IR-UWB in Intra-satellite Communications

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CSEM has defined, implemented and evaluated an intra-satellite, low latency, and high throughput real-time wireless communication system. The system is highly reliable and operates in a difficult environment made of several metallic cavities. The solution is derived from an extension to the IEEE 802.15.4 MAC sublayer and the 802.15.4a IR-UWB physical layer.

Spacecrafts currently use wires to support the communication between sensors, controllers and actuators for the ground tests as well as in flight control applications, for which the rising cabling complexity due to the ever-increasing number of sensors has become unmanageable. The first use case is typical of a data acquisition scenario, in which data is acquired by the sensor and transferred to a central node. The second use case corresponds to the replacement of the MIL STD-1553 master-slave bus, in which the on-board calculator is often the bus master, while the other units (typically sensors) respond to the master's polls, transferring data cyclically from up to 40 sensors sampled at 32 Hz with a bounded latency (around 1 ms). A third use case aims at interconnecting busses (MIL STD-1553, CAN or Spacewire) used in the spacecraft or its launcher), which imposes bidirectional data transmission, with a maximum latency compatible with the response time of a MIL 1553 slave and a throughput greater than 10 Mbit/s full duplex.

Replacing wires by wireless networks corresponds to a real demand. However, current protocols do not fully meet the requirements in terms of timeliness, energy consumption and throughput. A satellite is composed of several cavities with metallic walls, forming a complex metallic structure, which lead to the choice of the IEEE 802.15.4a [1]. Impulse Radio-Ultra Wide Band physical layer for its relative insensitivity to multipath.

IEEE 802.15.4 [2] is one of the most well-known wireless sensor network standards. Although the standard included real-time communications from the beginning, performance was limited [3]. Due to restrictions on the number of Guaranteed Time Slots and on the beacon periods, the original IEEE 802.15.4 MAC is not able to meet the requirements. IEEE 802.15.4e [4] introduced among other things, three new MAC behaviors that are possible solutions to the requirements: LLDN (Low Latency Determinist Networks) for factory automation; TSCH (Time-Slotted Channel Hopping) for process automation; DSME (Deterministic and Synchronous Multichannel Extension) for general industrial application requiring robustness.

In short, the three schemes have advantages and limitations. In the absence of transmission errors, they are capable of covering most of the requirements, with the notable exception of some very short latency constraints. Due to the PHY overhead of IR-UWB, throughput requirements can only be satisfied using two or more networks operating jointly on different channels. This shows that bandwidth should be used wisely. Satellites are made of different metallic cavities that create strong wave reflections. IEEE 802.15.4a is more resilient than narrow band transmission but does not eliminate transmission errors. The BER may be as high as 10-4. It is thus important to find an efficient scheme to recover from bit errors. Given the IEEE 802.15.4e principles, Forward Error Correction is not an option in the proposed MAC. The most logical choice is to use retransmissions. Possible error management principles include systematic repetition (babbling) and adaptive retransmission. The first option is typical of TSCH which statically assigns slots for retransmissions while the latter is used by LLDN where these slots may be assigned dynamically. A comparison of the two schemes shows that the latter is much more efficient in particular when all links do not degrade simultaneously. To overcome some of the limitations of LLDN, CSEM has designed a dynamic error retransmission scheme using a delayed acknowledge of correct reception in the beacons as well as on the fly slot assignments (in the beacon) for transmissions and retries.

The protocol is based on a TDMA approach (as LLDN) with a slot duration of 1 ms and a configurable cycle duration. The protocol is not limited in terms of number of nodes. A scheduler performs a dynamic slot allocation as a function of the traffic requirements and transmission errors. The beacon indicates the cycle size and slot allocations. Based on this information, nodes send their data (or retries), which are not directly acknowledged in order to reduce transmission overhead. An example of the TDMA cycle is given below.

Beacon	SN21	SN22	SN23	SN24	SN25	empty or retransmissions	...
1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	4 ms	

Figure 1: UCS TDMA cycle.

The protocols have been implemented and tested by Airbus Space showing the excellent performance and robustness of the solution.

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[1] IEEE Std 802.15.4a™-2007. IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs). Amendment 1: Add Alternate PHYs

[2] IEEE Std 802.15.4-2011 (Revision of IEEE Std 802.15.4-2006). IEEE Standard for Local and metropolitan area networks - Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

[3] S. Yoo, P. K. Chong, D. Kim, Y. Doh, M.-L. Pham, E. Choi, J. Huh, "Guaranteeing real-time services for industrial wireless sensor networks with IEEE 802.15.4," in IEEE Transactions on Industrial Electronics, 57 no. 11 (2010) 3868

[4] IEEE Std 802.15.4e-2012, Amendment 1: MAC sublayer (Amendment to IEEE Std 802.15.4-2011), (2012) 1