Analysis of Radio Communication Solutions in Small and Isolated Communities under the IEEE 802.22 Standard

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Abstract. In recent years the use of wireless communications has increased significantly. Rural communities without cable network communication have found a solution in wireless technologies. Based on previous fieldwork, this paper analyzes software development of integration based technologies for communication equipment. It focuses on the feasibility of the IEEE 802.22 standard as a solution to the wireless problem.

Keywords: IEEE 802.22, White Spaces, Cognitive Radio, Rural Communications, Digital TV Broadcast.

1 Introduction

In the framework of the Project ***Communitarian Private Networks*** [1], different technologies providing links to small and isolated communities have been analyzed and compared. These communities, with low population densities, hold no commercial interest to service providers [2], [3], [4]. Notwithstanding, several rural facilities maintain operations in these isolated areas, providing significant quantities of food products at different stages of manufacturing. They supply not only nearby cities, but also constitute an important source of export commodities and revenue for many countries.

The geographic dispersion of these facilities interfere with cable communications – either with copper pairs, coaxial or optic fiber cables – due to high costs and maintenance problems. Consequently, the solution consists of establishing full duplex links via radio waves at a 30 to 70 km distance between antennas and at frequencies not restricted by government regulations [5], [6].

Towards the end of the 90s and beginning of this century, technical problems evolved side by side with their solutions. The process lead to the approval, on July 1st, 2011, of the standard IEEE ***802.22 - Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Policies and Procedures for Operation in the TV Bands*** [7].

The present work analyzes the use of this type of links in the same area where our group is conducting fieldwork.

2 Previous Fieldwork and Testing of New Technologies

The Project *Communitarian Private Networks* [5] explores different technologies providing communications to small and isolated rural communities with low population densities and without telephone services, whether these may be landlines or cellular. Hence, these communities do not have access to voice, data or internet networks.

A small community which met the requirements of the Project was searched: an isolated and distant town where experiences can be appropriately implemented. The community Corral de Lorca, in the department of General Alvear, province of Mendoza was finally selected. Its location is shown in Figure 1.

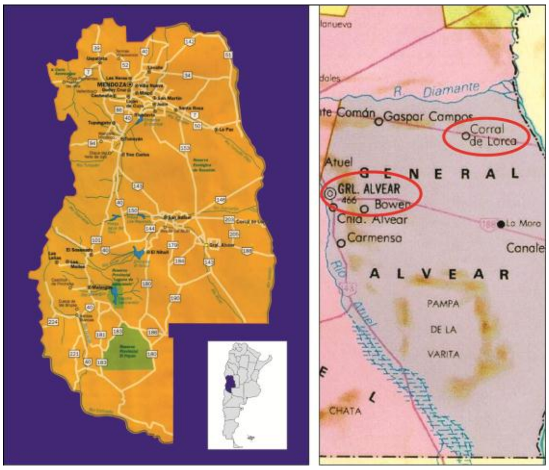

Figure 1. Geographic Location of Corral de Lorca

The technologies under study were: Power Line Communications (PLC) [2, 3] and the standard 802.11 [4]. Both experiences show that PLC technology is not recommended for outdoor links under the required conditions.

The considered solution involves establishing a point to point link where one endpoint is located in the department´s main city, General Alvear, with access to the PSTN network, and the other in the Corral de Lorca community, located in the southwest of the province of Mendoza, Argentina.

Two Motorola Canopy platforms are used at bandwidths of 2.4 GHz and 5.7 GHz (similar to WiMax). At the Corral de Lorca node [6], phone services can be implemented through VoIP as well as 802.3 to the Local Area Network and 802.11 for Wireless Internet Services.

The link is placed at a critical distance. Corral de Lorca is 70 kilometers from General Alvear in a straight line over a desert but with dense vegetation close to the base station area. To analyze the propagation issues the freeware ***Radio Mobile*** developed by Roger Coude [8] is used.

