Current Activities and Status of the ESA/ESTEC-Industry Wireless Onboard Spacecraft Working Group

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Abstract
Commercial Wireless, both optical and RF have significant implications for the future of intra-spacecraft data handling as well as inter-instrument communications as applied in a planetary science context. This paper summarizes current Wireless WG activities underway to further define, refine and develop these technologies for space application, as well as broadening current understanding of the potential benefits of their use. Input from the space and commercial wireless industries, and academia to the ESTEC sponsored "Wireless Data Communications Onboard Spacecraft Workshop" of April 2003, plus investigations of TEC-EDD and the Wireless Onboard S/C WG activities and sub-group activities over the last year provide the basis for this paper.

1 Introduction

Input from the space and commercial wireless industries, and academia to the ESTEC sponsored "Wireless Data Communications Onboard Spacecraft Workshop" of April 2003 [1], plus investigations of TEC-EDD and the Wireless Onboard S/C WG activities and sub-group activities over the last year provide the basis for this paper. See: www.wireless.esa.int [2], and http://groups.yahoo.com/group/spacewlan/ E-group on Yahoo. [3]

2 Motivations

2.1 Three motivations for COTS wireless for space [1]

(1) Mass reduction + (2) A-I-T labour saving = Program cost savings and,

(3) Mobility for man or machine for increased mission value

"In our business mass equals cost. Every kilogram of mass we fly to mars right now costs us approximately $1 Million. If you can reduce the mass, you reduce the amount of fuel you have to push it, you reduce the size of the launch vehicle you need to lift it and the cost of the whole mission comes down. "[4] "The mars craft will be made much lighter by replacing heavy cables with wireless technology." [5] "If you do not believe spacecraft data handling will change significantly over the next 15 years, you will not be interested in wireless." [6]

"Expected U.S. productivity gains attributable to the new wireless technologies are 3-5% of total GDP." [7] "There is no reason to believe that scale-similar benefits cannot be achieved when applying wireless to space." [8]

2.2 Technology characteristics

Characteristics of free-space optical wireless that are advantageous for space [1]:

• Low mass/volume
• Free of almost all EMC issues
• NLoS or LoS capable

Characteristics of modern RF wireless that are advantageous for space [1]:

• Ad-hoc networks
• Self-discovery
• Mobility
• Low mass/volume/power
• Plug-and-play

2.3 Worldwide wireless for space

Currently there are 17 known wireless for spacecraft activities in the US and Canada, involving [15]:

• 6 Universities
• 2 Research institutes
• US DoD + space industry
• NASA + space industry
• Independent US Space Industry

And currently there are 9 known wireless for spacecraft activities in Europe, involving:

• 5 Universities
• 2 Research institutes
• ESA + EU space industry
• Independent European Space Industry

2.4 Current space developments/investigations for Optical and /or RF wireless [1]

• New classes of wireless devices – handheld palmtops, such as the PSA (Personal Satellite Assistant – NASA Ames Research)

• Advanced rover data acquisition and control, other robotics (CSA and NASA)

• Additional wireless sensors types for s/c, e.g. accelerometer (ESA and NASA)

• Instruments, e.g. camera (ESA and NASA)

• Optical links for space environment simulator (ESA's LSS)

• Wireless intra-satellite TM-TC data handling (NASDA, ESA and NASA)

• Astronaut data communications (NASA)

• Astronaut health monitoring (NASA and ESA)

• Planetary local data communications (CSA and NASA)

• Formation flying test-bed control/data acquisition (ESA and NASA)

• PDA for AIT (Assembly-Integration-Test) ground activities (ESA)

2.5 Future wireless space applications [1]

• Advanced astronaut health monitoring

• Spacecraft manipulators, rotating sections

• EV Robotics

• Onboard spacecraft smart transducers, temperature, pressure, accelerometer, strain, etc. (traditionally simple)

• High-speed intra-satellite subsystem interconnects, 100 Mbps+

• Fully realized very-high-speed wireless onboard satellite TM-TC data handling

• Planetary robotics, planetary science microprobes and exploration

3 Working Group Background

3.1 Steering Team

The working group steering team, consisting of 24 members and observers from ESTEC, was established in January 2003. Their task has been to outline and implement a plan to identify and explore promising wireless technologies for space use with the fuller participation of the European Space community, academia, wireless technology/component companies and research institutions.

