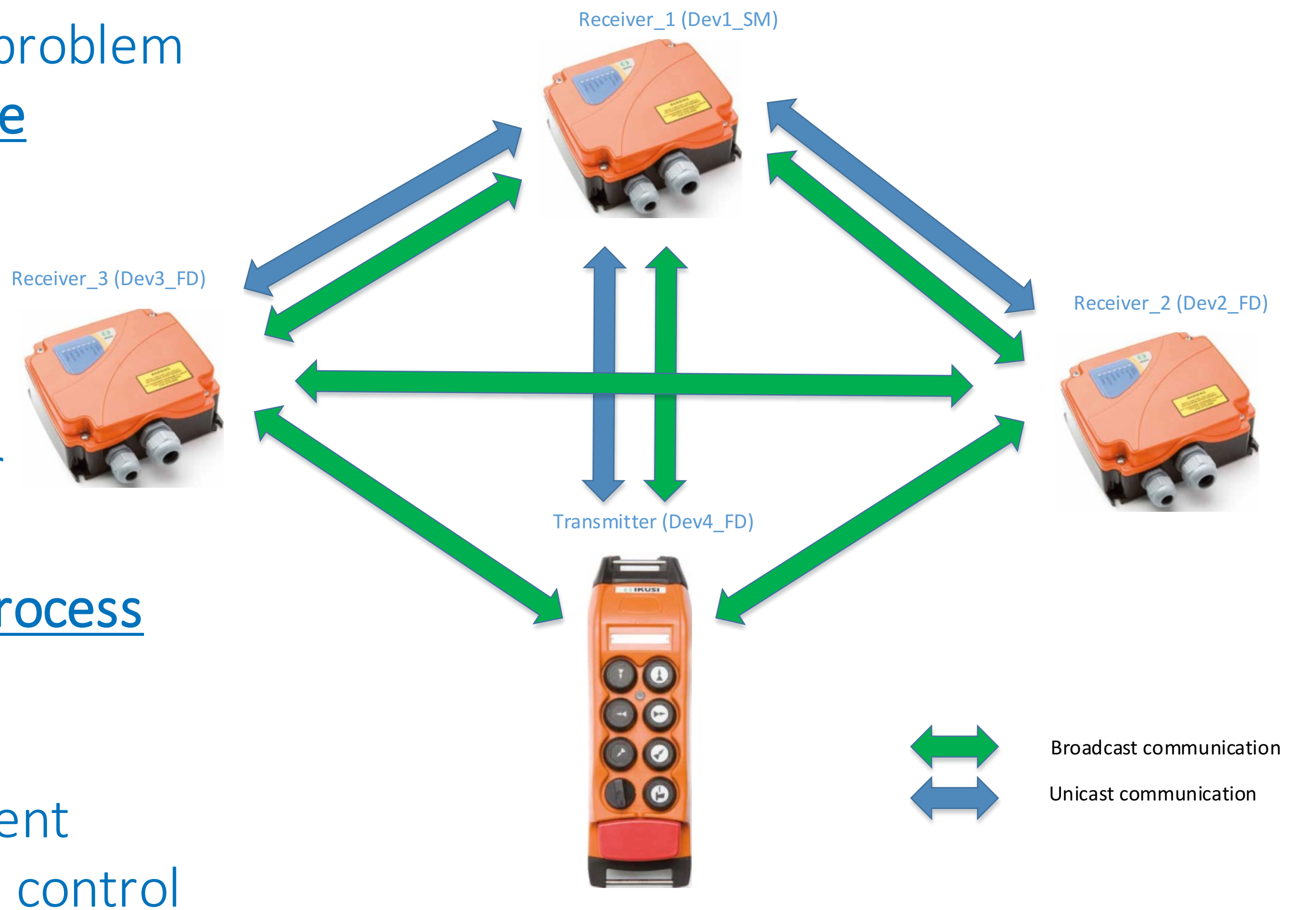
Industrial Wireless Communications

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

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



ISA100 Remote Control - Reliability

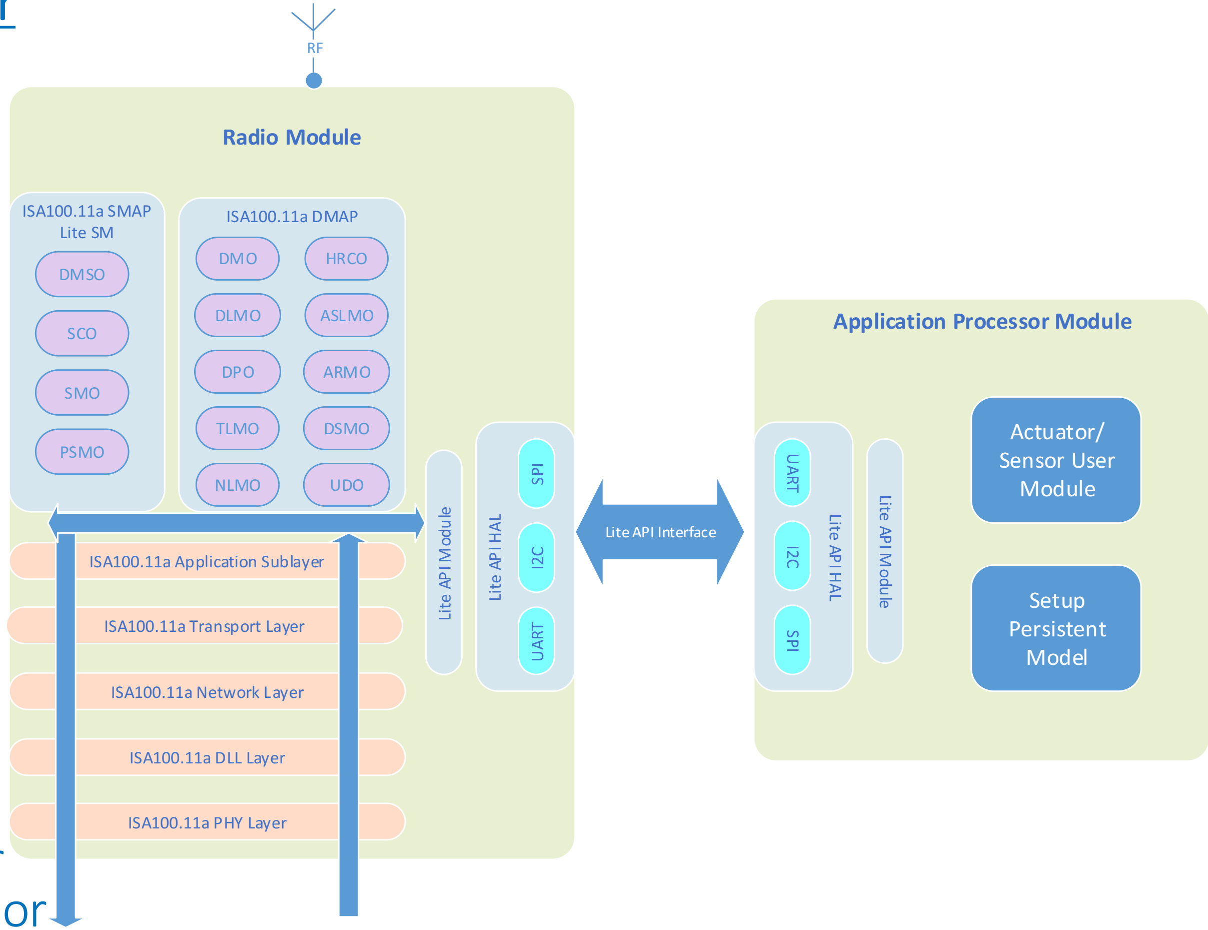
- ISA100 TDMA mechanism is used to avoid message collisions
  - Time is divided in 10 ms timeslots
  - Time slot sequence repeats after 12 slots
  - 3,000 time slots make a superframe
  - Each time slot has a dedicated role:
    - Advertisement
    - Shared transmission
    - Reception
- ISA100 Channel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

