SpW Evolutions

(ESTEC Contract 4000104023)

Deliverable D8
Executive Summary Report

Prepared for:
European Space Agency

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1 Scope

1.1 Scope and description of the document

The scope of this document is to provide the Executive Summary Report of the "SpaceWire Evolutions" contract (ESTEC CONTRACT 4000104023). The project tackled three different areas:

- Clarification on the SpW Node definition: the first two work packages of the project handled the update of the node definition for the next revision of the SpW standard, taking as an example case the Plug And Play.
- Sideband Signaling for Interrupt Distribution: Currently SpaceWire does not have a mechanism for signaling events of high importance although several ideas had been presented and discussed during the SpW working groups and conferences. Within the project alternative proposals were studied analyzed and their trade-offs were presented to ESA and to SpW Working Groups 17 – 19. The project took as basis the proposal by SUAI performed analyses from functional, performance, operation under failures points of view and also took into account the interoperability with existing devices and several proposals were made by ESA, SUAI and TELETEL. The refined proposal was implemented and by two different, independent implementations and validated.
- Simplex and Half-Duplex SpaceWire: SpW is full duplex but in many cases (e.g. simple devices) one of the link directions is not needed or the traffic passes through it is very limited and thus the mass, complexity, weight overhead is practically unused. Within the study two proposals were analyzed:
    - Simplex SpW: A proposal by SUAI, which specifies a unidirectional version of SpW for simple devices. The proposal was studied and refined and detailed the test set-ups and detailed procedures were compiled within the project
    - Half Duplex SpW: A proposal by 4Links which specifies a bi-directional version of SpW in which the two ends alternatively becomes transmitter and receiver. The proposal was studied from the functional, performance and implementation points of view and several proposals were made. Finally, the test set-ups and detailed test procedures were compiled within the project.

The project consortium consisted of two contractors (prime and subcontractor) and two suppliers. The two partners were:

- TELETEL which was the prime contractor of the project was responsible for the definition of the technical solutions for Interrupts, Simplex and half Duplex SpW, for the compilation of the respective ECSS specifications and for the definition of the test set-ups and procedures. TELETEL was also responsible for the development and validation of SpW nodes implementing legacy SpW functionality as well as the new SpW features introduced in the project.
- ASTRIUM was responsible for the review of the technical solutions provided by TELETEL and SciSys (see next paragraph) and for the review of the test set-ups and procedures

The two suppliers were:

- 4Links gathered the requirements for Interrupts Simplex and Half Duplex as well as for the provision of two SpW Evolutions switches incorporating legacy SpW functionality as well as the new SpW features introduced in the project.
- SciSys performed the work on the SpW Node clarification and defined the test set-ups and procedures for the validation of the updated node specification taking as an example case SpW Plug And Play.

2 Technical Work and Results

2.1 Updated Node definition and support for Plug And Play

The work performed for providing the update of the SpW Node Definition arose from the need for Plug And Play as well as from some inconsistencies found in the current version of the SpW standard and discussions performed in the SpW community on whether nodes can be implementing switching functionality and the option for having SpW node inside a SoC.

The current version of the SpW standard defines a stack from Packet Level down to the physical Level for a SpW device which means that Integrated Circuits that implement SpW character level and switching inside the IC cannot be considered as compliant to SpW simply because they do not implement the electrical level of SpW or because they do not have a sub-D connector. To this respect the SpW layer stack was reworked in the project proposing the segregation of “Physical” and “Functional” views of SpW thus being able to make a distinction to which levels of SpW standard each devices conforms to as well as to overcome the problem that SoCs implementing the upper levels of SpW cannot be considered as conformant devices.

In addition, the current version of the SpW standard defines nodes as sources or destinations of packets, which created confusion since with the emerge of Plug And Play, switches can also be destinations and target of configuration packets and therefore a switch could be also seen with the terminology used in the current version of the SpW standard. To this respect, a rework on the terms using in the SpW standard was made and new terms were proposed.

Finally, although the current version of the SpW standard defines that at a SpW switch, incoming packets with a first data char value zero are configuration packets, there was no such provision for the case of nodes. Four alternative options were analysed taking as example existing complex devices and it was agreed that PnP for nodes will not be part of the SpW standard but it will rather be left as an application.

2.2 Sideband Signalling for Interrupts Distribution in SpW

The work performed included the study of the existing proposals for interrupts distribution. The SUAI proposal was taken as basis but other options/proposals were analysed as well. The technical work included the study of the SUAI proposal both from functional and performance point of view. Its functionality in redundant/loop networks was studied as well as its robustness under the presence of failures so that the proposed mechanism is single-point-of-failure proof.

