Finnish Software Radio Programme

Topi Tuukkanen, Finnish Defense Forces **Ari Pouttu, Pentti Leppänen,** Telecommunication Laboratory and Centre for Wireless Communications (Eds.)

Finnish Defense Forces
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Finnish Defense Forces

FINNISH SOFTWARE RADIO PROGRAMME

Telecommunication Laboratory/
Centre for Wireless Communications

Topi Tuukkanen, Finnish Defense Forces, Ari Pouttu, Pentti Leppänen, Telecommunication Laboratory/Centre for Wireless Communications (eds.)
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Contents

Executive Summary

The roles and tasks of defense forces and their mutual relations are changing. International peace keeping is gaining a more significant role as the threat of armored attack diminishes. In addition, large scale national disasters and defense against terrorism necessitate the use of armed forces in support of Civil Society.

Simultaneously, technology developments enhance weapon and sensor capabilities. As a consequence, units and forces become more effective, costlier and therefore more valuable. Fewer units are needed for the same level of performance. On the other hand, reduction in the number of units necessitates an increase in their mobility. Improvements in the command, control and communications, battlespace management and situation awareness become necessary.

Since the 1980s the Finnish universities, research laboratories and industry have been developing data link systems in collaboration with the Finnish Air Force. The latest prototype of the National Tactical Data Link system based on spread spectrum technology and the flight tests are currently on-going.

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 (EW) and is more flexible than systems that were and are still used.

The parallel research projects were combined and a decision was taken that the Navy services are the first ones to be implemented in the advanced Finnish SDR demonstrator. In the future, advanced communication, navigation and adaptive antenna array systems will be used by the Finnish Defense Forces. The requirements for future advanced mobile communications systems to be used by the armed forces were obtained by analyzing the features that the envisaged future battlespace sets. The Finnish Software Radio Programme (FSRP) was established to support these requirements for:

- mobility
- localization capabilities
- interoperability between national and international civil authorities
- interoperability within own armed services and foreign armed forces
- bridging between nets of different kind
- operations in hostile electromagnetic environment
- extensive use of commercial components and standards

To summarize, 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.

Currently, the FSRP is in the demonstration phase – the Finnish Software Radio Demonstrator Programme. The demonstrator phase will be introduced in detail including general technological advantages, schedule, and sub-projects on software technology demonstrator. The demonstrator programme consists of

- software defined radio platform on which
- adaptive AJ/LPI/LPD networking waveform for Tactical Radio Communication System (TRCS),
- National Tactical Positioning System (NTPS) and
- Adaptive Antenna System (AAS) will be build.

This programme has been made possible by the success of Finnish telecommunications industry and by the support of related scientific community. All of these programme tasks contain both research and development tasks. The main research contract has been awarded to the University of Oulu, more precisely the Centre for Wireless Communications (CWC) within the Telecommunication Laboratory, and the development contract to Elektrobit Ltd. The demonstrators and acceptance tests shall be completed by March 2006. This document provides a brief introduction of the programme as well as each of the sub-systems and research areas.

Abstract

This document describes the evolution path toward Finnish Software Radio. The Finnish Software Radio Programme (FSRP) has been divided into several phases to manage research and development risks and currently the program is in its demonstrator phase - Finnish Software Radio Demonstrator Programme. The demonstrator platform, that is being build, is a software defined radio wherein the developed wideband applications can be demonstrated.

The document has been divided into three parts. The first part gives an overview of the programme covering some of the history of the development activities as well as the military operational requirements and expectations. The systems that will be deployed on the demonstrator platform - Tactical Radio Communication System (TRCS) and National Tactical Positioning System (NTPS) - are also introduced. Brief introduction of the Adaptive Antenna System (AAS) to be applied in the demonstrator is given. Part I also gives an discussion on the roadmap to possible future applications to be included in the Finnish software radio as well as a description of the co-operation model applied in the programme in achieving these new applications and also in the demonstrator phase.

Part II concentrates on future enhancements to be achieved through research. It first gives a more detailed description of the waveforms used in TRCS and NTPS as well as some future development trends related to TRCS and NTPS. It describes to some detail the physical layer parameters applied in the adaptive waveforms. Adaptive Wideband Networking Waveform (AWNW) used in TRCS has currently four main modes with large degree of adaptivity within each mode. The future development of the waveform includes higher data rates and capacity through MIMO techniques and multi-user receivers, enhanced antijam properties and inclusion of EW speech to name a few. The National Tactical Positioning Waveform (NTPW) used in NTPS has currently two main modes: one with excellent electronic protection (EP) properties through FH/DS/TDMA design and one with more capable positioning and navigation properties through DS/FDMA design. The physical layer parameters within these two modes can be rather freely chosen. Part II also discusses the possibilities and challenges to be resolved when choosing software radio as the implementation technique. In order to implement all signal processing operations in the digital domain, the whole operating frequency range of the radio has to be sampled and A/D converted. The radio platform has to be also able to handle multiple processes with unequal sampling rates including different synchronization and timing requirements. A software radio must be able to handle dynamic allocation of processing resources between different applications. If processing resources run out, the radio must have means to determine the priority of various connections. RF parts of a software defined radio must be able to handle wide bandwidths varying from HF frequencies to microwaves. It is presumed that a software radio can transmit and receive several signals simultaneously. Efficient, broadband linear transmitters are a necessity in an environment characterized by multiple transmitted signals, high data rates and multicarrier modulation methods. Therefore, a receiver must be able to handle signals that have highly differing power levels without use of the automatic gain control.

Part II is describing also the trends in development of the adaptive antenna system as well as the protocol stack in future versions of the SDR. In the field of adaptive antenna system, the main effort of the research is on applying algorithm bank methodology with appropriate algorithms. Another field of research is in the compensation and calibration techniques to resolve the problems that arise because of element misplacement, mutual coupling between elements, amplitude and phase mismatch between channels and quantization to name a few.

Software defined platforms and configurable radio networks constitute a flexible solution to enable communications between heterogeneous wireless networks. Such solutions are required in international co-operation tasks and joint operations where communications are needed across service boundaries. As a potential integrating backbone of joint military forces, SDR technology could be the key technology for future network centric warfare vision being created. Hence, the protocol stack will be gradually upgraded. The survivability of the protocol stack will be enhanced by intelligent routing and secure IP as well as mobile IP. This enables the use of tactical intranet and also connections to the public internet. Research and development aiming for implementation of adaptive protocol layers has been one of the major fields of study in networking recently.

Part III of the document is presenting the key players of the programme. It sheds light on the roles of different players and also gives a more comprehensive depiction of the core competencies of the companies and the Telecommunication Laboratory/CWC that are involved in the programme.

PART I: **Programme Overview**

1. Introduction

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LtCdr Topi Tuukkanen, *Finnish Naval Academy*
Lich.Tech. Ari Pouttu, Dr.Tech. Harri Saarnisaari, *University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications*

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. This variety of systems was studied in the Telecommunication laboratory of University of Oulu. Since the May 2003, the Centre for Wireless Communications of University of Oulu performs this research. In 2002, the three parallel systems were combined and a decision was taken that they are the first ones to be implemented in the advanced Finnish SDR demonstrator. In the future, advanced communication, navigation and adaptive array systems will be used by the Finnish Defense Forces.

The following sections provide a brief introduction to each of the three systems. In addition, other possible applications for SDR will be discussed. The communication system includes processes for routing and multiple access. However, connection to other systems as well as efficient usage of these systems requires further research in network protocols. Therefore, military network research will be included in the forthcoming presentation. The use of heterogeneous networks, both civilian and military, set new demands for the protocol stack of the SDR devices. The network centric aspect of the future is depicted in Figure 1-1.

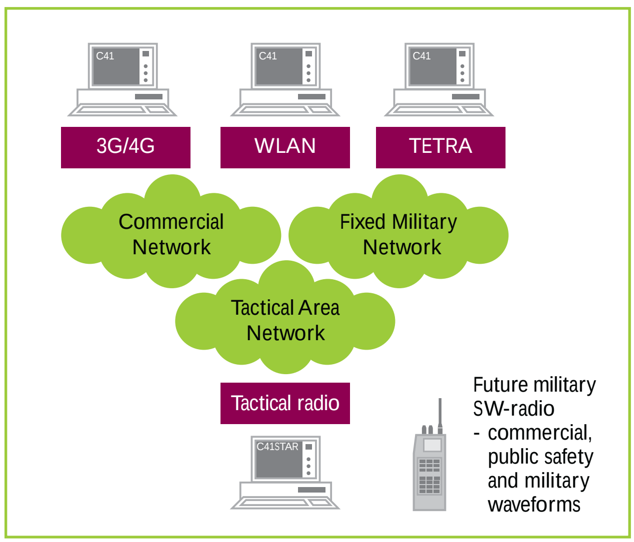
In addition to providing EP properties, it can be said that since adaptive arrays perform direction-of-arrival (DOA) estimation all the time, they provide Electronic Support (ES) information. Consequently, future communication networks form also electronic support networks. It is essential that the increasing information flow can be efficiently transmitted without blocking the primary communication flow.

The requirements for future advanced mobile communications systems to be used by the armed forces were obtained by analyzing the features that the envisaged future battlespace sets. Even though the ideal software radio carries huge potential for many fields of communications, the military expectations will be highlighted in this document. The Finnish Software Radio Programme (FSRP) was established to support these requirements and expectations as shall be portrayed next.

Currently, the FSRP is in the demonstration phase – the Finnish Software Radio Demonstrator Programme. The demonstrator phase will be introduced in the next sections including general technological advantages, schedule, and sub-projects on the software technology demonstrator. The latter consists of wideband adaptive networked waveform, positioning services and adaptive antennas.

This document is organized in eigth chapters and three parts. The first three chapters - Part I - discuss the program in a more general level and briefly introduces the structures chosen for the demonstrator, i.e. the first phase of the programme. After this introduction, military opera-

Figure 1-1. *Future network centric warfare exploits all available communication networks.*



tional and tactical requirements and expectations will be discussed in chapter two. An overview on the Finnish software radio programme will be offered in chapter three by concentrating on applications and technological aspects. Chapters 4-7 form Part II of this document. Part II is entitled future enhancements through research and will give insight to Finnish approach of developing SDR services in the future. Chapter four will portray some technical aspects of the applications to be deployed in the SDR-demonstrator but mainly concentrates on future enhancements. Chapter five will present the principle of 'ideal' software defined radio as well as the research challenges set by technological limitations of date. Chapter six will highlight the adaptive antenna system to be designed in the demonstrator phase and the challenges that lie a head in the future. Chapter seven will concentrate on the future versions of the protocol stack in the SDR-radio, to be achieved through research.The demonstrator stack will be developed in a phased process to allow time for new developments in the field. Chapter eight forms part III of this document and is presenting the co-operation and key partners within programme.

2. Military Operational and Tactical Requirements and Expectations

LtCdr Topi Tuukkanen, *Finnish Naval Academy*

2.1 Future Battlespace

The roles and tasks of defense forces and their mutual relations are changing. International peace keeping is gaining a more significant role as the threat of armored attack diminishes. In addition, large scale national disasters and defense against terrorism necessitate the use of armed forces in support of Civil Society.

Simultaneously, technology developments enhance weapon and sensor capabilities. As a consequence, units and forces become more effective, costlier and therefore more valuable. Fewer units are needed for the same level of performance. On the other hand, reduction in the number of units necessitates an increase in their mobility. Improvements in the command, control and communications, battle space management and situation awareness become necessary.

It is emptiness that characterizes the battlespace of the future. Units and forces are sparse. Advanced communications and sensor technologies supported by network centric information operations enable armed power projection and the use of weaponry deep into the battle space.

Although the end of the cold war has reduced the risk of a large scale armed confrontation, internal conflicts are possible. Between 1990 and 2001 the world saw 57 armed conflicts only 3 of which involved use of foreign or external armed forces. In 2001 there were 24 on-going conflicts and 51 on-going crises management operations. It has become evident that separation of warring parties is no longer sufficient – the requirements for crisis management have changed.

In a Peace Support Operation, requirements for advanced mobile communications vary depending on the phase of the operation. In the beginning, emphasis is on tactical mobility and operational security. Interoperability is, without a question, vital in multinational joint operations. As the operation progresses, consultation and cooperation with civilian crisis management, local authorities as well as Non-Governmental Organizations (NGO) gain importance. If the operation is prolonged, sustainment becomes complicated. Information security issues need special attention; otherwise they might become a showstopper. Figure 2-1 depicts the technical concept including all the elements that make future peace support operations successful.

As the figure illustrates, an advanced mobile communication system should support:
- mobility
- localization capabilities
- interoperability between national and international civil authorities
- interoperability within own armed services
- interoperability with foreign armed forces
- bridging between nets of different kind
- operations in hostile electromagnetic environment
- extensive use of commercial components and standards.

To summarize, 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. The expectations set for SDR shall be discussed next.

2.2 Expectations

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. This is demonstrated in Figure 2-2.

Figure 2-1. Software radio based CIS node in a Peace Support Operation.

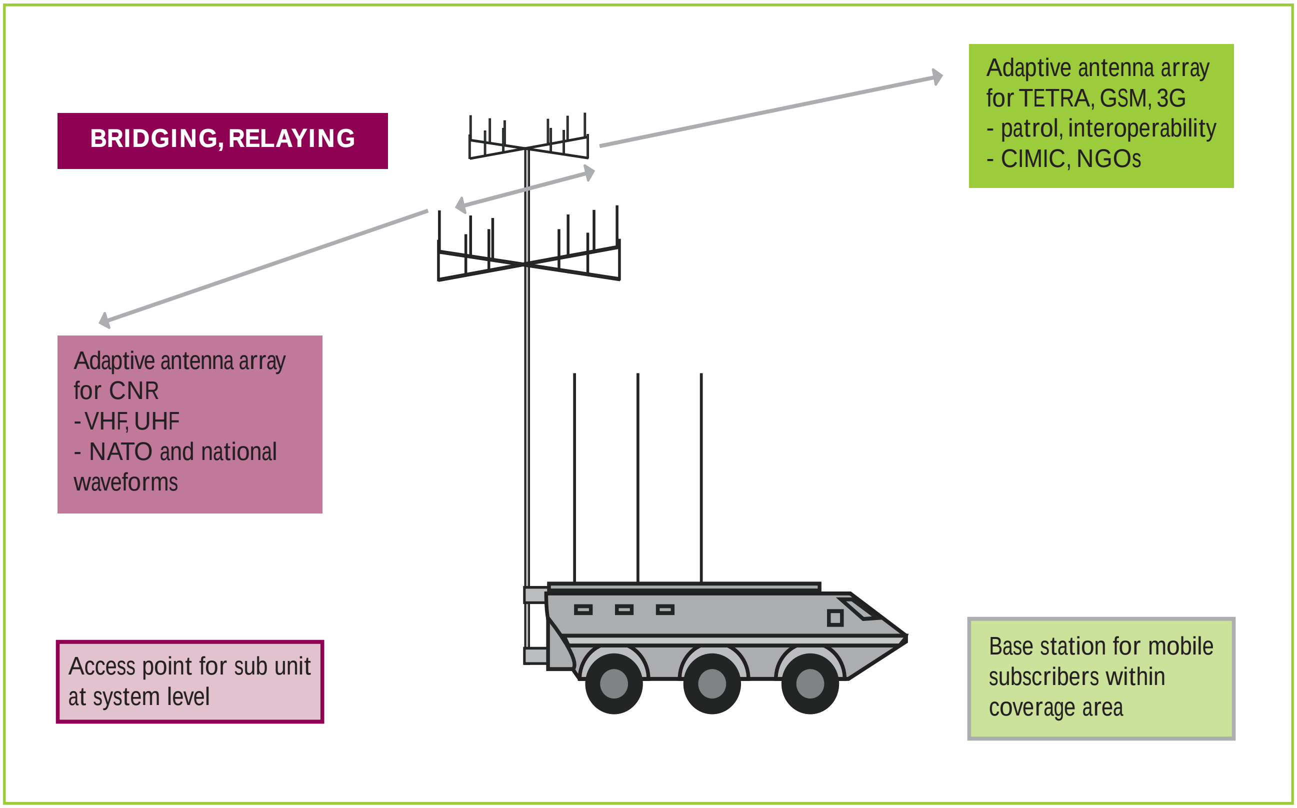
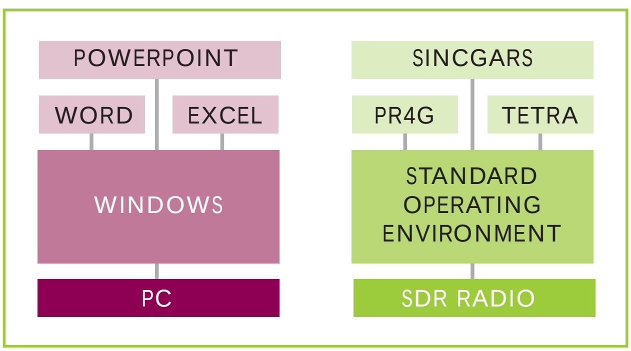


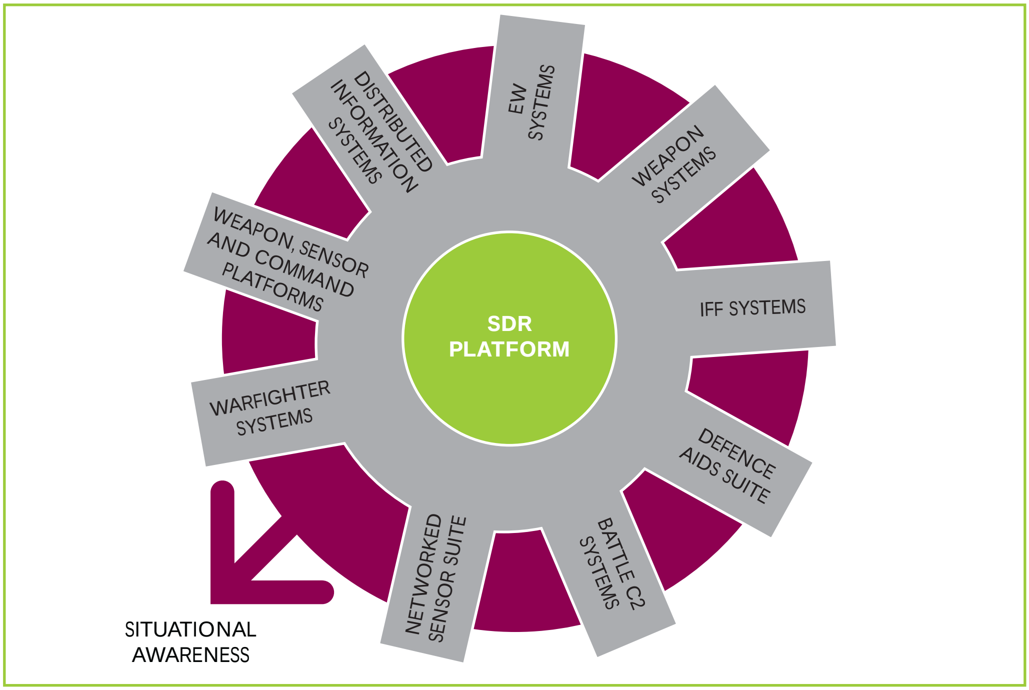
Figure 2-2. Comparison of PC/application world and a Software Radio Environment.



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. This can be depicted in a manner of Figure 2-3.