3.2 Full WG

The full Wireless OB S/C Working Group was established immediately following the 1st Wireless Data Communications Onboard Spacecraft -- Applications and Technologies Workshop, held at ESTEC in April 2003. Current membership consists of 36 members and 45 observers. The Working Group meets three times per year, with additional sub-group meetings held as needed.

3.3 Organisation

• WG Organisation:
  - Chairman, P. Plancke, Head of TEC-EDD
  - Secretary, R. Magness, TEC-EDD Systems Engineer

  - WG Steering (ESTEC members)
    - Meets typically 4 times per year
    - Purpose has been to help develop the full WG
    - Evaluate Full WG outputs

- Working Group (Space Industry, Wireless, Academia, Space Agencies, Industry, Components makers)
  - Meets 3x/year, (2004-2005 - 6 May, 28 September, 18 January 2005)
  - Purpose: Define and Develop potential applications for wireless, formalise wireless protocols for space use

- Member Status and WG Tasks
  - Member, Observer
  - Member: required to attend majority of WG meetings (3 per year)
    - May be asked to volunteer, or assigned small tasks

    Observer: attendance highly desired

    May be asked to volunteer for WG tasks -not required
  - Yet undecided: required to decide on either member

3.4 WG Steering Team Objectives and Progress

• Raise the awareness of the potential of these technologies within ESA and space industry

• Investigate both the various technologies and applications

• Foster and encourage co-operation within ESTEC on these investigations

• Generate interest and dialog within the European Space community

• Develop an ESA vision for the use of these technologies

• Request the Full WG to further the goals of the WG Steering

• Advise on funding appropriate technologies and adaptation to space use

• Educate inside ESA/ESTEC and the European Space community

• Fully develop the most promising and appropriate technologies to FM

• Utilise the Full WG to further develop/standardise wireless protocols and HLPs and protocol stacks for space applications use

3.5 The current makeup status of the WWG

	Total	**European**	**Canadian**
Members:	33	32	1
Observers:	42	41	1
Totals:	**75**	**73**	**2**

Composition: Academia and R&D - 11, Space Industry – 15, ESA/ESTEC - 29, Wireless – 7, Components – 4, Other Industry – 6, Space Agencies - 3

The current status of the Wireless WG discussion e-group, spacewlan

	Total	**European**	**Canadian**	**Other**

				(American)
Members:	**120**	**110**	**2**	**8**

Composition: Academia and R&D - 15, Space Industry – 30, ESA/ESTEC - 32, Wireless – 14, Components – 5, Other Industry – 10, Space Agencies – 4

3.6 Wireless Onboard Spacecraft WG Goals

- Short term
    - Space applications development, technologies exploration, cross-fertilization from other domains, grow our knowledge base thru technologies watches
    - Provide feedback to industry on past efforts and future plans, studies, TRPs, etc.
    - Provide industry a roadmap for ESA's intent in implementing wireless technologies
- Long term
    - Serve as a "clearing house resource" in wireless-related knowledge for industry and ESA interests and projects
    - Provide significant input into the ESA/Industry decision making process regarding wireless technologies
    - Lower Level S/W protocols formalisation and High Level Protocols (HLPs) and stack selection or definition for space use
    - Guide, advise and eventually, provide wireless IP cores to space industry

4 Conclusions from the Workshop

4.1 Optical Wireless [9]

4.1.1 One of the challenges of optical wireless in space is the transfer of technology from the commercial terrestrial market, where optical wireless is commonly found in a wide range of consumer electronics and then particularly light mobile devices. Especially the mechanical, thermal and radiation constraints in some cases make Off-The-Shelf opto-electronic devices unsuitable for space use. Restrictions on geometry and available power further complicate the technology transfer.
In spite of this, preliminary results of current ESA activities are now showing the advantageous potential of optical wireless over classical wired solutions: cost saving and ease of S/C integration and testing.

4.1.2 The strategy to be followed in the next years for applicability of Optical Wireless in space would be then:

First, ***Proof of concept on*** typical ***'use case'*** to demonstrate the capabilities and performances of this technology to provide on board communications and associated services with appropriate functionality and performance using selected OTS components in an emulated S/C internal environment.

