CENTER FOR SOFTWARE DEFINED RADIO

Software Defined Radio

Terms, Trends and Perspectives

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Center for Software Defined Radio

The Center for Software Defined Radio (CSDR) is a regional technology center, hosted at Aalborg University (AAU). The center was initiated July 2006 and funded for a four year period.

CSDR's position at Aalborg University makes it possible to establish cooperation between the research and teaching environments at AAU and local and national ICT industry.

The center is rooted in a consortium consisting of

- **Aalborg University**
- **The Engineering College of Copenhagen**
- **Danish Technological Institute**
- **NorCOM**, the association of mobile and wireless industry in Northern Denmark
- **ITEK**, a trade association for IT, electronics and communications enterprises under the Confederation of Danish Industries.

The center is mainly (60%) funded by the Danish Government (Ministry of Science, Technology and Innovation and Ministry of Economic and Business Affairs), partly by Aalborg University (20%), and industrial partners (20%). The total budget over the four-year period is approx. 6.4 million €.

The main objective of CSDR is to bridge the gap between research environments and industrial companies within the field of software defined radio (SDR). The major means of cooperation will be short and long term projects with at least two industrial partners. Other activities are courses, seminars, and workshops in order to disseminate high-tech knowledge into industry.

Another objective of the center is the development of the commercial aspects of SDR. It is the intention that continuing technological development will result in intellectual property rights (IPR).

This Document

This white paper has been created to provide an easy readable and brief overview of the challenges in SDR technology.

The document illustrates some of the many possibilities implicated in SDR, as well as some of the applications. The paper will also discuss the many facets that activities within the Center for SDR can take.

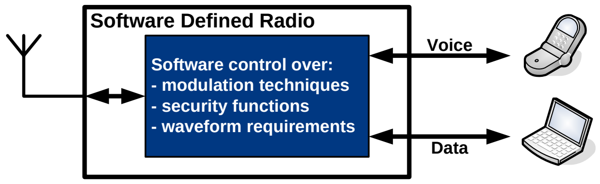
First, a brief overview of SDR will be given. This will be followed by the trends and visions for the technology. Next, some of the challenges within various SDR related domains will be outlined, followed by a conclusion.

Software Defined Radio

The term software defined radio was coined in 1991 by Joseph Mitola. Software defined radio concerns a wireless device whose behavior can be reconfigured in software. The SDR Forum (www.sdrforum.org) has suggested a five step definition in order to describe state-of-the-art.

0. Hardware Radio
1. Software Controlled Radio (SCR)
2. **Software Defined Radio (SDR)**
3. Ideal Software Radio (ISR)
4. Ultimate Software Radio (USR)

Although being the term normally used for state-of-the-art, SDR is an intermediate step. SDR represents a radio that has software control over some functions, and still being partly implemented in analog electronics. This is also illustrated in the figure below.

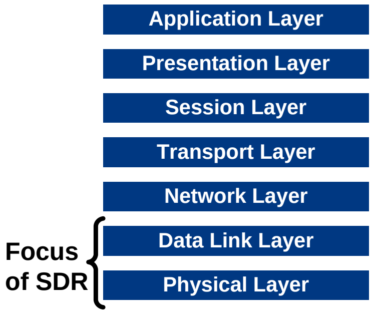


In relation to the figure, it is important to note that the term "software" does not have to be code executed on a microprocessor, but can as well be digitally implemented logic under software control.

Most cell phones today are capable of communicating over several modes. However, these modes are mainly implemented as dedicated electronics for each mode, making it possible to switch between modes via software.

According to the SDR Forum definition, the term for this type of radio is "Software Controlled Radio".

Another and somewhat different view of the software radio is in terms of the traditional OSI model of a communication system. In this regard, the software defined radio mainly concerns the two lowest layers of the OSI-model, as depicted in the figure below.



Based on the OSI model, it becomes very clear, that SDR is a software reconfigurable radio technology, but it is not the applications that are implemented on the radio. Since multiple types of applications and functions are main attributes of future wireless systems, the OSI inspired definition is somewhat debatable.

