INTRODUCTION

This paper has one and only one objective: to raise the awareness of those involved with robotics and autonomous systems for space and with future missions, of the desirable technical characteristics and feasibility, moreover the likelihood of PROXIMITY NETWORKS to be utilised for advanced robotics in several domains. These domains are: planetary surface and sub-surface exploration and analysis, human-robot cooperative robotics, heterogeneous and homogeneous cooperative robotics, robotic agents, in-situ analysis, on orbit assembly, fractionated spacecraft, among several others. This paper presents only the briefest summary of the full Dossier Annex A (approximately 106 pages total), consisting of PROXIMITY NETWORKS classifications, detailed use descriptions, deployment scenarios, desirable characteristics, survey of current state-of-the-art wireless technologies, survey of known European Space projects vs. technologies interest, conclusions and recommendations, and a final section on wireless trends for the future. The Dossier Annex A is extensively referenced (approaching near 190 references), incorporating ESA and EU space industry progress as well as NASA views and progress on the subject. This entire ASTRA paper may be viewed as an abstract for the full Dossier Annex A.

The Dossier Annex A summarizes an assessment performed by ESA ESTEC TEC-EDD, of technologies applicable to wireless proximity networks used in ESA space bound applications. It was compiled and written from a systems engineering perspective with knowledge of state-of-the-art wireless techniques, software protocols and protocol stacks, TEC-EDD personnel wireless background in both commercial wireless electronics and software, and a thorough, though informal, commercial markets survey. The work has been facilitated by investigations over the past two years and supported in part by the ESTEC Wireless Data Communications Onboard Spacecraft – Technology and Applications Workshop 14-16 April 2003 [54, 55], and the efforts of several members of the ESA / Industry Wireless Onboard Spacecraft Working Group and the international, inter-agency wireless e-Group, SpaceWLAN as well as numerous discussions with persons within the Science Directorate, Robotics section, the Aurora programme, ESA Advanced Concepts Team, individuals participating in CDF studies and several sections of D-TEC within ESTEC. The author offers a thank you to all these contributors.

From the Dossier Annex A, ESA-ESTEC shall, in the coming months of 2007, compose the more formal, executive summary-like Wireless Technology Dossier, eventually harmonised with the ESA Dossier 0 with the help of the European space community.

The dossier and annex should be viewed as a living document as research and development in RF spread spectrum and commercial applications are two of the most active areas in microelectronics and data communications today, and foreseen to remain so for a number of years. Within such an active area of R&D, the user can expect the document to be updated continually. The convergence of a diverse array of current developments, such as highly miniaturised mixed-signal SoC, zero (or near zero) intermediate-frequency and all CMOS radio, robust and high noise immunity digital data over RF, very positive EMC characteristics, mature IEEE standards, highly developed commercial firmware and available software (usually freeware) supporting ad hoc or self-organising networks, the positive implications of deep-sub-micron CMOS w.r.t. radiation tolerance, and the dramatically increasing availability of the European intellectual property (IP), facilitate considering commercially-derived RF wireless for many space applications.
Detailed discussion and specifications of the various commercial wireless PHY and MAC layers are not included here, but are found on the IEEE or ISO websites.

Also, the term spacecraft as used herein, applies to both payload and launcher. Several application categories listed in Table 3 are also potentially applicable to aircraft as well. And one potentially very beneficial area for ESA and the aerospace community that is not explicitly covered in this dossier is ground testing. Many wireless advantages are relatively simple to realise: wireless sensors for instance, in launcher booster testing, and spacecraft environment/validation/certification testing.

Much of the work in drafting the Annex A was facilitated by the ESA-Industry Working Group and these ESA-sponsored workshops:


The 2003 workshop proceedings are also available at the ESA ESTEC library:

<table>
<thead>
<tr>
<th>ESTEC Library</th>
<th>ESA-X-3410</th>
<th>400080345</th>
<th>CD-ROM</th>
</tr>
</thead>
</table>

The second in the workshop series was the **Wireless for Space Applications Workshop and Round Table, 10-13 July 2006**. Proceedings [136] are found at: ftp://ftp.estec.esa.nl/pub/ws/wireless2006-index.htm and http://www.congrex.nl/06c10/.