Second, ***Provision of a status of technology*** corresponding to a technology readiness level sufficient to cover technology flight demonstration to:

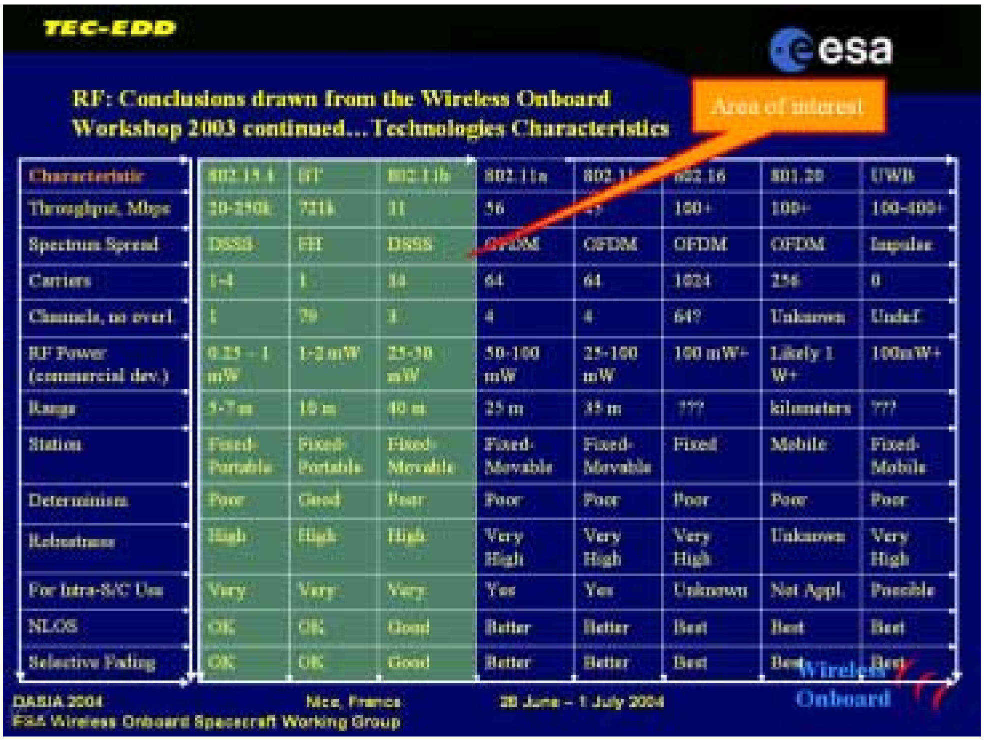
- Consolidate the application side
- Provide a basic tool-set to support design, performance prediction and analysis
- Provide a consolidated application demonstrator including the prototyping of a flight demonstration experiment
- Perform a flight demonstration to be cross-correlated with ground experimentation
- Tackle the standardization issues

Third, ***Pre-industrialisation issues*****:**

- Mature the support tools
- Develop the low level building blocks to be rad-tolerant at system level either using COTS selected components and/or rad-tolerant components [17, 18,19]
- Develop High-level building blocks for selected projects

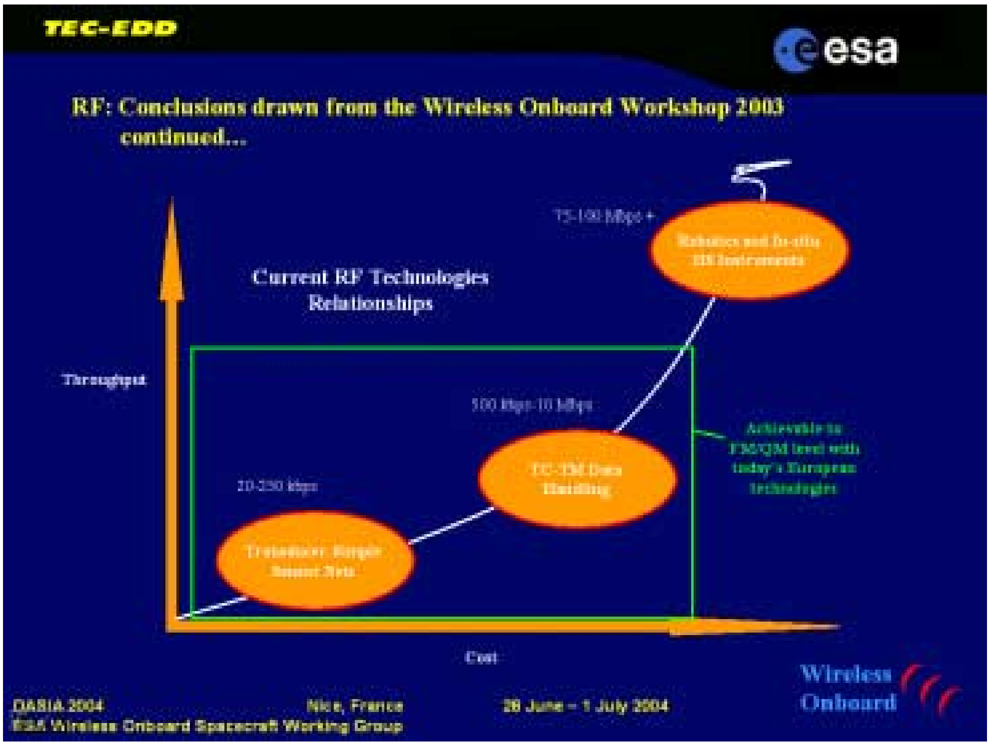
4.2 RF Wireless [9]

