PRACTICAL EVOLUTION OF TRUE SOFTWARE DEFINABLE RADIO

Ron Hickling, Oleg Panfilov, Tony Turgeon, Michael Yagi
(TechnoConcepts, Inc., 15531 Cabrito Road, Van Nuys, CA 91406, USA)
ronh, panfilov, tony, myagi@technoconcepts.com

ABSTRACT

This paper explains what the type of fundamental features that software definable radio (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 system. The latter, exemplified by 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.

1. INTRODUCTION

Cognitive Radio systems in general, and their subset TSR products in particular, are at the verge of revolutionizing the communication industry. TSR systems, by providing all signal processing in software, are asymptotically approaching the ultimate SDR systems goal of seamless system operation in highly fragmented, multi-terminal/multi-frequency communication environments.

These advancements are achieved by converting the received signal immediately after an antenna into digital form and dynamically downloading software corresponding to the specifics of the received signal. The progress toward the SDR's ultimate goal of seamless operation in multistandard environment (read the rate of TSR evolution) is driven by the rate of advancement in microelectronics, particularly the increase in microprocessor computational power and reduction in power dissipation.

The SDR Forum stipulates that real SDR products must possess two fundamental features – flexibility towards operational standards and independence from carrier frequencies [1]. According to this definition, TSR systems possess both above mentioned features. In contrast, Software Assisted Radio, in which only a portion of signal processing is done in SW or otherwise digitally, lacks the reconfigurability (which must include both carrier frequency and communication protocol) to ultimately provide both the features demanded by real SDR systems.

SAR systems, shown in Figure 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 Figure 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.

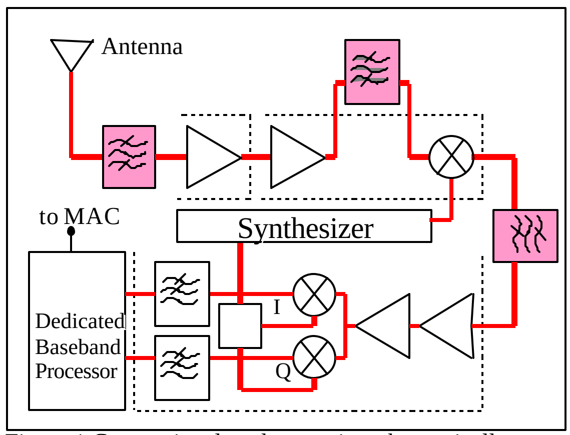

Figure 1 Conventional analog receiver that typically uses a double-conversion design. The architecture requires multiple external analog components (shown as red boxes – or light gray in black and white copies), contains many analog interfaces (shown as red – or light gray – lines), and can only decode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

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.

Effective quantization of the radio signal at the 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 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 to introduction of new functionality.

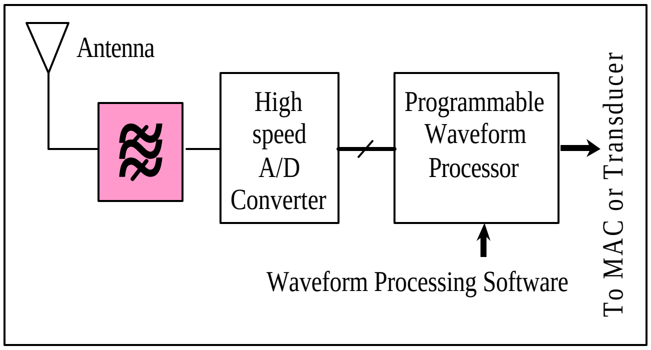

Figure 2 Generic architecture of the TSR system

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.

2. SDR SYSTEM REQUIREMENTS

Protocol-specific system parameters define the requirements imposed upon SDR systems. Initially, we expect that wireless communications systems will benefit most from SDR and therefore, offer the greatest demand at least in terms of volumes shipped. Thus, we will concentrate predominantly on SDR implementation requirements for these systems. The processing requirements for different communication protocols depend on many factors including the application (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 1 Processing requirements in [Mips]

GSM	GPRS	EDGE	UMTS/WCDMA	Wireless (OFDM) LAN
10	100	1000	10000	5000

As one can see, the estimated processing power may vary greatly between different types of communication protocols. Table 1 shows that the current generation of GSM phones requires about 10 Mips. GPRS systems require on the order of 100 Mips. An additional order of magnitude is required for the EDGE systems. The WCDMA systems, having signal bandwidth of 5 MHz push power requirements an additional order of magnitude to 10 Gips. The new generation of orthogonal frequency division multiplexing LANs is in the same league of processing requirements with 5000 Mips.