The 2006 workshop proceedings are also available at the ESA ESTEC library:

<table>
<thead>
<tr>
<th>ESTEC Library</th>
<th>ESA-X-3XXX</th>
<th>400080tbd</th>
<th>CD-ROM</th>
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</thead>
</table>

Additionally, the next workshop is jointly planned by CCSDS, ESA and NASA for 15 January, 2007, in conjunction with the CCSDS winter meetings in Colorado Springs, Colorado, United States. The CCSDS announcement and details to follow are found at: http://public.ccsds.org/meetings/2007Winter/wireless.aspx

The ESA sponsored Wireless e-Group: http://groups.yahoo.com/group/spacewlan/

The original ESA Wireless Onboard Spacecraft website: http://wireless.esa.int/ is currently being improved and redesigned to ESA web standards, and is to be relocated to a more secure ESA-ESTEC Spacecraft Engineering website.

The reader is expected to have already acquired a fundamental understanding of the underlying principles utilised and advantages offered in much of current wireless technology, e.g. spectrum spreading techniques, significantly lower Tx power spectral density, advanced coding and keying algorithms, topologies characteristics, etc. Those background documents, tutorials, and advanced topics papers are readily available on the web in enormous volume and for several technologies, as well as in the ESA workshops proceedings and references.

One further note for the reader: the papers and other references listed in the References section of the dossier annex are but a small representative fraction of the total the author has collected over the course of this assessment.

**WIRELESS PROXIMITY NETWORKS AND THEIR ASSESSMENT**

Wireless proximity networks are relatively small, fairly short-range, **often ad hoc**, wireless networks typically dedicated to tasks such as transporting in situ sensing data, among others. The number of nodes contained within a proximity network is expected to be comparatively small, perhaps tens or hundreds of nodes at most. While "short-range" is relative, many wireless proximity networks will have a physical diameter on the order of a few metres or less, hundreds or perhaps thousands of metres (although some have suggested that a few of these networks might be as large 100-400 km [13, 38]).

Wireless proximity networks will operate in a variety of distinctly different environments. These different environments are likely to impose different requirements on proximity networks and demand different networking
technologies. To facilitate this analysis, TEC-EDD initially divided proximity networks into five subclasses described in greater detail below:

- Microsensor Proximity Networks (e.g., microsensor-lander networks)
- Intra-Spacecraft Proximity Networks (e.g., spacecraft/human health monitoring networks)
- Inter-Vehicular Proximity Networks (e.g., lander-rover, robot-robot networks)
- EVA Proximity Networks (e.g., human and robotic EVA networks)
- Advanced Science Proximity Networks (e.g., mobile atmospheric planetary microsensors)

Informal descriptions of the operations of proximity networks in ESA application case scenarios were developed. These descriptions provided the basis for a more thorough examination of proximity networks. They were also intended to elicit more detailed information about the behaviour of and requirements for proximity networks from subject-area experts (a role analogous to that played by "use cases" in some object-oriented software analysis methodologies).

Furthermore, most of the proximity wireless technologies discussed herein are members of the IEEE 802.1 and IEEE 802.2 family of network management, and are for the most part, internet ready. To investigate wireless without the context of the Internet Protocol suite, Internet capability, or at least Internet interoperability is, in the author’s view, a mistake for the long term.

A detailed list of the characteristics of the different types of proximity networks was compiled. This compilation shows that the initial five subclasses of proximity networks can be usefully aggregated into two classes:

- Micropower Proximity Networks (microsensor, intra-spacecraft networks and Advanced Science networks) and
- Intelligent Proximity Networks (inter-vehicular, EVA).

These above classes should be considered in two separate time frames, as off-the-shelf technologies to achieve micropower proximity networks slightly lag the available technology to realise intelligent proximity networks.

