Wireless Communication Bus For Satellite Applications WI-SAT

Project data

Consortium
- Control Data Systems SRL – main contractor
- GMV Romania – subcontractor
- Technical University of Cluj-Napoca – subcontractor

Contract duration
- Started on March 2014
- Ended on October 2015
- Duration 18 months

Contract value
- 197.984 EUR
- Awarded under the Romanian Incentive Scheme

Project schedule

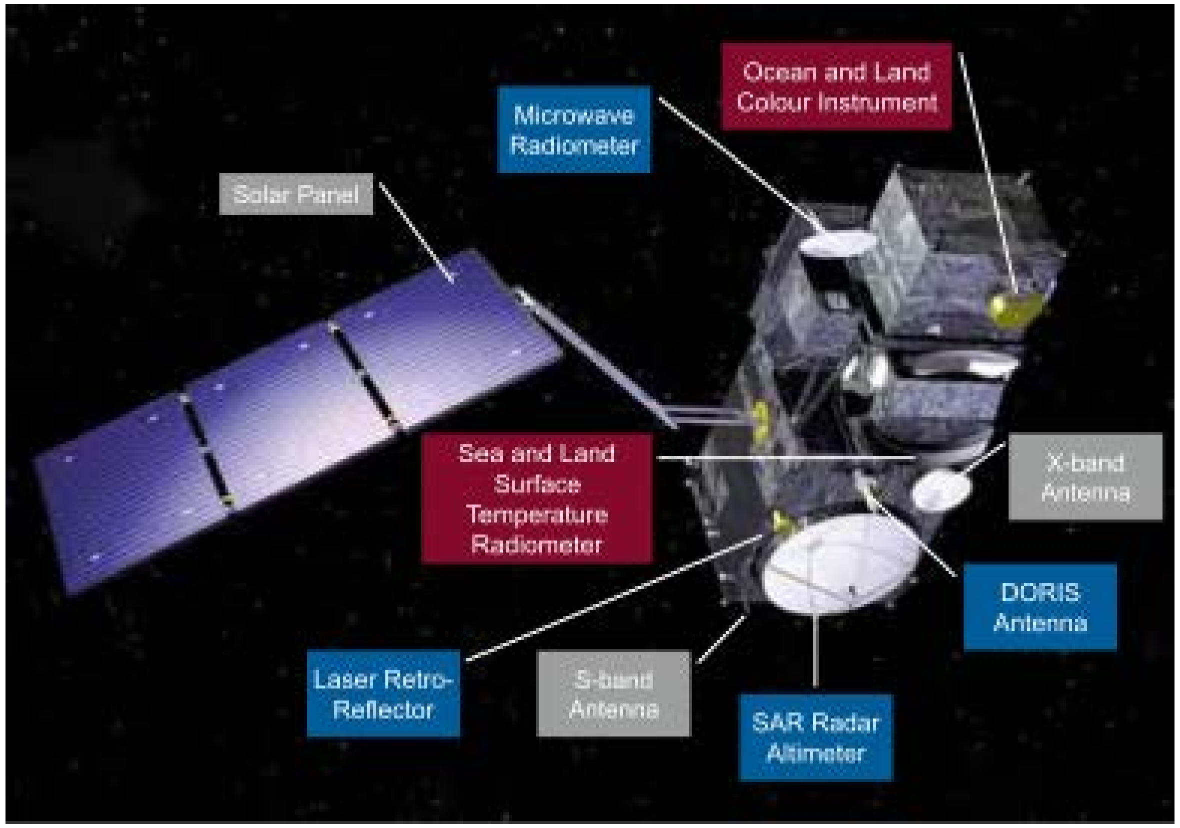
WP #	WP Title	Responsible	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
WP1000	Management & Product Assurance	CDS	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
WP2000	User needs & product requirements	GMV	■	■																
WP3000	ISA100.11a application for avionics	CDS			↔							↔								
WP3100	Study of ISA100.11a capabilities vs requirements	UTCN			■	■														
WP3200	Design and prototyping of ISA100.11a breadboard	CDS					■	■	■	■	■	■								
WP4000	ISA100.11a porting onto a faster PHY layer	CDS					↔							↔						
WP4100	Technology trade-off for PHY layer selection	UTCN			■	■														
WP4200	ISA100.11a implementation on new PHY layer	CDS							■	■	■	■	■	■						
WP5000	Trial definition & tests	GMV			↔													↔		
WP5100	Test plan definition	GMV					■	■	■	■										
WP5200	Test execution	GMV													■	■	■	■		
WP5300	Support to test execution	CDS													■	■	■	■		
WP6000	Conclusions	CDS																	↔	↔
WP6100	Study conclusions and next steps	CDS																	■	■
WP6200	Support to study conclusions and next steps	GMV																	■	■
	Milestone 1 (Requirements & Technology Review)					◆														
	Milestone 2 (Critical Design Review)											◆								
	Milestone 3 (Test Readiness Review)													◆						
	Milestone 4 (Final Report)																			◆

Problem addressed

- 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

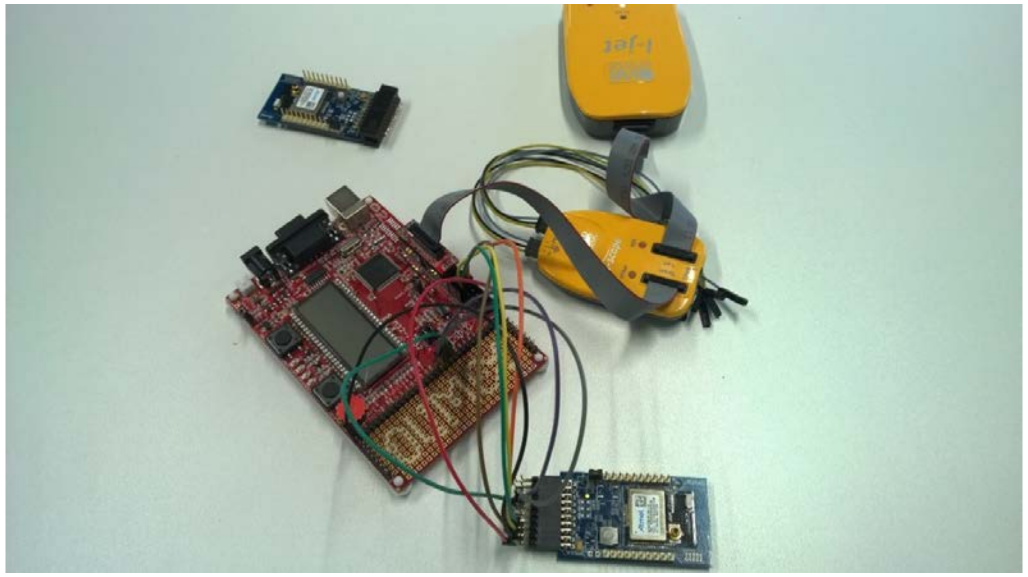
Requirements

- Based on **Sentinel 3 S/C**
- **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)



Hardware deliverables

- **Hardware deliverables**
  - Preliminary work conducted in 2.4 GHz
  - 2 HW spins built
  - 5 breadboards of VN360 UWB wireless node Spin 2 manufactured and tested
  - Same HW runs sensor, actuator and gateway FW
  - STM32L162 ARM micro-controller
  - Decawave DW1000 IEEE 802.15.4 UWB transceiver



The software stack: ISA100

[Routing Device]: Routes messages for other devices operating in the wireless subnet.