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 expected, eventually, 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 assurance 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 vehicle based systems (cars, planes, etc.). Next generation TSR components will implement Digital Signal Processing Primitives (DSPP) directly in the silicon, allowing for implementation in lower power consumer devices.

An SDR suitable 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 SR 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 a general-purpose workstation platform since it is by far the most flexible and cost efficient programmable hardware that could be used [7].

3. ARCHITECTURE OF TSR

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, and because it is in widespread use.

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

4. DELTA-SIGMA CONVERTERS

Delta-sigma 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 Figure 3.

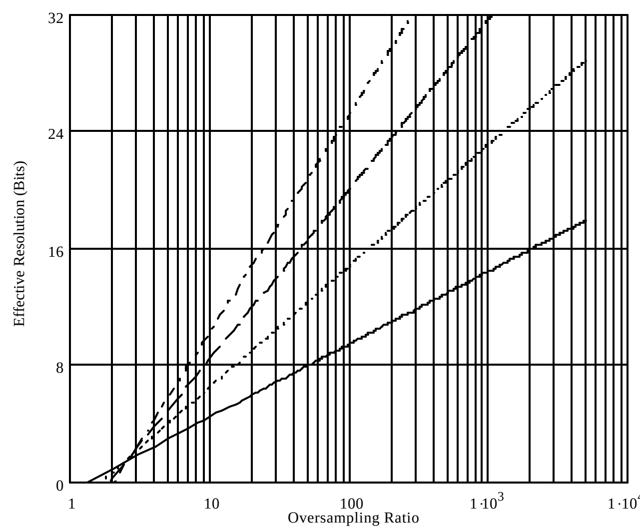

Figure 3 A plot of the effective resolution of a delta-sigma converter for the first, second, third, and fourth order modulators using one-bit quantization. The x-axis represents the ratio of clock rate to maximum input bandwidth (over sampling ratio). The y-axis represents resolution in bits.

TechnoConcepts Inc. has developed a delta-sigma converter technology that is capable of operating at clock rates in excess of 5 GHz. TechnoConcepts has further improved that technology by inventing an architecture that simultaneously extracts the modulation from an incoming wireless signal and digitizing 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 ΔF 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 2 Estimated performance characteristics of Delta-Sigma converter

Converter order	Second	Third
SNR[dB] for ΔF = 30 MHz	55	80
SNR[dB] for ΔF = 20 MHz	65	90
SNR[dB] for ΔF = 10 MHz	75	100
SNR[dB] for ΔF = 2 MHz	100	

Evolution of A/D and D/A converter parameters are shown in Tables 3, 4.

Table 3 A/D Converter parameters

Parameter	**GaAs**	**SiGe**
Maximum Clock Frequency	> 5 GHz	> 15 GHz
SINAD (Signal to noise+distortion)	> 70 dB	> 110dB
Eff. Resolution Bits at 2.5 GHz carrier: 10 MHz BW, 100MHz BW,	14 bits 11 bits	18 bits 14 bits
Matching I/Q	within –70 dBc	within –90 dBc
RF Input Voltage Range (Differential)	-1.5V < V_{in} < 1.5V	-0.5V < V_{in} < 0.5V
Power Supplies	Single +6V	Single +3.3V
Power Dissipation	5 W	< 1 W
High Speed Interface Levels	PECL	LVDS
Number of Taps in FIR	2048 I / 2048 Q	8192 I / 8192 Q
Digital Interface Levels	2.5V/3.3V CMOS	1.8V /2.5V CMOS

Table 4 D/A Converter

Parameter	**Initial Target**	**Next Target**
Max Clock Frequency	> 5 GHz	> 15 GHz
SINAD (Signal to noise+distortion)	> 70 dB	> 110dB
Eff. Resolution Bits at 2.5 GHz carrier: 10 MHz BW, 100MHz BW	14 bits 11 bits	18 bits 14 bits
Power Supplies	Single +6V	Single +3.3V
Power Dissipation	2 W	< 1 W
High Speed Interface Levels	PECL	LVDS
Digital Interface Levels	2.5V /3.3V CMOS	1.8V /2.5V CMOS

5. 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 Figures 4 and 5.