The technologies required to implement proximity networks were identified and categorised by proximity network subtype (microsensor, inter-vehicular, etc.) and protocol layer, scope or function (e.g., link layer, node architecture, gateway).

Finally, the maturity of each of the identified technologies was assessed. However, some of the discussion in this dossier is specifically not targeted to specific commercial-off-the-shelf wireless technologies, as the wireless world evolves very quickly. Regardless, the “spin-in” of off-the-shelf wireless intellectual property may have significant cost advantages, even if some characteristics are slightly less than ideal for space use. The intent is that this dossier identifies the space application roadmap, somewhat independent of particular off-the-shelf technologies or devices, from now to a horizon of 15 years or so.

This assessment concludes that the technologies required for micropower proximity networks are somewhat less mature than those needed for intelligent proximity networks. However, micropower proximity networks (the micropower category includes both microsensors and intra-spacecraft sensors) offer ESA the greatest potential return for its proximity network research investments. Common hardware and software platforms for micropower proximity network research, development, and deployment would enhance the opportunities for collaboration between projects, enable projects to more easily leverage the results of prior ESA-funded work and increase the overall productivity of ESA’s research euros. System-level demonstrations by ESA researchers of micropower proximity networks would help focus research on identifying and solving real-world problems, as well as provide an empirical assessment of the effectiveness of proposed technologies.

**ESA APPLICATIONS OF WIRELESS NETWORKS**

ESA identified five potential applications [53] of wireless proximity networks for the purposes of this study, which are summarized in the table below.
Upon initial examination, TEC-EDD concluded that each of these applications was distinctly different than the others. As a result, TEC-EDD divided proximity networks into five categories, corresponding to each of the applications identified. These categories were assigned shorter, more descriptive names:

- **Microsensor Proximity Networks** - robotic in situ sensing for planetary exploration (fixed nodes)
- **Intra-Spacecraft Proximity Networks** - robotic in situ sensing for spacecraft health or astronaut health monitoring
- **Inter-Vehicular Proximity Networks** - robotic in situ sensing for planetary exploration (mobile nodes), near formation flying, on-orbit assembly, etc.
- **EVA Proximity Networks** - data delivery for extra-vehicular activity (EVA)
- **Advanced Science Proximity Networks** (e.g., mobile planetary microsensors)

Informal overviews of the operations of these networks are presented in this section, including descriptions of the nodes that participate in the networks, and the deployment, configuration, organization, and operation of the networks. These operational scenarios represent how, in the view of the author, these networks *ought* to behave, assuming that the requisite technologies and products have been developed and matured. For brevity of this paper, the topics of Microsensor, Intra-vehicular, EVA communications and Advanced Mobile Atmospheric Microprobes have been omitted here.

**INTER-VEHICULAR PROXIMITY NETWORKS, INCLUDING ROBOTICS**

The term "inter-vehicular proximity network" is used in this document to denote ESA proximity networks composed of a small number (perhaps fewer than ten) of relatively capable (in comparison to microsensors), possibly mobile, nodes. Planetary landers, rovers, robots and robotic agents, formation flying spacecraft and orbiters are typical of the devices that might participate in this class of networks. An immediate example is that of ESA’s Eurobot (though an external-to ISS robot could be classified as “robotic EVA”. A thorough specification and study [65] was performed by a European space contractor, concluding with a clear preference for IEEE 802.11a WLAN among many possibilities. Concerning satellite constellations and formation spacecraft data inter-communications, a recent study from 2003, Architecture Study of Space-Based Satellite Networks for NASA Missions [133], the report states:

Media access between the mother ship and sensor spacecraft needs to be defined and will be determined by the requirements of the constellation. A new media access technique may be required depending on the type of timing, the synchronization, and the criticality of the data being transmitted between sensor spacecraft and the mother ship. However, it is highly desirable to develop communication solutions and a constellation design that will allow for use of existing media access techniques such as the IEEE 802.11 wireless Ethernet standards.