ESA has defined a roadmap presented at the First Wireless Onboard Spacecraft Working Group Meeting, 9-10 December 2003 in Noordwijk. Future immediate plans are to pursue both IEEE 802.15.4 for a wireless S/C sensor network and Bluetooth in a more traditional S/C TM-TC data handling application developed to at least a Flight Model (FM) level. [17,19] ESA shall be actively pursuing having these technologies ready for a flight opportunity as soon as early 2008. [9]



Characteristic	802.15.4	BT	802.11b	802.11a	802.11g	802.16	801.20	UWB
Throughput, Mbps	20-250k	721k	11	56	[illegible]	100+	100+	100-400+
Spectrum Spread	DSSS	FH	DSSS	OFDM	OFDM	OFDM	OFDM	Impulse
Carriers	1-4	1	14	64	64	1024	256	0
Channels, no overl.	1	79	3	4	4	64?	Unknown	Undef.
RF Power (commercial dev.)	0.25 – 1 mW	1-2 mW	25-50 mW	50-100 mW	25-100 mW	100 mW+	Likely 1 W+	100mW+
Range	5-7 m	10 m	40 m	25 m	35 m	???	kilometers	???
Station	Fixed-Portable	Fixed-Portable	Fixed-Movable	Fixed-Movable	Fixed-Movable	Fixed	Mobile	Fixed-Mobile
Determinism	Poor	Good	Poor	Poor	Poor	Poor	Poor	Poor
Robustness	High	High	High	Very High	Very High	Very High	Unknown	Very High
For Intra-S/C Use	Very	Very	Very	Yes	Yes	Unknown	Not Appl.	Possible
NLOS	OK	OK	Good	Better	Better	Best	Best	Best
Selective Fading	OK	OK	Good	Better	Better	Best	Best	Best

Future long-term plans may include IEEE 802.11/a/b/g for space adaptation. However, this task is quite complex and expensive. It remains to be seen when this may begin, going beyond the already ongoing demonstrator effort.



4.3 Final Conclusions

Overall Conclusions from the April 2003 Wireless Workshop and the way forward:

• The complete “Conclusions from the Wireless Workshop 2003” paper is available from ESA-ESTEC [9]

• An ESA cornerstone document, Wireless Technology Dossier [10]

The Technical Dossier entitled “Wireless Onboard Spacecraft and in Space Exploration” is currently being prepared and will be ready by September 2004.

The technology dossier will provide a vision and roadmap for both optical and RF wireless based on COTS technologies with applications from now, to a 15-year horizon.

5 Current WG Activities

Several specific WG tasks were initiated at the December 2003 WG meeting.

5.1 WG Task T-0 Application Case Scenarios, including:

Investigations to support ESA’s Aurora program and the ESA Science Directorate’s Advanced Science, Technical Reference Missions (TRMs) for both RF and optical potential solutions

5.1.1 One of the responsibilities of the ESTEC SCI-A office is to identify and develop key technologies necessary to enable long-term ESA-Science missions. This is achieved in part by introducing TRMs where identification and development of future technologies are ensured in a thematic context. The TRMs are not intended to replace the science mission proposal or selection procedure, which is the responsibility of the science community, but rather to ensure that long-term technologies are in place or under development so as to underpin future mission studies, selection and development processes in timely manner.