6. 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. In Figure 6, a single protocol cellular phone is being connected to a variety of networks through a software radio base station that serves both as a repeater and (when necessary) as a protocol translator. In this particular application of software radio technology, software radio handsets are not required to achieve universal access, at least in the nationwide context.

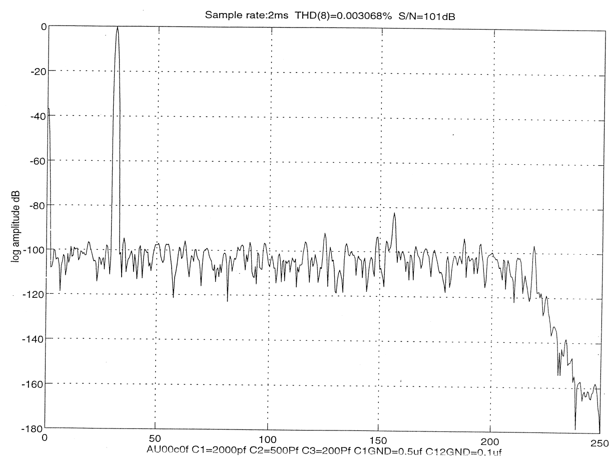

Figure 4. Performance of TechnoConcepts A/D converters CMOS technology converter at a clock rate of 10 MHz

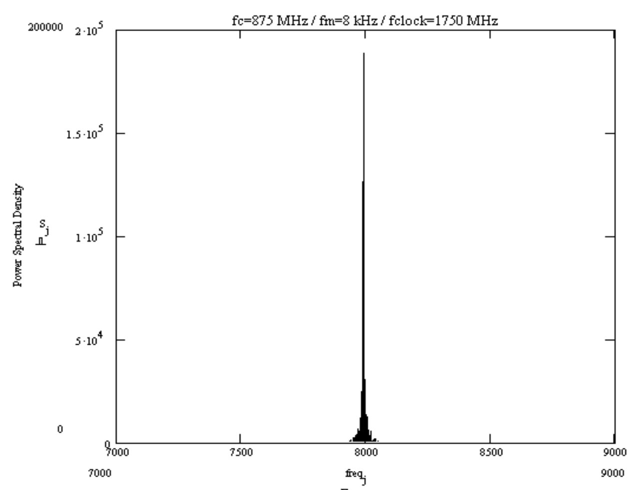

Figure. 5 Performance of GaAs MESFET A/D converters at a clock rate of 1.75 GHz with 50 dB dynamic range.

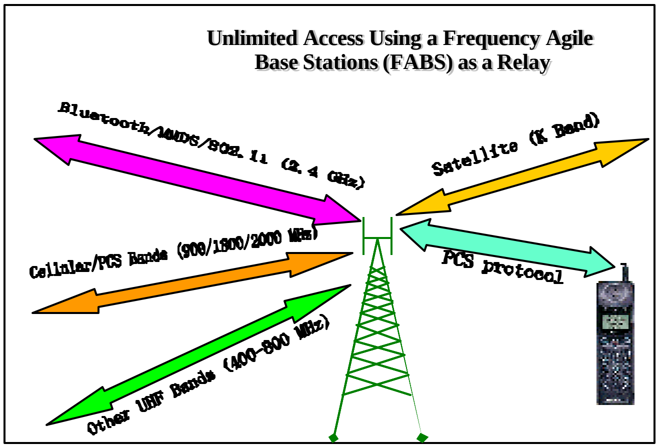

Figure 6. A software radio base station used as a relay/translator for a single protocol handset.

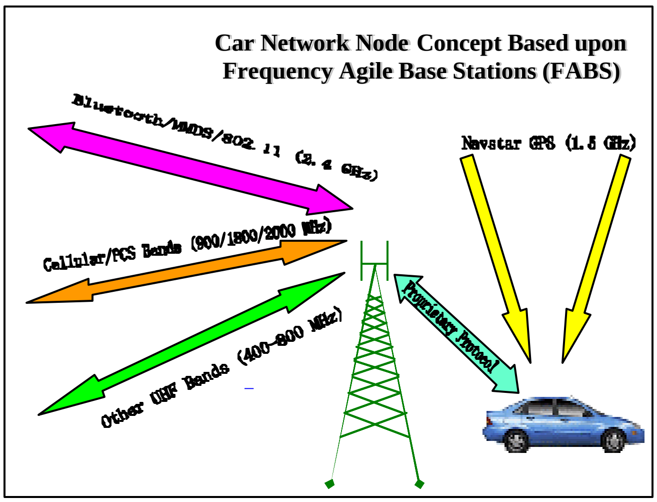

Figure 7. SDR base station used as a relay/translator for a vehicle with single protocol capability