Trends and Visions

The drivers for software defined radios come from many sides. However, the main issues are the perspectives of multiple functionality and flexibility.

The most promising application of SDR is the application of cognitive radio (CR). The radio spectrum becomes more and more sparse, making it an extensive task to allocate a new spectrum for new services. The idea of cognitive radio is that the radio itself senses the environment, and decides how to establish communication to another device in terms of e.g.

- Frequency band
- Modulation scheme
- Coding scheme
- Security functions

Furthermore, the employed frequency band might be used by other high-priority devices, which means that the cognitive radio should be capable of switching to another spectrum quickly – and that being transparent to the user.

However, in order to be able to switch to another mode, the most promising platform is expected to be the software defined radio. This is also the reason that the cognitive radio is seen as the main driver for SDR technology.

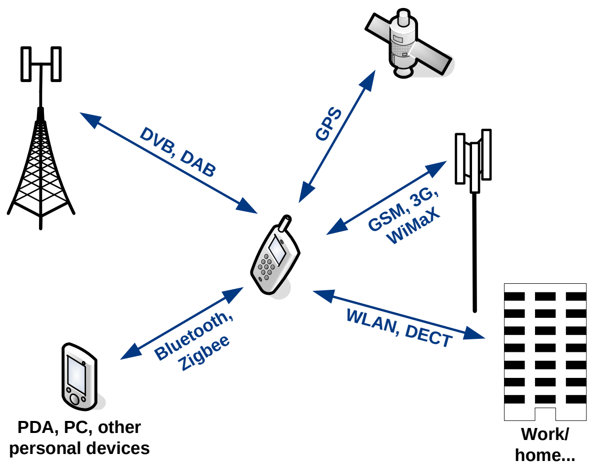
It is clear that cognitive radios have quite a long evolution, as there needs to be developed methods for multiple users interactively managing the radio spectrum. However, in relation to the multiple functionality and flexibility supplied by SDRs, such requirements are currently requested by the military as well as the commercial market.

Joint military operations like Gulf War I showed that it has been difficult to establish sufficient communication lines between the forces. The possibility of easy update and multiple modes in one device has caused a significant interest in SDR from the military. For example, the SPEAKeasy projects have shown the feasibility of integrating multiple military radios into one SDR.

Another request for SDR comes from other tactical radios. In disaster situations it has been shown that the communication infrastructure may be easily destroyed. This lack of infrastructure has made it almost impossible to obtain efficient communication links between police, medical assistance, fire fighters etc. It is expected, that reconfigurable radios, both for handsets and mobile base stations will enable a faster reconstruction of the communications infrastructure.

When looking at the commercial market, the request for SDR has not been quite as significant as for instance the military market. However, one supplier has launched a software defined base station, which makes it very easy for the service providers to upgrade their equipment and launch new services. Besides from base stations, the multi-functionality may be seen as a perspective for future cell phones.

In modern cell phones, multiple modes are seen to converge into one device. Most modern cell phones are capable of communicating via various GSM modes, UMTS and Bluetooth. The same is seen in personal digital assistants (PDA) that are capable of using both Bluetooth and WLAN to get connected to other devices as well as the Internet.



There are two basic solutions for devices that support multiple functions. Either, dedicated HW and SW architectures for each standard can be implemented – or units with multiple functionalities can be implemented. As there has been a tendency of launching products before the final release of standards, the latter solution will be preferred, as e.g. a software update could make the product correspond to the latest released standard.

Within 4G technology, the request for multi-mode radios is also expected to be an issue. A 4G communication device is expected to take part of traditional base station communication as well as cooperative networks, allowing the sharing of processing resources in order to save the overall processing power. This definitely calls for software defined radios.

