**Remote Telemetry in Rural Areas Using TV White Spaces - State of the Art**

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**Abstract**

Various technologies for remote telemetry systems in rural areas has been used in the past. The use of television white spaces (TVWS) is promising to reduce the cost and complexity of future remote telemetry systems. In this paper, the most important concepts involving the technology of wireless communications and networking suitable to support remote telemetry in rural areas are briefly reviewed with emphasis on the available hardware platforms for its implementation. The paper also summarizes the main international standards on the use of TVWS and issues related to the coexistence of networks sharing the same frequency bands. The paper concludes with a discussion on the main communication and network requirements of remote telemetry systems for rural areas.

**I. Introduction**

Remote Telemetry in rural areas has made great progress since its early days where isolated sensors were equipped with ISM band radios to send measured data in the ISM (Instrument, Scientific, Medical) band of 900 MHz to a central location. Today's telemetry systems are much more different and they currently are able to handle many sensors and typically use a wide of technologies and frequency bands in the radio frequency (RF) through sophisticated communication systems or network based systems. In addition, the collection, pre-processing of sensor data, and post-processing is usually automated using sophisticated signal and data processing equipment. The design of a complete telemetry system is multidisciplinary including various topics and technologies in electrical engineering, computer engineering, and computer science.

Wireless technologies to support widely diverse application areas such as remote telemetry, smart grid, energy automation, process and manufacturing automation, and radio astronomy are advancing rapidly in the last few years [1]. The main reason for this is the availability of powerful paradigms, algorithms, and processors to implement them and these include *cognitive radio* (CR), *software define radio* (SDR), GNU radio, and *orthogonal frequency division multiplexing* (OFDM). In particular, there is interest in using the so called television white spaces (TVWS) of the RF spectrum which are frequency bands originally assigned to broadcast television but because of increased use of Internet technologies by TV stations, some of these channels are becoming unused and thus becoming available for other uses that include telemetry systems and other regional and local area networking.

CR and SDR are very complex systems posing significant challenges to its implementation. However, recent developments are making it possible to have hardware and software solutions at a relatively low cost. Although many CR definitions exist, we will use the following one promoted by the SDR forum, Cognitive Radio is an "*Adaptive, multi-dimensionally aware, autonomous radio system that learns from its experiences to reason, plan, and decide future actions to meet user needs*." This definition highlights important characteristics of CR which are: *Adaptive behavior,* the capability to alter operational characteristics relative to its environment, *Awareness,* interpreted understanding of input data*,* and *Autonomous behavior,* not requiring user intervention. CR is able to achieve its goals by making use of many powerful resources such as SDR, MIMO, and powerful algorithms such as OFDM. Traditional RF systems use only one transmitter and one receiver, collectively called a *transceiver*, together with a

transmitting antenna and a receiving antenna. Advances in signal processing has enabled the use of multiple transceivers and corresponding antennas , a technology called MIMO (multiple input, multiple output) meaning that several transceivers and antennas are used on the transmitting side (output) as well as on the receiving side (input).

**A. OFDM**
OFDM is a technique and associated technologies that enables the efficient implementations of wireless communication systems and is used in a wide variety of technologies that include cellular telephone technology, WiFi, WiMax, and of course white space. OFDM is powerful in that it actually performs several important functions such as data encoding, modulation, spectral shaping, error correction in a very efficient fashion. An important feature of OFDM is that it performs data encoding and modulation functions in one step and automatically. The various data encoding (and modulation) options include: BPSK (Symbol = 1 bit), QPSK (4-QAM) (Symbol = 2 bits), 16-QAM (Symbol = 4 bits), 256-QAM (Symbol = 8 bits), 4096-QAM (Symbol = 12 bits), where PSK stands for *phase shift keying* and QAM stands for *quadrature amplitude modulation*. Fig. 1(a) illustrates the OFDM process where an incoming data stream is first multiplexed into a set of symbols (Symbol 1, Symbol 2, etc.) each modulating a sinusoidal carrier signal. The output of the various modulated signals are added together producing a final output modulated signal to be sent over the wireless medium. The frequency spectrum of the output modulated signal is shown in Fig. 1(b). Mathematically, the above process is equivalent to taking the Inverse Fast Fourier Transform (IFFT) of the incoming data stream and this is represented on the left side of Fig. 2 where the waveform in red (in the middle of the figure) represents the output modulated signal. At the receiver side, the operations done at the transmitter side must be "undo" to recover the original data stream and this is done by the FFT and Parallel to Serial Conversion blocks on the right side of Fig. 2.
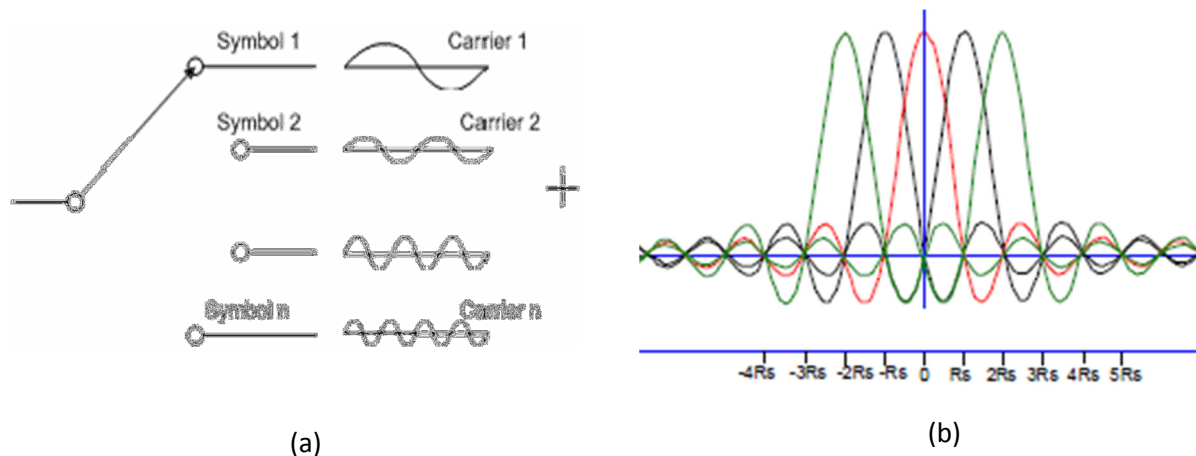


| (a) | (b) |

Fig. 1. OFDM process (a) and corresponding frequency spectrum of modulated signal (b).
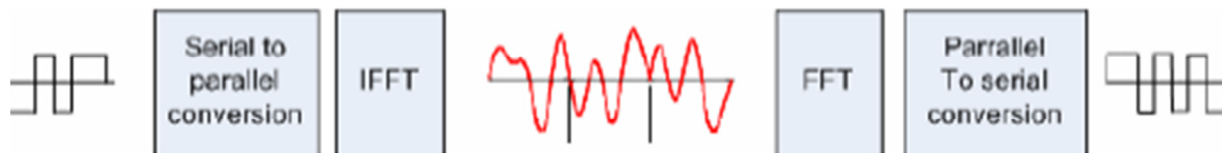


Fig. 2. Overall transmission and reception of digital data using the OFDM technique.

