Atlanta, September 15 2005

Position paper " Wireless Interfaces Services" as support to the proposal for a Working Group within the SOIS Area of CCSDS

1 Introduction

The development of Wireless techniques for data communications in domotics, bureautics, WLAN, WPAN covering a range of applications from industrial control to multi-media has been one of the most significant revolution in commercial and industrial data systems. It is a hard fact to-day and we have to acknowledge that Wireless data communications (as LAN or Sensor/Instrumentation bus) is here to stay and is to spread pushed by a growing commercial and industrial market. Also there is a clear interest for spin-in of those techniques in space systems to build upon the existing. technology investment and know how. Many initiatives in Europe and US for use of these techniques in space or aeronautics have been taken. However in such an active and fast moving domain, there is a clear risk of 'anarchical' bottom-up developments of this technology within space systems and international cooperation through CCSDS is necessary to ensure compatibility and interoperability between the different Agencies.
That has been the purpose of the S/C Wireless Interfaces Bird of a feather to investigate the state of the art, the potential applications and prospect for collaboration and inter-operability in this area.
The activity of the BOF was built on a step by step approach:

- identification of applications and requirements,
- existing standards,
- classification of wireless interface services,
- prioritization of services to be considered in the near term,
- definition of a Working Group scope and responsibility,
- Definition of the Working Group Charter

Also a strong emphasis is given on the reuse and compatibility with off the shelf available standards.

2 Background – Review of Applications

Technical note1 (see Annex 1) has provided:

1) a review of existing and potential applications for Space making use of wireless interfaces
2) a review of the experience existing within the Agencies in this field

Technical note 2 (see Annex 2) has provided a review of the commercial and industrial standards available on the market.

From the analysis of those data, it can be identified that:

1) "Wireless" can be based on RF link or optical link. Although for most people, the 'wireless' means RF, much work has also been done on optical. If most commercial standards exist based on RF, optical implementations are relatively easy to implement using either IrDa standard and related components or Mil compliant emitters and receivers. For direct line of sight communications, optical based communications are much power efficient than RF.

Both RF and Optical options shall be considered

2) Domains of applications cover manned S/C, unmanned S/C, AIT of S/C.

There is a need to identify commonalities between similar requirements from different domains in order not to duplicate efforts. For this reason, rather to classify per domain (Man space, Earth observation, Telecommunication, Science…), the classification effort shall try to regroup the applications and hence the related services in few categories based on quantifiable requirements or criteria.

3) Domains of applications cover on board and off board communications

If some techniques like 'diffuse optical' work mainly in closed environment, RF or optical line of sight techniques can work indifferently in closed or open environment. In many cases, the main difference will be the front end emitting power that could vary from few watts for local external communications to few milliwatts for closed environment. However some complex applications like planetary infrastructure and exploration will require to rely not on one protocol and modulation system but on a family of systems ranging from few cms to tens of kilometres and accommodate complex topography, non line of sight requirements, RF multipath environment.
In this case, multiple communication systems may be integrated within an appropriate spiral engineering approach to ensure that the complete system meet actual mission requirements. This type of internetworking on heterogeneous networks shall be however covered in the SIS area and in particular within the Cislunar WG. Within SOIS, the proposed logic is to identify first the services provided by homogeneous local network systems that may cover on board and off board communications or data acquisitions.

3 Classification of applications and services

The main criteria for the classification of applications will be related to:

Physical parameter*:* Distance or range (cm, m, km…)

The range will classify the domain of application from local to the S/.C (intra spacecraft), local to S/C and immediate vicinity (intra and inter S/C) such as short distances formation flying, local rovers and landers, free flyer auxiliary vehicles (for inspection, monitoring purposes etc..).
The fact is that a WLAN is implemented within a S/C or outside to connect separate elements in some collaborative work should not impact too much the protocol to be used. Of course, for RF main differences will be in the RF front end since within a

small S/C cavity, the transmitted power will be very small compared to off-board communications even if the same protocol is used for both applications.

Electrical or Optical environment: is it a clean or disturbed environment (noise, interferences). This may impact the complexity of the system (e.g. signal processing).

Required Performances: Throughput (in bps), Tolerated Delay (time bounded constraints on real time system) or both

Functional parameters:

Data systems in space applications can easily be categorized relatively to the RAMS requirements (Reliability, Availability, Maintainability, Safety) attached to the main function that they have to fulfil, allowing to rank them from non critical to safety critical applications:

Non critical: Housekeeping – engineering monitoring – science TM

The loss of data can be tolerated time to time as a function of the reliability figure required by the mission. Typically the loss of few thermistors data time to time will not jeopardize the mission or the lost of few bytes in the TM from an imager instrument is acceptable as long it does mot occur systematically.

Critical: monitoring related to system FDIR or Health monitoring for manned missions

Similar to above at the difference that the data to be acquired are part of some functional chain, related to FDIR (Failure Detection Isolation and Recovery) for example and hence the loss of those data shall be avoided. If this happens, an alarm may not be triggered. However in a sound designed system, the FDIR shall be made such that major system failure could be caught by different means (redundant paths, multi-level FDIR..)

Reliability critical: Fly by wireless types of applications for unmanned S/C

The failure can potentially reduce the life time of the mission, however the mission design shall have taken this into account by providing the necessary redundancies (cold or warm)

Availability critical: Fly by wireless types of applications for unmanned S/C

The system cannot tolerate any interruption of service, failure to do so can potentially endanger the mission or the spacecraft if not corrected. Typical example is a planetary orbit insertion manoeuvre that have to be executed in time and without interruption. The design shall have taken this into account by providing the necessary redundancies (cold providing a reasonable reconfiguration time in the order of 10 ms is tolerated, warm for a very short reconfiguration time (ms) or hot (no interruption of service is permitted, errors have to be masked on line).

Safety critical: Fly by wireless types of applications in man tended environment

Similar to either reliability or availability critical but in a man tended environment which means that the failure can potentially endanger directly or indirectly human health or life. Generally the system is designed with hot redundancies. Other difference is that the on board systems can be maintained by human (but not always like for ATV which is jettisoned after its mission)

4 Preliminary classifications based on performances and Robustness (RAMS) requirements

It can become easily a multi-dimension problem but we propose a relatively simple classification considering on one side the performances and on the other side the functional 'robustness' defined as the level of criticality supported by the services.

	Low rate	**Medium rate**	**High Rate**	**Comment**
Non critical	Sensor bus/transducer systems Many nodes	Audio data (information, multimedia)	TM interfaces to science instruments, Video data Visual monitoring cameras..	Include most monitoring functions of note 1, 2.2,2.3,2.4, 2.8,2.0,2.11,2.12,2.13,2.15, 2.16,2.18
critical	Sensor/Platform bus thermal/power monitoring Crew health sensing			2.1, 2.5,2.6,2.12,2.13,2.18
Reliability critical	Platform bus Control and command	Sensors (star tracker..) Actuators, Space link		Typical unmanned mission 2.14,2.18
Availability critical	Platform bus Control and Command	Guidance sensor i/f		Mission with very critical phases such as Orbit insertion, automatic RVD.. 2.12,2.13, 2.14,2.18
Safety critical	Platform bus (man tended) Control and command	RVD I/F links Operational Audio data		2.12,2.13,2.18 (*)

(*) Number refer to application review of Annex 1

When considering wireless candidates, it is obvious that non critical services can be covered by COTS standards: IEEE 802.15.4 for sensor bus type, WIFI for medium to high rate.
When increasing the robustness requirements, we may expect that the basic capability of the COTS standard will not be sufficient to cover the system needs. However, it does not mean that the COTS standard is not usable but it means that it has to be extended for providing the required level of robustness. The same approach has been used when flying automotive buses like CAN or multimedia like Firewire that are naturally robust for what concerns transmission errors but which do not provide natively cold, warm or hot redundancies. Also the BER or Frame error rate might be sufficient for lower criticality level but not sufficient for fly by wireless or safety critical mission, then extra coding might be necessary …
Also it might be necessary to complement an existing standard for what concerns real time control issues such as bounded delay.

Obviously the best COTS candidates will be those that will require a minimum effort to be upgraded to fulfil our needs and hence the work of SOIS Working group will be to define and propose what standard extension shall be provided and also the tailoring of the standard if this is appropriate.
This statement is of course mainly true for RF wireless, whilst for optical the available COTS solutions available are much less (mainly IrDA) but in counterpart it has been demonstrated that it is relatively easy to implement some standard protocols over optical wireless.

5 Added Value of Wireless services compared to wired solutions within system or applications

An other important criterion to be used for selecting the service to be considered in priority is the "added value" to the system or the Spacecraft that can be gained from the introduction of such a service.