At the beginning of the project the requirements were collected, in which it became apparent that the users would like to extend the number different interrupt identifiers, which however cannot be performed with the SpW character set since it provides limited capabilities for low transmission latency characters. Alternatives were proposed which can solve the limitation on the number of interrupt identifiers taking into account either existing proposals (e.g. 4Links Virtual Networks) or proposing new mechanisms. However all of these mechanisms were not compatible with the existing SpW standard nor with existing SpW implementations so it was decided that the number of supported interrupts would be limited by the capabilities provided by the existing SpW character set.

Having decided this, five alternative proposals were examined, all of which can be considered as options/extensions of the SUAI mechanism. The proposals were presented in SpW WG 17 and 18 and feedback was gathered by the SpW community and it was decided:

- The interrupts mechanism shall not require any configuration or configuration required shall be limited. To this respect, one of the options, which was introducing multi-casting, was abandoned
- The selected mechanism shall be robust. To this respect one of the alternatives was rejected since a single loss in a character was causing permanent problem in interrupts distribution

To this respect three alternatives remained, two of which are based on the SUAI proposal and are those that were qualified for implementation and validation, and another one which is very promising due to its simplicity but shall be further examined from its robustness point of view since a theoretical analysis performed in the project revealed a potential weakness which shall be further studied.

During the SpW WG discussions it became apparent that both qualified alternatives have their pros and cons and the SpW WG body was divided between them. Subsequent discussions proved that by imposing limitations on one of them could make both alternatives co-exist in the network at the same time and in it was the solution that was selected for specification, implementation and validation.

The qualified interrupts mechanism(s) was implemented in two different and independent implementations, one by 4Links which provided “SpW Evolutions” switches that can distribute interrupts and a TELETEL node implementation.

After the implementation the validation phase started with the following results:

- The two implementation are interoperable
- The functional and performance issues that resulted from the theoretical analyses were all validated
- The hazards for infinite interrupts looping in a network revealed during the theoretical analyses that happen if protection is not implemented in nodes/switches, was validated and demonstrated in respective tests.

2.3 Simplex SpW

Simplex SpW was proposed by SUAI as a way to save mass, complexity and power consumption for connection to simple devices. Within the project the SUAI proposal was studied and refinements were made since it was revealed that under certain cases the proposed mechanism could cause problems to the rest of the SpW network.

The refined mechanism was evaluated from performance point of view in which it was revealed that it can support only SpW packets of limited length if low cost implementation is the target. Extending its scope to support larger packet sizes requires additional memory resources at the Simplex SpW receivers due to the lack of one flow direction which sends flow control information, thus cancelling Simplex ‘s low cost/complexity advantage.

The specification of the Simplex SpW was compiled and detailed test specifications covering its base functionality and its interoperability with Full/Half Duplex SpW were also defined.

Simplex SpW was abandoned and not prototyped after being apparent that its range of use cases is extremely limited, it cannot support any of the latest SpW evolutions such as PnP, FDIR, N-MaSS, scheduled communication.

2.4 Half Duplex SpW

Half Duplex SpW was proposed by 4Links as a way to decrease cable mass for applications in which traffic is asymmetric. Within the project the proposal was studied several issues were revealed:

- The state machines implemented at both ends of the link cannot be the same: Since at each time instance one of them shall be driving the line and the other shall be listening to it, an asymmetry in the SpW state machine shall be introduced for Half Duplex support. Four alternatives were examined to overcome this problem:
    - Use a pseudo-random timer in the state machine: this is an approach similar to the Ethernet which however transfers the problem at a higher layer since it shall be ensured that the pseudo-random seeds at the two ends are different
    - Use timers with different offsets in switches and nodes states machines: Although this solution would prohibit switches from being connected through Half Duplex links, this was not considered as a major problem at the end and proved to be the favorite solution. Due to the fact that Half Duplex introduces excessive latency in Signaling Codes Half Duplex is expected to be used only at the periphery of the network connecting nodes and switches only.
    - For the connection of different ports of a switch it was decided that timer offsets related to the port number can be added to the state machine of each port providing a solution.
- Definition of the Half Duplex Signal Level: SpW uses LVDS signaling which is capable of driving a single load. With Half Duplex however, each driver drives two loads, its own receiver and the remote end’s receiver, and LVDS cannot be used anymore. Three alternatives were examined which are presented below. Experimentation in mock-ups was made with all alternative solutions which proved good interoperability among them and a couple of technical issues (for which proposed solution were provided) appearing during the time that the line is not driven by both ends.
    - BLVDS: Non-standard electrical level which for multi-point buses. It provides signaling rates similar to SpW, has the same receiver threshold but drives more current on the line and therefore shall pass through EMC qualification

