EXPLORING RECONFIGURABILITY; TOWARDS A FUTURE OF SPECTRUM RENTAL

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ABSTRACT

This paper focuses on the area of dynamic spectrum management and explores how reconfigurable radio can play a major role in its realization. In particular the paper presents a case study based on IRIS (*Implementing Radio in Software*), which introduces software radio configurations that can be used for new spectrum allocation and spectrum management regimes. IRIS is a general-purpose processor based system for creating reconfigurable radios.

1. INTRODUCTION

The allocation and management of spectrum are issues that need to be seriously addressed with a view to improving spectrum capacity. There are two main reasons why these topics are of great importance. Firstly there has been an enormous growth in wireless communications over the past two decades and we now live in a world where there are ever-increasing numbers of wireless communication devices in operation. This situation has generated an increase in demand for spectrum. Secondly, and more importantly, if we continue to retain the present methods of spectrum allocation we are in danger of stunting the potential of wireless communication systems of the future. The traditional ideas of network infrastructure and ownership and the centralist model of a public carrier network and licensed spectrum must be challenged in an attempt to go beyond present systems and to design for the future in an innovative manner[1],[2],[3].

It is therefore welcome that in response to the increased demand for spectrum, communications regulators of many governments around the world have been taking a fresh look at how spectrum is allocated and managed with a view to improving spectrum capacity. These bodies have recognized that software radio is an enabling technology in achieving more effective spectrum regulation. This paper focuses on the role that software radio will play in a future world where spectrum management is handled in a more innovative manner. In particular, it will present a case study of how a software radio design framework, created as part of our current research, can be used to design reconfigurable radios for alternative spectrum management paradigms. Section 2 of this paper presents a brief overview of spectrum management. Section 3 discusses the levels of reconfigurability needed in a radio to satisfy the demands of dynamic spectrum allocation regimes. Section 4 of the paper introduces the software radio design platform, known as IRIS (*Implementing Radio in Software*). IRIS runs on a general-purpose processor platform and can be used to create software radios that are reconfigurable in real-time. Section 5 details how IRIS can be used for dynamic spectrum management. Section 6 deals with the notion of spectrum rental and shows how the reconfigurable radio designed in section 5 can be incorporated into a communication system that provides a means of electronic payment for spectrum use. And section 7 concludes.

2. SPECTRUM MANAGEMENT

One organization making considerable progress in this field is the U.S. Federal Communications Commission (FCC). In their Spectrum Policy Task Force report [4] they outline bold new strategies for spectrum reform by introducing fundamental changes in spectrum management. (Existing methods for spectrum management are discussed in [5]). The main point emerging from the FCC report is that the current methods used to regulate spectrum are outdated and do not reflect current technological capabilities. In essence, the technological needs of today were unforeseen when these regulations were put in place. For example mobile communication users have significantly changed the use of spectrum. Previously, the broadcasting model of a small number of transmitters serving a large number of receivers was valid (e.g. TV, Radio, Paging Systems). Whereas the broadcast model requires only a small number of frequencies to serve sometimes millions of users, a mobile phone requires both a downlink and an uplink channel for each individual user of the system and consequently spectrum demand increases with each new user. In addition to the increasing demand there is also the fact that a number of existing users (e.g. T.V. broadcasters) do not necessarily make most efficient use of the spectrum they have been allocated.

To date spectrum has been allocated on frequency basis. Typically users (broadcasters, network operators) are given (buy) a license for a defined band of frequencies for exclusive (and permanent) use. It is however possible to allocate spectrum on a range of other bases, on a non-permanent footing with a result in increased capacity. For example dynamic allocation on a spatial basis would allow organizations in different regions to use the same frequencies. In time, the granularity of space could be reduced and in the extreme examples users would be permitted to use the same frequencies within much smaller vicinities (e.g. on different floors of a building). Allocation on a temporal basis would allow users access to underutilized spectrum, effectively filling the unused gaps of available spectrum time. Transmit power, although partly regulated today, could be made a more effective means of allocation and would go hand in hand with regulation by space. In summary it is clear that there are many options for dynamic allocation of spectrum that greatly improve on the static and permanent allocation of frequency bands that exists at present.