5.1.2 The TRMs focus on development of nano and micro spacecraft to achieve the science objectives in a cost-effective manner. These spacecraft will, through the development of low-resource payloads, make new mission concepts feasible. The emphasis is not on a single spacecraft approach, but on a phased strategic approach. If mission cost can fall dramatically then such an approach has virtue.

5.1.3 The TRM's strong focus on resource and cost reduction makes the use of wireless communication an interesting alternative for onboard communication. By saving mass by removing cables more payload can be delivered to the final orbit. Additionally, by using wireless communication cost can be saved during the AIT. These two points are the main rational for the Science Payloads & Concept Office (SCI-A) interest in use of wireless communication. However, other benefits may exist as well. Two of the missions will use microprobes to make in-situ measurements of the atmosphere and the surface. Wireless communication would therefore be of interest for communication with the probe and localization of the probe. Wireless communication could also be of interest in the payload data transfer. The TRM's focus on the use of Highly Integrated Payload Suites (HIPS), *the use of wireless sensors and wireless data transmission within the HIPS would further reduce mass of the spacecraft.* Additionally, some science payloads are required to be placed far away from the spacecraft bus (i.e. on a boom) the data transmission for such payloads could possibly use wireless communication.

5.1.4 It is clear that all the TRM's are potential users of wireless communication. Further studies of each of the missions will give better understanding and more specific requirements to the future use of wireless communication in science missions.

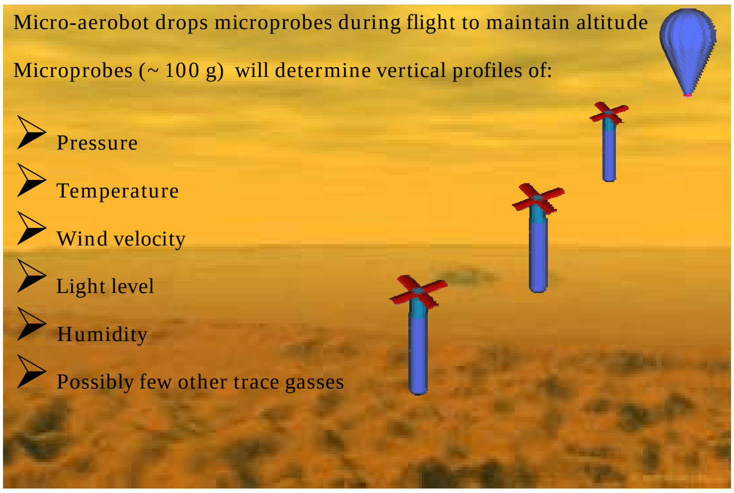
5.1.5 The SCI-A TRMs:

- TRM - Venus planetary surface exploration science: wireless for a Venus probe

Venus Entry Probe Technology Reference Mission

Objective: ***Study in detail the Venus lower atmosphere (physics, chemistry and exobiology)***

Venus Atmospheric microprobes Technology Reference Mission



Key challenges: Localization and communication and Resistant against harsh environment

- TRM – Heliopause mission

Interstellar Heliopause Probe

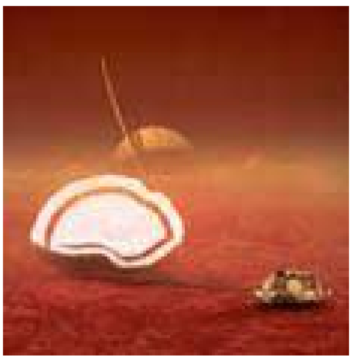
Technology Reference Mission

***Objective*: To explore and investigate the interface between the local interstellar medium and the heliosphere**

- TRM – Titan planetary surface and atmospheric science: Microprobes data communications

Titan planetary surface and atmospheric science: Microprobes data communications

Technology Reference Mission



***Objective*: Next generation micro, in-situ probes are desired to be roughly the size of a writing pen – extremely low mass, volume and power!**

- TRM - Highly Integrated Payload Suite electronics for "very resource-limited" spacecraft: wireless data handling interconnects

TRMs may use Highly Integrated Payload Suites to reduce resource requirements (e.g. extremely low mass, volume and power).