	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)

SuperframeOffset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	... 2999
Device_1(SM)																
Device_2(FD)																
Device_3(FD)																
Device_4(FD)																

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

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 networ
- 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**

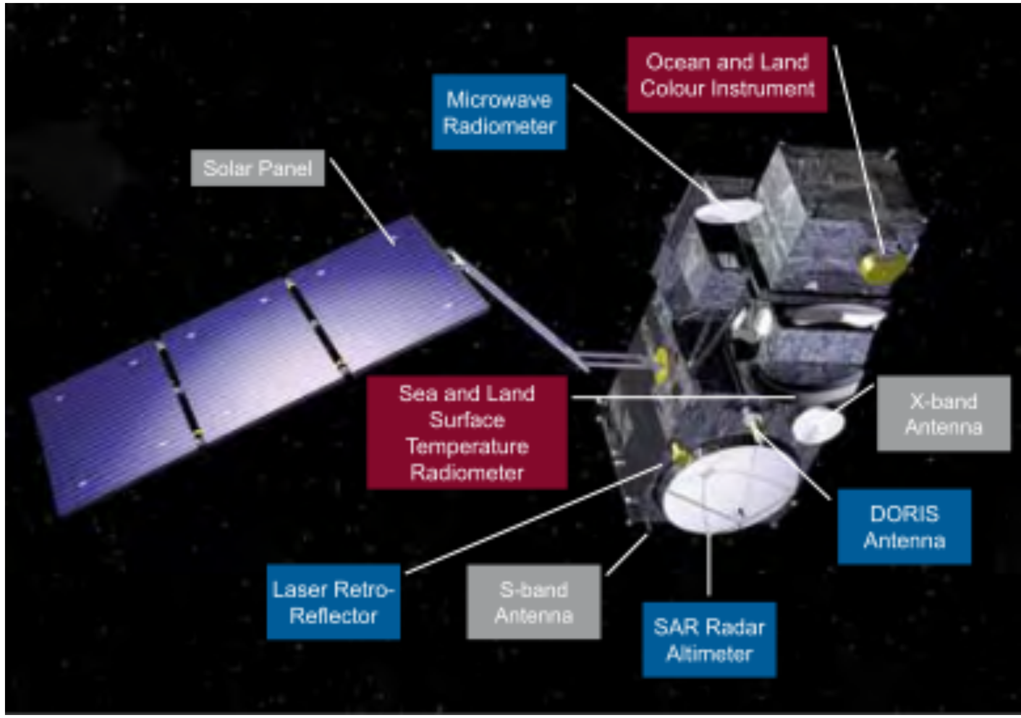
Use case 2 – Intra satellite communications