The outcome is not entirely satisfactory. Significant attenuation is registered due to the distance of the trans-horizon link and to the strong attenuation resulting from the dense vegetation at the outskirts of General Alvear. These factors contribute to a low value in the signal/noise ratio at the reception end in Corral de Lorca.

The conclusions are:

- The link is studied as a typical case to solve the general problem of rural populations. Hence, it could be generalized later for the application of analogous situations. In these cases, the distance to cover should range between 60 to 70 kilometers.
- Coordinates and terrain conditions are detailed between the two endpoints. Estimates for different bandwidths are established, i.e. 2.4 GHz and 5.7 GHz.
- The distance between the endpoints (60 km) is greater than regular distances contemplated in the theory for the application of standard 802.11.
- In addition, the analysis focuses on the fact that, in practice, transmitted signals in rural areas behave differently from those in urban settings because the former suffer less from noise spectrums. Radio Mobile software is considered to be a valuable tool in the design of radio electric links.

As a result of these experiences, continuing work is focusing on the new 802.22 standard.

3 Technical Problems and New Solutions

3.1 Introduction

The boundaries between the fields of communications and computer science have merged over time. Several concepts used in the field of telecommunications are now encountered in computer science and vice versa. Also, methodological practices of computer science are an integral part of telecommunications nowadays.

Consequently, today we refer to both disciplines as Information and Communications Technology - ICT[1] or as Teleinformatics, as referred to by European and American scholars.

Moreover, by the end of the 90s and beginning of this century, wireless communications increased exponentially. For instance, currently the total number of mobile phone users exceeds the number of existing landlines.

The pervasive use of mobile communications presents several technical difficulties, which in turn lead to the development of their consequent technical solutions. In the following section, the main changes of the advance in wireless technology are outlined.

[1] Also known as TICs in Spanish

3.2 White Space and Congestion Bands

Modern societies are increasingly relying on radio spectrum use. The pervasiveness of wireless services and communication devices (mobile phones, police communications, Wi-Fi and digital TV broadcasting) are examples of this dependency. It has become one of the most necessary resources of modern times [9].

Global demand growth for mobile data traffic has increased between 2011 and 2012 at a rate over 100%. The expected growth rate of this demand for the period 2008 and 2013 is estimated to average at 131% per year [10], exceeding 2.000.000 Terabytes per month by the end of the current year. The intense spectrum use, up to 5 GHz, and more specifically at the coverage below 1 GHz, has lead to a thorough review of regulatory policies, along with a renewed interest in ***White Space*** research [2] [11].

Possible solutions to the increasing traffic, especially below 1 GHz, are: review and redesign of the regulatory framework, reduction of wireless services broadcasting, improved compression standards, replacement of various services by satellite or cable, dynamic spectrum access, and development of cognitive radio technologies. The latter is oriented to take advantage of under-utilized frequencies, temporary voids of primary signals, and different types of white space.

The CEPT, ***European Conference of Postal and Telecommunications Administrations***, has defined ***White Space*** as "a label indicating a part of the spectrum, which is available for radio communication applications (service or system) at a given time in a given geographical area on a non-interfering or non-protected basis with regard to other services with a higher priority on a national basis" [12]. Currently, several research efforts from different organizations, national and international, are working on white space.

Cognitive Radio Technology (CRT) is considered another possibility to address the rising spectrum shortage. When fully operational, CRT could provide technologies for a variety of applications (rural broadband, public safety and emergency response, and urban frequency use). This technology will also have significant consequences for dynamic detection and spectrum management.

3.3 Software Defined Radio

With the exponential growth of the ways and means by which people need to communicate through wireless communications, modifying radio devices easily and cost-effectively has become critical.

The technology ***Software Defined Radio (SDR[3])*** provides flexibility and profitability, as well as grants end users with comprehensive benefits from service providers and product developers *[13]. The* ***Wireless Innovation Forum*** defines ***Software Defined Radio*** as "radio in which some or all of the physical layer functions are software defined."