**Inter-Vehicular Proximity Network Nodes**

A renewable power source, such as solar or nuclear cells, and a larger power storage capacity are the distinguishing characteristics of nodes that may participate in this class of proximity networks. The resulting larger system-level power budget permits these devices to possess much greater functionality than found in the minimalist designs of microsensor nodes. This has numerous implications for the design of the devices and the networking solutions.

- The lifetime of the inter-vehicular nodes is long compared to that of battery-powered microsensors; planetary orbiters have design lifetimes measured in years. Of significance to the design of the communications systems, these longer-lived devices are likely to need to interact with devices that were designed by a variety of organizations and

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Table 1. ESA Applications of Wireless Proximity Networks

<table>
<thead>
<tr>
<th>Application</th>
<th>Number of Nodes</th>
<th>Max link range</th>
<th>Node mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robotic &amp; in situ sensing for planetary exploration (fixed nodes)</td>
<td>5-100</td>
<td>100-1000 m</td>
<td>None</td>
</tr>
<tr>
<td>Robotic &amp; in situ sensing for spacecraft health monitoring</td>
<td>2-100</td>
<td>100 m</td>
<td>None</td>
</tr>
<tr>
<td>Robotic &amp; in situ sensing for planetary exploration (mobile nodes)</td>
<td>1-5</td>
<td>1000 m</td>
<td>Medium</td>
</tr>
<tr>
<td>Data delivery for EVA</td>
<td>2-5</td>
<td>100 km</td>
<td>High</td>
</tr>
<tr>
<td>Advanced planetary exploration (mobile atmospheric microprobes)</td>
<td>2-10</td>
<td>100 km</td>
<td>None/ Medium</td>
</tr>
</tbody>
</table>
launched over a period of years. As a result, interoperability between independent protocol implementations is important for this class of proximity networks.

- The power budget of the communications system is not traded off directly against the lifetime of the device (i.e., every extra bit transmitted does not correspondingly reduce the overall life of the device). Increased power for communications can be applied towards improved interoperability, enhanced reliability, increased flexibility and greater functionality, perhaps at the expense of additional bits transmitted.
- Individual nodes in inter-vehicular proximity networks are generally critical to the success of the mission. This contrasts with sensor webs, for example, where the web can continue to provide valuable data in spite of the demise of some of the microsensor nodes. Poor protocol design must never cause contact to be unnecessarily lost between, for example, a lander and a rover.
- Additional computational power may be available in these nodes, which may be used to provide services to lower-functioning devices. As described above, this class of devices might host gateways for microsensor proximity networks that would perform some functions on the relatively electrical power-rich inter-vehicular proximity network nodes, rather than the severely resource-constrained microsensor nodes.

**Inter-Vehicular Proximity Network Deployment and Configuration**

The mobility characteristics of these devices influence the requirements for and design of network solutions. Nodes in inter-vehicular proximity networks will exhibit one of three types of mobility:

- Immobility, such as planetary landers
- Self-mobility, such as autonomous or teleoperated rovers, robotics, and
- Planetary orbits.

As a result of these mobility characteristics, the potential for communications between two nodes may be very predictable, or may be difficult to predict. For example, communications opportunities between an orbiter and a lander are very predictable and are determined by the orbit and the lander's location. In a similar fashion, communications between a teleoperated planetary rover and a lander may predictable, inasmuch as the rover is never driven out of range of the lander. On the other hand, some have suggested that radio repeaters may be necessary be deployed to extend the range of communications between a lander and rovers [2]. Depending on the networking characteristics of these repeaters (i.e., whether they behave, in networking terms, as bridges or routers) potential or optimal communications paths become more difficult to predict. In particular, it may be difficult to predict in advance for a particular location whether the rover should communicate with the lander directly or via the repeater. Inter-vehicular proximity network technologies should effectively adapt to the different styles of connectivity experienced by these devices, including continuous (e.g., a rover near a lander or other robotics), predictable and episodic (e.g., an orbiter and a lander), and unpredictable (e.g., a rover potentially using a repeater). Protocols that can autonomously adapt to a changing environment (e.g., determine whether a rover should communicate with a lander directly or via a repeater) are required by more complex networking environments, such as those represented by repeaters. Moreover, many planetary surface scenarios involving humans and/or robotics may well be supported by the latest out-of-doors wireless, namely IEEE 802.16 or commercially, WiMax, without the need for repeaters.

