RF SDR for Wideband PMR

Ling Gao, Ronan Farrell
(Centre for Telecommunications Value Chain Research,
National University of Ireland, Maynooth, Co. Kildare, Ireland;
lgao@eeng.nuim.ie, ronan.farrell@nuim.ie)

ABSTRACT

TErrestrial Trunked Radio (TETRA) offers capabilities equivalent to the second generation of mobile phones with voice and limited data capabilities. TETRA needs to evolve to satisfy increasing user demand for new services and facilities as well as gleaning the benefits of new technology. An initial enhancement (TETRA Enhanced Data Service, TEDS) has been agreed. The enhanced TETRA services allows for more flexibility in the communication modes used, so as to provide adaptability in applications. We propose that it is possible to deploy Software Defined Radio (SDR) technologies into the basestation to economically provide this level of flexibility and to further extend the capability of TETRA services by deploying a WiMAX channel into the proposed TETRA tuning range. Thus delivering true broadband data service while simultaneously supporting the original and enhanced TETRA services.

1. INTRODUCTION

TETRA is a Private Mobile Radio (PMR) standard that has been developed by the European Telecommunications Standards Institute (ETSI) for the needs of the transport, civil and emergency services [1]. TETRAPOL is another PMR standard, developed by Matra Nortel Communications. TETRA and TETRAPOL are competitors in the PMR market in Europe. In this paper we focus on TETRA services as it is a more recent standard than TETRAPOL. For perspective, we will compare the radio characteristics between TETRA and TETRAPOL later (Table 1).

There is increased interest in the delivery of broadband data services over the TETRA network, for example video imagery of accident scenes. An enhanced form of TETRA (TEDS) has been agreed which can offer data rates of up to 600 kbps [2]. However successful deployment of TEDS requires additional spectrum to be allocated and this has proved to be problematic. An investigation was carried out by ETSI which concluded that a single standardised frequency band cannot be agreed; however the concept of a tuning range for enhanced TETRA services is gaining acceptance. In addition to the difficulty in agreeing a standardised spectrum allocation, enhanced TETRA supports a range of communication modes depending on individual user bandwidth and signal quality. This implies a greater complexity on the radio systems. Though the new TETRA services will offer improved capabilities, it is necessary to provide backward compatibility with existing TETRA users and as there are over 1000 networks currently deployed around the world [3]. The greatest challenges will be experienced by the TETRA basestations which must support new and legacy systems. SDR, specifically in the concept of flexible hardware transceiver systems, offers an economical solution to both the challenges of implementing TEDS and supporting legacy systems and provides a development route for new TETRA services.

This work is on integration of deploy a WiMAX sub-channel into the TETRA framework for true broadband services on demand. Similar initiatives, WiMAX overlay over TETRA demonstration for emergency call-handling system by Alcatel Lucent and TelMAX project by Teltronic have also explored the issue of integration WiMAX channels over TETRA bands. This work is focussed on the integration of TETRA and WiMAX standards within a single physical layer SDR transceiver rather than the use of separate radio front-ends.

This paper will present the requirements for a SDR platform with an investigation of various radio architectures to support the proposed and legacy schemes. Then we will show the implementation of our proposed RF receiver architecture plus the design challenges for this experimental platform.

2. COMBINING WIMAX AND TETRA

TETRA services were initially deployed in Europe in a 20 MHz band between 380 and 400 MHz as two 5 MHz bands with a 10 MHz duplex separation [1]. To deploy the new enhanced TETRA data services additional spectrum is required to complement the existing band. The Electronic Communications Committee (ECC) within European Conference of Postal and Telecommunications

Administrations (CEPT) has proposed a "tuning range" within which enhanced TETRA services can be deployed [4]. It recommends three bands within that tuning range, including the original TETRA band, as shown below (Figure 1). The tuning range requirements are further complicated as non-European deployments have used other frequencies ranges. One particularly interesting aspect is the Federal Communications Commission (FCC) proposed national public service network at 758-793 MHz [5] which would be attractive to any future TETRA-type network.

