THE EVOLUTION OF UNLICENSED LOW POWER RF STANDARDS

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Abstract

802.11 was the first mainstream short range wireless technology, but initial generations were too power hungry for mobile devices. The Bluetooth SIG came up with a robust RF specification which made the breakthrough into mobile handheld and wearable devices by dramatically reducing power requirements. The Zigbee Alliance responded with another low power RF specification based on IEEE 802.15.4, and WiMedia is still trying to push UWB, again coming out of the IEEE 802 family. This talk looks at the future for short range RF, including regulatory changes opening up spectrum for TV Whitespace, new groups such as the WiGig alliance, and new developments in existing specification development organizations.

Introduction – the attraction of unlicensed low power RF

Unlicensed wireless RF technology has been readily available to the consumer in various forms for decades. Licensed wireless RF technology has also been available, but at a greater price. Cellular telephony has been one of the main success stories of modern-day consumer electronics, with a relatively low-cost RF transceiver in the hands of the general public where before it was mainly restricted to the high-spending military and diplomatic corps.

Relatively is the operative word in this respect since, even today, licensed wireless RF technologies such as GSM, GPRS, EGPRS, the different types of 3G mobile wireless tech (WCMDA, TDCMA (CDMA-2000) SC-TDCMDA) provide an RF transceiver to the man in the street, but with a hefty subsidy paid by the respective network operators, to be repaid (unwittingly or otherwise) over the course of sometimes lengthy and fairly expensive contracts. The unsubsidised cost is usually (especially in the case of recently developed high-end smartphones) several hundred pounds more than the up-front cost.

What, however, does unlicensed technology deliver to the end user that licensed technology doesn't? They can both replace cables in some form or other, whether those cables belong to a connecting device such as a headset or microphone/speaker combination, or to a PSTN-connected telephone set, the respective purposes of both transceivers are broadly similar.

One obvious difference is that unlicensed technologies to date have been low power short range, so are typically encountered in PANs (Personal Area Networks) and LANs (Local Area Networks). By comparison the licensed technologies have been longer range providing WANs (Wide Area Networks).

Another answer is that unlicensed RF technologies provide the end user with certain freedoms that they will generally not receive when purchasing licensed technology. Modern cellular devices can ring-fence the end user into installing only authorised content, from authorised sources. Short range data transfer is often omitted from licensed devices, and enabling this transfer is a major use case for unlicensed devices.

A brief history of unlicensed low power RF standards

In the United States of America, the body responsible for regulating communications and the use of radio spectrum within the national borders is the Federal Communications Commission (FCC). On May 9, 1985, the FCC adopted changes, proposed by FCC staff member Dr Michael Marcus in 1980, to parts 2, 15 and 90, of the FCC Rules designed to allow the operation of unlicensed radio transceivers applying spread spectrum operation in what are now known as the Industrial, Scientific and Medical (ISM) bands[1], at frequencies spanning 902-928MHz, 2400-2483.5MHz and 5725-5280MHz. The amendments made by the FCC eventually propagated around the world in various similar legislative forms.

The frequency bands outlined above form a part of the complete ISM band spectrum allocation outlined in the Table of International Frequency Allocations and published via the International Telecommunication Union Radiocommunication Sector (ITU-R) Radio Regulations (RR), Article 5, RR no’s 5.138 and 5.150, with exceptions mentioned in (RR) 5.280[2], and reproduced here as Table 1:

Frequency Span (MHz)	Centre Frequency (MHz)
0.6765 – 0.6795	0.6780
13.553 – 13.567	13.560
26.957 – 26.283	27.120
40.66 – 40.70	40.68
433.05 – 434.79	433.92
902 – 928	915
2400 – 2500	2450
5725 – 5875	5800
24000 – 24250	24125
61000 – 61500	61250
122000 – 123000	122500
244000 – 246000	245000

Table 1 - ISM band spectrum allocation

One of the first standardisations of unlicensed RF technology came via the Institute of Electrical and Electronic Engineers (IEEE) 802.11 Working Group, which ratified the initial 802.11-1997[3] standard for use in Wireless Local Area Networks (WLANs). Later would follow the 802.11a[4] and 802.11b[5] standards in 1999. 802.11a operated using the Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme to achieve spread spectrum operation, and used the 5GHz ISM band. 802.11b used the lower-frequency 2.4GHz band and employed Direct-Sequence Spread Spectrum (DSSS) technology. Both variants used a 20MHz channel bandwidth, however 802.11a was capable, theoretically at least, of much higher data rates approaching 54 megabits per second (Mb/s) in comparison to the maximum theoretical rate of 11 Mb/s of 802.11b.

