WHITE PAPER

QLS1046-Space based IoT platform for small LEO communication satellites enabling high-performance protocols.

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ABSTRACT

The "Internet of Things" (IoT) has been developing exponentially in the past few years, and this development is supported by the launch of small LEO communication satellite constellations to cover remote areas. IoT needs efficient communication protocols to support its fast growth, to improve the service quality to the end user, and to increase the number of end users or terminals. These advanced protocols help increasing the bandwidth, reducing the latency and error rate, and increasing the number of channels supported.

MBI Group has developed the LEOnida approach, which is based, on the Return Link (RL), on an improved Enhanced-Spread Spectrum Aloha (E-SSA) air-interface [1]. E-SSA is a random access (RA) technique, based on an evolution of the older Aloha protocol which allows demodulation of asynchronous bursts received with signal-to-noise ratio (C/N) well below 0 dB, thanks to the combination of direct sequence Spread Spectrum (SS) and Successive Interference Cancellation (SIC) for the cancellation of Multi Access Interference (MAI) at the receiver. Besides, the protocol does not need signaling nor coordination among the terminals, minimizing their complexity and network management. The LEOnida solution offers a delay tolerant implementation, meaning it can be operated with discontinuous service link and low-density constellations in order to speed-up the service implementation. It also provides Store & Forward capabilities in case of discontinuous feeder connectivity.

The RL LEOnida solution was previously implemented by MBI Group resorting to ground processing, while the on-board processing case has never been addressed, since it implied to be capable to realize the complex demodulation scheme on-board the satellite. With the appearance of compute intensive Space grade devices offering a high power-efficiency, it becomes possible to implement such high-performance computation protocols on small LEO satellites.

In this case study, a novel architecture for small LEO communication satellites is presented and tested to improve the terminal to satellite communication by implementing the RL LEOnida solution, and with the embedded demodulation algorithm. The architecture presented in this study takes advantage of the Space grade processing module QLS1046-Space from Teledyne e2v. It is shown that the LEOnida IoT platform proposed can be embarked on LEO satellites to provide narrowband IoT applications to large populations of low-power IoT terminals.

First, the required processing architecture is elaborated, and the options to implement it in Space are evaluated. Then, the practical implementation and test setup are presented. Performance testing is performed, and results are commented. Finally, the possible next steps are discussed.

1. PROCESSING ARCHITECTURE

The processing architecture for the E-SSA communication protocol can be split into two main parts:

- The front-end part which is interconnected with the A/D and D/A converters, and which handles the digital samples. It implements the preamble searcher in reception, and the modulator in emission. This requires simple operations but very deterministic execution, hence it is typically implemented in the Programmable Logic (PL) of a low-power FPGA.
- The back-end part connected to the front-end and which implements the receiver and the on-board HUB. This requires complex operations and heavy computing capabilities. For that purpose, high performance processor cores are best-suited.

A hybrid architecture combining Programmable Logic (PL) and processor cores is thus recommended for an efficient implementation. Figure 1 presents several possible component combinations versus the computing capabilities offered. Some solutions offer intermediate performance and could fit for nanosatellites. For microsatellites, however, large computing capabilities are required.

