A HANDHELD SOFTWARE RADIO BASED ON THE IPAQ PDA: HARDWARE

Jessica Forbess (Vanu, Inc., Cambridge, MA, USA; jforbess@vanu.com);
Mark Wormley (General Dynamics Decision Systems, Scottsdale, AZ, USA;
Mark.Wormley@gdds.com)

ABSTRACT

Vanu, Inc. and General Dynamics Decision Systems have created a handheld software radio capable of switching between an analog FM two way radio and a digital APCO Project 25 radio. These two waveforms are in different frequency bands. The handheld is an iPAQ handheld running Vanu Software Radio under Linux, exchanging digital RF samples with a General Dynamics radio transceiver. Neither the Vanu half nor the GD half of the system had been designed specifically to work together, yet a handheld demo was working six weeks after the project was conceived. This paper discusses the design, integration, and testing of the handheld, and lessons learned from the process. Future additions and challenges are also explored.

1. INTRODUCTION

Vanu, Inc. and General Dynamics Decision Systems have created a multi-standard handheld software radio. The unit is currently capable of supporting two waveforms that are in different frequency bands. The device, an iPAQ running Vanu Software Radio under Linux, exchanges digital RF samples with a General Dynamics radio transceiver. Both the Vanu, Inc. and GD components were developed independently, yet an integrated unit was working within six weeks of project conception. This paper discusses the project, lessons learned, and the upgrade path for the device.

Compared to desktop and infrastructure environments, the handheld is limited in power and processing, but is rapidly evolving. It is important to provide support for waveforms now, while retaining the ability to easily run on future platforms. Vanu, Inc. and General Dynamics have designed a handheld software radio to take advantage of the flexibility of software radio, while using software portability to make the development cycle faster. The team focused on the interoperability problem within the public safety community. Currently, each police or fire department purchases its own equipment, generally at the county level. When an emergency requires a variety of departments to work together, the various radios cannot interoperate, because each department uses different frequency bands and/or waveforms. This is becoming a problem even within departments, as new waveforms are introduced, and the older radios can't interoperate with newer radios.

The team has designed a software radio to address these problems, including the opportunity to upgrade as waveforms mature. The handheld currently runs analog FM two way radio and the digital APCO Project 25 waveform. It can tune anywhere between 100 MHz and 500 MHz.

2. SYSTEM DESCRIPTION

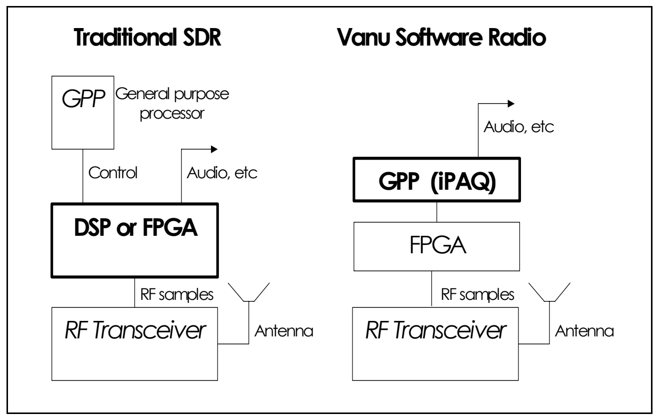

Figure 1: A comparison of the traditional software defined radio architecture and the Vanu Software Radio architecture

The system is divided into three subcomponents, the radio transceiver, the FPGA interface card, and the iPAQ containing the general purpose processor, on which the Vanu, Inc. software runs. The system diagram is shown in Figure 1, where it is compared with a traditional software defined radio. A traditional SDR performs the signal processing in a DSP or FPGA, and uses a general purpose processor, such as a StrongARM, to select between a number of waveforms or operating bands already programmed into the system. Vanu Software Radio performs the signal processing on a general purpose processor. Vanu, Inc. uses the same code to run waveforms on Intel x86 platforms or the iPAQ StrongARM, or even the newer, faster Xscale. New waveforms can easily be added to the handheld, or upgraded to match a changing specification.