**Advantages of OFDM**

- Superior spectral shaping including bandwidth packing, as shown in Fig. 1(b).
- Flexible data multiplexing, as shown in Fig. 1(a).
- Provides an effective error correction scheme, not shown in above Figs.
- Efficient data encoding and modulation. For example, it helps IEEE 802.11ac implementations to achieve a 6.9 Gbps data rate.

**Disadvantages of OFDM**

- Peak to average power can be large thus leading to decoding problems such as signal resolution.
- Need for precise time synchronization particularly at high data rates.
- Needs high computing power

Although the idea behind OFDM has been around for a long time, its efficient implementation is fairly new due to several stringent challenges in terms of signal processing, memory requirements, and real-time behavior. The implementations has been possible by the availability of powerful processors including FPGAs (field programmable gate arrays) [7,8].

**B. Software Defined Radio (SDR)**

The designing of RF system requires several typical operations such as filtering, shifting frequency of operation, amplification, antenna interfacing which is highly specialized particularly at high frequencies. Basically, a radio is a *transceiver* (i.e. a transmitter and a receiver) with associated filters, frequency shifters (called *mixers*), amplifiers, and antennas. Rather than producing a specific design for each situation, a *software define radio* is a unique and flexible design with generic components (filters, amplifiers, mixers, and others) that can be programmed externally through software defined parameters. An additional feature of a SDR is that it accepts information to be transmitted or received in digital format through high performance ADC (analog to digital converters) and DAC (digital to analog converters). Thus, a SDR enables a complete rf system in digital format enabling the automation of most of its functions and this is illustrated in Fig. 3. SDR actually involves two types of processing, hardware and software and this is illustrated in Fig. 4.
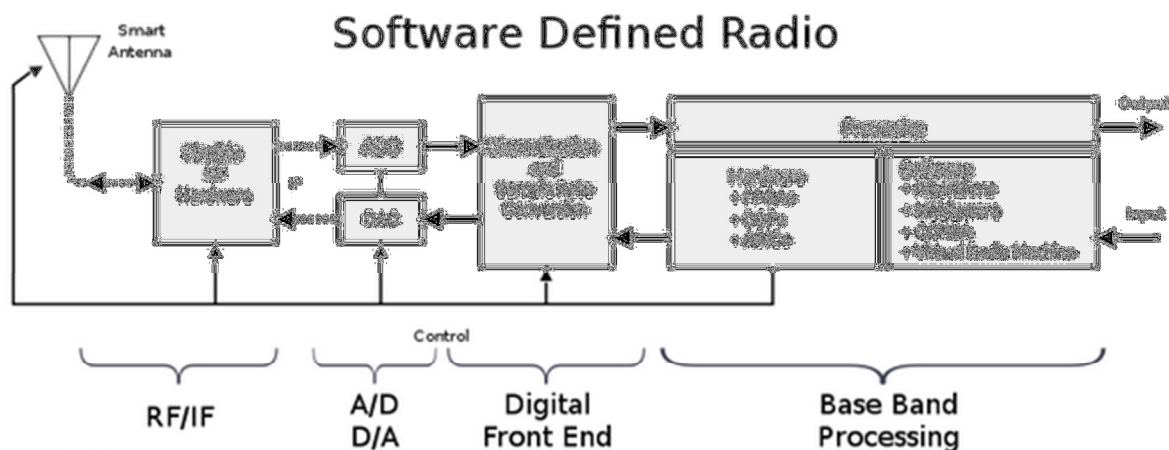


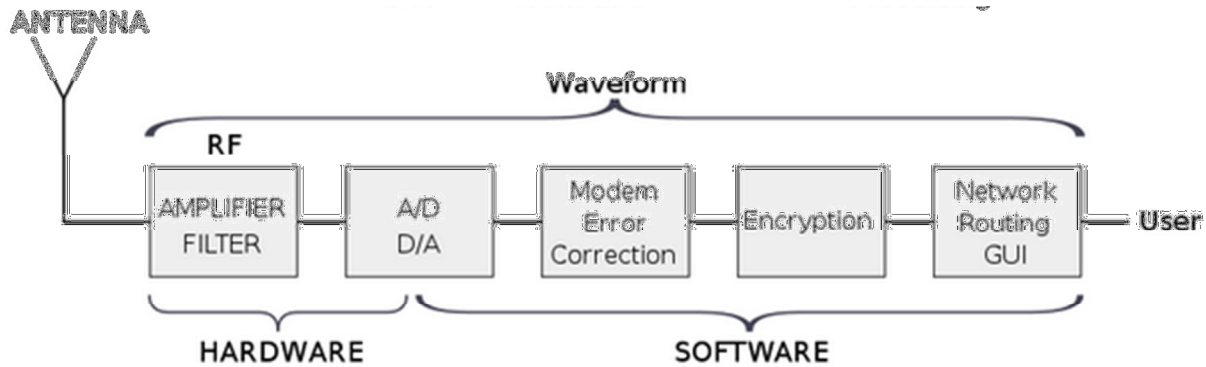Fig. 3. The concept of software defined radio (SDR)

Fig. 4. Hardware and software processing components of SDR.

To support the hardware in SDR, the software community has worked on open source solutions to many signal processing functions associated with SDR, one good example is *GNU radio* which is a set of software that performs the most used processing blocks of radio transmission and reception such as filtering, FFT (Fast Fourier Transform), modulation, demodulation, encoding, decoding, etc.