The radio is a device which transmits or receives wireless signals using a portion of the radio spectrum. Traditional radio devices exclusively based on hardware (e. g.:

[2] Or white holes.
[3]Also known as **S*oftware Radio***.

mixers, filters, amplifiers, modulators/demodulators, and detectors) are limited because their features can be modified only by physical intervention.

On the other hand, a ***Software Defined Radio (SDR)*** is implemented by means of software on a computer or embedded system. The concept is not new, but the rapidly evolving capabilities of digital electronics render practical many processes which used to be only theoretically feasible before [13].

Under this technology, the software proves to be efficient at a relatively inexpensive cost, with multimode and multiband wireless devices which can be continuously improved with software updates. In some cases, the software manages some or all of the functions to operate the radio equipment (including those of the physical layer processing).

3.4 Cognitive Radios [4]

At the end of the decade of the 90s, Joseph Mitola[5] and Gerald Maguire, researchers from the Royal Institute of Technology[6] developed what they called ***Cognitive Radio,*** an improvement of their previous work on ***Software Defined Radio*** technology [14] [15],

While Software Defined Radio offers great potential, it also requires arduous processing, limiting its flexibility and adequacy of network response.

Cognitive Radio embedded in communications software, such as ***Radio Knowledge Representation Language - RKRL***, can be considered an intelligent and efficient system for radio communications and protocols. Basically, it provides mechanisms based on the use of smart technology to optimize the spectrum.

As mentioned in 3.2, the allocation of frequencies in a saturated spectrum is not optimal, originating ***White Space***. A special range is assigned to the operators for the use of ***Digital TV Broadcasting***.

Those were the reasons which led to develop Cognitive Radio for wireless communications: ***to detect the parts of the radio frequency spectrum used inefficiently and to allow reuse without causing interference with the services assigned to them.*** The solution of these problems by variable frequency allocation, allows others to take advantage of unused parts of the spectrum.

Using intelligent software, Cognitive Radio periodically scans the spectrum in search of white holes, detects the use given to each of them, and then determines whether it is reusable.

The system operates by changing the transmitter parameters based on interaction with the environment. It has the ability and the technology to capture or sense the information from other radio equipment, providing spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed.

It can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design.

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[4] Mitola defines ***cognitive*** as ***the mix of declarative and procedural knowledge in a self-aware learning system***.

[5] Joseph Mitola III received his doctorate in the Royal Institute with his thesis ***Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio***.

[6] Located in Stockholm, Sweden.

These operating procedures show the interaction between hardware design and application software development. They also represent a typical teleinformatics application, as characterized by Minola in his thesis.

3.5 Digital TV Broadcasting

Frequency spectrum use for TV broadcasting has varied since the first black and white broadcasts to the current digital high definition systems. Two bands are used: VHF (54 to 88 and 174 to 216 MHz) and UHF (512 to 806 MHz).

Figure 2a. Province of Buenos Aires

Figure 2b. Rest of the country

In several South American countries, the Japanese standard **Integrated Services Digital Broadcasting** (**ISDB**) has been adopted with a few variants, such as the replacement of the compressing system MPEG-2 for MPEG-4[7]. It was developed by the ***Association of Radio Industries and Businesses,*** known as ***ARIB,*** *w*hich promotes the efficient use of the spectrum.

ISDB include four standards depending on the used medium: ISDB-S (satellite), ISDB-T (terrestrial), ISDB-C (cable) and 2.6 GHz mobile broadcasting. All of them are based on multiplexing with a transport stream structure and are capable of High-Definition Television (HDTV) and standard definition television. The name of the standard was chosen for its similarity to ISDN (Integrated Services Digital Network). Both allow the simultaneous transmission of multiple channels of data through the multiplexing method.

In most cases, broadcasting stations have antennas reaching about 150 meters high, with significant coverage areas.

In the case of Argentina, more that 50 broadcasting stations have been set up as of July of 2013, covering a significant area of the country. The plan is to cover practically all of the populated areas, giving service to 90% of the population. Figures 2a and 2b illustrate the cities where these stations have been installed.