**Inter-Vehicular Proximity Network Organization**

Because of the small number of nodes involved, the topologies of inter-vehicular proximity networks are fairly simple. These networks can easily be treated as a small collection of point-to-point links. In fact, in current and near-term implementations, these networks are simply a single point-to-point link. For example, the Proximity-1 Space Link protocol [13, 14a, 14b, 14c] implemented on the Odyssey Mars orbiter creates a point-to-point link between the orbiter and a lander, but does not provide a mechanism for routing traffic through intermediate nodes.

When several of these devices can potentially communicate with each other simultaneously, traditional network-layer functions (specifically, routing through intermediate nodes) can significantly enhance the functionality of communications solutions. For example, the operating range of a rover could be extended if it were able to route data through an intermediate device, such as a strategically placed repeater or another rover. While this section uses the term "repeater", a stationary communications device intended to extend the range of a network will be much more capable and much more useful if it is a network device, specifically a router, rather than a simple analogue RF repeater.
Inter-Vehicular Proximity Network Operation

There are two potential strategies for operating an inter-vehicular proximity network. The network could be remotely operated from Earth, with detailed configurations and operational plans uploaded into the vehicles. Alternatively, the network could operate autonomously, requiring manual configuration or intervention only rarely and under exceptional circumstances.

In an analogous fashion, devices that participate in these networks could be operated remotely (presumably from Earth) or could operate autonomously. For example, a rover could be teleoperated from Earth, with the activities of the vehicle controlled by carefully planned, detailed commands issued by earthbound engineers. Alternatively, a rover could operate autonomously, where the vehicle uses onboard intelligence to achieve higher-level goals (e.g., search for a rock different than what has been collected so far).

Network technologies designed to operate autonomously can be used with systems that are operated remotely (e.g., autonomous network technologies could be used with a teleoperated rover or other robotics, either homogenous or heterogeneous robotics). However, it is unlikely that protocols designed to be operated remotely can easily or reliably be modified to either operate autonomously or to support autonomous systems. To the extent that ESA intends to investigate the autonomy of planetary exploration devices, inter-vehicular proximity network technologies should be able to operate either autonomously or under remote control, depending on the requirements of the mission. Much work and research in these areas was presented at the iSAIRAS 2005 Symposium in Munich.

Inter-vehicular network nodes will generally need to be able to determine their location and synchronize their clocks with a standard time reference. A variety of communications- and network-based mechanisms have been proposed or developed to provide these services [40, 42, 51].

Wireless Technologies and ESA Inter-Vehicular Applications

The table on the following page summarizes the author’s assessment of currently available and soon available commercial technologies versus known and anticipated ESA space applications and missions, including the Aurora Programme and Science Directorate that potentially involve inter-vehicular data communications. In addition to the more typical use cases and scenarios listed in Table 2 (Lunar and Mars excursions) are close-range formation flying spacecraft (from 1 to 1000s metres) where extreme electronics miniaturisation is required to form space sensor webs (analogous to terrestrial networked and correlated space telescopes); fractionated spacecraft [76] (a virtual spacecraft composed individual identical (ideally), multiple independent spacecraft) function as an integrated unit in many or all respects – and are likely to benefit from economies of scale (in numbers) as well as minimised launch costs; autonomous on-orbit assembly [81]; and mobile or robotic agents with or without SWARM intelligence. Recent investigations have shown that the COTS-derived Wireless LAN PHY Layer Intellectual Property may be adapted to allow networks to range several thousands of km for formation flying proximity network scenarios [123, 124]. The Aurora Technologies for Exploration Dossier, (ESA Document Nr. SP-1254) describes that “innovative activities are planned for wireless onboard communication and evolvable/reconfigurable hardware” [69].