•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

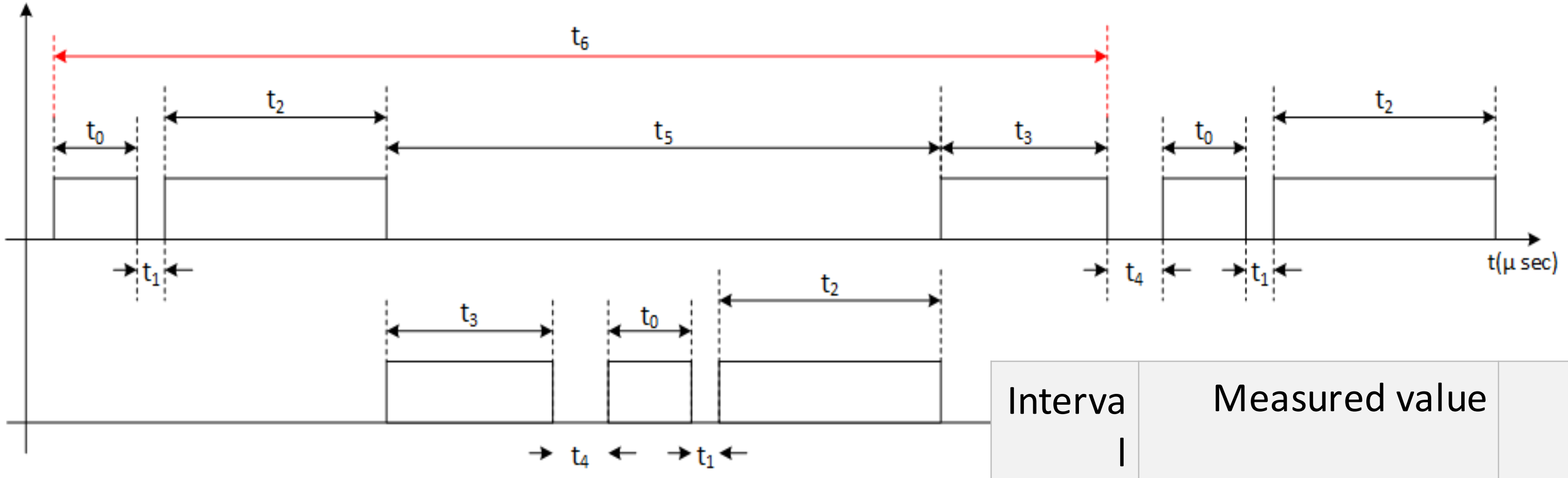
Intra Satellite Communications – the Challenge

- 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 from 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

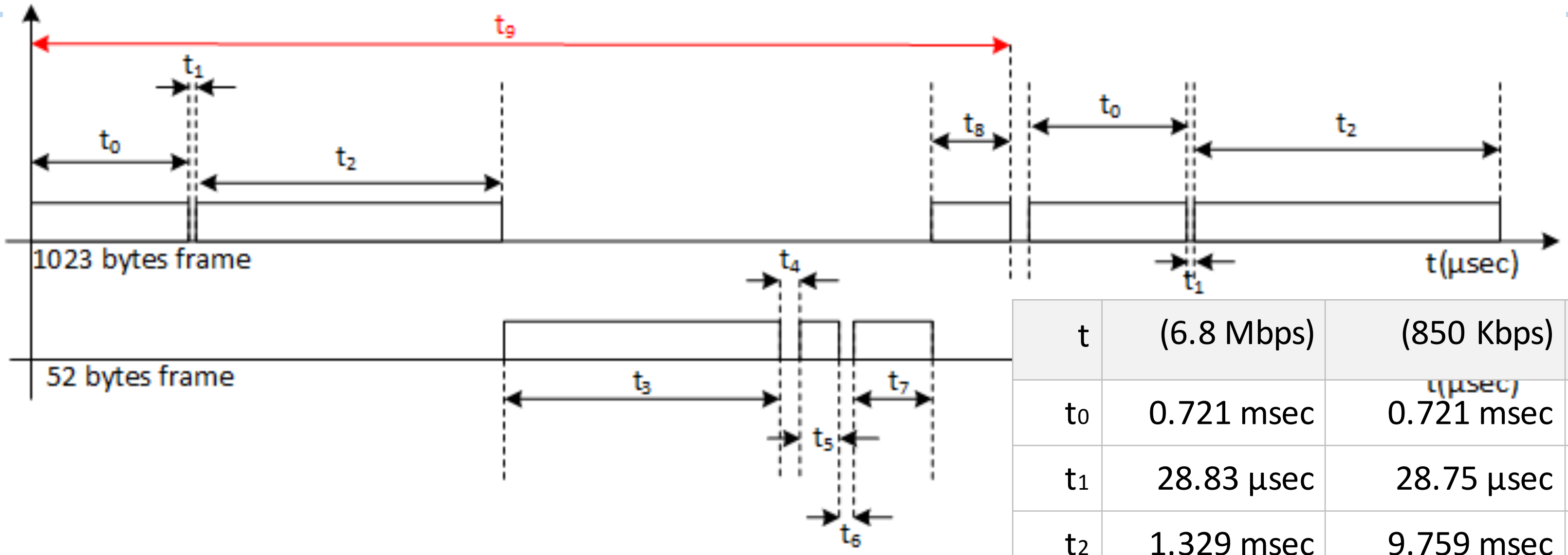
Intra Satellite Communications - Timings for 128 B frame



