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THE CHALLENGES OF INTRA-SPACECRAFT WIRELESS DATA INTERFACING

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Abstract

The onboard computer, various subsystems and the data handling system of a spacecraft can be viewed as the nodes of a sensor/actuator network. Wireless sensor networks for monitoring and control have been in existence for several years, however, their adoption to space applications is still under discussion. Despite the fact that many communication protocols with adequate power and reliability characteristics are commercially available, the selection of a suitable standard for spacecraft onboard communication remains an open question. This paper enlists the challenges related to wireless interfacing onboard spacecraft in general. Thereafter, characteristics of major intra-spacecraft data traffic types in a typical microsatellite are discussed. Based on this information we evaluate Bluetooth, WiFi and ZigBee as three potential candidates and suggest Bluetooth and ZigBee as two good options for onboard data communication of a microsatellite.

1 Introduction

Miniaturization of spacecraft modules by applying Micro-Electro-Mechanical Systems (MEMS) and recently Nano-Electro-Mechanical Systems (NEMS) along with advanced electronics has reduced the size and mass of spacecraft and has enhanced microsatellites. Furthermore, technology advancements have provided the possibility of employing additional sensors and actuators to improve the understanding of the environment and advance the precision of the spacecraft reactions. All those additional components are interconnected by the onboard data handling system. Traditionally, wired data handling standards such as MACS, RS-422, MIL-STD-1533B, FireWire, CAN Bus, I^2C and recently SpaceWire are used [1]. The majority of these standards employs redundant cables to provide higher reliability. Statistics shows that 6 to 10 percent of the mass of a spacecraft is due to wires and electrical interfaces [1]. Major problems of wired data handling can be categorized as follows:

- Failure of wires and connectors;
- Mass overhead of cabling and electrical interfaces;
- High cost of late design changes;
- Development time overhead for allocating routes and places, shields, connectors, brackets, cable trays, fasteners, supporting structure, etc.;
- Additional physical dimension restrictions;
- Undesired ground loops on the communication paths;
- Electromagnetic compatibility issues (EMC) and crosstalk.

Applying a wireless communication strategy can potentially solve the majority of the above problems and also reduce the integration time/effort and enhance the flexibility of the design.

The wireless data transmission can be introduced to an existing subsystem either as an add-on module or integrated in the original electronics. However, in both cases, the following issues should be evaluated for each candidate subsystem:

- Communication bandwidth requirements;
- Wireless processing computational overhead;
- Power budget overhead;
- Data integrity requirements;
- Volume and mass overhead;
- Fault tolerance level.

Two recent examples of wireless subsystems are the wireless digital sun sensor developed by TNO [2] and EADS Micropack wireless temperature transducers [3]. In addition, a complete fly-by-wireless Unmanned Aerial Vehicle (UAV) platform was developed in Portugal [4]. Despite those examples, the employment of wireless communication technology onboard spacecraft is still in the early technology demonstration phase. The aim of this paper is twofold: to address the traditional concerns about wireless communication onboard spacecraft and to comment on the limitations of the wireless technology in space missions.

The reminder of this paper is organized as follows. In Section 2 a number of research challenges for intra-spacecraft wireless communication are presented. Section 3 presents a selection study of wireless communication standards onboard a typical microsatellite. In Section 4 a summary is given and conclusions are provided.

2 On-board wireless communication research challenges

In this section we review the major challenges related to onboard wireless communication that were previously reported in the literature. These are the four main problems that need to be addresses when wireless technology is applied to a spacecraft.

Real-time communication

For some specific cases of scientific payloads, real time data delivery may play a key role. A permanent or temporary real time data transmission may be required by such nodes while other subsystems, such as ADCS sensors/actuators, may not demand this. In addition, on the system level the priorities and the communication requirements of different nodes may significantly change over time. Most of the existing communication standards either ignore real time completely or attempt to increase the data processing power to approach the real time requirements closely [5, 6]. Solutions to dynamic prioritizing of the nodes' traffic demands and design of true real-time protocols are considered to be the two major research challenges in this area.

Power management

Power is a tight source especially within microsatellites. Within WSAN, nodes can be self-powered (by a battery or local power scavenging techniques [7]) or powered by the central spacecraft power subsystem. Depending on the mission, the life time of the nodes may vary from several months to many years. In the near future, especially by introducing inter-planetary explorations, power management of onboard WSAN will become the major concern of employing any type of WSAN on spacecraft. Moreover, power constraints are naturally highlighting safety and reliability concerns. Adding more intelligence to the nodes to adjust the data transmission rate and/or data resolution upon power shortage could be a solution to this problem [8, 9]. A research challenge is developing algorithms to reconfigure the transmission strategy or the sampling rate in an efficient way [10, 11].

