THE SDR APPROACH IN A WIDEBAND AIRBORNE COMMUNICATION NODE

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ABSTRACT

The Airborne Communication Node (ACN) demonstrator has been developed by EADS for the French MoD (DGA / SPOTI) in order to enhance telecommunication and network capabilities, providing up to 40 Mbps capacity on the IP standard, for both civilian and military applications (Network Centric Operations concept). It is based on an airborne node which covers a 100km diameter area for up to 10 ground mobile gateways. The ambitious specifications for the ACN demonstrator such as the very high data rate combining WCDMA and TurboCodes, a low latency and a high robustness in electronic warfare environment and the short development time conducted to use a SDR approach. The hardware part is based on a platform with an open and modular architecture and is completely reconfigurable: it is composed of COTS products interconnected through a very high speed network ring. On the software side new MBD and SoC techniques have been tested successfully with a direct result of a great gain in development time and even more in the validation process. The SDR approach combining a modular and flexible platform and a MBD plus SoC methodology has been very efficient to build the ACN demonstrator. The WCDMA waveform demonstrates then its greatest potential and gives to the ACN demonstrator an outstanding performance with double IP capacity compared with the specifications.

1. INTRODUCTION

"Software Defined Radio" (SDR) is one of the biggest issue for the next decades in the telecommunication area, both for military and civilian applications. For instance, on the Network Centric Warfare (NCW) concept, SDR is the key technology to connect and share information between different military and civilian systems. But the SDR subject implies a lot of key technologies, methods and architectures to be developed, designed or invented as the obstacles are important. This paper shows some techniques successfully implemented in the design of a demonstrator of an Airborne Communication Node (ACN) system.

This paper is organized as follow. The first paragraph presents the ACN concept, the key facts and its features along with the awaited performances of the future ACN and its demonstrator where the SDR approach was used. The next paragraph shows the detailed approach used to design the ACN demonstrator both on hardware side and software / firmware side. Then some results and performances are presented in the third paragraph.

2. THE AIRBORNE COMMUNICATION NODE DEMONSTRATOR

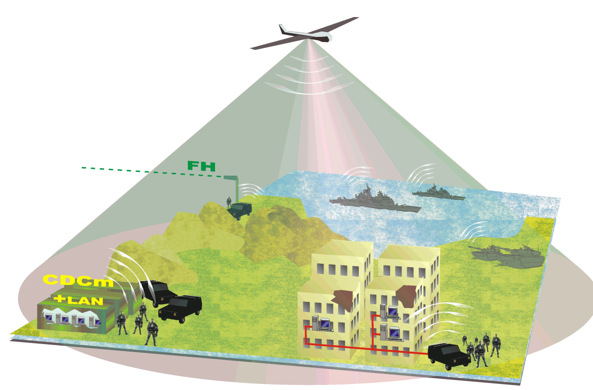

Figure 1: operational view of the Airborne Communication Node

New technologies and concepts such as the SDR allow us to imagine more the communications needs on the theatre of operations around 2015-2020. On one hand there will be necessary for armies to benefit from wireless communication systems having similar performances as fixed infrastructure communication systems without restrictions on mobility and also based on the IP standard. Moreover these new high data rate communication systems have to be easily and quickly deployable. On the other hand actual wireless communication systems

exhibit long deployment delays for a limited mobility and slow data rates.
The idea of an airborne communication node has been expressed from these two statements. The demonstrator of the Airborne Communication Node (ACN) is an advanced study project to verify, demonstrate and try the future communication systems on the theatre. The ACN demonstrator can be seen as a tile of the Network Centric Operations concept.