__Figure 2-3.__ SDR platform is one of the means in connecting the different systems of the digital battlespace.



PART I: **Programme Overview**

3. Programme Description

SA-kuva

LtCdr Topi Tuukkanen, *Finnish Naval Academy*
Lich.Tech. Ari Pouttu, M.Sc. (Tech.) Matti Raustia, Prof Pentti Leppänen, *University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications*
M.Sc. (Tech.) Harri Romppainen, M.Sc. (Tech.) Tero Manninen, M.Sc. (Tech.) Antti Kolivuori, M.Sc. (Tech.) Anna-Maria Kähkönen, M.Sc. (Tech.) Timo Nikola, *Sofnetix Ltd.*

3.1 Introduction

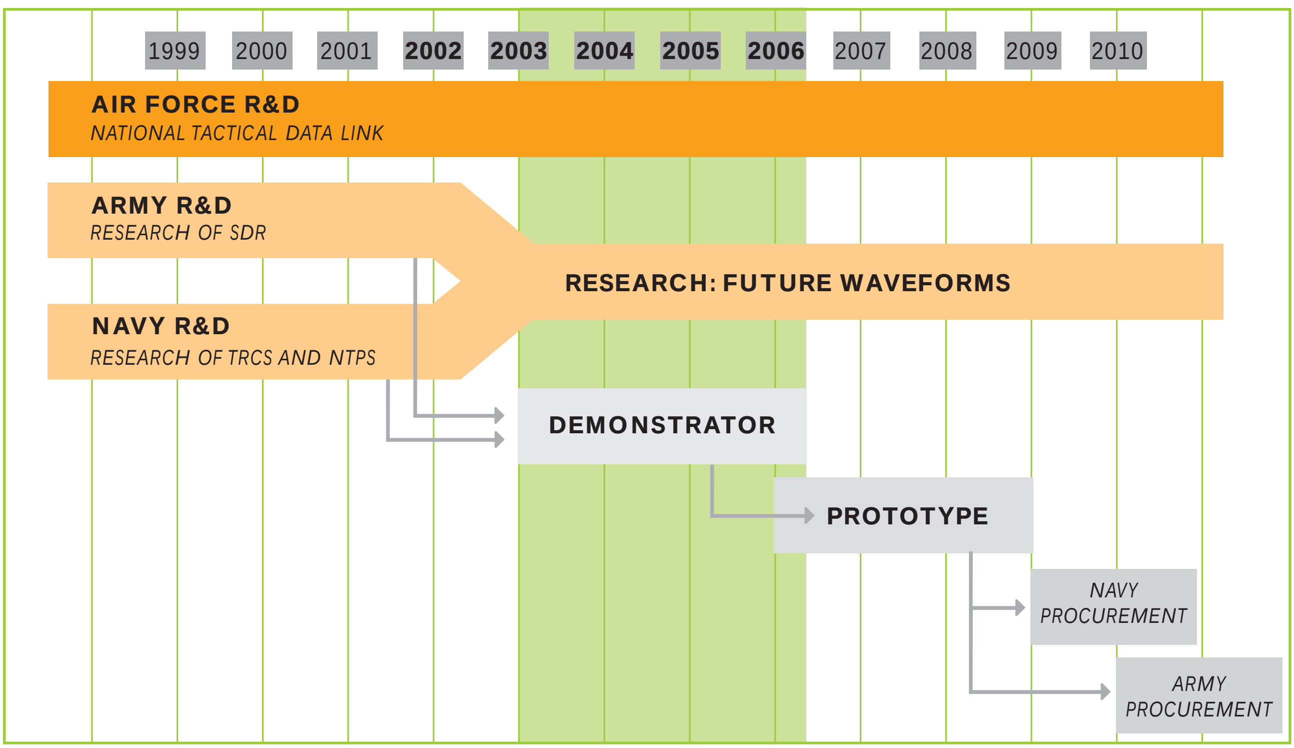
Research and development activities within the Finnish Defense Forces and those in industry and research institutes are incorporated under the demonstrator phase of the Finnish Software Radio Programme. The demonstrator phase alone is a huge undertaking within the Finnish Defense Forces. The whole SDR programme has thus been divided in several subprojects. As described in the introduction section, the programme was launched by the Defense 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 Figure 3-1.

The demonstrator programme consists of three major subprojects, namely:

1) Tactical Radio Communication System (TRCS) with
   - software defined radio platform
   - 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. The content of the subprojects is defined next.

Figure 3-1 *The time schedule of the Finnish Software Radio Programme (Note emphasis on the Demonstrator phase as a precursor prior to prototyping decisions).*



3.2 Tactical Radio Communication System

The subproject Tactical Radio Communication System (TRCS) is a research project originally 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 battlespace 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 AntiJamming (AJ) capabilities as Figure 3-2 shows. On the physical layer, these demands are fulfilled by efficient use of direct sequence spread spectrum and frequency hopping techniques. The main emphasis in the project has so far been on issues concerning specific techniques: synchronization, interference suppression, advanced modulation methods and diversity combining methods to name a few.

Figure 3-2. *The waveform (AWNW) for Tactical Radio Communication System is versatile and adaptable to a variety of operational scenarios.*

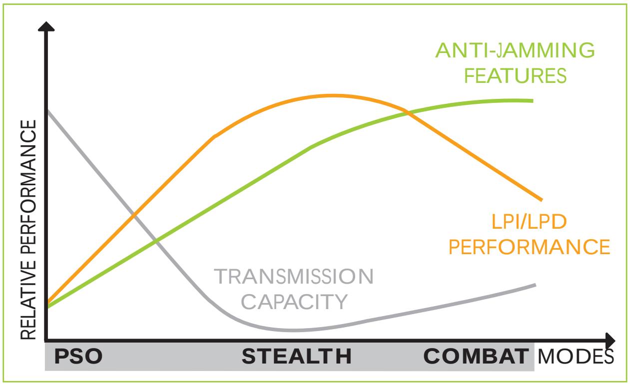
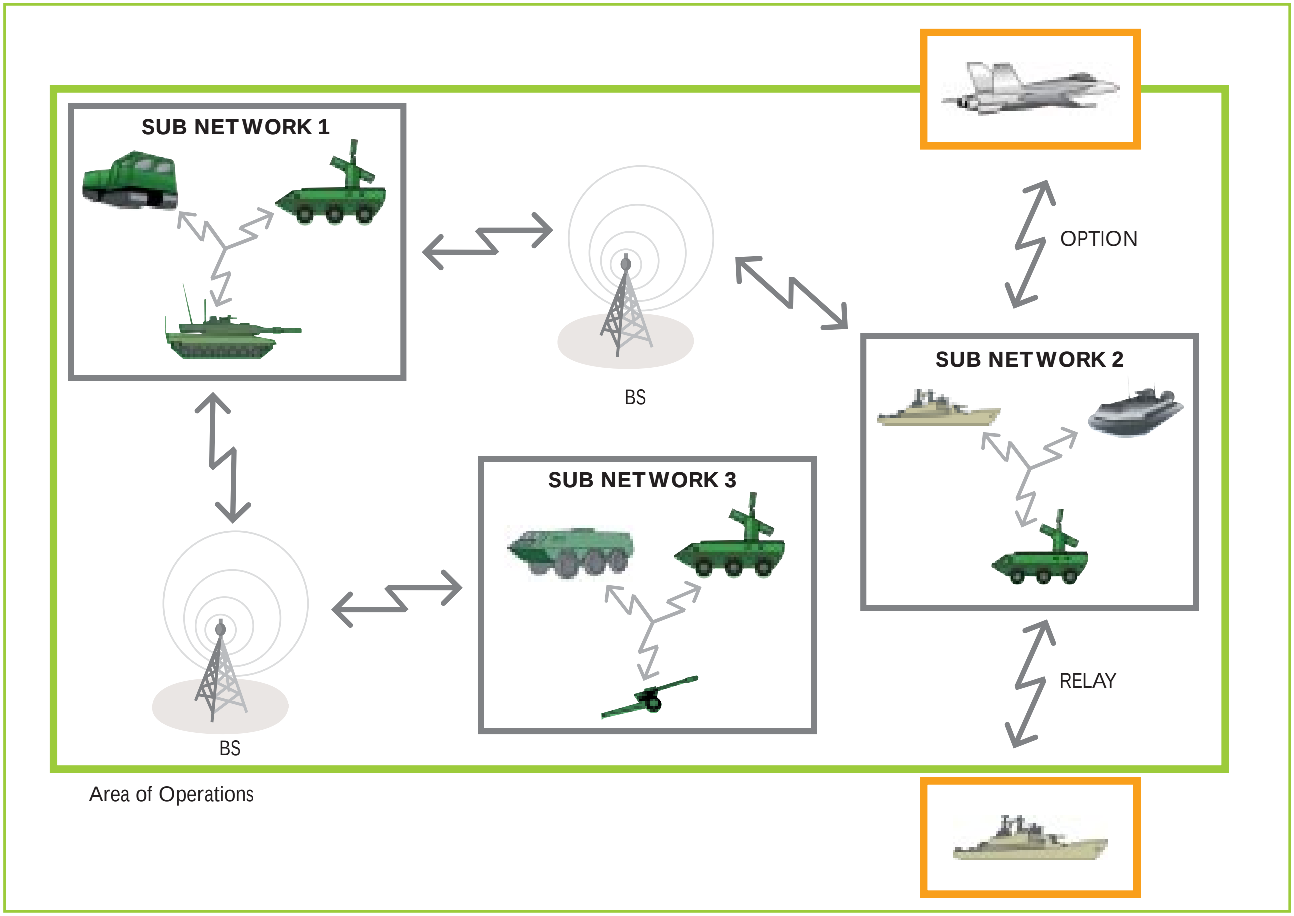


Figure 3-3. *TRCS networks in area of operations.*



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. 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. A typical operation scenario is depicted in Figure 3-3.

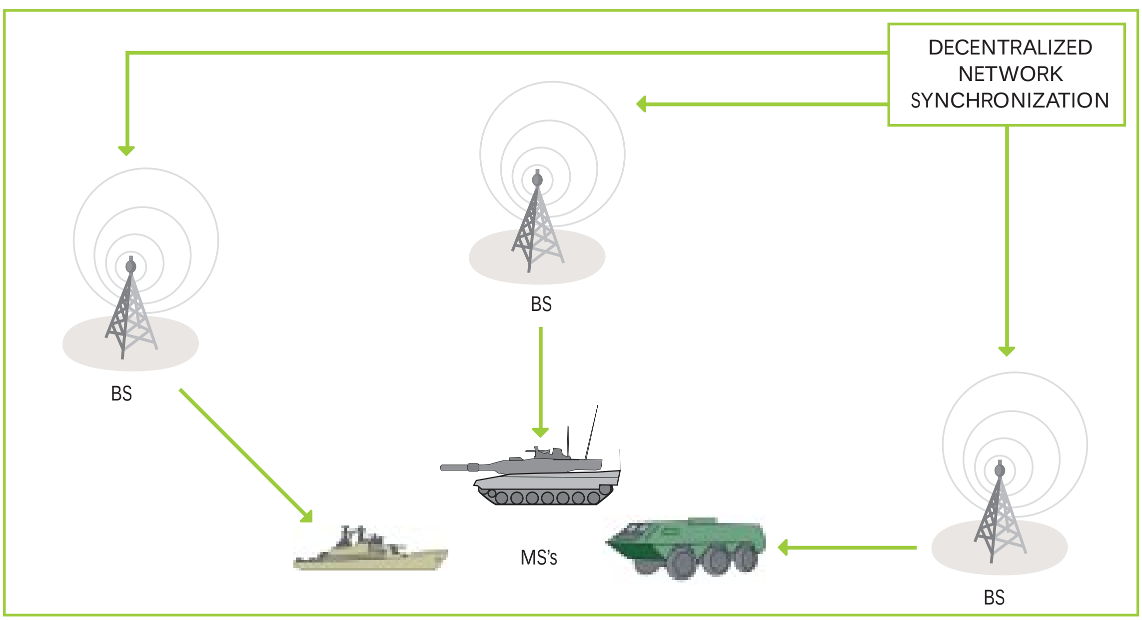
3.3 National Tactical Positioning System

The second subproject of the demonstrator 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 principle of positioning is illustrated in Figure 3-4. Therein Base Stations (BS) transmit navigation signals in typical positioning systems. Mobile Stations (MS), on the other hand, estimate time-of-arrival from

Figure 3-4. *Principle of the National Tactical Positioning System.*

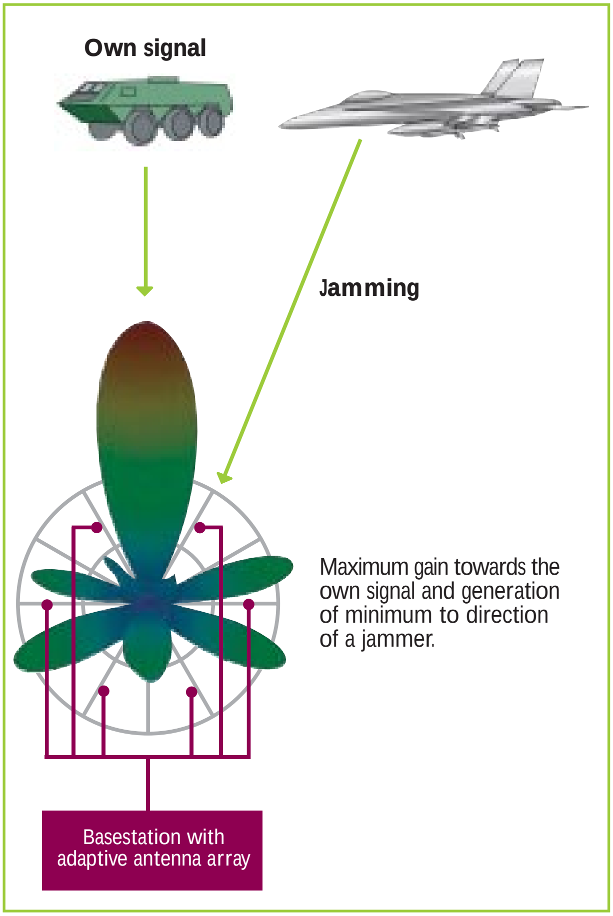


at least three navigation signals in order to be able to estimate their 2-D positions. The specification process has included the definition of system parameters such as navigation signal waveform - National Tactical Positioning Waveform (NTPW) -, transmitter and receiver design, receiver algorithms etc. Within this project funded by the Finnish Defense Forces and other related ones the Univ. of Oulu has developed many AJ signal processing methods.

3.4 Adaptive Antennas for Tactical Radio Systems

The objective of the third subproject Adaptive Antenna System (AAS) is to specify adaptive antenna arrays and algorithms for tactical radio systems of the Finnish Defense Forces such as the Tactical Radio Communication System (TRCS). 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 of an adaptive antenna system in such circumstances are presented in Figure 3-5.

Figure 3-5. *Adaptive antenna system in hostile signal environment.*



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, 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.

3.5 Roadmap for Future Applications

Figure 3-6 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 described in sections 4.1 (AWNW) and 4.2 (NTPW). 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.

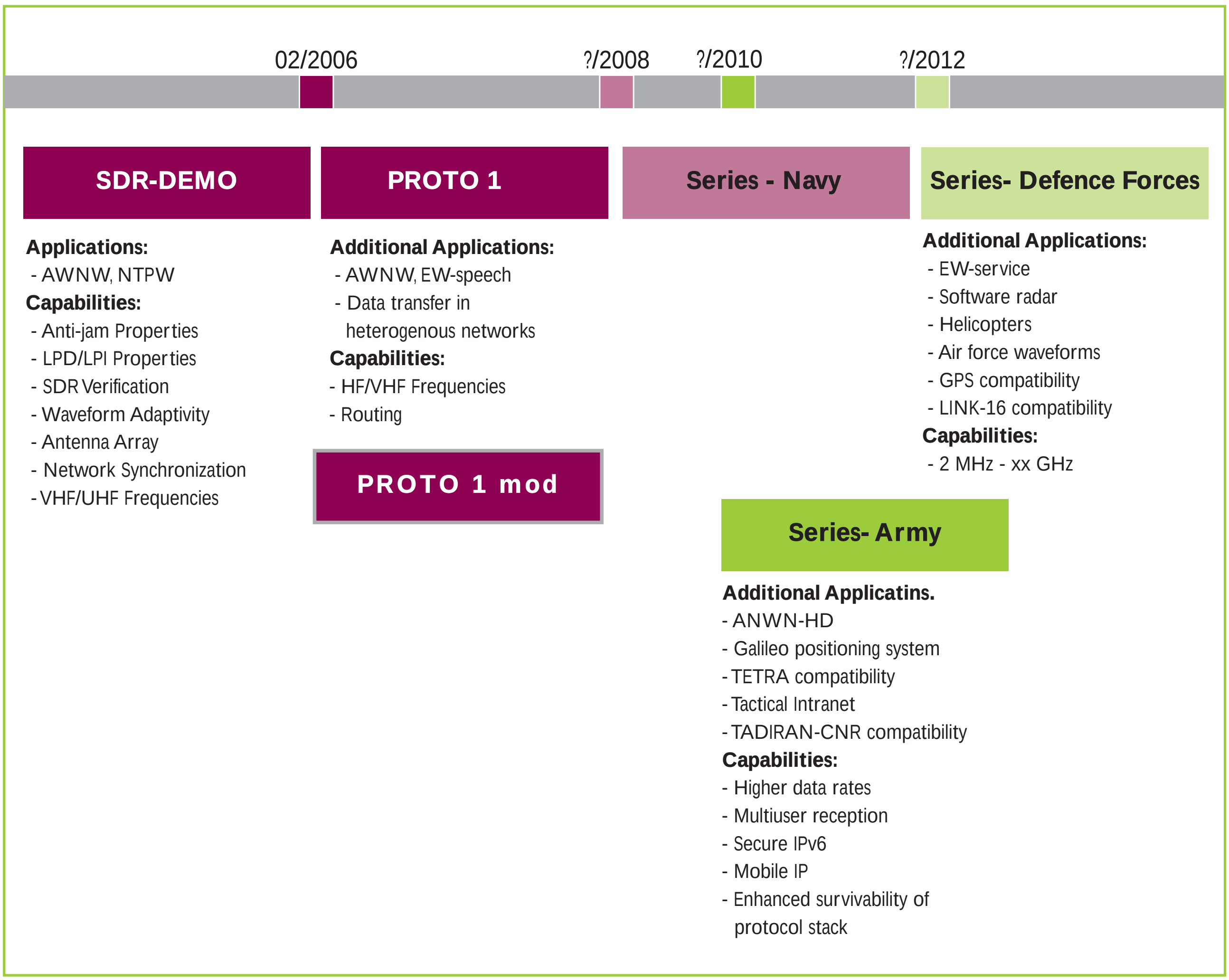
In prototype stage (PROTO 1) EW speech will be integrated into the AWNW waveform. The protocol stack of the SDR-DEMO will be upgraded in PROTO 1 to allow data transfer in heterogeneous networks. The frequency range in PROTO 1 will also be enlarged to include HF and lower VHF frequencies leading to the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

With some verifying modifications made to the PROTO 1 (PROTO1 mod), the army series (Series-Army) could include some new applications including AWNW-HD, GALILEO, TETRA (Terrestrial Trunked RAdio) and TADIRAN. First of these, - AWNW-HD - is a high data rate modification of the TRCS's AWNW waveform and already under development. The data rates will be increased to n*16,384 Mbit/s serving for instance the future wireless backbone radio link system. The second - GALILEO - is a European initiative to build a satellite based global navigation and positioning system. As the NTPS waveform (NTPW) is not easily or economically deployable for instance in artillery applications, GALILEO is a strong candidate for certain branches of services. The third - TETRA - is an encrypted, narrow-band, cellular, TDMA based ETSI standard developed for authorities such as fire and rescue services, police, military, frontier guard etc. In Finland, the TETRA standard (with acronym VIRVE) has been adopted nation-wide. Hence TETRA compatibility will easily allow connections with civilian organizations and the Public Switched Telephone Network (PSTN). The fourth application is TADIRAN - a frequency hopping narrow-band CNR radio adopted by the Finnish army. The TADIRAN compatibility of the SDR will allow high speed access down to the platoon level for databases containing real time information of the dynamics of the battlespace. The survivability of the protocol stack will be enhanced by intelligent routing and secure IP as well as mobile IP. This enables the use of tactical intranet and also connections to the public internet.

The development path of SDR will lead to joint services series (Series-Defense Forces). This SDR platform can be tailored for different uses by software reconfiguration. The new additional applications in the defense forces series could include electronic warfare services, software radar (radar signal processing), air force waveforms as well as GPS compatibility. The air force programme is described in a separate document but the industrial partners and products of the programme are briefly touched in chapters 8.7 and 8.9 The additional applications that are under consideration are introduced in Figure 3-6.

The GPS inclusion has been left for this stage due to the fact that numerous improvements in GPS signal antijam properties will be introduced in the future. The simultaneous use of this high variety of applications in SDR platform necessitates the enlargement of the frequency range of the transceiver to cover frequencies from HF to SHF.

Figure 3-6. *Possible roadmap for additional services to be included in the SDR platform.*



3.6 Co-operation Model of the Programme

The research and development (R&D) process within the programme is iterative in nature. The players in the programme have leading roles in different phases of the development cycle but they contribute to improve the process through the whole cycle. The R&D process within the programme is depicted in Figure 3-7.

This co-operation model has proven very fruitful in the air force data link development programme and is applied also in this programme.

3.7 Finnish Software Defined 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. 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 standardized SDR architectures and waveform software compatibility. This can only be achieved with waveform portability. 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. Also, Elektrobit Ltd is a member of the SDR Forum and follows actively the API standardization work of the Forum.

SCA version 2.2 is used as a baseline for the software architecture of the SDR demonstrator. An SCA based Core Framework 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. Elektrobit Ltd competence in base station software architectures is fully utilized in the software development.