Signal interference and fading

In the spacecraft, the propagation and the strength of the electromagnetic waves of wireless links are to be influenced by the mechanical structure and electronic systems. It is possible to add relays to strengthen the signals but their optimal number, locations and gains are to be analyzed. On the other hand, the electromagnetic waves produced by wireless interfaces may be harmful for some of the sensitive devices e.g. high precision sensors. Optimizing the location of the nodes to achieve the highest SNR and the lowest interference is a challenge to be faced [12].

Distributed task control

To exploit the benefits of onboard wireless communication better, the onboard WSAN can be used to implement a distributed task accomplishing strategy. For example, sensors and actuators of ADCS may talk to each other directly in a point-to-multipoint configuration. If the control can be accomplished by different actuators, algorithms should be developed to trade off time and precision vs. power consumption to identify the best actuator to be used depending on the particular situation [13]. In case of a failure or power shortage in one actuator, the network should be able to reconfigure and update the decision.

All of the aforementioned challenges are equally important and should be addressed in case of developing a new standard for spacecraft onboard wireless communication. On the other hand, it is possible to employ one of the existing commercial Off-The-Shelf (COTS) wireless standards for the same purpose. In this case, a different methodology should be applied in order to select the best standard based on clearly defined design requirements. The next section will focus on the selection of a COTS wireless communication protocol for onboard spacecraft communication.

3 Intra-Spacecraft communication standard selection

The intra-spacecraft wireless network provides wireless links between various nodes inside the spacecraft. As mentioned earlier, the nodes are either self-powered or powered by the spacecraft central power system. In both cases, the main engineering objective is reducing the wiring harness and improving the intra-spacecraft interfacing flexibility. In the case of a typical microsatellite, the wireless network could be in charge of handling the following data traffic types:

- Payload data to the main computer to be communicated to the ground station;
- House-keeping information from the sensors to the main computer for monitoring the spacecraft's health and operation;
- ADCS sensors and actuators data traffic.

House-keeping information may include data from small wireless temperature sensors which can easily placed in any microsatellite [3]. Payload data is usually coming from a single or multiple scientific devices onboard the spacecraft. ADCS information may contain several data types generated/used by different sensors/actuators, e.g. magnetometer, GPS receiver, star camera, reaction wheels, magnetorquer and more. As it will be presented later, ADCS and house-keeping data traffics have different characteristics. Therefore, they form two separated categories.

The different data traffic types impose various requirements on the data handling system. The following parameters are selected as the criteria for determining the best wireless networking standard for intra-spacecraft communication:

- Data rate: represents the maximum data bandwidth required by the wireless nodes;
- Data robustness: A requirement for higher data robustness means that the impact of data loss during the communication is severer;
- Fault tolerance: represents the requirement on graceful degradation and data recovery. The cause of failure could be temporary or permanent power loss or interference;
- Reconfigurability: represents the ability of the network to reconfigure itself in presence of a permanent power loss of some nodes.

Table 1 depicts the aforementioned requirements for the three typical data types for an average microsatellite. The presented data is gathered after careful evaluation of recent microsatellite projects such as BIRD [14], PRISMA [15] and Ørsted [16]. For example, the BIRD microsatellite ADCS uses a GEM-S GPS receiver which communicates its data

	Data rate	Data robustness	Fault tolerance	Reconfigurability
Payload data delivery	High (>10 Mbps)	Low	High	Low
Monitoring & House keeping	Low(<50 kpbs)	Low	Low	Medium
Attitude determination and control	Medium (50 kbps - 1 Mbps)	Medium	High	High

Table 1: Requirements on network features for different subsystems in a typical microsatellite

at maximum 76800 bps [17, 18]. The BIRD spacecraft carries two main science payloads. The payloads (infra-red camera and CCD camera) need a maximum data rate of 4790 kbps [19]. More examples from other microsatellite missions, motivated the data rate margins presented in the table. Generally, the attitude has a relatively slow dynamics. ADCS sensors usually have a relatively low sampling rate and the samples are very correlated. For example, ASTRO15 star camera onboard BIRD microsatellite operates with an update rate of 4Hz, that means each 250ms the full telemetry information can be submitted to the spacecraft control computer [14]. It is safe to conclude that ADCS data traffic do not demand a highly robust and fault tolerance communication link. Nevertheless, in presence of a faulty node, the ADCS should be able to reconfigure and maintain operation. Considering the same aspects, house-keeping data shows even a lower demand because the space environment is very stable and quiet, e.g. temperature changes very smoothly.

