OVERVIEW OF WHITE SPACE STANDARDS

12

Ermanno Pietrosemoli
The Abdus Salam
International Centre for Theoretical Physics
Italy
ermanno@ictp.it

Standards are very important for the success of any technology. A good example is Spread Spectrum technology. Although the idea first appeared in a 1941 patent application submitted by Hedy Lamarr (Hedy Kiesler Markey) and George Antheil for a "Secret Communication System" [1], it was not until the publication of the IEEE 802.11 Standard in 1997 that the technology took off and became the basis of the enormous success story known as WiFi.

1. http://www.hedylamarr.org/hedystory1.html

IEEE is an international institute based in U.S., but with worldwide membership. Although it is not an official standards body like the ITU (International Telecommunications Union) or the ISO (International Standards Organization) it is very respected and very often the IEEE standards are later incorporated into official standards. For instance the IEEE 802.3 has been adopted by ISO as ISO/IEC 8802-3, the *de jure* standard for Ethernet.

It also happens that products that enjoy considerable market success can become a *de facto* standard, even without any international organization's backing. Standards are generally very advantageous for customers, since they lead to competition among different manufacturers, which drives prices down, benefitting also from economy of scale, protects the investment in case of a manufacturer going out of the market, and avoid vendor's lock in, the dependence from a single manufacturer that can take advantage from their dominant position.

For the vendors, it is a mixed blessing, since driving the price down is not an objective for the incumbent (although it is for other manufacturers who aspire to get a piece of the market), and also sometime standards stifle innovation. That is why many vendors offer additional features, extensions of the standard, which are proprietary, that is, exclusive to a single vendor. So it is frequent to find a product that complies with a certain standard, but in top of that a particular vendor has added additional capabilities, that, when used, inhibit the interoperability with equipment

Figure 12.1: Photograph of Hedy Lamarr, movie star and inventor of Spread Spectrum http://www.uh.edu/engines/epi435.htm

from other vendors. For example, standard WiFi radios are not well suited for long distance point to point links, because the medium access protocol was designed for short distance point to multipoint links. Many manufacturers have addressed the issue by offering, alongside CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance), the standard WiFi medium access protocol, alternatives based on TDM (Time Division Multiple Access), which can significantly enhance the throughput at long distances at the sacrifice of interoperability

12.1 EXAMPLES OF WIRELESS STANDARDS

Official standards take a long way to be ready for publication, since very often they affect vested interests and compromises must be reached among the different stakeholders in order to reach consensus. Figure 12.2 shows some of the wireless standards with respect to geographic coverage, spanning from WPAN (Wireless Personal Area Networks) with reach of less than 15 m, to WLAN (Wireless Local Area Networks) extending to some 150 m, going to WMAN (Wireless Metropolitan Area

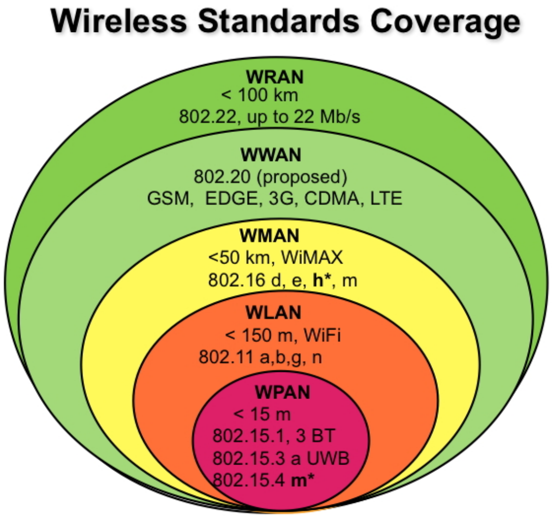

Figure 12.2: Geographical range for some wireless standards.

Networks) covering about 50 km. A special case is that of WWAN (Wireless Wide Area Networks), the cellular networks, in which each base station defines a cell of few kilometers of radius, but the cells are interconnected with backhaul links that can extend the coverage indefinitely. WRAN (Wireless Regional Area Networks can extend up to 100 km from a single base station.

12.2 WHITE SPACES STANDARDS

In general, all the standards specify fixed and mobile stations with different capabilities, and further differentiate between stations that can operate independently and those that need to be enabled by a primary station before attempting to use the channel.

Spectrum sensing is another common feature, which consists of the scanning of the RF energy in a given channel to detect the presence of incumbents. This can be augmented (at the cost of added complexity) by processing the received signal plus noise in order to obtain statistical features that help to discriminate between the signal and the accompanying noise (without prior knowledge of the signal or the propagation channel). Further signal detection precision can be obtained when either the propagation features of the channel or the type of signal to be detected are known, at the cost of more complexity, detection time and loss of generality [2].