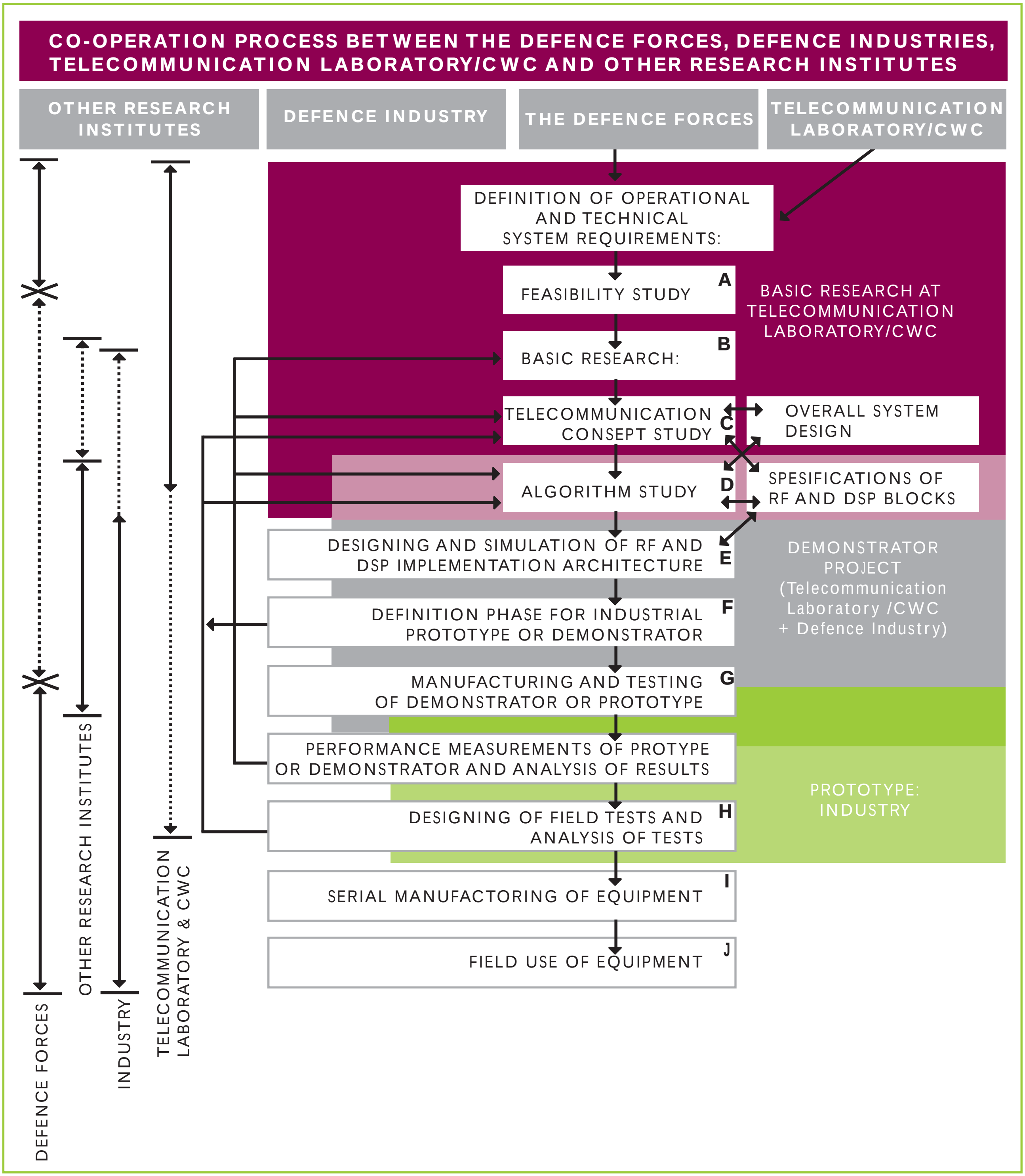
Hardware development of the SDR demonstrator is pragmatic and practical. The demonstrator is maximally based on Commercial Off-The-Shelf (COTS) components and subsystems in order to minimize development risks and shorten the development cycle. The general structure that Elektrobit Ltd has chosen for the SDR demonstrator is depicted in Figure 3-8. 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 developed by the Univ. of Oulu 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 Defense

Figure 3-7. *Co-operation model of the R&D process within the programme.*



Forces the necessary 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.

Physical Layer Functionalities in Finnish SDR Demonstrator

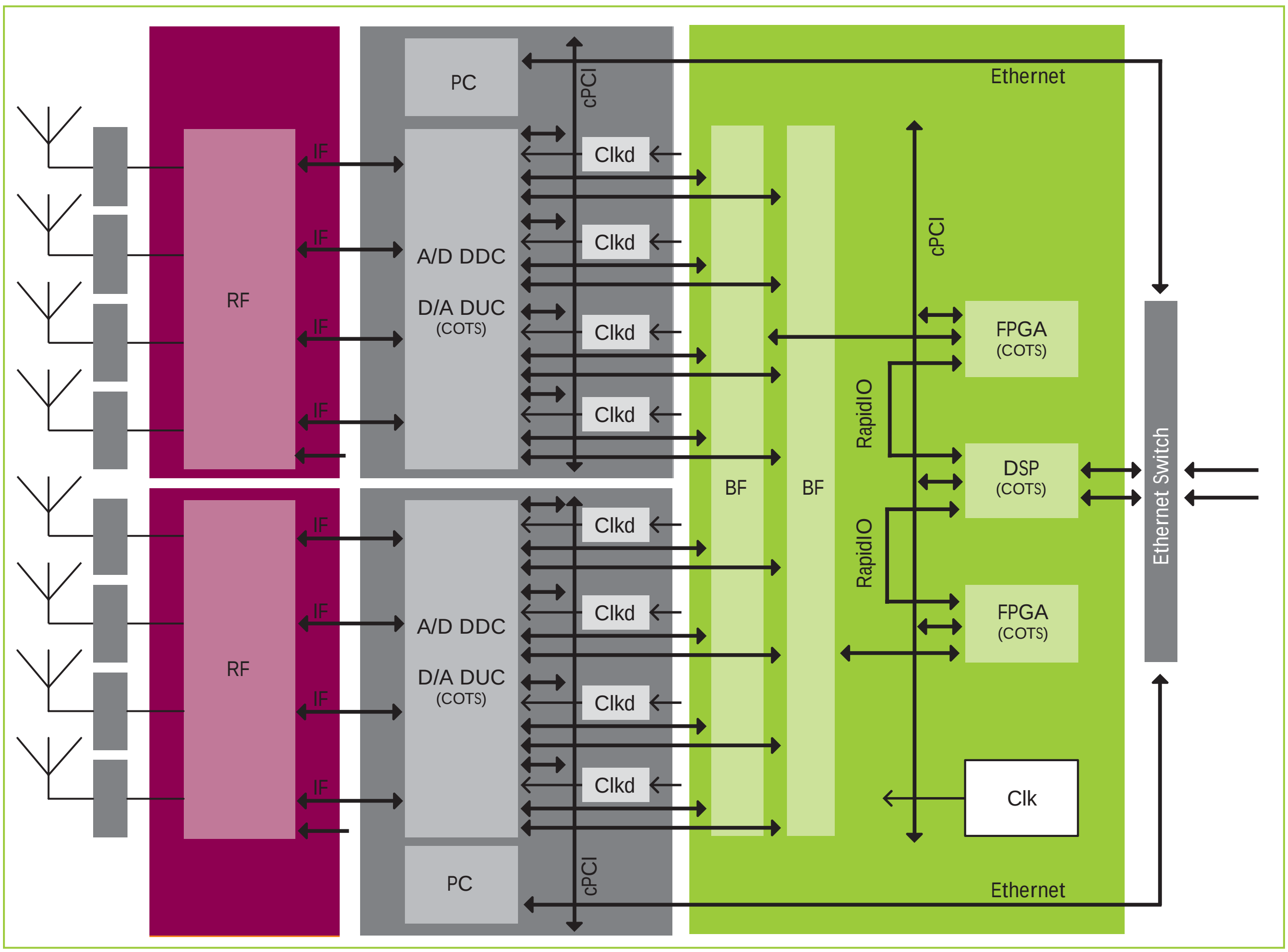
The more detailed description of the actual AWNW waveform will be given in chapter 4. Here we state the parameters for AWNW that will be implemented in the demonstrator phase. Within the Finnish Software Defined Radio demonstrator project, we have examined the feasibility of the SDR and defined a few sub-modes for three main operating modes of the waveform. The modes will be used to verify that the SDR demonstrator can indeed support a specified waveform and also that new ideas implemented in the waveform give additional performance as expected. Some characteristics of the waveform that will be implemented are presented in Table 3-1.

The NTPS will be implemented as described in chapter 4.

Table 3-1. *Key characteristics of AWNW modes that will be implemented in Finnish SDR demonstrator.*

	Peace Time Operations Mode	LPI/LPD Mode	Anti Jam Mode
Frequency band	VHF/UHF	VHF/UHF	VHF/UHF
Frequency hopping	Yes	Yes	Yes
Data rate	Up to 2 Mbit/s	< 5 kbit/s	< 10 kbit/s
Range	Up to radio horizon	Up to radio horizon	Up to radio horizon
Diversity	No / Time	Time	Time & frequency
Channel coding	Convolutional code	Convolutional code	Convolutional code
Duplexing method	TDD	TDD	TDD
Secure voice	Yes	No	Yes

Figure 3-8. *SDR demonstrator structure.*



SDR demonstrator protocol stack

Sofnetix Ltd in co-operation with the University of Oulu has carried out feasibility studies and requirement specification work for a special purpose software radio system for the Finnish Defense Forces. As a continuation of this work, Sofnetix Ltd is currently participating in a joint effort to develop a software radio technology demonstrator. Figure 3-9 illustrates the selected protocol architecture in the demonstrator. In the joint effort, Sofnetix Ltd is responsible to deliver layer L2 and layer L3 protocol software. In the future versions the protocol stack will be upgraded to full SCA compatibility and to the demands of the digital battlespace.

Conclusions on SDR demonstrator

To summarize this section of the document, Figure 3-10 collects the approach and ideas used in the SDR demonstrator, i.e. SCA compatible software architecture where COTS hardware and required software is designed to demonstrate layers L1 and L2 of the protocol stack and L3 is demonstrated with an assosiated software network simulator.

Figure 3-9. *Protocol stack in the SDR platform in the demonstrator stage.*

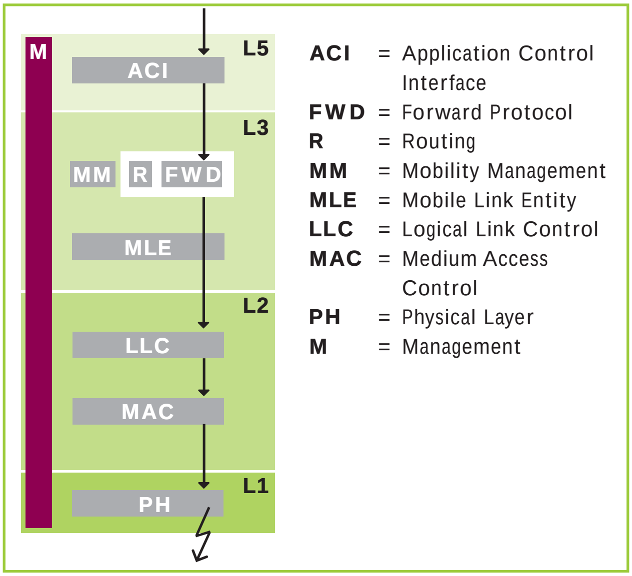
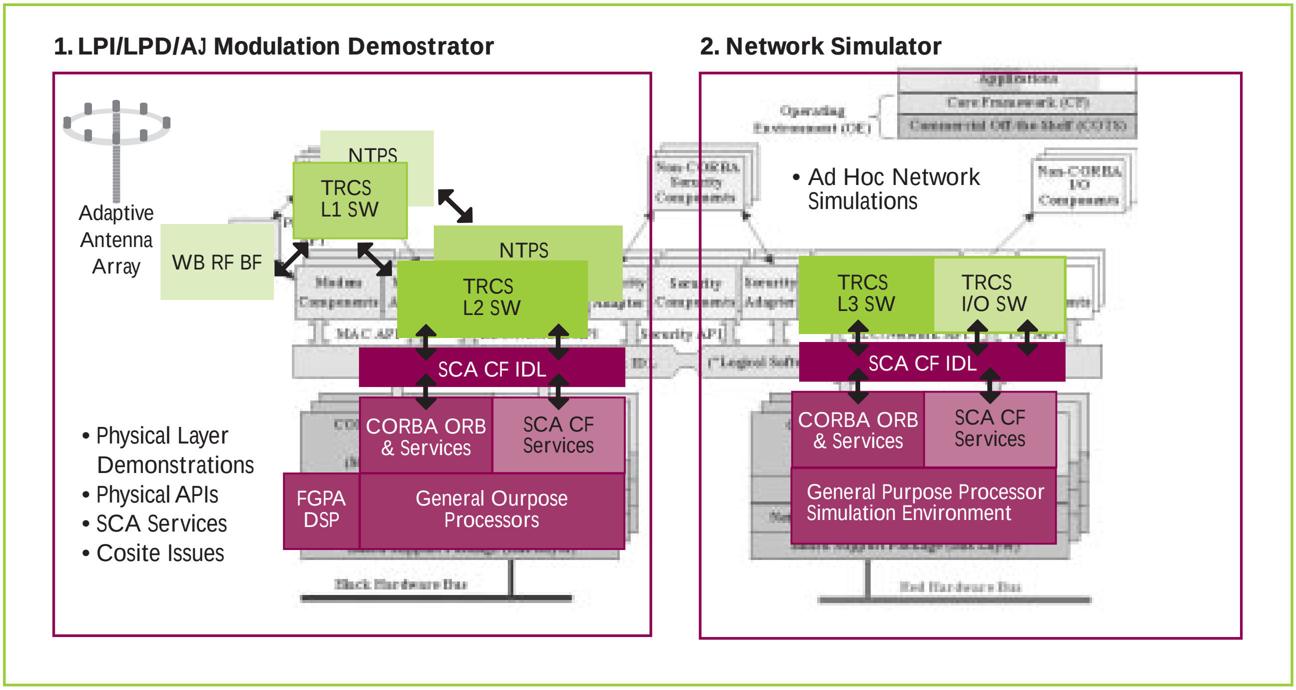


Figure 3-10. *Software architecture of SDR demonstrator vs. SCA*



PART II: **Future Enhancements through Research**

4. Wideband Waveforms

SA-kuva

M.Sc. (Tech.) Matti Raustia, Dr.Tech. Harri Saarnisaari, Lich.Tech. Ari Pouttu, Prof Pentti Leppänen
University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications

Waveforms used in the Tactical Radio Communication System (TRCS) for communication needs and the National Tactical Positioning System (NTPS) are introduced in this chapter. The general properties of the waveforms will be described.

4.1 Adaptive Wideband Networking Waveform for TRCS

This section describes the communications waveform - Adaptive Wideband Networking Waveform (AWNW) developed in the University of Oulu - being deployed on the SDR demonstrator. The aim is to give an overview of the capabilities and features of the waveform in a general level.

4.1.1 Tactical Background

The goal of the AWNW specification project was to develop a highly flexible waveform with excellent antijam (AJ) and low probability of detection and interception properties (LPD/LPI) for VHF/UHF band. The specification work begun by initiation of Finnish navy. Later it was decided that the new waveform under development must be able to satisfy needs of the army as well. At that point, the Finnish Air Force (FAF) did not participate in the waveform specification as FAF has its own data link programme (National Tactical Data Link). The interoperability with FAF waveform will be obtained by implementing it as a different waveform in the Finnish SDR.

Analysis of the requirements of the Finnish Navy initiated the waveform development. It was understood that all the requirements cannot be fulfilled with just one operating mode of the radio. It was thus concluded that there should be at least four different modes to serve all needs.

In normal peace time operations AWNW must be able to transmit data at high speeds, may it be speech, images or video. Whether the signal can be easily detected is not critical under such circumstances. On the contrary, it may be even desirable to show that actions are taking place.

However, when the international situation becomes more strained, the communication and security needs are different. It may be crucial that units (naval vessels, coastal infantry etc.) can operate without being detected. The need for maximum secrecy means that the data rate has to be reduced to as low a value as possible. For example, speech transmission is not necessarily needed in this mode if it increases the probability of signal detection. There might also be situations where some mobile station is in complete radio silence and is not allowed to transmit but must be able to receive. Consequently, the radio system in place must support one-way transmissions.

In combat, it is crucial that important information - data, speech, images or video - can be transmitted reliably. Therefore, it was decided in the waveform specification that the speech transmission capability is needed. Correspondingly, the minimum data rate in this mode is higher than in the LPI/LPD mode.

4.1.2 Data Formats, Priorities and Communication Security

All the data format adaptations and communication security aspects are dealt within the application layer. This means that the transfer media offered by the waveform is perceived just as a pipeline that transfers data. It has to be noticed that secure speech is only one application among others utilizing data transmission resources provided by the waveform. This approach enables the sharing of transmission resources between different applications. For example, secure speech and data can be transmitted at the same time. The defined waveform has application-level priorities that dictate the usage of the radio resources in situations where data transmission rates are limited. The priority can be application or message-specific.

4.1.3 Specification of the Waveform

When specifying the nature of the system, a cellular system was a logical choice in fulfilling the peace time requirements. Namely, a cellular system can provide dedicated base stations which take care of all the functions that belong to normal base stations. The base stations, however, need not necessarily be static. Mobile stations must be able to relay traffic to other mobile stations (MS) possibly located outside the cell coverage. The waveform also supports point-to-point traffic and operates in an Ad Hoc mode without dedicated base stations. Its other functionalities are, e.g. receive-only mode and asymmetric data rate mode. The basic operating mode of AWNW is introduced in Figure 4-1 and the Ad Hoc mode in Figure 4-2.

At the physical layer, the waveform has four main modes that will be discussed next.

Physical Layer Functionalities

Table 4-1 introduces the main parameters of the modes in AWNW. The four main modes that the waveform currently has at the physical layer are Peace Time Operations Mode (PTOM), the LPI/LPD Mode (LPIM), the AntiJamming Mode (AJM) and High Data Rate Link Mode (HDRLM). The operating mode of the network or link can be selected either by a mobile station (MS) or by a base station (BS). All three modes contain sub-modes which provide more flexibility to the system. Consequently, the radio can adapt to different kind of channel conditions and tactical needs.

In all the modes, the instantaneous RF bandwidth of the system is the same. The modes and their sub-modes are implemented by varying modulation methods, spreading factor and coding.

In the PTOM, the maximum data rate can be several megabytes per second which supports data, speech and video transmissions. Traffic is relayed through the base station except when mobile station relays traffic for a mobile station outside the cell coverage. Adaptive antennas are used to improve the performance of the system. The sub-networks are separated by different frequency hopping patterns.

In the LPIM, the transmitted RF power level is minimized while conserving desired coverage. Currently, the LPIM does not enable transmission of speech since good LPI/LPD properties require a very low data rate. Intelligent power control and directional antennas (either conventional or adaptive) allow further reduction of the RF power level.

The AJM is meant to be used under difficult EW conditions. The data rate is reduced from that of the PTOM by increasing the spreading factor and using time-frequency diversity. Ability to transfer voice is con-

Figure 4-1. *Basic operating mode of the waveform.*

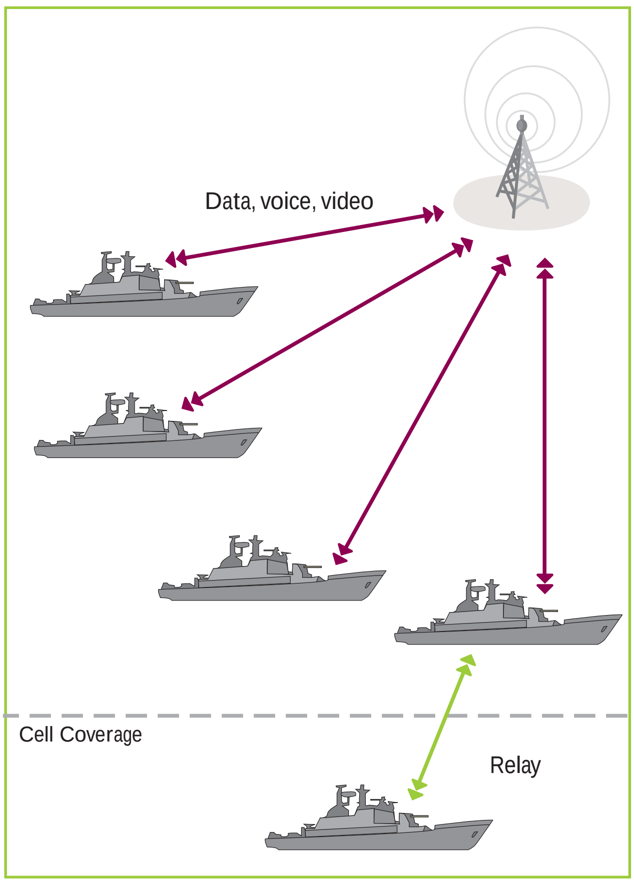
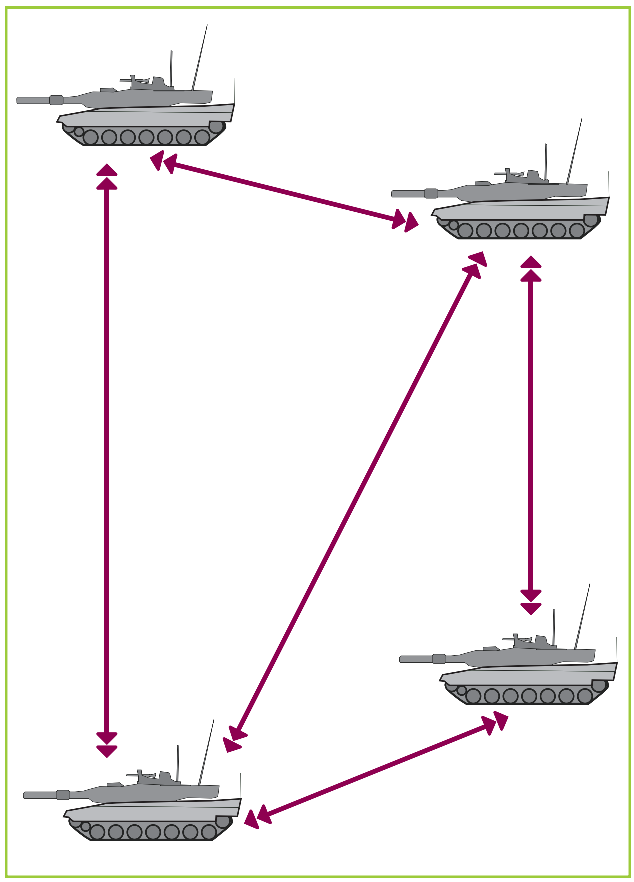


Figure 4-2. *Waveform in Ad Hoc mode.*



served by contrast to the current LPIM. An advanced diversity combining method and interference cancellation algorithms are utilized to improve the jamming resistance.

