FINNISH SOFTWARE RADIO PROGRAMME

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ABSTRACT

This article describes the developments in the field of emerging new military radio systems to be deployed in Finland. Finnish software radio programme is the tool to deploy these new systems. The demonstrator platform, that is being build, is a software defined radio wherein the developed wideband applications can be demonstrated. The systems that will be deployed on the demonstrator platform - Tactical Radio Communication System (TRCS) and National Tactical Positioning System (NTPS) - are introduced in this paper. Brief introduction of the adaptive antenna system to be applied in the demonstrator is also given.

1. INTRODUCTION

In the early 1990s, it was understood that Software Defined Radio (SDR) provides a platform that will be used in implementation of future radio systems. Research of the Finnish SDR concept began by the initiative of the Finnish Army Staff and is supervised by the Finnish Defense Forces' Technical Research Center. About at the same time, Finnish Navy realized that it needs a communication radio system which is better protected against electronic warfare and is more flexible than systems that were and are still used. The Navy was also concerned about the fact that navigation on sea areas is more and more based on techniques not under national control. Later on, it was demonstrated that adaptive antennas provide increased protection against electronic warfare. In 2002, the three parallel system R&D projects - communication, navigation and adaptive antennas - were combined and a decision was taken that they are the first ones to be implemented in the Finnish SDR Demonstrator. The following sections provide a brief introduction to the SDR demonstrator and to each of the three systems. The systems are described more thoroughly in [1]. The demonstrator development was awarded to Elektrobit, Ltd. March 2003 and estimated delivery of the demonstrator is February 2006.

2. SOFTWARE DEFINED RADIO - KEY ENABLER

Better, costlier and more capable armed forces need improved communications to support their operations and to maintain proper command and control as well as situational awareness in a variety of scenarios yet still providing operational security, information security as well as communications security appropriate to the task at hand. Software Defined Radio (SDR) is an excellent solution which assures efficient wireless communications in network centric warfare because it fulfils all the requirements stated above.

SDR includes wideband sampling of the extremely wide radio frequency band. This allows simultaneous connections to multiple different radio communication networks thus providing flexibility in frequency ranges and waveforms. Importantly, several simultaneous waveforms can be used in one radio platform. As SDR is software based, upgrading to new waveforms and functions is possible. Together with proper hardware architecture design and the use of open interfaces, the insertion of new hardware technology without extensive waveform verification becomes possible.

In the future, the appealing features of SDR may create a totally new radio technology market where the customer procures software based waveforms and hardware from different vendors. It is also envisaged that multi-channel operations reduce the number of radio equipment needed for instance in a command vehicle or on a ship. The emergence of radio set families reduces the number of different radio types thus improving maintenance effectiveness. Furthermore, software based waveform development allows access to new independently developed waveforms even for small non-aligned countries. The demands of national security and information security on Electronic Protection (EP) aspects may be relaxed when developing and operating specific new waveforms for crisis management in joint combined peace support operations.

One can summarize the expectations set for the SDR-platform as being bridge between different battlespace systems that are used for acquiring enhanced situational awareness.