ESA Advanced Concepts Team is investigating many future mission classes that utilise highly integrated RF wireless, such as: spider robots (along with JAXA and Vienna University of Technology) that create functional structures on-orbit over flexible fabrics [84].

### Colour Code Key for table 2.

- Proposed initial ESA areas of interest.
- Proposed secondary ESA areas of interest.
- Proposed third ESA area of interest.
- Proposed tertiary and future ESA areas of interest.
<table>
<thead>
<tr>
<th><strong>Inter-Vehicular and EVA</strong></th>
<th>Wireless</th>
<th>Micropower over microwave (RFID based)</th>
<th>Narrow band RF or Low ISM Band</th>
<th>IEEE 802.15.4 and 802.15.4a/b UWB/DSSS</th>
<th>ESA Custom Spread Spectrum @2.2GHz</th>
<th>IEEE 802.11 a/b/g/n DSSS/OFDM</th>
<th>IEEE 802.16/e OFDM</th>
<th>IEEE 802.15.3 Very hi-rate OFDM</th>
<th>ESA Custom Deterministic UWB (Pulsed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Networked planetary surface robotics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (e, m?) repeaters likely needed</td>
<td>X (e, m?)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile or robotic agents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Networked in-orbit robotics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (a, b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-rate formation flying networked S/C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (c2)</td>
<td>X (c1, c2?)</td>
<td></td>
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</tr>
<tr>
<td>Fractionated S/C and On-orbit Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (?)</td>
<td>X (?)</td>
<td>X (n)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hi-rate formation flying networked S/C, Sensor Webs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (c2, p?, j, t)</td>
<td>X</td>
<td></td>
<td></td>
<td>X (future?)</td>
</tr>
<tr>
<td>S/C Docking ranging / data comms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (d)</td>
<td>X (d)</td>
<td></td>
<td></td>
<td>X (future)</td>
</tr>
<tr>
<td>Gossamer, inflatable or flexible structures and smart materials sensors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (future)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X (future)</td>
</tr>
<tr>
<td>Spacesuit advanced com’d and control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X (k)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manned Lunar/Mars intersystem comms and EVA short range &lt;8km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (o, q)</td>
<td>X (e, f, i, o, q)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manned Lunar/Mars intersystem comms and EVA medium range &lt;30km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (c, f, i, o, q)</td>
<td>X (e, f, i, o, q)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manned Lunar/Mars intersystem comms and EVA long range &gt;30km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X (c, f, i, o, q)</td>
<td>X (e, g)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Table 2. ESA Applications of Inter-vehicular Wireless Proximity Networks**

**Note:** this table does not attempt to account for the already known non-European applications, e.g. NASA, DARPA, U.S. Air Force and U.S. University, of which there are hundreds of activities.
(a) ESA/Alenia Spazio study for ISS-to-Eurobot data communications, robot operations control and video data (completed February 2005) baseline: IEEE 802.11a. Project expected to have full Phase B funding in early 2006.

(b) Investigation ongoing by Terma/Dutch Space for adding a wireless colour camera to ESA European Robotic Arm.

(c) c1 -- ESA CDF study, Xeus near formation flying spacecraft study (completed January 2005) baseline: based on IEEE 802.15.4.

c2 – Surrey Satellite, University of Surrey, U Kent, U Edinburgh, others (UK) and BNSC are currently investigating low-rate wireless and WLAN for inter-spacecraft formation flying data communications and large aperture synthesis, integrating ESA’s LEON2 microprocessor and WLAN in a SoC, AES encryption, and efficient microprocessor operating systems for nanosatellite formation flying.

(ESPACENET: Evolvable Networks of Intelligent and Secure Integrated and Distributed Reconfigurable System-On-Chip Sensor Nodes for Aerospace Based Monitoring and Diagnostics, http://www.see.ed.ac.uk/~SLIg/ESPACENET.html)

(d) ESA custom (non-COTS) SS for ATV to ISS docking to fly on first ATV, Jules Verne in 2006. Astrium is investigating COTS based WLAN for next generation ATV.