Mission	P/L Mass Range (kg)	Data Rate
Solar Orbiter	< 150	75 kps (750 kbps max)
BepiColombo - MPO	40 - 50	~ 60 kbps
Deimos Sample Return (TRM)	< 10	~ 10 kbps
Venus Entry Probe - Relay Sat (TRM)	10 - 20	~ 10 kpbs
Venus Entry Probe - Orbiter (TRM)	40	~ 50 kbps
Jupiter Explorer (TRM)	20	~ 50 kbps
Interstellar Heliopause Probe (TRM)	15-20	~ 200 bps
Venus Entry Probe - Aerobot	5	~ 5 kbps
Venus Entry Probe - MicroProbes	0.1-1	100 bps

- HIPS Characteristics:
    - State of the art micro-& nano technologies, MEMS
    - Use developing concepts such as stacks, 3D electronics in a block and surface mounted devices etc.
    - Sharing common functionalities (power supply, processors, optics, coolers)
    - Use of appropriate wireless interconnects – optical or RF
    - Use high levels of integration and COTS when possible

- Aurora - Advanced robotics communications

Advanced Robotics Communications

<u>Advantage</u>: High-rate, Robust, Low Power, NLoS Communications

- Aurora – Mars base camp data handling

Mars/Lunar Base Camp

<u>Advantage</u>: Mass/Fuel Reduction = Programme Cost Reduction

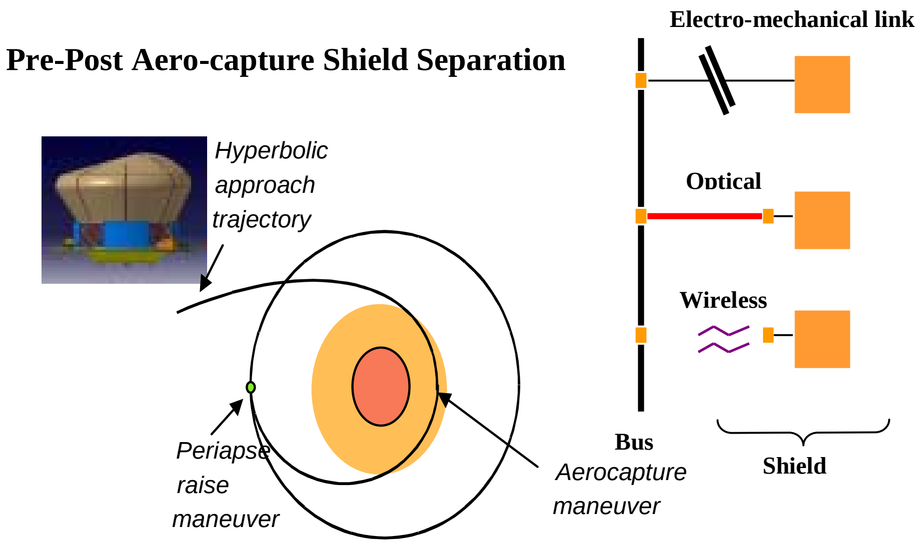
5.2 Developing wireless Application Case Scenarios to outline wireless solutions for several currently planned missions, or candidate applications for the short-term to long-term covering the WG's three themes of: (1) mass reduction, (2) easing the A-I-T process and (3) mobility for man or machine
Including:

- Wireless intra-spacecraft data communications, Theme 1

Intra-spacecraft data handling

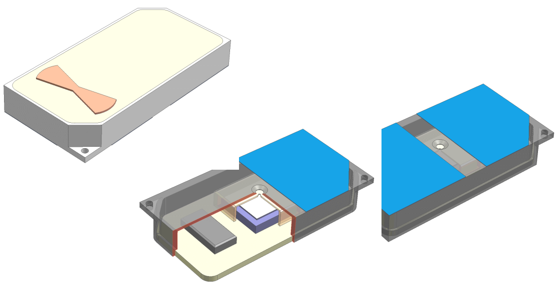
Advantage: ***Low and High-data-rate, robust comms, lower mass, A-I-T savings***

Data bus separation utilising wireless during aero-capture manoeuvres – Aurora, Theme 3



- A completely wireless sun sensor, Theme 1

Conventional Satellite Data Handling



Advantage: ***Completely self-contained, including solar-cell power supply, very low mass and volume***