- **Mass and AIT effort reduction:**
  This is an obvious one by reducing drastically the number of wires and connectors, the flight harness mass is decreased as well as the integration and testing time during S/C integration. It is also worth to note that much time is lost during testing and integration due to errors or faults in the auxiliary equipment and related test harness.
- **Mobility and Portability:**
  This is particular interesting for Man in space and Man tended systems. Typical case is the crew heath monitoring of astronauts: they need to be constantly monitored in a non intrusive manner and keep their full freedom for moving around the station or man tended vehicle. In case of concerns of possible interferences with or from on board instruments for such a safety critical application, the use of optical wireless communications is an attractive option.
- **Non intrusive monitoring of S/C during launch:**
  Wireless techniques could provide the possibility of monitoring in real time the passenger S/C (thermal, vibration, mechanical) whilst being launched

which is not possible to day. Due to their intrinsic EMI-free and immunity optical technologies may be easily accepted by the launcher authorities.

- **Rotating mechanism-Articulated structures-Separable composites**
  Wireless techniques would be the easiest and sometimes only way to implement contact-less data communications and acquisition systems.
- **Retrofit**
  Wireless techniques when available would allow to bring new or up graded functionalities to existing platform for a minimum cost. Typical examples are the wireless sensor (micro-accelerometers) flown on the last Shuttle flight.
- **Opportunity payload in late development phase**
  Wireless techniques can allow the late integration of opportunity payloads on a S/C at a stage where modification of the harness is not possible. Typical example is the introduction of monitoring devices such as micro-camera for the deployment of appendices or separation manoeuvres.
- **Flexibility in S/C design and equipment accommodation**
  Wireless techniques can provide new options to the S/C designer when accommodating equipment in the 3D space, especially when coupled with autonomous powering or power scavenging techniques
- **Common network for on board and off board communications**
  The possibility offered by wireless techniques to be used both for on board and off board can be of interest for some special cases such as robotic surface elements within some Exploration mission scenarios.
- **New functionalities**
  Different users communicating at different speed can share the same Wireless channel. This is not possible with standard wired solutions since high speed signals required specific cables (shielding, coaxial).
  New redundancy concept/ reconfiguration/plug and play: being layout independent, wireless techniques may bring additional flexibility when implementing fault tolerance and system reconfiguration. In standard systems, the cross-strapping of on board equipment is always a delicate issue.

6 Prioritization strategy

The strategy is to consider as being a priority:

1) The services that bring a high ‘added value’ to existing systems (compared to ‘wired’ based services)
2) Low risk in term of feasibility
3) Progressive introduction in on board systems giving initially the preference to the support to low criticality functions such as monitoring unless we have a good case (project support) for implementing a higher criticality level (crew health monitoring? for example) in a short term.

7 Identification of the services to be considered in priority within the CCSDS

Three classes of services have been defined covering the spectrum of applications identified to-day. The work effort shall follow a ‘spiral’ approach, starting first by monitoring services that are relatively easy to implement whilst providing an interesting added value to on board systems and finishing by the more stringent requirements of command and control related applications.

7.1 Proximity low power sensing network

This relates to the current interest for the wireless acquisition of the data from miniaturized low power sensors ranging from few tens up to the order of thousands. There is to day a large interest for this approach in commercial and industrial systems with standards such as the 802.15.4 and the IEEE 1451.
For space, application can be found on board S/C (housekeeping, engineering monitoring), off board (science mission) as well as in the integration and test facilities that are great consumer of small sensors (thermal vacuum and mechanical tests).
The added value is obviously the reduction of harness, especially if the sensor is autonomously powered or self-powered (power scavenging…).
The technology risk is limited since this is currently an active field and we may expect spin-in from terrestrial industrial systems and in addition benefit from synergies with on going R&D activities within Esa and ? .

The services to be specified shall cover non critical monitoring (capability set A) and critical monitoring (capability set B). Main difference will be that Capability set A shall basically relate to low power sensing network with many nodes (for example thermistors channels can be in the order of several hundred to thousand on a single S/C) whilst capability B shall relate to a network for a reduced number of sensors but requiring a higher quality of services.

7.2 Proximity intelligent network

In our context, the qualifier of "intelligent network" relates to the communications of data between intelligent units or nodes (computer based) by opposition to the low power sensing network composed a priori of numerous non-intelligent sensors connected to a few intelligent units acting as concentrators.
The services to be specified shall cover non critical (capability set A) and critical data (capability set B) information transfer allowing peer to peer communication and broadcasting among users. Non critical information transfers will generally be IP based.

Capability set A shall basically rely on existing standards (at least for RF) whilst Capability set B may add additional requirements or QOS to those standards.

7.3 Command and Control network

This relates to the data transfer of information participating to command and control functions on board a S/C or off board (commanding of external elements).
The capability set A shall be defined to cover Reliability critical applications and the capability set B shall be defined to cover Availability/Safety critical.

8 Schedule

The activity of the Working group shall be phased such as to cover first the monitoring services, then the intelligent networking services to finish by the definition of the services covering command and control applications.

9 Resources

In addition to the manpower that may be made available by the Agencies, we have identified synergies with on going and planned R&D activities in the technology support programs, notably on ESA side (TRP, GSTP, GSP programs).

Annex 1

Technical Note : Review of applications – State of the Art within Agencies – State of the art commercial systems – Lessons learnt from hand-on experience

Annex 2

Technical Note :Review of commercial available standards

ANNEX 1

WIRELESS BOF. Chapter 1: Scenarios for future missions.

1.-INTRODUCTION

Commercial Wireless, both optical and RF have significant implications for the future of intra-spacecraft data handling , inter-instrument communications, as well as communications outside the spacecraft as applied in a planetary science context. This chapter summarizes case studies for the application of wireless technologies and techniques currently under investigation by different agencies. The purpose would be to further define, refine and broaden current understanding of the potential benefits of the use of wireless technologies, with the eventual goal of concluding whether the standardised use of wireless interfacing technologies for spacecraft is appropriate.

1.1- Motivation

Not only the characteristics of free-space optical wireless advantageous for space (low mass/volume, free of almost all EMC issues, NLoS or LOS capable) and RF wireless (ad-hoc networks, self-discovery, mobility, plug-and-play),but also the low cost that wireless COTS has reached nowadays allows these solution to be a competitive alternative specially in the following domains:

-Monitoring systems (environmental, physiological, structural…) and
-Fundamental design choices for advanced concepts solutions

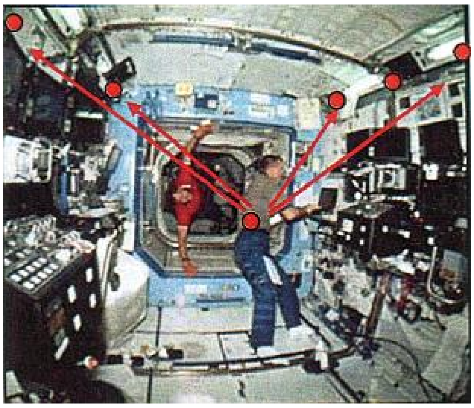
where the main advantages provided will be translated into a considerable mass reduction, general A-I-T labour saving and mobility for man or machine, with the automatic increase in mission/programme value.

2.-CLASSIFICATION

- **Belonging to the first category, wireless for monitoring systems, we highlight:**

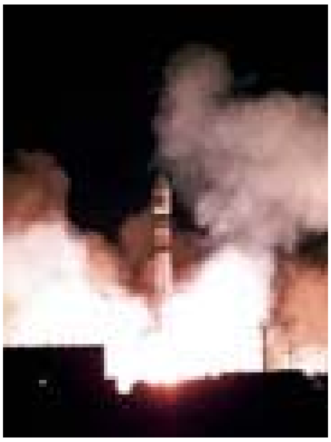
2.1- OPTICAL WIRELESS DATA HANDLING FOR LIFE SCIENCE AND CREW HEALTH MONITORING (physiological monitoring)

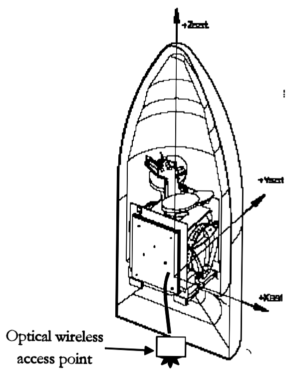
In the context of observation of biomedical parameters, the presence of human in the loop requires, on one side, safe and reliable measurements and frequently on the other, very low intensity variables need to be measured/observed/monitored. This requires acquisition and transmission of information in a safe and reliable manner. The optical approach to data transmission is of great advantage for the elimination of parasitic currents that can be originated due to presence of ground loops.