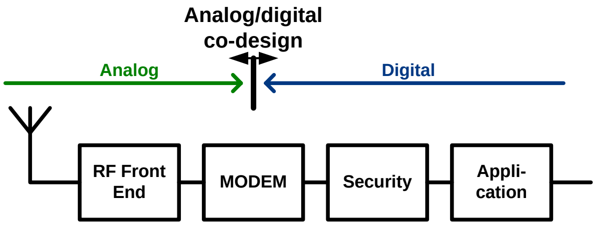
However, in order to fully gain the previously mentioned possibilities, the concepts of software defined radio must be applied. The ideal software radio, on the other hand, has not yet been obtained. The overall reason is that there are many challenges within various research domains, some of which are described in the following.

Challenges

There are many challenges inherent in the design of SDR terminals. This goes for transmitters as well as receivers.

The task of designing a SDR is a relatively complex problem. Even though much of the required technology is available, it is often a matter of trade-off to find the best solution for a given application. In terms of a software defined radio, the most flexible solution is most likely the most expensive in terms of money or power dissipation. This trade-off calls for methods to optimize several parameters simultaneously.

Furthermore, the problem is even more complex, as an SDR will contain both an analog and a digital part. In order to find the best solution for an application, it will be necessary to be able to perform what is known as analog/digital co-design, illustrated in the figure below.



Basically analog/digital co-design concerns describing the system without being constrained by hardware and software limitations. Later in the design process, it will then be possible to find the most optimal analog/digital partitioning for the following separate analog and digital design. This is illustrated in the figure above, where analog/digital co-design is illustrated as finding the right point of digitalization.

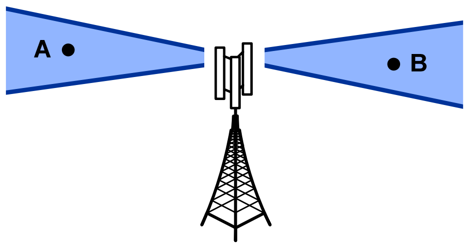
The actual cross-over point is however, very dependent of the available technology. For some applications, an analog modulator will be the most feasible solution, while a digital modulator will be the most appropriate in many other cases.

In the following, the challenges will be categorized, to provide an overview.

Antennas

The antenna is the transducer between the radio waves and the electrical signals. The multimode software defined radio requires that the antenna is capable of supporting a huge bandwidth. However, wide bandwidth antennas is an area that needs to be further investigated – also for cognitive radio applications.

Another very interesting aspect of antennas is the area of software antennas and beamforming. Beamforming makes it possible, via a range of antennas, to direct the radio signal in a specific direction and thereby allow reuse of the same frequency for more devices. This is illustrated for a transmitter and two receivers in the figure below.



RF Front End

The RF front end is a major challenge in SDRs. The main functions of the front-end are:

- Down/up conversion
- Channel selection
- Interference rejection
- Amplification

The challenges lie within the creation of both receiver and transmitter front-ends that are flexible enough to support a wide range of frequencies. The principles for transmitters and receivers are considered similar, hence only receivers are concerned in the following.

In order to support the wide range of frequencies while still providing good channel selection and separation is a relatively difficult trade-off. There are two general down conversion structures:

- **Direct down conversion** receiver, where the signal is converted directly to baseband and digitized in an analog-to-digital converter (ADC).
- **Superheterodyne** receiver, which is outlined in the figure below. The signal is up or down converted to an intermediate frequency (IF), which is performed in the blocks that are marked by the blue color. The IF step is followed by conversion to baseband and digitization in an ADC.

