System Interoperability Solution – Frequency Agile and Protocol Independent Systems

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Abstract
This paper describes the coming new generation of communication systems solving interoperability problem between systems operating in different frequency bands and using different standards. These software definable radio (SDR) systems provide all processing in digital form. The paper explains what type of fundamental features the SDR products must possess to function as true software radio (TSR). It will examine the evolutionary path of such products from software assisted radios (SAR) which are hybrid in nature utilizing signal processing in analog as well as in digital form to true software radio systems.

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system interoperability, software radio, digital signal processing, signal conversion, system communication
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Abstract This paper describes the coming new generation of communication systems solving interoperability problem between systems operating in different frequency bands and using different standards. These software definable radio (SDR) systems provide all processing in digital form. The paper explains what type of fundamental features the SDR products must possess to function as true software radio (TSR). It will examine the evolutionary path of such products from software assisted radios (SAR) which are hybrid in nature utilizing signal processing in analog as well as in digital form to true software radio systems. The latter, exemplified by the TechnoConcepts, Inc’s. TSR system, an industry first, does all signal processing in software by converting the received signals into digital form immediately after an antenna. It provides a new qualitative leap in frequency agility as well as protocol standard independence and solves the problem of system incompatibility in a highly fragmented communication environment typical for the current state of affairs in communication industry.

Keywords - system interoperability, software radio, digital signal processing, signal conversion, system communication

1. INTRODUCTION

The unabated revolution in microelectronics has brought us to the verge of revolution in communication. The old dream of communication engineers to have frequency agile and protocol independent systems is becoming a reality. Forming a new class of communication products, called Software Definable Systems, they are capable to solve system interoperability problem by providing seamless system operation in highly fragmented, multi-terminal/multi-frequency communication environments typical for today communication by performing all essential signal and data processing functions in software.

The SDR Forum defines ideal SDR products as ones possessing two fundamental features – flexibility towards operational standards and independence from carrier frequencies [1]. According to this definition, TSR systems satisfy both these criteria. With the ideal SDR radio, software can be used to act as an interpreter between completely incompatible radio frequencies and modulation techniques. 900 MHz radios can talk to 2.4 GHz radios, GSM cell phones can communicate with CDMA phones. And the military can start to move to radios that allow all of the services to communicate seamlessly.

In contrast, Software Assisted Radio, in which only a portion of signal processing is done in SW, lacks the reconfigurability (which must include both carrier frequency and communication protocol) to ultimately provide both features demanded by real SDR systems.

SAR systems, shown in Fig. 1, can be viewed as an intermediate step on the evolutionary path towards TSR. The path to that goal lies through direct down conversion from RF to baseband immediately after antennae (see Fig 2). Like any ultimate goal, it can be approached asymptotically while each generation of new semiconductor processes bringing the elusive SDR goal of multiterminal/multifrequency operation successively closer.

![Fig. 1. Conventional analog receiver that typically uses a double-conversion design. The architecture requires multiple external analog components (shown as red boxes – or light gray in black and white copies), contains many analog interfaces (shown as red – or light gray – lines), and can only decode one type of waveform.](image)

There are good historical reasons [2, 3] for different types of SDRs depending upon where the signal processing starts in microprocessors. In a true software defined radio the ADCs are placed as close as possible to the antenna, which places great demand on the performance of ADCs.

All subsequent signal processing of the digitized antenna output is done by fast logic circuits and fast microprocessors using downloadable signal processing SW selected according to a system operational environment.
This is precisely the TechnoConcepts approach.

![Diagram](attachment:image.png)

**Fig. 2. Generic architecture of the TSR system**

Effective quantization of radio signals immediately after antenna enables fast reconfiguration of the air interface parameters of communication terminals. The dynamic switching of frequencies and communication protocols in the user's terminals enable the remote reconfiguration of the terminal by adding or removing system software components with the result of being greater flexibility.

Thus TSR is the only technology that currently shows promise in delivering the ultimate SDR goal of a truly “universal” radio terminal. Other approaches are vulnerable to changes in applied standards and functionality.

The many advantages of TechnoConcepts’ TSR approach include its single analog interface, requiring very few external analog components and its programmable ability to process any type of waveform. This paper explores the first steps of TSR, describes facets of the technological possibilities, and tries to gaze into the ‘crystal ball’ to see how its utilization will develop.