2.2-WIRELESS ACCESS POINT ON LAUNCHERS (Structural monitoring)

The objective is to provide a monitoring facility to the satellites during the launch (thermal, mechanical, vibration...).
Particularly interesting the implementation at S/C interface level. Optical technologies are suitable candidates because of the short distances to be covered. Non-collimated beam need to be used to allow a wide area of implementation for the S/C terminals.
Due to their intrinsic EMI-free and immunity optical technologies will be easily accepted by the launcher authorities.





2.3: WIRELESS TECHNOLOGIES FOR THERMAL, AGEING, RADIATION MONITORING.(Environmental monitoring)

Autonomous wireless sensors (with non rechargeable batteries) can be used. Several years life time is achievable. Low consumption can be obtained with stand-by modes (only receiving). Ultra low comsumption can be obtained in "power down" mode with only a wake-up timer running.
RF technology is probably more suitable for a late implementation in several locations.

2.4-WIRELESS TECHNOLOGIES FOR MECHANICAL CONSTRAINTS MONITORING IN HIGH SPEED ROTORS WITH MAGNETIC BEARINGS.(Structural monitoring).

An example of application would be the energy storage in kinetic momentum. Typical speed > 50 000 rpm. Strength gauges and/or accelerometers will probably be implemented in the composite (rotor). Wireless links are the only possibility to transmit information. Optical technology seems to be the most suitable.

2.5.- WIRELESS TECHNOLOGIES FOR RADIATION DOSIMETRY MONITORING.(Environmetal monitoring).

Crew-worn monitors and deployable monitors that provide local and remote alarming of off-nominal radiation conditions, to safeguard the crew and vehicle electronic subsystems from radiation storms and cumulative radiation effects.

2.6.- WIRELESS SENSORS MEASURING AMBIENT ENVIRONMENTAL PHENOMENA.(Environmental monitoring).

This is to ensure specified range for long term habitation, safeguarding the crew and the vehicle from hazardous environmental contaminants and off-nominal physical conditions.

Sub-categories: Atmospheric monitoring – contaminant assessment; atmospheric pressure monitoring – leak detection assessment; in-situ water quality monitoring; EVA suit monitoring; temperature, pressure, relative humidity monitoring; light level monitoring, acoustic level monitoring.

2.7.-WIRELESS TECHNOLOGIES FOR CREW MEMBER LOCATION TRACKING

This is to optimize crew member activities and detect potential crew member psyche problems.
The use of high-precise 3D wireless localization systems would provide precise crew member location tracking.

2.8.- WIRELESS SENSORS TO MEASURE STRUCTURAL DYNAMICS OF SPACE VEHICLES.(Structural monitoring)

To ensure vehicle structural and critical-systems integrity.
Sub-categories:Structural monitoring, spacecraft avionics monitoring, propulsion system monitoring

- **And in the category of advance concept solutions:**

2.9.- SMART ASTRONAUT VEST FOR EXTREME ENVIRONMENTS

To investigate the potential of using smart materials and optical wireless techniques based on the integration of sensors and actuators into the clothing of astronauts.

2.10- COMMUNICATION SCHEMES FOR ARRAY OF MEMS DEVICES WITH OPTICAL FRONT-END TRANSCEIVERS.

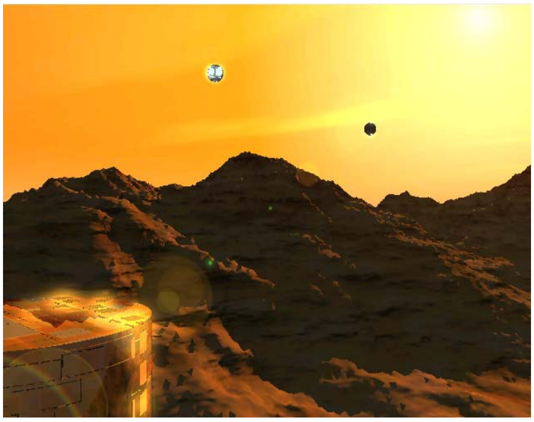
Optical front-end transceivers are expected to be more suited than RF ones for MEMS (MicroElctroMechanical Systems) devices on-board spacecraft. With communication schemes based in repeaters not only any obstacle can be easily contoured, but also great flexibility would be given to the spacecraft designer for the placing of the MEMS devices..

2.11.-WIRELESS SENSORS FOR LAUNCHER TURBINE ENGINES VALIDATION INSTRUMENTATION .

Simply stated, the turbine engine industry has a need for wireless sensors that can be installed and operated at virtually any location and temperature on a modern engine. These sensors should be small, communicate via wireless and provide their own power. With these sensors, installation and maintenance become straightforward and have little or no integration impact on the engine and its associated mounting structure.

2.12.-WIRELESS TECHNOLOGIES FOR INTERPLANETARY MISSIONS

This is to provide communication between robots or probes and the satellite before separation avoiding the use of special connectors. The advantages expected are very low mass and power requested. Both, RF and optical links are suitable. Transmission of power to compensate the battery losses (low with lithium-ion batteries) should be also supplied by wireless means , for instance using a laser beam (see optical power transfer study under ESA contract) or by magnetic loops. The objective is to simplify the connectors and the locking devices.

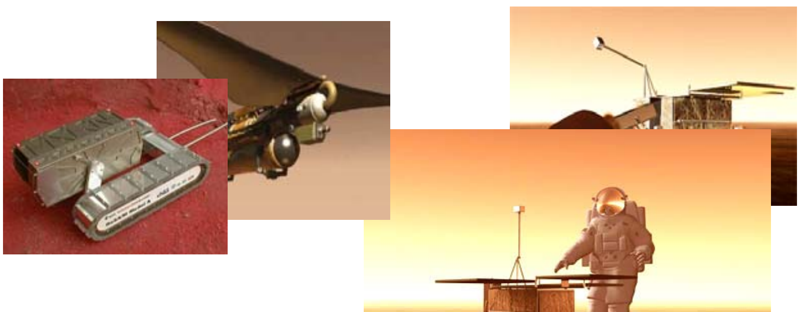


2.13-WIRELESS TECHNOLOGIES FOR SPACE SHUTTLE MISSIONS.

Wireless data acquisition and communications systems for monitoring critical areas of the Shuttle during pre-flight, ascent, on-orbit, and re-entry phases. Wireless sensor and data logger applications include monitoring the structural dynamics of payloads, collecting data for modal analysis of the flexhose assemblies, and measuring strain on both the Main Engine struts and the Remote Manipulator System (Shuttle Arm). Additionally, the Wing Leading Edge Impact Monitoring System is being installed within the Shuttle wings for the Return to Flight mission, STS-114, and subsequent missions to assist in detecting, locating, and characterizing the severity of impact events similar to the debris impact that caused the Columbia disaster.

2.14.-WIRELESS TECHNOLOGIES FOR GENERAL SPACECRAFT COMMUNICATION SYSTEMS

Wireless communications systems for space vehicle inter- and extra-vehicular activities, to eliminate cabling and provide for user or system mobility.
Sub-categories: PDAs and laptop communications; EVA communications; planetary base communications infrastructure.

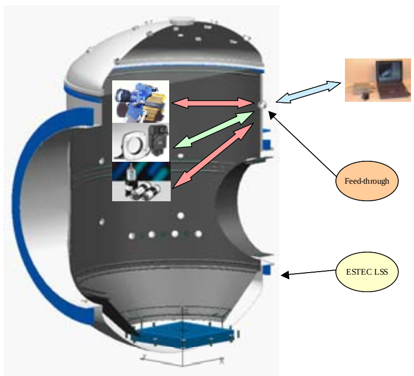


2.15.-WIRELESS TECHNOLOGIES FOR INVENTORY MANAGEMENT.

Wireless sensors (RFID tags) affixed to all inventory critical resources, to provide automated inventory management and inventory location for improved efficiency.

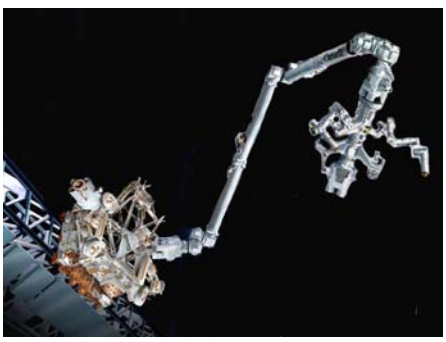
2.16.-WIRELESS TECHNOLOGIES FOR SPACECRAFT ASSEMBLY, INTEGRATION AND TEST (AIT)

Advanced computer diagnostic systems that have wireless communications to provide mobile wireless systems to improve efficiency of the AIT process.