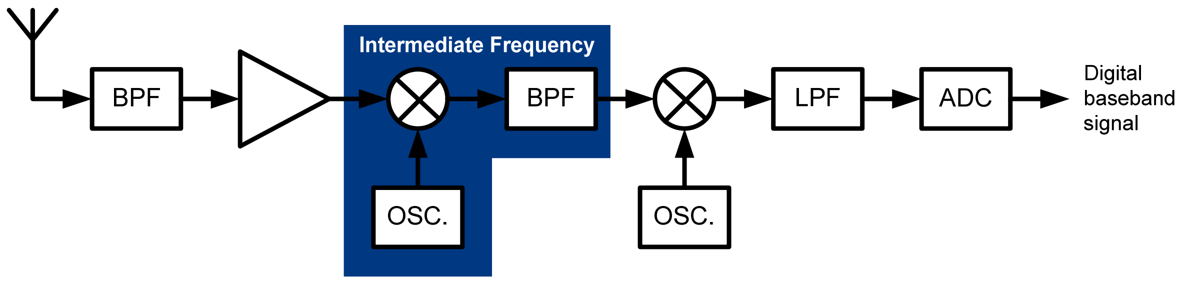
There are very good reasons for choosing the superheterodyne receiver, as it provides a very good channel selection. However, the flexibility of this type of receiver is very limited, as the filters are fixed to the frequency of the incoming signal. However, some flexibility can be obtained by the development of digitally tunable filters.

The direct down conversion receiver is the type that promises the most flexible approach. The whole frequency band is down converted, leaving it to the following processing to provide selectivity. Obviously, the signal still has to be low-pass filtered before down conversion.

For wide-band applications, an alternative to down conversion of the whole frequency band is to filter the signal into subbands, and down convert these at a lower ratio.

The front end will introduce inherent non-linearities which to a certain extent can be reduced by careful design. These non-linearities can also be accounted for in the preceding or following signal processing for the transceiver or receiver respectively.

The preceding indicated that the design of a RF front end is a relatively complicated task. However, many of the decisions depend on a trade-off between flexibility and power or design complexity with consequences related to component cost.



Converter Technology

The converter is the interface between the analog and the digital representations of the radio signals.

Many arguments are that the converter is the area that requires the most research since there are not converters available that meets the requirements for speed, bit resolution, power consumption and price.

Current state-of-the-art SDR development platforms have ADCs capable of 125 MSamples/sec, with a resolution of 14 bit, while the DACs are capable of 500 MSamples/sec at 16 bit resolution. These speeds are sufficient for some applications, but still requires flexible front-ends for wide-band applications.

One method to limit the requirements for speed is to sample higher than twice the bandwidth of the signal instead of twice the highest frequency in the signal. However, this will require a flexible converter as well as a very flexible front-end for multimode receivers.

Processing Architectures

Processing architectures is a major field of investigation in the digital domain.

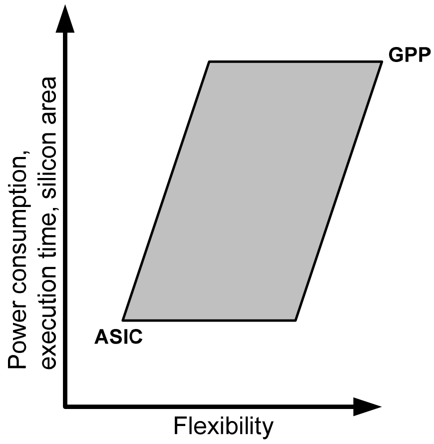
In the most general SDR, the processing tasks were expected to be conducted by general purpose processors (GPP). However, the signal processing tasks has proven to be very extensive, and the GPP is not well suited for many signal processing algorithms. Another candidate is the digital signal processor (DSP), which is utilized in many audio applications as well as communication systems. The DSP is a specialized microprocessor optimized for performing multiply and accumulate operations.

The DSP has also proven to be inefficient for some tasks, where a customized architecture actually is more suitable. One solution has been the application specific IC (ASIC), which is the least flexible, but most optimal solution with regard to execution time, power dissipation and cost. The cost factor is however, only low for a very large number of units, as the development of an ASIC is very expensive and time consuming.

As the applications that request SDR technology continue to require systems that can be reconfigured fast, as well as provide a massive amount of processing power – the need for powerful reconfigurable architectures emerges. One solution for this is the use of field programmable gate arrays (FPGAs). FPGAs offer the possibility of programming logic to be more suitable for certain algorithms than the general DSP. This goes especially for algorithms where parallelism can be exploited efficiently, but also more special operations like square root, cosine etc. are very suitable for FPGA implementation. The use of FPGAs in handheld devices might be limited, as the cost and power dissipation are still relatively high compared to an ASIC solution.