[7] ***International Services Digital Broadcast***, Terrestrial Brazilian version ISDB-Tb.

3.6 IEEE 802.22 as a Solution for Rural Areas

In Argentina, as in many countries with large rural areas, most cities are located within a range of 40 to 80 km apart in average.

The Project *Communitarian Private Networks* focuses on evaluating solutions to the communication problems of rural areas, in particular, isolated communities with low population density.

In our countries, the intensive use of spectrum and saturation in many of its frequency bands is due to wireless communications which has been the only feasible solution.

The 802.22 standard aims at using the vacancies in the TV spectrum. These frequencies are particularly suitable for remote areas where cables signal transmission are expensive or difficult to implement. Cables could only be replaced by costly satellite services. Thus, to implement a link using spare frequencies in these bands may be a practical and inexpensive solution.

In our country, the TV on the VHF band will be eliminated in 2016 (analogic blackout), liberating most of the UHF band, considering that the ***Argentine National Authority for Broadcasting Services - AFSCA***[8] has licensed only a few channels in the main cities (22 to 36).

As the new digital TV technology allows several standard definition programs in the same bandwidth of one high definition channel, there is a significant spectrum saving, and we still can get lots of free frequencies (channels 38 to 69), mainly in small cities.

It is an opportunity for this IEEE 802.22 standard to be considered in the spectrum reallocation under study by the ***National Argentine Spectrum Authority - CNC***[9].

4. IEEE 802.22. Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY)

4.1. Introduction

On July 1st 2011, the standard ***IEEE 802.22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Band*** was approved under the sponsorship of the LAN / MAN Standards Committee.

The standard aims to set up criteria for the deployment of multiple interoperable products of the 802.xx series[10], offering fixed broadband access in various geographical areas, including especially those of low population density in rural areas, and avoiding interference to services working in the television broadcasting bands.

The standard, commonly known as ***Wireless Regional Area Networks – WRANs***, has been developed to operate primarily as broadband access to data networks in rural areas.

[8] ***Autoridad Federal de Servicios de Comunicación Audiovisual***.
[9] ***Comisión Nacional de Comunicaciones***.
[10] Wireless.

4.2. General features

The standard includes cognitive radio techniques to moderate interference to other existing operators, to grant geolocation capability, to provide access to a database of incumbent services, and to detect the presence of other services through spectrum-sensing technology, such as different WRAN systems or IEEE 802.22.1[11] wireless beacons.

The WRAN systems involve the use of channels ranging from 54 to 862 MHz in the VHF and UHF bands. The use of cognitive radio technologies scans for spare frequencies while avoiding interference with TV stations operating in the same bands.

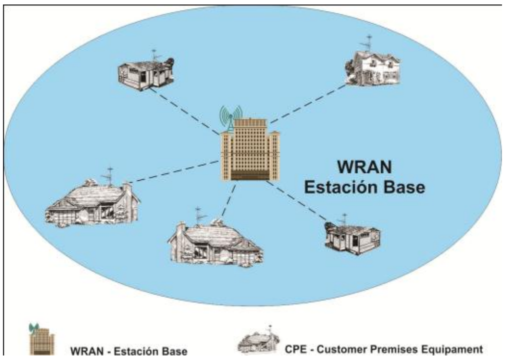

Figure 3. 802.22: Working scheme

Figure 3 illustrates a typical design. Assuming different quality of service (QoS), a Base Station - BS complying with the standard provides high-speed Internet services of up to 512 ***Customer Premise Equipments - CPEs***, fixed or portable, or groups of devices.

4.3. Cognitive Radio Capability

The cognitive radio capabilities supported by the standard are required to meet regulatory requirements for protection of frequency of incumbent's operators as well as to provide for efficient operation. They include: spectrum sensing, geolocation services, database access, registration and tracking of channel set management [8].