2.17-WIRELESS TECHNOLOGIES FOR EXTRA-VEHICULAR ROBOTIC OPERATIONS

To provide communications to extra-vehicular systems and instruments (such as roving cameras for external inspection activities).Advantages : high data rate, mobility,robust comms., lower mass.
Uses include roving cameras for external inspection, specialized extra-vehicle instruments, drone command and control, drone formation flying.



2.18.-WIRELESS TECHNOLOGIES FOR RETRO-FIT EXISTING VEHICLE WITH NEW CAPABILITIES

Too expensive to run cabling for new electronics, instead use wireless communications
Structural vibrational monitoring, external collision monitoring.

WIRELESS BOF. Chapter 2: Experiences and best practises developing wireless interfaces for spacecraft.

1.- INTRODUCTION

This chapter is based in NASA and ESA past and present activities on the wireless technologies and their applicability to space. As well, inputs from the space and commercial wireless industries, and academia, plus investigations of TOS-EDD

2.-NASA EXPERIENCES AND BEST PRACTISES DEVELOPING WIRELESS INTERFACES FOR SPACECRAFT.

NASA-JSC has developed a wireless instrumentation capability that has been directed toward addressing Space Shuttle Program (SSP) and International Space Station (ISS) vehicle and biomedical applications. This capability is a mean to enable NASA programs to consider alternative(s) to traditional methods of acquiring and routing data to the user community, but it is not a Standard-based approach. The migration to a standards-based approach (that enables custom/proprietary devices to be integrated) has been identified as the strategy to reduce development, integration and operations costs/schedule/risk.

See presentation on “Exploration Vision” and paper on “Wireless Sensor Systems for Near-term Space Shuttle Missions” at
http://public.ccsds.org/sites/cw/sois-wir/default.aspx

3.-ESA EXPERIENCES AND BEST PRACTISES DEVELOPING WIRELESS INTERFACES FOR SPACECRAFT.

ACTIVITIES IN THE FIELD OF THE RF WIRELESS COMMUNICATIONS

General Studies and Technology Research Programmes: RF Wireless:

New Wireless TRP ESD-007 -- now re-writing SoW. This TRP is now retargeted for spacecraft RF wireless applications with future migration to internal S/C data handling:

SpaceWire-to-Wireless LAN Bridge
SpaceWire-to-WPAN (IEEE 802.15.4) Bridge for a S/C wireless sensor network

Ongoing RF Wireless/Optical Intra-spacecraft Demonstrator TRP, ESD-020 utilising WLAN and Bluetooth: WP4100 and WP4200 output, among others, received, “Analysis of S/C environment and implementation constraints”. This includes link budget, RFI and EMC modelling and analysis – results are quite positive.

Duolog Technologies (Ireland) RF Wireless for Sensors - Baseband IEEE 802.15.4, 3rd GSTP Announcement of Opportunity. Initial proposal approved, Duolog is requested to submit a full proposal. ESA has requested a license for the Intellectual Property (IP).

Duolog Technologies (Ireland) RF Wireless for Sensors - MAC HW/FW/SW IEEE 802.15.4, 3rd GSTP Announcement of Opportunity. Initial proposal approved. Duolog is requested to submit a full proposal. ESA has requested a license for the Intellectual Property (IP).

ESA European Space Incubator proposal, Y-Lynx (Swiss). Low-Power RF Wireless and ESA’s LEON2 employed as the MAC layer processor. Initial proposal approved by the ESI board. Y-Lynx is requested to submit a full proposal for approval. ESA has requested a license for the Intellectual Property (IP).

ESA-ESTEC RF Wireless Technology Assessment:

RF Wireless Technology Dossier; Annex A, *RF Wireless Short-Range (Proximity Networks) for Spacecraft and in Space Exploration,* is currently under review within ESA-ESTEC D-TEC.

Ongoing are several internal ESTEC RF Wireless discussions involving: HME-telemedicine; robotics; sensor networks; gossamer, lightweight, or inflatable structures; and planetary science.

Also discussions/meetings with several Universities and EU R&D institutions involved with robotics and next generation RF COTS-based wireless mesh sensor networks for planetary science and/or robotics.

Within ESTEC, new discussions have just begun with the mechanical-thermal group over RF Wireless temperature sensing, both for onboard transducers (possibly using micro-generators, micro-batteries, or thick-film batteries).

Other ESA RF Wireless Activities (not funded from TEC-EDD or without direct technical supervision by TEC-EDD):

Surrey Space, Surrey Satellite, and BNSC (all British) secure funding for a TRP for Wireless LAN in formation flying, utilising FF S/C and RF wireless as a distributed S/C sensor. This work is in connection with ESTEC's microelectronics section next version ChipSat SoC utilising a LEON2.

On the ISS, Alenia Spazio selects Wireless LAN (IEEE 802.11a) for ESA's Eurobot-to-ISS data handling. A specification and Technical Note are completed.

ESA's RF Wireless Heart Beat Monitoring was an option to fly on the ISS during the Eneide mission, but was not ready in time. The work, by an Italian University, may yet be completed and flown on a later mission.

Other EU RF Wireless for Space Activities (funded by other than ESA):

Dutch Space and Terma (Denmark) are planning a wireless colour camera for ISS European Robotic Arm.

TNO-TPD and a Dutch consortium secure funding for one new student satellite per year, over several years. The first will have an UWB data link and a completely wireless quadrant sun sensor. This is in addition to the MicroNed national technology satellite, planned for launch in 2010 that will employ UWB as the onboard TM-TC S/C data-handling network.

CNES (France) materials group is planning to employ RF Wireless transducers for spacecraft health monitoring.

Contraves Space (Swiss) is investigating RF Wireless for ground testing.

ESA-Industry Sponsored Wireless Onboard Spacecraft WG:

See the ESA-ESTEC Space Internet Workshop 4 (SIW-4) paper over the status and activities of this WG.

http://siw.gsfc.nasa.gov/presentations-siw2004/SIW4_ESA_Wireless_WG.pdf

Wireless Onboard Spacecraft e-group:

http://groups.yahoo.com/group/spacewlan/

Proposed ESA RF Wireless Technologies and Space Applications:

See the associated document.

ACTIVITIES IN THE FIELD OF THE OPTICAL WIRELESS COMMUNICATIONS

See the ESA-ESTEC Optical wireless Website:

http://www.wireless.esa.int/optical/index.html

General Studies and Technology Research Programmes: Optical Wireless:

1) Studies to ***Proof the concept*** *on* typical *'case scenario'* and to demonstrate the capabilities of this technology to provide on board communications and associated services. This should use selected OTS components in an emulated S/C internal environment:

-*"Ultra-stable Optical Link for Time/Frequency transfer On board the ISS"*
Concluded in May 2002.

-" ***Study on Optical Wireless Links for intra-satellite communications"***
Concluded in May 2001.

To study the State of the Art of optoelectronic technologies and analyse in detail implementation problems.

Outcome: A demonstrator of a fully operational optical COST-based network on a spacecraft mock-up with data rates fulfilling the requirements for some satellite applications.

-"Validation of wireless optical layer for on-board data communications in an operational context".

To review and identify an optical wireless communication system fulfilling the basic requirements of the internal data communication function of an on board control and data system and its suitability for space applications.

Two contracts, two consortiums. Both concluded in 2004.

-EADS-Astrium with UPM →Take the option of using 'COTS' IrDa standard compliant and developing and ad hoc protocol. For the outcome see document Astrium_OW 16431 at
http://public.ccsds.org/sites/cw/sois-wir/default.aspx

-INTA with Alcatel → Take the option of using COTS parts to implement a full wireless physical layer fulfilling STD-1553 Bus specifications and a low rate 'sensor bus type' with ad hoc (SPI based) protocol. For the outcome see document Inta_OW 16428 at

http://public.ccsds.org/sites/cw/sois-wir/default.aspx

-"Optical wireless data link for videogrammetry applications inside ESA's LSS"
Non conclusions yet.

A key element of the ESA Test Centre is the Large Space Simulator (LSS). ESTEC.It is equipped among others with videogrammetry tool. Data transmission from the above mentioned cameras to their acquisition systems will be implemented by an optical wireless system.

2) Studies with the goal of ***Provisioning of a status of technology*** corresponding to a technology readiness level sufficient to cover technology flight demonstration. This is 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,
-Tackle the standardization issues.

