A Software Radio Design Approach for Heterogeneous Wireless Access Protocol Transceivers.

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ABSTRACT

A study on the design of heterogeneous transceivers using the software radio approach is presented. The objective of the study is to extend the research on software radio towards the design of multi-protocol transceivers which can communicate between two or more heterogeneous wireless access technologies. A critical overview of some of the current multi-protocol software radio devices is presented. This is then followed by a proposal for a dual band WiFi/WiMAX transceiver based on software radio techniques. This design incorporates a multiband antenna as well as an RF WiFi/WiMAX mode switch which uses the WiFi received signal strength (RSS) to perform handover between the underlying WiFi and WiMAX networks.

(Keywords: software radio, multiband antenna, wideband antenna, WiFi, WiMAX, vertical handover, seamless vertical handover, heterogeneous wireless networks)

INTRODUCTION

In traditional hardware radio, the transceiver section consists of hardware components such as Radio Frequency (RF) amplifiers and filters, Radio Frequency to Intermediate Frequency (RF to IF) converters, modulators and demodulators [1]. In a generic digital hardware radio, the signal is converted from analogue to digital form after the above mentioned processes are done. Due to its hardware-based nature, digital hardware radio offers little or no flexibility in handling multiple radio transceiver protocols. This is because if a hardware radio is required to implement multiple transceiver protocols, each of these protocols has to be implemented in a separate dedicated silicon area.

Software radio is a more recent term used as opposed to the traditional hardware radio. Software radio has evolved from software controlled radio, and is rapidly evolving into cognitive radio. In software radio when the signal is received from antenna, it is digitized and the transceiver functions stated above are performed in software instead of hardware. Since the transceiver functionality is implemented entirely in software, it means that software radio offers flexibility in terms of switching between different radio transceiver protocols, depending on requirements. In addition, unlike hardware radio which requires separate silicon area sections for each transceiver protocol, in software radio the same silicon area is used for all radio transceiver protocols to be handled by the radio.

In software-controlled radio, as the name implies, the transceiver functions such as modulation, filtering, up conversion and down conversion are performed in hardware and software is used to control these functions. Software controlled radio offers some flexibility when compared to hardware radio. However, since all the transceiver functions are implemented in hardware, software controlled radio offers little or no savings in terms of silicon area when compared to hardware radio.

On the other hand, whilst software radio implements the traditional transceiver functions entirely in software, cognitive radio goes beyond this by incorporating the ability to sense the environment and generate and make use of the appropriate radio protocol automatically [2], [3], [4]. Like software radio, cognitive radio offers flexibility in terms of the choice of radio transceiver protocol and also provides savings in silicon area. In addition to this, cognitive radio also offers the flexibility to perform over-the-air updates.

The aim of this project is to develop a dual-mode WiFi/WiMAX radio transceiver using software radio techniques. WiFi [5][6], which stands for W*ireless Fidelity,* is a wireless local area network (LAN) belonging to the IEEE 802.11 family of standards. WiMAX [7][8], stands for *Worldwide Interoperability for Microwave Access*. WiMAX technology enables ever-present delivery of wireless broadband service for fixed as well as mobile users. The air interface of WiMAX technology is based on the IEEE 802.16 standards.

The proposed software radio architecture will involve processing and switching based on software. It will be capable of deciding itself on which stage and what time the handover must be initiated. However, the designed architecture will not be a cognitive one because the issues of re-configurability and environmental sense-making are not addressed in the scope of this project.

RELEVANCE OF SOFTWARE RADIO TO HETEROGENEOUS TRANCEIVER DESIGN

Software radio offers the opportunity to reuse the between two or more heterogeneous modes within a single transceiver. For example, in a dual mode WIFI/WiMAX transceiver, the same hardware can be configured to use it as a WiFi transceiver at one moment and WiMAX at the other.

The spread of wireless services and platforms has increased the number of wireless devices which need to be integrated. This has triggered the demand for multiprotocol, reconfigurable end user devices. Software radios have the capability to operate across heterogeneous air interface technologies such as WiFi, WiMAX and the various 3G networks currently available [1].