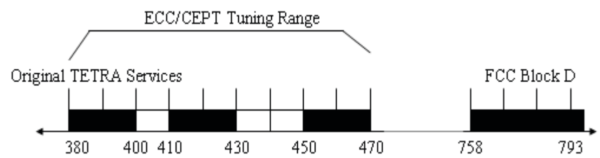

Figure 1 system tuning range

Enhanced TETRA allows for channel widths up to 150 kHz, offering users a range of data rates, up to 600 kbps. This is a significant improvement on existing TETRA services, however it does not offer data rates that would support full multimedia transmissions or rapid delivery of large files. Though TEDS has identified a maximum channel width of 150 kHz, there is nothing inherent in the TETRA framework that prevents wider channels to be used. We propose that WiMAX (IEEE 802.16e) offers features that are highly suited to TETRA-type applications such as quality-of-service guarantees and scalable OFDM access. The WiMAX standards allows for 1.25 MHz channel [6] which would allow up to three 1.25 MHz WiMAX channel to be deployed with the remaining spectrum then used to support voice and data services whether using TETRA or TEDS, thus maintaining legacy support (Figure 2).

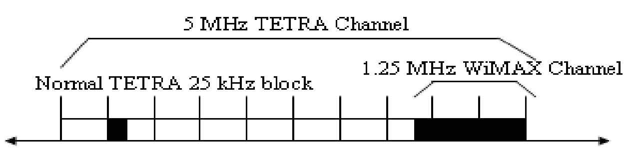

Figure 2 5 MHz TETRA channel

The key advantage to using the WiMAX standard is scalable OFDM access schemes (OFDMA) where users are dynamically allocated bandwidth as needed for their application, according to their quality of service metric and allow users to obtain bursts of data throughput of up to 6 Mbps when needed. WiMAX presents low cost of delivery of higher data rates over large geographical areas and also perform very well in mobile conditions. With WiMAX's enhanced channel efficiency of up to 5 bits/hertz, greater number of users plus applications can be supplied.

The use of high data rate OFDMA modulations brings in challenging requirements for the transmitter in terms of spectral quality and Error Vector Magnitude (EVM). Also the receiver faces some difficulties. The high EVM required is difficult to attain because it demands a high Signal-to-Noise Ratio (SNR) from the Low Noise Amplifier (LNA), about 35 dB. Other challenges are that the receiver must exhibit low power consumption, high bandwidth and high dynamic range. [7]

If basestations are to be designed using full channel capture and channelisation in the digital domain, implementing this WiMAX sub-channel requires only a small modification of the software implementation of the physical layer and then subsequently a separate WiMAX stack.

3. SOFTWARE DEFINED RADIO PLATFORM REQUIREMENTS

To develop a new system suits our proposal, the main radio characteristics of the TETRA, TEDS, TETRAPOL and WiMAX standards are studied as follow:

Table 1 Compare radio characteristics of TETRA, TEDS, TETRAPOL and WiMAX

	TETRA	**TEDS**	**TETRA POL**	**Mobile WiMAX**
Frequency (MHz)	380-410	350-470	80/380/450	410-470, 758-793
Spectrum Allocation	Two 5 MHz bands	additional 5 MHz bands	similar to TETRA	similar to TETRA
Duplex Spacing (MHz)	10	10	similar to TETRA	similar to TETRA
Channel BW (kHz)	25	25-150	<8	1250
Channel Spacing (kHz)	25	matches channel spacing	10/12.5	50-100
Access Scheme	TDMA FDMA	TDMA FDMA	FDMA	SOFDMA
Modulation	$\pi/4$ DQPSK	$\pi/4$, $\pi/8$ DQPSK up to 64 QAM	GMSK	QPSK, up to 64 QAM
Tx Power (dBm)	28 to 46	similar to TETRA	42	similar to TETRA

Rx Sensitivity (dBm)	-103 to -106	similar to TETRA	-113 to -111	-90.8
Efficiency (bits/Hz)	1.4	<3.5	similar to TETRA	3-4

TETRA and WiMAX are two different standards, the terminologies of the system specifications are described quite differently (TETRA is an ETSI standard, WiMAX is an IEEE standard). To explore the viability of this approach, a low-cost demonstrator is going to be developed according to an initial suggestion for an integrated wideband transceiver as shown below (Table 2) that can offer the necessary tuning range and channel capture. It is challenging to produce common specs as different standards and modulation schemes are involved in each channel. Linearity and dynamic range are key transceiver criteria.