  - MLVDS: ISO standard interoperable with BLVDS which drives mode current on the line and having a receiver input threshold half that of LVDS which means that EMC susceptibility qualification shall be performed as well
  - Pseudo-BLVDS: non-standard implementation of BLVDS/MLVDS through CMOS and resistor network. This solution injects the same current on the line as LVDS meaning that EMC behavior is expected to be the same but the existence of resistors makes it sensitive to temperature variation
- Link direction reversal: 4Links initial proposal was making direction reversal of the link by sending a single NULL character which cannot be done with easy modifications of mainstream SpW Cores since a NULL character is decoded when part of the next character is received, containing NULL character's parity bit. For this reason a modification on the SpW character level was initially proposed, introducing a new character, the TURN character which consists of a NULL and its parity bit

The Half-Duplex SpW was evaluated from the performance point of view in which it was found that

- It introduces excessive latency to signaling characters, such as Time-Codes
- Efficiency and latency competing factors and trade-off analysis per application may be required
- In redundant topologies excessive jitter may be introduced between the arrival times of the two copies arriving at the receiver introducing difficulties/cost to the redundancy filter

After having proposed solutions for the problems mentioned above the protocol specification was done following the ECSS guidelines and the detailed validation test set-ups and procedure were defined covering functional and performance test as well as interoperability tests with Full Duplex SpW, PnP and Interrupts Distribution.

The next step was to assess the implementation feasibility of Half Duplex SpW using the UoD SpaceWire Core which would be modified in order to support both Full and Half Duplex SpW Modes. For this purpose the code was modified and experimentation took part through simulations.

Early in the simulations it was found that Link Initialization could not be established between the two ends. The problem lied in the fact that mainstream SpW Cores implement a specific solution for recovering the data sent by the remote end, which is the technical solution suggested by the SpW standard, which however, it was found that in the case of Half-Duplex SpW this solution is not the optimum.

Mainstream SpW receivers cannot decode all characters sent by the remote end due to the fact that the remote end ceases transmission at some point, causing the receiver circuits to run out of clock pulses. The result was that the performance of the Half-Duplex SpW was dropping dramatically much less than 60% of what was predicted during the theoretical analyses.

In order to support Half-Duplex SpW the receiver of the core had to be re-written which meant that in order to deliver a common block supporting both Full and Half Duplex SpW a core should have two different receivers, inferring increase in cost complexity and power consumption.

Given the fact that ESA works towards more promising solutions for low-mass SpW and in addition since it was proved that Half-Duplex performance is degraded, especially in asymmetric traffic which is the traffic model for which Half Duplex SpW was proposed, it was decided not to continue with prototyping and validation.

3 Administrative Issues

The project had a scheduled duration of 12 months and a total budget of 150KEuros. Due to the increased effort spent by TELETEL for Interrupts Distribution, addition of extra demonstration scenarios and due to the change in ESA's IP Cores licensing policy a CCN was issued resulting in total project cost of 164331 Euros and total duration of 15 Months.

The project constituted of the companies shown in Table 1.

Company	Role
TELETEL	Prime Contractor
ASTRIUM SAS	Sub-Contractor
4Links	Supplier
SciSys	Supplier

Table 1: The SpW Evolutions project consortium

Meeting	Dates	Place
Progress Review Meeting 1	16 December 2011	ESTEC
Progress Review Meeting 2	27, 28 March 2012	Athens
Preliminary Acceptance Review	15, 16 November 2012	Athens
Final Acceptance Review	11, 12 December 2012	ESTEC

Table 2: Review meetings

The list of deliverables is shown in Table 3.

Item	Name	Date
Software		
SW1	SpaceWire 1.1 test and demo setup software in binary and source code	T0+11
Hardware		
HW1	SpaceWire 1.1 test and demo setup hardware	T0+11
Documentation/Other		
D1 version 1	SpW Evolutions - clarification of SpW node definition and support to Plug-And-Play	T0+2,5
D2 version 1	SpW Evolutions - introducing sideband signaling for interrupt distribution into the SpaceWire protocol	T0+2,5
D3 version 1	SpW Evolutions - introducing simplex and half-duplex SpaceWire	T0+2,5
D1 version 2	SpW Evolutions - clarification of SpW node definition and support to Plug-And-Play	T0+3,5
D2 version 2	SpW Evolutions - introducing sideband signaling for interrupt distribution into the SpaceWire protocol	T0+3,5
D3 version 2	SpW Evolutions - introducing simplex and half-duplex SpaceWire	T0+3,5
D4	SpW Evolutions Detailed Design Document	T0+8
D5	The SpW Evolutions Test Report	T0+14
D6	The SpW Evolutions Demo Manual	T0+14
D7 draft	Final Report	T0+15
D7 final	Final Report	T0+15
D8	Executive Summary Report	T0+15
D9	Abstract	T0+15
D10	Poster	T0+15
D11	Web Site	T0+15
D12	Technical Data Package	T0+15
D13	Commercial Evaluation	Descoped

Table 3: SpW Evolutions list of deliverables