2.1. ACN Description

In a frist approach, the Airborne Communication Node can be seen a satellite-like system, but without the drawback of the satellite communication solution. It consists of an airborne high data rate communication payload – the node – which serves mobile ground gateways (vehicles, ships, static) over a large coverage area as pictured on the figure 1.
The ACN has very ambitious operational characteristics: as a multi user communication system the radio capacity is very high compared to non satellite based current system with up to 40 Mbps per connected gateway. This data rate is achieved while keeping a top of the art robustness in an Electronic Warfare environment thanks to a WCDMA (Wideband Code Division Multiple Access) waveform. But most importantly the whole system is based on the IP (Internet Protocol) standard to allow a complete interoperability with existing networks and other IP based communication systems. The radio capacity is managed with dynamic radio and network resource allocation between the users to allow a global smart Quality of Service (QoS) management. The QoS is also made easier with a low latency comparable with xDSL connections.
The whole system is moreover very quick and easy to deploy as there is no specific infrastructure constraints and as all the gateways are highly mobile across the coverage area. Through the mobility of the airborne platform, the coverage area can as well follow the ground operations. Despite in the sky, the node flies at a very hughaltitude (stratosphere) to ensure a limited vulnerability.
The ACN demonstrator, developed by EADS Defence & Security for the french MoD (DGA – Délégation générale à l'Armement /SPOTI), exhibits most of these performances with the main features gathered in the Table 1.
For the full scale demonstrations, the chosen airborne platform is an EADS Socata TBM 700, a commercial turbo propeller test airplane and the ground gateways are utility vehicles with a positioned antenna under a radome on the top.

2.2. The ACN waveform

The waveform is one of the innovative concepts of the ACN. It has been designed to provide a high flexibility with a strong implication in the upper layers: the management of the QoS is then facilitated without relaxing the robustness against interferences and jamming. Moreover the physical layer should handle up to 50 users with a high capacity, that is why the WCDMA waveform type has been chosen in conjunction with TurboCodes [1,2,3,4]. WCDMA has a natural protection against jamming and combine a low probability of detection (LPD) and a low probability of interception (LPI). Moreover the code spreading allows dynamic resources management in real time which is necessary to offer a smart network management. One other great feature of this kind of waveform is that the frequency plan is simple as for the 3G cell phones system: all users share the same frequency resource, but they are differentiated through their unique code and scrambling. As for 3G it is also possible to create a cell architecture of many ACNs.
In order to get all these advantages, the drawback is that it requires a quite high algorithm complexity: some functions such as the first acquisition of the WCDMA signal or both phase and time (to match the codes) tracking are very decisive on the global performance of the communication system even more in an Electronic Warfare environment. That point is one of the reasons why new techniques (described in paragraph §3) have been chosen to design and implement such complex algorithms.

Table 1 : the ACN and its demonstrator features

	Full Scale Demonstrator	Target ACN (awaited)
Ground mobile gateways (up to 60 km/h)	10	50
Global Network Capacity (IP)	2x20Mbps	2x100Mbps
Max. Data Rate per User	10 Mbps up	20 Mbps up
Ground Coverage Area	100 km diameter	200 km diameter
Airborne Platform	Commercial airplane (EADS Socata TBM-700)	Open: Stratospheric Balloon, airship, stratospheric airplane, UAV …
Platform Altitude	10 km (33000 ft)	20 km (66000 ft)

2.3. True networking on the theatre of operations

The use of the standard IP protocol ensures the maximum interoperability providing end to end connections. The global ACN is then completely seamless for all users. On a network architecture point of view, the ACN can be seen as an airborne backbone as the node is not a simple communication relay but a true node with routing capabilities and smart QoS management. Each gateway can be connected to a LAN to extend the connection to local networks and/or to existing wired or wireless network architecture.

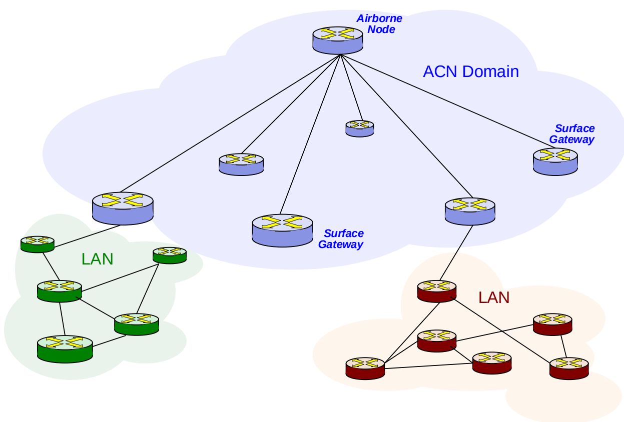

Figure 2: ACN equivalent network

Indeed one other innovative concept of the ACN system is the management of the quality of service that is eased thanks to the dynamic radio resource allocation in real time. The optimized QoS mechanism protects the priority flows and ensures a minimum data rate safeguard to each gateway. The algorithm manages of course a real time estimate of users needs with an optimal use of the global radio capacity according to the traffic volume of each gateway and the type of traffic.
Then standard network applications such as streaming video, voice over IP, video conference, emails and data can be used through the ACN communication system as if it was a wired infrastructure thanks to the very high data rate and the QoS management and so the seamless and transparent aspect for the end user.