Table 2 Combined system specs for transceiver

	Combined TETRA, TEDS, TETRAPOL and WiMAX
Receiver	
Signal Sensitivity (dBm)	-106
Signal Sensitivity (dBm / Hz)	-152
Maximum Acceptable Signal (dBm)	-30
SNR/CNR @ BER = 1e-4 (dB)	24
NF (dB)	7 (MS), 4(BS)
Linearity IIP2 (dBm)	37
Linearity IIP3 (dBm)	-13
ACPR (dBc)	-70 @ 75 kHz offset
Transmitter	
Tx Power (dBm)	42
Tx Dynamic Range (dB)	80
EVM (%)	<3

4. PROPOSED TEST PLATFORM

For our investigation of the combined radio system, we propose to adapt an existing mobile communication system SDR platform MARS developed by the Institute of Microelectronics and Wireless Systems (IMWS) at NUI Maynooth, operating in the frequency range 1.8 to 2.4 GHz [9]. This platform functions, sub-optimally, in the range 380-480 MHz and requires further work to meet linearity and noise requirements. The main issues that need to be addressed are attenuation induce due to matching networks; oscillator performance, and linearity. This platform works with the software framework developed within the Centre of Telecommunications Value Chain Research (CTVR) and is being integrated with the OSSIE framework developed by Virginia Tech.

Our two candidate architectures are a homodyne (direct-to-RF) transmitter and receiver, or a homodyne transmitter with a superheterodyne receiver. With the development of modern transmitters, the direct-to-RF transmit path is an increasingly mature technology and with new developments in wideband mixers and PAs, achieving the needed reconfigurability will be relatively straightforward. For the receiver, the challenges are more difficult. In any implementation, there will be a strenuous sensitivity and linearity requirements. This will be complicated by the large tuning range. While MARS SDR receiver is currently configured to support a direct-from-RF architecture, this approach faces challenges in terms of linearity, noise and DC offset cancellation. An alternative approach, which we have chosen, is to use a more traditional two-stage approach with a low frequency IF stage. The following table lists some of the advantages and disadvantages for the two approaches for the receiver stage [7]:

Table 3 Summary of Tx/Rx architectures suitable for our system

	Direct	**Superheterodyne**
Adv	• Fewer components • simple frequency plan for multi-standard, • high integratability, no image problem	• more reliable performance • flexible frequency plan • no DC offset • no 1/f noise issues • high blocker and interferer rejection • improved tunability
Dis	• LO leakage and DC offset issue • 1/f noise • Vulnerability to blocker and ACPR issues • More challenging RF filters	• More components • Potentially more power • IF bandwidth typically fixed

Compared with the two candidate radio architectures (Table 3), we use a more traditional superheterodyne approach for the receiver. This offers advantages in that we have a fixed 5 MHz slot. The RF stage can deal with tuning, linearity and noise, while the IF stage can use highly selective filters to achieve the required adjacent channel & blocker rejection. The proposed test platform is shown below:

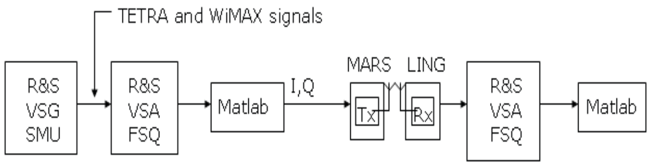

Figure 3 Proposed Test Platform

The equipments needed are Rohde Schwarz Vector Signal Generator SMU, Rohde Schwarz Vector Signal Analyzer FSQ, PC, low cost experimental SDR system MARS from IMWS NUIM. We plan to get TETRA+WiMAX I&Q analog signals from R&S vector signal generator SMU200, connect it to R&S vector signal analyzer FSQ. Use R&S matlab transfer toolbox to get the IQ files from FSQ. The reason for doing this is due to the internal IQ files within the firmware of the SMU200 is not available to users. Then we transmit the IQ data to the MARS transmitter and our new designed superheterodyne receiver (Figure 3). This platform requires further work to meet linearity and noise requirements. The main issues that need to be addressed are gain, matching networks, oscillator performance and singal/power level. Then we will connect Tx & Rx to the FSQ to see how the TETRA + WiMAX signals perform.

5. RECEIVER IMPLEMENTATION

The SDR receiver is implemented using as many off the shelf parts as possible. The receiver implementation diagram is shown in figure 4.

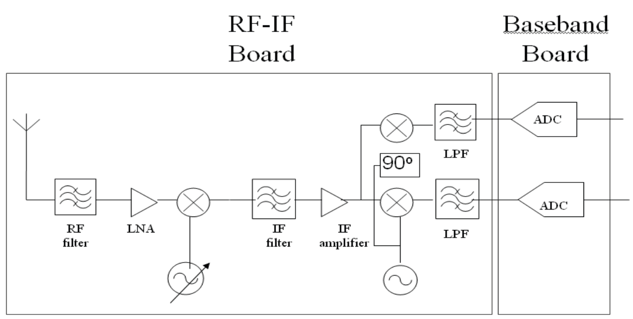

Figure 4 Receiver Implementation

We will have one RF-IF board on top of a baseband board.