What is needed to take advantage of these mechanisms is both a shift in mindset and the right wireless technology. Software radio can offer the flexibility required to deliver devices that are dynamic in their use of frequency, power and time and therefore is ideally positioned to form the basis of systems that facilitate creative spectrum management.

3. RECONFIGURABILITY

To achieve the flexibility that is needed to operate in a wireless network that is based on dynamic spectrum allocation a real-time reconfigurable radio is needed. It is therefore necessary to go beyond software radio platforms that can only perform limited reconfiguration or that need to be taken off-line to reconfigure. To expand on this it is useful to develop a definition of reconfigurability. A software radio can be viewed as a number of signal processing stages that are linked together in a certain order to deliver the functionality required. With this in mind three levels of reconfiguration have been defined:

Level 1 - Parametric Reconfiguration involves the dynamic alteration of individual parameters of signal processing functionality. An example of parametric reconfiguration is a change in filter coefficients. An example specific to dynamic frequency management is the change of frequency setting in accordance with change of spectrum allocated to that particular radio.

Level 2- Structural Reconfiguration involves the alteration of the layout of the radio system or the replacement of some aspect of the software of the system while still performing the same overall application. For example structural reconfiguration occurs when the way in which a signal is processed is altered as in the case of the introduction of two stages of filtering instead of one. In this case the radio will still perform the same function but the reconfiguration may have the benefits of improving signal quality, power consumption or performance. An example specific to alternative frequency management regimes would be in the insertion of some new extra functionality within the existing software radio configuration, to make decisions about which frequencies the radio should use.

Level 3 - Application Reconfiguration involves completely replacing the software of the software radio with an entirely different software radio configuration. This type of reconfiguration allows a radio to completely change the application it performs. The same hardware being reconfigured from being a two-channel analogue FM transceiver to being a 10 channel digital BPSK transceiver is an example of application reconfiguration. Software download also falls into this category of reconfiguration. In terms of dynamic spectrum allocation it may be necessary for a radio to use an entirely different communication means to best take advantage of the new band of frequencies it has been allocated.

A general-purpose processor based software radio can facilitate these 3 levels of reconfiguration in real-time without taking the software radio offline.

4. A RECONFIGURABLE PLATFORM

The platform for the research described in the paper is IRIS (*Implementing Radio In Software*). IRIS is a general-purpose processor based system for designing reconfigurable radios. Details of IRIS can be found in [6], [7]. Other general-processor approaches to software radio can be found in [8], [9]. Figure 1 is a block diagram of the IRIS architecture, (an architecture in this case being a superset of principles prevailing a system).

The fundamental unit for building reconfigurable radios in the IRIS Radio Architecture is the Radio Component (a unit of radio functionality). A user of IRIS creates a radio from an existing suite of Radio Components or by creating new components when necessary. These basic building blocks of the system are key to its ability to reconfigure. The Radio Components are designed to encapsulate radio functionality in a way that would facilitate their reuse among many applications and permit ultimate flexibility in the design of the over all system. In other words the Radio Components facilitate *Parametric Reconfiguration*, *Structural Reconfiguration* and *Application Reconfiguration*.

The IRIS Radio Component Framework is an infrastructure that allows Radio Components to be composed together to form a reconfigurable radio. The Radio Engine is the core of the Radio Component Framework. The engine is responsible for assembling a reconfigurable radio from a set of Radio Components. In order for a radio to be assembled by the engine a definition of the exact radio must be supplied.