2. Yucek, T., Arslan, H., "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", IEEE Commun. Surveys & Tutorials, vol. 11, No 1, 1st qtr.2009, pp. 116-130. http://xanthippi.ceid.upatras.gr/courses/mobile/2009_10/cognitive.pdf

Spectrum occupancy is also determined by compiling a database of all known primary users, with precise geographical coordinates, transmitted power, frequency and antenna pattern. This information is used to produce estimates of coverage area for each using detailed terrain elevation maps and/or RF propagation models. A White Space device must query such database to obtain information about which channels are available in its location at a given time, to avoid interfering with incumbents. In the following we give an overview of some wireless standards in TV white spaces.

12.2.1 IEEE 802.22

The IEEE 802.22 is the first world wide effort to define a standardized air interface based on Cognitive Radio (CR) techniques for the opportunistic use of TV bands on a non-interfering basis [3]. Cognitive Radio is a device capable of adjusting its operating parameters accordingly with the environment in which it is currently deployed. The standard covers the whole TV spectrum from 54 MHz to 862 MHz, although its application in different countries will use only portions of this range which is also used by many other services besides TV, like emergency and aeronautical communications, radioastronomy (RAS, 608-614 MHz), aeronautical radionavigation (ARNS, 645-790 MHz), trunking and so on. The primary target of IEEE 802.22 is to use Cognitive Radio techniques to enable sharing of geographically unused spectrum allocated to TV broadcast services to build Wireless Regional Area Networks (WRAN), to deliver wireless broadband access to rural and remote areas. Numerous other crucial markets for this standard include single family residential, multi-dwelling units, small office/home office (SOHO), small businesses, multi-tenant buildings as well as public and private campuses. In terms of service coverage, the standard is capable of facilitating access ranging from a minimum of 10 km to a maximum of 100 km, if enough transmitted power is allowed and propagation characteristics are exceptional, but to accommodate the longer distances will require adjustments in the timing protocol. With the current EIRP (Equivalent Isotropic Radiated Power, the actual power transmitted after taking in consideration the transmitting antenna gain) of 4 W in the US, the maximum range is about 30 km with reasonable CPE antenna gains, and without any change to the basic timing protocol. This enhanced coverage range offers unique technical challenges regarding interference as well as opportunities for offering cost effective services in sparsely populated areas.

3. C. Cordeiro, K. Challapali and D. Birru, IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios, Journal of Communications, VOL. 1, NO. 1, April 2006

The topology is the same as that of a typical cell phone operator, point to multi-point with a Base station (BS) and several clients, the CPEs (Consumer Premise Equipment). The BS can serve up to 512 fixed or portable CPE units equipped with outdoor directional antennas. Target service capacity is to deliver to a CPE at the edge of coverage a minimum throughput, 1.5 Mb/s in the downstream direction and 354 kb/s in the upstream direction, comparable to DSL services. Closer CPEs might enjoy higher throughput, and the total capacity of the Base Station is up to 22 Mbit/s per channel. IEEE 802.22 requires two separate antennas at each CPE: one directional and one omni-directional. The directional antenna is pointed towards the base station and is used for communication purposes, while the omni-directional antenna is required for sensing purposes. The advanced radio capabilities include dynamic spectrum access, incumbent database access, accurate geolocation techniques, spectrum sensing, regulatory domain dependent policies, spectrum etiquette, and coexistence for optimal use of the available spectrum [4].

4. http://standards.ieee.org/news/2011/802.22.html

Currently, there are 3 active standards in this family officially approved: 802.22 for physical and media access layer, 80.22.1 for Interference Protection and 802.22.2 covering Installation and Deployment, issued in 2012 [5]. The standards are available from the IEEE page, at no cost for the ones that are older than 6 months.

5. http://standards.ieee.org/develop/wg/WG802.22.html

In an IEEE 802.22 cell, multiple CPEs are managed by a single BS that controls the medium access. The downstream is TDM (Time Division Multiple Access) where the BS transmits and the CPE receives. The upstream transmissions, where the CPEs transmit and the BS receives, are shared by CPEs on a demand basis, according to a DAMA/OFDMA (Demand Assigned Multiple Access/Orthogonal Frequency Diversity Multiple Access) scheme. The MAC (Media Access Control) implements a combination of access schemes that efficiently control contention among CPEs while at the same time attempting to meet the latency and bandwidth requirements of each user application. This is accomplished through four different types of upstream scheduling mechanisms: unsolicited bandwidth grants, polling, and two contention procedures; one based on MAC header and another based on CDMA (Code Division Multiple Access). This provides flexibility to accommodate different types of traffic, while preventing interference to the incumbent and also managing the access to the shared channel among different secondary users, in what is called self-coexistence mode. The sharing of the channel is accomplished by dividing the frame in two parts: a downstream subframe (DS) and an upstream (US) subframe. The boundary between the two subframes is adaptive to better accommodate traffic asymmetries. Time division duplexing (TDD) is the only mode currently supported by the standard. The difference between propagation times of far away and close CPEs is taken care of by time buffers inside the frame.