[Backbone Router]: Routes data via the backbone. Mitigates between devices operating in the wireless subnet and devices operating on the backbone.

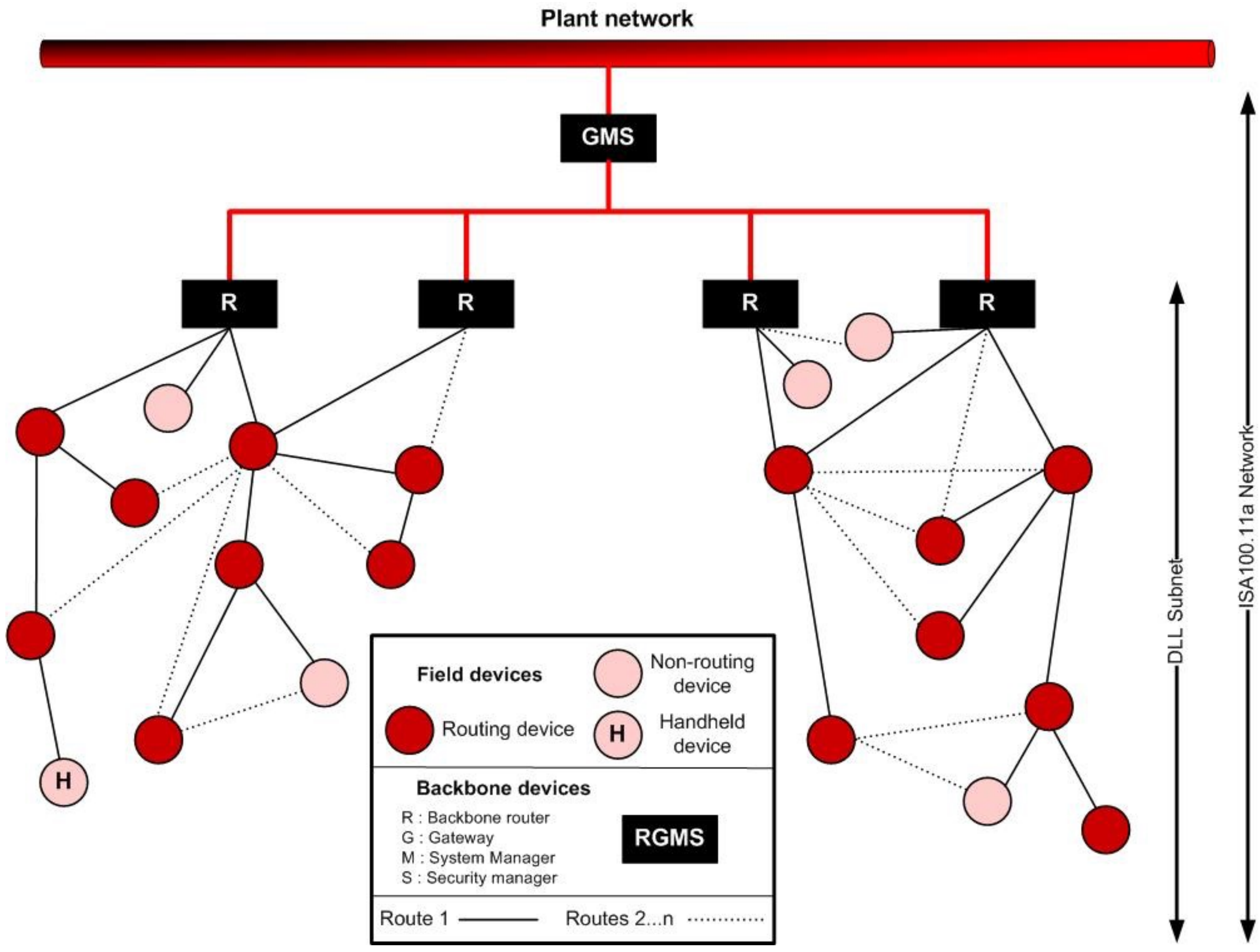
[System Manager]: The "brains" of the network. Manages all network devices through policy controlled configurations based on collection of performance parameters reported.

[Security Manager]: Enables, controls and supervises the secure operation of all devices present in the network.

[Gateway]: Provides an application interface between the wireless network and the plant network.

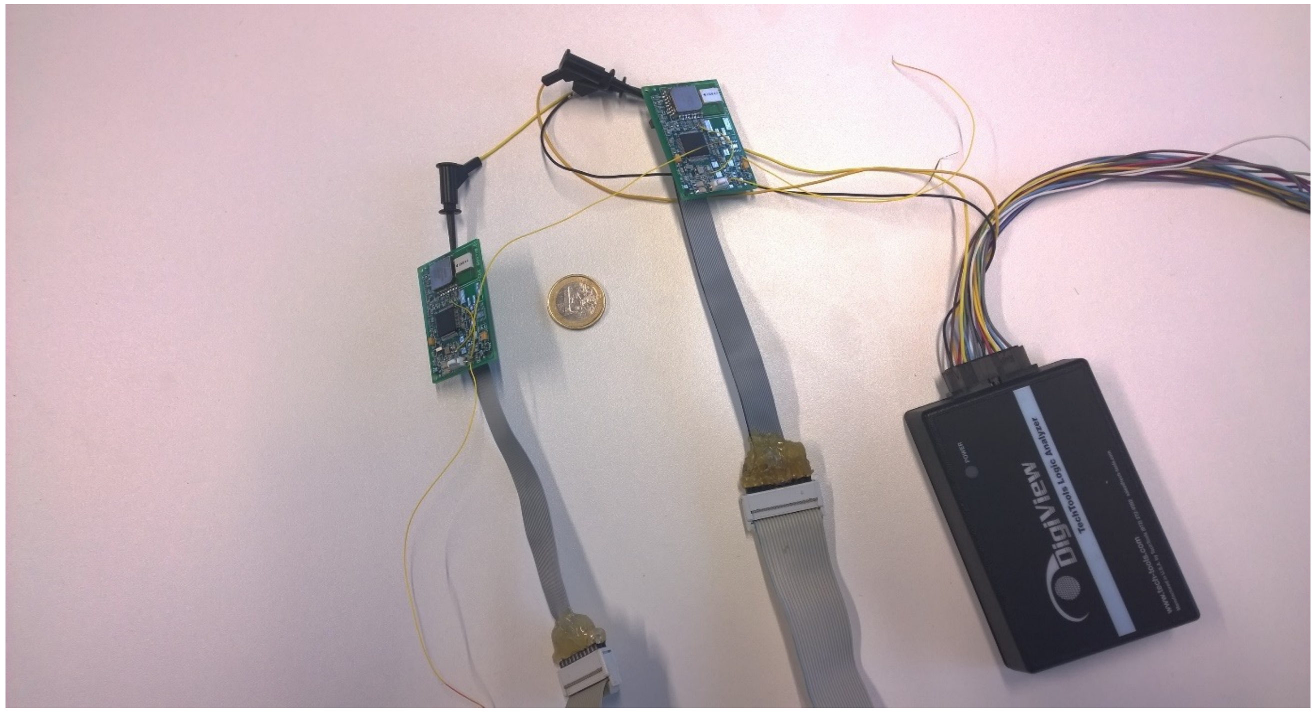
[Handheld device]: Provisions devices with configurations required for operation within the network.