**C. Applicable Standards**

Remote telemetry in rural areas is not a new area as it has been researched from several points of view that includes wireless sensor networks (WSN) and systems based on cellular telephony, WiFi (IEEE 802.11 versions a,b,g and n), and networks based on the IEEE 802.15.4 protocol such as ZigBee, WirelessHART, and others [4-6]. Many early telemetry systems were based using 2G (second generation) cellular technology (GSM) and WiFi but these solutions presumed service availability that is not usually the case in rural areas and involved high costs particularly when the number of nodes or stations is large.

Remote telemetry based on the above mentioned communication technologies suffer from a number of problems that include high cost and limited physical coverage. The fairly recent decision of the FCC in the U.S. and similar government bodies across the world of making available the use of the so called tv-white spaces (TVWS) provides opportunities to use alternative frequency bands to the above mentioned communication technologies that promise larger physical coverage and to decrease costs [12]. This is so because the white spaces frequencies are in the range of 300 to 700 MHz thus enabling electromagnetic waves to go through walls and buildings thus increasing physical coverage. The feasibility of decreased costs is due to the miniaturization of the electronics due to the use of latest advances such as cognitive radio (CR) and software define radio (SDR).

There are several international standards that govern the use of TVWS that include IEEE 802.22, IEEEE 802.11af, ECMA92, and IEEE 802.19 [2,3, 10. 11]. Although the target applications of 802.11af and ECMA 392 are similar and include wireless home network and wireless internet access at campus, park, hotspot, etc., the major differences between two standards are incumbent protection mechanisms and channel bandwidth to be supported that includes small variations of communication parameters such as the window size of FFT operations and others. On the other hand, 802.22 is considered a wireless regional area network (WRAN)with major differences with 802.11af, considered a wireless local area network (WLAN), in just about every aspect. For example, 802.22 has a TDMA like MAC structure, a maximum transmitted power of 4 W (36 dBm), a receiver sensitivity of -97 dBm, and a physical range of up to 100 Km. In contrast, 802.11af has a CSMA type of MAC protocol, a maximum transmitted power of 100 mW (20 dBm), a receiver sensitivity of -64 dBm, and a physical range of up to 5 Km. Thus, although 802.22 and 802.11af share the same frequency bands they are different at almost all levels in the

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protocol stack. IEEE 802.19 is the Wireless Coexistence Technical Advisory Group (TAG) within the IEEE 802 LAN/MAN Standards Committee. The TAG deals with coexistence between unlicensed wireless networks. Many of the IEEE 802 wireless standards use unlicensed spectrum and hence need to address the issue of coexistence. These unlicensed wireless devices may operate in the same unlicensed frequency band in the same location. This can lead to interference between these two wireless networks.

These standard specifications for TV white space communications impose tight requirements. For example, the 802.22 standard is based on OFDMA modulation for downstream and upstream links with the ability to channel bond adjacent TV channels should more bandwidth be required. The standard supports modulations schemes up to 64QAM, producing a data rate of 19 Mbps per 6 MHz TV channel. The standard also makes use of a geo-location spectrum database or an Eigen Value method of Spectrum Sensing to detect other primary users. These specifications require a hardware platform with a powerful  processing in terms of CPU and/or FPGA as well as compliance with strict RF power and spectral mask regulations. At the same time, any design or commercial product to be used as an integral component of the system has to be low-cost.

**D. Key Specifications**
In this section, we briefly discuss the impact of some of the key FCC and 802.22 specifications on the hardware design aspects.
***Bandwidth of Operation.*** The first specification is the bandwidth of operation. As per the Whitespace regulations defined by FCC, the allowed channels are the frequency bands of 512 – 608 and 614 – 698 MHz for all TV band devices (TVBD), with each channel having a bandwidth of 6 MHz. For communication between fixed TVBDs, the allowed channels are, 54 – 60, 76 -88, 174 – 216, and 470 – 512 MHz. The allowed frequency bands are part of the VHF and the UHF spectrum. This specification directly impacts the choice of the Radio Frequency hardware of the system.  The choice of the RF hardware shall not only decide the operational bandwidth of the system but it will also play a part in deciding the price of the system.
***Transmit Power.*** Another specification emerging from the FCC regulations is the maximum transmit power. It says that maximum Equivalent Isotropically Radiated Power (EIRP) of the system shall be less than 4W (36 dBm). The choice of transmit power class of the system as shown in Table 1 shall decide the choice of the high power amplifier. General trend is that higher the power rating of the amplifier, higher is the price of the amplifying device.

Table 1. In band power level specifications from the FCC.

| Device Type | Typical conducted power output (dBm) | Typical antenna gain (dBi) | Absolute Maximum EIRP (dBm) | Max PSD (in dBm EIRP) | Power Control |
|---|---|---|---|---|---|
| Fixed devices | 30 | 6 | 36 | 12.6 | Required |
| Personal/portable device (operating @ adjacent channel to TV channels) | 20 | 0 | 20 | -1.4 | Required |
| Sensing only devices | -- | -- | -- | -0.4 | Required |
| All other personal/portable devices | 20 | 0 | 20 | 2.6 | Required |

**NOTE:** PSD = power spectral density in 100 KHz band.

*Computational Specifications*

The IEEE 802.22 WRAN architecture defines many computationally intensive tasks. These tasks require powerful processing units as well as onboard memory elements. Some of these tasks are as follows:

- *OFDM and OFDMA*: The specification defines 2,048 point FFTs for the transmit OFDM and receive OFDMA which are highly computationally intensive. The OFDM/OFDMA specifications are shown in Table 2.
- *Spectrum Sensing*: The spectrum sensing sensitivity specifications defined by the FCC require a sensitivity threshold of -114 dBm for the three types of signal types: ATSC (digital TV), NTSC (analog TV), and wireless microphone with an integration bandwidth of 6 MHz, 200KHz, and 100 KHz respectively. In order to sense the spectrum at such sensitivities, the system requires to implement efficient spectrum sensing algorithms. The spectrum sensing algorithms like the Eigen Value based sensing necessitate generation of huge covariance matrices and fast iterative calculations. Such tasks require sufficient memory as well as computational elements.
- *Control and Management*: In addition to the above resource intensive tasks, the control and the management plane defined in the Protocol Reference Model (PRM) of the IEEE 802.22 also requires storing and running of many routines at the same time.