2.4. Concepts of Operation

Considering the networking capabilities of the ACN system plus the ease of deployment, it can be used in many operational contexts both for civilian and military applications.
Thanks to the native IP connectivity, the system can connect many heterogeneous networks to provide a true **cooperative engagement** for joint operations between nations. Ground gateways can be mobile, static, on ships …etc.
As the node is airborne and flies at very high altitude, the communication system can also serve for **lacunary missions** even if a gateway is in a deep valley. The ACN covers a wide area and then allows an interconnection between isolated operational units and a command and control centre for example.
As its deployment is quick, the ACN can be used for a **crisis management**: in case of non-existent, destroyed or overloaded communication infrastructure the system restores quickly the communications on a wide coverage area and with a high communication capacity. It can help for example for peace restoration, homeland security or to cover a natural disaster.

3. THE ACN DEMONSTRATOR AND THE SDR APPROACH

The ACN demonstrator is only a 3 year project including full scale in-flight demonstrations. The asked performances were quite ambitious in 2003. Indeed there were many problems to surpass:
The high radio capacity of the system requires high speed and large bandwidth digital converters but also high speed components in conjunction with efficient algorithms such as a fast implementation of the Turbo channel coding/decoding.
The link budget and the waveform need a iso-power airborne antenna (as the power control is very important in WCDMA systems to maximize the capacity) and a performing positioning device for the ground antennas and above all to guarantee a high mobility to the ground gateways.
These were just some examples of the encountered constraints that lead us to use a SDR approach. The designed radio system is only SDR “like” in the way that the demonstrator is not based on the SCA architecture for many reasons. Indeed at the beginning of the project we feel that the SCA architecture was already mature but unfortunately it was not the case of the tools to develop a SCA compliant system. Moreover the WCDMA waveform needs a lot of hardware and computational resources, then letting less room for the software components of the SCA architecture (Core Framework, Corba). And the last point is a political one as we did not feel any big interest at the beginning of the project to conform to the SCA architecture used in the JTRS program.
But if we have decided not to use SCA, other sides of SDR technology have been explored. The global approach goes with the hardware side and the platform and then on the software side with the design tools and methods.

4. THE HARDWARE PLATFORM

4.1. The hardware architecture

The chosen architecture for the hardware platform is based essentially on components off the shelves (COTS) products due to the limited schedule of the whole project. The ambitious wanted performances imply a smart architecture doubled with a high level of performance: high speed broadband converters are needed plus high speed multi million gates FPGAs and DSPs to cope with the algorithms complexity.