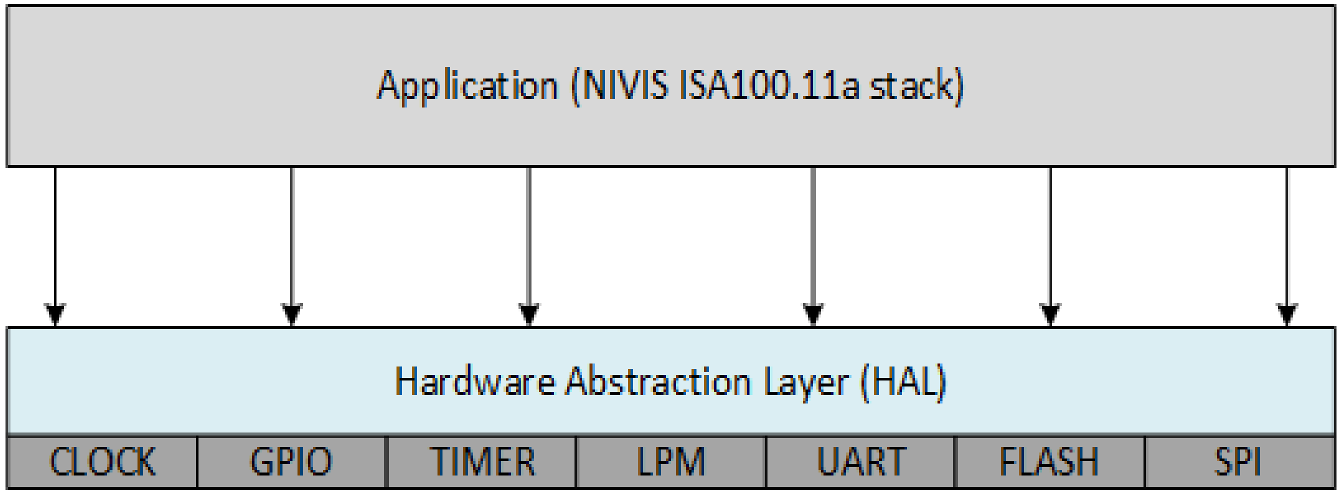
[System Time Source]: Responsible for maintaining the master time source of the network.



ISA100 ported to UWB

- Started with open source implementation by Nivis LLC
- Code analysis & decomposition performed
- Layer separation according to OSI model
- Data Link Layer separated for timing testing
- SW toggles GPIO lines for accurate timing measurement
- Hardware Abstraction Layer (HAL) developed



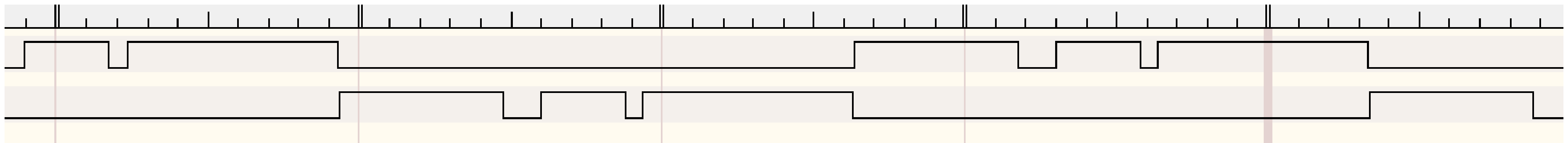


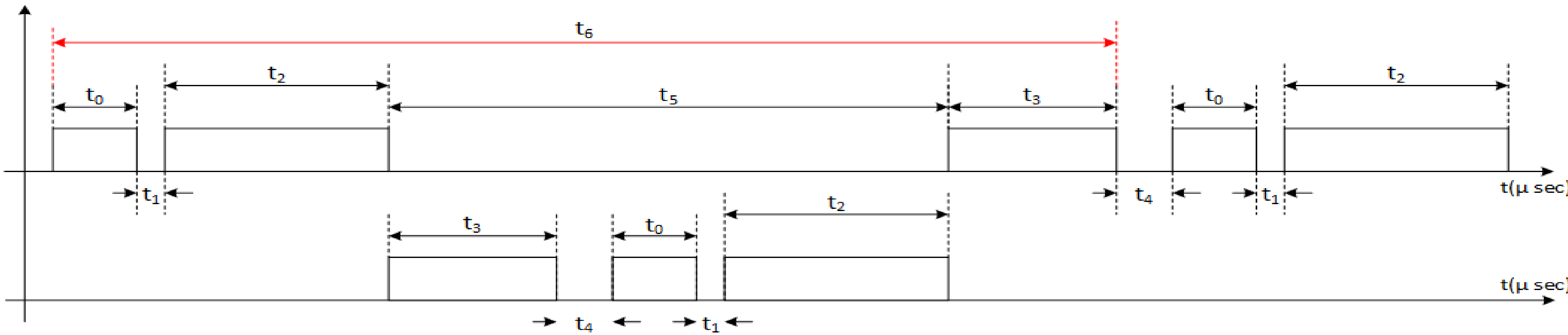
ISA100 porting to UWB

- **ISA100 Wireless Features retained**
  - 10 msec time division. The gateway – device time synchronization is done on the second timeslot of each 250 msec slot.
  - Time synchronization mechanism.
  - 10 msec timeslots. Each 250 msec timeslot is divided into 25 timeslots.
  - The types of frames available are advertisement frames, acknowledgement frames and data frames.
  - Types of timeslots: idle slots, receive slots and transmit slots.
  - Receive and transmit time templates.

- **Removed/not implemented features**
  - Channel hopping – useful only for large networks with complex structures.
  - Encryption – the data send by the sensors is plain data. Encryption on 1023 byte frames is time consuming and not necessary for this application.
  - CCA – the idle, receive and transmit slots are pre-programmed in each of the sensors' flash memory. With the current implemented logic, only one node transmits at a given timeslot.
  - Network configuration engine – being a simple 5 node star network, this module which includes graph processing and contract/path allocation is not needed.