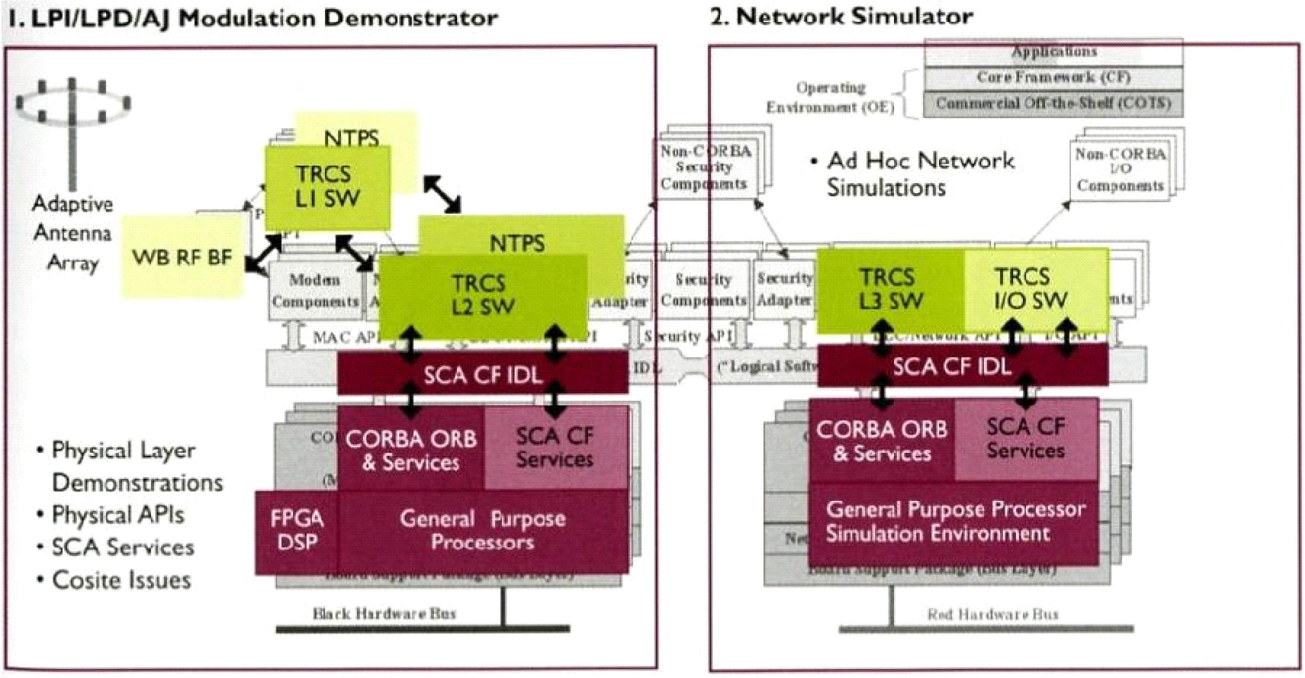

Fig. 1. Architecture of SDR demonstrator vs. SCA.

3. FINNISH SOFTWARE RADIO DEMONSTRATOR

The Finnish Software Defined Radio Demonstrator project is a national technology demonstration required before full-scale SDR system development and acquisitions can be started. The key technologies involved are seen immature and need to be demonstrated in order to ensure that both technical and cost risks are understood and are at acceptable levels prior to decision-making and acquisition. The demonstrator project focuses on the following four key technologies:

1. New national wideband waveforms
2. SCA based software architectures
3. COTS based hardware architectures
4. Smart antenna in SDR.

Two wideband waveforms, Adaptive Wideband Networking Waveform (AWNW) and National Tactical Positioning Waveform (NTPW) as well as SDR architecture, which have been developed in the research programs carried out by the University of Oulu, are implemented in the demonstrator project. The implementation and demonstration of the AWNW waveform is divided into two separate testing platforms (Fig. 1). The physical and link layers are implemented, verified and validated on the SDR platform, whereas the network layer protocols are implemented and simulated in a simulating environment developed in the project. Implementation of these novel waveforms is a challenging task and requires careful design. For example, the two waveforms, although being similar in their air interfaces but serving different purposes, are required to function simultaneously on the SDR platform. This raises some challenging co-site issues.

Interoperability requires waveform portability. This can only be achieved with standardized SDR architectures and waveform software compatibility. The Software Communications Architecture (SCA) developed in the U.S. Joint Tactical Radio System (JTRS) program is becoming a de facto standard providing maximum waveform portability. In addition, the demonstrator R&D contractor Elektrobit Ltd sees standardized physical Application Programming Interfaces (API) critical for true waveform portability. Therefore, the waveforms are developed to be compatible with the SCA specification, version 2.2.

SCA version 2.2 is used as a baseline for the software architecture of the SDR demonstrator. An SCA based Core Framework and Operating Environment is developed by Elektrobit Ltd to gain valuable hands-on experience in the area of SDR software architectures in general and SCA in particular. Deep understanding of SCA is seen as a key technology for future portable waveform development, as well.