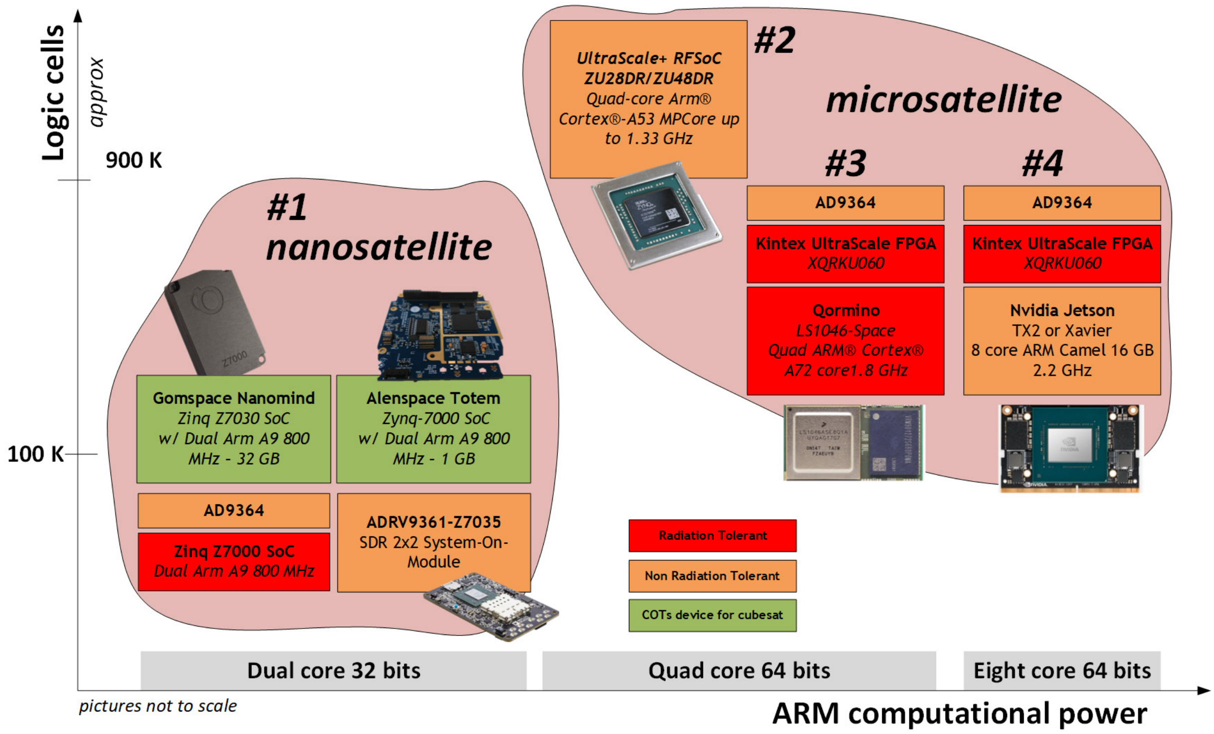

Figure 1 - Performance of the possible processing architectures.

Among these options, the Teledyne e2v QLS1046-Space processing module coupled with the XILINX XQRKU060 FPGA has the advantage of being a fully radiation tolerant combination. The QLS1046-Space is a Radiation Tolerant Space grade device combining a 1.8GHz quad-core 64-bit Arm® Cortex A72 processor and a high speed 4GB DDR4 memory in a compact form factor [2], as show on Figure 2.

Processor	QorIQ® LS1046 integrating ARM® Quad core / Dual core at 1.8 GHz
Memory	4GB DDR4 stacked memory 72-bit BUS with ECC protection
Attributes	Temperature performance -55° to +125° Compact size ≈44mm x 26mm Long-term support +15 years

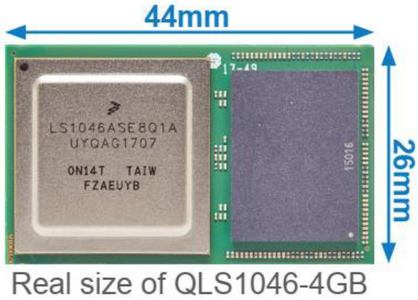

Figure 2 - QLS1046-Space presentation.

The block diagram of the proposed processing scheme using a QLS1046-Space combined with a FPGA is depicted on Figure 3. It shows a realistic on-board data processing architecture that can be adopted to embark the LEOnida IoT platform on a small LEO satellite. The E-SSA preamble searcher is hosted on the FPGA to manage the multiple frequency hypothesis needed to cope with the large Doppler shift of LEO satellites, which can be up to tens of kHz. The modulator is also hosted in the PL of the FPGA to run it in real-time. A preliminary study has already shown that both tasks can be implemented on a low-power FPGA. The E-SSA receiver and the on-board HUB are executed on the processor. It will be shown in the test results that the choice of the processor is critical to fully exploit LEOnida protocol, which is why the QLS1046-Space was selected.

