An Introduction to Software Radio

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Abstract

A software radio is a wireless communications device in which all of the signal processing is implemented in software. By simply downloading a new program, a software radio is able to interoperate with different wireless protocols, incorporate new services, and upgrade to new standards. This paper provides an introduction to software radio and the advantages that it can provide in a world of rapidly changing standards. We begin with various example situations in which software radio solves real problems. Then we survey various software-defined radio architectures which have been proposed or implemented. Finally, we introduce Vanu Software Radio and describe the specific advantages enabled by our approach.

1 Introduction

The last two decades have seen an incredible proliferation of wireless devices around the world. From cellular phones to pagers to wireless PDAs, people can be constantly connected no matter where they are. However, this wireless connectivity is achieved by using many different devices, each one implementing a different protocol. For example, in the United States alone there are currently at least four cellular standards and four data standards in operation, with new ones on the way. People are forced to carry around a bag full of devices to take advantage of the connectivity options. And to make matters worse, when a new standard comes out, literally billions of dollars worth of equipment must be replaced.

Consider the case of a cell phone user who wants to switch wireless providers (ie, AT&T Wireless to Sprint PCS). Since most of the cellular providers in the US use different protocols, she would likely be forced to replace her phone with one compatible with the new provider's protocol.

The reason that wireless devices are so inflexible is that they are generally implemented in hardware. There is a chipset in each device that performs the signal processing to allow the device to communicate with its wireless network. This inflexibility led researchers to consider alternate software-based designs; these fall under the heading of software-defined radio (SDR). SDR systems come in different forms, as described in Section 3. Vanu, Inc. has taken SDR to the extreme, something that we call Vanu Software Radio. A software radio is a wireless communications device in which *all* of the signal processing is implemented in software. This strategy leads to device flexibility, software portability, and system upgradeability.

2 Why Should You Care?

Imagine that you are building a car. Nowadays the big push in the automotive industry is wireless communications. Car buyers want to be able to push a button to speak with someone for roadside assistance or concierge services. In the future, they may want wireless data inside the car or high-speed video to the car. The standard AM and FM stations have been joined by satellite and terrestrial digital radio, but it is not clear which of the digital standards will survive. And the car that you are designing right now will not be sold until the 2007 model year. Are you comfortable guessing what wireless services people will want in their cars five years from now? The **Vanu software radio solution** is to defer that decision by installing a general hardware platform into each car and downloading the required software as the car rolls down the assembly line. In fact, mass customization can be achieved by downloading different standards into each car.

Imagine that you are awakened one morning by a major earthquake. The damage to the entire city is severe, and hundreds of people are trapped or need medical attention. The police and fire departments rush to the scene, along with EMS, the American Red Cross, and other rescue organizations. In a situation like this, effective communication between the various groups is critical. But the men and women of the police force use 800 MHz analog two-way radios, while the firefighters' radios are digital and in the VHF band. Members of the other organizations use any number of incompatible radios in different frequency bands. One solution to this communication situation is to bring thousands of compatible radios to the accident scene and hand them out to the emergency personnel, as was done at the Pentagon in 2001, but this approach is not generally feasible. The **Vanu software radio solution** is a system that could be brought to the accident scene as a "patch" between incompatible standards. A policeman could use his radio to communicate with a firefighter, with the software radio patch receiving the 800 MHz analog transmission and retransmitting the speech as a VHF digital signal. And since the system is software-based, it can be quickly configured at the incident scene to the particular standards and frequencies in use.

Imagine that you are the CEO of a wireless service provider. Your company has spent billions of dollars on infrastructure for a second-generation cellular network. Now customers are clamoring for data services to their handsets. In order to offer them these services, you have to upgrade your network to 2.5G technology. But your company's debt burden from the last buildout has not been repaid, and the market for new debt offerings is soft. To make matters worse, by the time you purchase and install the 2.5G infrastructure, customer interest has moved on to watching video on their phones, which requires third-generation infrastructure and another billion dollars. The **Vanu software radio solution** is to build infrastructure that can be upgraded over time. The hardware platform gets installed, and then software upgrades allow the service provider to offer advanced technology and services.

3 SDR Architectures

There are a number of different ways to approach software-defined radio. The simplest solution is to put multiple hardware chipsets into a radio, but this is only minimally flexible. Other techniques achieve flexibility using specialized hardware configurations, but these systems have their own disadvantages. Vanu Software Radio employs general-purpose processors (GPPs) and off-the-shelf hardware to gain full flexibility of operation.

3.1 Modal SDR

As analog cellular networks were superseded by digital networks in the 1990s, service providers needed handsets which could offer digital service most of the time but back off onto the analog network in areas where there was no digital coverage. For such a limited flexibility requirement the obvious solution was to simply combine the analog and digital chipsets inside the handset, with software doing control and configuration. Figure 1 shows such an architecture, using TDMA and AMPS as an example. The chipsets are generally ASICs designed specifically for a single standard, but the microcontroller software adds just enough flexibility to satisfy the needs of this application.

Modal SDR units are not limited to combinations of AMPS and a digital standard, however. Recent examples include a GSM/iDEN handset from Motorola and a GSM/TDMA handset from Nokia. As the world moves to 2.5G and 3G standards, the modal SDR solution will continue to be viable for limited flexibility applications.