The High Data Rate Link Mode (HDRLM) is specified for point-to-point link usage. E.g., the HDRLM is specified such that it can be used to build up data link between an aircraft and a ground station. It can also be used as backbone link system waveform. It supports also multiple simultaneous logical connections with different level of protection against jamming. This way there can be highly protected but lower data rate command links and high data rate links with more relaxed AJ properties.

Multiple Access and Multiplexing

Multiple access is implemented using Code Division Multiple Access (CDMA). Duplexing is made possible by utilizing Time Domain Duplexing (TDD). This means that base stations and mobile stations transmit at the same frequency but at different time. To assure a highly flexible information distribution between stations, station specific and broadcast codes are used.

Table 4-1. *Some key characteristics of the waveform.*

	PTOM	LPIM	AJM	HDRLM
Frequency band	VHF/UHF	VHF/UHF	VHF/UHF	SHF
Frequency hopping	Yes	Yes	Yes	Yes
Data rate	63 kbit/s – 8 Mbit/s	1,5 kbit/s – 63 kbit/s	3,5 kbit/s – 63 kbit/s	Up to 16.384 Mbit/s
Range	Up to radio horizon	Up to radio horizon	Up to radio horizon	Up to radio horizon
Diversity	No / Time	Time	Time & frequency	Time & frequency
Multiple Access within Network	DS/CDMA SDMA	DS/CDMA SDMA/ TDMA	DS/CDMA SDMA/ TDMA	One user per network
Inter-Network Multiple Access	FH/CDMA	FH/CDMA	FH/CDMA	FH/CDMA
Duplexing method	TDD/FDD	TDD/FDD	TDD/FDD	TDD/FDD
Communication modes	BS-MS, BS-MS-MS, MS-MS, point-to-point asymmetric, receive-only	BS-MS, BS-MS-MS, MS-MS, receive only	BS-MS, BS-MS-MS, MS-MS, receive only	Air-to-Ground, Ground-to-Ground
Secure voice	Yes	Yes	Yes	Yes
Channel coding	Convolutional/ Turbo	Convolutional/ Turbo	Convolutional/ Turbo	Convolutional/ Turbo

When adaptive antennas are available, the data rate can be increased thanks to a Space Division Multiple Access (SDMA) component. Since usage of the adaptive antennas also reduces Multiple Access Interference (MAI), the total capacity of the system increases considerably. Features of Time Hopping (TH) are incorporated in the system and no repetitive timing epochs are used.

4.2 National Tactical Positioning Waveform in NTPS

4.2.1 Background

A feasibility study initiated the project to design the National Tactical Positioning System (NTPS) in 1997 and the decision to continue the project was taken two years later. The goal was to define the NTPS that should fulfill a number of requirements. First, the position accuracy of the system in severe jamming should fulfill the demands of navigation in archipelago. Second, limits for velocity accuracy could be somewhat relaxed since fast frequency hopping, that LPI and AJ properties need, does not allow very precise velocity measurements. Third, the transmitted signal power needed to be planned so that the required accuracy is attained at the edges of the desired coverage area. This means that the accuracy and AJ properties are better close to the base stations than on the edges of the coverage area. These improvements are due to higher signal level. The system naturally provides the network time, which may depend on the Greenwich Mean Time. Thus, the NTPS offers a way for a precise timing of actions in the field.

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.

4.2.2 Design Principles

In typical positioning systems, Base Stations (BS) transmit navigation signals. Mobile Stations (MS), on the other hand, estimate time-of-arrival (TOA) at least from three navigation signals (2D 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.

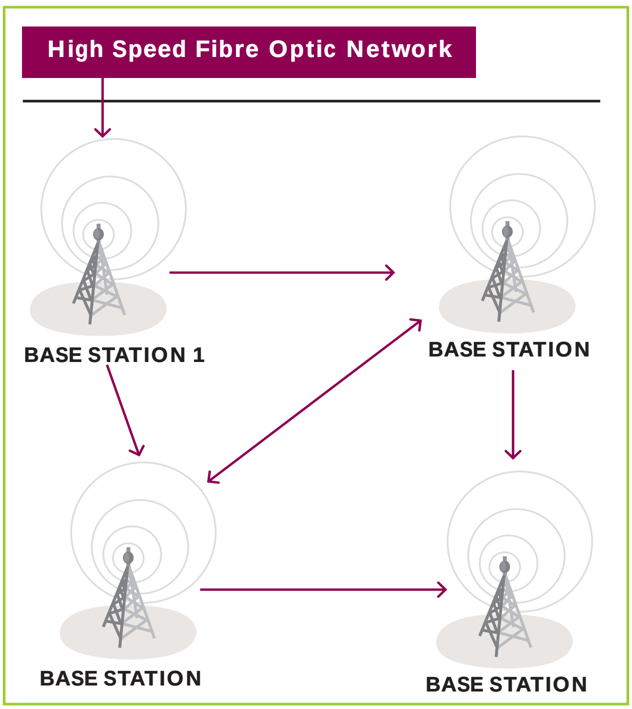
The accuracy of the NTPS depends on the accuracy of TOA measurements and mutual BS synchronization. TOA estimation accuracy in the presence of interference has been studied a lot in the literature as well as in the University of Oulu. The results of these investigations have already led to receiver structures illustrated in chapter 5.

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. Figure 4-3 shows a possible network synchronization situation, where BS1 is at the top of the hierarchy and connected to high speed fiber optic network that provides a time reference. The time reference is not necessary but is a useful tool whenever available.

4.2.3 Positioning Network

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.

Figure 4-3. *A possible network synchronization situation.*



Synchronization of a BS and users to a network has to be carried out in two possible cases. First, the receiver to be synchronized may have totally lost the network time. Second, difference between the receiver's time and the network's time is not too large and is caused by movement or clock drifts. In the latter case, the synchronization is typically much faster than in the first case. 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.

4.2.4 Positioning Signal

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. Table 4-2 shows the main properties of the NTPS.

4.2.5 Future Developments

The NTPS is designed to offer reconfiguration or adjustment of its parameters, e.g. used codes, code length, averaging time and hopping rate may be changed. With the NTPS it is also possible to switch to continuous transmission and FDMA multiple access in order to allow accurate velocity measurements if this is required and if the capacity of the channel permits it.

Table 4-2. *Main properties of the National Tactical Positioning System.*

Frequency band	VHF/UHF
Waveform	DS
Frequency hopping	yes
Range (requires ≥ 2 BSs)	up to horizon
BS separation	TDMA
2D positioning accuracy	< 5 m
Time service	yes
AJ properties	yes
Decentralized network synchronization	yes

The NTPS design is a starting point to mobile positioning and navigation systems that can support operations in a certain geographical area (hot spot). These systems use movable, light base stations that form rapidly a network that can be used for navigation.

PART II: **Future Enhancements through Research**

5. Software Defined Radio Platform

M.Sc. (Tech.)Visa Tapio, Dr.Tech. Harri Saarnisaari, M.Sc. (Tech.) Matti Raustia, Lich.Tech. Ari Pouttu, Prof Pentti Leppänen
University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications

In all military research, the goal is to provide survivable, battle-proof systems that operate under electronic warfare and weapon actions. Accordingly, the overall system cannot depend on a single element. Other requirements are that the signal should have significant inherent AntiJamming (AJ) capabilities and, if possible, AJ devices should be used to provide additional protection. The need for additional protection has been noticed in respect of the Global Positioning System (GPS) which is rather sensitive to jamming although it is a spread spectrum system that are believed to have relative good inherent AJ properties. One way to respond to the need of further protection is to use signals that are difficult to detect. This means that the existence of the signal can be concealed or, at least, that the signal source is made difficult to locate. In addition to these general military goals, it is appropriate that the system offers flexible services (data, data rates, voice, pictures and video), can co-operate with other systems and is future proof. The SDR offers a solution to all of these demands, since, in principle, it makes reconfiguration and adding of new applications to the radio possible. Updating existing capabilities of the radio is also a feasible option as far as it is guaranteed that the interface between different building blocks supports this. This chapter describes the eventual SDR architecture suggested by the Univ. of Oulu. Section 3.7, on the other hand, presents the architecture chosen for the SDR demonstrator which takes into account limitations dictated by the current technological state.

5.1 General Structure of the Transceiver

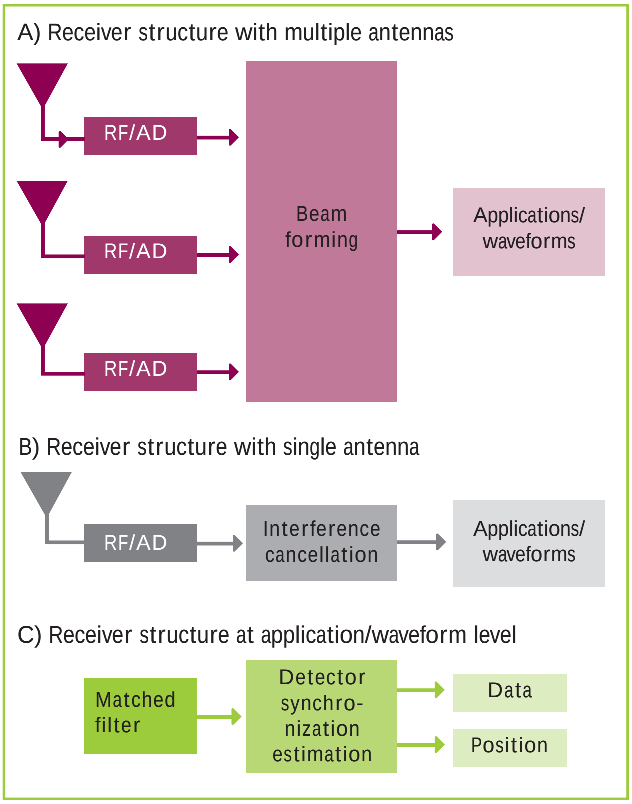
In order to meet the objectives set for a protected signal and flexibility for the radio platform, we have defined a general structure for the receiver and transmitter. Each application or waveform (existing or under development) can use these general structures. The possible structures of the receiver in multiple antennas and single antenna cases are presented in Figure 5-1 a) and b). The general structure at the application level is shown in Figure 5-1 c).

Interference cancellers (ICs) used in the single antenna case can typically mitigate interfering signals that have a narrower bandwidth than the desired signal has. Adaptive antennas can typically mitigate both wideband and narrowband interference and, thus offer enhanced performance.

The general structure of the transmitter is presented in Figure 5-2. If the transmitter contains an adaptive array, it can independently transmit each waveform to its desired direction.

Importantly, the receiver consists of a matched filter for each application. The matched filters provide fast synchronization that has always been a necessary requirement in military systems. The matched filters are realized in frequency domain, not as a correlator or a bank of correlators in time domain which is the case with typical implementa-

Figure 5-1. *Structures of the receiver system.*



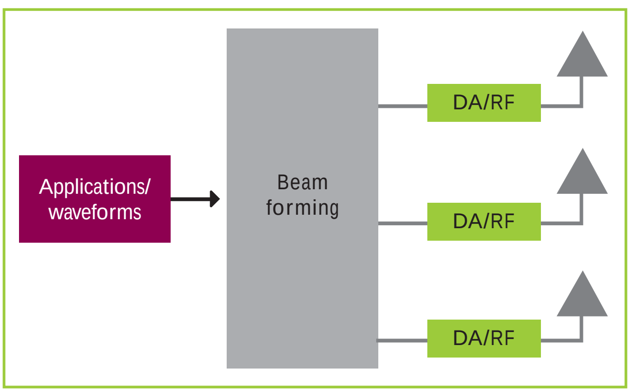
tions. The frequency domain realization was selected, first, due to its flexibility because it allows an easy use of signals even with different lengths. Second, the frequency domain approach is the most promising because it offers the lowest computational burden of all matched filter implementations for general waveforms. The reason for the rareness of frequency domain realizations is that, so far, a sufficiently fast technology has not been available.

The University of Oulu has performed a lot of research to find the best interference cancellers (ICs) for wideband single antenna systems. Such ICs have the asset that if the desired signal is wideband, i.e. if it has processing gain, then the part of the signal where the narrowband interference lies can be attenuated without affecting too much the performance of the system. Even more efficient versions of the notch filter were developed that are called Consecutive Mean Excision (CME) algorithms. These algorithms find iteratively the corrupted frequency bins whereas traditional notch filters are not iterative.

According to our results, the Forward CME (FCME) algorithm can find corrupted frequency bins even if they cover over 80 % of all frequency bins whereas traditional methods can detect interfered frequency bins only if they cover 50 % or less of the frequency band, depending of the interference search rule. It was also discovered that the best overall performance in jammed environments is obtained by a bank of different kind of simple ICs. The used IC was selected based on SNR estimates.

In beamforming, it has been studied what beam forming algorithms (that often are computationally very demanding) can be implemented and how. Based on the research, conclusion was that a simple null-steering algorithm can certainly be implemented but also decided to implement a more advanced ones which potentially offer enhanced AJ properties. In their basic forms, these advanced methods are adaptive. However, fully adaptive versions cannot be implemented at reasonably low cost with the current technology because of the limitations set by a rather high bandwidth used in these systems. Therefore, implementation can be defined as "semi-adaptive" meaning that once the beam forming weights are computed, they are kept fixed until new weights are available.

Figure 5-2. *Structure of the transmitter.*



All the applications using the SDR platform have to inform users about their state and show the estimated SNR so that the channel quality can be surveyed. Applications must also indicate if the channel is jammed or not. This knowledge can be obtained from interference cancellers or from the direction-of-arrival (DOA) estimation circuit.

5.2 SDR Research for Future Generations

What is expected of military troops in a rapidly changing international environment is that they communicate efficiently with each other and with civil authority organizations. Traditionally different countries and different kind of units have used non-compatible radio systems. This has led to the situation where there are multiple radio systems operating in the same geographical area without ability to move messages efficiently from one system to another. The use of Multi-Mode Multi-Band radios (MMMB radio) can decrease the amount of radio equipment needed and enable efficient communication between different players at the operational area. MMMB radio is also a key element in network centric warfare. The digital battlespace of the future is based on a flexible communication platform that connects separate systems together.

5.3 SDR Platform

The objective of the Finnish Software Defined Radio Programme is to enable the design and implementation of multi-mode multi-band radios that can be configured by software to operate in several radio systems simultaneously. This means that all signal processing operations are performed using programmable digital circuits and waveforms are defined completely with software. The features of the SDR platform are shown in Figure 5-3.

The software defined radio consists of a general purpose programmable radio hardware platform, an operating system and software defined waveforms. Applications (App. N) needing radio resources can be implemented in the same platform. Alternatively, systems that need radio services can use software radio as a peripheral device. Waveforms will be implemented to the SDR platform with Software Communications Architecture (SCA).

In addition, software defined radio platform offers processing capacity to implement time and frequency domain interference cancellation (IC) algorithms. Adaptive antennas are also used to enhance system performance. Software radio offers resources to adaptively control radiation pattern of an antenna array using beam forming (BF).

Software defined radio offers the possibility to implement future proof radio equipment that is compatible with legacy radio systems. With SDR, new features to present-day radio systems and novel radio waveforms can be introduced. Since it is possible to receive and transmit several signals simultaneously, software radio can act as a bridge between different radio networks. In addition to implementing different radios in the system, software defined radio can also offer means to realize new kind of networks and services. Research in the Univ. of Oulu aims at finding new ways to utilize software defined radios and solving technical challenges related to implementation of SDR platforms.

5.4 Technological Challenges

When designing and implementing a SDR, one must recognize limitations of current technology. The key element in a software defined radio is the A/D conversion. In order to implement all signal processing operations in the digital domain, the whole operating frequency range of the radio has to be sampled. This requires very fast sampling and wide dynamic range from the A/D conversion unit. Current technology does not allow sampling of required bandwidths using a single A/D converter. This is mostly due to too low a dynamic range that the current converters offer. Implementation of A/D conversion affects considerably the overall architecture of a software defined radio.

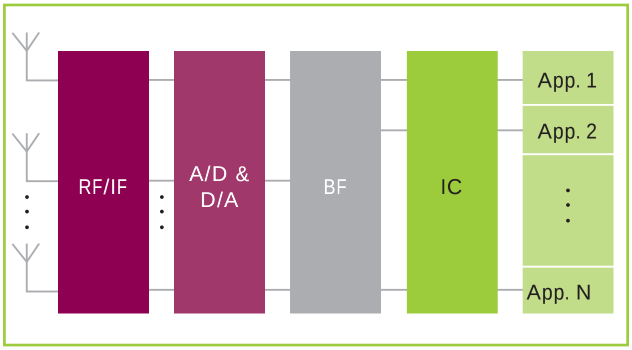
During the channel filtering and down conversion process, the sampling rate is reduced. Separate systems need different sampling rates in symbol rate processing. Since there can be simultaneous connections running in a software defined radio using different waveforms, the radio platform has to be able to handle multiple processes with unequal sampling rates including different synchronization and timing requirements.

SDR has many benefits including its ability to add new features to radio systems and to implement completely new radio systems without hardware updates. Enough processing capacity is required from a SDR platform so that it can realize these future demands. It can be stated that the number of connections change dynamically. A software radio must be able to handle dynamic allocation of processing resources between different applications. If processing resources run out, the radio must have means to determine the priority of various connections.

RF parts of a software defined radio must be able to handle wide bandwidths varying from HF frequencies to microwaves. It is presumed that a software radio can transmit and receive several signals simultaneously. Efficient, broadband linear transmitters are a necessity in an environment characterized by multiple transmitted signals, high data rates and multicarrier modulation methods. Therefore, a receiver must be able to handle signals that have highly differing power levels without use of the automatic gain control.

Traditionally, radios have been designed to fulfill the requirements of a specific radio system. If the existing software defined radio is used to implement new systems, system designers have to take into account the capabilities of software radios already in use. This may constrict the system design. Software defined radio and radio system (waveform) design methods and tools must be linked so that desired properties of new systems can be realized without the need to build or purchase new radios. Possible future demands have therefore be taken into account in the design process of a software defined radio.

Figure 5-3. *Block diagram of the software defined radio demonstrator.*



PART II: **Future Enhancements through Research**

6. Research on Adaptive Antennas

SA-kuva

***M.Sc. (Tech.) Pekka Lilja**, University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications*
***Dr.Tech Taavi Hirvonen**, PJMicrowave Ltd.*

For enhanced performance, adaptive antenna arrays for tactical radio systems were specified. The main fields of the research have been digital beamforming, environment sensing, space-time adaptive processing and electromagnetic simulations of antenna arrays. By using antenna arrays, the antenna patterns in transmitter and receiver can be adjusted in a dynamic way depending on the (hostile) signal environment.

6.1 Benefits of using Adaptive Antennas

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 detectors' directions. 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.

6.2 DOA Estimation and Digital Beamforming

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. An estimated 3-D received spatial power spectrum of an 8 element circular array is presented in Figure 6-1. Polar angle is the angle from the zenith towards the horizon. Two strong interference signals can be detected as well as the desired spread spectrum signal in the horizon. 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. A simulated radiation pattern is presented in Figure 6-2. The maximum gain is towards the desired signal and minima are generated adaptively in the directions of the strong interfering signals.