In areas where a computer with the IEEE 802.22 standard is intended to operate, the detection of operational channels which could be subject to interference includes the following:

- Television broadcasts.
- Wireless microphone transmissions.
- Transmissions from protecting devices, such as a Wireless Beacon[12].
- Other transmissions such as medical telemetry that may need to be protected in the local regulatory domain.

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[11] ***IEEE 802.22.1: Standard to Enhance Harmful Interference Protection for Low-Power Licensed Devices Operating in the TV Broadcast Bands.*** 2010.

[12] IEEE 802.22.1.

4.4. Topology

The standard topology is point-to-multipoint. The protocol works in a master/slave procedure, so that each CPE requires approval from the BS to transmit.

The system functions with a ***Base Station - BS*** and multiple ***Customer Premise Equipment - CPEs***. The base station controls the whole link, as well as its own performance and the CPE stations. It executes media access control, modulation of the RF transmission, coding, and selection of operating frequencies.

The CPE uses an antenna system as shown in figure 4. It has a directional antenna similar to those used for transmitting/receiving TV signals, one sensing antenna that surveys the spectrum to determine which frequencies are available and a GPS antenna to determine the exact location of the transmitting station [8].

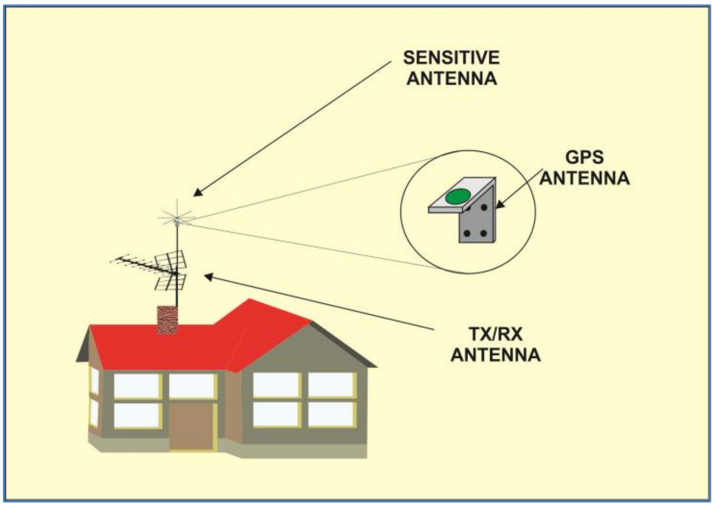

Figure 4. Customer Premise Equipment Antennas

When the sensing antenna detects a band of the spectrum in use, the cognitive radio system changes the transmission features to avoid interference while granting priority to TV operators.

The GPS determines the exact location of the detected signal, so that the system searches the database service of the regulatory agency and find free frequencies for frequency hopping. According to the received information, the base station changes or not the parameters of transmission/reception.

4.5. The IEEE 802 LAN/MAN Committee: Family of Wireless Standards

The ***IEEE 802 LAN/MAN Standard Committee*** has developed a large and diverse family of wireless data communication standards. Since the first 802.3 version to the present, they have dealt with different requirements in wireless communications.

Figure 5 illustrates the most significant wireless standards and the relative position of the 802.22.

