THE USE OF THE SOFTWARE COMMUNICATIONS ARCHITECTURE (SCA) FOR SONAR AND UNDERWATER COMMUNICATION APPLICATIONS

Emma Jones (SEA Group Ltd, Bath, UK. emma.jones@sea.co.uk)

ABSTRACT

The Software Communications Architecture (SCA) is an Open Standard for communications equipment developed for the Joint Tactical Radio System (JTRS) program. Although the architecture is primarily aimed at software defined radio applications, the technique is equally applicable to sonar and underwater communications systems, promising to take the benefits of JTRS in terms of development, support and openness to the underwater domain. This paper discusses the application of Software Defined Radio techniques to Sonar and Underwater Communication Applications.

1. INTRODUCTION

The ability to use the same equipment for sonar and underwater acoustic communications (acomms) on Unmanned Underwater Vehicles (UUV), by making use of the Software Communications Architecture (SCA), is a potential benefit.

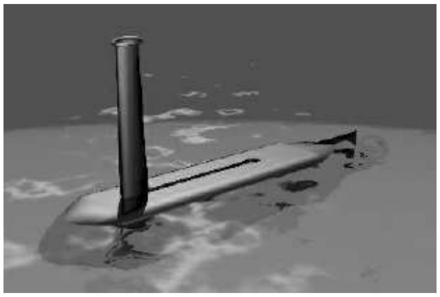

Figure 1 – Concept Military UUV

Current UUV technology (Figure 1) assumes that sonar and acomms systems are distinct, and in most UUV applications this is a necessity as both functions must be supported simultaneously. However, in the case of UUVs with strict power requirements, the amount of acomms-transmitted information can potentially be reduced to allow reassignment of the equipment for sonar sensing.

The SCA [1] provides a framework for the design and implementation of Software Definable Radios and its generality makes it suitable for a range of other applications, including sonar and acomms. With sonar, and in particular acomms systems rapidly developing over the last few years (Figure 2 [2][3][4][5][6][7]), and with a resulting increase in the processing available, the possibility of providing a software definable solution which supports both applications is both tractable and appealing. In addition, the ability to provide a solution that can map different acomms or sonar applications with the same hardware is also a considerable benefit: acomms systems that operate in covert scenarios, or provide long distance connections, or are installed in mesh networks, require similar communication components and can potentially be implemented on the same platform.

2. THE UNDERWATER ACOUSTIC CHANNEL

The underwater acoustic environment [8] provides a very challenging communication channel. At sea, temperature and salinity changes the refraction of acoustic waves creating time-varying divergent paths and ducts. The surface not only performs as an excellent reflector but also adds background noise with increased sea state. The sea floor also acts as a reflector creating multi-path within the channel, particularly in shallow or littoral waters, leading to ISI. Reverberation, Doppler, and in particular the narrow bandwidth of the channel (typically around 8kHz-32kHz or less for acomms) all contribute to the problem.

Doppler is a particular issue in comparison to radio channels because the speed of sound in water is typically only 1500m/sec and varies with temperature, salinity and depth (pressure). The narrow channel bandwidth is a result of frequency dependent attenuation, which causes the range to reduce dramatically with increased frequency. Although sonar systems with frequencies of 500kHz to 1MHz or more provide very accurate measurement for high resolution mapping for example, the useful range may only be a few tens of meters at most. Typically, sonar systems work at well below 500kHz, with long distance sonar systems operating in the 1kHz-10kHz band. Acomms systems use low frequencies, typically in the 8KHz – 24kHz band, for the same reason.

3. SONAR

Active sonar, as we know it today, was developed early in the last century by Langevin primarily as a means to detect submarines. The ‘ping’ method is identical to that later used for radar, and with suitable transducers and processing can detect bearing and range. Active Sonar is complemented by Passive Sonar techniques, which use platform radiated noise as the active element.