In the Vanu Software Radio system, the radio transceiver pulls in an RF signal, mixes it down to baseband and digitizes it, streaming it to the FPGA interface card, which simply acts as a DMA to pull it into memory so that the iPAQ can access it. To transmit, the iPAQ supplies baseband complex data to the FPGA, which streams it to the RF card, which converts it to analog, mixes it up to the appropriate frequency, and transmits it. The FPGA interface card and the RF transceiver are contained within a standard iPAQ dual slot expansion sleeve, with an additional lithium-ion battery.

2.1 Radio Transceiver

The RF transceiver covers the UHF/VHF spectrum from 100 MHz to 500 MHz. Full frequency control of the radio transceiver is available via serial data commands, however the demonstration implementation for simplicity made available 16 preprogrammed channels. The receiver currently supports a 12.5 kHz bandwidth at I and Q, with a sample rate of 48 kHz on each arm. The demo has a maximum transmit power of 100 milliwatts. The power out was limited for demonstration purposes to accommodate the minimal available battery capacity of the demo design. The transceiver contains circuitry to boost the power to 1 watt continuous, 5 watts peak, if it is included in the signal path. The higher power level is appropriate for public safety applications.

In its present configuration, the radio transceiver is composed of two modules, one for the RF circuitry and the other for baseband processing. This transceiver was designed to serve multiple needs, and as such, is highly programmable. Filter bandwidths, transmit power levels and other such parameters are selectable via software. The baseband processing module contains both the A/D and D/A circuitry, a 33 MHz processor used to configure the system, and an FPGA used to provide a flexible external interface to the Vanu, Inc. part of the system. Both modules contain power management circuitry to support battery life requirements.

2.2 FPGA Interface Card

The interface card provides a programmable interface to the radio transceiver. Data and control interfaces are provided separately. Baseband I/Q data is streamed to and from the transceiver serially, with additional discrete lines for control. The data is moved to dual port memory where the iPAQ can access it. The memory holds 64k complex samples, which is evenly divided between receive and transmit buffers. The FPGA is simply a data transfer engine; it does no signal processing in this system.

The interface card also includes power circuitry, a PLL, and a GSM SIM card connector. For high volume production, the functions of the interface card would be integrated on to the RF transceiver.

2.3 IPAQ

Figure 2: Vanu, Inc. iPAQ Software Radio

The iPAQ contains a 206 MHz StrongARM processor running Linux, with 32 MB of DRAM and 16 MB of Flash. The system could be upgraded easily to a 400 MHz Xscale iPAQ, with significant power savings, in addition to an increase in processing capability. The radio applications run under Linux, and can be controlled locally using the touch screen, or remotely via a serial link. On the current 206 MHz StrongARM, we can support two way FM radio and APCO Project 25, plus other low bandwidth waveforms like TDMA and CDPD, provided the RF transceiver can access the appropriate bands. Upgrading to a 400 MHz Xscale will add GSM capabilities to the list.

2.4 Vanu Software Radio

The Vanu Software Radio infrastructure and applications are discussed in depth in a separate SDR Forum paper, [1].

3. SYSTEM INTEGRATION AND TESTING

The system's design eased the integration process by providing a flexible interface, which can be adjusted to match whichever RF transceiver is most suitable. Having an FPGA at the interface provides the most power to match data speeds and protocols, in addition to providing very flexible control solutions. Past Vanu, Inc. handheld prototypes divided the interface between the RF transceiver and the Vanu, Inc. system at the analog baseband stage. However, it was determined that integrating the A/D and D/A stages onto the RF transceiver results in a more compact and power efficient solution, as the designer of the RF board is far more capable of determining the best overall trade-offs in the analog design. In addition, it is easier to reprogram an FPGA to match the new digital interface than to redesign, build, and integrate a new analog circuit in the space constraints of a handheld device.