Seen in the light of the fact that processing architectures will have to be able to perform both control operations, reconfiguration management, and very intensive signal processing tasks, it is expected that an architecture will be heterogeneous and consist of DSPs, FPGAs and microprocessors, executing the tasks that the processing units are most suitable for.

The relationship between flexibility and power consumption, silicon area, and execution time is illustrated in the figure below.



In relation to a reconfigurable radio, the reconfiguration time is an important issue, where there are three main types of reconfiguration:

- **Static** (at manufacturing)
- **Pseudo-static** (download and reboot)
- **Dynamic** (between calls or between packets, during a call)

Obviously, the latter case is the one that sets the highest requirement for the reconfigurable hardware itself as well as the reconfiguration management.

Furthermore, it must be noted that the power consumption of a digital circuit is proportional to the clock frequency. This means that it is very essential to keep clock frequency as low as possible, when power dissipation is an issue.

Algorithms

The algorithms are the mathematical descriptions of the software that will be executed on the above mentioned processing architectures. However, the more complex the communication scenario becomes, the more complex the corresponding signal processing algorithms become.

However, developments of the signal processing algorithms are necessary, as more and more functions will need to be moved into the device, there will be a need to investigate more optimal algorithms for communication signal processing.

Furthermore, it is not necessarily the most optimal solution to perform digital signal processing like it would have been performed in the analog domain. Among other, a lot of work has been performed on efficient algorithms, mainly by the use of polyphase filters.

Another area would be frequency domain substitutes for time-domain algorithms. In some cases it might be the most optimal solution, as the processing is followed by another frequency domain algorithm.

The interacting development of algorithms and architectures can also show an increasing need for algorithms that will be able to efficiently utilize the parallel processing capacities in e.g. FPGAs.

As described in the preceding two sections, there is an increasing complexity in architecture as well as algorithm development. This calls for more complex design methods, which will be treated in the following section.

Design Methods and Tools

The design methods for software defined radios are required to be able to handle both heterogeneous architectures and complex algorithms. However, this is expected to be covered partly by ongoing development for embedded systems that also include heterogeneous architectures.

In SDR design one of the more complex problems is how to handle multiple functionalities, and how to select between function candidates, that suits one or more functionalities. In this relation, a lack of tools has been identified.

One solution that has caught a lot of interest is the area of parameterization, where common functions are found for several modes. The change of parameters is then performed to let the function be used for another mode. The parameterized approach has proven useful for known communication standards, but a modular approach must also be considered when new communication standards are introduced.

Another issue in SDR design is that the software becomes very complex, making it difficult to port different waveforms to the same platform. This problem is treated in the military domain, where the Software Communications Architecture (SCA) seems to become a standard.

The SCA is a framework that allows the definition of several waveforms on the same platform. The framework does not tell how functionalities are implemented, but provides encapsulation of the behavior onto the processing units.

Conclusion

As the document has described, the area of software defined radios is multi-disciplinary. The successful integration of SDRs requires knowledge about antennas, RF hardware design, reconfigurable computing, algorithm development and design methods that provides an efficient design.

It has also been described that there are many challenges left, and a significant amount of research is to be done. However, the technology is mature enough to start employing software radio technology in existing products. Later, cognitive radio is expected to be the key application that requires SDR. Cognitive radio has also attracted focus from the SDR Forum as well as the European Telecommunications Standards Institute (ETSI).

It is clear that SDR covers many of the core competences of the Danish telecommunications industry. However, the remaining research topics leave a space where it is necessary to disseminate knowledge from the research environments to the industry.

It is exactly in this phase that Center for Software Defined Radio will be able to show a difference.

The center will take part in projects and thereby bridge the gap between the research conducted at Aalborg University and the development of industrial products in the Danish telecommunications industry.