Unlike hardware radio or software controlled radio, the software radio maximises hardware reuse. Transceiver blocks such as framing, pulse shaping filter, modulator, up sampler, demodulator, receive filters and down samplers are common to both WiFi and WiMAX transceivers. These blocks can be implemented collectively on software while saving the cost of redundant hardware. Reuse of hardware reduces die area and the power needed to drive the transceiver. This gives longer battery life –which is a key selling point in mobile transceivers.

Concurrently, as the number of standards increases, software supported architecture becomes cheaper while hardware supported architecture becomes more expensive [9]. Buracchini [1] defines software radio as "*...* an emerging technology thought to build software radio systems that are multiservice, multi-standard, multiband, reconfigurable and reprogrammable by software."

The re-configurability of software radio guarantees the compatibility of a software radio system with any defined radio. The two main features that distinguish software radio from traditional radio are:

1. Software radio moves the analogue to digital and digital to analogue wideband conversion close to the antenna at both the transmitter and receiver side.

2. Software radio replaces dedicated hardware with general purpose hardware for baseband processing [1].

Compared to hardware radio, software radio has advantages to offer to both end users and manufacturers [1][10]. These advantages include:

1. Less development duration and cheaper production costs for device manufacturers

2. End users can add new functionality on their devices without needing additional hardware

3. End users can roam their communications to other cellular systems

4. End users can configure their terminals according to their own choice

5. Implementation of software radio increases the life time of the underlying hardware

6. Since the system can be reprogrammed, hardware can therefore be reused.

OVERVIEW OF EXISTING SOFTWARE RADIO BASED HATEROGENEOUS TRANCEIVERS

The use of software radio in the development of multi-protocol transceivers for use in potential ubiquitous network has been covered extensively in existing literature. In this section we draw from the work in [11], [12], [13] and [14] to give a representative overview of recent and current trends in software radio design.

Glossner et al. [11] describe software radio architecture capable of running three different communication protocols. This architecture comprises a common analogue to digital convertor and a single hardware clock to receive samples. Software techniques are used to resample and track the signals.

The three communication protocols are each handled by a separate RF block. Each of these RF blocks consists of components such as Low Noise Amplifier (LNA), an external Surface Acoustic Wave (SAW) Band Pass Filter (BPF), and external Phase Locked Loop (PLL) synthesizer. The baseband processing of all the three protocols' waveforms is done in software.

Sugar et al. in [13] describe a similar kind of wideband radio transceiver system which is used for running to multiple communication protocol standards. This system requires that the multiple protocol standards should operate in the same frequency band**.**

The RF components are implemented with analogue RF hardware designs and are designed such that they can operate over the entire frequency band covering the communication protocols to be handled. All the other components of transceiver are implemented either using application specific or general purpose processors to process the signals of each of the desired communication protocol. The software for each protocol is incorporated into the transceiver's up convertor (and down convertor) and modulator (and detector) blocks.

Another example of software radio is the Vanu Software Radio System [12]. The purpose of this software radio is to maximise software reuse and minimise the resources needed for technological advancement. The hardware architecture of the Vanu Software Radio System uses three main blocks, namely; antenna, RF to digital and processing blocks. The antenna block is interfaced with RF transmit and receive lines and with a digital control interface. The RF to digital block contains radio specific analogue components. The processor block contains memory and processor components.

There is one significant difference between the Vanu Software Radio System and the Glossner et al. software radio architecture. Whilst the software radio proposed by Glossner et al. [11] comprises a separate RF front ends for each of the communication protocols, the Vanu Software Radio System has an antenna block comprising an RF card with several antenna ports. The active port can then be selected through software to enable the use of different antennas for different bands. The software infrastructure of Vanu is designed to handle several heterogeneous processors running concurrently within the system.