Each part of the handheld system was developed separately from the others. The software radio applications were developed initially for other platforms and users. The waveform engineers used Intel-based desktop computers, a StrongARM-based desktop computer for profiling and benchmarking, and a PCI-card-based radio transceiver. The interface board was developed in the spring of 2002, and was intended to interface with a different radio transceiver. A good deal of planning and design took place to optimize the interface card for its position between the iPAQ and the specific radio transceiver we were targeting. In the winter of 2002, the software radio applications were integrated with the software modules and drivers for the handheld transceiver, which allowed for testing of the control messages and the GUI, but the lack of a handheld transceiver meant the data path timing of the transceiver module was untested. However, the high-level software approach made it easy to test the data path of the rest of the processing chain by substituting data files for the transceiver.

Integration with the General Dynamics handheld radio transceiver went incredibly smoothly, considering neither the interface board nor the transceiver had been designed to interface with the other. In just a few weeks, the radio transceiver was modified to supply the appropriate bandwidth and sample rate, the frequency band was shifted to cover the 400 MHz region, and the data and control interfaces were set to match the Vanu, Inc. system.

The FPGA interface needed a simple adjustment to match the serial data stream to the transceiver. The control interface was a little more involved, but an initial setup with discrete lines to select a channel made it easy to get an initial prototype working. A simple asynchronous serial control line will be added as the prototype matures.

3.1 Difficulties

As everyone in system integration knows, the most difficult task is setting up tests across varying components, each with a different testing and development environment. The spectrum analyzer was the most useful tool for system-level debugging. However, the addition of the Vanu, Inc. receive-only laptop system, allowed the team to gather and analyze traces with in-house tools, which are discussed in [1]. The ability to collect traces and transfer them to Vanu, Inc. to be examined by engineers more familiar with a specific waveform sped up the integration considerably.

The laptop system was primarily developed for demos, but it is a convenient way to test other transmit systems. It can receive the same waveforms as the handheld, and those signals can be examined at each point in the signal processing chain. Because the team was using in-house tools for data collection, the analysis could be done on the fly, using Vanu, Inc.'s waveform applications or 'octave', a signal-processing program much like Matlab. The ability to use the Vanu, Inc. custom tools made it much easier for the team's software engineer working at Vanu, Inc. to assist the hardware engineer in the lab at GD. The Vanu, Inc. laptop system collected data in a familiar manner, which could be transferred and analyzed easily at Vanu, Inc. assuming there was network access, which was somewhat limited for visitors at General Dynamics. The lack of network access made it difficult to draw upon the additional resources at Vanu, Inc. while debugging. It wasn't always possible to send the traces collected with the laptop software radio system to engineers who had worked on the specific waveforms at Vanu, Inc. for their insights.

As convenient as the standard Vanu, Inc. toolkit could be, it could not always be used on the handheld itself. The limited permanent storage space and the mutual-exclusivity of the radio transceiver and network connection made familiar tools like 'gdb' much less useful. They were useful when debugging the processing chain, but not as much when debugging the entire system.

Multiple testing sessions were required to finalize the hardware integration, as each round of testing shook out a few more bugs, which required individual attention to each part of the system.

The battery life of the device is currently very limited, as the additional battery in the RF sleeve is only 600 mAh. The battery life of the device can be expanded by taking advantage of the built-in power management capabilities of the transceiver by writing control software and by making design changes in the power supply circuitry. Other approaches involve running the iPAQ at a slower speed and lower voltage, and increasing the size of the battery. The newest iPAQs can hold a 2500 mAh battery, so there is confidence that battery life can be improved by both decreasing the amount of power used, and increasing the power supplied in the system battery.

There were two major limitations inherent in the hardware used. Most notably, the system is only as flexible as the RF hardware. The team ended up with a less flexible front end than had been designed for, which limited the choice of waveforms. This is only a problem in the short term, as the radio transceiver can be extended to 900 MHz, and the bandwidth can be increased, enabling us to provide TDMA, CDPD and GSM in the near future.