### II. SDR SYSTEMS

There are many types of SDR systems depending upon the target application environment to be satisfied. It would be not be exaggeration to say that wireless communication systems will be the most probable beneficiaries from SDR. Thus, this paper will focus predominantly on SDR implementation requirements for these systems. The processing requirements for different communication protocols depend on many factors including applications (different applications such as voice, video, multimedia, etc. require different bandwidths to carry the information) and the way in which signal processing algorithms are implemented. Table 1 shows the estimates for the resource demand in processing different protocols [4, 5].

<table>
<thead>
<tr>
<th>Protocol</th>
<th>GPRS</th>
<th>EDGE</th>
<th>UMTS/WCDMA</th>
<th>Wireless (OFDM) LAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>10</td>
<td>100</td>
<td>1000</td>
<td>10000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5000</td>
</tr>
</tbody>
</table>

As one can see, the estimated processing power may vary greatly between different types of communication protocols. From a processing standpoint, the challenge in software radio is to exploit the three basic processor types — fixed architecture processors, FPGAs, and programmable DSPs/RISCs/CISCs — in order to optimize the three-way trade-offs between speed, power dissipation, and programmability. Regarding programmability, the issues of high level language interfaces, portability, and reprogramming speed must be considered.

SDR technology is eventually expected to offer complete programmability and reconfigurability to both multimode and multi-functional communication terminals and network nodes. The significant lack of sufficient processing power currently prevents it from becoming a full-scale reality. However, unabated doubling processing power each 18 months allows hoping that SDR based multimode and multi-functional communication terminals and network nodes come to life in the not so remote future.

For now, we aspire to the more realistic immediate goals of enabling TSR systems capable to implement a couple of protocols per unit installed in environment having no problems in steady supplying tens of watts of power required for performing signal and data processing. It limits the range of current possible TSR implementations to a stationary environment such as base stations (BS) or moving platforms (cars, planes, etc.). Next generation of TSR chips will implement Digital Signal Processing Primitives (DSPP) directly in the silicon, allowing for implementation in lower power consumer devices.

An SDR targeted for commercial narrow-band and broadband applications will typically cover the frequency spectrum between 400 MHz and 6 GHz. This range embraces most of the existing and emerging standards alongside with likely future developments.

The basic ingredients in the design of TSR hardware are mixers and analog-to-digital converters (A/Ds), reconfigurable hardware such as field programmable gate arrays (FPGAs) and programmable logic devices (PLDs), digital signal processing (DSP) boards, and general-purpose computers [6]. The embedded software can reside in all the programmable entities used in the design. There are several issues that must be addressed in the design of any TSR unit, including:

- Transceiver partition between hardware and programmable hardware entities;
- Deciding which type of programmable hardware should be used;
- Ability of the designed architecture to adapt to evolving communication protocols.
- Interfacing the various entities used in the design of the TSR unit for real-time operation of the platform.
In choosing TSR architecture we have to respond to the above issues with the goal of achieving some degree of optimization based on the design objectives of the TSR platform. The above issues have a direct impact on system performance by selecting:

1. How much radio frequency (RF) bandwidth the TSR platform can process;
2. Degree of programming flexibility in the design, and how much time it would take to reprogram the hardware; and
3. Choice of hardware architecture given that different components have to be able to operate in real time.

It is worthwhile to mention that after the direct conversion front-end it would be preferable to use multiprocessor systems to satisfy system processing requirements [7].

III. TSR SPECIFICS

The architecture of TSR has to be able to accommodate operation in different environments characterized by different standards, carrier frequencies, power levels and bandwidths. Architecturally TSR is best defined as the software implementation of the radio transceiver receiving digitized down converted signals from an antennae. Direct down conversion from RF to its baseband equivalent is done by our patented delta sigma loop circuitry. Digitization of the wireless signals’ functionally at the antenna in TSR systems dramatically simplifies the implementation of transmitters and receivers. It uses direct down conversion receivers (DDCR) versus traditional superheterodine type receivers. Low cost and simplicity is the result. It is especially true for the broadband receivers typical for the CDMA or WCDMA cellular systems. It can be implemented in a single integrated circuit vs. the bulky discrete component filters required for the superheterodine receivers. The architecture requires few external analog components and can be programmed to process any type of signal or multiple types of signals.

The operating system adopted for TechnoConcepts’ TSR implementation is Linux. Linux guarantees maximum accessibility to all computer resources, such as device drivers for input/output (I/O) operations. Its widespread use is an additional benefit favoring its application.

The transceiver of TSR is powered by signal conversion circuits capable to operate at clock rate in excess of 5 GHz.