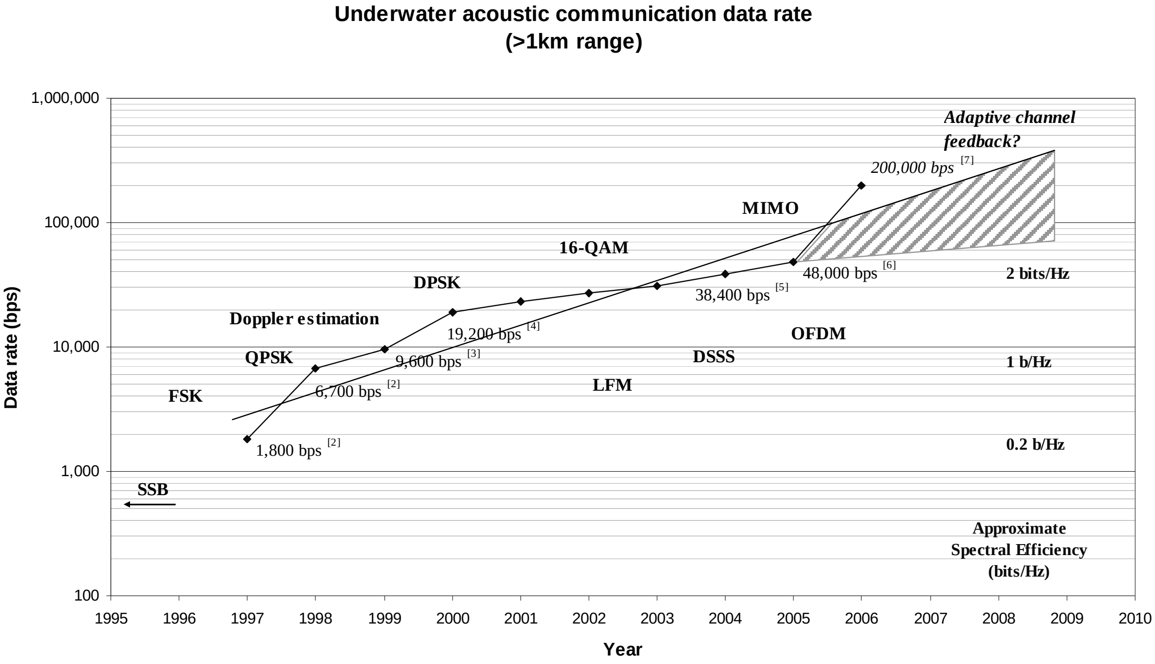

Figure 2 – Acomms communications data rates and associated technology

In addition to location finding, sonar is also used in bathymetry to determine ocean depth, and by analyzing the reflected signal, seafloor or lakebed classification can also be performed. Sonar systems are also used for fish-finding and environmental monitoring.

Imaging sonar [9] is relatively common, and sonar systems typically utilise multiple-beams, provide interferometric swath measurements (Figure 3), use synthetic aperture sonar approaches, and beam forming techniques.

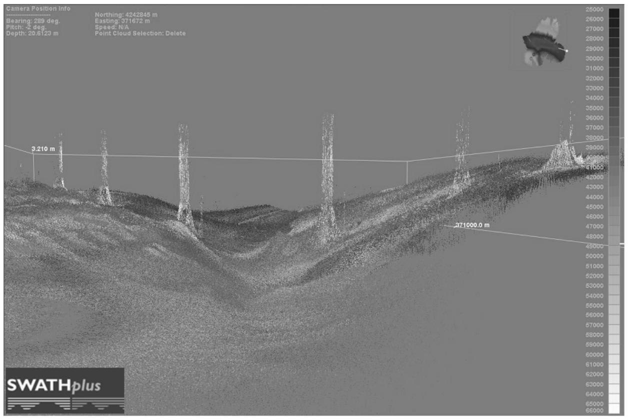

Figure 3 – Interferometric side-scan sonar image of a bridge support survey

4. UNDERWATER ACOUSTIC COMMUNICATIONS

Acomms systems originally utilised Single Side-band (SSB) techniques and modulated the voice channel around a carrier frequency of typically 25kHz or so. This approach provides acoustic communication data rates of several hundred bits/second at best [4]. However, in the 1990's, significant developments in modulation and coding techniques were successfully transferred to the acomms domain resulting in increased data rates for underwater data communications (Figure 2).