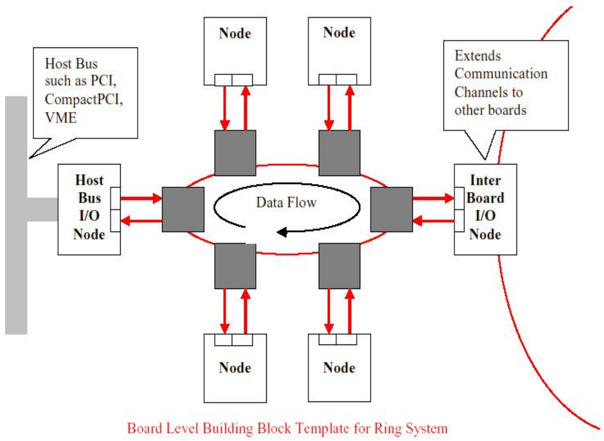

Figure 3: hardware architecture organized in a network

The SDR approach relies on a more generic platform to be used for other waveforms. The “generic” aspect takes place on one hand on the hardware side (the platform’s capacity) and on the other hand on the software side for the interface, the reprogramming and the reconfiguration. That is why a modular architecture has been selected to get the desired performances and flexibility.
The solution consists in a PCI carrier board where you can plug in daughter boards. These boards are simple hardware bricks or modules. 3 main types are available: a single FPGA plus memory module, a single DSP module or an I/O module with 2 pairs of converters (ADC+DAC) connected to a FPGA. But the interface’s standard for the daughter boards is open and so it is possible to design its own module. The PCI motherboard offers a multi gigabit interconnection between these daughter boards through a high speed ring.
Then the software architecture is based on this ring network between the hardware modules or nodes as in the Figure 3..
Each module concentrates on dedicated functions of the waveform such as the acquisition, time and frequency synchronization, phase and time tracking, the de/modulation or the TPC (TurboProduct Code) FEC and the hashing and reconstruction of the Ethernet frames. A DSP manages the high speed ring and the modules and interconnects with the main software and GUI.
The carrier boards are mounted in an industrial type PC which makes up the whole digital signal processing of the node or a gateway. Only a router for the IP interconnection, a hyper frequency part and an antenna are added: the whole system (except the antenna positioning system) remains also quite compact taken into account the performances and fits in less than half a standard 19 inches bay.

Figure 4: carrier board with 2 modules

4.2. The architecture advantages

The main advantage of this kind of architecture is to offer at the same time a modular development of the waveform but also to offer a large opportunity for the future ACN system.
Indeed each module implements specific functions of the emission / reception chain which can be tested as single units independently of the other modules. Thus the complete design of the firmware for a board becomes less dependent of some problems that can be encountered on a specific module.
Moreover a module can be easily be exchanged: either a module can be faulty or the design specifications need a bigger FPGA to run the functions. It is then possible to follow the FPGA evolutions without changing the whole system and most importantly the architecture. As the silicon world is changing rapidly this approach let us view a smooth change to the final ACN.
Finally the hardware platform is flexible at the same time at the hardware level but also at the software level, as all the programming, the reconfiguration, the management is done by software through the high speed link between the modules.

5. THE SOFTWARE APPROACH

The software approach is based on two techniques. The Model Based Design (MBD) is more a methodology to master the development of a project at a "system" point of view and the System on a Chip (SoC) approach which is a technique to accelerate the development process. Both approaches are now detailed.

5.1. Model Based Design (MBD)

Within the framework of the ACN demonstrator development, all the waveform creation has been done with Matlab/Simulink [5]. This tool allows to set up a complete waveform implementation and then to simulate it to get an access to the main global performances at a very early stage of the development. That is why a modeling of the ACN demonstrator has been developed at the beginning of the project to validate the choices and parameters for the waveform.

The design has then been completely led by following this model based approach. The major problems are isolated from the beginning and the global performances of the system, radio link, is mastered: so you can choose and test the right solutions even before the coding phase.

For example, the impact of the power amplifier's non linearities on the radio capacity has been simulated in the early stages to refine the specifications for the supplier. But also these simulations have allowed us to relax some constraints on certain parameters while knowing the precise impact on the global performances.

In other cases, possible technical solutions can be tried and tested through the use of global simulation models: it was the case when choosing a channel coding technique to cope with strong military jammers.

5.2. The System on a Chip (SoC) approach

Simulink as a MBD tool was also the main tool to design some specific algorithms such as phase and code tracking. For these examples a SoC approach has been used via a rapid prototyping tool under Simulink. Indeed this tool allows a more hardware oriented modeling of the function to test it and validate it with more real world considerations. Once validated the main feature of this tool is to generate automatically the VHDL code or a Netlist from the model under Simulink, then bypassing the classic hand coding stage.

This process is entirely compatible with the MBD methodology as we also keep the "above" system view while allowing the design of complex algorithm up to quite a deep level. The simulation has then 3 levels of abstraction:

– Software only via Simulink: completely hardware independent
– Software only with quantization Simulink
– Hardware co-simulation of the algorithm with automatic code generation: true simulation of the future FPGA firmware.

These 3 levels offer a full control on algorithms to be implemented into a FPGA. Thanks to the MBD approach, the system validation and the parameters optimization can be successfully done under simulation which can be accelerated through the hardware co-simulation. The global and detailed views are kept at all steps of the design on the contrary of a validation on the bench with the final hardware platform.