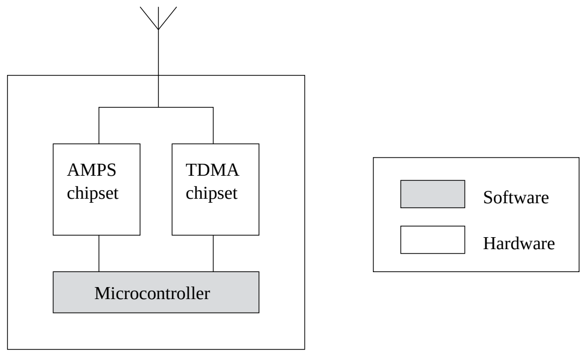

Figure 1: An example dual mode cellular handset architecture

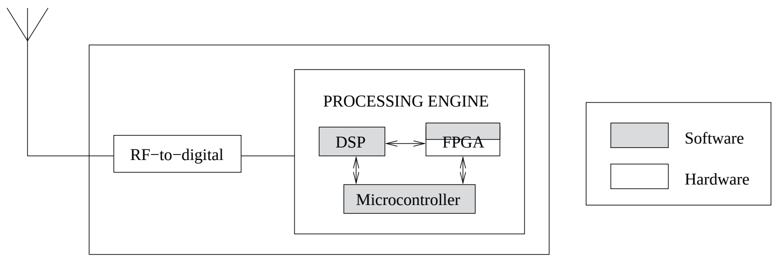

Figure 2: An example reconfigurable SDR architecture

3.2 Reconfigurable SDR

Of course, there are many applications for which modal SDR is an inadequate solution. Modal SDR systems are unable to scale as the number of waveforms increases. To support two waveforms it might be reasonable to simply use two chipsets and a microcontroller, but a modal SDR solution for a system requiring support for, say, five waveforms will likely take up too much space and cost too much.

A significantly more flexible approach to SDR employs programmable hardware to perform signal processing. This approach is often termed reconfigurable SDR, because the hardware itself can be configured for a particular application. As shown in Figure 2, the processing hardware is made up of FPGAs and/or DSPs, both of which can be programmed to perform high speed signal processing operations.

However, the software that runs on programmable hardware tends to be specific to that particular device. Efficient program execution on FPGAs often requires the use of either Verilog or VHDL, two FPGA-specific languages. Similarly, the use of DSPs generally requires writing most of the code with the assembly instruction set of that particular processor family. While many FPGA and DSP platforms now offer C/C++ compilers, the software produced by the compilers tends to be an order of magnitude less efficient than hand-optimized code. In general, code written for FPGAs and DSPs is not easily portable to other platforms.

Another concern with reconfigurable SDR systems is that FPGAs and DSPs have limited operating system support. In fact, FPGAs have no operating systems to speak of. DSP OSes are focused on being lightweight and providing real-time operation, which often makes them unable to support other valuable services. This limited functionality makes it more difficult to write modular, reusable software.

4 Vanu Software Radio

Vanu, Inc. has developed a solution that provides numerous advantages over the reconfigurable SDR architecture. These advantages result from a handful of key design decisions:

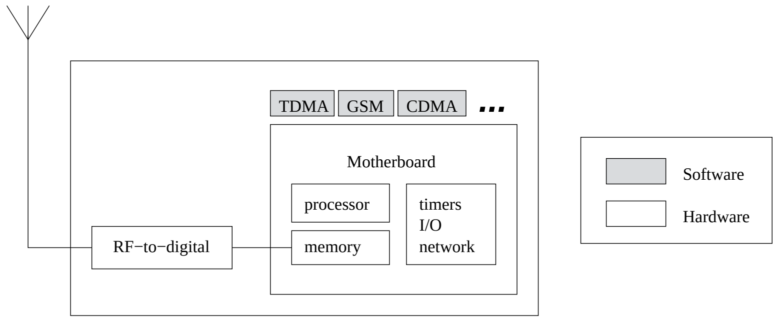

Figure 3: The Vanu Software Radio architecture

- All of the signal processing of a wireless device is performed in software.

  RESULT: The flexibility of an all-software approach leads to systems that can change dynamically. For example, a GSM handset could change its equalization algorithm dynamically based on the quality of the received signal.

- The software is written in a high-level language.

  RESULT: The use of a high-level language enables true software portability and reusability. It also simplifies implementation and opens up a huge base of programming and debugging tools.

- The system runs on general-purpose processors.

  RESULT: General-purpose processors follow Moore's Law. By tracking Moore's Law and having portable software, Vanu Software Radio systems double in price/performance and other measures of quality every 18 months. In addition, many general-purpose processors support operating systems with useful features like virtual memory and individual application processes.[1]

- The system uses commercial-off-the-shelf hardware.

  RESULT: Minimizing in-house hardware development leads to shorter product development cycles and allows radio manufacturers to focus on what they do best. Competition in the hardware market keeps costs low and spurs improvement.

Figure 3 shows the Vanu Software Radio architecture. The wideband signal is received at the antenna, gets downconverted and digitized, and moves directly into processor memory. It is important to note that no waveform-specific processing occurs in hardware. All of the signal processing occurs in software running on the processor. Contrast the Vanu Software Radio architecture with the reconfigurable SDR architecture of Figure 2, which relies on a combination of DSPs and FPGAs for the signal processing in addition to a microcontroller unit to handle control functions; the Vanu platform does signal processing and control on the same processor.

5 Summary

Just as the application-specific word processing machine has been replaced by a more general-purpose personal computer, hardware radios will soon be replaced by software radios for many applications. Spending huge amounts of money on waveform-specific wireless infrastructure that cannot be upgraded to new standards and services is simply not a good business decision.

A number of companies are developing systems to fill these marketplace needs. Solutions vary greatly in the flexibility that they will provide, and for certain applications a limited flexibility solution is sufficient.

[1]It is important to note that Vanu Software Radio systems also run on DSPs that have strong C/C++ compilers. At the moment, however, general-purpose processors tend to provide a better platform for sophisticated software radio systems.

However, in many applications the true flexibility, software portability, and upgradeability of Vanu Software Radio systems are the right choice.