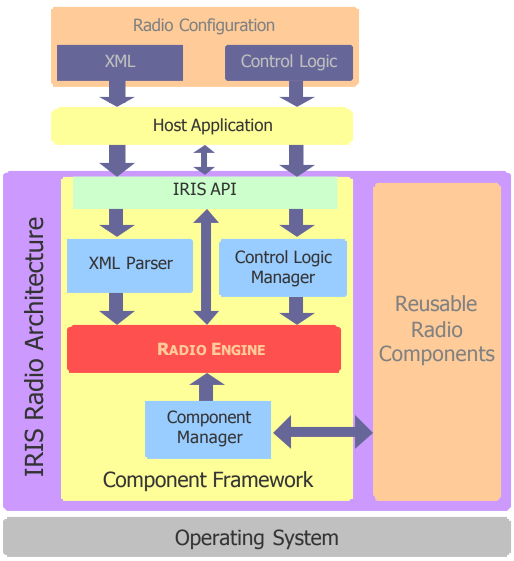

Figure 1: IRIS Architecture

XML is used to define the radio configuration as it allows the representation of hierarchical data and thus is suitable for defining the structure of a radio system. A description of the Radio Components that form the radio configuration via an XML file is however not enough to fully describe the functionality of a configuration. The Radio Engine also needs to make use of Control Logic. The Control Logic is application specific and defines the interaction between components. In addition, Control Logic is also abstracted from the overall structure of the radio implementation. This means that even if additional components are added into a structure (such as inserting a new components between existing components) the Control Logic will still function. The XML Parser reads the XML configuration and translates it into an internal representation of a radio design that can be used by the Radio Engine. The Control Logic Manager loads and unloads various types of Control Logic for use by the radio engine. The API encapsulates all the functionality of the Component Framework into one API that can be used by other applications to create reconfigurable radio systems.

The typical steup of the IRIS testbed consists of IRIS running on a PC containing ADC and DAC hardware that interfaces with an RF frontend. Radio Components have been developed allowing signals to be input from hardware and output to hardware. For example, a data acquisition component allows the input of digitized signals from an ADC PCI (Peripheral Component Interconnect) card.

5. RECONFIGURAING FOR SPECTRUM MANAGEMENT

IRIS can be used to create any radio configuration of interest. Figure 2 depicts an FSK transceiver designed in IRIS.

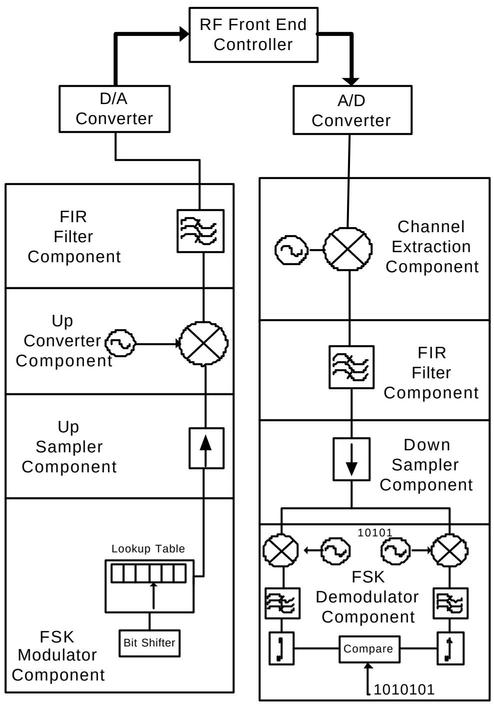

Figure 2: FSK Software Radio

In the IRIS system all the specification of the application is independent of low-level hardware details. At this higher abstraction system specifications are more decoupled from hardware, for example the hardware architecture is never changed in response to a change in transmission data rate. The one parameter that the system is dependent on is the overall processing power of the architecture and once the GPP system provides enough processing capability many radio types using different specifications can be implemented. This type of capability radically changes the radio design paradigm affecting how radio systems can be viewed and constructed. For example instead of creating an FSK modulator for voice and another for data, one generic FSK modulator Radio Component is created and by changing the parameters of this component many different types of information can be accommodated. With this approach in mind, designing the FSK transceiver becomes less about choosing operating parameters and more concerned with functional partitioning of the system via software components. Once the appropriate generic components have been built, the radio system can be configured via parameters to deliver the required specification. Radio Components are specified via properties, events, ports and commands. This model allows radio functionality to be encapsulated most effectively. In Figure 2 each block indicates the functionality of the individual Radio Components that have been linked together by the Radio Engine, based on an XML description that shows how the system is structured, to form a workable radio. More details on the design of IRIS radios can be found in [6], [7].

5.1. Interference Temperature

To explore how IRIS can facilitate new spectrum management approaches, it is useful to look the concept of 'Interference Temperature'. The FCC has proposed the use this as a metric that measures the RF power available at the receiving antenna per unit bandwidth. The idea is that spectrum aware devices can dynamically calculate the current temperature to determine whether it is permissible to communicate or whether the device should try a new band. Regulators can assign different threshold levels for each band, effectively allowing them to control the noise floor. This requires a device that can measure the interference temperature and react accordingly.