- 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

Interval	Measured value	Comments
t_0	139.28 µsec	Write frame over SPI to DWM1000
t_1	28.59 µsec	End write frame to start TX
t_2	347.18 µsec	Frame transmission
t_3	268.4 µsec	Read frame over SPI from DWM1000
t_4	62.56 µsec	RX to TX mode switch
t_5	846.01 µsec	TX to RX ($t_0+t_1+t_2+t_3+t_4$) wait
t_6	**1.63 msec**	**Slot time**

Intra Satellite Communications - Timings for 1023 B frame

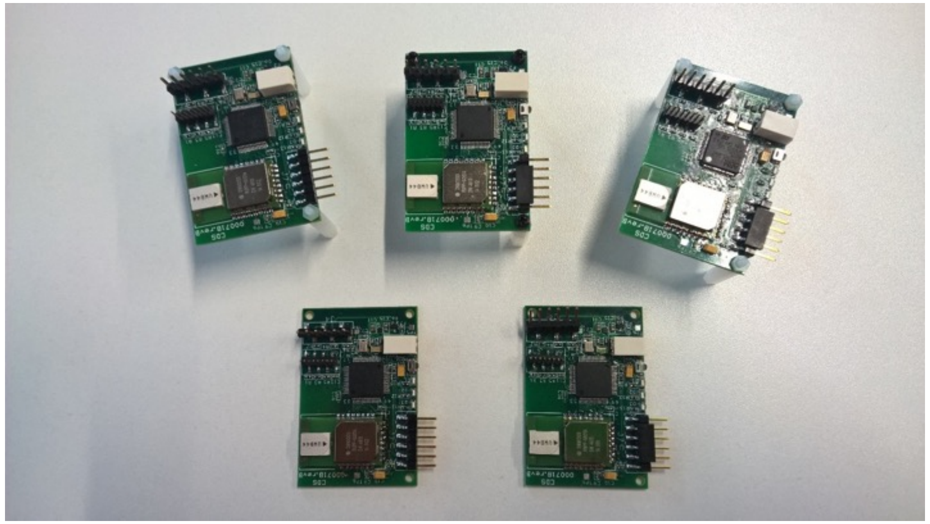


t	(6.8 Mbps)	(850 Kbps)	(110 Kbps)	Comments
t_0	0.721 msec	0.721 msec	0.716 msec	Write 1023 bytes frame over SPI
t_1	28.83 µsec	28.75 µsec	31 µsec	Delay before starting transmission
t_2	1.329 msec	9.759 msec	78.32 msec	1023 bytes frame transmission
t_3	1.202 msec	1.202 msec	1.2 msec	Read 1023 bytes frame over SPI
t_4	62.33 µsec	62.37 µsec	61.5 µsec	RX to TX mode switch
t_5	92.08 µsec	92 µsec	92 µsec	Write 52 bytes frame over SPI
t_6	29.08 µsec	29.12 µsec	30.5 µsec	Delay before starting transmission
t_7	0.1913 msec	0.658 msec	5.513 msec	52 bytes frame transmission
t_8	0.1863 msec	0.272 msec	0.187 msec	Read 52 bytes frame over SPI
t_9	**3.852 msec**	**12.74 msec**	**80.155 msec**	**Slot time**