Hardware development of the SDR demonstrator is pragmatic and practical. The demonstrator is maximally

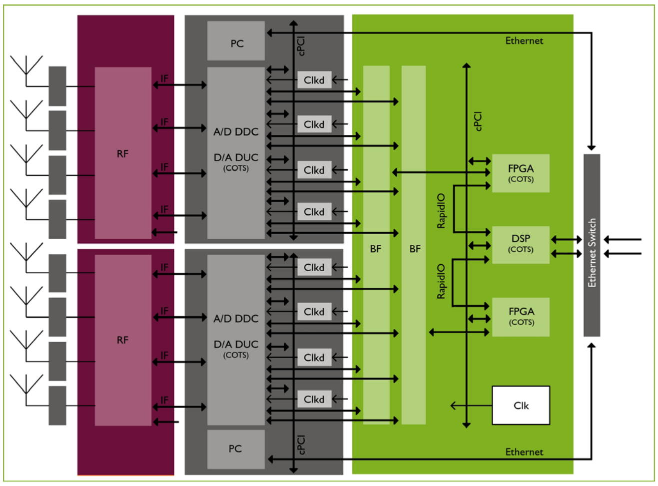

Fig. 2. SDR demonstrator structure.

based on Commercial Off-The-Shelf (COTS) components and subsystems in order to minimize development risks and shorten the development cycle. The general structure chosen for the SDR demonstrator is depicted in Fig. 2

The SDR-3000 subsystem of Spectrum Signal Processing, Inc, is evaluated as a baseband processing engine in the demonstrator. Another COTS subsystem under evaluation is the A/D interface based on the wideband ADC boards of Nallatech Ltd. These subsystems provide standard interfaces and form factors suitable for laboratory environment, together with mature development tools. However, proprietary hardware is needed for the most demanding tasks. These include wideband radio frequency (RF) subsystems, digital beamforming of the waveforms, and accurate clock reference generation and control for positioning.

Implementation of a smart antenna in the SDR platform demands for special architectures both in hardware and in software. Antenna element studies are carried out by PJ Microwave in the project and a circular antenna array prototype will be developed according to specification given by the University of Oulu. The antenna array will be integrated into the SDR demonstrator. Real-time implementation and performance of selected adaptive algorithms will be demonstrated. Wideband adaptive beamforming requires complex high-speed interconnection circuitry and logic. In addition, the logical interfaces of the smart antenna in the SDR need to be specified. The smart antenna and the adaptive algorithms linked to it are seen as a part of the platform providing services to the waveforms.

The Finnish SDR demonstrator project will provide the Finnish Defence Forces the sufficient information for prototype development and acquisition decisions of software defined radios and national waveforms in 2006. The demonstrator equipment itself will serve as a powerful, modular and scalable development platform for future military and commercial 4G waveform development.

4. NEW TACTICAL RADIO SYSTEMS

In addition to building a software defined radio platform, the demonstrator programme consists of three major subprojects, namely: 1)Tactical Radio Communication System (TRCS) with adaptive AJ/LPI/LPD networking waveform, 2) National Tactical Positioning System (NTPS) and 3) Adaptive Antenna System (AAS).

4.1. Tactical Radio Communication System

The Tactical Radio Communication System (TRCS) was originally a research project funded by the Finnish Navy but has since grown to specify a joint tactical radio system for the Finnish Defense Forces. The objective of the project is to specify and develop a radio communication system which will enable efficient and flexible communications, control and co-operation in the battlefield of the future in demanding electronic warfare environment. The concept research has resulted in Adaptive Wideband Networking Waveform (AWNW).

The radio communication system must be capable of inter-operating between the defense services - it must contain different modes with different data rates for different purposes as well as exceptionally good Low Probability of Intercept/Low Probability of Detection (LPI/LPD) and Anti-Jamming (AJ) capabilities. On the physical layer, these demands are fulfilled by efficient use of direct sequence spread spectrum, multicarrier and frequency hopping techniques. The radio system must be future proof. Implementation by a software defined radio (SDR) platform guarantees easy upgrading of the system and compatibility between different radio systems. On the network layer, the emphasis has been on semi Ad Hoc routing and the survivability and zero configurability of the protocol stack. The new TRCS system:

- is based on software defined radio platform
- is a spread spectrum system with advanced and highly flexible waveform (AWNW)
- allows data rates from few bits to megabits per second
- supports interoperability
- exploits advanced network operations
- has different modes of operation and priorities for different communication needs
- can transport voice, data, still pictures, video and sensor data
- uses adaptive antennas to enhance LPI/LPD and EP capabilities
- enables several simultaneous logical connections for dedicated datalink applications, e.g. UAV communications.