-"Optical Wireless Intra-Spacecraft Communications"
To be initiated kicked-off 4Q 2005

To implement and validate an optical wireless intra-satellite communications subsystem (elegant breadboard) in a realistic model of a satellite and prepare a flight demonstration (elegant model) of a selected application.

-Optical wireless data handling for life science and crew health monitoring.".

Currently under negotiation.

To investigate the potential of optical wireless communications for human life science and crew health monitoring and breadboard a and OW system for a selected experiment in Columbus.

WIRELESS BOF. Chapter 3: Lessons learnt and key issues for implementation on a S/C

1.-INTRODUCTION

Wireless communications are widely used on ground. Space studies and developments are quite new but some results are already available from US and European studies, for both RF and optical technologies. The goal of this paper is to made a synthesis of the experience acquired on these projects and to highlight the key issues for a future implementation of wireless communications on a spacecraft.

2 - REFERENCE DOCUMENTS

RD1 – Wireless technologies summary - Kevin Gifford
RD2 – Wireless Sensor System for Near-term Space Shuttle Missions – Kevin Champaigne
RD3 – Validation of an Optical Wireless Layer – ESA/Astrium
RD4 – Validation of an Optical Wireless Layer – ESA/INTA
RD5 - Characterization of wireless data acquisition systems -Astrium

3 - MAIN LESSONS LEARNED ON WIRELESS SYSTEMS

3.1 - The wireless media is not fully reliable: obstacles, interferences, capture of the network in failure case...etc. Non essential missions should be preferred.

Wired systems can easily achieve a 100% reliability (BER = 0) if the length and the data rate is not at the limit of the capability of the link. Wireless systems are much more sensitive to the environment so that special techniques have been used to minimize the number of transmission errors: multi-antenna transceivers, automatic repeat, multi-carrier frequencies (RD1). This makes acceptable most ground transmissions where the data transfer can be delayed until the link is operational again.
It is not the case for some essential data buses on a spacecraft, for example the avionic bus where guidance data from the sensors and to the actuators can not be interrupted.
Moreover, a failure in a self powered terminal can result in a permanent emission which collapses the entire network, including the redundant units. This “out of service” of both nominal and redundant bus may also occur in presence of EMI.

For these reasons, the wireless technology seems to be more dedicated to non essential missions like environment monitoring or health monitoring in manned mission

3.2 - Standards define systems with a direct line of sight: there is no guaranty for a « real » transmission path (walls, screens, reflections…) Additional specific work shall be done to validate the wireless transmission.

Wired standards include generally a description/specification of the physical media: type and max length of the cable, tolerance to injected noise... The real hardware can then manufactured in such a way it meets the boundary conditions of the standard, whatever the implementation of the spacecraft is.
Wireless transmissions use the “free space” . The physical configuration of the environment (room, car, buildings, spacecraft) is of prime importance for the degradation of the signal. It is very dependant of each application and can not be included in the standard. The standard is therefore normalized with a direct sight of view, the only condition which allows a quick computation of the level of received signal.
That means that a system which meets the standard does not necessarily work. Significant analyses and/or test have to be done in addition to validate the quality of the data transmission.

3.3 - Passed ground development are in the field of mobile systems or implementation of new communication link in an existing system.

Ground wireless applications are focused on mobile devices: keys for car doors or garage doors, TV command, laptops, PDA, telephone, cordless mice... A competitive advantage w.r.t. wires is mainly the degree of comfort or freedom of the user. That means that wireless applications are most often for human people in a moving activity.
Another market is the upgrading or renovation of existing systems. A wireless system can be competitive even for a totally static application if it avoids installing cables (difficult and costly task). Some examples are the WiFi transmission between two computers, a shared printer, an alarm with many detectors of presence in a building, light switches in renovated offices.
For space, most promising application seems to be manned missions (like MIR wireless project) and late installation of data transmission system (like monitoring of shuttle wings – RD2)

3.4 - Power supply for remote self powered terminals:

- **replaceable batteries → medium data rates**
- **non replaceable batteries → very low data rates**

The wireless data transmission is much more attractive if the remote terminal is self powered: there is really no wire. This

requires an energy source: a rechargeable or a non rechargeable battery. The management of the power consumption will be totally different according to the expected life duration of the battery. Emitting phases are very consuming for optical heads and for 802.11 terminals. There shall be limited, giving a low duty ratio. The instantaneous data rate may be reasonably high but the average one shall be kept low. Internal data processing tasks (compression) may also consume a lot.
As an example, a 100g primary battery of the best technology can provide about 50W.h = 5 mW x year. This figure shows that the remote units shall have a sleeping mode with a ultra low consumption. The management of the sleeping/active modes may impact the network architecture, H/W design, protocol and S/W services.
For very short mission (like a launch phase – RD2) or operation with maintenance (manned mission), long active operations can be done.

3.5 - COTS not so easy to adapt for space: qualification costs, radiation tolerance, obsolescence, derating rules.

Space components and standards are most of the time issued from military developments for parts and communication systems. This ensures a minimum level of quality, reliability, and product durability. The complement of qualification to upgrade the component to a space level is limited. Most specific topic is the radiation tolerance.
COTS are attractive because of the vendor price and sometimes the "effective" reliability based on proven statistics from a mass production. But the final acquisition cost is very different and depends mainly on the tests performed on the device. At the end, the acquisition cost of a COTS is similar to the cost of a full qualified HiRel part. However, the risk of unsuccessful qualification is much higher and back-up solutions difficult to implement. That explains why COTS are not as used as expected.
Many types of components (like high integration µP) are specifically designed for ground application and have no chance to survive in a radiation environment or with a poor cooling through the vacuum. Moreover, long missions require applying derating rules which degrade significantly the performance of the product.
Last, the life cycle of a commercial product is shorter and shorter with no guaranty from the manufacturers to maintain the product available. This is a penalty for long developments or for a re-use policy.

3.6 - « intelligent terminals » (microprocessors + EEPROM + chip sets) not popular in the space H/W (same drawbacks as COTS). Life time of a µP is around 20 years. Introducing frequently new µP devices raises funding problem

The problem of µP's is similar to the COTS. The specificity is the development cost which is more important due to the complexity of the device, the development tools and the associated software.
Wireless terminals or transducers often include microprocessor or "intelligent" die. It may make difficult

the translation from commercial product or standard to a space one.
We can hope that the development of IP's and SOC (system On Chip) will allow to transfer any complex "wireless" digital function into a space compatible ASIC or FPGA.

4 - MAIN LESSONS LEARNED ON OPTICAL WIRELESS SYSTEMS

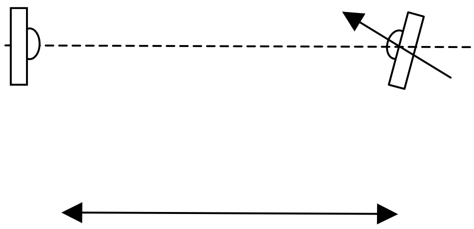
4.1 - High power consumption in emitting mode

The low sensitivity of the light detectors and the medium efficiency of the LED require to feed the emitters with several 100's of mA. Current in the order of 1A will be even better to secure the transmission in worst environment. It gives a peak power in the range [1 to 5W]. This consumption limits the life duration of the battery in case of self-powered terminals for two reasons: total energy used by the emitter and battery losses at high current. The last point can be reduced by a local filtering. The total energy can be reduced only by working with a low transmitting ratio, that is to say a low averaged data rate.

4.2 - No applications, SW & mature standard for high rate networks.

The main standard for optical wireless link: IRDA. It defines the Physical Layer based on a direct line of sight, the Link Access Protocol and the Link management Protocol.
Most applications used a maximum data rate of 115 Kbps (SIR). A wide range of interface devices and application software is available.
Many transceivers are compatible with a 2Mbps or 4Mbps rate (MIR). Network management software is not widely distributed (only one new product by Agilent).
The IRDA standard is expected to include a higher rate at 16 Mbps (VFIR) but HW products and support S/W are not mature. Competition with the RF technology is not in favour of deep development/investments in this field.
IEE 802.11 standard includes also a specification for an optical physical layer. The communication is based on diffused transmission but there is no definition of the environment.