- 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

UWB Test System

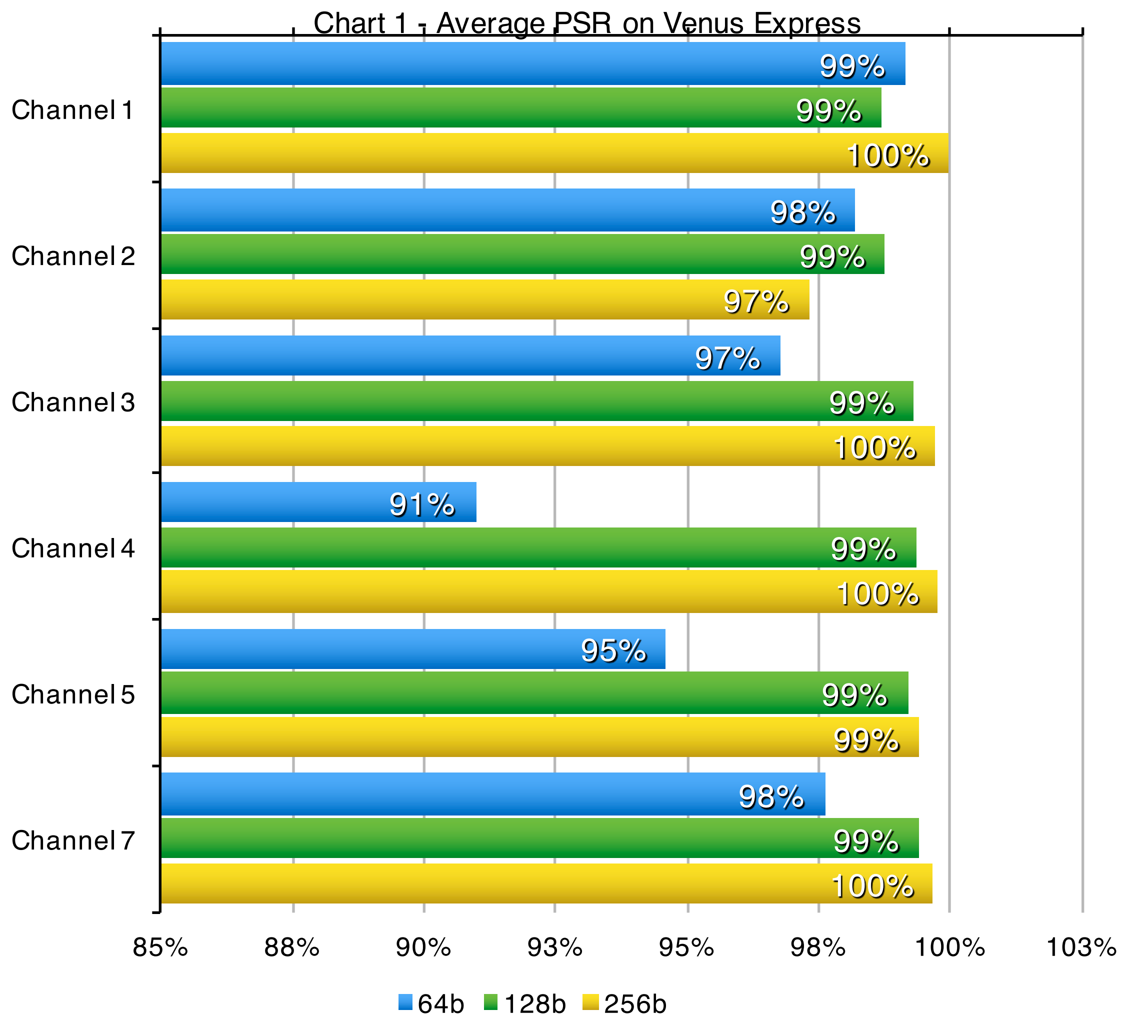
- 6 nodes network
  - 1 BBR/SM
  - 2 sensors
  - 1 actuator
  - 1 provisioning device
- Test performed on 2 satellite mock-ups
  - Venus Express (at ESA)
  - Sentinel 3 (at CDS)