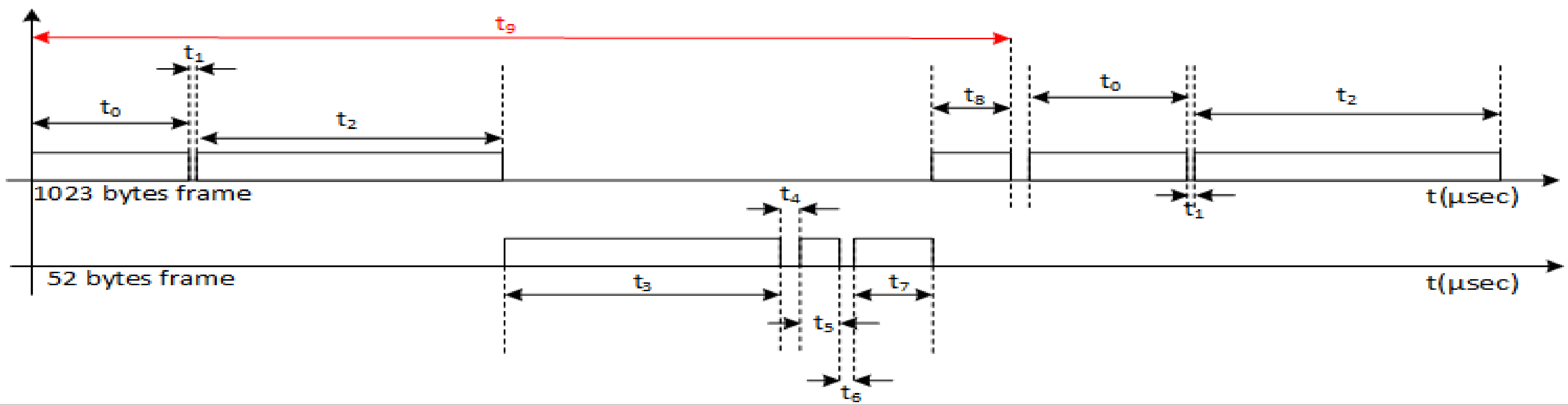
Timings for 127B frame





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

Timings for 1023 B frame



Interval	Measured value (6.8 Mbps)	Measured value (850 Kbps)	Measured value (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

Frame length trade-off

- The required data throughput is 126472 bps or 15809 Bps (15.43 KBps)
- The required latency is 1s
- To optimize for data throughput we would use the 1023 B frame length
- To optimize for latency we would use the 127 B frame length
- Decision was made to use the 1023 B frame length
- Optimization for latency at the expense of data throughput is also possible

Test System

- 6 UWB nodes: 1 Gateway, 3 sensors, 1 actuator, 1 provisioning device
- PC application for configuration and statistics

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																									

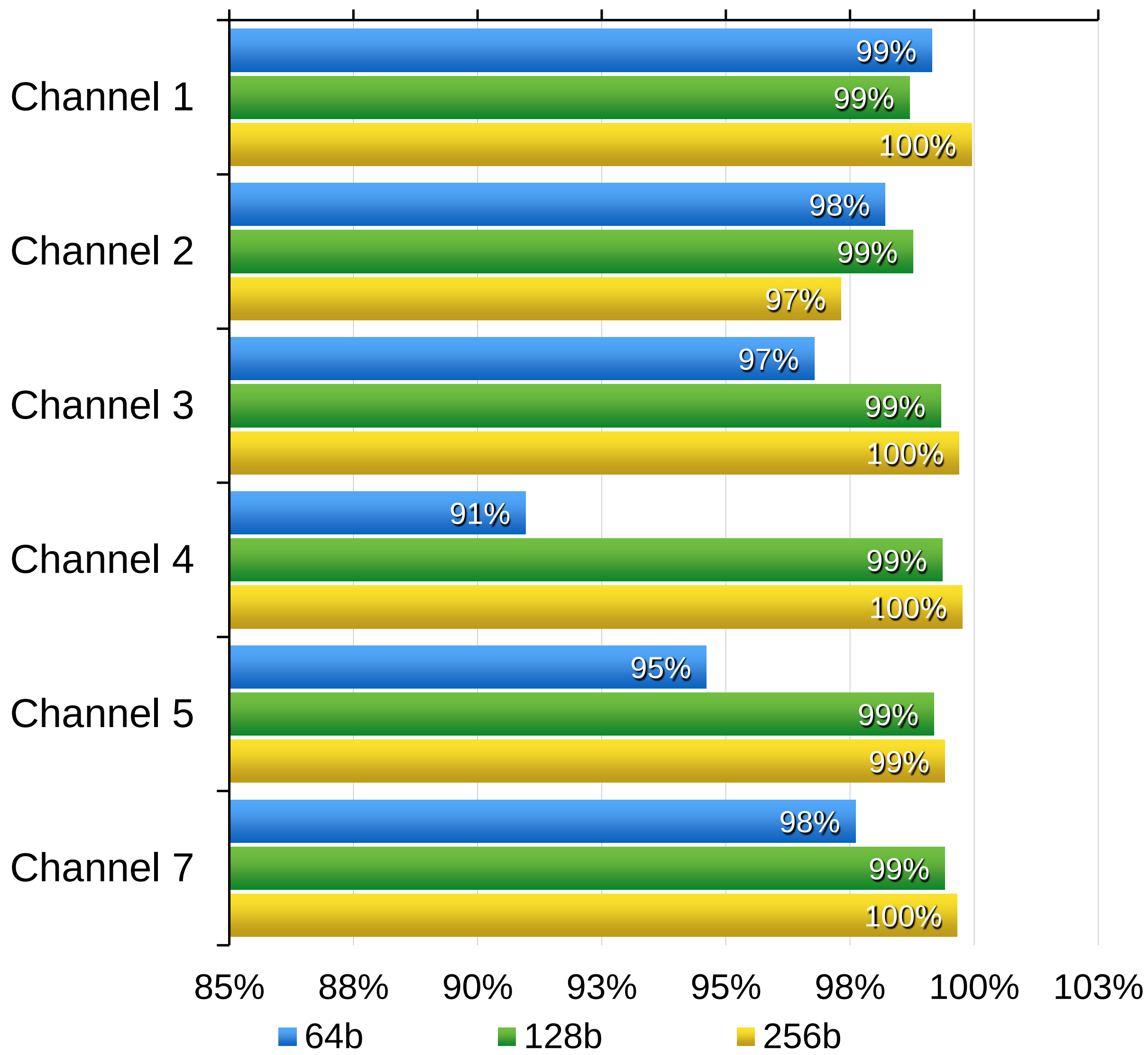
Test conditions

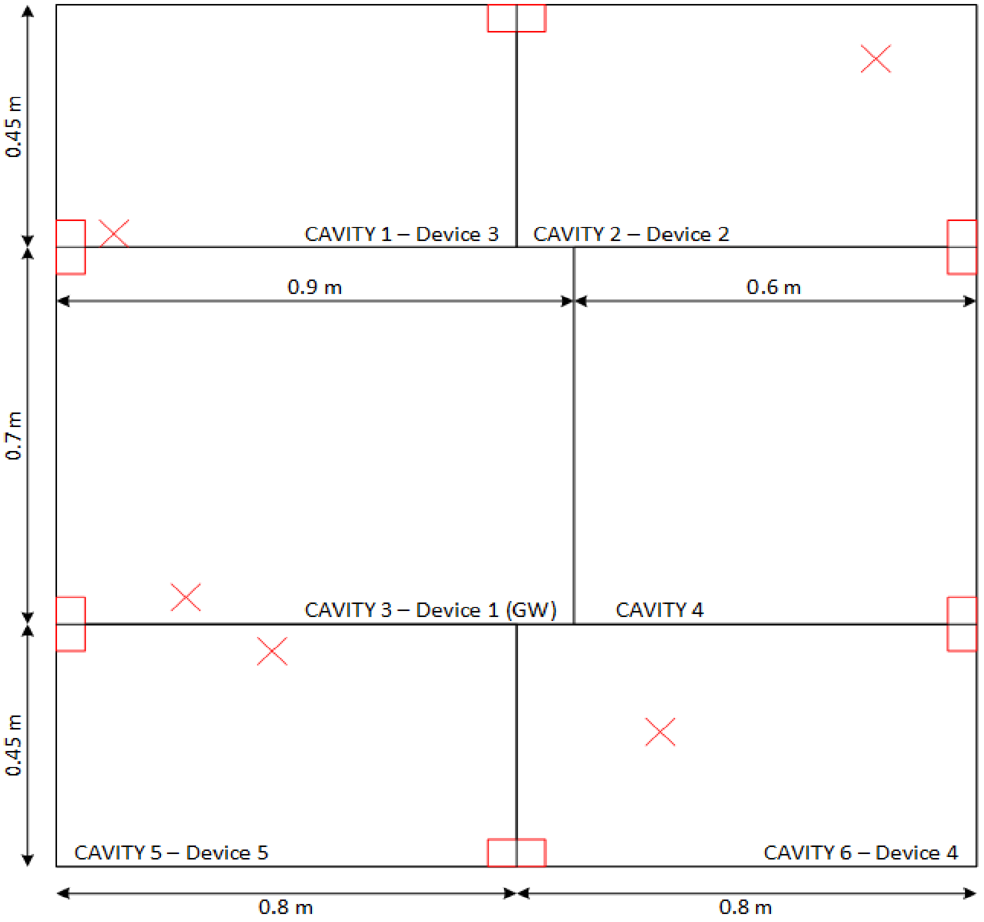
- Data rate: 6.8 Mbps
- Premble: 64, 128 and 256 symbols
- Frame Length: 1023 Bytes