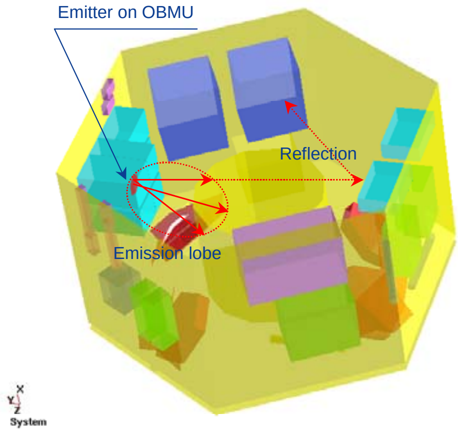
4.3 - COTS are designed for direct line of sight and short distance (1 meters)

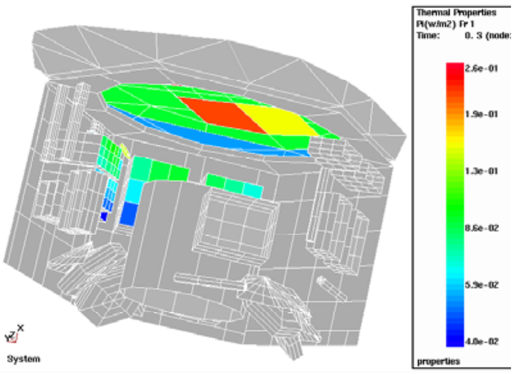


The optical wireless transmissions are basically designed for a short distance. It can be extended with some care in favourable environment by using high power transceivers at derated data rates. With a direct visibility, the attenuation analysis is quite simple.
It becomes much more complex if there are obstacles between the terminals. The signal is transmitted through multiple reflections and diffusions. This is of course highly dependent on the surface properties of the materials, the incidence angle, the divergence of the light beam...etc. Spacecraft internal cavity is not favourable to the light transmission. All walls are black painted for thermal reasons. However, systems based on the use of repeaters can easily overcome this issue.
Large satellites have several internal walls and floors which share the structure into several cavities.0ISS is probably more close to a ground application with larger area and white environment.

4.4 - Need for analysis tools to compute the link budget/BER in worst case conditions.

If a direct line of sight cannot be guaranteed, an analytic approach is mandatory to predict the link budget/BER before implementing the wireless network in the spacecraft. The analysis is usually made by a 3D simulation based on a ray tracing method. Attenuation as well as multipath are considered. Inputs are the 3D model of the spacecraft, the material optical properties, the emitter and receiver parameters (emittance, sensitivity, distribution angle.)
The simulation program can be issued from a thermal flux simulation program.





Results obtained on a small satellite match very well the experimental measurements.

4.5 - Components are used at their maximum peak rating

The low performance for distance on the optical links pushes the manufacturer to specify the emitting devices (LEDs) at their maximum capability, using the thermal inertia to average the dissipation during the pulses. Ambient temperature (25°C) is often the reference. The question is double:

- How to derate the power versus the operating temperature range required in the unit specification? And what will be the degradation in performance?
- Is it necessary to apply an additional derating for reliability purpose, as usually required in the quality applicable documents (ECSS Q-60)? And which rules shall be used for these new components?

4.6 – The AIT configuration is very different from the flight one

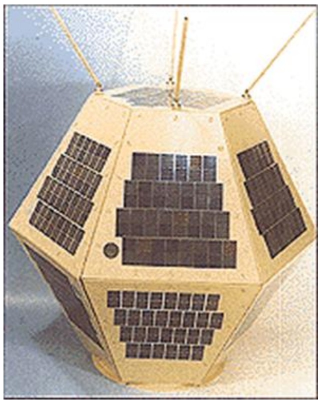
The configuration of the satellite is changing continuously during the integration phase: installation of units, walls, multi-layer isolation. The test configuration may make impossible an optical link which need a reflection and make possible another link which will be stopped later by the implementation of a obstacle.

The test and validation method for optical network shall therefore be reviewed to be sure that:

- the network is working with margins in the final configuration
- The network can be operated during the integration phase to test the other functions of the satellite.

This problem is also applicable, maybe with a lower criticality, to a wireless RF networks.

4.7 - Experiment in flight on a Spanish Nanosat

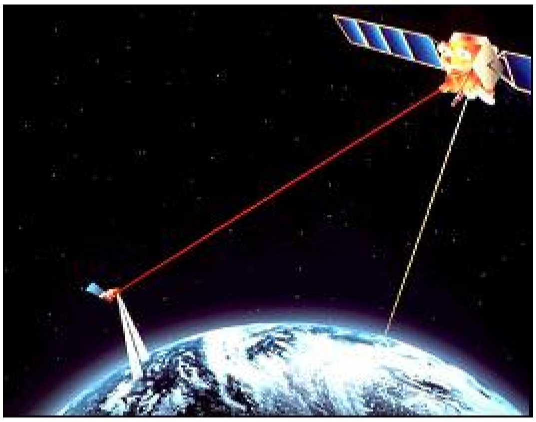


INTA launched a nano satellite in last December 2004 on ARIANE 5, with the french satellites HELIOS 2, ESSAIM and PARASOL.

On this small satellite (20 Kg), there are two experiments. One of them is an optical wireless data transmission from a magnetometer unit with a measurement of the BER.

Up to now, no anomaly has been reported.

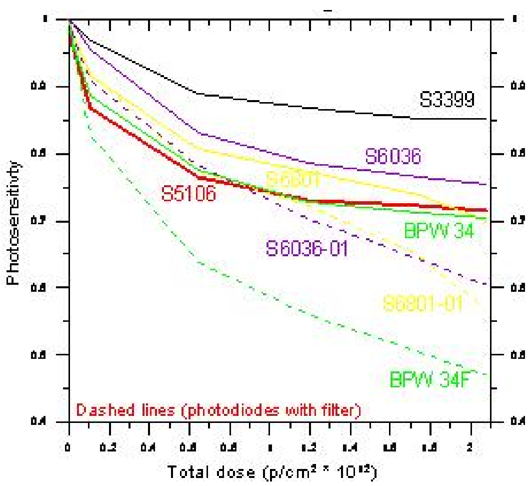
4.8 - No problem for long distance & high speed with a collimated laser beam



A free space laser transmission allows both long distance and high bit rate. This technique is already used for communication between satellites. SILEX is a very successful experiment and transmit image from a LEO helio-synchronous satellite (SPOT4) to a geostationary satellite (ARTEMIS). The bit rate is 50 Mbps.
The same type of communication is currently under development for communication between a plane and ARTEMIS and will be validated next year.
Similar communications by laser beam are operational on ground between buildings over several kilometres distance.

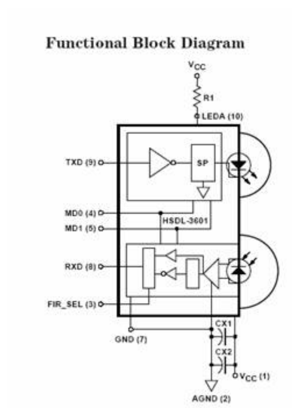
4.9 - Opto components are sensitive to radiations

Most components used in commercial application have a chance not to be tolerant to radiation. But optical devices are particularly sensitive to heavy particles which degrade significantly the performance. Some parts may loss a decade in emissivity or sensitivity.
The tolerance to radiation is one of the most important criteria for the selection of the component. Radiation test campaigns shall be done very early in the development. High particle energy is required and the tests are rather expensive.



4.10 - Low complexity electronic

In optical transmission, there is no really carrier. Moreover, the conversion electricity to light is very simple, using only one device. The conversion light to electrical signal is also simple.
There is no need for high frequency oscillator, complex modulator. With the exception of opto-electronic components, all other functions can use very common components.



4.11 - Business of IR wireless is dropping (replaced by WiFi). Competitive advantage is mainly the low cost in mass production → not suitable for space products.

Space applications are searching for high quality/reliability parts. The problem of attenuating the signal in case of reflection or diffusion leads to require also top performance products.
It is not adequate with commercial products optimised for low cost.

4.12 - Optical physical layer can be coupled very easily to existing protocols (OBDH, MIL1553)
The signal in the light is identical to the electrical signal. The optical transmission can therefore use electrical “two-state” protocols.
Wireless optical demonstrators have been built with a Manchester code, with the benefit of a direct plugging to the well known 1553 standard.