The Vanu Software Radio System is more reliant on software approaches. It makes use of high level programming languages such as C and C++ to implement the radio functions on a general purpose processor operating on a standard operating system. The software radio system in [9] depends on dedicated DSP techniques and is therefore not as flexible as the Vanu Software Radio System. The approach used in the Vanu Software Radio System maximises software reuse through use of the application level programs running on top of standard operating system. This also allows the underlying hardware to be easily upgraded without spending greater software redeveloping costs. With the development of low power processors, radio systems like Vanu Software Radio System will provide longer battery life.

A limiting factor for the three approaches described in this section is that all the three approaches make use of separate antennas. This makes them inflexible since a separate antenna is required for each protocol. This also limits the amount of hardware savings through since each communication protocol requires a significant portion of dedicated RF components.

A single wideband or multiband antenna can be used in place of multiple antennas, thereby bringing about savings in hardware. A multiband antenna is one that can be used in more than one frequency band. For instance, Naeem, Ahmed and Mazhar [14] have used a single multiband antenna in place of multiple antenna modules in their implementation of a dual band WiFi/WiMAX transceiver for Internet connectivity. Their architecture consists of one hardware module, with a single antenna, used for both WiFi and WiMAX.

In the implementation in [14], switching between WiFi and WiMAX mode is carried out manually by the user. This approach can lead to a loss of connectivity if the user is moving out of range of one network, WiFi or WiMAX, and into the range of the second network, WiMAX or WiFi. Internet users now expect to stay connected to the Internet even as they move through different underlying networks. Hence, ideally, the transceiver should be able to switch between the two modes automatically and seamlessly, without the user having to intervene manually.

The process of switching between different underlying networks is called vertical handover. The vertical handover process is a three-stage process and takes a finite amount of time to complete [15]. The first stage is the network discovery stage where the user's mobile device identifies all the possible underlying networks it can use to access the Internet. This is followed by the handover decision stage, where the transceiver selects the network to switch to and the time to do so. The last stage is the handover execution stage when the mobile device switches over from its current network to the other network. For handover to be seamless, all these stages have to be completed prior to the mobile terminal leaving the coverage area of the access point to which it is currently connected to, otherwise the connection is dropped.

A SWITCHING MECHANISM FOR SEAMLESS HANDOVER

Naeem and Nyamapfene [16] have proposed a switching algorithm for seamless vertical handover between WiFi hotspots and an overlay WiMAX network. The inputs to the algorithm are the WiFi received signal strength (RSS) and estimated end-to-end TCP handover latency.

Figure 1 shows the computational steps implemented when a mobile terminal is approaching and when it is moving away from a WiFi access point. In both cases, samples of the WiFi RSS are measured at regular time intervals and a moving average value (MRSS) is computed for each RSS sample.

Considering first the case when the mobile terminal is approaching the WiFi access point, if the computed value of MRSS is less or equal to the receiver sensitivity R_{th} it means that the mobile terminal has already left the WiFi reception area. In this case handover from WiFi to WiMAX is immediately initiated. If, on the other hand, the MRSS value exceeds the receiver sensitivity, the current position and velocity of the mobile are computed. These two values are used to determine the amount of time remaining before the mobile terminal crosses the WiFi reception boundary. If this time exceeds the specified end-to-end TCP handover latency, a make-before-break routine initiated to ensure seamless handover to the WiMAX network. A make-before-break handover routine was adopted to ensure that connectivity to the Internet is maintained throughout the handover process.

Considering next the case when the mobile terminal is moving away from the WiFi access point, if the computed value of MRSS is greater or equal to the receiver sensitivity R_{th} it means that the mobile terminal is already in the WiFi reception area. In this case handover from WiMAX to WiFi is immediately initiated. If, on the other hand, the MRSS value is less than the receiver sensitivity, the current position and velocity of the mobile are computed. These two values are used to determine the amount of time remaining before the mobile terminal crosses into the WiFi reception area. If this time exceeds the specified end-to-end TCP handover latency, a make-before-break handover routine to the WiFi network is initiated. The make-before-break handover routine guarantees connectivity to the Internet through the WiFi network as soon as the mobile terminal reaches the boundary of its reception area. This ensures that the mobile terminal maximizes connectivity via the WiFi network

A SOFTWARE RADIO DESIGN FOR A TRANCEIVER WITH SEAMLESS HANDOVER

The Internet is increasingly becoming the only platform catering to diverse information needs such as telephony, data and the World Wide Web. Consequently there is a growing need for users to be able to access the Internet on the move as well as at home and in the offices. The Internet operates as an overlay on top of different physical layer networks, both wireless and wireline.