Table 2. IEEE 802.22 WRAN requirements for ODFM implementations.

| Property of OFDM | Value | Comments |
|---|---|---|
| Total number of sub-carriers (N_FFT) | 2048 | -- |
| Number of guard sub-carriers (N_G) | 368 | (184,1,183) |
| Number of used sub-carriers (Nt=Nd + Np) | 1680 | -- |
| Number of data sub-carriers (Nd) | 1440 | -- |
| Number of pilot sub-carriers (Np) | 240 | -- |
| Data sub-carriers /channel | 24 | Total of 28 subcarriers/channel |
| Data sub-carriers /channel | 4 | |
| Total number of channels | 60 | -- |
| Length of cyclic prefix | 74.7 | In µsec. |
| Total size of the guard bands | 1.08 | In MHz |

Hence, the hardware designers needs to ensure that necessary steps have been taken to provide enough memory and computational resources to perform the above mentioned tasks. The designer also needs to optimize the design of the radio frequency hardware subsystems. The design decisions shall impact both the price and performance of the system. After having discussed some of the key specifications (from hardware perspective), we next discuss some of the currently available SDR platforms.

**II. Available SDR Hardware Platforms**

Cognitive radio and other recent hardware developments such as SDR (software define radio) are enabling the implementation of communication systems and networks using TVWS. Designing a hardware platform for white space Technology is a complex task. For example, the IEEE 802.22 standard for white space communications imposes tight specifications that require powerful CPUs and FPGAs as well as compliance with strict RF regulations. In addition, a commercial product needs to be produced at a low cost.

SDR has been used in a wide variety of applications that includes amateur radio, cellular telephones, wide and local wireless networks, radio astronomy, etc. thus there exists a great deal of hardware platforms depending upon the nature and requirements of the applications [9]. For our

purposes we will consider only some recent hardware platforms that would enable the use of TVWS. This list includes Ettus USRP N210, Fairwaves UmTRX, BladeRF, Myriad RF, and the EVB7 kit. These platforms are costly considering the component cost of the hardware supplied and have been designed with different goals and hence don't meet the full white space communication requirements. However, these boards can be used as a yardstick for the design of a white space hardware and useful inferences can be drawn by observing their advantages and disadvantages.

Most of the hardware platforms to be reviewed next are based on the highly successful LMS6002D chip from Lime Microsystems due to its open source nature, flexibility, and low cost. The latest development in this area includes the availability of the LMS7002M chipset (a second generation LMS6002D) that includes two set of transmitter/receivers thus enabling MIMO (multiple input/multiple output) processing. The EVB7 kit makes use of the LMS7002M whose characteristics include:

- Dual transceiver chip thus enabling MIMO processing
- Continuous coverage of the 0.05 - 3.8GHz RF frequency range
- Programmable RF modulation bandwidth: 0.1 to 108 MHz
- Single 1.8V supply voltage option, or operation using 1.25, 1.4 and 1.8V from integrated LDOs
- Low power consumption, typical 550mW in full 2x2 MIMO mode (330mW in SISO mode) and extensive power down options thus enabling low cost devices.
- On chip integrated microcontroller for simplified calibration, tuning and control. Offloads the baseband device.
- Integrated clock PLL for flexible clock generation and distribution
- User definable analog and digital filters for customized filtering
- RF and baseband Received Signal Strength Indicator (RSSI)

### A. Ettus USRP N210

The USRP(Universal Software Radio Peripheral) N210 is an SDR platform from Ettus Research, Fig. 5, is a complete system which includes digital and RF subsystems allowing users to use this piece of hardware for various applications. Assembled with high speed FPGA, dual ADC's, DAC's and Ethernet connections, it is very powerful for data streaming to and from host processors. The USRP also provides seamless integration with the GNU radio which makes it an convenient platform for rapid prototyping.

The notable features include:
- Xilinx Spartan 3A-DSP 3400 FPGA: Comprises of 54 K logic cells.
- Interfaces: Gigabit Ethernet, 2Gbps expansion interface, RF interfaces with SMA connectors etc.
- ADC/DACs: The USRP comes with high speed dual 100Msps 14-bit ADCs and dual 400Msps 16-bit DAC.
- Software compatibility: GNU Radio, LAB VIEW and Simulink.



Fig. 5. Ettus USRP N210 hardware.

Other features: DC—6 GHz operation bandwidth, fully coherent MIMO capability, 2.5ppm TCXO reference.

***Hardware Architecture***

The Hardware Architecture of the USRP is shown in Fig. 6. As we can see, the Spartan 3A-DSP FPGA forms the core of the USRP N210 system. The control and management is handled by a soft-core microblaze processor. At the backend, it connected to one Ethernet PHY and at the front end, its connected to the high-speed dual ADCs and DACs. The FPGA is also connected to a MIMO expansion header. Two USRP have to be connected to form a 2×2 MIMO configuration. The USRP without connecting to the RF daughter board consumes around 8 Watts of power. With the WBX daughter card designed to work with the USRP, it can transmit a maximum RF power of 15dBm. The WBX has a receive noise figure of 5 dB.
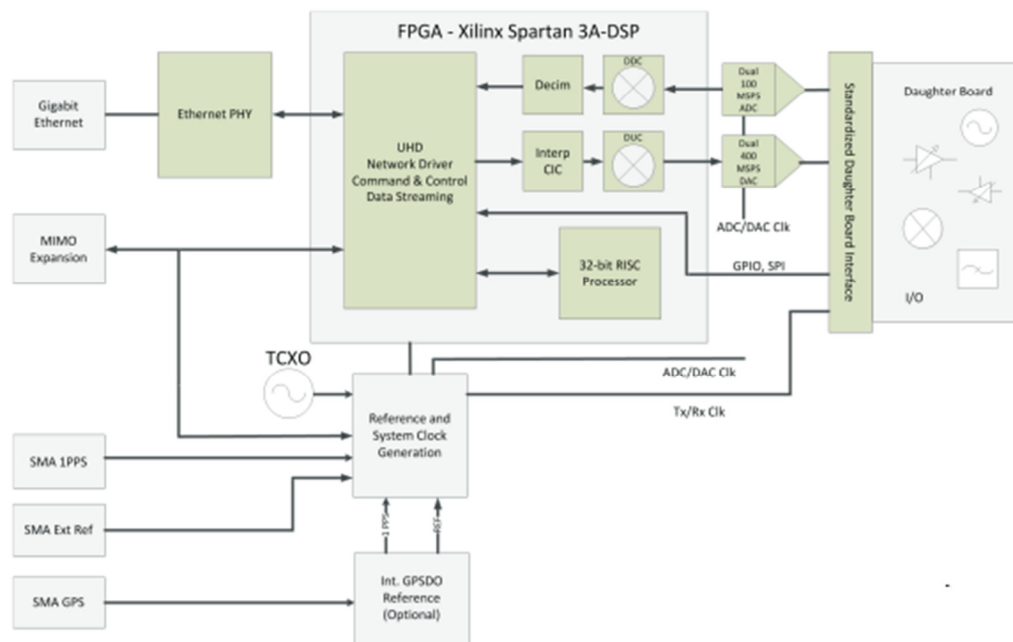


Fig. 6. Hardware Architecture of the Ettus USRP N210.