Incumbent Protection

Understandably, this has been the focal point for White Spaces viability. It is accomplished mainly by two mechanisms: database query and channel occupancy sensing. A third mechanism, using beacons to signify channel occupancy is also part of the standard, but it is not normally used since it entails modifications of incumbent's transmission protocols. Neither the BS nor the clients shall operate on the same channel or on the first adjacent channels of a TV operation within the TV protected contour, as defined in the respective coverage database (if one exists). However, they may operate on co-channels or adjacent channels outside this protected contour as long as they are located at sufficient separation distances beyond this protected contour. The parameter used to quantify this aspect is the Adjacent Channel Leakage Ratio (ACLR). The protected contour corresponds to the geographical area potentially served by a given TV transmitter, which is derived from its coordinates, transmitted power and antenna radiation pattern using some propagation model like the Longley-Rice, Hata, or any other indicated by the corresponding administration.

The BS must perform incumbent detection by means of spectrum sensing in each of the channels listed on the available channel list and also each adjacent channel if its EIRP (Equivalent Isotropic Radiated Power) exceeds the limit specified by the corresponding regulatory domain. This is done by means of an omnidirectional antenna independent of the one used for actual communication that can be directional.

Main Features

The main features of IEEE 802.22 are:

- Spectrum Sensing
- Spectrum Sharing (by agreement or compulsory)
- Location Identification by the Mobile
- Network/System/Service Discovery
- Frequency Agility
- Dynamic Frequency Selection
- Avoidance of co-channel operation
- Adaptive Modulation/Coding
- Transmit Power control
- Dynamic System/Network Access
- Mobility and Connection Management
- Security Management

The major challenges facing the deployment of IEEE 802.22 in developed countries are the self coexistence and the hidden incumbent problem. The self coexistence issue is associated with challenges raised by other cognitive radio systems in the same geographical area. This led the creation of the IEEE 802 committee project 802.19.1 to develop standards for TV white space coexistence methods in 2009. The hidden incumbent refers to the fact that a WS device assessing channel occupancy with its low gain omni-directional antenna might not be able to detect an incumbent signal that could on the other hand be detected by a high gain TV antenna. This aspect is analyzed in the Bute case study described in this booklet.

Recently, the IEEE 802.22.b working group (WG) is specifying an amendment standard for supporting the smart grid network using WRAN.

12.2.2 IEEE 802.11af

The IEEE 820.11af study group was formed in January 2010 to adopt 802.11 for TV band operation. The concept behind 802.11af is to leverage the success of WiFi while addressing the limitations due to propagation characteristics and unlicensed spectrum congestion, implementing wireless broadband networks in the bandwidth allocated to TV broadcasts stations, and has been called super WiFi and also White-FI. The advantages of IEEE 802.11af are:

Propagation characteristics 802.11af systems operate at frequencies below 1 GHz, which would allow coverage of greater distance. Current WiFi systems use frequencies in the ISM bands, at 2.4 GHz and 5 GHz, where signals are more absorbed by walls and suffer greater free space and obstacle losses.

New Spectrum Availability The greatest challenge of current WiFi implementations is that the 2.4 GHz band is very crowded and the 5 GHz one is also approaching saturation, hence the need to make use of other frequencies. However, it will be necessary to aggregate several TV channels to reach the 20 MHz bandwidth currently employed in WiFi and thus match the throughput at the higher frequency. Nevertheless there are many applications that can make do with lower data rates and can be accommodated in the bandwidth of a single TV channel which can be 6 or 8 MHz, depending on the country allocation. In the IEEE 802.11af draft standard, four bandwidths: 5 MHz, 10 MHz, 20 MHz and 40 MHz are defined regardless of regulatory domain. It means that channel bandwidth can be adaptively changed when several adjacent TV channels are available, which is often the case in developing countries.

802.11af includes three different stations types: fixed, enabling, and dependent [6].