***Figure 6-1.** Estimated 3-D spatial power spectrum of an 8 element circular array. Desired signal is visible in the direction (90,90) and two strong interfering signals in the directions (60,40) and (30,200).*

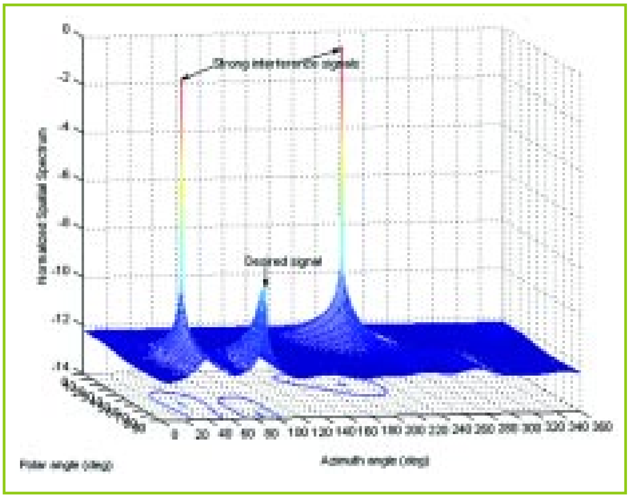
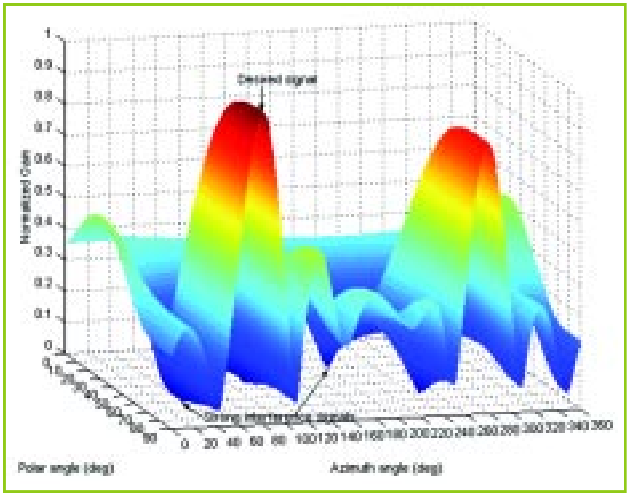


***Figure 6-2.** Simulated 3-D radiation pattern of an 8 element circular array. Maximum gain in the direction of the desired signal (90,90) and minima in the directions of interfering signals (60,40) and (30,200).*



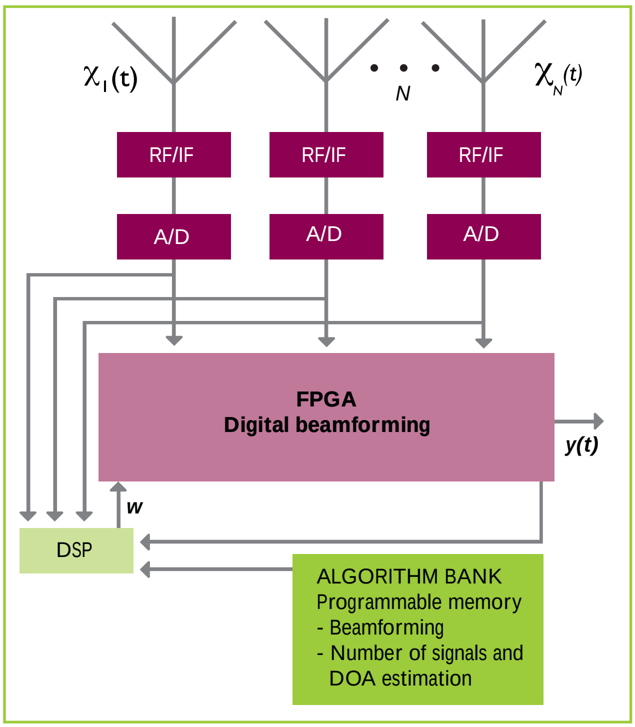
In Space-Time Adaptive Processing (STAP) a Tapped-Delay-Line (TDL) is used in each antenna branch to make the response of the antenna array the same over a wide bandwidth. In addition to the spatial domain used in the classical beamformers, STAP algorithms also use the frequency and time domain offering enhanced interference mitigation capability

6.3 Adaptive Antenna Demonstrator

An adaptive antenna system is implemented as a part of the SDR demonstrator. The advent of powerful low-cost digital signal processors (DSPs), general-purpose processors (and ASICs), as well as innovative software based signal processing algorithms have made smart antennas practical. A multitude of various algorithms can be used depending on the scenario by an SDR implementation platform. This also guarantees easy upgrading of the system.

A simplified block diagram of the adaptive antenna part of the SDR demonstrator is presented in Figure 6-3. Algorithms for beamforming and for estimating DOA and number of impinging signals are stored in a programmable memory. Algorithm diversity depending on the operational scenario can be used. For example in the PTOM, classical beamforming can be used to ensure highest possible gain to high data rate links. Digital Signal Processor (DSP) uses the selected algorithm to calculate the beamforming weights (w) and the digital beamforming can be made for example with a FPGA-circuit.

Figure 6-3. *Block diagram of the adaptive antenna part of the SDR demonstrator.*



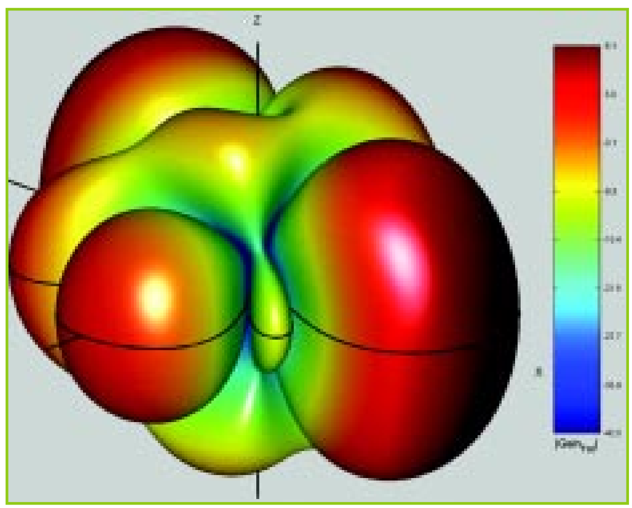
6.4 Practical Aspects

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.

Antenna arrays have been designed in co-operation with the Univ. of Oulu and PJ Microwave Ltd. With electromagnetic simulations 3-D radiation patterns of antenna arrays can be calculated with real antenna models (Figure 6-4). Such simulations account for the effect of mutual coupling between antenna elements and, if necessary, the effect of the mast and its surroundings.

The adaptive antenna array design requires careful selection of antenna elements. In PJ Microwave Ltd., antenna array elements from HF up to mm-wave frequencies are designed. The design is based on an efficient use of electromagnetic simulators and prototype measurements. For frequencies up to UHF, the most typical antennas are wire antennas of different type. Typical microwave antenna elements are based on PCB tech-

Figure 6-4. *3-D radiation pattern of an 8 element circular array. Maximum in the direction of x-axis and two generated minima are visible in the middle.*



nologies. An example of such an antenna element is a broadband patch-antenna, which is used e.g. in the antenna array presented in Figure 6-5.

Different antenna array geometries must be considered for different applications. Figure 6-5 and Figure 6-6 show two examples of adaptive antenna arrays. The first array (Figure 6-5) is designed for hemisphere coverage, whereas the second array (Figure 6-6) is assumed to work in the horizontal plane. This antenna is also one of the early antenna array prototypes for the SDR-demonstrator.

The co-operation between PJ Microwave Ltd and the University of Oulu has resulted so far in a quasi-real-time adaptive antenna demonstrator at 2.45 GHz (Figure 6-7), which is the first step toward the SDR demonstrator. The antenna demonstrator has been used to test several beam forming algorithms, such as null steering accounting for mutual coupling. The Direction-of-Arrival (DOA) methods appropriate for circular arrays, such as different versions of the MUSIC algorithm, have also been demonstrated. This experience forms a solid basis for fully digital beamforming.

Figure 6-5. *Adaptive antenna for hemispherical coverage. This antenna array is designed at PJ Microwave in collaboration with Elektrobit AG and is used in Elektrobit AG's PROPSound (www.propsound.com) radio channel sounder.*

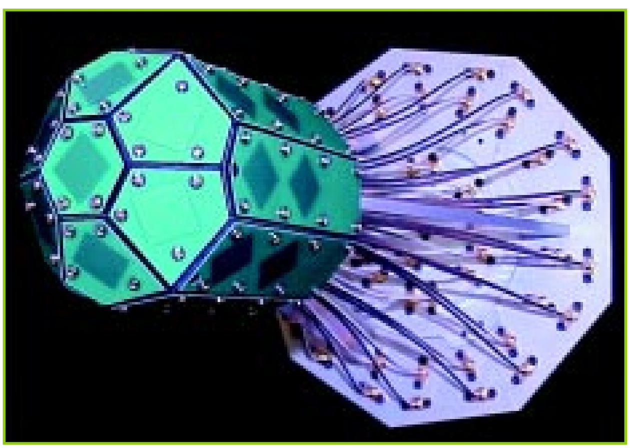


Figure 6-6. *Adaptive antenna for plane coverage. This antenna array prototype is designed at PJ Microwave Ltd for the University of Oulu.*

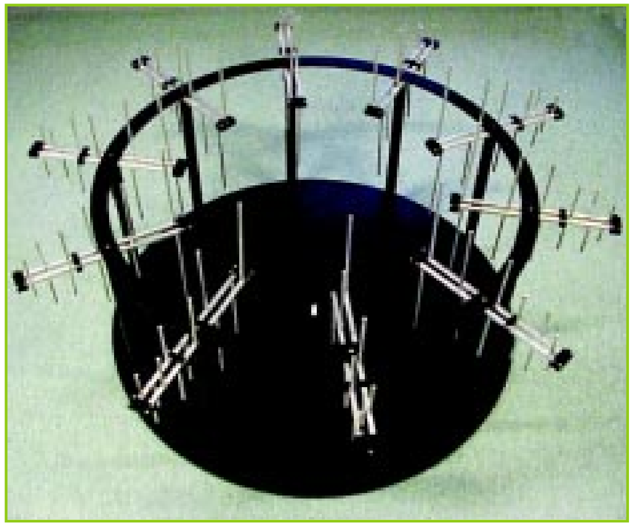
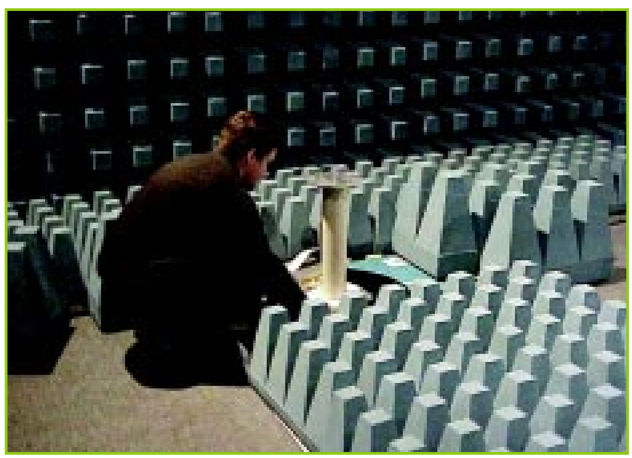


Figure 6-7. *Adaptive antenna demonstrator in calibration measurements at the University of Oulu.*



6.5 Associated research: Smart Antenna Algorithm Research at SMARAD CoE, Helsinki Univ. of Technology

Visa Koivunen,
Signal Processing Laboratory, Helsinki Univ. of Technology,
P.O. Box 3000, FIN-02015 HUT, FINLAND
visa.koivunen@hut.fi

Research on signal processing algorithms for smart antennas is conducted at SMARAD Center of Excellence (CoE) in research, Helsinki University of Technology. The SMARAD CoE nominated by the Academy of Finland is formed by the Radio Laboratory and Signal Processing Laboratory. The research topics include high resolution array processing algorithms for different antenna array configurations, robust statistical methods for smart antennas, space-time receivers for broadband communication systems including DS-CDMA based systems as well as beyond 3G and 4G systems. In addition, antijamming receivers for satellite navigation systems are derived. Antenna array algorithms used in different electronic warfare applications are developed. The following references from year 2003 give a snapshot of the smart antenna algorithm research work at SMARAD CoE. The research work is done in co-operation with the Finnish Defense Forces Research Centre and it is associated with the Finnish Software Radio Programme.

Esa Ollila and Visa Koivunen (2003), "Robust space-time scatter matrix estimator for broadband antenna arrays," in Proc. IEEE Vehicular Technology Conference, VTC'03-Fall, Orlando, USA, Oct. 6-9, 2003.

Esa Ollila and Visa Koivunen (2003), "Influence functions for array covariance matrix estimators," in Proc. IEEE Workshop on Statistical Signal Processing, SSP'03, St. Louis, USA, Sept. 28- Oct. 1, 2003.

Esa Ollila and Visa Koivunen (2003), "Robust antenna array processing using M-estimators of pseudo-covariance," in Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC'03, Beijing, China, Sept. 7-10, 2003.

Esa Ollila, Luca Quattropani and Visa Koivunen (2003), "Robust space-time covariance estimation for smart antennas," in Proc. NATO RTO Symposium on Smart and Adaptive Antennas, Chester, England, Apr. 7-9, 2003.

Esa Ollila and Visa Koivunen (2004), "Robust ML-estimation of the transmitter location," a book chapter in Statistics for Industry and Technology, Birkhäuser publishing, in print.

Sirbu, Marius and Koivunen, Visa., "Multichannel Estimation and Equalization Algorithm for Asynchronous Uplink DS/CDMA". Wireless Personal Communications, 2003. Nr. 26, pp.33-52.
Oja, Eino, Koivunen, Visa., "Tracking Mobile Radios Using Antenna Arrays and Particle Filters Antenna Arrays". in Proc. NATO RTO Symposium on Smart and Adaptive Antennas Chester, UK, 7-9 April 2003.

Belloni, F., Koivunen, V., "Unitary root-MUSIC technique for Uniform Circular Array", submitted to IEEE International Symposium on Signal Processing and Information Technology. A preliminary version will appear in Proc. International Seminar on Signal Processing Advances and Smart Antenna Systems, Finnish Defence Forces, Helsinki, October 7-9, 2003.

With, M., Werner, S., Aittomäki, T., Koivunen, V., "Anti-jamming receivers for satellite navigation systems", in Proc. International Seminar on Signal Processing Advances and Smart Antenna Systems, Finnish Defence Forces, Helsinki, October 7-9, 2003.

7. Research on Network Protocols

SA-kuva

Ph. D. Timo Bräysy, M.Sc. (Tech.) Jarmo Prokkola, M.Sc. (Tech.) Lasse Leppänen,
University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications
Lt. Sg., M.Sc. (Tech.) Petteri Kuosmanen (M.Sc.), *National Defense College*
M.Sc. (Tech.) Henri Koskinen, M.Sc. (Tech.) Laura Nieminen, M.Sc. (Tech.) Aleksi Penttinen, Prof. Jorma Virtamo,
Helsinki University of Technology, Networking Laboratory

7.1 Introduction

Software defined platforms and configurable radio networks constitute a flexible solution to enable communications between heterogeneous wireless networks. Such solutions are required in international co-operation tasks and joint operations where communications are needed across service boundaries. As a potential integrating backbone of joint military forces, SDR technology could be the key technology for future network centric warfare vision that is being created. This chapter discusses some of the networking research efforts in the National Defense College, the University of Oulu and the Helsinki University of Technology aiming to realize these visions for the Finnish defense forces. The protocol stack in SDR demonstrator has been already briefly introduced in chapter 3-7.

Most of the research efforts in software radio technology have considered the physical layer aspects such as configurable and programmable baseband, transceiver and antenna functions. However, recently, upper protocol layers and applications of SDR networks have gained more attention. To fully benefit from smart devices and to enable software download through air, the interface requires considerable support from network infrastructure, including software repositories, version handling and authentication of software downloads. On the other hand, vertical handoffs cause changes in physical layer parameters, which in turn have direct effects on the upper layers. Most obviously, changes in the data transmission speed (bandwidth) and quality (delay, jitter, BER) affect the quality of service (QoS) observed by the user. The latest trend is to jointly optimize all the layers with cross-layer design.

When designing configurable radio network architecture, a balance between programming of SDR platforms prior and during the operations must be found. In the most extreme cases, SDR devices can be seen only as reusable platforms with no support for operation time configuration, or as fully configurable and adaptive smart devices, which act together with network infrastructure to adjust themselves to any environment and do not require any configuration efforts from the users.

The decision concerning the level in which configurable platforms are going to be used dictates at least some of the solutions related to the network architecture. Almost certainly, programmable platforms will in the first stage be used only as nodes in backbone networks for reasons of cost and technical concerns. SDR backbones are used to connect separate local area networks consisting of legacy wireless technologies. Ultimately, the SDR technology may be advanced enough to be applied in handheld devices and can thus be part of wireless local area networks (WLANs).

7.2 Ad Hoc Networks in Support of Mobility

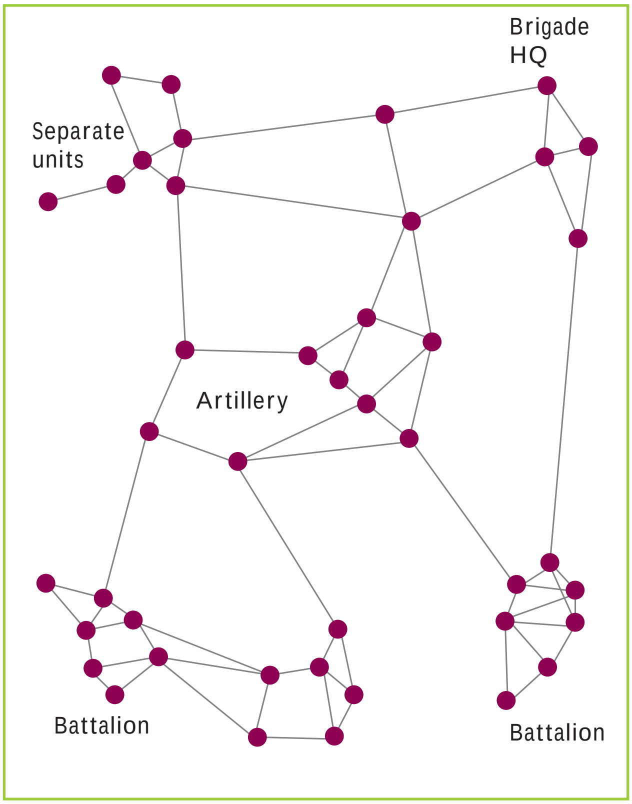
Ad Hoc networks are unpredictable wireless environments by nature. Channel conditions, number of nodes in the network, amount of traffic and degree of mobility are all essentially unknown variables during the design of the communication device. Yet, the device is expected to operate and provide fluent services for users in all Ad Hoc mode networks. Configurable protocol stack of smart device can be adjusted to essentially any form of radio technology and routing policy in use in any Ad Hoc network. This idea further enhances the autonomous nature of Ad hoc networking. However, it requires that the distribution of software modules and protocol parameter settings inside the networks is optimized with respect to additional traffic load, power usage and efficiency. Also special channels for resource negotiation and discovery may be required.

Ad Hoc networks are typically considered as autonomous wireless networks with no connection to the outside world (=backbone networks). Such stand-alone Ad Hoc networks are useful for information sharing inside a group. Even more useful is an architecture where connection to infrastructure is provided through one or more nodes in the Ad Hoc network. We call these semi Ad Hoc networks. Essentially, a semi Ad Hoc network extends the infrastructured network, and therefore same policies considering e.g. authentication and addressing architecture must be applied. Another useful scenario is to interconnect two or more Ad hoc islands. Using flexible SDR devices as bridges, even Ad Hoc networks with different wireless technologies can be connected.

Military environment differs from a typical civilian environment when Ad Hoc networks are considered. Some important differences are an uneven node distribution, hostile acts of the enemy and difficult radio propagation conditions. That is why the circular and equal radio transmission range for all nodes is not a realistic assumption. At the same time, connectivity is among the most important criteria for Ad hoc networks. If connectivity is poor, there exist individual nodes or cluster of nodes which do not have connections to the other nodes. Connectivity cannot be improved by increasing the radio transmission ranges of all nodes, because then neighboring nodes disturb each other, and thus MAC level throughput decreases. In addition, using too high transmission power shortens the lifetime of batteries in portable radio equipment.

As a solution, a two level hierarchical node structure is suggested (semi Ad Hoc concept). In this solution, the lower level nodes are portable, battery driven radios and the upper level nodes are vehicle-mounted devices having high transmission power such as SDR platforms. By using two levels it is possible to form relative high bandwidth capable core links between the upper level nodes. With the core it is possible to distribute traffic to multiple parallel routes, and thus decrease congestion. The upper level nodes can have adaptive antennas, and thus the ability to distribute transmission power spatially in order to reach the best possible connectivity. On the other hand, the lower level nodes should be as simple as possible. In this way, the lower level nodes can be relatively reasonable by their price, and the penetration level of the devices can be high. An Ad Hoc network providing the communications services of the brigade can be seen in Figure 7-1. A typical radio link distance with the same brigade model could be around 2-3 km, assumed that there is dense enough node population in the operational area.

Figure 7-1. *Ad Hoc radio network to fulfill the communications needs of the brigade.*



As mentioned above, all network structures have their own specific features, which dictate how the network can be formed. These features and some relevant comparison values have been listed in Table 7-1. The total number of nodes, in the table, is only an estimate about the useable number of nodes in the corresponding network. The number is the smaller the longer the radio links are. This is because long radio links with high transmission power reserve more of the total available media capacity. On the other hand, on the same channel there cannot be too many stations, because the channel congestion increases as the number of subscribers grows.