Because the IRIS system exists primarily in software, enabling interference temperature is straightforward, only requiring the inclusion of a new component and some additional Control Logic. Structural reconfiguration can be performed to add this to the existing system and 'grow' the radio. Figure 3 is a diagram of the previous FSK transceiver with the added component.

In this design the radio monitors the temperature via an Interference Temperature Component. Using Control Logic the value of this temperature can be the basis for change of operating frequency of the radio system by controlling the RF front-end. The temperature could also change other aspects of the radio system perhaps changing the modulation scheme or data rate of the radio to reduce the interference it causes. The fact it is written in GPP-based software also means that the interference temperature component can be reused in many other designs requiring this functionality. It is also interesting to note that such software components are a suitable method of deployment. For example, regulatory bodies, such as the FCC, could instead of regulating the requirements of individual radio devices regulate and approve particular software components for use in Interference Temperature calculations.

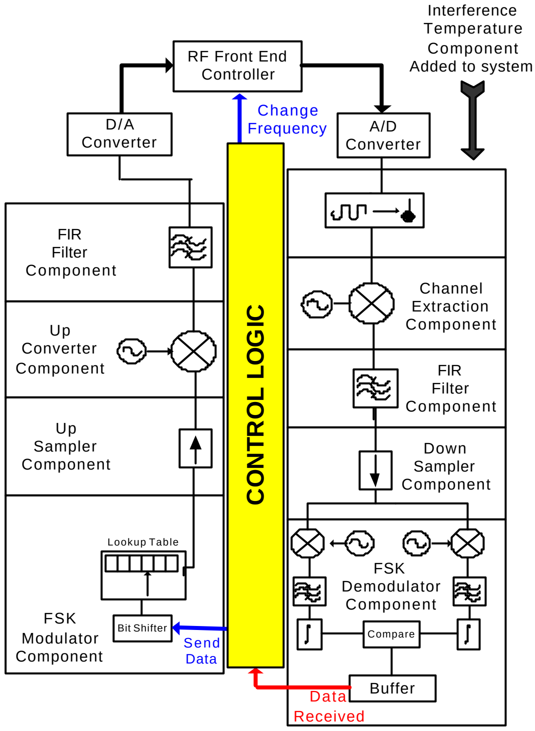

Figure 3: FSK Software Radio with Interference Temperature Component

5.2. Spectrum Monitoring

Besides the actual terminals that communicate, there are other types of devices that will be required in a dynamic spectrum environment, one such example being a device for monitoring spectrum usage. Many regulators already monitor spectrum on a regular basis but in a more demanding and dynamic environment communications will have to be more closely monitored to ensure that the policies in place are effective. This will require monitoring stations that can detect the Interference Temperature but possibly also to analyze individual transmissions. This could be of use in enforcing regulations by tracking misuse of spectrum or in producing statistics and feedback information regarding the

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types of transmissions occurring in the medium. With this in mind IRIS can be also used to develop such a monitoring device such as that shown in Figure 4.

This system sweeps any band of interest continually analyzing any communications occurring in that band. The signal of interest is down converted to baseband where it enters a signal buffer. The buffer makes use of the large amounts of RAM available within a GPP design to store the most recently received radio signals. The Control Logic on receiving a particular signal of interest can retrieve a previous occurring signal and record it to disk for later analysis. A signal database is also included and this can be used to store statistical information resulting from the analysis.