The use of Direct Sequence Spread Spectrum (DSSS) using long PN-code sequences and improvements in equalisers allowed both a dramatic increase in the data rate and in the covertness of the communications link. Experiments with OFDM and MIMO (space-time coding) illustrate techniques that promise up to 200kbps at distances of a kilometer [7].

As the properties of the channel are better understood and the capabilities of equalization, modulation and coding improve, further increases in data rate, up to the Shannon limit, may be possible in the near future.

5. SONAR SYSTEMS AND ARCHITECTURE

Sonar systems have a similar structure to radio systems (Figure 4). A modulated transmit signal pulse train is created, based on a timing source, which is passed to a power amplifier that then drives a transducer. On the receive side, front-end low noise amplifiers (LNAs) boost the signal

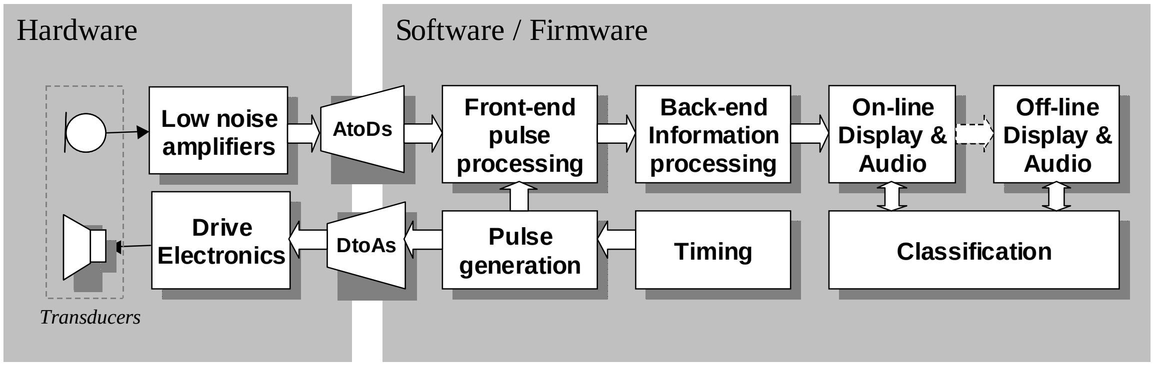

Figure 4 – Sonar system architecture

and pass it to a bank of analogue-to-digital converters. The digital data is then processed and timing used to compute range. Relative phases of the incoming signals are used in interferometric sonar systems.

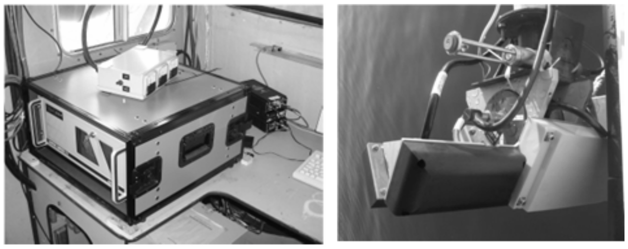

Figure 5 – Typical equipment of a side-scan survey sonar set

Back-end processing takes the digitised pulse information and applies a number of filters before passing the data for display. Sonar information is typically presented as a waterfall diagram of angular position against frequency, or against time. For bathymetric and imaging sonar, the on-line and off-line display processing converts the bearing/range information into a 3-dimensional image (Figure 3).

The following table indicates the similarities in the capabilities of a number of common sonar applications. All the examples listed can be implemented using the architecture in Figure 4.

Application	Transducers	Front-end	Back-end
Echo sounder Lakes, rivers, estuaries, ocean.	Single or dual transducers	Simple signal processing, time-stamping and pulse generation	Filtering and 'time of flight' calculation.
Survey sonar (Figure 5) Lakes, rivers, estuaries, coast.	Multiple transducers	Multi-beam or interferometric signal processing.	Complex filtering and image reconstruction
Mine clearance (MCM) Rivers, estuaries, Littoral zone, Continental shelf	Multiple transducer arrays	Synthetic aperture signal processing (current state of the art).	Complex filtering, location, image construction and classification
Surface / Submarine (ASW) Littoral zone to abyssal plains	Multiple transducers arrays	Complex beam forming & matched filter processing, correlation and FFT.	Complex filtering, location, image construction and classification

Table 1 – Typical Sonar applications

The conclusion of this part of the study is that although there are many and varied applications of sonar, they all share the same or similar system architecture and they all map similar software functions to those components.