The assets of TRCS are manifold as can be seen from the previous list.

4.2. National Tactical Positioning System - NTPS

The second project of the programme is the National Tactical Positioning System (NTPS). As a spin off of the TRCS research, it has been identified that mobility in difficult terrain, weather and/or visibility, is a necessary requirement in future warfare. On the other hand, features that support battle space management and situation awareness are also requested. These demands are met by an AJ and LPI/LPD position and navigation system. The globally available Global Positioning System (GPS) is one possibility. Whereas GPS is not under national or European control, GALILEO - the European controlled satellite positioning system - will be. According to current plans, it will be taken into use in 2008.

Despite of the global availability of GPS or GALILEO, the satellite systems are vulnerable. The positioning signals they provide are quite easily jammed due to their very low power level at a positioning receiver. This means that local usability of the current satellite based positioning systems is debatable in a hostile environment. In this light, it is not surprising that AJ device research for the GPS system is active right now. This research mostly rises from the need for smart munitions.

Considering that precise timing information is already needed and maintained by the software radio platform to perform synchronization of advanced waveforms, it is by minor natural extension, that positioning services can be implemented to the system. The operational requirements of the national tactical navigation and positioning system are fulfilled using signal design, spread spectrum techniques, advanced signal processing and adaptive antennas. The specification process has included the definition of system parameters such as navigation signal waveform -National Tactical Positioning Waveform (NTPW) - transmitter and receiver architecture design, receiver algorithms etc. On network layer, NTPS relies on the solutions given in TRCS system.

A separate navigation system was designed because transmissions in the jointly designed communication system need not be regular so that the communication signals cannot be used for continuous navigation. Also, the communication network does not necessarily offer dense enough coverage.

In typical positioning systems, Base Stations (BS) transmit navigation signals. Mobile Stations (MS) estimate time-of-arrival (TOA) at least from three navigation signals (2-D positioning) in order to be able to estimate their positions. It is indeed true that ambiguous position estimates can be computed from two navigation signals. Positioning estimates are ambiguous in the sense that two solutions are provided. If the ambiguity can be solved using a previous unambiguous solution, it is possible to build a more sparsely spaced navigation BS network that saves costs.

The accuracy of the NTPS depends on the accuracy of TOA measurements and mutual BS synchronization. TOA estimation accuracy in the presence of interference has been studied a lot in the literature as well as in the University of Oulu.

In satellite systems, the accuracy of the mutual BS synchronization is attended by earth based control station networks. Local positioning networks are typically synchronized differently. For example, master station based systems can be used but they are very vulnerable against weapon actions. This is the reason why future military systems employ decentralized network synchronization strategies where synchronization is attained by using good clocks, several kinds of synchronization algorithms and hierarchical systems.

A new BS can be added to the system rather easily because it merely synchronizes itself to the network and is ready for use. Subsequently, users are informed about the new BS. It is possible for the new BS to be placed in a predetermined location or that its location is determined by positioning measurements. Since the (new) BSs are immobile, they can average signals for a longer time than a mobile receiver. Longer averaging time increases the positioning and network synchronization accuracy and, at the same time, increases AJ properties of the network.

The accuracy of clocks chosen for the system defines the time in which BS synchronization may be totally lost. It may be minutes, hours, days or even months. When a receiver is synchronized to the network, it simply tracks possible changes on time delays.

The signal used in the NTPS is a DS/FH signal. The BSs are separated by TDMA so that the positioning system does not bite too much of the frequency band allocated for the systems. Navigation and communication systems are separated by hopping codes (FH-CDMA). The NTPS receiver has to give an estimation of the positioning accuracy. The communication and navigation systems can share BSs but it is also envisaged that in some situations a simpler navigation BS is required.