***Advantages***

The merits of the USRP N210 are as follows:
1. The board has standard connectors and standard interfaces which makes it a ready to use commercial platform.
2. The processing bandwidth is 100MHz which is very useful for spectrum sensing kind of applications.
3. Since, it integrates well with GNU Radio, fast prototyping capability of this board is a great advantage.
4. It does not have unnecessary extra-peripherals and hence, very application specific.

***Disadvantages***

The USRP N210 has several disadvantages:
1. Spartan 3A-DSP is a low end FPGA.

2. By implementing a soft-core processor like the micro blaze consumes a third of its space leaving out very less space for other blocks.
3. Absence of on-board RAMs make it almost impossible to perform much signal processing on the board.
4. Not a low power solution.
5. Priced at about 1,800 USD, it is not a very cheap platform.

### B. Fairwaves UmTRX

The Fairwaves UmTRX RF board is an open source Gigabit Ethernet software defined radio (SDR) board, Fig. 7. It  contains a GPS unit, an FPGA for configurable logic and two LMS6002D RF transceivers. It has SMA connectors which have to connect to an RF front end. This board is capable for MIMO operation and has GNU Radio software support. The primary end application of this board is cellular telephone particularly the implementation of inexpensive mobile base stations (BTS) sub-systems.
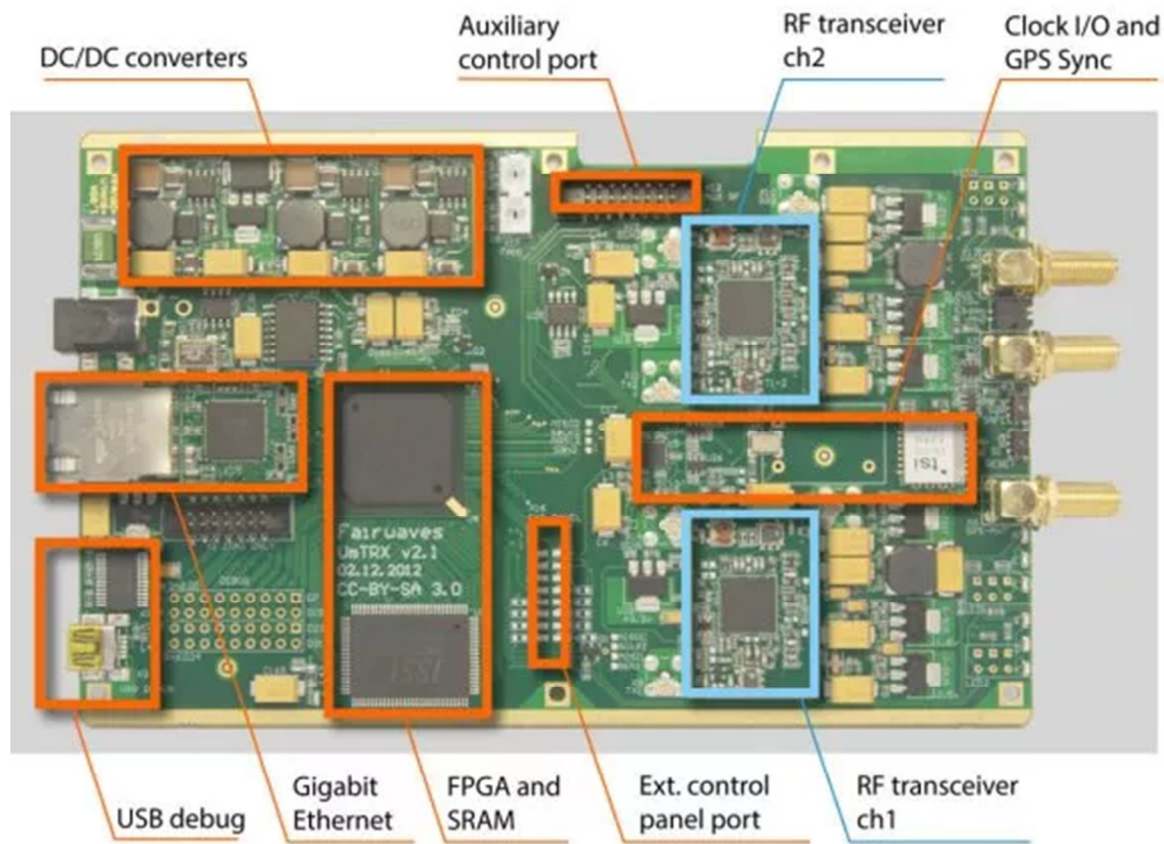


Fig. 7.  *UmTRX Version 2.1 Board.*

### Hardware Architecture

The UmTRX board has a processing core which the Spartan 6 FPGA with 74K macrocells and two LMS6002D RF transceivers. The FPGA provides the interface between external processing hardware through a Gibabit Ethernet port and the transceivers. Its RF section provides full duplexing facilities. The transceiver is configured through the SPI interface from FPGA . The board comes with external Gigabit Ethernet and USB interfaces for debug and configuration.