The 802.11 family was based on the Aloha protocol designed for Satellite communication in the Hawaiian islands. This uses a contention based access method. Basically a device listens before talking and if it hears another device it implements a random back off. This means that when the medium becomes congested the throughput drops dramatically. This can be overcome by having a central arbiter co-ordinating devices, but without such a central co-ordinator the system does not degrade gracefully when many devices try to communicate simultaneously.

Another limitation of 802.11 is that to date a length exchange has been required to set up a secure network. This makes connections slow to set up, and restricts its use for informal ad hoc networking, but 802.11 has been extremely successful in local area networking.

Soon after the ratification of the 802.11a and 802.11b standards, the Bluetooth™ Special Interest Group (SIG) published the first public version of the Bluetooth™ Core Specification, version 1.0a[6], in 1999. Operating in the 2.4GHz ISM band, this new specification addressed the Wireless Personal Area Network (WPAN) segment, and was superseded the same year by an updated release, version 1.0B[7]. Early problems discovered within this fledgling Bluetooth™ standard saw another revision, the Bluetooth™ Core Specification, version 1.1[8], released in 2001. This latest version was ratified by the IEEE 802.15 Working Group as IEEE802.15.1-2002[9].

Bluetooth Wireless Technology was targeted at ad-hoc networking and designed to overcome the restrictions of the Aloha protocol. The Bluetooth specification divides the 2.4 GHz band into 79 channels and devices use these in pseudo-random sequences. This has the effect of causing a more gradual degradation in bandwidth as the band becomes congested.

Bluetooth Wireless Technology also implements a key exchange system which allows much faster connection set up than the 802.11 family, again this was specifically targeted at ad-hoc applications.

Another major difference between the Bluetooth Specifications and the 802.11 family is the Bluetooth profiles. These specify application level functionality, and again are targeted at ad-hoc use cases. This is because the provision of a well defined upper layer application facilitates interoperability between devices without requiring user configuration.

2002 saw the group responsible for the testing and certification of 802.11 devices, the Wireless Ethernet Compatibility Alliance (WECA) (originally formed in 1999), change their name to the Wi-Fi Alliance (WA).

New specification releases in both the IEEE802.11 and 802.15 working groups, and also within the Bluetooth™ SIG, occurred in 2003; the release of the 802.11g[10] standard saw the introduction of higher data rates in the 2.4GHz band, up to a maximum of 54Mb/s like the earlier 802.11a standard. Indeed, 802.11g employed significant reuse of the 802.11a core features, but was also specified carefully in order to interoperate closely with the existing

802.11b radios. The Bluetooth™ SIG released their newest update, Core Specification v1.2[11], which introduced many new features including Adaptive Frequency Hopping (AFH), designed to improve resilience in the presence of interferers such us 802.11 based devices in the 2.4GHz band by employing Frequency-hopping Spread Spectrum (FHSS) techniques to avoid occupied channels. The specification release also saw the introduction of the eSCO (Extended Synchronous Connection) transport, allowing retransmissions of audio data in case of packet corruption, and higher-layer flow control & retransmission modes. The IEEE802.15 Working Group would go on to ratify this specification as IEE802.15.1-2005[12].

The development of WPAN technology continued during 2003 with the ratification of the IEEE802.15.4[13] standard, which specified a radio capable of sustained operation over very long periods at low data rates, and using the 868MHz (EU), 915 MHz (US) and 2.4GHz bands dependent on territory.

Analogous to the IEEE802.11/Wi-Fi Alliance relationship, the formation of the ZigBee Alliance and the release of the first ZigBee specifications, building on the earlier release from the IEEE802.15.4 standard the year earlier, occurred in 2004 with ZigBee 1.0, designed as low-power, self-organising mesh or star topology networks, with maximum raw data rates ranging from 20kb/s (868MHz, single channel) to 250kb/s (2.4GHz, multi-channel). The standardisation of only the 802.15.4 MAC and PHY necessitated the development of the ZigBee upper layers, including the Network and Application layers, and also Zigbee Device Objects (ZDO's) governing device roles, network management and security.

Late 2004 would see the release of the Bluetooth™ Core Specification v2.0+EDR[14] which would be the first version not subsequently ratified by the IEEE802.15 Working Group, a divergence which remains to this day. This edition introduced two new modulation schemes; π/4 DQPSK and 8DPSK, boosting the maximum raw data rate of the Bluetooth™ baseband from 1Mb/s to 2Mb/s and 3Mb/s respectively, and enabling power savings via lower duty cycles.