4.3. Adaptive Antenna System (AAS) for Tactical Radio Systems

The objective of the third project -Adaptive Antenna System (AAS)- is to specify adaptive antenna arrays and algorithms for tactical radio systems of the Finnish Defense Forces such as TRCS and NTPS. It is well known that with adaptive antenna arrays, or smart antennas, it is possible to adjust transmitter and receiver antenna patterns in a dynamic way according to the (hostile) signal environment. The functions

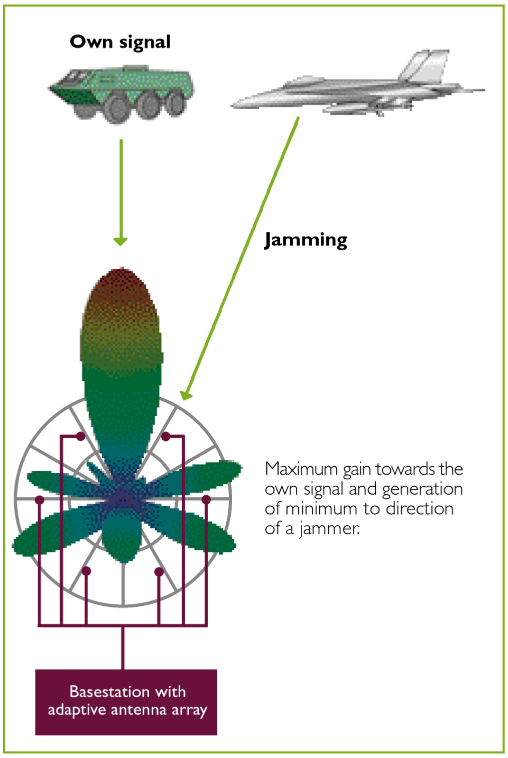

Fig. 3. Adaptive antenna system in hostile environment.

of an adaptive antenna system in such circumstances are presented in Fig. 3. The advent of powerful low-cost Digital Signal Processors (DSPs), general purpose processors (and ASICs), as well as innovative software based signal processing techniques (algorithms) have made smart antennas practical. A multitude of various algorithms can be used by an SDR implementation platform depending on the scenario. This also guarantees easy upgrading of the system which is crucial for usability.

The main fields of the adaptive antenna array research have been digital beamforming, signal environment sensing, space-time adaptive processing and electromagnetic simulations of antenna arrays. With electromagnetic simulations, 3-D radiation patterns of antenna arrays can be simulated with real antenna models. Similarly, simulations have been performed to test the effect of mutual coupling between antenna elements and the effect of the mast and surroundings. The simulation models of designed antennas can be used in array simulations which enables the study of the effects of electromagnetic phenomena to various algorithms.

An adaptive antenna array is able to improve the performance of a tactical radio system in a number of ways. An antenna array is a spatial filter, which property may be exploited in transmitting as well as in receiving modes to reduce interferences. In the transmitting mode, it can be used to focus radiated energy by forming a directive beam in a small area where a receiver is likely to be. As a result, the probability of interception is reduced and demands put up to power amplifiers are relieved. Further improvement in LPI/LPD properties can be achieved by actively steering the nulls in the radiation pattern towards assumed enemy detectors' directions. In the receiving mode remarkable improvements in interference rejection can be achieved by steering the nulls in the radiation pattern toward jammers. By an N element array we can generate a maximum in the direction of desired signal and N-2 nulls toward the jammers.

By using sophisticated signal processing algorithms, DOA (Direction-Of-Arrival) estimation and beamforming can be made digitally in the base band. DOA estimation is needed when the directions of desired signals or the interference signals are unknown. After the DOA estimation, the adaptive beamforming can be performed. Using digital beamforming different types of beams, such as scanned beams, multiple beams, shaped beams or steered nulls can be produced in software.

When implementing an adaptive antenna system, many practical aspects have to be considered such as element misplacement, mutual coupling between elements, amplitude and phase mismatch between channels and quantization to name a few. The element patterns and misplacements as well as amplitude and phase errors can be eliminated by using sophisticated calibration algorithms.