6. D. Lekomtcev and R. Maršálek, Comparison of 802.11af and 802.22 standards - physical layer and cognitive functionality, Electrorevue, vol.3, No.2, June 2012

Fixed and enabling STAs are stations that broadcast its registered location. The enabling STA controls the operation of unregistered STAs, i.e. dependent STAs. The enabling STA gets the available channel information from the TV WS database, and transmits the Contact Verification Signal (CVS). The CVS is used for establishing that the dependent STAs are still within the range of enabling STAs, as well as for checking the list of available channels. In addition, Channel Power Management (CPM) is also used to update the list of available channels for work in a Basic

Service Set (BSS), change the maximum transmission power or change the channel frequency and bandwidth. Unlike 802.22, which is aimed at outdoors operation, 802.11af also addresses the indoor scenario, in which the new spectrum available and reduced wall absorption can be an advantage. The use of CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) is also an advantage here, but at longer distances the TDM (Time Division Multiplexing) used in 802.22 achieves higher throughput while solving the well known hidden node problem of WiFi. On the other hand, WiFi's "listening to the channel before transmitting" protocol provides a mechanism of protection for other secondary users which is lacking in 802.22. Both standards require geolocation accuracy of 50 meters, obtained by GPS, but 802.22 also has an option of terrestrial based position determination.

802.11af has not been approved, currently is still a draft Standard [7].

7. "IEEE P802.11afTM/D1.02 Draft Standard for Information Technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 3: TV White Spaces OperationU.S.", June 2011.

12.2.3 IEEE 802.15.4m

The IEEE 802.15 Task Group 4m (TG4m) is chartered to specify a physical layer for 802.15.4 and to enhance and add functionality to the existing standard 802.15.4-2006 MAC, meeting TV white space regulatory requirements. The amendment enables operation in the available TV white space, supporting typical data rates in the 40 kb/s to 2 Mb/s per second range, to realize optimal and power efficient device command and control applications. Eight proposals for baselines for standard drafting were submitted and presented in July 2012 [8].

8. http://www.ieee802.org/15/pub/TG4m.html

The 802.15.4m design inherits the two physical layers specified in 802.15.4g Smart Utilities Networks (SUN), frequency shifting and OFDM, and adds a narrowband OFDM to accommodate different requirements. It also introduces peer-to-peer mesh network architecture in the White Spaces arena, allowing range extension and increased network reliability [9].

9. C.-S. Sum, G. Porto Villardi, M. Azizur Rahman, T. Baykas, H. Nguyen Tran, Z. Lan, C. Sun, Y. Alemseged, J. Wang, C. Song, C.-W. Pyo, S. Filin and H. Harada "Cognitive Communication in TV White Spaces: An Overview of Regulations, Standards, and Technology", IEEE Communications Magazine, pp 138-145, July 2013

12.2.4 IEEE P1900.4a

The "Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks" was published in February 2009. The IEEE draft standard P1900.4a for "Architecture and interfaces for dynamic spectrum access networks in white space frequency bands" defines additional entities and interfaces to enable efficient operation of white space wireless systems [10].

10. S. Filin, K. Ishizu and H. Harada, "IEEE draft standard P1900.4a for architecture and interfaces for dynamic spectrum access networks in white space frequency bands: Technical overview and feasibility study", 2010 IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops (PIMRC Workshops), pp 15 - 20, September 2010

12.2.5 IEEE P1900.7

This standard is a result of the DYSPAN (Dynamic Spectrum Access Networks) Standards Committee Working Group, the successor of IEEE P1900 Standard Committee. They are developing standards related to dynamic spectrum access with a focus on improved spectrum usage and addressing the 'Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation'. The goal is to facilitate a variety of applications, including support of high mobility, both low-power and high-power, short, medium, and long-range, and a variety of network topologies while avoiding causing harmful interference to incumbent users [11].

11. http://standards.ieee.org/develop/wg/DYSPAN-1900.7.html

12.2.6 ECMA392

ECMA International is the successor of the European Computer Manufacturers Association. Founded in 1961, it has promoted almost 400 standards, most of which have been approved as international standards.

ECMA 392 is a standard that specifies a physical layer and a medium access sub-layer for wireless devices that operate in the TV frequency bands. It was originally published in 2009 with a second edition in June 2012, fully aligned with the 1st edition of ISO/IEC 16504:2011. It is mainly directed at personal and portable wireless devices. The standard aspires to serve a broad range of applications, including multimedia distribution and Internet access. Applications include high speed video streaming and Internet access on personal/portable electronics, home electronics equipment, and computers and peripherals. ECMA 392 also designates a MUX (a session management protocol) sublayer for higher layer protocols and numerous incumbent protection strategies that may be used for protecting the primary spectrum user.