Table 7-1. *Comparison between different network structures according to the brigade model.*

	Chain of command	Base station	Ad Hoc
Average link distance	15 km	Subscriber links normally under 7.5 km. Core links 10-15 km.	Under 2.5 km. But also over 7.5 km in some cases (depends on the node distribution)
Link directions	Mostly towards the frontline	Subscriber links mainly towards the frontline. Core links also towards the frontline	Arbitrary
Example of number of nodes and critical nodes	500 / -	1000 / 20	3500 / -
Benefits	Simple	Good coverage	Robust
Disadvantages	Reveals the structure of organization Long vulnerable links	Base stations are single points of failures	Needs complicated and distributed control mechanism to be effective

Adaptive and perhaps even "intelligent" learning nodes in an Ad Hoc network may be designed to constantly learn about their operation environment and adapt their own behavior accordingly. This could be applied through the use of protocol boosters, parameter setting of standard protocols and even selection of the best protocol (e.g. for routing) in different conditions.

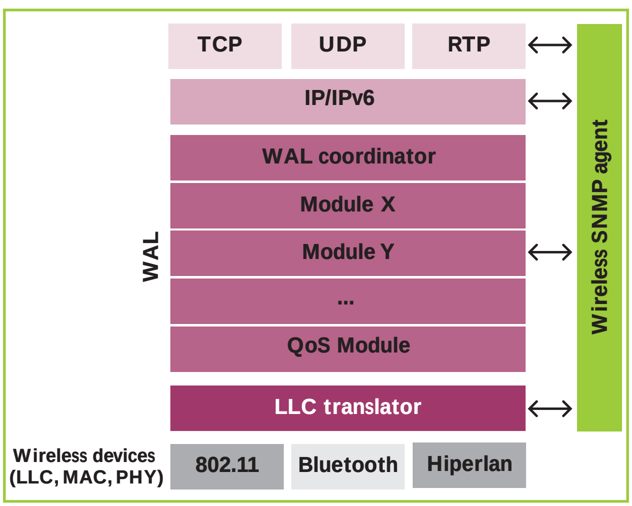
7.3 Research at the Univ. of Oulu for Future Enhancements

In this chapter, we will discuss the operations and applicability of smart SDR devices in various IP network scenarios and architectures. We will consider SDR devices that are capable of operation time mode changes or general scenarios where upper layer adaptation is a desirable feature even if the underlying physical interface remains unchangeable. By this we refer to cases where wireless devices are supposed to operate in highly variable environments and adaptive protocols can to some extent mitigate the effect of such variations.

7.3.1 Adaptive Protocols

Research and development aiming for implementation of adaptive protocol layers has been one of the major fields of study in networking recently. The Univ. of Oulu research group was one of the partners in European Wireless Internet NEtworks project (WINE) the main result of which was the implementation of a Wireless Adaptation Layer (WAL). WAL coordinator, presented in Figure 7-2, is responsible for applying various protocols boosters, such as packet level error correcting codes, different retransmission policies, header compression and TCP specific proxies, e.g. Snoop. The principal motive in WAL design was to enable protocol layer adaptivity with respect to variable wireless link conditions. The WAL design aimed at complete independence of the underlying wireless technology. As a result of this objective, WAL was operated on top of 802.11b, Bluetooth and Hiperlan/2 platforms.

Figure 7-2. *Wireless Adaptation Layer (WAL) design in WINE project.*



In SDR related research, adaptive protocols can be further developed by including various heavily radio link technology dependent booster modules as part of the loadable and configurable software. For example, in a military related environment, a SDR device can enhance its jamming tolerance by downloading tailored retransmission policies or error correcting codes. In upper protocol layers (network and transport), SDR devices can be tailored to fit the common policies used in a particular network. In this way, for example, a particular routing protocol can be downloaded in the field. In a military environment, the adaptive protocol stack can be used to adapt the communications to match specific needs in different operational modes and services (the Navy, the Army, the Air Force).

By using properly defined and open Application Programming Interfaces (APIs), it is possible to utilize software components by third-party vendors. This and the modular design of protocols and protocol boosters are the key enabling software technologies aiming at a flexible use of adaptive protocols in SDR devices.

7.3.2 Heterogeneous Wireless Networks in Network Centric Warfare

Heterogeneous wireless networks with multi-homed nodes and related vertical handoffs present a challenging environment for protocol design. Devices with multiple wireless interfaces are available today which allows the performance of vertical handoffs from technology to another (e.g. from 802.11 variants to Bluetooth and GPRS). Clearly, different wireless interfaces may offer drastically different services to the upper layers. Bandwidth (bit rate), delay, jitter and packet error rate may differ leading to remarkable differences in attained QoS (Quality of Service). Adaptive methods in various layers can be used to mitigate the effect of a variable wireless environment. For example, applications can be adjusted to decrease the required quality of video transmission if a slower wireless link is taken into use. Similarly, in an inherently secure radio link, security functions at upper protocol layers can be loosened which results, e.g. in enhanced processing of applications and decreasing power consumption.

The protocol architecture designed in the WINE project is further developed in 6HOP project funded by the European Union. The 6HOP protocol architecture is presented in Figure 7-3. Note that in 6HOP, the IP layer protocols are purely IPv6 compliant. (Univ. of the Oulu is part of a world-wide 6NET consortium aiming at the development and wide use of IPv6 infrastructure, as well as fluent cross-over from IPv4 to new technology). With the 6HOP protocol architecture, we are developing a wireless platform capable of operating in a heterogeneous wireless multi-hop environment. Protocol boosters are still present as also in the WINE design. In addition, several managers are being designed to assist the operations: Wireless Adaptation Manager (WAM) is essentially the WAL coordinator presented in WINE -project with similar functions. It is now accompanied by Connection Manager (CM) whose function is to detect and analyze the available connection methods by accessing the information from wireless drivers. Another task of CM is to assist the upper layer protocols and applications in vertical handoffs to make the handoff as seamless as possible from the users' point of view. Power Manager (PM) collects and offers information about the power usage of the device. Note that PM will not be implemented in 6HOP, rather, its functionality is only outlined in order to demonstrate the flexibility of our protocol architecture. Different managers communicate with wire-

Figure 7-3. *High level protocol architecture of 6HOP devices.*

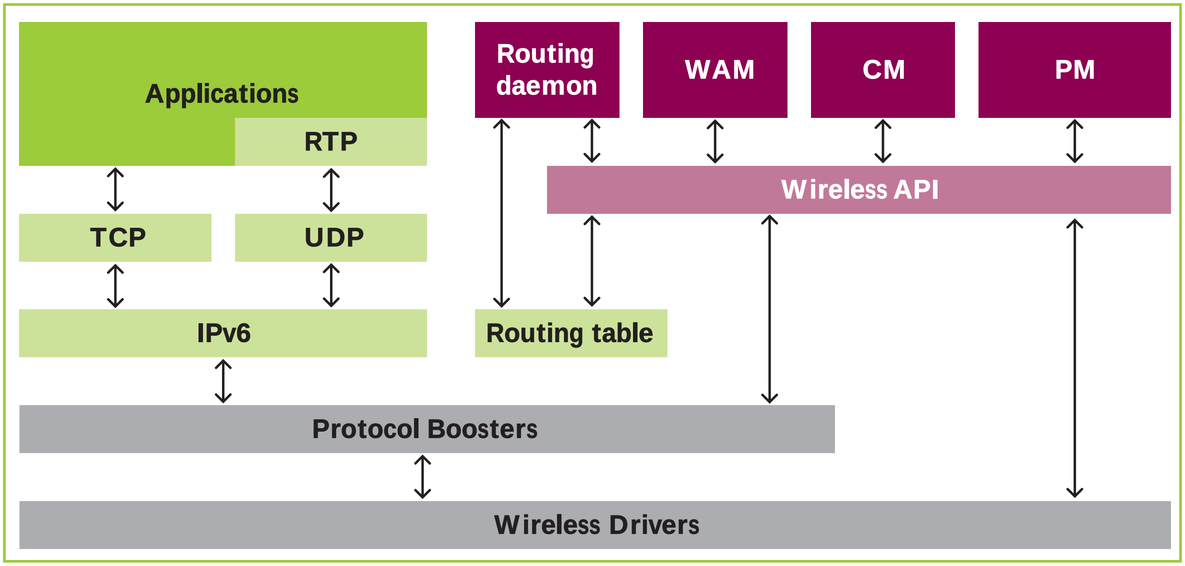
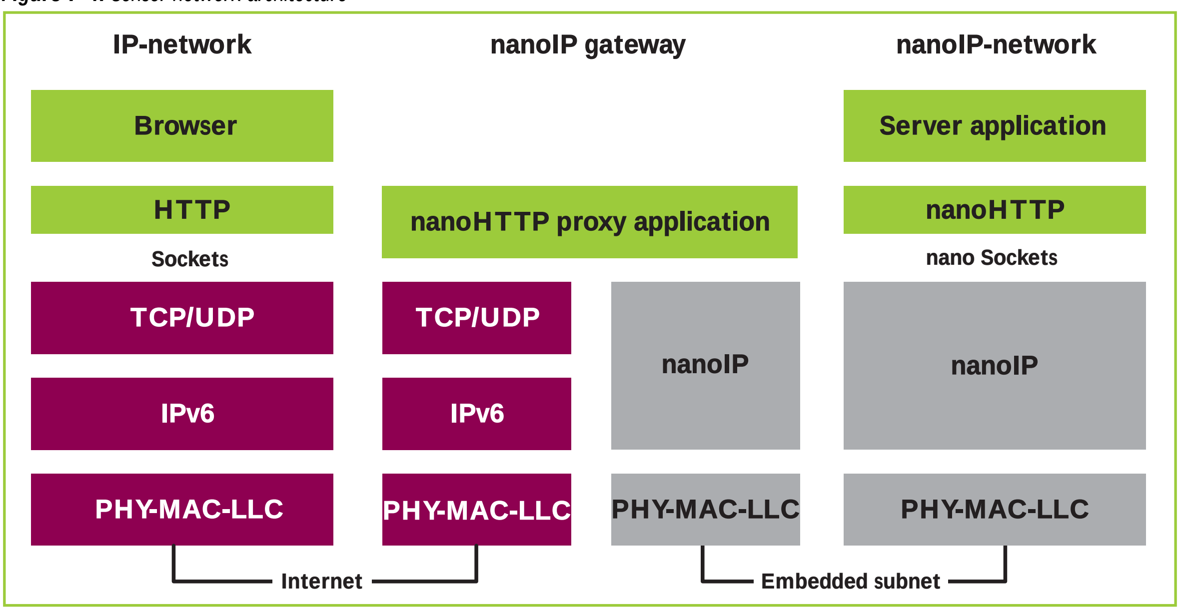


Figure 7-4. *Sensor network architecture*



less drivers through Wireless API. Similarly, WAM operates the boosters through Wireless API. The whole construction of managers, booster modules and API constitute a Wireless Adaptation Framework (WAF).

IP layer mobility support must be defined in SDR networks. Macro-mobility protocols, i.e. mobility support for users crossing local network boundaries and their usability in large-scale heterogeneous wireless environment, are also part of 6HOP research. Especially the scalability of mobility protocols in wide scale networks is studied.

7.3.3 Sensor Networks through Tactical Intranet or Internet

Wireless embedded networking and its application to wireless sensor networks is one of the main research areas at the Univ. of Oulu. Our group has designed and implemented an embedded networking protocol and architecture. The implementation includes a nanoIP-protocol and supporting CSMA/CA MAC designed to be used with low power, low bandwidth wireless networked devices such as sensor devices. NanoIP protocol architecture is presented in Figure 7-4. Our sensor network architecture is based on gateway nodes, which act as proxies and offer sensor data to the IP network.

In our sensor network architecture smart SDR devices would act as gateway nodes. SDR devices are supposedly capable of performing sophisticated sensor fusion tasks, in addition to pure proxy-functions. Furthermore, with configurable gateway, information can be gathered and fused from various sensor networks, even if they are based on different wireless technologies.

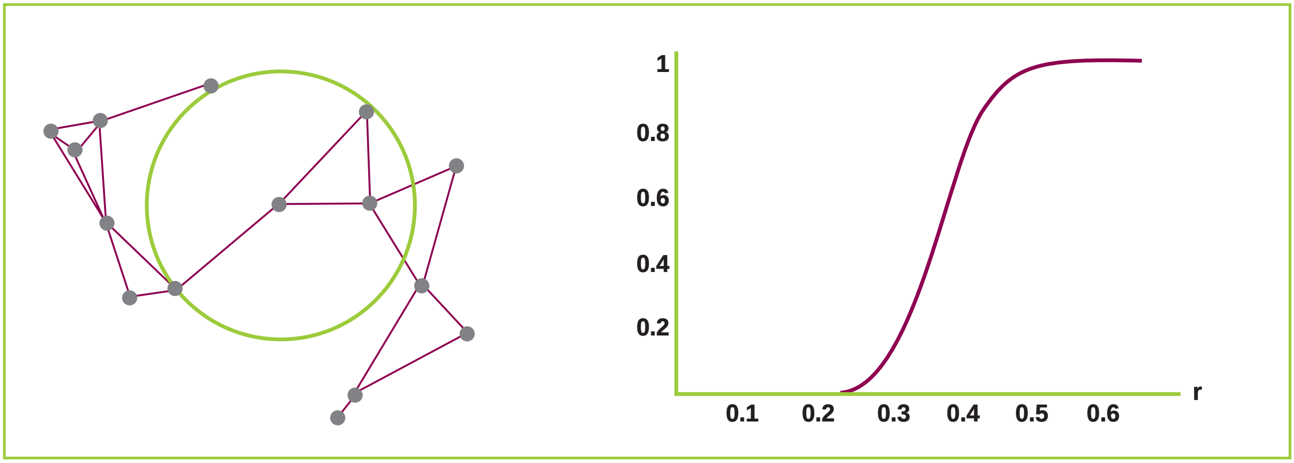
7.4 Supporting research at the Helsinki University of Technology: Performance of Ad Hoc Networks and Their Protocols

Guaranteeing a given level of performance or quality of service in packet networks, e.g. in the Internet, has proven difficult even in the context of fixed networks. In Ad Hoc networks the problem is even more difficult because of the specific features of such networks. First, the nodes of Ad Hoc networks may be mobile, and even if the nodes are stationary, as for instance in some sensor networks, their positions may not be fully controlled. Moreover, the nodes may be vulnerable to enemy attacks. Then meeting even the most fundamental performance criterion that of having connectivity between all the nodes cannot be taken for granted. Second, the nodes are often battery powered with a limited energy reservoir. In some situations, this is a real consideration and must be taken into account in the planning of the routing protocols, for example, in order to lengthen the lifetime of the network. Ad Hoc network specific performance problems are studied in the HUT Networking Laboratory. In the following, we describe in more detail the above problem areas, as well as the Ad Hoc network simulator that has been built to support the performance studies.

7.4.1 Connectivity, Survivability and Coverage of Ad Hoc Sensor Networks

Consider an Ad Hoc network of randomly placed nodes (e.g. sensors scattered in the terrain) with a common transmission range, so that any two nodes can communicate directly if and only if they are within that range from each other (see Figure 7-5). Then the probability that these nodes make up a connected network reduces to knowing the distribution of the greatest edge length in the Euclidean minimum spanning tree

Figure 7-5. *The network topology formed by a set of nodes with their transmission range equaling the threshold range for connectivity (left). The probability of connectivity of 15 randomly located nodes in a unit square as a function of the transmission range r (right).*



of randomly placed nodes (it can be shown that for a given node set, this is the threshold range for connectivity). The distribution is known only asymptotically when the number of nodes tends to infinity. This can, however, be utilized in finding empirical models with correct asymptotic behavior for predicting connectivity.

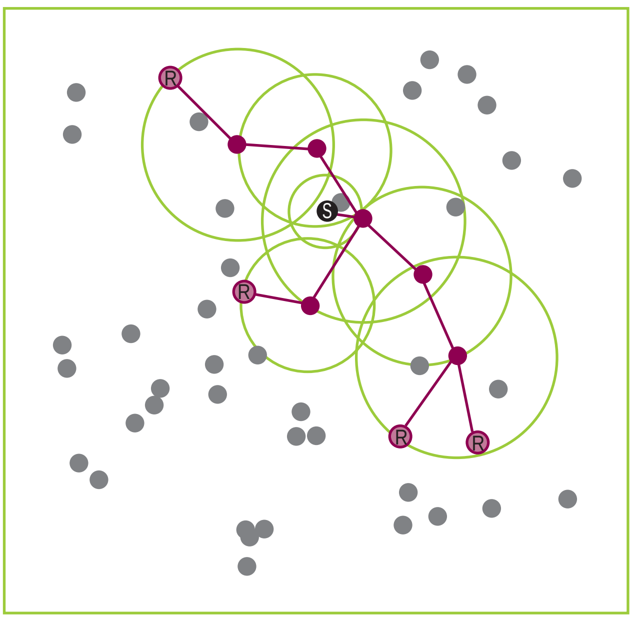
The concept and modeling the distribution of the threshold range can be generalized to k-connectivity. A k-connected network remains connected after the removal of any k-1 nodes. The degree of connectivity is therefore a measure of network survivability.

Yet another problem where the threshold range appears is that of full coverage. Assume that all the nodes in a sensor network have the same sensing range. Then, for a given set of sensors deployed on a bounded domain to be covered, the threshold range for full coverage can be found from the Voronoi diagram of the sensors, combined with the boundary of the domain. There are known asymptotic results regarding this problem as well, allowing the use of empirical models with predictive power.

7.4.2 Energy Efficient Routing of Multicast Transmissions

In some military applications of Ad Hoc networks, such as sensor networks, the node energy resources are limited and difficult or sometimes even impossible to replenish. Given that the sensor nodes are fairly stationary and their transmission powers are adjustable, well-designed multicast transmissions can significantly reduce the energy consumption and prolong the network lifetime.

Figure 7-6. *Minimum energy multicast tree from a sender (S) to four recipients (R) found by the ISPT algorithm.*



Energy efficient multicast-tree construction consists of selecting a set of nodes and their transmission powers to connect a sender to a set of receivers so that the sum of the transmission powers is minimized. We have introduced a novel algorithm to generate source-based multicast-trees and analyzed its performance. The proposed algorithm depicted in Figure 7-6, Incremental Shortest Path Tree (ISPT), starts with an initial tree and then grafts the receivers one by one to the tree using paths that yield the lowest incremental power costs. The algorithm is especially suitable in cases where the number of multicast receivers is fairly small (for larger receiver groups, the previously known algorithms based on pruning a broadcast tree performs equally well).

On the other hand, there is a trade-off between energy efficiency and the throughput; energy efficient routes tend to use only a few power efficient routes causing traffic to concentrate on these routes. In addition, due to the signal attenuation, these routes tend to prefer numerous short hops to a few longer ones, which increases the number of store-and-forward operations required.

Generally, the effect of routing on throughput is an important consideration. Even if primary objectives of routing development are elsewhere, e.g. in energy efficiency or in robustness, the contingent side effects to the network throughput should be investigated as the network capacity is a scarce resource. In general, this is not an easy task due to the interaction between routing and scheduling. However, the flow level throughput characteristics of any routing scheme and traffic pattern can be approximated by a recently developed method.

7.4.3 Simulation of Ad Hoc Network Protocols and Algorithms in Mobile Environment

Including even a limited number of the features of real Ad Hoc networks in the network model easily brings the problem beyond analytical tractability. Therefore, a simulator flexibly supporting different kinds of mobility of the nodes is needed. To this end, the AHN-simulator has been developed. This is not a packet level simulator but it has rather been designed for studying how the algorithms function at a higher level, focusing on the effects of node mobility.

Several mobility models, such as Gauss-Markov, Random Waypoint, Random Direction and Reference Point Group models have been implemented in the simulator. The user can choose different mobility parameters for different nodes and node groups in a single simulation. With the Open Plane mobility model the studies can be extended to the cases where the nodes can leave the considered area and new nodes can arrive during the simulation. Finally, in addition to the pure Ad Hoc model, a two-layer semi Ad Hoc model has been implemented.

The simulator has been written in C++. It takes traffic parameters and network parameters (such as number of nodes and their mobility models) as input and returns the simulation results in an output file. The output can then be analyzed or presented graphically. The simulator can be used for modeling topological changes and connectivity in the dynamic Ad Hoc and semi Ad Hoc networks with different mobility models. Additionally, it supports studies of different routing algorithms at the connection level.