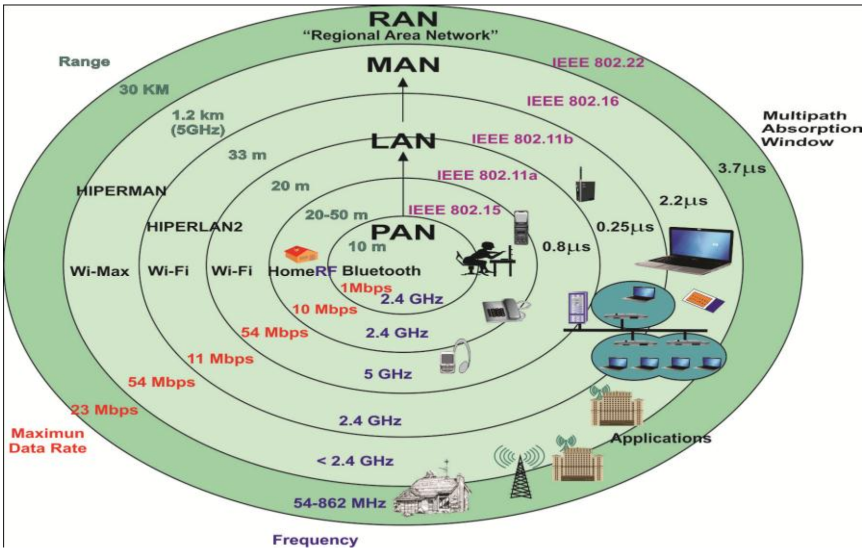

Figure 5. Different Wireless Standards Developed by the IEEE 802 Committee

The standard provides wireless broadband access in rural areas within a range of 30 up to a maximum of 100 km from a base station.

4.6. Physical Layer - PHY

Similarly to the ***Asymmetric Digital Subscriber Line – ADSL***, the IEEE 802.22 standard provides broadband access at a data transfer rate of 1.5 Mbps for uplink and 384 kbps for downlink (Figure 6).

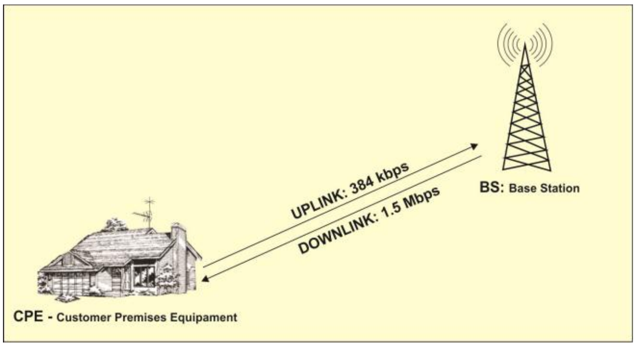

Figure 6. Different Wireless Standards Developed for the IEEE 802 Committee

It works with multiplexing ***Orthogonal Frequency Division Multiple Access - OFDMA*** and defines twelve combinations of three modulations: QPSK - Quaternary Phase Shift Keying, 16-QAM, and 64-QAM Quadrature Amplitude Modulation; and convolutional coding for error handling with the procedure ***Forward Error Control - FEC***.

Parameters	Specification
Frecuency range	54-862 MHz
Bandwidth	6 MHz, 7 Mhz, 8 Mhz
Payload modulation	QPSK, 12-QAM, 64-QAM
Transmit effective isotropic radiated power	Default 4 W for CPEs
Multiple access	OFDMA
Cyclic prefix modes	1/4, 1/8, 1/16, 1/32
Duplexing	TDD

Figure 7. Details the Different Features of the Standard

4.7. Medium Access Control Layer - MAC

The MAC layer supports cognitive capabilities. Thus, it must have mechanisms for flexible and efficient data transmission. It must guarantee the reliable protection of services in the TV band and should be allowed to coexist with other 802.22 systems.

This layer is applicable to any region in the world and does not require country-specific parameter sets.

It is ***connection-oriented*** and provides flexibility in terms of QoS support. It also regulates downstream medium access by TDM, while the upstream is managed by an OFDMA system. The BS manages all the activities within its cell and the associated CPEs are under the control of the BS.

5. Conclusions

Societies today have become highly dependent on the radio spectrum with the intensive use of wireless devices and communication services. Cognitive Radio, using intelligent software and taking advantage of white holes, may be a solution to spectrum saturation.

The Project Communitarian Private Networks has focused on evaluating solutions to the communication problems of rural areas. It has concluded that wireless communications may be among the feasible solutions.

Taking advantage that Argentina has a plan to cover a significant area of its territory with a TV broadcasting system, the conditions may be the ideal to introduce simultaneously the 802.22 standard to the problem of rural communications.

The Project ***Communitarian Private Networks*** continues its work on this line of research.

6. Acknowledgements

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