IV. SIGNAL CONVERTERS

Sigma delta converters are used for conversion of transceiver signals. These converters digitize signals by modulating the analog input into a high-speed one-bit digital data stream that is subsequently processed digitally to produce a high resolution word stream at a slower data rate. The converter is a closed-loop system in which the order of the loop and the input bandwidth may be traded for resolution. A plot of the ideal resolution for a given relative bandwidth and loop order is shown in Fig. 3.

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Fig. 3. A plot of the effective resolution of a delta-sigma converter for the first, second, third, and fourth order modulators using one-bit quantization. The x-axis represents the ratio of clock rate to maximum input bandwidth (over sampling ratio). The y-axis represents resolution in bits.

TechnoConcepts has further improved delta-sigma technology by inventing an architecture that simultaneously extracts the modulation from an incoming signal and digitizes it with extremely high resolution. The company projects that a dynamic range of 55-100 dB (depending on bandwidth) is achievable using this architecture. The performance analysis of high order delta-sigma ADC converters operating at 5 GHz shows that expected signal-to-noise ratio (SNR) depends on the operational spectrum width \( \Delta F \) and the order of delta converters. The estimated values of SNR in decibels for different converter orders as well as operational bandwidths, measured in MHz, are shown in the Table 2.

<table>
<thead>
<tr>
<th>Converter order</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR[dB] for ( \Delta F = 30 \text{ MHz} )</td>
<td>55</td>
<td>80</td>
</tr>
<tr>
<td>SNR[dB] for ( \Delta F = 20 \text{ MHz} )</td>
<td>65</td>
<td>90</td>
</tr>
<tr>
<td>SNR[dB] for ( \Delta F = 10 \text{ MHz} )</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>SNR[dB] for ( \Delta F = 2 \text{ MHz} )</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

V. EXPERIMENTAL RESULTS

TechnoConcepts has already demonstrated 100 dB dynamic range using CMOS technology at a clock rate of 10 MHz and recently demonstrated roughly 50 dB dynamic range in
its preliminary demonstration system using GaAs technology at a clock rate of 1.8 GHz. These results are shown below on Fig. 4 and 5.

![Fig. 4. Performance of TechnoConcepts A/D converters CMOS technology converter at a clock rate of 10 MHz](image1)

![Fig. 5. Performance of GaAs MESFET A/D converters at a clock rate of 1.75 GHz with 50 dB dynamic range.](image2)

VI. EVOLUTION OF APPLICATIONS

Software radio makes possible many new types of applications. Evolution and the widening range of new applications will happen by new TSR products with more powerful processing capabilities. A few examples are given here. Fig. 6 shows a scalable base station with a steerable antennae. Its capacity may be increased by adding new transceivers operating at different frequencies. In Fig. 7, a single protocol cellular phone is being connected to a variety of communications systems through a software radio base station that serves both as a repeater and (when necessary) as a protocol translator.

Specialized services and capabilities (such as automobiles serving as repeaters for other automobiles and/or handsets) can be implemented without disrupting its access to “standard” services. In this configuration (where both the base station networks and the access device utilize software radio technology), any wireless access device can communicate with any other wireless access device with multiple choices to network services.

In broadband applications, that are bandwidth intensive, TCI’s Software Radio technology allows service providers to dynamically utilize unlicensed frequency domains to meet additional client needs when saturation has been realized on a certain frequency domain. Fig. 9 shows residential customers receiving video feeds on unlicensed frequency domains while the business customer locations concurrently receive video feeds on licensed frequency domains. Figs. 9 and 10 show two self-explanatory scenarios of using TSR based systems for the emergency first responders.
VII. CONCLUSION

True Software Radio (TSR) systems are destined to solve system interoperability problems by using direct down conversion from RF to baseband immediately after an antennae. All subsequent signal processing of the digitized antenna output in such systems is done by fast logic circuits and fast microprocessors using downloadable signal processing SW. As a result such systems becomes frequency agile and standard independent capable to provide reliable communication between systems using different frequency bands and communication standards. Available processing power limits the range of communication systems capable to use TSRs. Each iteration of new processes in microelectronics brings us closer towards multiterminal/multifrequency operation. The rate of introduction of these new processes, especially the ones enhancing microprocessor performance, defines the rate of TSR evolution. In that respect the TSR system offered by TechnoConcepts, Inc. (TCI) can be viewed as the first harbinger in the hopefully large flock to come in the immediate future. The list of TSR potential applications constantly evolves. It crosses boundaries of many technologies including HDTV, GPS navigation, civilian and military wireless communication, public safety organizations, etc. That list will expand as time passes and more powerful microprocessors and other essential microelectronics components become available. It is up to you, the reader, to expand that list.

VIII. References