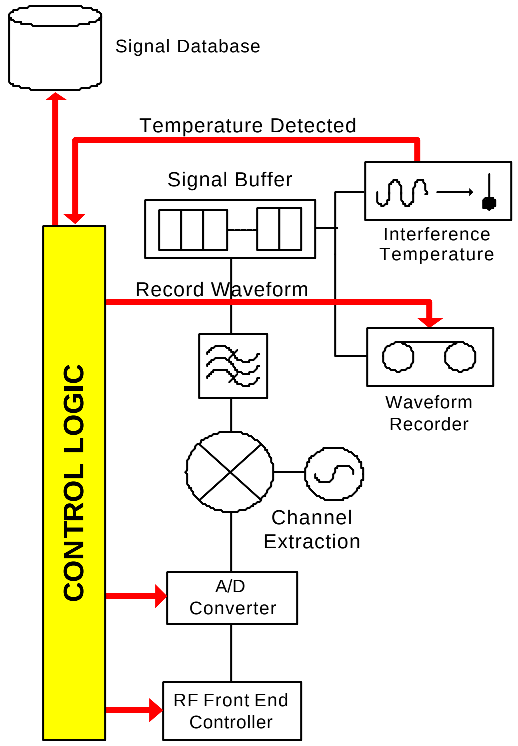

Figure 4: Spectrum Monitoring System

6. A FUTURE OF RENTAL?

In related research to this work, the NTRG (Networks and Telecommunications Research Group) in Trinity College have developed a test bed for developing wireless networking applications [2]. This testbed is a software environment for dynamically creating network communication stacks and allows for experimentation with a wide range of networking technologies. As part of this ongoing research in the wireless communications field a number of electronic payment schemes have been designed and implemented [10]. Among those is a micropayment scheme that allows a stream of cryptographic payment tokens to be travel from node to node of the network, interspersed with the normal data packets that make up the end-to-end flow. Before communication commences a pricing phase takes place to negotiate the costs involved. Tokens are then inserted in to the network, at the agreed rate, and communication continues as long as payments are received by the entities in the network due payment. The particular system referenced here is a multiparty micropayment system and all entities involved can recoup their due part of any payment token as it passes through the system.

The spectrum management scenario in the previous section can be extended further by introducing the notion of payment and spectrum rental. The NTRG testbed can be used in conjunction with IRIS to explore this possibility. While the research is still at a very stage it nonetheless provides a framework for designing for the future.

Consider the case of a cellular type infrastructure in which users pay for the use of spectrum. Using the IRIS API, a layer has been written that allows the IRIS system to act as a physical layer of a communication stack as shown in Figure 5. The micropayment system is altered to allow for spectrum rental in a hierarchical or cellular like networks. Tokens are inserted in to the network to pay for use of the spectrum. The higher layers of the system feed the tokens down the stack and they are sent to the central controller node (e.g. basestation, access point) or 'owner' of the spectrum. The Control Logic within the IRIS physical layer can react to this. If payment stops the Control Logic can react in a number of ways. The power of the radio can be significantly reduced or turned off or the radio can be retuned to another 'free for all' band in which no payment is demanded but in which the user just takes pot luck in terms of the levels of interference that exist.

A pricing-phase could also be introduced in this scenario before communication begins. Supposing a number of possible 'owners' of different spectrum exist in an area. An IRIS reconfigurable radio can retune to the frequency band with the best offer. This introduces the possibility of offering better rates for spectrum usage at quiet times of day or night and brings a whole other level of flexibility to the system.

While it is clear that there are a wide range of issues to be considered before payment for spectrum can be properly addressed, and that this example has many weaknesses, it is also clear that the general-purpose processor reconfigurable radio allows us to begin the investigation.

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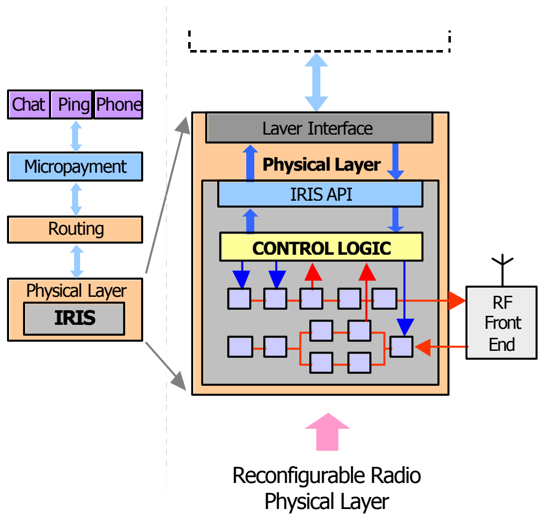

Figure 5: Spectrum Rental – linking the higher layers with the Reconfigurable Radio

7. CONCLUSIONS

The area of dynamic spectrum management is rich in ideas and possibilities. It is clear that reconfigurable radios have a strong role to play in providing the technology that can make new ways of managing spectrum a possibility. This paper focused on IRIS and how it can be used to create reconfigurable radios to enable dynamic spectrum management. The work research presented here has laid a basis for further explorations in this field.

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