*Advantages*

The board has the following advantages:
1. GNU Radio support.
2. With an FPGA processing capability and on-board SRAM, it offers high amount of onboard programmable resources.
3. Gigabit Ethernet capability

*Disadvantages*

In spite of the obvious merits, the UmTRX has the following disadvantages:
1. Relatively higher cost than comparable boards.
2. It is particularly suited for GSM applications
3. Not particularly suited for telemetry applications

*C. BladeRF*

The NUAND Blade RF board is an open source USB 3.0 software defined radio (SDR) board, Fig. 8. It contains a micro processor (inside the FX3 interface processor), an FPGA for configurable logic and the LMS6002D RF transceiver. It has SMA connectors which have to connect to an RF front end. This board is capable for MIMO operation. The platform runs Linux, Windows, Mac and has GNU Radio software support.
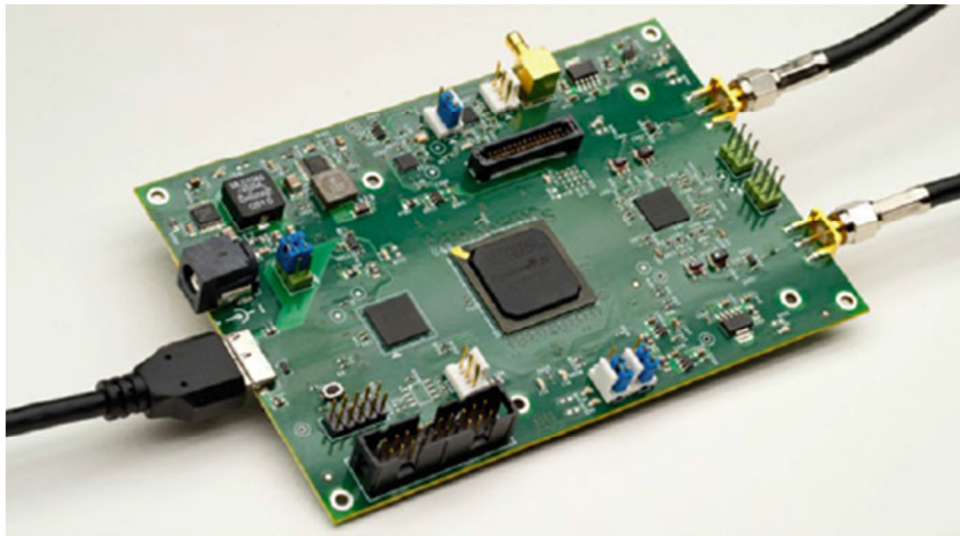


Fig. 8. BladeRF hardware.

*Hardware Architecture*

The bladeRF board has a processing core which is the ARM A-9 microprocessor, a programmable logic IC which is the Altera Cyclone-4 FPGA and the LMS6002D RF transceiver. The FPGA provides the interface between the ARM and the transceiver. Its RF section does not provide any duplexing facilities. It just makes the transmit and the receive outputs available at two SMA connectors. This board can be powered by USB and has a 512MB embedded SRAM. The transceiver is configured through the SPI interface from the Cyclone-4 FPGA. The board comes with external JTAG interfaces for both the processor and the FPGA for the debug and configuration.
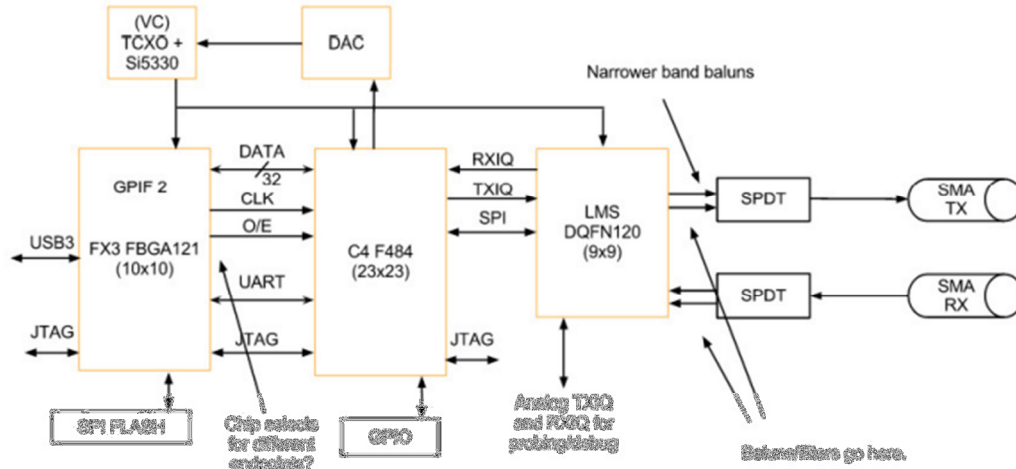
Fig. 9. BladeRF hardware architecture.

*Advantages*
The board has the following advantages:
1. Priced at 450 and 650 USD depending upon processing capability, it is a cost effective board which has all elements for a radio frequency system functionality.
2. GNU Radio support.
3. With an FPGA processing capability of 115 KLE (K logic elements), it offers high amount of onboard programmable resources.
4. High Speed USB 3.0 functionality.
5. Small form factor of 5" by 3.5"

*Disadvantages*
In spite of the obvious merits, the NUAND bladeRF has the following disadvantages:
1. Absence of Ethernet functionality. In order to interface the board with packetized networks, an additional board has to be connected.
2. Absence of a duplexing system for transmit and receive ports.
3. Peak output power of 6dBm is low.

**D. DIgiRED and MyriadRF**
The digiRED board together with the MyriadRF board is a special purpose hardware for specific applications (such as radio astronomy) that do not require the use of special interface hardware such as FPGAs, see Fig. 10. The MyriadRF board is really a bare bones wrapper board around the LMS6002D chip and acts as a daughter board to the DigiRed board which performs digitization and control functions. The original MyriadRF development system from Lime Microsystems included a "DEO Nano" FPGA board and a DEO Interface board that provided an FX2 interface.
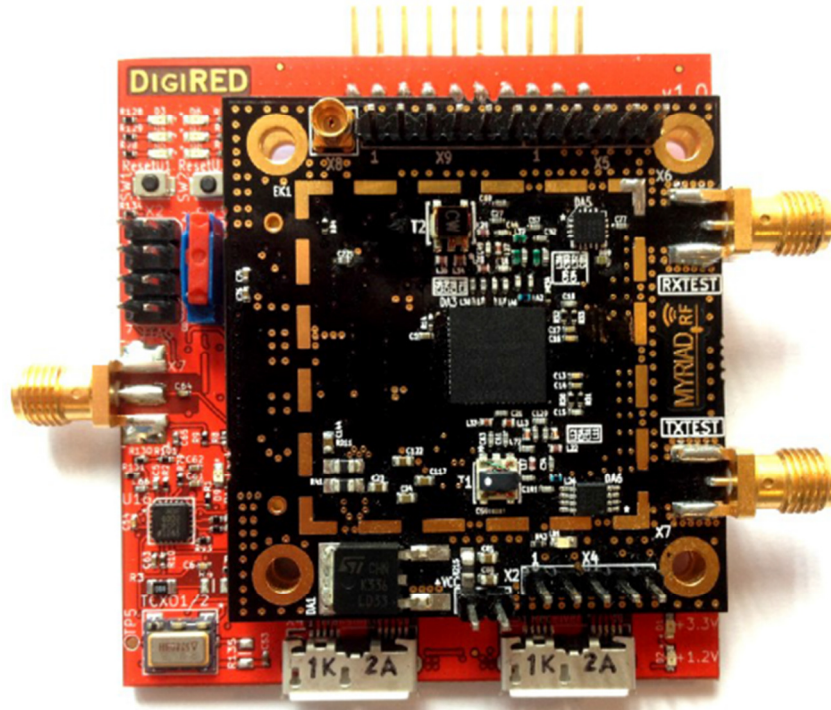
Fig. 10. DigiRED board (in red) together with its daughterboard MyriadRF board.