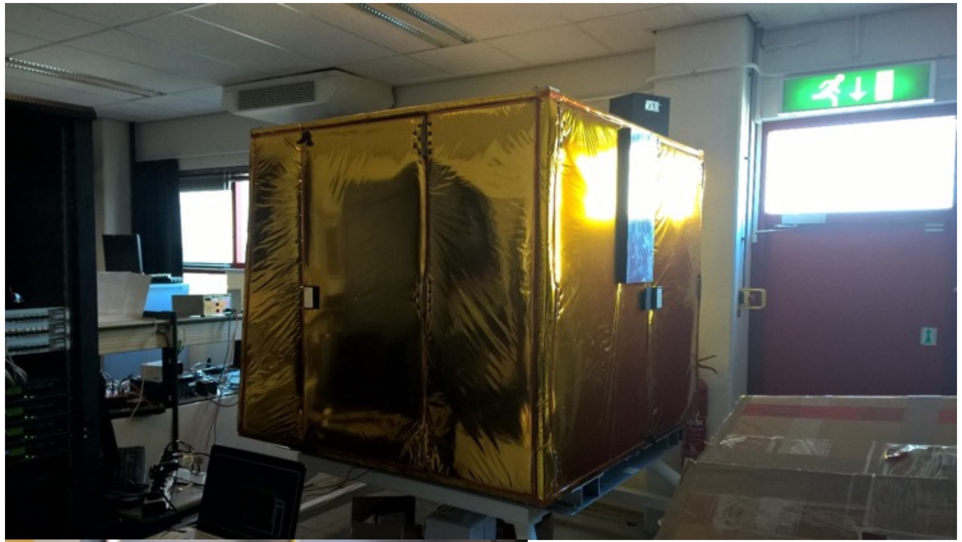


Legend	
Idle slot	
Receive slot	
Transmit slot	

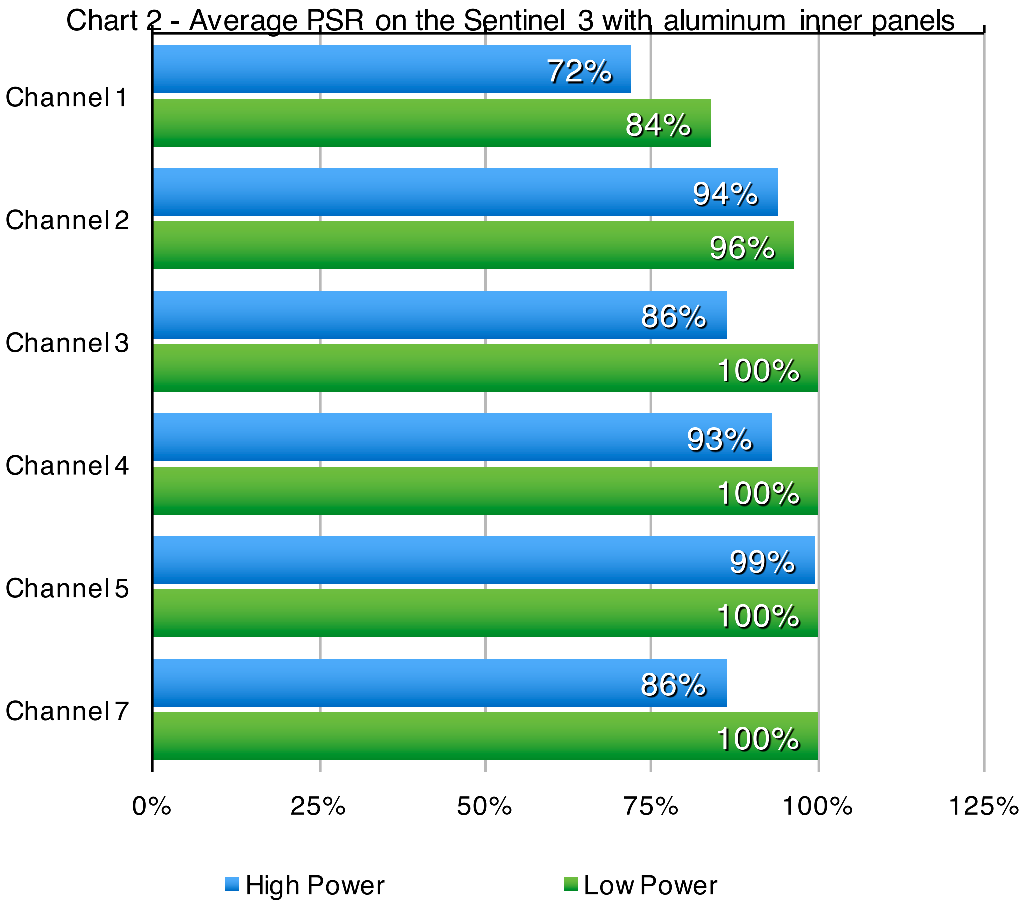
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
01																									
02																									
03																									
04																									
05																									