5. PROGRAMME SCHEDULE

Research and development activities within the Finnish Defence Forces and those in industry and research institutes are incorporated under the demonstrator phase of the Finnish Software Radio Programme. The whole SDR programme has been divided in several subprojects. As described in the introduction section, the programme was launched by the Defence Staff in November 2002 and may be viewed as a logical continuation of previous broadband wireless techniques (spread spectrum, multicarrier techniques) and software radio architecture research projects as can be seen in Fig. 4**.**

In addition to building a software defined radio platform, the demonstrator programme consists of three major subprojects, namely: 1) Tactical Radio Communication System (TRCS) with adaptive AJ/LPI/LPD networking waveform, 2) National Tactical Positioning System (NTPS), 3) Adaptive Antenna System (AAS).

All of these subprojects contain both research and development tasks. The main research contract has been awarded to the University of Oulu and the development contract to Elektrobit Ltd. The demonstrators and acceptance tests shall be completed by March 2006.

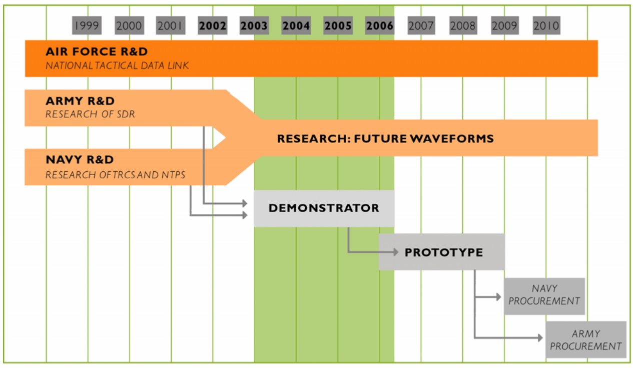

Fig. 4. The time schedule of the Finnish software radio programme.

Fig. 5 illustrates a vision of how new applications can be introduced to the SDR -platform. Currently, an SDR-demonstrator (SDR-DEMO) is being built to demonstrate the antijam and LPD/LPI properties of the adaptive waveforms in TRCS and NTPS. The SDR-DEMO will utilize antenna array to further enhance the performance. The sufficient accuracy of network synchronization for NTPS application will also be demonstrated. The SDR-DEMO will demonstrate its capability of serving simultaneously multiple wideband applications under Software Communications Architecture (SCA), i.e. to verify the SDR principle.

In prototype stage (PROTO 1) speech will be integrated into the AWNW waveform. The protocol stack of the SDR-DEMO will be upgraded in PROTO 1 to allow data transfer in heterogeneous networks. The frequency range in PROTO 1 will also be widened to include HF and lower VHF frequencies leading to the first operational series (Series-Navy)

The development path of SDR will lead to joint services series (Series-Defence Forces). This SDR platform can be tailored for different uses by software reconfiguration. The new additional applications in the defence forces series could include electronic warfare services, software radar (radar signal processing), the developed Finnish air force waveforms as well as other non-national waveforms (e.g. TETRA, GALILEO, GPS).

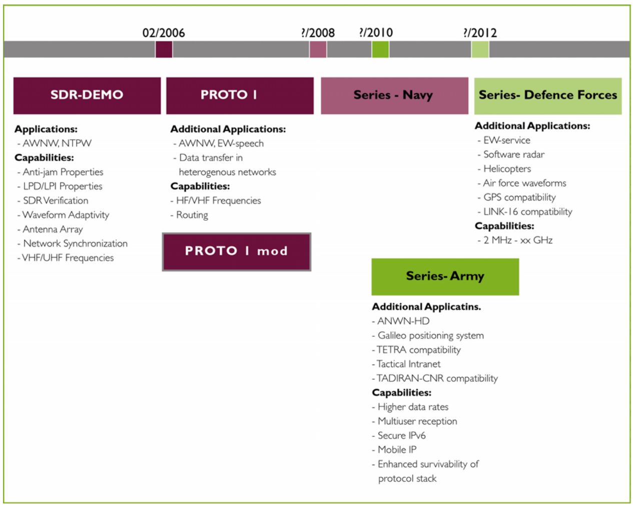

Fig. 5. Possible roadmap for additional services to be included in the SDR platform.

6. CONCLUSIONS

We have presented the Software radio demonstrator and the radio systems to be deployed onto it.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] T. Tuukkanen, A. Pouttu and, P. Leppänen, *Finnish Software Radio Programme*, ISBN 951-42-7187-4, 2003.