6. ACOMMS SYSTEMS AND ARCHITECTURE

Acomms systems follow similar architectures to RF radios [10] with front-end power amplifiers (drive electronics), low noise amplifiers and complex equalisers in the receive path (Figure 5). Modulation and demodulation of large constellations is possible, and processing techniques such as MIMO and beam forming are also used. Error and data

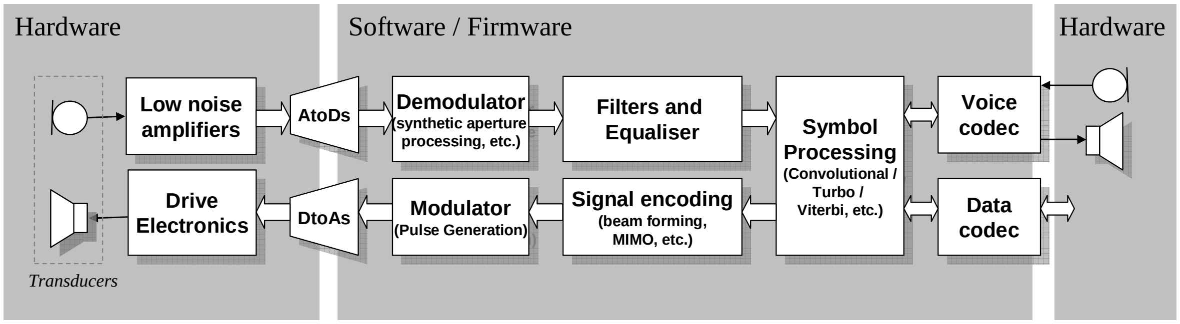

Figure 6 – Underwater Acoustic Communications system architecture

protection is provided by coding and encryption. Typical Acomms applications are listed in Table 2.

Application	**Description**
Diver comms	Voice, data and video communications from diver to diver and from diver to surface
UUV comms	Data and video communications between Unmanned Underwater Vehicle (UUV) formations and between UUVs and divers, sensors or the surface.
Sensor comms	Ad-hoc and mesh networks carrying data information such as underwater sensor information or environment sampling data, for example.
Sonobuoy gateways	Providing a data bridge between above water radio networks and the sub-surface acomms domain.
Underwater GPS	Allowing a mapping of standard GPS information signals to a similar set of data transmissions in the underwater domain based on acomms transmissions.
Safety aids	Man-overboard locator units using transmitted position data.

Table 2 – Typical Acomms applications

The conclusion from this section is that acomms applications have an identical focus to radio communications systems, and provide voice, video and data in an analogous manner. The system architecture, which is based on a transmit and receive line-up (Figure 6) has many similarities to the sonar system architecture (Figure 4), and as such it is fair to conclude that there is a high degree of overlap between the software and hardware components of acomms and sonar applications that can be exploited.

7. THE SOFTWARE COMMUNICATIONS ARCHITECTURE (SCA)

The Software Communications Architecture (SCA) is summarized in Figure 7. There are six main constructs that make up an SCA solution:

An *Application* (i), of which there may be many, consisting of a number of *Software Components* (ii). These are mapped to Hardware elements, represented by their device drivers (*Devices*) (iii), the sum of which hardware constitutes the solution *Platform* (iv). The mapping of software components to devices is defined in a number of XML files called the *Domain Profile* (v). The profile is used by the *Component Framework* (vi) to construct the application.

In the definition of a ‘line-up’, which typically consists of new, legacy and software defined elements, the SCA provides a mechanism for defining *Adapters* to allow the integration of non-SCA conforming elements into the common SCA framework. The SCA also simplifies and creates compatibilities between similar equipments through the use of *Domain Specific APIs*.

8. MAPPING SONAR AND ACOMMS ARCHITECTURES TO THE SCA

Given that suitable front-end hardware is available, the software processing can be implemented straightforwardly on a DSP/Processor array. The array size depends, for example, on the complexity of the application and the number of transducers to be supported.