### Hardware Architecture

The hardware architecture is depicted in Fig. 11. A complete system based on these set of boards consists of a PC that interfaces to the digiRED board through two USB3 interfaces (using two FX3 chips each having an ARM 9 microprocessor) which in turn interfaces to the MyriadRF board containing the LMS6002D chip. DigiRed does not require a FPGA since it makes use of a unique scheme to control the handshaking via GPIO pins on the FX3 chip thus reducing system costs. The set of boards can be powered by USB and includes two sets of EEPROM and an interface to feed an external reference clock for the internal PLLs (phase locked loops).
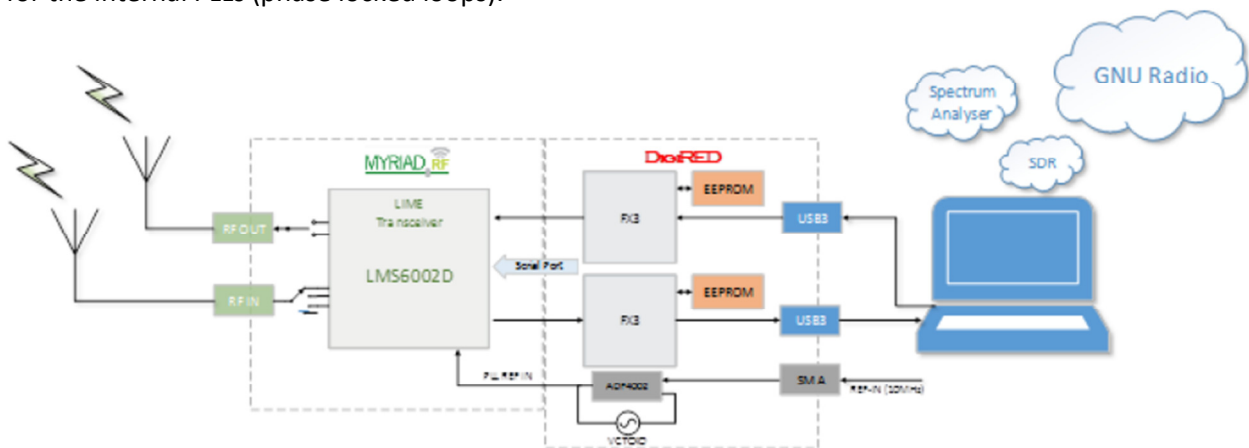


Fig. 11. DigiRED board (in red) together with its daughterboard MyriadRF board.

*Advantages*

The board has the following advantages:
1. It is a cost effective board which has all elements for a radio frequency system functionality.
2. GNU Radio support.
3. No need for FPGA processing capability.
4. High Speed dual USB 3.0 functionality.
5. Small form factor.

*Disadvantages*

In spite of the obvious merits, the digiRED and MyriadRF board set has the following disadvantages:
1. Absence of Ethernet functionality. In order to interface the board with packetized networks, an additional board has to be connected.
2. Absence of FPGA might preclude some high data processing intensive applications.
3. Peak output power of 6 dBm is low.

*E. EVB7 kit.*

The EVB7 kit from Lime Microsystems is one of the latest developments of hardware SDRs based on the LMS7002M chip, a second generation of the highly successful LMS6002D chip, see Fig. 12. The current version of the EVB7 kit is geared towards easily processing several analog input signals. It is expected that later versions will also process digital inputs.
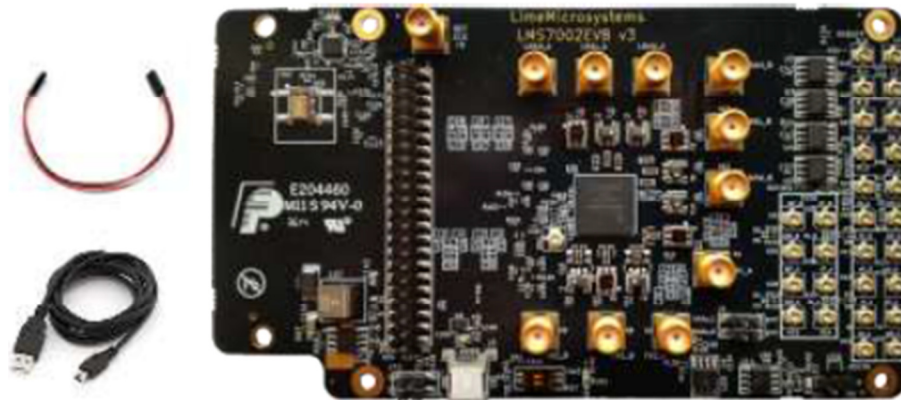


Fig. 12. EVB7 Development kit from Lime Microsystems.