Channel	Center frequency (MHz)	Band (MHz)	Bandwidth (MHz)
1	3494.4	3244.8 -3744	499.2
2	3993.6	3744 – 4243.2	499.2
3	4492.8	4243.2 – 4742.4	499.2
4	3992.6	3328 – 4659.2	1331.2
5	6489.6	6240 – 6739.2	499.2
7	6489.6	5980.3 – 6998.9	1081.6

Venus Express mock-up

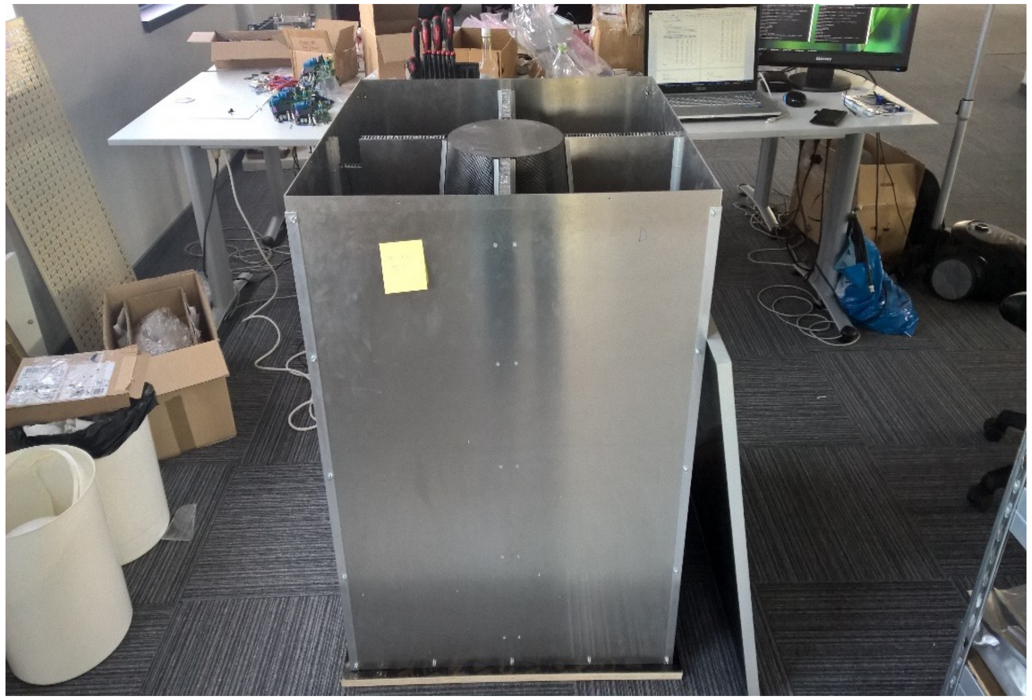
- 3 preambles tested: 64b, 128b and 256b
- 256b preamble performed best
- No retries were used

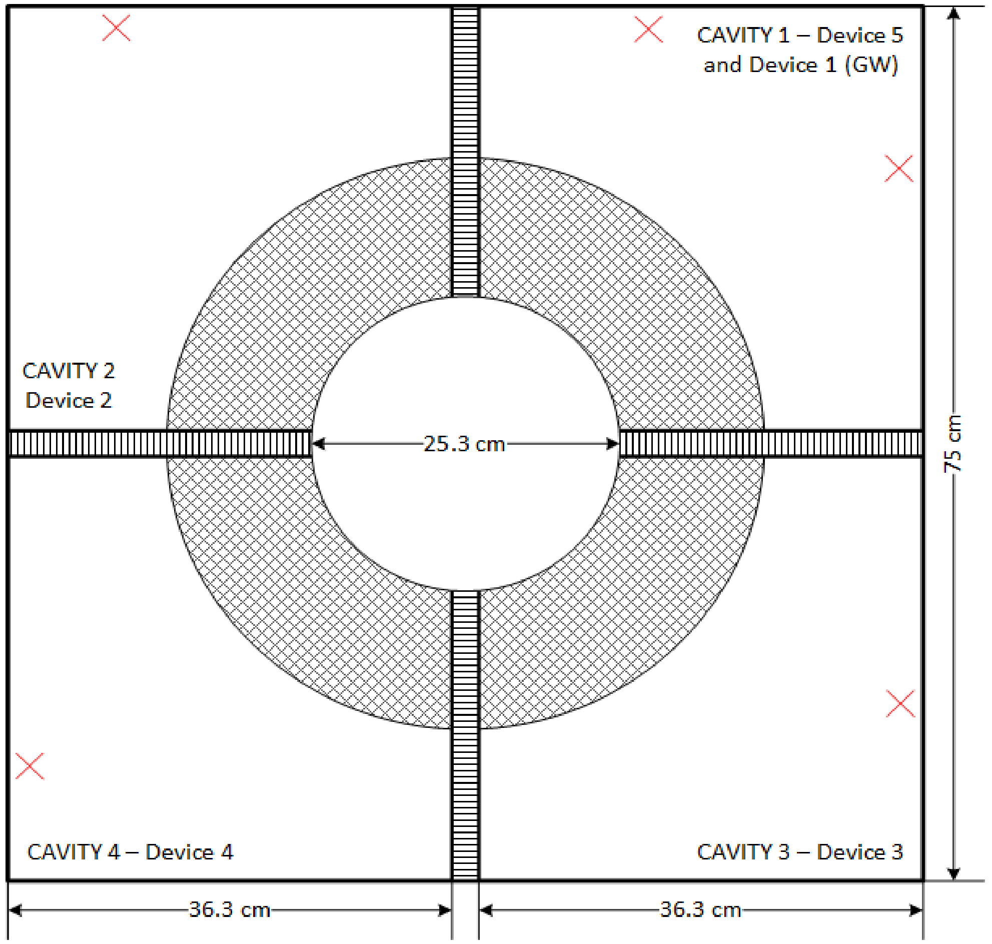




Sentinel 3 mock-up

- 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
- High power vs low power was tested
- Low power resulted in better results