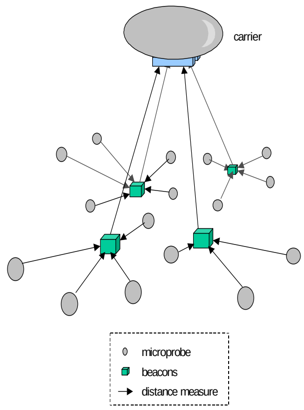
- Advanced robotics control and data communications, Theme 3

Advanced robotics control

Advantage: ***High-data-rate mobility, robust comms, lower mass***

- Sea-of Sensors for planetary science, Themes 1 and 3

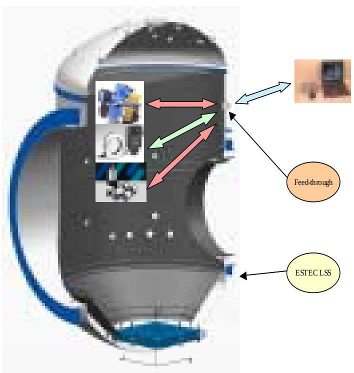
Planetary Science: Sea-of-Sensors

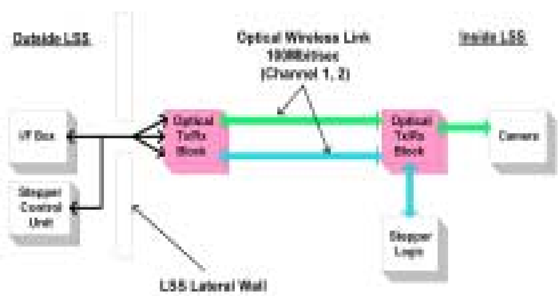


Advantage: ***Sensors Localisation utilizing RF wireless, very low mass and power***

- An optical data link for the ESA-ESTEC Large Space Simulator, Theme 2

A-I-T Optical Links for ESTEC LSS





Advantage: ***Non-intrusive, optical data connections experiment***

- Rotating spacecraft section: slip-ring replacement, Theme 1

Satellite: Slip-Ring Replacement

Advantage: Eliminates many, many cables and massive slip-ring

5.3 Task TW, Technology Watch for both relevant application domains and standards applicable to wireless

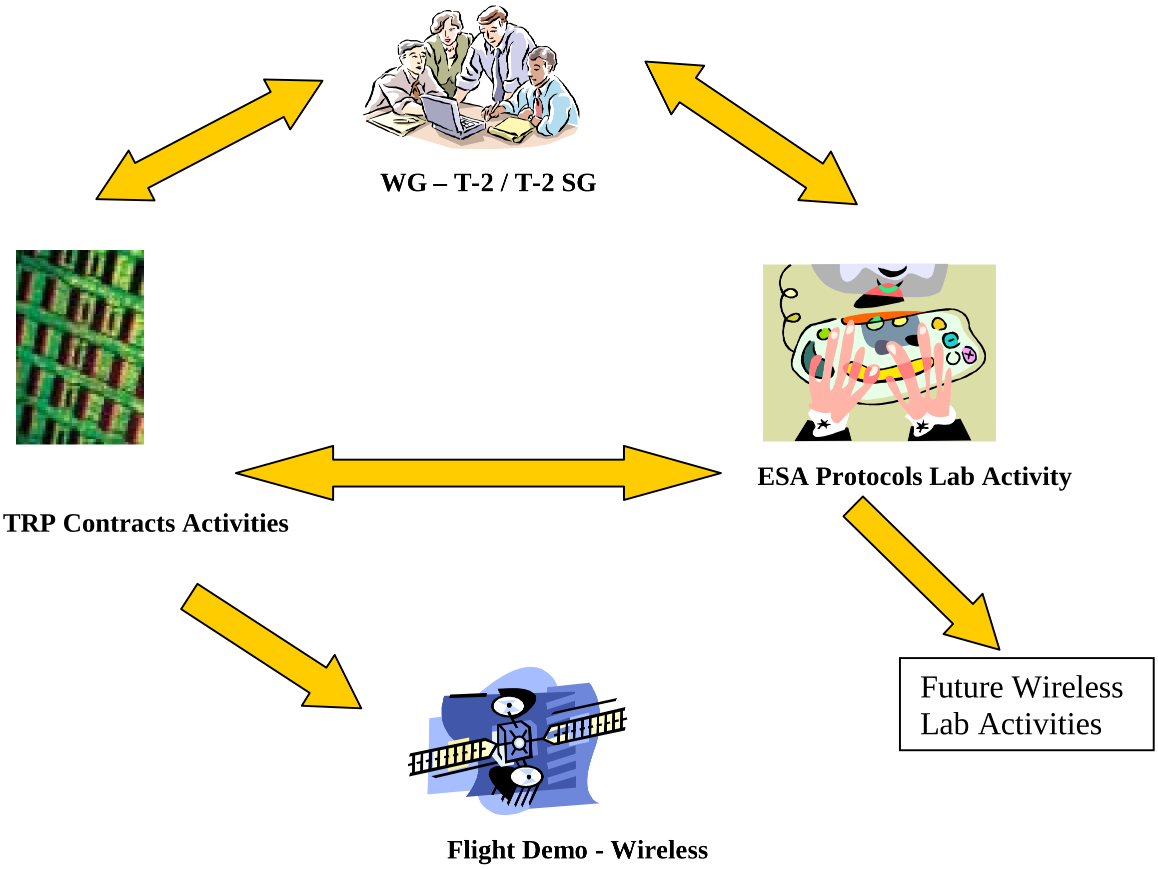
Domains:
- Automotive
- Medical
- Industrial
- Aerospace
- Others