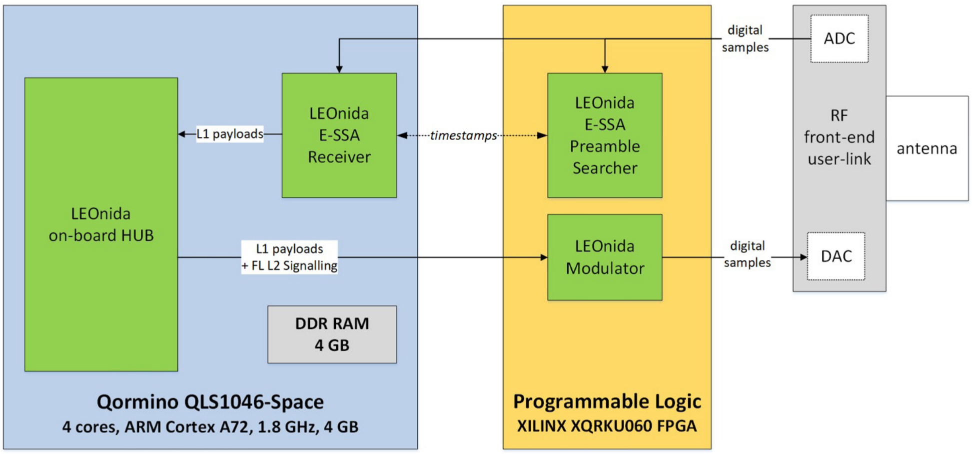

Figure 3 - Proposed processing strategy with QLS1046-Space and FPGA.

In the next sections, the performance of the proposed platform is evaluated in practice.

2. TEST SETUP AND SOFTWARE IMPLEMENTATION

The practical test setup is based on the QLS1046-Space development kit, which is a complete development platform, including interfaces, as shown on Figure 4.

MBI Group had already developed a software implementation of the E-SSA for ground applications. This software was developed in C++ to run on CPU and GPU servers. In the frame of this study, MBI group performed the porting of the existing software to run it on the QLS1046-Space. To minimize development time, the software was not optimized for the QLS1046-Space, hence the results presented in this paper could be further improved by optimizing the execution on this new target platform.

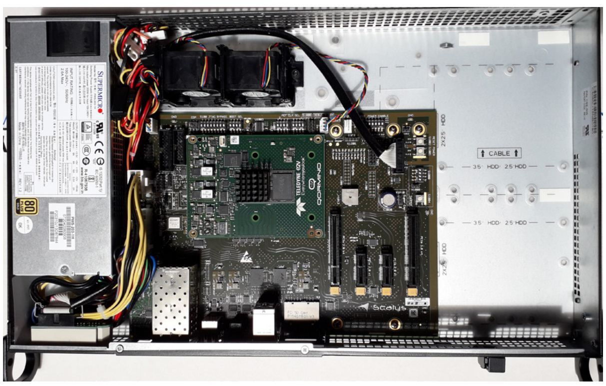

Figure 4 - QLS1046-Space development kit.

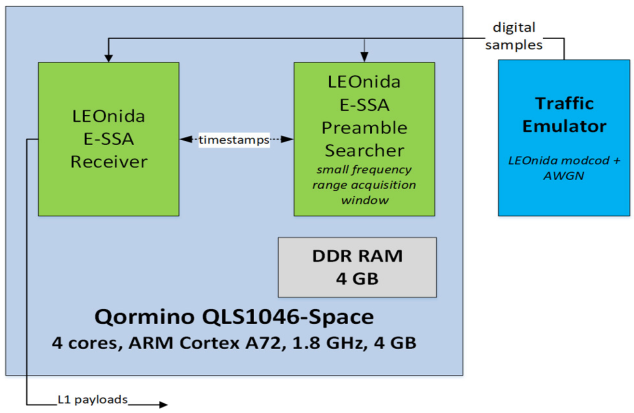

Figure 5 - Software implementation for practical tests.

Since the main focus of the activity is to evaluate the performance of the E-SSA receiver on the processor, there is no FPGA included in the setup.

Thus, the full E-SSA receiver including the preamble searcher has been ported on the QLS1046-Space. The preamble searcher is configured with a smaller frequency range acquisition window to reduce resource utilization (since it should normally run on the FPGA). A traffic emulator is used to provide the samples to the development kit. The block diagram of the test setup is shown on the Figure 5.