The RF bandpass filter is designed of 3rd order Chebyshev filter operating a frequency range from 380 MHz to 480 MHz. The LNA is Agilent ATF55143, with a gain of 17.7 dB at a noise figure of 0.6 dB and an IP3 of 24.2 dBm capable of operating across a frequency range from 450 MHz to 6 GHz. Although 380 MHz to 480 MHz is out of this LNA frequency range, we re-designed the matching network then simulated it in Agilent Advanced Design System tool. An Analog Devices part AD8348 was chosen as a downconverter. It has a conversion gain of up to 44 dB by the use of AGC, with a noise figure of 11dB, and IIP3 of 28 dBm. The AD8348 can be interfaced with a detector such as the AD8362 rms-to-dc converter to provide an automatic signal-levelling function for the baseband outputs. The ADF4360-7 is an integrated integer-N synthesizer and voltage controlled oscillator (VCO). The ADF4360-7 centre frequency is available and is set by external inductors. This allows a frequency of between 350 MHz to 1800 MHz.

The IF filter that we have chosen is an EPCOS SAW filter. Its centre frequency is 140 MHz with a bandwidth of 8.8 MHz. The ADL5530 is a broadband, fixed-gain, linear amplifier that operates at frequencies up to 1000 MHz. This provides a gain of 16.5 dB and achieves an OIP3 of 37 dBm with an output compression point of 21.8 dB and a noise figure of 3 dB. The IF downconverter is the same component as the RF stage, an Analog Devices part AD8348. Separate I and Q outputs of the mixers. The oscillator signal comes from ADF4360-9, an integrated integer-N synthesizer and voltage controlled oscillator (VCO). This configuration is capable of producing a frequency in a range from 65 MHz to 400 MHz, which the fixed centre frequency is 140 MHz. Two low pass filters are followed which the bandwidths are 3.5 MHz for both I and Q.

Next the signal is digitised using two 16-bit Analog Devices ADC's capable of operating up to 80 Msps in the baseband board developed by IMWS at NUIM. This digitised information is then transferred to the host computer for final processing and data extraction over a USB2 interface.

The receiver PCB board layout is then developed in Easily Applicable Graphical Layout Editor (EAGLE) (Figure 5).

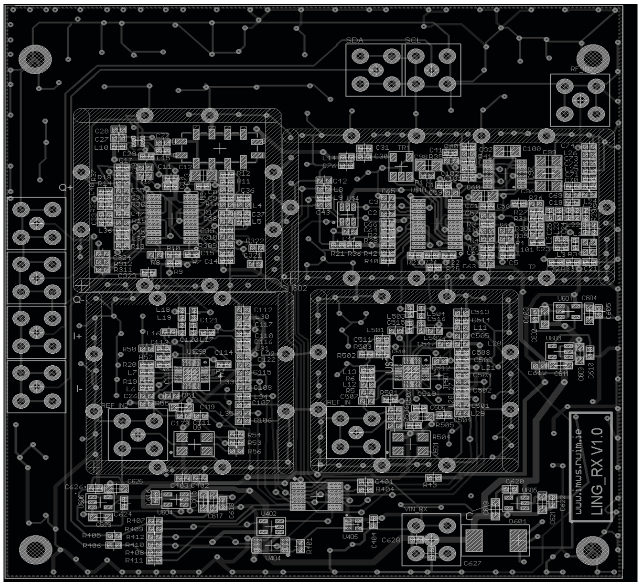

Figure 5 Receiver PCB Board

6. DESIGN CHALLENGES

From a basestation perspective, this proposed test platform offers a number of challenges, specifically maintaining noise and linearity performance over such a range of frequencies and handling the different modes of operation. One of the challenges of designing a combined communication systems is that it must remain compatible with legacy TETRA services. This is particularly challenging as the TETRA specifications were designed for very narrowband 25 kHz channels, specifically the figures on linearity and sensitivity. High sensitivity is needed as TETRA basestations are not typically as densely populated as comparable mobile telephony systems. Complicating the matter is the needs for TETRA clients to be capable of sustaining high receive power levels when close to such basestations [8]. The basis of our analysis was the need to be compatible with legacy systems, while accepting that some compromises would be needed on adjacent channel specifications as the legacy values are not appropriate to our wideband solution. As we are focussed on basestation radios, we are also assuming that receiver power levels can be assumed to be low.