As the rapid prototyping tool produces a reliable VHDL code with regard to the simulated algorithm, the validation stage is reduced to a global functional validation, then by-passing conventional unit validation. For the demonstrator a full validation process has been conducted in the lab as this kind of tool is new but the behaviors are so comparable between the real implemented function and its model that with this tool full detailed validations are now useless.

6. FIRST RESULTS AND CONCLUSIONS

6.1. Some conclusions regarding the software approach

At the beginning of the project a detailed model of the communication system (up to information bits) has been made under the Simulink environment to validate the waveform choices (multiple access technique, channel coding, etc. …) and the early theoretical calculations to size the system. With this model, simulations of the radio capacity, the robustness to interferers, the filter characterization and the modeling and validation of the performances of the algorithms have been simulated and the results were a very good starting point for the global real validation of the demonstrator. All measurements show a direct match between the simulated and real performances.

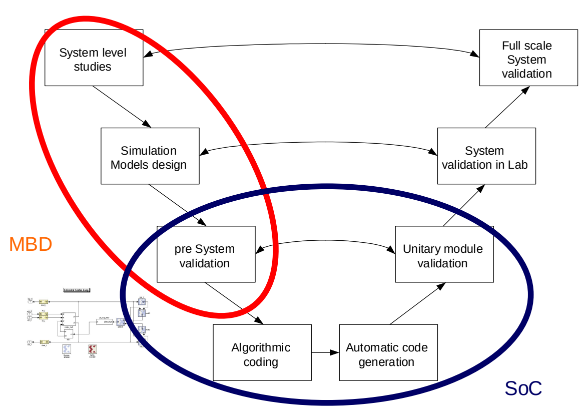

Figure 5: development process of the ACN demonstrator

Indeed both the MBD and SoC approaches set a perfect control on the system from the beginning. The Figure 5 shows the overall process. The good technical choices are then rapidly done without forgetting the global performances. It is true that more time is used for the system simulation but the automatic code generation and most importantly the reduced validation process thanks to the perfect match simulations / real world save a lot more time during the development stage.

The global approach used for the ACN demonstrator system development is fully compatible with the one used in the SCA architecture [6] where waveforms are applications running on a generic architecture platform. Here the waveform is a Simulink model which runs on a GPP and a FPGA (for hardware co-simulation). Simulink plus a rapid prototyping tool provide the hardware abstraction layer.

6.2. First results

Thanks to the MBD + SoC methods combined with a proprietary waveform design the system is showing a great potential: first results show a radio capacity up to 40 Mbps, so the double of the specifications.

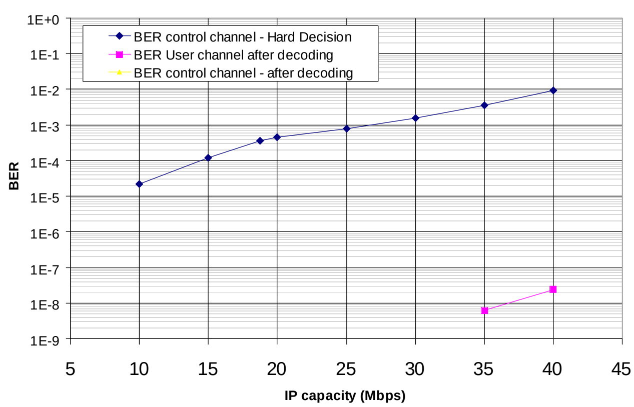

Figure 6: Bit error rate versus IP capacity for 4 connected gateways

7. CONCLUSION

This paper shows the successful SDR approach used to build the ACN demonstrator. It shows today the performances of tomorrow's communication systems. The specifications were ambitious but the SDR approach conducts to a perfectly controlled system in a reduced schedule. The MBD and SoC approaches use a model almost compliant with the final system which decrease dramatically the validation process and bring a total control over the whole system at any stage of the project.

Moreover the ACN demonstrator delivers a high level QoS, management capabilities and mobility through a wide coverage area and it is really easy and fast to deploy. The demonstrator is now a R&D system but could be a part of future Network Centric Operations.

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