3. RESULTS

Figure 6 shows the different LEOnida modcods and the configuration of the traffic generator used to realize the performance assessment. In particular, the parameters that were modified were the Spreading Factor (SF) and the data size.

LEOnida Waveform Constant Envelope					
Modcod	Bandwidth	Modulation	Code rate	Spreading Factor	Data Size bytes
MODCOD#1	60 kHz	QPSK	1/3	16	38
MODCOD#2	60 kHz	QPSK	1/3	16	78
MODCOD#3	60 kHz	QPSK	1/3	64	38

Testbed configuration AWGN channel + small Doppler shift			
C/N (dB)	Power Spreading (dB)	Doppler (Hz)	# IC Loops
-10	5	10	32
-10	5	10	32
-16	5	10	32

Figure 6 - Test conditions.

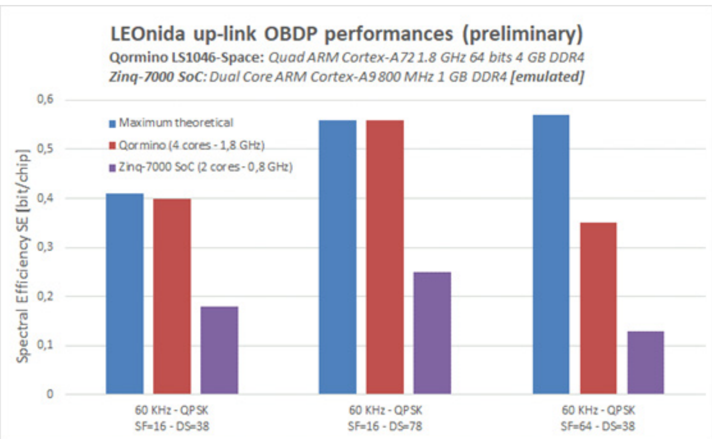

Figure 7 - Practical performance.

The results of the performance assessment are presented on Figure 7 for the three test conditions. The maximum theoretical performance of the protocol is in blue, the performance with QLS1046-Space in red, and the emulated performance on a ZYNQ-7000 in purple. The ZYNQ was emulated by running the QLS1046-Space with only two cores and with a lower CPU frequency of 800MHz.

The results clearly show that the obtained spectral efficiency is not limited by the QLS1046-Space, for a SF of 16. This means that the LEOnida protocol can be full exploited in these conditions. For a spreading factor of 64, however, the QLS1046-Space becomes the limiting factor, but this is expected. The code was not yet optimized for this study, hence a code optimized to run on the QLS1046 will bring even higher performance. It should also be noticed that the QLS1046-Space outperforms by far the emulated ZYNQ-7000 performance in this application in all conditions.

4. DISCUSSION AND NEXT STEPS

In this case study, a Space processing platform to offer IoT on small LEO communication satellites was proposed and evaluated. MBI Group demonstrated with practical testing that this platform would be able to handle advanced protocols such as the LEOnida E-SSA on-board the satellite thanks to a Teledyne e2v QLS1046-Space processing module combined with a FPGA. An in-orbit demonstration of the LEOnida receiver hosted on the QLS1046-Space could be carried out by reusing the architecture of the testbed and using the ground terminal design to pre-compensate the Doppler shift.

MBI Group is also investigating the possibility to use this computing platform to perform signal intelligent algorithms, such as interference frequency detection, source localization, and mitigation. Even if the current TRL on such algorithms is still low, they could be ported on the QLS1046-Space and tested during a possible in-orbit demonstration. The first step is to realize a laboratory demonstrator with the development kit to validate the feasibility of the approach.

5. REFERENCES

[1] Del Rio Herrero O, De Gaudenzi R., «High efficiency satellite multiple access scheme for machine-to-machine communications," IEEE Trans Aerosp. Electron Syst., vol. 48, no. 4, October 2012.
[2] QLS1046-Space product page http://semiconductors.teledyneimaging.com/en/products/processors/qls1046-space

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