In 2005, the WiMedia Alliance was formed to further the progress of ultra-wideband (UWB) technology using the Multi-Band Orthogonal Frequency Division Multiplexing (MB-OFDM) variant of the UWB PHY which would latterly see the dissolution of the IEEE802.15.3a Task Group who were unable to agree a choice between two differing implementations of UWB (MB-OFDM and Direct-Sequence UWB (DS-UWB)

The latter half of the decade would host several more releases from the various groups involved. In 2006, IEEE802.15.4-2006[15] would be released, incorporating changes designed to enhance available bandwidth in the 868MHz frequency band via new modulation types. The following year would see the release of the ZigBee2006 and afterwards the ZigBee PRO specifications, which incorporated the new IEEE802.15.4-2006 standard and added application profiles including the Home Automation profile, later in the year. The Bluetooth™ SIG would also use this year to release their latest Core Specification, version 2.1+EDR[16], which brought with it several new features designed to enhance security, power consumption and pre-connection device filtering.

2008 saw the Bluetooth™ SIG release an amendment to the 2.1+ EDR Core Spec: Core Specification Addendum 1 (CSA.1[17]) which introduced new retransmission and flow control modes in the Logical Link Control and Adaption layer (L2CAP) responsible for the multiplexing of higher layer data. This year would also see the ratification of the

IEEE802.11y[18] standard, allowing operation in the 3650-3700MHz band in the United States of America, and the formation of the Wireless-HD Consortium, also known as WiDi, with the intention of developing the market for products operating in the 60GHz ISM bands, in parallel with the work being undertaken by the IEEE802.15.3c task group, established in 2005, to develop a new PHY underneath the IEEE802.15.3/3b MAC layer.

The Bluetooth™ Core Specification underwent a further revision in 2009 with the release of the v3.0+HS[19] "High-speed" specification, which for the first time provided the ability to utilise an alternate MAC/PHY in order to provide even higher data rates. The IEEE802.11 MAC/PHY was chosen as the alternate transport, with many surprised when it became apparent that the 802.11 MAC/PHY would not be accompanied by the WiMedia UWB MAC/PHY. IEEE802.11n[20] was finally released in October 2009, years after the Wi-Fi Alliance had begun to certify products based on the draft-802.11n standards. This highly anticipated release allowed theoretical maximum data rates of up to 6000 Mb/s and operated in the 2.4 GHz and 5GHz bands.

Further developments in high-bandwidth standards arose during 2009 with the incorporation of a new industry body: the WiGig Alliance and also the ratification of the standard specifying a new PHY operating in the 60GHz band; IEEE802.15.3c-2009[21].

More recent developments include the Bluetooth™ SIG releasing their heavily anticipated Core Specification v4.0[22], including Bluetooth™ low energy (formerly known as Wibree, initially developed by the Finnish handset manufacturer Nokia and donated to the Bluetooth™ SIG in 2007). For the first time, the possibility of connecting classic Bluetooth devices, with their huge handset attach rates, to low-power sensors, afforded designers the freedom to link two previously disparate device ecosystems and enabling such use cases as low energy keyboards and mice (Human Interface Devices (HID)), 3D Glasses, Heating Ventilation & Air-Con (HVAC), sports & fitness devices and health monitoring.

The ZigBee Alliance were developing their Smart Energy Profile v2.0 specification, introducing a divergence from the IEEE802.15.4 MAC/PHY, although unfinished at the time of this writing. Also during 2010 saw the release of the Wireless USB specification v1.1[23], designed as an alternative to 60GHz radios, operating in the 3.1-10.6GHz bands, based on WiMedia UWB technology.

Trends in existing groups

Certain trends have been noted in existing standards development organisations (SDO's). Restructuring to allow quicker response to changing market conditions, by the Bluetooth™ SIG with the abolition of both their Evangelisation and Ecosystem committees, and the introduction of 5 new Bluetooth Ecosystem Teams[24] (BETs):

- Consumer Electronics/Personal Computer (CEPC) BET
- Mobile Phone BET
- Health & Fitness BET
- Automotive BET
- Smart Energy BET

This restructuring was effected to allow the SIG the opportunity to drive innovation by leveraging input from industry leading companies in the respective market segments, and also to cope with the anticipated market changes following the introduction of Bluetooth™ low energy devices into the ecosystem. The few-supplier, high-volume market of classic Bluetooth ™ devices is expected to be joined by both high-volume and multiple low-volume 'niche' manufacturers as the technology matures. Driving the differing market segments individually brings a departure from the old SIG policy, and could afford Bluetooth™ the ability to address quickly-changing requirements more so than in the past.

ZigBee has recently been developing a new specification – the Smart Energy Profile v2.0, which will allow the technology to be used with non-IEEE802.15.4 radios. This development allows designers the ability to select radios capable of transmitting longer packets for example, but retaining the lightweight protocols above, based on IPV6-complaint 6loWPAN.