The notable feature include:
- Based on the LMS7002M chip which includes dual transceivers.
- It is able to process analog inputs in a direct and simple fashion.
- USB interface to a local processor or PC

*Hardware Architecture*

The Hardware Architecture of the USRP is shown in Fig. 13. The blocks in blue represent the board external interface, the blocks in brown represent control, memory, and management components, and the block in green is the LMS7002M chip. The kit includes both an analog I/O interface on the right side of Fig. 13 and a digital I/O interface on the left side of the Fig.
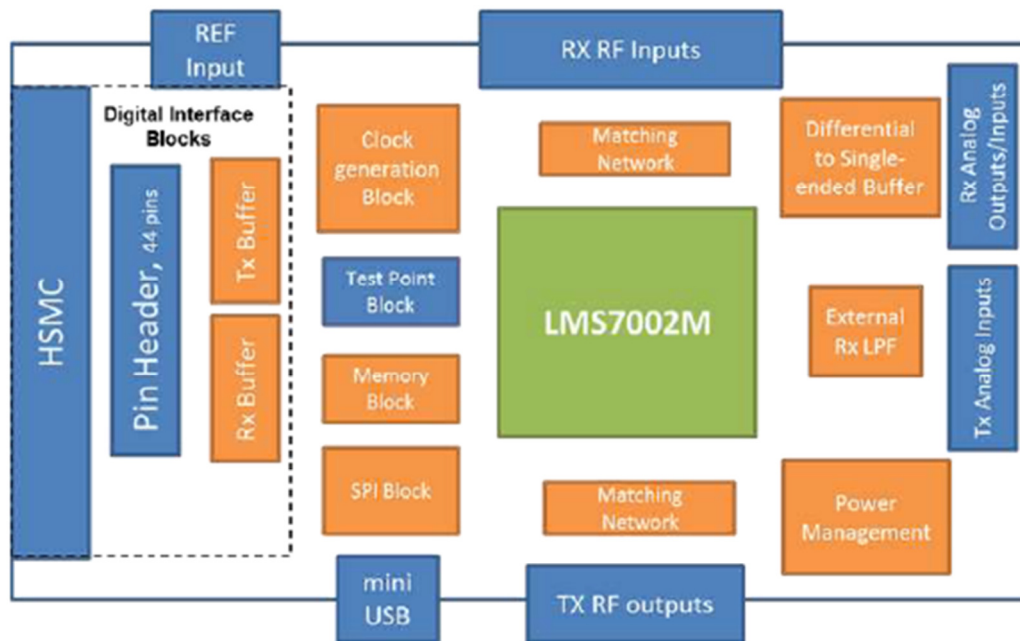
*Fig. 13.  Hardware Architecture of the EVB7 kit.*

*Advantages*

The merits of the EVB7 kit are as follows:
1. It features the powerful LMS7002M dual transceiver chip.
2. It has extensive internal memory, chip, clock, and power management options.
3. Available support for Windows and Linux platforms.

*Disadvantages*

The EVB7 kit has the following disadvantages:
1. Additional processing power (e.g., an FPGA or other CPU) is required to interface to the digital I/O blocks.
2. Priced at about 3,300 USD, it is not a very cheap platform.

**III. Coexistence problems**

Communication systems or network systems sharing the same frequency bands poses serious co-existence problems because only one transmitter can successfully transmit at any given time in a specific frequency band [13]. The co-existence problems of 802.22 and 802.11af networks is particularly severe because the large transmitter power of 802.22 stations (36 dBm) actually blocks 802.11af stations. A similar problem is the low sensitivity of 802.11af nodes which cannot detect 802.22 transmissions and thus becomes a hidden terminal [17]. The IEEE 802.19 protocol aims at solving the coexistence problem of dissimilar networks using the same frequency channels using centralizes control and assuming that the communicating devices have common interfaces. There is also a great deal of research at solving the coexistence problem of dissimilar networks using TVWS channels that do not use the 802.19 protocol [14-18].

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**IV. Main requirements for telemetry in rural areas**
Even though one can use commercially off the shelf (COTS) network solutions to design a telemetry system for rural areas, their cost and complexity are typically high. In addition, the functionality of these type of networks do not match precisely those of telemetry for rural areas. One example of such COTS network is WirelessHART that is primarily intended for process monitoring and control applications, particularly those including DCS (distributed control systems) and SCADA (supervisory control and data acquisition) components [5,6]. The rural environment where telemetry systems must work is such that there is typically no WiFi, no cellular phone service, and no AC power available, however it is possible to find few locations with an Internet connection. Thus, any wireless network solutions must cater to the specific requirements imposed by typical applications of telemetry in rural areas.
    The most fundamental requirements for wireless telemetry systems for rural areas are:

**A. Most fundamental problems of telemetry in rural areas?**

- Many sensors scatted in an area with several kilometers in diameter.
- Extremely low power at sensor nodes to enable batteries lasting several years.
- No high data throughput requirements
- Soft real-time requirements
- Extremely low cost
- Use of TVWS bands
- No need to interface to packetize networks (perhaps with the exception of the central station)

**B. Architectural Issues for Remote Telemetry Systems in Rural Areas**
Modern telemetry systems use some kind of a network, but a crucial design questions remain, for example what kind of network? Since a network is a rather complex system of many components it makes sense to address options of each network constituent component. Let us begin with the network architecture, and more specifically, which architecture is most appropriate for telemetry systems a decentralized (i.e., peer to peer) or a centralized (e.g., Master/Slave)? [19]. What types of network nodes would the architecture support? For example, some network nodes could be very simple with just sensing functionality while other nodes might support routing functions and even other nodes might support security functions. Another important option is the frequency bands of operation that range from tvws bands in the region of 400 – 700 MHz, GSM bands in the regions around 800, 900, and 1800 MHz, the regions around 2.4 GHz and 5 GHz, and even higher than these. Another crucial option is whether Internet connectivity for each sensor node is an important requirement. Proponents of the Internet of Things (IoT) technology would argue that each sensor node would need an IPv6 address, but is this really necessary? If peer to peer networking is the choice then a related question is whether a routing protocol or a relaying protocol needed? All of these design questions and issues are defined once a complete design of a specific network for remote telemetry systems is completed but this is beyond the scope of the present paper.

**V. Summary**
Important paradigms, techniques, and technologies are enabling the design and implementation of wireless communication and networks to support the design and implementation of remote telemetry systems at low cost and high performance. The paradigms, techniques and technologies include cognitive radio, software defined networking, orthogonal frequency division multiplexing, MIMO technologies. Powerful and low cost computers, and the availability of small board hardware platforms to implement complete wireless systems using television white spaces for communications hold great

promise for the design and implementation of remote telemetry systems at low cost. Much of the available hardware platforms are based on powerful SDR on chip such as the LMS6002D and future hardware is expected to use the successor chip, the LMS6002M.

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