The standard supports flexible network architecture with three types of devices: master, peer and slave, originating different networks topologies including master-slave, peer-to-peer and even mesh. Although in a master slave configuration the master controls the communication, a slave device may also directly communicate with another slave device under the coordination of the master. On the other hand, a peer device can access the channel by distributed reservation without the intervention of the master and therefore can construct a self organizing and self healing ad-hoc network. Two or more networks can share the same channel and may also communicate with each other in a coordinated way. It also opens the possibility to form a large scale network in a mesh topology.

Its target applications are wireless home network and wireless Internet access at campus, park, hotspot and so on. Ecma-392 additionally supports the spectrum sensing functionality to periodically check the existence of incumbent signals on current operating channel. It supports operation in only a single TV channel of 6 MHz, 7 MHz, or 8 MHz according to the regulatory domain.

The medium Access (MAC) design is based on a hybrid medium access architecture which allows reservation based channel access and contention based access. Medium access slots may assume reserved or unreserved form, the former may be invoked periodically for QoSdemanding audio/video stream. The latter may be invoked in prioritized contention (PCA), based on four access schemes, including background (BC), best effort (BE), Video (VO) and voice (VI). Highly efficient data transmission is supported by numerous frame processing mechanisms encompassing Frame Aggregation, burst transmission and block acknowledgement (B-ACK). Self coexistence and mitigation of interference between near-located networks is taken care of by additional mechanisms. The standard is freely available [12].

12. http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-392.pdf

12.2.7 *IEEE 802.16h*

This amendment of the 802.16 standard was ratified in July 2010 as "Air Interface for Broadband Wireless Access Systems Amendment 2: Improved Coexistence Mechanisms for License-Exempt Operation" and describes the mechanism for implementing the protocol over which WiMAX (Wireless Microwave Access) is based in uncoordinated operation, licensed or license exempt applications. Although most deployments have been in the 5 GHz band, it can also be applied to lower frequencies and specifically in the TV bands. In general, interference can be caused by licensed user or by other unlicensed users. It is now superseded and its content is part of IEEE Std 802.16-2012 [13].

13. http://standards.ieee.org/findstds/standard/802.16h-2010.html

12.2.8 *ETSI EN 301 598*

This draft of the Harmonized European Standard "White Space Devices (WSD); Wireless Access Systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive" was issued in July 2013 and applies to TVWS devices controlled by a geolocation database that operate between 470 MHz and 790 MHz.

The document is freely downloadable [14].

14. http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.00.00_20/en_301598v010000a.pdf

It specifies two types of devices; type A, that can have any type of antenna, and type B which can have only integral or dedicated antenna, precluding the use of other antennas. There are also two device categories, master and slave. The master cannot transmit in absence of communications with the approved database (TVWSDB) and the slave cannot transmit in absence of communications with its master. The slave must communicate to its master the corresponding Device Parameters, which will then communicate them along with its own to the corresponding TVWSDB which will use them to compile the Operational Parameters allowed. The master will use this information to produce a list of Channel Usage Parameters to be used for transmission, both for itself and the slaves. This information will be forwarded to the TVWSDB. Equipment must comply with one of the five Device Emission Classes according with the level of emission leakage on adjacent channels. A detailed list of tests to be performed in the devices is described in the document.

12.3 CONCLUSIONS

Although the idea of using TV White spaces has been around for more than a decade, it was only in June 2011 that the IEEE officially approved IEEE 802.22 for long range "Wireless Regional Area Networks". The IEEE 802.11af for short range transmission is still being debated, as is the IEEE 802.15.4m for device control and command applications.

Still pending are the IEEE 802.19 for coexistence among multiple TV white space networks and the IEEE DySPAN aimed at Dynamic Spectrum Access Networks. On the other hand, the IEEE 802.16h, originally meant for the 3650-3700 MHz contention band is now also specified for the TV bands.

The European Computer Manufacturers Association is still working on the ECMA 392 directed at personal and portable wireless devices. Likewise, the IETF (Internet Engineering Task Force) submitted in April 2013 a proposal for "Accessing a Radio White Space Database" for publication as a Proposed standard named Protocol to Access WS database (PAWS) [15].

15. https://datatracker.ietf.org/wg/paws/charter/

Weigthless, described elsewhere in this booklet, is mainly focused at Machine-to-Machine interactions at low speed.

It is worth noting that, to the best of our knowledge, none of the vendors that offer WS equipment comply with the only officially approved standard. Although IEEE 802.11af is still in draft, its specifications are less stringent and easier to be met by manufacturers in the near future.