UWB Test results – Venus Express at ESA





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

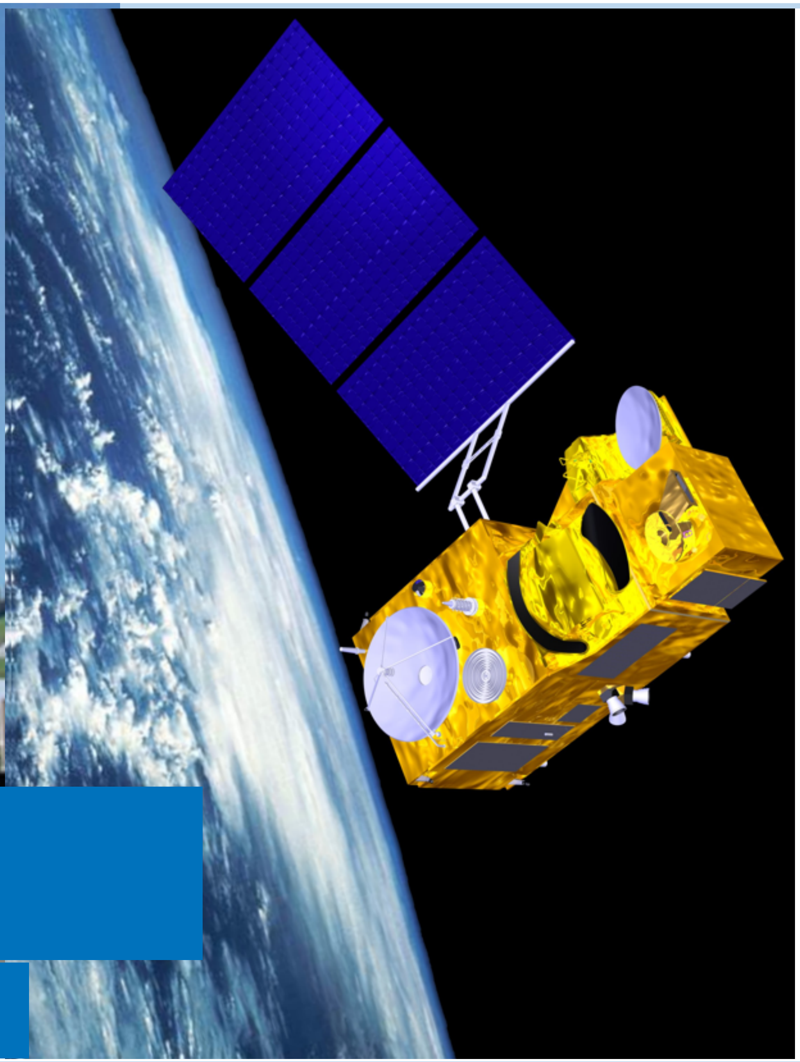
Intra Satellite Communications – Conclusions

- 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

ISA100 Wireless for Control Applications

CDS control data systems WIRELESS



Control Data Systems

Industrial Wireless Communications

ISA 100 WIRELESS