For users to maintain their Internet connection on the move they need to switch between underlying wireless networks seamlessly. The IEEE, 802.11 and 802.16 standards, also called WiFi and WiMAX respectively, are potential networks for a promising approach towards seamless interoperability [17].

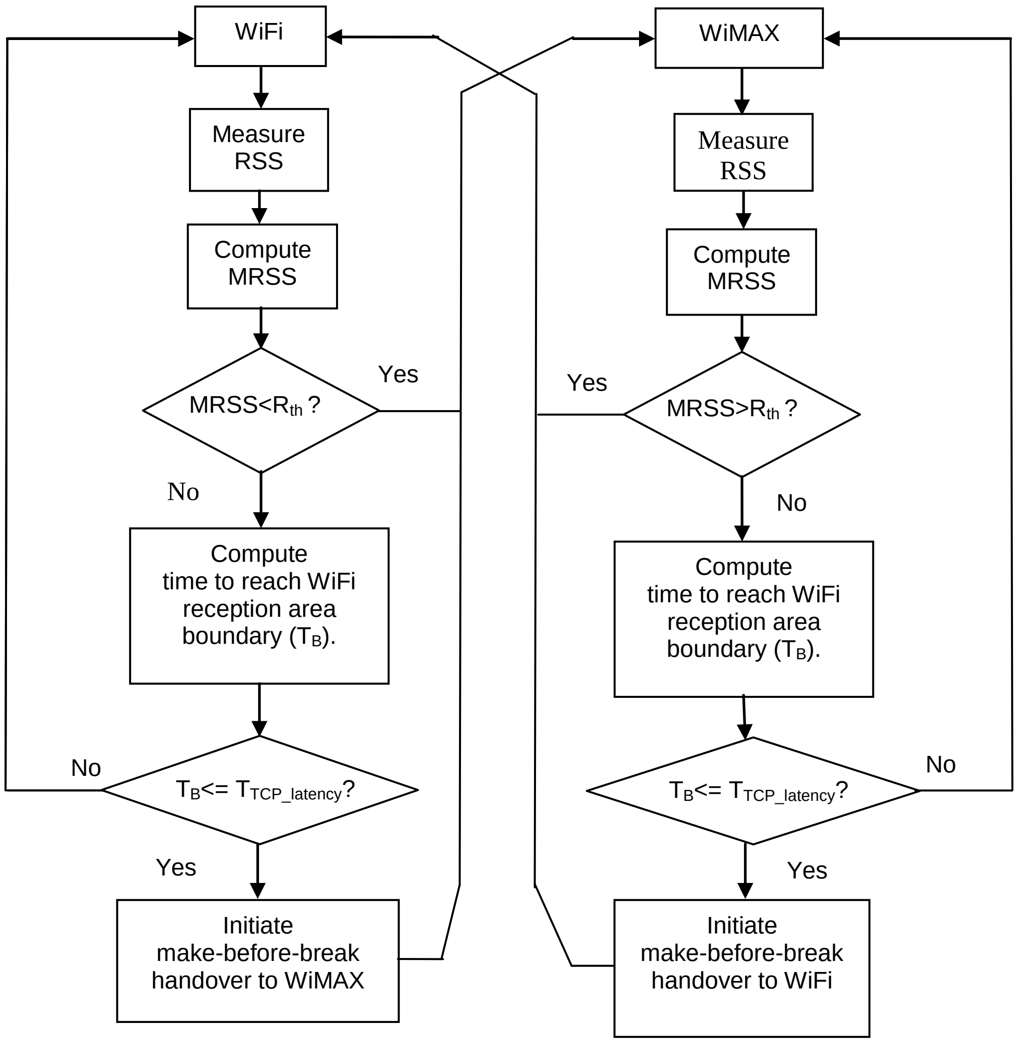

Figure 1: A Flowchart showing the RSS-Based Seamless Vertical Handover Algorithm [16].