List of the Helsinki University of Technology, Networking laboratory publications can be found at web sites:
www.tct.hut.fi/engl.shtml
keskus.hut.fi/tutkimus/ahras

PART III: **Research and Development Co-Operation within Programme**

8. Key Players in Programme


SA-kuva

LtCdr Topi Tuukkanen, *Finnish Naval Academy*
M.Sc. (Tech.) Heikki Rantanen, *Finnish Defense Forces' Technical Research Center*
Lich.Tech. Ari Pouttu, Prof. Pentti Leppänen, *University of Oulu, Telecommunication Laboratory and Centre for Wireless Communications*
LtCdr GS (ret.) Tommi Malinen, Lich.Tech Eino Keränen, *Elektrobit Ltd.*
M.Sc. (Tech.) Anna-Maria Kähkönen, *Sofnetix Ltd.*
Dr.Tech. Taavi Hirvonen, *PJMicrowave Ltd.*
M.Sc. (Tech.) Ulf Holm, *Instrumentointi Ltd., C3i Systems*
B.Sc. (Tech.) Kari Äyrämö, *Patria*

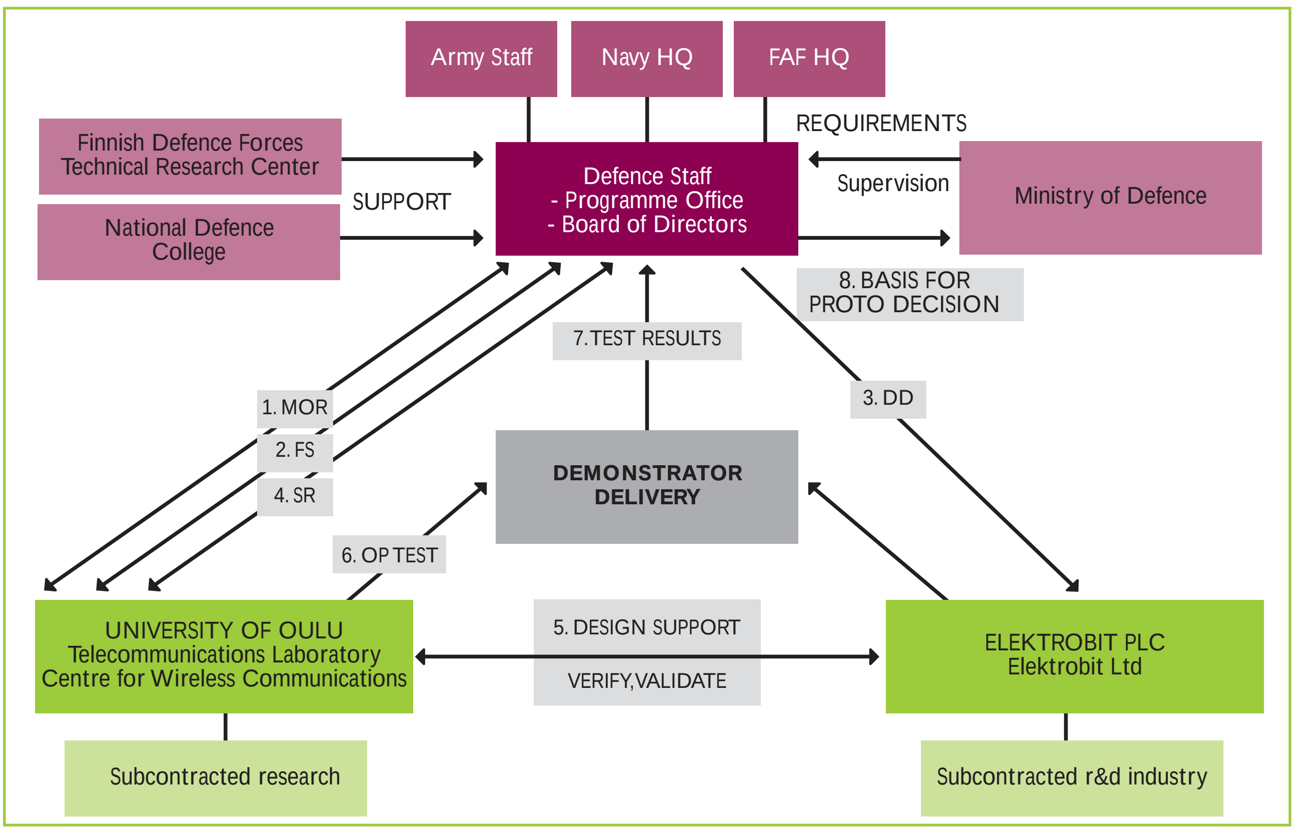
8.1 The Consortium and Assigned Tasks

The Finnish Software Radio Demonstrator Programme is a result of previous and still continuing work of many organizations and projects. However, the process may be summarized as depicted in Figure 8-1

The process description is as follows:

1. Armed services identify military operational requirements (1. MOR).
2. The feasibility of the requirements (Feasibility Study, FS) is analyzed and a proposal for implementation is recommended by the university (2. FS).
3. Design and development contract (DD) is awarded to the industry (3. DD).
4. Supporting research contract (4. SR) guarantees the transfer of latest technical and scientific know-how as support to design and development process. At the same time, the scientific community, as an independent third party, will verify and validate (VV) technical solutions and designs proposed by the industry (5. DESIGN SUPPORT, VERIFY, VALIDATE).
5. The industry delivers the demonstrator platform already passed through internal quality assurance programme for operational testing (6. OP TEST), planned and supervised by the scientific community. The test results reported (7. TEST RESULTS) will form the basis for prototyping decisions (8. BASIS FOR PROTO DECISION).

Figure 8-1. *Co-operation within FSRD Programme.*



Principal partners in this process are:
- Finnish Defense Forces
- Main research partner: University of Oulu
- Main contractor: Elektrobit Ltd

Main partners themselves have already created a network of subcontractors specializing in their own areas of expertise. However, from the Defense Forces point of view, there are only two partners, two processes, to monitor and manage. From the administration point of view this is an advantage and allows the military to concentrate on the management and validation of military operational requirements. The next chapters present the key players in the programme.

8.2 Finnish Defense Forces

Finnish Software Radio Demonstrator project was launched by the Finnish Defense Staff where the programme is supervised by Chief of C3 Division and supported by the Chief Engineer of the Technology and Acquisition Support Division. The Programme Board of Directors includes representatives from the Ministry of Defense, Army Staff, Air Force Headquarters, Navy Headquarters as well as research and industrial partners. Organic scientific and technical advice is provided by the Finnish Defense Forces Technical Research Center.

Finnish Defense Forces' Technical Research Center (PvTT) is in charge of providing the technological and scientific research, development, testing and trialing services that are required by the Defense Forces and the country's defense.

The Center is focusing on the areas of research where Finland's other research institutions do not have the expertise, or where the Defense Forces' own research is deemed necessary. The Center's field of research encompasses weapons and ammunition, explosives, materials used in military equipment, non-conventional weapons and protection against them, optronics, signature management, and electronics and information technology.

The center is the largest of the Defense Forces' research centers and operates directly under the command of the Defense Staff. The centre is subordinate to the Chief of Logistics and the Chief Engineer directs its activities.

The center carries out the work ordered by the Defense Forces, or outsources it to other research institutions. The assignments are mainly involved with threat and research into different materials: their development and comparison, reception and storage, and durability and defects.

PvTT provides the assessments and forecasts required for management and development. It also provides training in military training establishments and disseminates its research in a publication series.

The number of personnel is approximately 160, of which more than 85 % are civilian staff. The number of researchers is more than 70.

PvTT has three research divisions, one of which is the Electronics and Information Technology Division. This division is in charge of the research work that supports the Software Demonstrator Project. However, the bulk of the actual research work is done by PVTT's research partners, which include various laboratories in the University of Oulu, Helsinki University of Technology, and VTT - Technical Research Center of Finland.

8.3 University of Oulu - Telecommunication Laboratory and Centre for Wireless Communications

Laboratory and CWC Facts

The Telecommunication Laboratory (TL) and Centre for Wireless Communications (CWC) are part of the Department of Electrical and Information Engineering of the University of Oulu, Finland. Wireless communications techniques have been investigated at the Telecommunication Laboratory since 1986. The Centre for Wireless Communications was formed within the Telecommunication Laboratory in 1995. The number of staff members is 110 (7.10.2003).

Laboratory and CWC Strategy

Wireless communication techniques have been investigated in the Telecommunication Laboratory since 1986 and since 1995 in co-operation with the Centre for Wireless Communications. The mission of the CWC is to conduct scientific research supporting users and developers of wireless communication systems in their research, development and application projects, as well as to enhance the exchange of know-how between the University and society in an academic environment.

A strategic decision to concentrate on spread spectrum and code division multiple access (CDMA) techniques was made at the TL in the mid-1980's. The decision has proven to be very fruitful. Due to multiple co-operation projects between the TL, Finnish companies and the Finnish Defense Forces, spread spectrum and CDMA techniques have been utilized by them far before significant commercial break through such as 3rd generation mobile phone systems. The knowledge of the CWC has been transferred to industry, which has successfully used both trained people and available research results in influencing the standardization of 3rd generation systems. Another example of the success of spread spectrum communications research is the new tactical radio air interface concept for the Air Defense C3 system of the Finnish Air Force, which was developed in the TL. Today the TL and CWC have established highly successful cooperation with the most important foreign and Finnish international companies and the Finnish Defense Forces.

The Vision of Future

The vision of future commercial and military communication systems in the research is the following:

- To increase capacity, the systems should fully utilize the available spectrum by using the most advanced modulation, coding and data multiplexing techniques in space-frequency-time domain.
- Physical layer must be adaptive (coding, modulation, data multiplexing, MAC layers, etc.); space-time-frequency domain must be fully utilized in optimizing physical layer.
- Future networks will utilize Ad hoc networking principles.
- Flexible radio systems can be built by using Software Radio techniques (Univ. of Oulu is a member of the SDR Forum).

Research Strategy

Based on the vision, the CWC and TL have a well-defined research strategy which is annually revised. The research is categorized in two ways (Figure 8-2): according to the time span for real applications (Application Area) and according to technical research area (Research Area). Theoretical research is carried out in different Research Areas. Gathered Technology Knowledge is utilized in several application-oriented projects (Application Knowledge). This research strategy is formed to improve understanding of new incoming fundamental theories behind wireless communication systems, i.e. to conduct long term research at different Research Areas which are defined as Wireless Networks, Physical Layer Techniques and Transceiver Techniques. The strategy combines the knowledge and applications of both commercial and military communication systems in order to develop flexible radio concepts for future needs.

Figure 8-3 describes the system design procedure what has been applied in telecommunication system research. The outcome for the Defence Forces is the telecommunication system technical description. The description documents is based on research (using analysis, modelling of different functionalities of the system, computer simulations, etc.) starting from military operational and technical requirements, then using system models, and analyzing system alternatives .

The Focus of Research

Since the establishment of the CWC in the mid 1990's, the scope of research has been systematically enlarged. Focus has been shifted towards future broadband air-interface and wireless networking technologies. Research of beyond 3G systems and Ultra Wide Band (UWB) techniques was started already in 1999. Currently the major research application areas for the CWC are UWB and 4G systems.

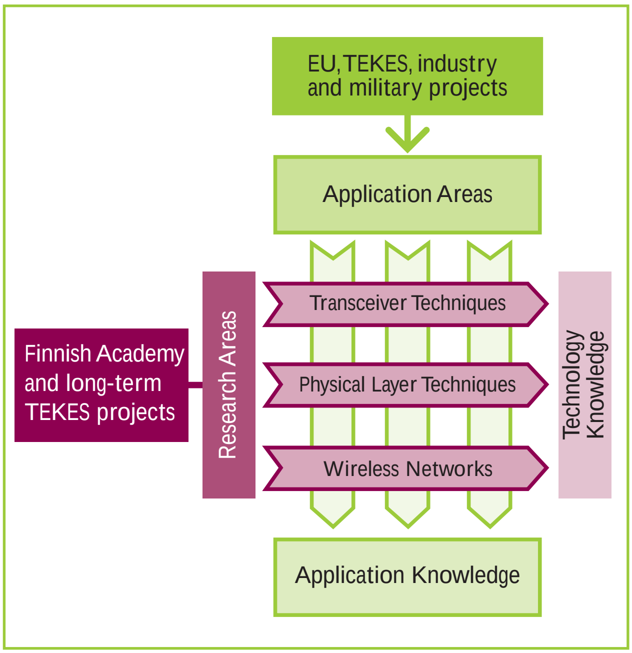
The focus of the research funded by the Finnish Defense Forces has been broadband radio communication systems for the Air Force, Navy and Army and applications of spread spectrum techniques; tactical radio systems; tactical Intranet network architectures; adaptive high data rate AJ and LPI radio links; use of mobile communication systems (e.g. GSM/GPRS/EDGE /UMTS and TETRA concepts) and WLANs in military applications; and location and navigation systems.

The National Technology Agency of Finland (TEKES) has chosen CWC´s FUTURA project as one of the spearhead projects in the area of mobile communications. The CWC has also created new types of cooperative networks between Japan and the EU for future mobile communication systems development. These networks strengthen the position of the CWC and Finland as a major force in telecommunications research.

Research Topics and Methods

The research work at the TL and CWC has addressed a wide variety of issues in wireless communication systems and techniques. A system engineering approach had to be taken in order to be able to develop novel wireless transmission systems for the needs of Finnish society.

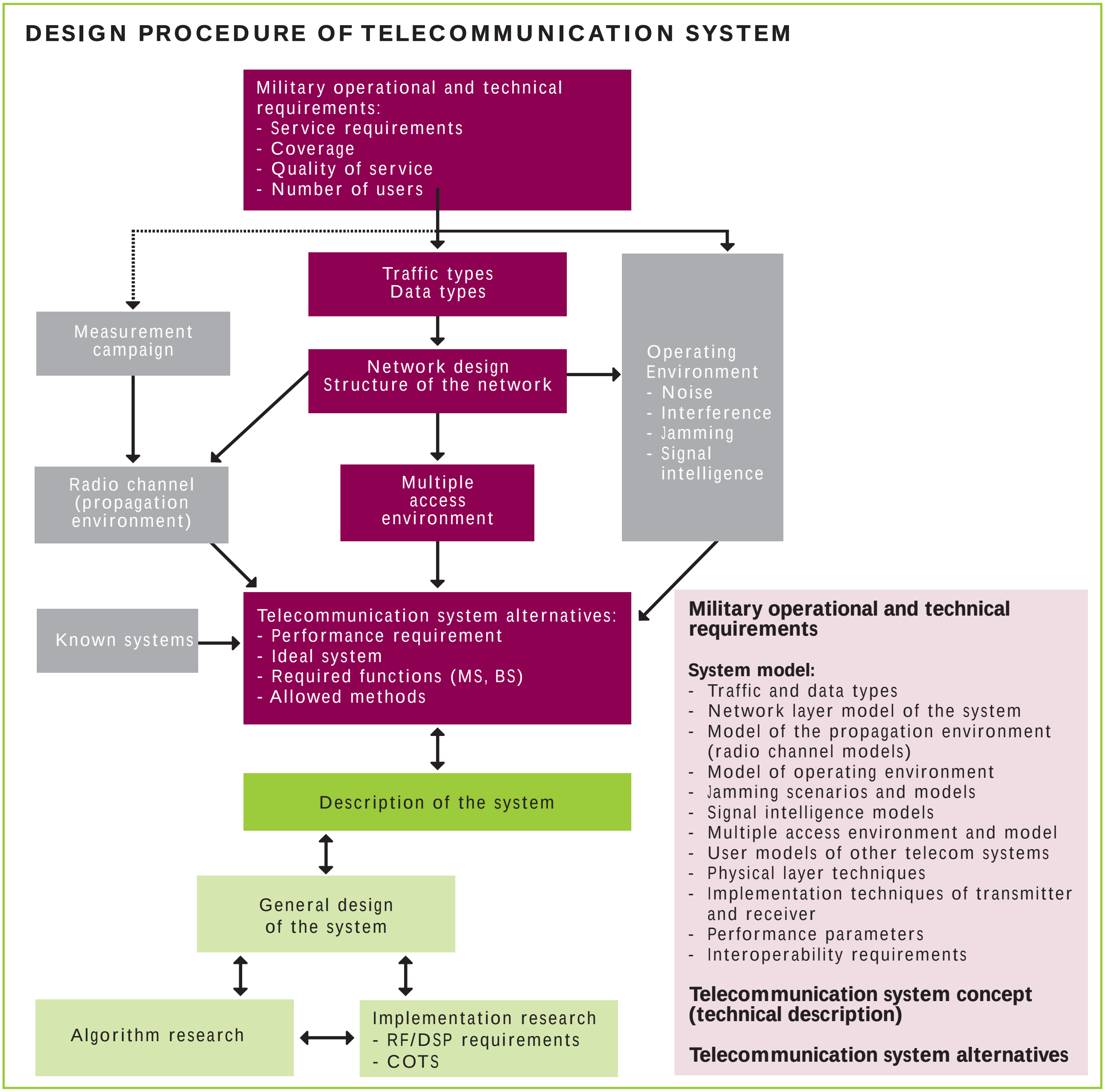
Figure 8-2. *Research strategy structure.*



Therefore, several diverse research issues are currently covered by the TL and CWC:

- Future broadband wireless techniques (Orthogonal Frequency Division Multiplexing (OFDM), Multicarrier CDMA (MC-CDMA) and Ultra Wideband (UWB))
- Wireless Internet
- Radio location and navigation
- Radio network analysis, design and control in CDMA and Ad Hoc networks
- Channel access protocols and multiple access techniques
- Multidimensional space-time channel coding
- Interference cancellation and suppression in commercial and military communication systems
- Parameter estimation in wireless communication systems

Figure 8-3. *System design approach applied in the Telecommunication Laboratory and CWC.*



- Signal waveform analysis and design
- Wideband and microwave RF techniques and adaptive antennas
- Software defined radio architectures for wideband communication systems
- Radio wave propagation and multidimensional wideband channel modeling.

Publications and more information
More information about the Centre for Wireless Communications and Telecommunication laboratory as well as the list of recent scientific publications can be found on the Biennial Report 1.1.2001–31.12.2002 (ISBN 951-42-6899-7) and on the following web-sites:
www.cwc.oulu.fi and www.telecomlab.oulu.fi

Other results of the Finnish Software Radio Programme are 4 doctoral theses, 2 licentiate of tech. theses, 11 M.Sc. (Tech.) theses, 8 patents (pending), 3 international journal papers, 29 refereed international conference papers and 101 classified research reports.

8.4 Elektrobit Group Plc

Elektrobit's own research work since the early 1990's has actively aimed at developing next generation radios based on SDR technologies. This work and co-operation with Finnish research laboratories, especially the Telecommunication Laboratory and CWC of the University of Oulu, and Finnish Defense Forces has created capabilities and made it possible to establish the Finnish SDR programme.

Elektrobit has a long-term cooperation relationship with the Finnish Defense Forces. In March 2003 Elektrobit Ltd and the Finnish Defense Forces signed a three-year research and development contract for a software radio demonstrator for research and test purposes. The value of the contract is 12 million euros and the project will be completed in the beginning of 2006. The contract awarded clearly indicates Elektrobit Group's high-skill competence in the areas of radio technology and wireless communications. In demonstrator project Elektrobit works in close co-operation with Finnish sub-suppliers. Elektrobit's own SDR product concept will be launched by the end of 2005.

Elektrobit is capable and is willing to provide national and multinational SDR technology solutions and products. Elektrobit is also aiming to provide SDR related contract research and development work including waveform development services worldwide.

Defense sector is defined as a strategic growth area in the group. In future Elektrobit is targeting to be a major player and a partner in the SDR product business and to co-operate in the SDR technology development and manufacturing with other selected companies worldwide.

Elektrobit's business idea is to improve the competitiveness of the customer's product and production by assuming total or partial responsibility for product development, product design, and the implementation of production and testing solutions. Company's objective is to be the leading supplier of productization solutions within industry and a leading technology partner behind the best brands. Long-term partnerships with customers and research institutes, and a strong enterprising spirit provide a leading expertise in the areas of Radio Channel and Air-Interface technologies.

The Group operates in 15 countries and employs approximately 1100 experts within its field, including 800 R&D engineers. The Group recorded pro forma net sales 136 million euros in 2002. Elektrobit Group Plc. is listed on the Helsinki Exchanges.

The objective of Elektrobit's international expansion was to operate close to the customers as well as in locations with access to expert resources. In the beginning of 2002 Elektrobit had operations in Switzerland, Great Britain, Germany, France, Japan, Singapore and the United States. Elektrobit operates in ten locations in Finland.

Operations
Elektrobit is a versatile engineering company, which, in addition to its design services, develops, sells, and markets its own technologies and products to customers.

The management of defense projects and customers is centralized to Elektrobit Ltd., which is the largest subsidiary in the Group with more than 500 employees. There is a specific growing Defense Solutions business line for the defense projects with more than 50 dedicated experts and project managers. The employees in the Defense Solutions have been approved by the Finnish Defense Forces and the company sites in Kajaani, Oulu and Kauniainen have been prepared for highly classified projects. In addition to the personnel in the defense business line the whole resource pool consisting of hundreds of experts will be utilized whenever needed.

Elektrobit is strengthening the preparedness for international co-operation. The Group's global infrastructure is a significant existing resource for this. We are actively present in technology forums, such as the Software Defined Radio Forum (SDRF). Our focus is on export of the products being under development. As a good example of this is the Delta/PCM- transcoder, that was originally designed for the Finnish Defense

Forces and is now at the responsibility of the Elektrobit AG in Switzerland and marketed globally.

Three Business Units

Elektrobit's operations are divided into three Strategic Business Units (see Figure 8-4). The SBU's are responsible for their know-how, technologies, and competitive edge. The three SBU's are contract R&D, Test, and Automation Solutions. Contract R&D, which is related to the programme, is described in more detail in the following.

Contract R&D

The Contract R&D business unit works as a product development partner for companies that use wireless technologies and need high tech solutions and outsourcing services.