By definition, not every module and subsystem in a microsatellite qualifies for wireless communication interface. Adding wireless connectivity feature to a sensor or actuator can highly increase its mass, computation overhead and power consumption. For example, equipping a tiny pressure or temperature sensor with a wireless communication interface is not efficient considering the significant overheads even when state of the art technology is applied. Thus, the number of wireless nodes in a microsatellite will not be very high. In case of the BIRD microsatellite, a total number of 11 nodes are potential candidates for being equipped with wireless interfacing. These nodes are two science payloads, two star cameras, gyroscope, magnetometer, two sets of sun sensors, reaction wheels, magnetic coil system and the onboard computer.

It should be mentioned that the mass of a microsatellite is typically less than 100kg and can generate a limited amount of power due to the limited surface of its solar panels. Therefore, not only mass reduction is a key requirement in the design but also low power consumption is considered to be very important (even if the wireless enabled module is not self-powered). By taking the later fact into account and browsing the requirements presented in Table 1, one can conclude that a low power, reliable and fault tolerant communication protocol which supports low to medium data rates can fulfill most of the intra-spacecraft communication requirements defined earlier. As it is shown in Table 2, ZigBee and Bluetooth meet these needs very closely. A high speed data communication such as WiFi can be used for payload data delivery if it meets the power budget requirements.

Both, Bluetooth and ZigBee, are categorized as low rate data transferring standards. ZigBee and Bluetooth have very similar specifications, but they are two different technologies with different areas of application and different means of designing for those applications. While ZigBee is focused on control and automation, Bluetooth is focused on connectivity for data communication between devices and it is designed for reducing harness and cable replacement. ZigBee uses low data rate, low power consumption, and works with small packet devices (128 bytes) [20] while Bluetooth uses a higher data rate, has relatively higher power consumption, and works with large packet devices (339 bytes) [21].

In cases where the size of network is important, ZigBee networks can contain more nodes than a Bluetooth network. A basic Bluetooth network can not contain more than 7 nodes while a ZigBee network can comprise up to 65,000 nodes. Several techniques to increase the number of nodes in a Bluetooth network are available but this adds to

Standard	Bluetooth (802.15.1)	WiFi (802.11b)	WiFi (802.11a)	WiFi (802.11g)	ZigBee (802.15.4)
Max data rate [Mbps]	0.72	11	54	54	0.25
TX power [mW]	1	100	100	100	0.1-10
Network topology	Ad-hoc piconets	Point to Multipoint	Point to Multipoint	Point to Multipoint	Ad-hoc, Star, Mesh
System complexity	High	High	High	High	Low
Typical current consumption [mA]	<150	<400	<500	<400	<60

Table 2: Specification of a number of commercial off-the-shelf wireless standards, as candidate for intra-spacecraft wireless communication.

the complexity of the network [22]. This significant difference, however, is not very essential when we recall the fact that a typical microsatellite will not contain that large number of wireless subsystems as mentioned earlier on our BIRD mission analysis.

Comparing to Bluetooth, ZigBee development targets completely different applications which do not have much overlapping with Bluetooth applications. Depending on the type of nodes, microsatellite designer should choose which of the two standards suits the requirements better. As an example, Bluetooth must rely on fairly frequent battery recharging, while the whole goal of ZigBee is to provide the designer with devices that work for months to years without battery replacement. In time critical applications, ZigBee is designed to respond quickly, while Bluetooth takes much longer and could be detrimental to the application. It is suggested that ZigBee is more suitable for house keeping and low data rate onboard applications while Bluetooth suits specific sensor/actuator networks such as ADCS better. In some specific cases of payloads where more communication bandwidth is necessary, other types of higher data rate wireless communication standards such as WiFi could be considered. In such cases, care should be taken in selection of the standard since a higher data rate translates into a higher power consumption.

4 Conclusions

In this paper we described the main challenges related to the wireless network application in spacecraft. We also defined a set of typical requirements in respect to the wireless data handling system for microsatellites. These requirements were determined based on a careful investigation of three recent microsatellite missions. Thereafter, we evaluated three potential industry standard protocols and rated them based on the criteria defined before. Our study showed that ZigBee and Bluetooth can be used as communication standards onboard microsatellites.

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