Table 3 illustrates the similarities between components required for sonar and acomms applications.

If we assume that these common software components are designed to conform to the SCA framework, then Figures 8-13 illustrate the relative simplicity with which sonar and acomms applications can be mapped. The mapping is defined in the SCA *Domain Profile* XML files. Since the SCA framework is extremely rich, the figures shown here illustrate only those mapping elements necessary to highlight the general principle.

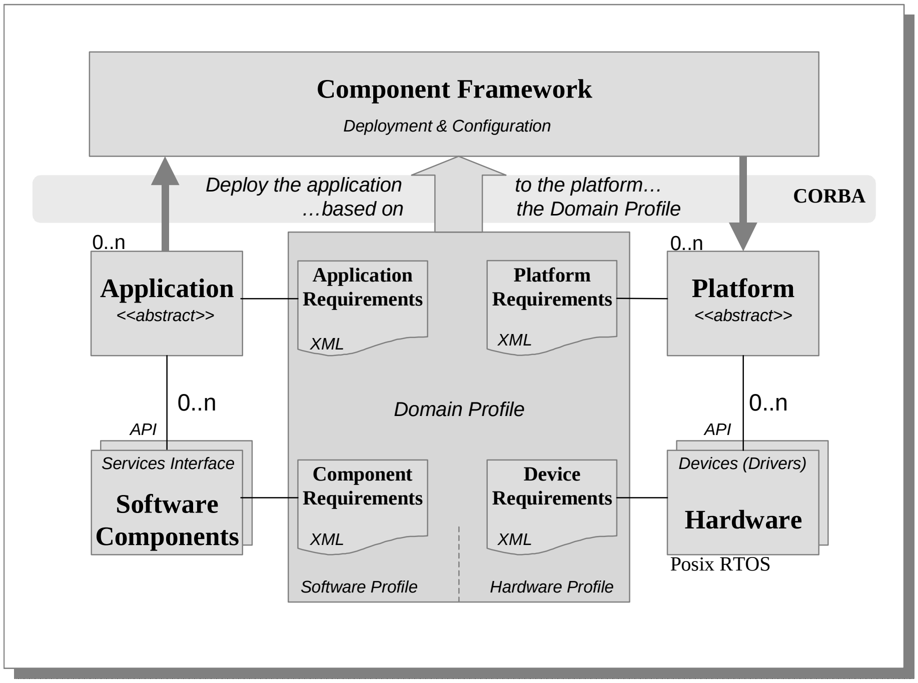

Figure 7 – Software Communications Architecture (SCA) elements

Component	**Sonar**	**Acomms**
Classification	Classify target	
Video codec	▦ Video output	▦ Video input/output
Audio codec	▦ Audio output	▦ Audio input/output
Image processing	▨ Image construction	▨ Video reconstruction
Symbol and Signal processing	▨ Synthetic aperture, interferometric, beam-forming, MIMO, FFT	▨ Convolutional, Turbo and Viterbi coding, beam-forming, MIMO, FFT
Equalisers	▦ Complex equalisers	▦ Complex equalisers
Filters	▦ Complex feed-back and feed-forward filters	▦ Complex feed-back and feed-forward filters
Demodulator	▨ Front-end pulse processing	▨ Demodulation
Modulator	▨ Pulse generation	▨ Modulation
Timing	▦ Time reference	▦ Frequency reference

▦	Very similar
▨	Some similarity

Table 3 – Component similarities

The Application package is defined in the *Software Assembly Descriptor* (Figure 8) with the *Domain Manager Configuration Descriptor* and the *Profile Descriptor* providing additional configuration information.

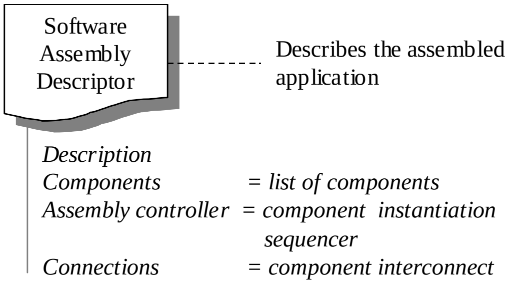

Figure 8 – Software Assembly Descriptor (SAD)

Software Component properties are defined in the *Properties Descriptor* file (Figure 9). Component executables are defined in the *Software Package Descriptor* (Figure 10) with their inputs and outputs defined in the *Software Component Descriptor* (Figure 11).