The lack of a floating point processing unit is the other difficulty stemming from the hardware. The StrongARM and its descendant, the Xscale, are not capable of doing floating point processing speedily. Therefore a number of fixed point processing modules for our library have been implemented in order to run the software radios on many of the low power processors. The major limitation of fixed point processing is its requirement for a tighter dynamic range and a correspondingly higher signal-to-noise ratio on the signal processed. This is discussed in more detail in [1].

4. ABOUT THE TEAM

Vanu, Inc. evolved out of the SpectrumWare software radio research project at MIT in the mid 1990s. Since its inception in 1998, the company has focused on waveform software development for software radios. The extent to which we implement signal processing in software distinguishes our technology from other software radio design techniques. Our systems perform as much signal processing as possible in application-level software running on top of standard processors and operating systems. The advantage of moving signal processing into software is increased flexibility: a Vanu, Inc. waveform (air interface) implementation can run on a range of devices, from handhelds to scalable infrastructure.

Vanu, Inc. licenses software radio technologies and waveforms and provides design-consulting services to wireless device manufacturers, system integrators, and service providers. Our core competencies include strong software engineering, use of innovative signal processing algorithms, development of portable code, and the creation of commercial-off-the-shelf-based system design.

Vanu, Inc. partners with pioneering companies with an interest in building advanced software radio devices, like General Dynamics Decision Systems. General Dynamics Decision Systems has been a pioneer in the area of Software Definable Radios (SDR). Beginning in 1995 with the development of the very first SDR called Speakeasy, General Dynamics has developed and is presently producing two other SDRs: the US Navy AN/USC-61(C) Digital Modular Radio and the AN/PRC-112G handheld Combat Search and Rescue Radio. Decision Systems is an active member of the Software Defined Radio development and customer communities. The company has been instrumental in creating the SDR Forum, and continues to hold prominent SDR Forum positions including membership on the Board of Directors.

General Dynamics has a significant ongoing investment in miniature software defined radio technologies. The company is currently producing the PRC-112G handheld SDR survival radio, has invested IRAD dollars and has created and recently demonstrated a prototype JTRS Cluster 5 radio to many in the customer community. Because of this experience, Decision Systems is well aware of both the benefits and the challenges of small form factor Software Defined Radio. Decision Systems has formed partnerships with industry leaders in the key technology areas, and is prepared to offer innovative solutions in order to make a small form factor SDR a practical offering for the marketplace.

5. CONCLUSIONS

In conclusion, the Vanu, Inc./General Dynamics team has created a very successful demonstration system, which illustrates the power of software radio. In its current state its waveforms are competitive with current products available in the public safety market. With additional modifications to the hardware and software, it is expandable to be an even more flexible radio for the public safety market.

The design provided a flexible interface to connect with a separately designed RF transceiver. The RF transceiver was initially designed and produced for the PRC-112G Combat Search and Rescue Radio.

While the radio transceiver was less flexible than the one with which the system was designed to work, it was possible to make it work in a useful demonstration. The fixed point modules were more difficult to incorporate than anticipated, as the signal-to-noise ratio was lower on the handheld than the desktop. The integration and testing procedures were developed along the way, and tools from both the RF and the software side of the system made the debugging proceed faster and more efficiently.

In the near future, Vanu, Inc. plans to extend the frequency range to 900 MHz to support the 800 MHz trunking band for P25, plus the cellular band for TDMA, GSM, and CDPD. The company will also expand the bandwidth to 30 kHz and 200 kHz, to support those waveforms. A more rugged housing is also in the works.

Further on, Vanu, Inc. will expand the frequency bands to 2.5 GHz and the bandwidth to 1.2 MHz and beyond to support CDMA and 3G waveforms, plus other waveforms in the 900 and 2.5 ISM bands.

10. REFERENCES

[1] A.G. Chiu, J. Forbess, “A Handheld Software Radio Based on the iPAQ PDA: Software,” SDR Forum Technical Conference 2003.