Standards:
- Irda
- IEEE 802.15.4
- IEEE 802.11a/b/g…
- Bluetooth
- Ultra-wideband
- Others

5.4 Wireless for spacecraft protocol requirements and standardisation; several other WG tasks have been initiated

Currently:
- **T-1a:** IEEE 802.15.4 and Bluetooth RF Wireless protocols harmonisation with the Spacecraft Onboard Interface Services, SOIS (formerly, SOIF) WG
- **T-1b**: Optical Wireless protocols harmonisation with the Spacecraft Onboard Interface Services, SOIS WG
- **T-2:** Protocol requirements specification for Wireless Sensor Network utilising IEEE 802.15.4 [11, 12]
- **T-3**: Protocol requirements specification for Wireless TC-TM Network utilising Bluetooth

5.4.1 In connection with the WG T-2 and T-3 subgroups, the ESTEC lab and TEC-EDD members are currently also engaged in prototyping the wireless IEEE 802.15.4 and Bluetooth protocols and protocol stacks for S/C usage on actual wireless devices/development kits, according to the requirements specifications developed in the subgroup. The relationship in these activities is illustrated below:



5.5 Providing input for funding decisions for wireless for intra-spacecraft data communications development

For now, current and near-term, 2004 – 2006, ESA studies and research activities have been decided. We expect the next research funding cycle, 2007 – 2009, will bring opportunities for even broader application for wireless in several of the more long-term scenarios listed above.

6 Optical Wireless: ESA Studies and Research Activities [13-16]

6.1 An on-going project within the frame of the General Studies Program, “Validation of wireless optical layer for on-board data communications in an operational context” aims the identification and testing of and optical wireless communication system fulfilling the basic requirements of the internal data communication function of an onboard control and data system, and the assessment of its suitability for space use.

6.2 A second activity, “Optical wireless link for videogrammetry data transmission inside the LSS “ with the objective of verifying the benefits these technologies offer to EGSE and testing, will conclude in 3Q 2004.

In parallel, significant budget has been allocated in the field through the Innovative Technology Research Program (TRP) that will allow the Agency to be in the position of performing a qualified experiment within three years period.

7 RF Wireless: ESA Studies and Research Activities

7.1 There is currently one RF Wireless TRP underway: “Optical / [RF] Wireless Intra-Spacecraft Communications” that should conclude near the end of 2005. This activity is for a desktop/earth-bound demonstration system for both WLAN and Bluetooth TM-TC data handling.

7.2 A second activity, “RF Intra-Spacecraft Data Communications” for flight demonstrations of both an IEEE 802.15.4 (WPAN) based wireless S/C sensor network and a Bluetooth TM-TC data handling network is due to kick-off before the end of 2004. [20]

8 In Conclusion

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Also, we attribute the video clip credit to: John F. Connolly, NASA, and images from ESA, NASA and CSA; and SEA Ltd., SCISYS, TNO -TPD Nederland.

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