Sentinel 3 mock-up (2)

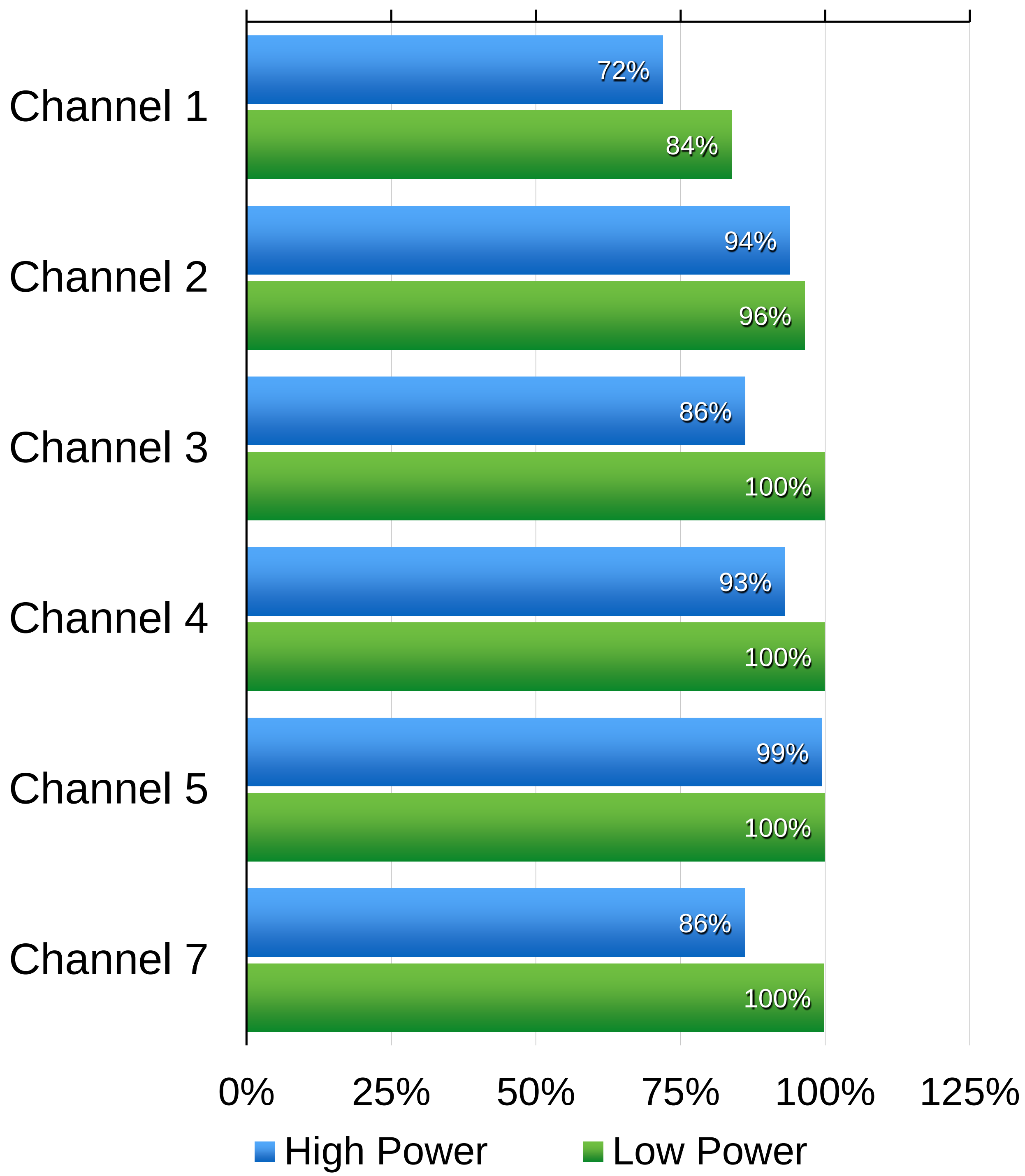


Chart 2 - Average PSR on the Sentinel 3 mock-up with aluminum inner panels

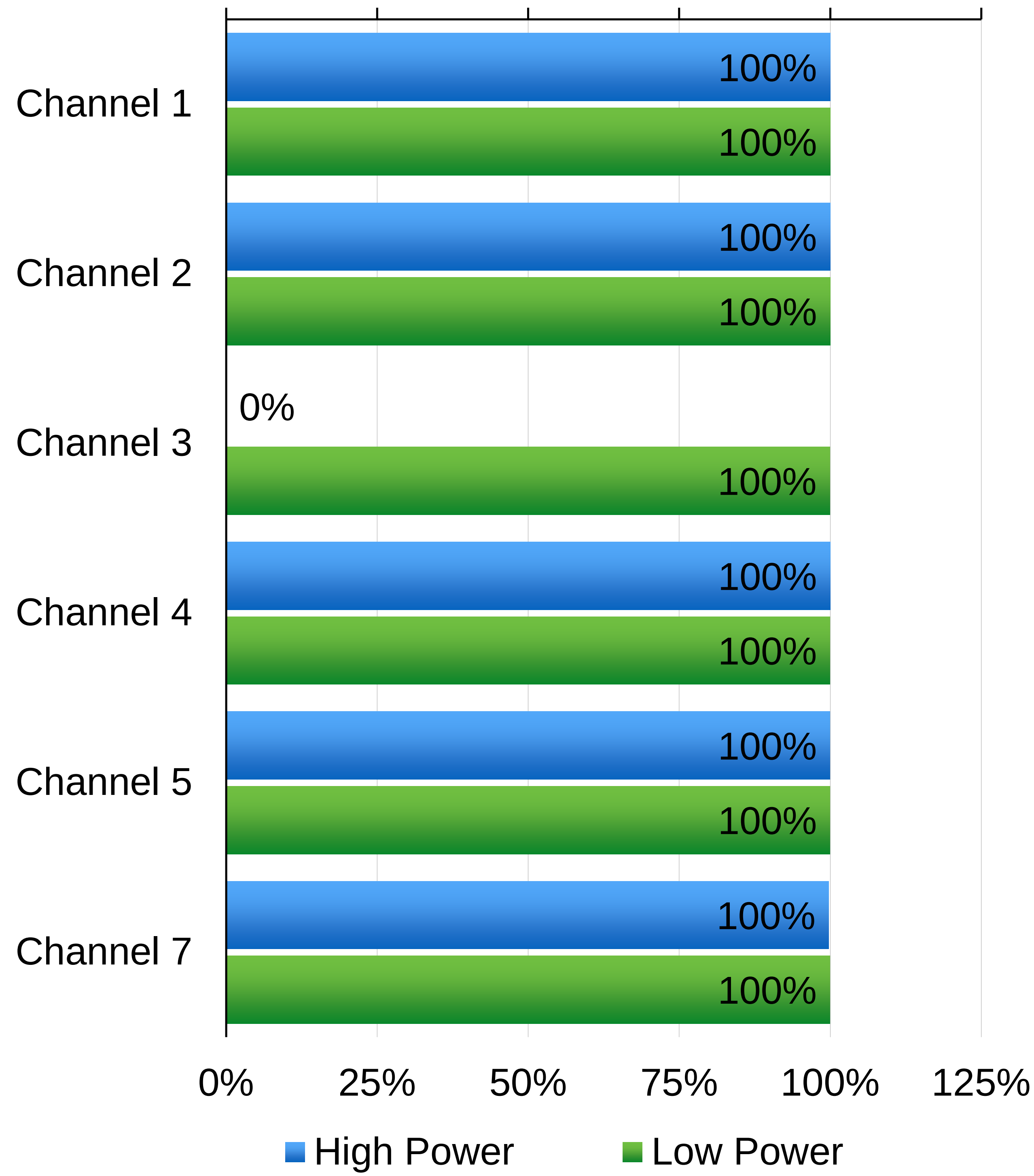
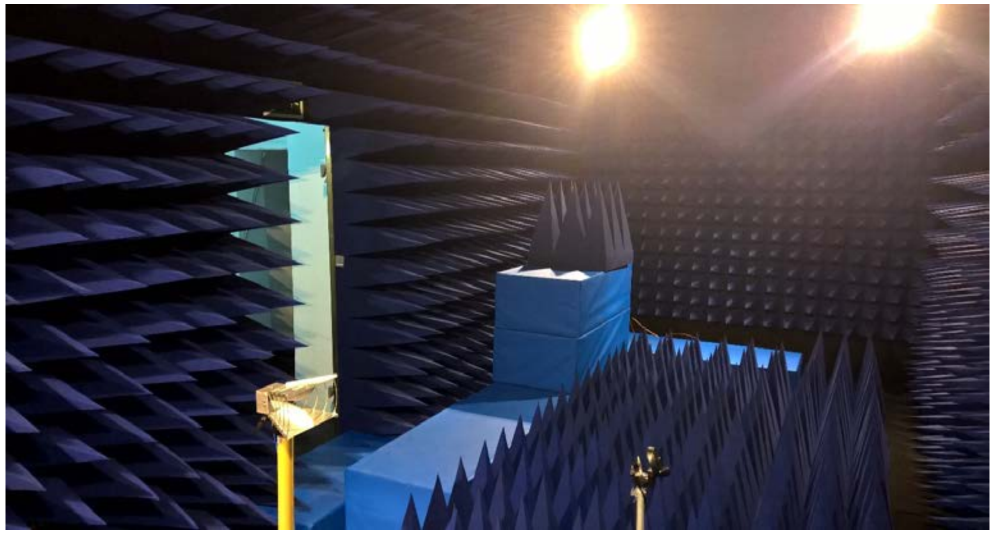