Figure 7 shows a similar concept for automobiles. In this case, the car has a "dual mode" transceiver that is capable of transmission and reception using a proprietary protocol and is also capable of receiving navigation signals from the Global Positioning System (GPS). This concept permits the car to transmit position information to the base station and further allows it the universal access that is enjoyed by the handset shown in Figure 6. The diagram in Figure 8 shows a car that uses software radio technology. In this configuration, the automobile is capable of accessing any service and potentially is able to roam internationally. Furthermore, 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 as to network services. In such an environment, the user can utilize the service best able to

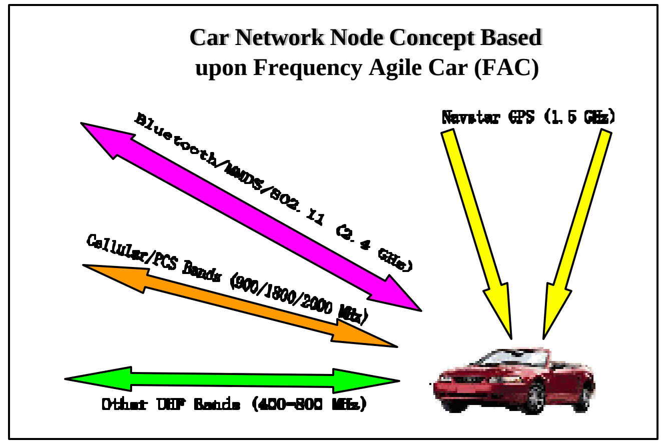

Figure 8. A software radio communicator used to enable an automobile to access any wireless network.

meet his needs whether that is the bandwidth, the cost, or the latency. This will create a competitive cognitive radio environment where limited bandwidth use can be efficiently allocated so that the user pays only for the bandwidth he needs and no usable bandwidth remains idle.

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. In the following Figure 9, the residential customers could be receiving video feeds on unlicensed frequency domains while the business customer locations concurrently receive video feeds on licensed frequency domains.

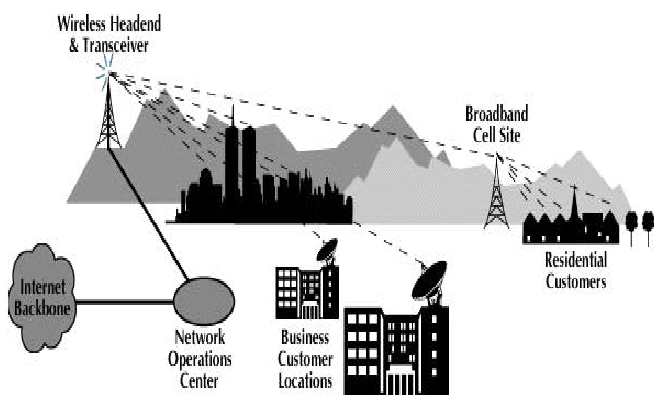

Figure 9. Dynamic distribution of signals in the licensed and unlicensed frequency domains

7. CONCLUSION

The ideal software defined radio (SDR) products have to possess two fundamental features – flexibility towards operational standards and independence from carrier frequencies of received signals. Two quite different lines of SDR products are emerging. The first one – Software Assisted Radio is a hybrid kind, where a portion of signal processing (usually at high or intermediate frequencies) is done in hardware, and the rest in software. Such systems are capable of satisfying only one criterion – partial independence on standards while are still dependable on analog components for filtering and other signal processing operations making them reconfigurable but not frequency agile. True Software Radio (TSR) systems use direct down conversion from RF to baseband immediately after an antennae. As a result they satisfy both above mentioned criteria. Such systems correspond to the spirit and expectations put on SDR. Like any ultimate goal, it can be approached in an evolutionary manner, with each iteration of new processes in microelectronics bringing us 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.

8. REFERENCES

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