The challenges for a SDR platform are focused on the RF-IF stages rather than the software framework. Specifically there are demanding receiver requirements on signal sensitivity, adjacent channel rejection, and linearity. These issues were manageable when dealing with narrowband signals at a specific frequency but become much more challenging when dealing with a wide tuning range. One particular issue is the problem of the transceiver filter which must be wideband or reconfigurable in some way. This will limit our ability to minimize adjacent channel interference. To address the issue of varying sub-channel widths, it will be necessary to undertake full channel capture and subsequently digitally undertake channelisation, filtering and de-modulation. If this approach is taken minimizing wideband noise contributions from the electronics and adjacent channels becomes particularly important. To investigate the interference issue, we had a look into blocker specifications for TETRA 25 kHz QAM receiver is shown (Figure 6).

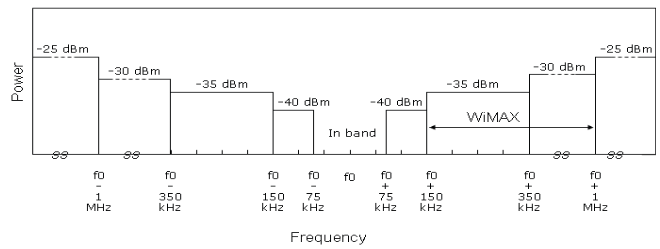

Figure 6 Blocker Specifications for TETRA 25 kHz QAM receiver

At +/-75kHz offset, the level of interfering signal is -40dBm. At +/-150kHz offset, the level of interfering signal is -35dBm. At +/-350kHz offset, the level of interfering signal is -30dBm. At +/-1MHz offset, the level of interfering signal is -25dBm. WiMAX signal has to be lower than -35dBm/-30dBm. The max tolerated input power is 0 dBm. The filter specs and how far we put WiMAX channel next to TETRA channel are critical.

7. CONCLUSION

In this paper, we have reviewed the TETRA, TEDS, TETRAPOL and WiMAX standards. A new combined system specification for the transceiver has been presented to show how a WiMAX sub-channel can be integrated into a TETRA channel and retain legacy compatibility. We focused on RF frontend receiver architectures with a discussion of the relative benefits of homodyne and heterodyne architectures. The challenge of adding a broadband channel into the existing TETRA framework is complex and places significant constraints on future TETRA receivers, but we propose that following a software-defined radio philosophy allows for implementation with minimal additional hardware complexity. Our next step is to adapt the LING superheterodyne receiver with an existing MARS transmitter and demonstrate this proposed reconfigurable radio platform. If successful, this approach may allow future TETRA users to avail of broadband data rates minimal additional cost for either the user or the basestation provider.

ACKNOWLEDGEMENTS

The authors wish to thank Philippe Mege, Gilles Latouche and Laurent Martinod of EADS Secure Networks for their assistance and support. Also the authors extend thanks to the sponsors EADS and IRCSET for the PhD programme.

REFERENCES

[1] Whitehead, P., “The other communications revolution [TETRA standard]”, *IEE Review,* volume 42, pp. 167-170, 1996

[2] Nouri, M., Lottici, V., Reggiannini, R., Ball, D., Rayne, M., “TEDS: A high speed digital mobile communication air interface for professional users”, *IEEE Vehicular Technology Magazine*, volume 1, issue 4, pp. 32 - 42. 2006

[3] Juan Ferro, “A TETRA market overview”, TETRA Experience China, TETRA association, 2006

[4] Draft ECC Report on Public Protection and Disaster Relief Spectrum Requirements, ECC/CEPT/102, Electronic Communications Committee, September 2006

[5] Don Bishop, “Coming to America: TETRA-One way or another”, *Mobile Radio Technology (MRT) Magazine*, January, 2001

[6] IEEE 802 Working Group, http://standards.ieee.org/getieee802/802.16.html

[7] Luis Abraham Sanchez-Gaspariano, Alejandro Diaz-Sanchez, “IEEE802.16e design issues and transceiver architecture selection for mobile WiMAX systems”, *IEEE Computer Society*, February, 2008

[8] Private conversation with Philippe Mege, Gilles Latouche and Laurent Martinod of EADS Secure Networks.

[9] G. Baldwin, L. Ruíz, R. Farrell, “Low-Cost Experimental Software Defined Radio System”, *SDR Technical Forum 2007,* November 2007