Chart 3 - Average PSR on the Sentinel 3 mock-up with carbon fiber inner panels

Test Setup - EMC

Equipment

- Anechoic chamber (8 m x 4 m x 4 m – L x W x H) operating on frequencies from 80 MHz to 40 GHz, manufactured by Siepel France
- Rohde & Schwarz FSV 10 Hz – 40 GHz Signal Analyzer
- Rohde & Schwarz SMB100A 100 KHz – 40 GHz Signal Generator
- DAP 20 Ridge Horn antenna
- Omnidirectional antenna
- 4 UWB wireless nodes (1 gateway + 3 sensors



Test results - EMC

Tests performed

- Emission measurements on the operating frequency (in band) for one wireless node set in continuous wave mode for each channel
- Emission measurements in the 80 Mhz – 40 GHz band for one wireless node set in continuous wave mode for each channel;
- Emission measurements for the wireless network with the signal generator creating noise on the operating frequency for each channel

EMC TESTS FOR 1 NODE SET IN CW

CDS control data systems WIRELESS

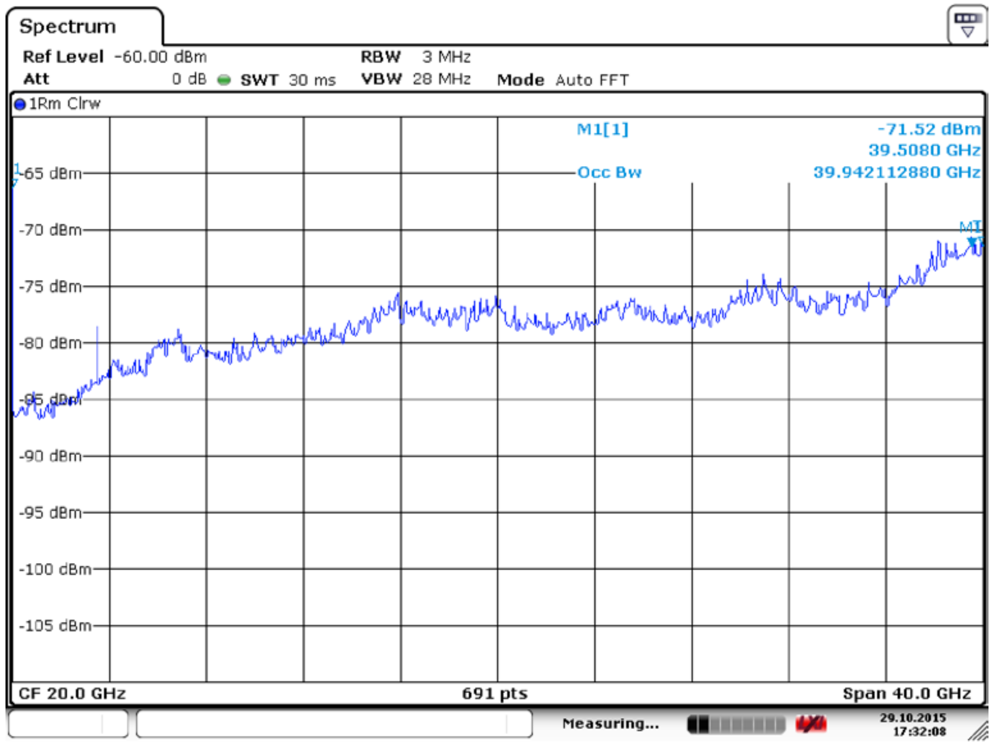
gmv INNOVATING SOLUTIONS

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

Test results - EMC

Channel	Measured power (dBm)	Measured power (dBµV)	E-field (dBµV/m)	Limit (dBµV/m)
1	-67.77	39.23	79.36	120
2	-73.86	33.14	79.00	120
3	-79.37	27.63	79.23	120
4	-73.65	33.35	79.21	120
5	-71.71	35.29	109.82	120
7	-66.16	40.84	115.37	120

The E-field values are below the required threshold of 120 dBµV/m on all channels.