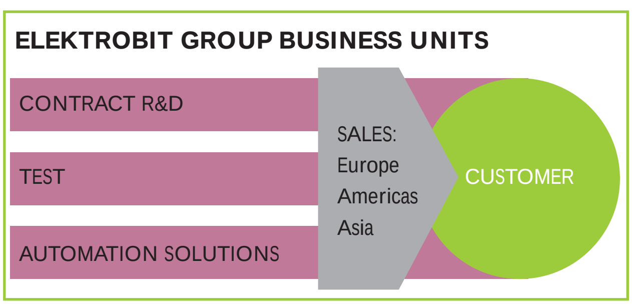
- Total or partial responsibility for the customers design and product development projects,
- Often based on long-term strategic customership,
- Own research aiming at continuous development of top know-how,
- Various business models from hourly billing to the sharing of risk and reward.

Contract R&D aims to offer product development services to companies that work with wireless products and have their own distribution and marketing organization required for product launches. The unit's business consists of product development services and clearly segmented wireless products that support product development. This emphasizes Elektrobit's pioneering role in the radio interface of wireless telecommunications as well as in the integration of technologies.

Core Competencies

Elektrobit's future success and pioneering role is based on its core competencies. The competence centers of different business units are responsible for developing their core competencies. The core competencies that are related to SDR programme, divide into many different fields of know-how as described below.

Figure 8-4. Elektrobit Group Business Units.



Radio technology, electronics and software design

Radio channel expertise covers radio technology and analogue technology as well as signal processing algorithms. Electronics design includes ASIC design with fast digital logic circuits and layout simulation as well as electromechanical design fulfilling EMC and ESD requirements. Software design refers to know-how in demanding telecommunications and electronics products and systems.

Elektrobit has invested significant amount of resources on air interface research since the early 1990's. The research activities were focused on CDMA and spread spectrum technologies today utilized for example in 3G (UMTS) mobile communications systems. In addition, video coding has also been one of the research areas as the importance of image and real time video transfer is increasing in future's mobile communications.

At the current moment Elektrobit is looking at the technologies that are utilized in the systems beyond 3G and current WLAN. These technologies, also referred to 4G, shall make it possible to transmit information at much higher bit rates than before providing the users new possibilities to access services and networks such as the Internet.

Some of the most relevant research areas are:

- Multicarrier modulation methods
- Multidimensional coding (e.g. space-time-frequency coding)
- MIMO
- Adaptivity

To understand and measure in practice the performance and limitations of the new technologies resulting from the research projects, Elektrobit has developed an air interface demonstrator. The demonstrator is able to run a high-speed real time link over the radio channel thus allowing real bit-error ratio and other performance measurements in a controlled environment. In addition, it is possible to build a real communications system comprising mobile terminals, base stations and the network section running real time applications such as live video between the terminals.

Customer Groups and Selected References

The customers of the Elektrobit Group are leading players within their own industry. The main customer group is the telecommunications industry including equipment manufacturers, operators, contract manufacturers, and component and subassembly manufacturers. Customer groups of the Elektrobit Group include:

- Telecommunications operators
- Telecommunications manufacturers
- Electronics contract manufacturers

– Component and subassembly manufacturers
– Automotive electronics manufacturers
– Industrial automation manufacturers
– The defense and space industry

As an outcome of R&D programs Elektrobit has developed e.g. the following products:

– PROPSim, radio channel simulator (Figure 8-5),
– PROPSound, radio channel sounder,
– WUCS- wireless underground communication system for mining vehicles,
– ESBT -spread spectrum modem for the European Space Agency (ESA),
– REPEATER, for TETRA networks,
– Delta/PCM -transcoder (Figure 8-6):
  • Gateway between different communication networks, for voice and data
  • Various voice coding schemes and communication protocols
  • Flexible platform for mobile and fixed environment
– Mobile Subscriber System,
  • to connect the Combat Net Radio Networks (CNRN) and the Tactical Telecommunication Networks together
  • to offer the Phone and Data Services to the Mobile Subscribers of the CNRN
– Smart antennas,
– Muzzle velocity radars.

More information on Elektrobit can be found on web-site:
www.elektrobit.com

Figure 8-5. *PROPSim radio channel simulator.*

8.5 Sofnetix Ltd

Sofnetix is a R&D contracting company specializing on real-time software for wireless systems covering protocol software as well as wireless applications. The company has comprehensive experience both in standard, and non-standard, special purpose wireless software systems. Sofnetix is also a member of the SDR Forum.

Sofnetix has comprehensive experience in GSM, GPRS and UMTS systems, which are representing standard based commercial wireless technologies. The company is specialized especially in layer 2 and layer 3 software. To mention an example of wireless application solution, a vehicular machine-to-machine communication solution based on GPRS can be mentioned. Also years of experience in development of services of the Symbian platform falls into wireless application category.

In addition to commercial and standard based wireless systems, Sofnetix is also developing tailor made wireless software solutions for special purposes. As an example, Sofnetix has carried out feasibility studies and requirement specification work for a special purpose software radio system for the Finnish Defense Forces. As a continuation of this work, Sofnetix is currently participating in a joint effort to develop a software radio technology demonstrator.

More information on Sofnetix Ltd can be found on web-site:
www.sofnetix.fi

8.6 PJMicrowave Ltd

PJ Microwave Ltd, locating in Technopolis Science Park in Oulu, is an engineering company specialized in microwave and millimeter wave technology. The company was established as a spin-off of Elektrobit Ltd in

Figure 8-6. *Delta/PCM -transcoder.*

May 2000 and it has rapidly grown having today about 20 microwave engineers.

PJ Microwave has strongly invested on the state of the art simulation software and measurement tools. It has measurement tools (vector and scalar network analyzers, spectrum analyzers, signal generators and power meters) up to 40 GHz and the following simulators are in active use:

- Agilent and Ansoft HFSS and CST Microwave Studio:
  3D EM modeling
- Zeland IE3D:
  2.5D EM modeling
- Nittany Scientific NEC:
  Metal structure simulator
- Agilent ADS and Ansoft Designer:
  System and circuit simulators
- Analog devices C - compliers and emulators.

The core competences of the company are:
- Millimeter wave radio design
- Integrated antenna design
- Adaptive antennas and associated algorithms
- Microwave instruments for process industry
- Microwave defense systems
- RFID systems
- FMCW technology applications
- UWB radio
- Designs based on LTCC and multi layer PCB technology.

PJ Microwave is capable of offering total solutions from research to production by using the effective network of companies and universities.

More information on PJ Microwave Ltd can be found on web-site:
www.pjmicrowave.fi

8.7 Instrumentointi Ltd, C3i Systems

Instrumentointi Ltd is a family-owned Finnish high technology company having business history from 1960. The company started in industrial automation installation business but has during the decades been developed to a multi-business automation, defense and information technology expert.

The Insta Defense business sector was started in 1973 with an aircraft instrument and electronics repair shop for the Finnish Air Force, air transport companies and general aviation operators. From 1980 a growing part of our activities has been development and integration of sophisticated C3i and simulation systems. Air defense systems are the main focus of our development work, but we are strongly expanding also towards Land and Naval systems. The development of ADCC-systems (Air Defense Command and Control), Data Link systems and simulator systems have been organized as the C3i Systems Division.

In C3i Systems, our operating principle is to understand our customers' needs for air defense and simulation systems and to carry out development work in close co-operation with the customers.
C3i Systems' core competence areas are:
- Excellent knowledge and a deep understanding of the application field
- Development of real time and embedded systems
- Management of major development projects
- Demanding software and electronics development
- Simulation and training systems
- Geographical information and positioning technology
- Radio communications and telecommunication networks
- Radio channel performance measurements
- Strong skills on development and implementation of algorithms.

In software radio demonstrator phase the role of Instrumentointi Ltd is to develop the application software required to obtain positioning and navigation capabilities. The SDR platform provides the necessary parameters for the application software.

In the next section, a brief description of related R&D performed by Instrumentointi Ltd is given.

Data Link System development

In collaboration with the Finnish Air Force, Instrumentointi Ltd and Patria have developed and manufactured a powerful and secure Data Link System. It forms part of the existing ADCC System and has been installed in Finland's F-18 HORNET fighter aircraft.

The Finnish Air Force Data Link System is a secure and robust airborne data link system with excellent ECCM EP capabilities. The system objectives are to enhance the situational awareness of the fighter pilot and ensure the integrity of the airborne military communications.

Instrumentointi and Patria have developed and manufactured the system at the initiative and under the guidance of the Finnish Air Force.

Instrumentointi is responsible for the radio channel parts both in aircraft and in the base station, and of the entire ground system.

Target and own ship data are transmitted on ground-to-air, air-to-air and air-to-ground links. The fighter controller's ability to control the mission is supported by commands that can be transmitted to any selected aircraft.

The Data Link System has been proven in operational use. Different versions of the system have been integrated and operationally used in the J-35 Draken and in the Finnish F-18 Hornet. The Data Link is also easy to integrate in other fighter aircrafts.

Continuous development and easy modification of the system are supported by software-based algorithms and modular system architecture.

ADCC System development

Instrumentointi has been developing and improving the Air Defense Command and Control (ADCC) System for the Finnish Air Force for more than fifteen years. The functions of the ADCC System include data collection from various sensors, compilation and distribution of real-time air display, several sophisticated decision support applications, and an embedded simulation subsystem for both training and research.

More information on Instrumentointi Ltd can be found on web-site: www.insta.fi/english/

8.8 Secgo Ltd

Secgo Group Ltd develops and delivers secure, high-quality networking solutions for companies and the public sector. These comprehensive and flexible solutions consist of products, consulting and other services. With two decades of expertise in the development and implementation of demanding security solutions, Secgo is an experienced pioneer in the field. The solutions include:

- Secure remote access for employees
- Secure extranets for customers and partners
- Secure intranets and wireless LANs
- Highly secure military and governmental networks
- Secure, interoperable collaboration solutions.

Secgo's role in SDR demonstrator phase is to provide the management system enabling both local and remote management of the SDR.

Large customer base

Secgo's solutions are widely used in demanding business sectors, such as the public, banking and finance, service provider, manufacturing industry and military sectors. Secgo's customers include Nordea, the leading provider of financial services in the Nordic countries, Sonera, Finland's largest telecommunications service provider, global mobile communications corporation Nokia, global pulp and paper industry supplier Kvaerner Pulping, Finland's Slot Machine Association, Finnish Ministry of the Interior and the Finnish Defense Forces.

Secgo's business areas

Secgo is divided into two strategic business areas. The Secgo User to Net business area provides complete networking solutions for companies with telecommuters, mobile users, subsidiaries or partners around the world. The solutions allow companies to provide telecommuters with secure and flexible access to the network services and systems. Secgo Confidence to Net concentrates on innovative, customer-specific and highly-specialized technology projects, such as mobile infrastructures for public authorities and financial as well as governmental and defense applications. Such projects are characterized by extremely rigorous security demands.

Secgo's consulting services and Secgo Service Centre serve the customers of all Secgo business areas. The services of Secgo Service Centre have been awarded the international BS7799 Information Security Certificate.

Secgo employs over 70 professionals in Tampere and Espoo, Finland, in Stockholm, Sweden, and in London, UK.

Solutions for secure networking

- Secure, interoperable collaboration solutions to enable more efficient business operations
- Communication software solutions for C4I systems.

Secgo's products include

- Secgo Crypto IP VPN product family
- Secgo Mobile IP mobility management products
- CA certificate services
- Consulting services.

More information on Secgo Ltd can be found on web-site: www.secgo.fi

8.9 Related R&D Industry: Patria

Patria is not currently part of the demonstrator programme but has conducted feasibility study in HDRLM integration to aircraft environment. The feasibility study concentrated on directional antenna deployment in BS as well as aircraft.

Mission

Patria is a defense, aviation and aerospace technology Group whose main customers include defense forces, public authorities and other enterprises in Finland and abroad.

Patria's main product portfolio includes military vehicles and weapon systems and their life cycle support services.

The product portfolio includes also life cycle support of military helicopters and aircraft. Also solutions within defense electronics, systems integration and demanding composite structures are included in Patria's main product portfolio.

Operations

Patria is a technology group focusing on defense, aviation and aerospace industries. Its customer base includes defense forces, public authorities and enterprises in Finland and abroad. The history of Patria's Business Units dates back over 80 years. Patria was founded in 1997 and current Patria results from subsequent restructuring of the Group.

Patria's business activities are divided into four Business Areas: Land Systems, Aviation, New Technologies and Civil Products and Services. Each Business Area Management is responsible for its own area's financial result and asset-liability management. Operational activities are divided between Business Units, which are responsible for marketing, selling and delivering their products to the customer.

Aviation

The Aviation Business Area is responsible for life cycle support services of military aircraft and helicopters as well as their systems. The services include assembly, maintenance, repair, modifications as well as development of new systems. The operations cover fuselage, engines and avionics. The Business Area's most important customers are the Finnish Air Forces, helicopter operators and the aviation industry both in Finland and abroad. The main market area consists of the Nordic and Baltic countries. Within Aviation Business area, the Avionics Business Unit is responsible for the related R&D efforts.

Avionics Business Unit

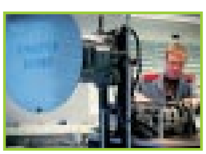
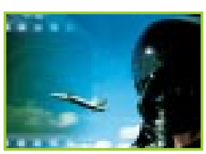
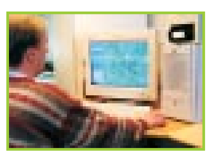
Core Competencies and Selected References

Patria Aviation's Avionics Business Unit (see Figure 8-7) is the primary source for intermediate and depot level support for military electronics and avionics systems in Finland. Specialized in Radio, Electronic Warfare (EW), Data Link and Radar Technologies and Ground Support Systems, we offer a wide range of services including:

– Airborne Electronics and Software Development and Integration
– Harsh Environment Electronics and Systems
– Mission Support Systems
– Test Equipment and Software Development
– Avionics and Military Equipment Repair, Maintenance and Overhaul
– Mechanical Equipment Maintenance
– Final Assembly and Testing
– Technical Support and Training
– International Offset Trade Co-operation.

The main customer of Avionics Business Unit is the Finnish Air Force. Other customers include the Finnish Defense Forces and some major international military system suppliers.

Figure 8-7. *Avionics Business Unit*

AVIONICS WORKSHOP (MS-AW)	RADAR AND EW APPLICATIONS (MS-AR)	AVIONICS APPLICATIONS (MS-AA)	F-18 SOFTWARE SUPPORT (MS-AS)	MISSION SUPPORT SYSTEMS (MS-AI)	SUPPORT FUNCTIONS (MS-SF)
- Overhaul and repair - Test Systems - Calibration - Production	- Special Test Equipment - Test Software - Preformance Research - Systems and Software	- Airborne Electronics - Software Production	- F-18 System and Software Support - F-18 Software Test Systems	- Support Systems - Systems Integration	- Quality assurance - Development - Support functions - Electric, mechanic and harness design
					

An example of Avionics Business Unit's major R&D programs is given in the next section.

Finnish National Data Link Program

This highly sophisticated system for tactical air situation awareness communication helps ensure the security in the air for Finland's self-defense capability. Developed in co-operation between Patria Aviation, the Finnish Air Force and other Finnish industry, the system gives Finland an independent and secure communications system for transmitting target track files and commands between a ground-based command center and fighter aircraft. The heart of the system located within the fuselage of the F-18, is called Data Link ECCM Computer, or DLEC.

More information on Patria can be found on web-site: www.patria.fi

List of Acronyms

AAS	Adaptive Antenna System
ACI	Application Control Interface
AD	Analog-to-Digital
ADCC	Air Defense Command and Control
AHN	Ad Hoc Network (simulator)
AJ	AntiJam
AJM	AntiJam Mode (in AWNW)
API	Application Programming Interface
ASIC	Application Specific Integrated Circuit
AWNW	Adaptive Wideband Networking Waveform
AWNW-HD	Adaptive Wideband Networking Waveform - High Data rate
BER	Bit Error Rate
BF	Beam Forming
BS	Base Station
CA	Collision Avoidance or Certification Authority
CDMA	Code Division Multiple Access
CIMIC	Civil and MIlitary Co-operation
CIS	Command and Information System
CM	Connection Manager
CME	Consecutive Mean Excision
CNR	Combat Net Radio
COTS	Commercial Of The Shelf
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CWC	Centre for Wireless Communications
C2	Command and Control
C3	Communications, Command and Control
C3I	Communications, Command, Control and Intelligence
C4I	Command, Control, Communications, Computers and Intelligence
C4ISTAR	Command, Control, Communication, Combat Information, Surveillance Targeting, Acquisition and Reconnaissance
DA	Digital-to-Analog
DD	Design and Development
DOA	Direction Of Arrival
DS	Direct Sequence
DSP	Digital Signal Processing
ECCM	Electronic Counter Counter Measures
EDGE	Enhanced Data rate for GSM Evolution
ELINT	ELectronic INTelligence
EMC	Electro Magnetic Compatibility
EP	Electronic Protection
ESD	Electro Static Discharge
ETSI	European Telecommunications Standards Institute
EU	European Union
EW	Electronic Warfare
FAF	Finnish Air Force
FCME	Forward Consecutive Mean Excision
FDMA	Frequency Division Multiple Access
FH	Frequency Hopping
FMCW	Frequency Modulated Continuous Wave (radar)
FS	Feasibility Study
FSRD	Finnish Software Radio Demonstrator
FUTURA	Univ. Oulu/CWC project: FUTUre Radio Access
FWD	ForWarDing algorithm in protocol stack
GALILEO	European satellite based positioning system
GPRS	General Packet Radio System
GPS	Global Positioning System
GSM	Global System of Mobile communications
HDRLM	High Data Rate Link Mode
HF	High Frequency (3-30 MHz)
HQ	HeadQuarters
HTTP	Hyper Text Transfer Protocol
HUT	Helsinki University of Technology
IC	Interference Cancellation
IFF	Identify Friend or Foe
IP	Internet Protocol
ISPT	Incremental Shortest Path Tree
JTRS	Joint Tactical Radio System
LAN	Local Area Network
LLC	Logical Link Control
LPD	Low Probability of Detection
LPI	Low Probability of Interception

LPIM	Low Probability of Interception Mode (in AWNW)
LTCC	Low Temperature Co-fired Ceramic
M	Management function of protocol stack
MAC	Medium Access Control
MAI	Multiple Access Interference
MC	Multi Carrier
MIMO	Multiple Input Multiple Output
MLE	Mobile Link Entity
MM	Mobility Management
MMMB	Multi-Mode Multi-Role Multi-Band (radio)
MOR	Military Operational Requirements
MS	Mobile Station
MUSIC	MUltiple SIgnal Classification
NanoIP	Reduced IP-protocol for power aware systems
NATO	Northern Atlantic Treaty Organization
NGO	Non-Government Organization
NTPS	National Tactical Positioning System
NTPW	National Tactical Positioning Waveform
OFDM	Orthogonal Frequency Division Multiplexing
OT	Operational Testing
PC	Personal Computer
PCB	Printed Circuit Board
PH	PHysical layer
PM	Power Manager
PR4G	French CNR-radio
PSO	Peace Support Operation
PSTN	Public Switched Telephony Network
PTOM	Peace Time Operations Mode
PvTT	Finnish Defense Forces' technical research center
QoS	Quality of Service
R	Routing function in the protocol stack
R&D	Research and Development
RF	Radio Frequency
RFID	Radio Frequency IDentification
RTP	Real Time Protocol
SBU	Strategic Business Unit
SCA	Software Communications Architecture
SDMA	Space Division Multiple Access
SDR	Software Defined Radio
SDRF	Software Defined Radio Forum
SHF	Super High Frequency (3-30 GHz)
SINCGARS	SINgle Channel Ground Air Radio System, US CNR-radio
SNOOP	TCP aware proxy service
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
SR	Supporting Research
STAP	Space Time Adaptive Processing
TADIRAN	Israeli CNR-radio supplier
TCP	Transport Control Protocol
TDD	Time Division Duplexing
TDL	Tapped Delay Line
TDMA	Time Division Multiple Access
TEKES	National Technology Agency (in Finland)
TETRA	Terrestrial Trunked Radio
TH	Time Hopping
TL	Telecommunication Laboratory (of University of Oulu)
TOA	Time Of Arrival
TRCS	Tactical Radio Communication System
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UHF	Ultra High Frequency (300-3000 MHz)
UMTS	Universal Mobile Telephony System
UWB	Ultra Wide Band
VHF	Very High Frequency (30-300 MHz)
VIRVE	Acronym for TETRA based network in Finland
VPN	Virtual Private Network
VTT	Technical research centre of Finland
VV	Verify and Validate
WAF	Wireless Adaptation Framework
WAL	Wireless Adaptation Layer
WAM	Wireless Adaptation Manager
WINE	European Union funded WINE-project (Wireless Internet NEtworks)
WLAN	Wireless Local Area Network
2-D	Two Dimensional
3-D	Three Dimensional
3G	Third Generation
4G	Fourth Generation
6HOP	European Union funded project
6NET	European Union funded project

Telecommunication Laboratory and Centre for Wireless Communications, P.O.Box 4500, FIN-90014 University of Oulu, Finland
Street address: Tutkijantie 2 E, Technopolis Park, Oulu, Finland
Tel. +358 8 553 1011, Fax +358 8 553 2845 www.telecomlab.oulu.fi, www.cwc.oulu.fi
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