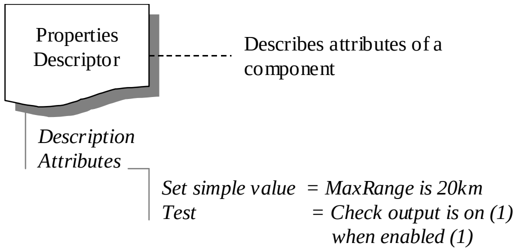

Figure 9 – Properties Descriptor

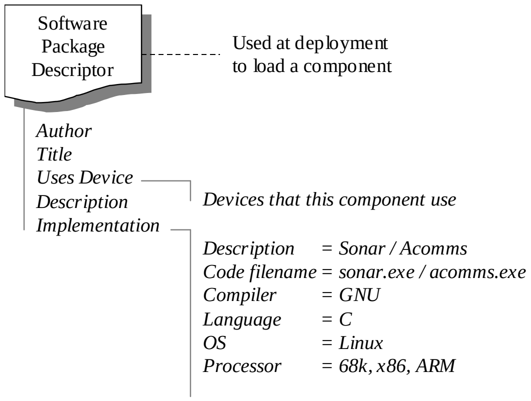

Figure 10 – Software Package Descriptor (SPD)

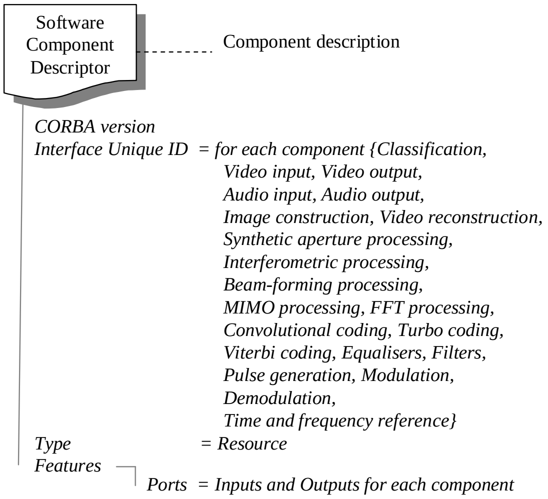

Figure 11 – Software Component Descriptor (SCD)

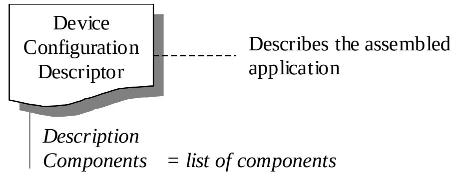

Figure 12 – Device Configuration Descriptor (DCD)

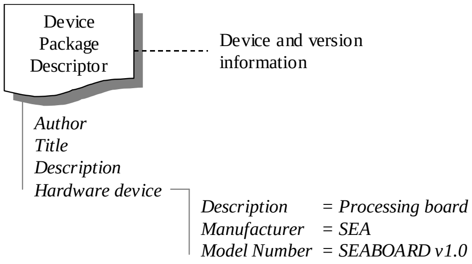

Figure 13 – Device Package Descriptor (DPD)

The Platform is defined in the *Device Configuration Descriptor* file (Figure 12) and describes how components can be assembled into the sonar and acomms solutions.

The Hardware is defined in the *Device Package Descriptor* file (Figure 13) and consists of a processing board which in turn can contain general purpose processing elements, DSPs and FGPAs.

9. CONCLUSIONS

This paper provides an overview of modern Sonar and Underwater Acoustic Communications systems. The commonality between these systems is highlighted and it is shown that this provides a way to realise a software-defined sonar that shares many of the same modules with a software-defined acoustic communications system. This has potential resource savings for UUV applications. The paper then illustrates how a common solution could be implemented using the SCA Framework.

10. REFERENCES

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