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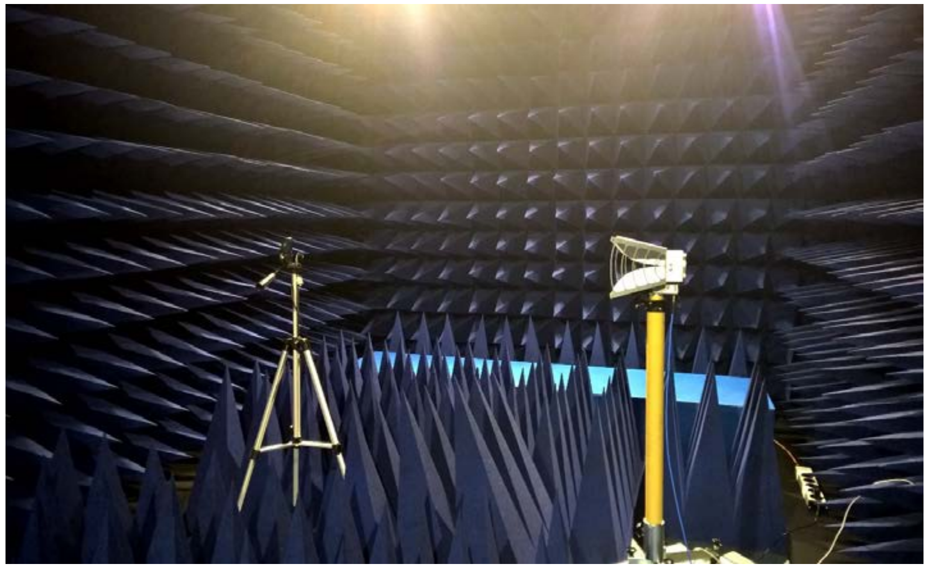


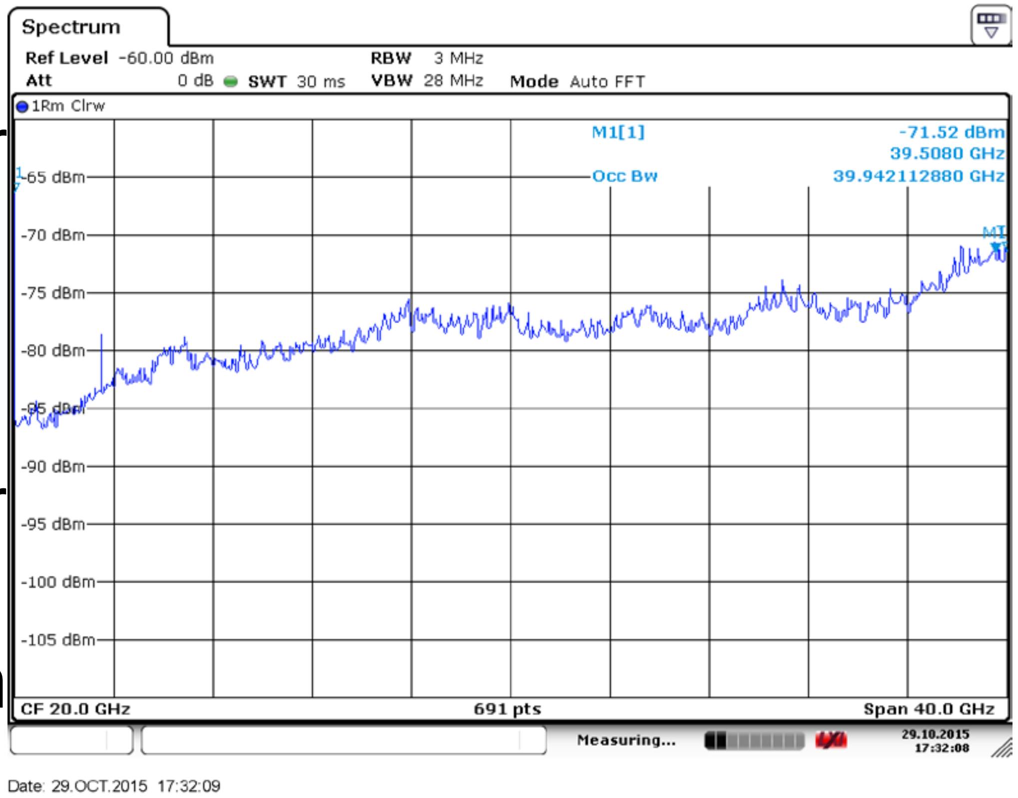
EMC TESTS FOR 1 NODE SET IN CW

Out of band EMC measurements

- there was no difference with nodes on or off
- only ambient noise was measured

Susceptibility measurements

- Noise was generated with signal generator on each channel
- Output power was set higher than requirements
- Network continued to function unaffected



Channel	Channel frequency (Hz)	E-field (dBµV/m)	Antenna factor (dB/m)	Required Output power (dBµV)	Generated Output power (dBµV)
1	3.500.000.000	114	40.1342	73.87	86.99
2	4.000.000.000	114	45.86766	68.13	86.99
3	4.500.000.000	114	51.60112	62.4	86.99
4	4.000.000.000	114	45.86766	68.13	86.99
5	6.500.000.000	114	74.53495	39.47	86.99
7	6.500.000.000	114	74.53495	39.47	86.99

Test conclusions

- The PER and the RSSI are better when we use a longer preamble, the best results are when using a 256 symbol preamble.
- There is no major difference in the communication on channels 1, 2, 3 and 5 with a 499.2 MHz bandwidth and channels 4 and 7 with 1331.2 MHz and 1082.6 MHz bandwidth.
- The node placement inside the cavities does not influence the overall performance of the network.
- The overall health of the UWB network is in direct relation to the material composition of the mock-up; having interior metal walls causes wireless reflections which cause a higher packet error rate. Consequently, the network communication is better when using carbon fiber reinforced plastic plated interior walls.
- The position and type of the openings between the cavities affect the performance of the device in that cavity. Devices in cavities with round openings (3) perform better that devices in cavities with square openings (2 and 4).
- Devices close to the gateway perform better if they are set to transmit with a lower power setting.
- On smaller enclosures, using a higher transmission frequency results in a healthier wireless network.
- The wireless node emissions do not surpass the 120 dBµV/m E-field value limit in the operating frequencies and the 70 dBµV/m E-field value limit in any bands from 1 MHz to 40 GHz excluding the operating frequencies.
- The wireless network is not affected by a generated noise signal of 114 dBµV/m.

Test conclusions

- The overall results show that ultra-wide band technology is suitable for replacing the intra-satellite sensor wired communication.
- Composite interior panels allow better functioning than the aluminum interior panels due to improved scattering of the signal inside the satellite mock-up or actual RF signal leakage. Composite panels are a better solution (since they are lighter), and they are the case of the study (for the real Sentinel 3 the interior walls are made from composite panels).
- The implemented ISA100 Wireless based communication protocol uses bidirectional communication (time advertisements and acknowledgements from the gateway to the node and data frames from the nodes to the gateway). In this configuration, the RW is used as sensor, and not for control. RW node sends telemetry to the Gateway.
- The antenna has to be in the same position for all the devices to have a better communication (polarization compatibility of the antennas)
- If a device is too close to the gateway, it will have a very high packet error rate – the high amount of reflections will cause an effect similar to a saturation of the receiver.
- Only the 6.8 Mbps configuration allows the required data rate.
- The required data rate and 0 PER are achievable with a packet retransmission protocol which was avoided in this study in order to gather accurate measurements of the PER.
- With the setting used in this study, the WI-SAT system is suitable for applications for which the navigation filter and the satellite attitude control system need 1 Hz input. For faster attitude control, the time slots of the communication between the nodes should be reallocated.

Further steps

TRL increase to 5/6

- Selection and testing of space grade connectors for connecting the sensors
- Specific enclosure designed in order to withstand environmental tests

Integration with on-board systems

- Gateway integration with on-board computer
- Integration of the RF nodes with the on-board instrumentation
- CAN bus support

Power supply and energy harvesting

- Optimization for battery power
- Use of energy harvesters: solar, temperature gradient, wireless power

Thank you