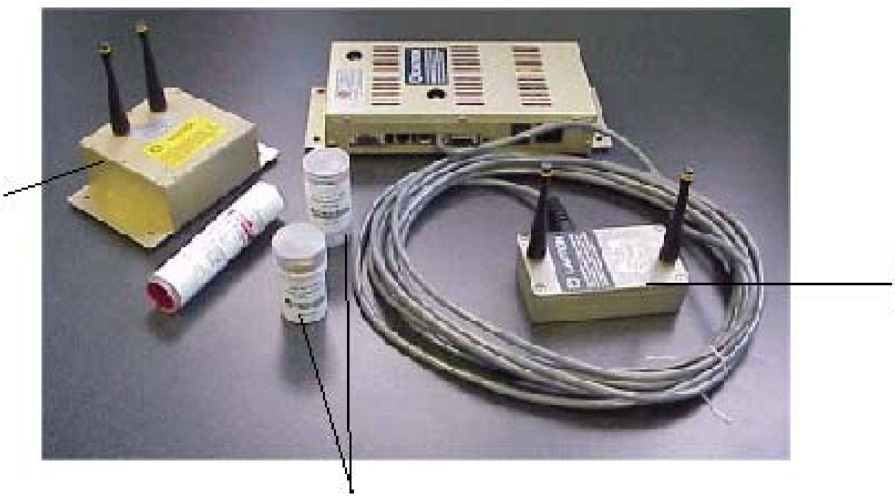
4 - MAIN LESSONS LEARNED ON RF WIRELESS SYSTEMS

5.1 Wide background on commercial applications (computed world).

The success of the laptops and PDA market develops the wireless techniques. If some PDA's use still IR ports (for size and cost reason), most devices are equipped with RF wireless transceivers.
Standards become mature, hardware is reliable. Multi-source procurement is possible. Prices are affordable even for domotic market.

5.2 – There are few systems in analog data acquisition (selfpowered transducers). Protocols are proprietary. Frequency band is home RF. Internal processing (µP). Difficulties for high rate streaming.

The wireless analog data acquisition is one of the targeted applications for space. Ground equipment exists with small (not miniature) self powered transducers. The market is still small and there is no real normalization.
The systems use home RF frequency bands (433 MHz, 900 MHz) with proprietary coding and software. High rate streaming is not possible.
The remote terminal (or transducer) includes often a processing capability and a memory to store the data locally.



5.3 - Security problems (forbidden in classified projects)

Wireless RF communications can be easily detected by external people. Encryption can be used but it becomes more complex. Classified projects require secured links.
Moreover, wireless network may not share the global network, again for security reason.

5.4 - Link budget checked by test rather than by analysis

The good operation of a RF wireless communication is checked mainly by go/no-go test. Margins are not known, excepted if there is automatic trimming of the bit rate versus the quality of the transmission.
Early predictions (before H/W testing) require complex analyses similar to antenna and EMI analyses.

5.5 - Successful development (MICROTAU by INVOCON).

Advantage w.r.t a wired system is rather on the easy upgrading of the shuttle monitoring than on the technical performance. The development has been initiated by a strong recommendation from the investigation commission after the accident of Columbia: increase the monitoring capability of the shuttle wings. Wireless system was found attractive because it does not need a modification of the existing harness.
The system combines high bandwidth transducers, digital processing with compression algorithms, self-powered units with sleeping mode.

6 -KEY ISSUE FOR IMPLEMENTING WIRELESS LINK ON A SPACECRAFT

- **Target preferably:**
  - **a low bit rate**
  - **a non essential network**
  - **a mission with a key advantage on a wired system (system upgrading, mobile terminal, self-powered transducers …)**
  - **a RF link for a long distance without direct line of sight. For short distances or a direct transmission, both technologies are possible: optical link are maybe simpler and have no concern with EMI.**
- **Do not rely only on test if the AIT configuration is not representative: perform analysis.**

ANNEX 2

IEEE Standard	Data Rates	Frequency Band	Network Size	TX peak power	Omni Range	Network Topologies	Com-plexity	Power Req't	System Resources	Battery Life (Days)	Modulation Techniques	Typical Applications
802.11	1, 2 Mb/s 2, 11 Mb/s	2.4 GHz		1 W	100 m	Point-to-multipoint			1 MB+	0.5 - 5	FHSS (few systems exist) DSSS, even diffuse IR	WLAN base standard
802.11a	{6,9,12,18,24} 54 Mb/s	5.7 GHz	32	1 W	100 m	Point-to-multipoint	High	High	1 MB+	0.5 - 5	ODFM w/ built in error correction	Hi-speed WLANs
802.11 b Wi-Fi	1, 2 Mb/s 1,2,5.5, 11Mb/s	2.4 GHz	32	1 W	100 m	Point-to-multipoint	High	High	1 MB+	0.5 - 5	DSSS w/ DBPSK, DQPSK HR/DSSS w/CCK+PBCC	Hi-speed WLANs
802.11 e	Multimedia	2.4 GHz	32	1 W	100 m	Point-to-multipoint	High	High	1 MB+	0.5 - 5		WLANs with QoS
802.11 g	Up to 54 Mb/s	2.4 GHz		1 W	100 m	Point-to-multipoint	High	High	1 MB+	0.5 - 5	OFDM w/ built in err. correction	Hi-speed WLANs Provides 20+ Mbps
802.11 i	Adds AES	2.4 GHz	32	1 W	100 m	Point-to-multipoint	High	High	1 MB+	0.5 - 5		Adds AES security
802.15	WPAN	2.4 GHz		1 W	100 m	Point-to-multipoint						WPAN base standard
802.15.1 Bluetooth	1 Mb/s	2.4 GHz	8 in a piconet	1 W	10+ m	Ad hoc piconets	High	Medium	250 KB+	1 - 7	FHSS	Cable replacement
802.15.3 WiMedia	55 Mb/s	2.4 GHz	8 in a piconet	1 W	10 m	Ad hoc piconets	Medium	Low			HR-WPAN	High-rate, low power Low power multimedia apps
802.15.4 Zigbee	40 kb/s 250 kb/s	900 MHz 2.4 GHz	255 65535	1 W	10 m 1 - 100m	Ad hoc, star, mesh	Low	Very Low	4 – 32 KB+	100 - 1000+	LR-WPAN	Wireless sensor networks Med rate, very low power
802.16	40, 80, and 120 Mb/s	2-11 GHz 10-66 GHz				Point-to multipoint, mesh					OFDM w/ modulations: QPSK, 16 QAM, 64 QAM	Broadband (>1.5 Mb/s) wireless access Important coexistence issues to solve
UWB	100 – 500 Mb/s	3.1 - 10.6 GHz			< 10 m	Point-to point	Medium	Low				Streaming video, high bandwidth applications Note that UWB is being considered as an alternate PHY layer for 802.15.3, 802.15.4
UHF	10 - 100 kb/s	260-470 MHz 902-928 MHz			10 m - 10 miles	Point-to point	Lowest	Low				Remote controls, remote keyless entry, garage doors
Wireless USB	62.5 kb/s	2.4 GHz			10 m	Point-to point	Low	Low				PC peripherals
IR Wireless	20-40, 115 kb/s 4 & 16 Mb/s	Infrared 800 - 900 nm			1 - 9 m los	Point-to point	Low	Low				Data relay with line-of-sight constraint Remote control, PC-PDA-laptop links
Near Field Magnetic	64 - 384 kb/s	Magnetic coupling			1 - 3 m	Point-to point	Low	Low				Wireless headsets, automotive

WLANs, WPANs, and LR-WPANs

Wireless Local Area Networks (LANs) were created as the wireless extension of the IEEE 802.3 LAN which was designed for high-end data networking. Among the system requirements of a WLAN are seamless roaming, message forwarding, longest possible range, and capacity for a large population of devices distributed throughout the network. In contrast, WPANs are designed to function in the Personal Operating Space typically considered a 10 m radius (20 ft diameter) sphere centered upon an individual whether moving or stationary.

WPANs are used to convey information over relatively short distances among the participant receivers. Unlike WLANs, connections effected via WPANs involve little or no infrastructure. This allows small, power efficient inexpensive solutions to be implemented for a wide range of devices.

The IEEE 802.15 Working Group has defined three classes of WPANs that are differentiated by data rate, battery drain, and QoS. The high-data rate WPAN (802.15.3) is suitable for multimedia applications that require very high QoS. Medium-rate WPANs (802.15.1/Bluetooth) are designed as cable replacements for consumer electronic devices centered on mobile phones and PDAs with a QoS suitable for voice (9.6 – 64 kb/s) applications. The last class of WPAN, LR-WPAN (802.15.4/Zigbee) is intended to serve applications enabled only by low power and cost requirements not targeted in the 15.1 or 15.3 WPANs. LR-WPAN applications have a relaxed need for data rate and QoS. Figure 1 (shown below) illustrates the operating space of the 802 WLAN and the WPAN standards. Notice that the IEEE 802.15.4 standard is not designed to overlap with higher end wireless networking standards. LR-WPAN technology is designed for applications where WPAN solutions are too expensive, or extremely low-power operation is needed, and/or the performance of a technology such as Bluetooth is not required.