(e) Steve Braham, Simon Fraser University, Vancouver Canada [2]. Review this work at the Haughton-Mars Project (HMP). http://www.marsonearth.org/

(f) ESA CDF Aurora Manned Lunar study (completed March 2005) baseline: IEEE 802.11g WLAN with option for IEEE 802.16e WMAN.

(g) Scenarios greater than 30 km have not yet been fully studied by ESA.

(h) University Bremen exploring self-assembly space robotics utilising RF wireless.

(i) CCSDS C15-Lunar draft rationale documents include WLAN for lunar surface communications.

(j) Innovation Triangle Initiative proposal from Surrey Satellite Tech. Ltd. and University of Surrey for adapting free standing compact (COTS) wireless motes for comm between spacecraft subsystems and between low cost formation-flying spacecraft or ad-hoc swarm. Study kicked-off June 2006.

(k) Steve Braham, Simon Fraser University, Canada; CSA and NASA: advanced spacesuit control -- were the first to demonstrate remote command and control of a spacesuit test bed in 2000, with Hamilton-Sundstrand at the Haughton-Mars Project (HMP).

(l) ESA “Mission Concept for Autonomous on Orbit Assembly of a Large Reflector in Space” [81], Dario Izzo, Mark Ayre, ESA Advanced Concepts Team, ESTEC, Lorenzo Pettazzi, ZARM, University of Bremen, Germany, 56th International Astronautical Congress, Paper IAC-05-D1.4.03.


(n) The Japanese Aerospace Exploration Agency (JAXA) is planning to test a Furoshiki spacecraft in January 2006. Assisted by ESA's Advanced Concepts Team, it has chosen the robotics institute of the Vienna University of Technology to develop the small (Spider) robots to demonstrate on-orbit assembly of functional structures using flexible fabrics.

(o) ESA D-TEC ETC/ETN soon to issue in 2006 a GSP for identifying potential and methods to couple localisation, ranging and eventual navigation capabilities to existing WPAN, WLAN and WMAN technologies for planetary exploration.

(p) ESA-ESTEC EUIT Telecommunication planning a study in 2006 involving the adaptive Internet Protocol (IP) suite routing, ad hoc routing and on-satellite data processing as a possible future experiment among close-formation, multiple micro-satellites in collaboration with University of Wurzburg and others.

(q) ESA-ESTEC EUIT FEASIBILITY STUDY FOR A REDUCED PLANETARY NAVIGATION AND COMMUNICATIONS SYSTEM, Programme Ref. GS 06/B24. The study will assess the feasibility and preliminary performance and system definition for a reduced planetary (Lunar/Martian) navigation and communications system, complemented with local navigation and local communication infrastructure for specific areas under special interest [121].

(r) ESA TEC-SP FORMATION FLYING DEMONSTRATION MISSION, AO Nr. 1-5088. The mission shall validate RF and optical metrologies, coarse and fine formation flying, main type of formation configurations and related manoeuvres and GNC as well as advanced technologies required by formation flying (e.g. collision avoidance, propulsion). The launch shall take place before 2009 to bring sufficiently in advance valuable results for future missions. Specific wireless technologies investigated are unknown.

(s) ESA TEC-EDD CDF study for “Fly-by-Wireless” executed in 2006. Several wireless technologies investigated based on ESA Venus Express concept.

(t) Study and paper: IEEE 802.11 Optimisation Techniques for Inter-Satellite Links in LEO Networks – possibly as a SpaceWire extension, Kasuo Sidibe and Tanya Vladimirova, Surrey Space Centre, University of Surrey [123, 124].

CONCLUSIONS, RECOMMENDATIONS AND TRENDS FOR THE FUTURE

You are invited to discover these via the full Dossier Annex A, “An Assessment of Wireless Proximity Networks for Space Applications”, available through this conference, ESA ESTEC-ED or via the ESA e-group SpaceWLAN: http://groups.yahoo.com/group/spacewlan/

REFERENCES

All references [N] are to the referenced document as numbered within the Technology Dossier Annex A.