Switching between WiFi and WiMAX networks can be done by developing a dual band WiFi/WiMAX transceiver. We now propose a design for such a dual band transceiver based on software radio techniques.

Software radio can enable us to design a transceiver that is able to communicate through both the WiFi and WiMAX multiple broadband access protocols. In our proposal, the entire transceiver functionality, with the exception of the antenna functionality, will be implemented in software. Figure 2 shows the block diagram of the proposed dual band WiFi/WiMAX transceiver. The transceiver comprises dual software transceivers, one for WiFi and the other one for WiMAX. This works in conjunction with a single wideband antenna. The software radio transceiver also contains a switching mechanism which makes use of the RF signal output from the antenna to decide which protocol should be used. The switching algorithm is based on the approach by Naeem and Nyamapfene [15] discussed earlier.

As in the architecture in [14], a multiband fractal antenna is used. A multiband antenna is one that can be used in more than one frequency band. Fractal antennas use self-similar shapes to maximize the length of transducer and consequently the bandwidth across which they operate. Fractal antennas are very compact and this makes them ideal for applications such as software radios where the objective is to maximise hardware savings and to extend the substitution of hardware with software as far back to the antenna as much as possible.

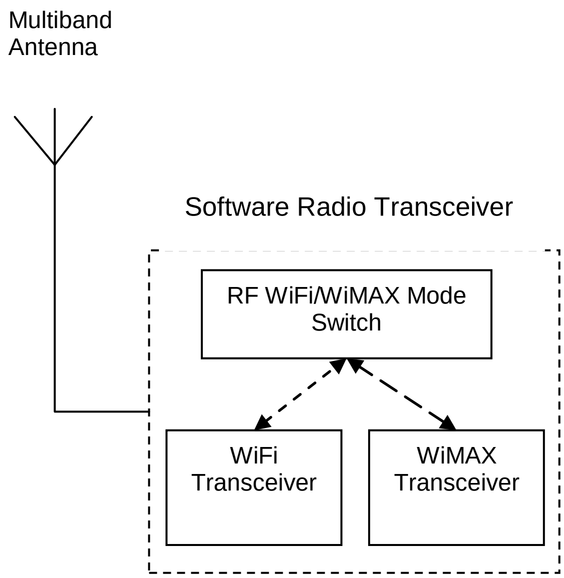

Figure 2: A block Diagram of the Proposed Dual Band WiFi/WiMAX Transceiver.

The proposed software radio transceiver has been implemented in MATLAB® and Simulink®. The WiFi and WiMAX software modules have been taken from [14], and the switching software module has been taken from [15].

MATLAB® code is used to implement the software switch whereas Simulink is used to model the physical layer architecture. MATLAB® and Simulink® have digital signal processing and communication libraries which consist of vast collection of blocks needed to implement protocols such as Bluetooth, WiFi, WiMAX, CDMA (Code Division Multiple Access) and many more. The advantage of using MATLAB® is that it is widely used for similar kinds of simulation, the software is easily available and most importantly, the MATLAB® algorithms can be implemented in fixed point C code. Also, it is expected in future that MATLAB/Simulink® models will be easily converted to a working software radio simply by porting the MATLAB/Simulink® code to an appropriate high speed, portable and high level programming language such as C or C++.

CONCLUSION AND FUTURE WORK

The work described in this paper suggests that software radio is becoming increasingly important as a tool for implementing heterogeneous wireless protocols within handheld Internet access devices. The use of multiband antennas promises to increase the penetration of software towards the antenna input stage to a degree that is much higher than what has been currently done in software radio research.

Whilst simulations have shown promise, there is a need to build a working device. Field Programmable Gate Arrays (FPGAs) are being actively explored as a potential technology to implement the software radio based transceiver. In addition, work is being carried out to fully characterise multiband fractal antennas for use on this project. This will help to address electronic coupling issues between the antenna and the RF front-end analogue circuitry.

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