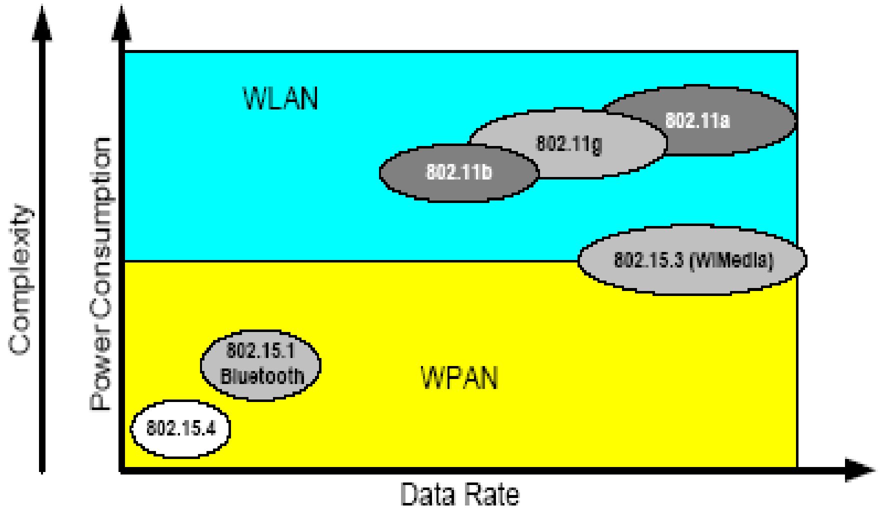


Figure 1 – Operating space of various WLAN and WPAN standards. From IEEE Standards Wireless Networks Series.

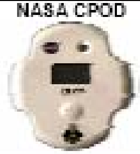
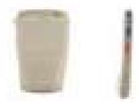
For any spacecraft or planetary wireless application there are several evaluative factors to be considered before deciding upon a specific wireless standard. The first two factors are typically the required network topology such as an ad-hoc topology, a star topology, a point-to-point, or a point-to-multipoint topology along with the maximum number of devices the network is expected to support at any one time. The next factors to evaluate are the required bandwidth and the required battery life (assuming the radio is not wall-powered). Note that due to the relatively small size of a spacecraft transmit (Tx) power and transmit range typically are not design discriminating factors. Typically, for wireless spacecraft applications low power radio transmissions are desirable to reduce multipath reflections and to simply maximize battery lifetime.

Depending upon the specifications of the application, one or more IEEE standards may be applicable. As the application is specified in greater detail, it is anticipated that a single IEEE standard will emerge as the optimal wireless protocol.

Table 1, shown above summarizes key characteristics and operating specifications for several wireless protocol standards. Table 2, below, maps these wireless standards to broad classes of expected spacecraft applications.

Wireless Spacecraft Applications and IEEE Wireless Standards

Wireless S/C Application	Data Rates	Network Size	Omni Range	Network Topologies	Power Requirement	Battery Life (Days)	IEEE Applicable Standards
Environmental Monitoring	Low / Medium	10s to 100s	10 - 50 m	Ad hoc, Star, Mesh	Very Low	1 year typical	LR-WPAN 802.15.4
Radiation Dosimetry	Low / Medium	10s	10 - 50 m	Ad hoc, Star	Low / Medium	30 days 1 day	LR-WPAN 802.15.4 WPAN 802.15.1 Bluetooth
Physiological Crew Monitoring	Medium / High	1 to 10	1 to 10 m	Ad hoc, Star	Low / Medium	30 days 1 day	LR-WPAN 802.15.4 WPAN 802.15.1 Bluetooth
Crew member location track	Medium / High	1 to 10	10 - 50 m	Ad hoc, Star	Medium	1 week	HR-WPAN 802.15.3 WiMedia
Structural Monitoring	High	10s	1 - 20 m	Star, point-to multipoint	Medium / High	1 day	HR-WPAN 802.15.3 WiMedia IEEE 802.11 a/b/g Wi-Fi (Custom/proprietary)
Intra-spacecraft communications	High	10s	1 - 20 m	Point-to Multipoint	High	None to 1 day	IEEE 802.11 a/b/g Wi-Fi HR-WPAN 802.15.3 WiMedia
Inventory Management	Low	1000s	1 - 10 m	Star	Low or self-powered	Years or self-powered	LR-WPAN 802.15.4
S/C assembly, integration and test	High	10s to 100s	1 - 50 m	Star, point-to multipoint	Medium / High	None to 1 day	LR-WPAN 802.15.4 HR-WPAN 802.15.3 WiMedia IEEE 802.11 a/b/g Wi-Fi
Extra-vehicular communications	High Very High	1 to 10	1 m to 1000 m	Point-to multipoint	High	None to 1 day	IEEE 802.11 a/b/g Wi-Fi Cellular, satellite, others

Wireless S/C Application	Data Rates	Network Size	Omni Range	Network Topologies	Power Req't	Battery Life (Days)	Specific Apps & H/W	IEEE Applicable Standards
Environmental Monitoring	Low / Medium	10s to 100s	10 - 50 m	Ad hoc, Star, Mesh	Very Low	1 year typical	Crossbow Motes  JPL Sensor Pod  Invocon CO2 	LR-WPAN 802.15.4
Radiation Dosimetry	Low / Medium	10s	10 - 50 m	Ad hoc, Star	Low / Medium	30 days 1 day	Radiation dosimeter 	LR-WPAN 802.15.4 WPAN 802.15.1 Bluetooth
Physiological Crew Monitoring	Medium / High	1 to 10	1 to 10 m	Ad hoc, Star	Low / Medium	30 days 1 day	NASA CPOD  VitalSense Monitor 	LR-WPAN 802.15.4 WPAN 802.15.1 Bluetooth
Crew member location tracking	Medium / High	1 to 10	10 - 50 m	Ad hoc, Star	Medium	1 week	UbiSense UWB tags 	HR-WPAN 802.15.3 WiMedia
Structural Monitoring	High	10s	1 - 20 m	Star, point-to multipoint	Medium / High	1 day	Invocon MicroTau 	HR-WPAN 802.15.3 WiMedia IEEE 802.11 a/b/g Wi-Fi (Custom/proprietary ala Invocon)
Intra-spacecraft communications	High	10s	1 - 20 m	Point-to-multipoint	High	None to 1 day	NASA Wireless Crew Communication System 	IEEE 802.11 a/b/g Wi-Fi HR-WPAN 802.15.3 WiMedia
Inventory Management	Low	1000s	1 - 10 m	Star	Low or self-powered	Years or self-powered	RFID tag 	LR-WPAN 802.15.4

S/C assembly, Integration, & test	High	10s to 100s	1 - 50 m	Star, point-to multipoint	Medium / High	None to 1 day		LR-WPAN 802.15.4 HR-WPAN 802.15.3 WiMedia
Extra-vehicular communications	High Very High	1 to 10	1 m to 1000 m	Point-to-multipoint	High	None to 1 day		IEEE 802.11 a/b/g Wi-Fi Cellular, satellite, others

IR Standards

Standard	IrDA	IEEE 110 73
Data Rate	**From 115 kb/s to 16 Mb/s**	**115 kb/s**
Frequency Band	**Baseband**	**Baseband**
Network size (n° nodes)	**Up to 127 (supported by high level protocols)**	**Up to 127 (supported by high level protocols)**
TX peak power	**100 mW**	**100 mW**
Omni range	**Designed for LOS transmission**	**Designed for LOS transmission**
Network Topologies	**Only Master-Slave configuration**	**Only Master-Slave configuration**
Complexity	**Low**	**Very Low**
Power requirements	**Assuming a 1% emission time, consumption below 10 nA on standby**	**Assuming a 1% emission time, consumption below 10 nA on standby**
System resources	**Integrated emitter-receiver device + software controller**	**Integrated emitter-receiver device + software controller**
Battery Life (Days)		
Modulation Techniques	**OOK, PPM**	**PPM**
Energy/txd bit	**~0.2 nJ**	**~0.2 nJ**

1.- Data quality category

a) state application expected requirements at a high-level
b) transport type **TinyTP protocol**
c) latency **<10 ms**
d) accuracy (BER) **$<10^{-9}$**

2.- Base transmit power (either 1 mW or 1 W) associated with transmission range

For about 100 mW, IrDA is supposed to have a range about 1.5 m. This range can be increased by means of optically lenses to 3-4 meters

3.- Overview of modulation techniques with their advantages and disadvantages

PPM is less bandwidth efficient but shows an increased robustness against multipath penalty on diffuse or quasi-diffuse channels. On the other hand, OOK is simpler to implement and easier to receive on a DD basis. It is also possible a "direct translation" of an OOK system on a Direct-sequence spread-spectrum one.