The Wi-Fi Alliance has also begun to move away from the traditional role of tracking IEEE802.11 standard, with the 60GHz initiative considering both the WiGig specifications and IEEE802.11ad. Consensus on which of divergent areas to drop from Wi-Fi certification is likely to remain a point of contention however. The WFA are independently developing their Wi-Fi Direct standard, to compete in the WPAN space.

Regulatory developments – an outline of TV Whitespace

As numerous countries across the globe have begun the process of migrating their terrestrial television transmissions from analogue to digital, the question of how best to utilise the free spectrum between television channels (Television White Space, TVWS) has given rise to the possibilities of allowing both mobile and fixed access points to utilise the spectrum, in the United States this spectrum exists below 900MHz and in the 3GHz band.

Considering spectrum overlap in neighbouring areas is mitigated by reusing frequency channels only in non-overlapping areas, this leaves large parts of spectrum unused in any given locale available for use. Location awareness would therefore be mandatory for all devices hoping to make use of the available spectrum

There are various companies working with the FCC in the United States with the intent of establishing and maintaining TVWS databases with the intent of administering provision of free spectrum for unlicensed devices to operate in. The FCC announced conditional designation of nine device database administrators in March 2011[25]:

- Comsearch
- Frequency Finder Inc
- Google Inc
- KB Enterprises LLC
- Key Bridge Global LLC
- Neustar Inc
- Spectrum Bridge Inc
- Telcordia Technologies
- WSdb LLC

Each database administrator was required to demonstrate[26]:

1. The technical expertise to administer a TV band database and its business plan to operate it for a five-year term
2. The scope of the database functions the entity intends to perform and how it would synchronize data between multiple databases
3. Diagrams of the architecture of the database system and a detailed description of how each function operates and interacts with the other functions
4. Information on any other entities performing database functions and the business relationship between itself and these other entities
5. The methods that will be used by TV bands devices to communicate with the database, the procedures that it plans to use to verify that a device can properly communicate with the database, and the security methods that will be used to ensure that unauthorized parties cannot access or alter the database

The next RF standards

There are several trends apparent in RF standardisation. Co-operation of specification groups, focus on applications, and evolution towards higher data rates.

Co-operation of specification groups

Many of the specification development organizations which dominate the unlicensed radio market have begun to appoint liaisons to one another. Initially these liaisons have looked at issues of coexistence, attempting to foster inter-group co-operation to allow the different technologies to coexist efficiently maximising use of the scarce bandwidth available in the unlicensed bands.

There are signs that the liaisons may extend to influencing other specification decisions. Already multiple radio technologies going into single devices such as laptops and smart phones, but there are signs that even smaller devices such as headsets may implement multiple radios. This puts pressure on UIs and applications to provide common features between specifications, and there may be a role for the inter-standard liaisons in facilitating co-operation at application level.

Focus on applications

The Zigbee Alliance and Bluetooth SIG have developed application profiles targeted at specific use cases. IEEE 802.11/Wi-Fi Alliance have so far concentrated on the lower layers. This has left a gap in standardising applications. Special interest groups have sprung up to fill this gap, for example the Digital Living Network Alliance targets Home Entertainment and Continua Alliance targets Healthcare and Wellness applications. Many groups are emerging targeting Smart Energy applications and it is as yet unclear which will dominate this market space.

Interoperability at an application level typically enlarges the total available market (TAM). So whether application level interoperability is handled in the same group that defines the radio, or in a separate special interest group we can expect to see an increase in groups focussing on applications.

Higher data rates

The driving use cases for high-bandwidth radios in the consumer space are rich displays (via smartphones) and the wireless desktop, providing HDMI output.

For example, the IEEE802.11ad task group is concerned with the development of a high data rate PHY in the 60GHz band. The 2009 hibernation of the WiMedia Alliance and the lack of subsequent adoption of the WiMedia UWB specifications have meant 60GHz, for the moment, is the only realistic method of achieving the high throughput desired. The Bluetooth™ SIG evaluated the possibility of including the WiMedia UAB MAC/PHY in to the core specification, but ultimately chose not to include the technology.

The WiGig Alliance are working alongside IEEE and the Wi-Fi Alliance to decide on the next 60GHz standards to be used as the baseline for WFA certification, although there are competing implementations in the WiGig specifications and IEEE802.11ad itself. The

Bluetooth™ SIG has also expressed interest in 60GHz as a possible next alternate MAC/PHY for high-speed data transfer.

60GHz may deliver the desired throughput, but brings with it new problems to be overcome before realisation of developing standards and specifications, such as line-of-sight: 60GHz requires a clear line of sight from transmitter to receiver to operate properly. Millimetre wave radiation is readily absorbed by intervening bodies. The same is not true for lower-frequency UWB, which operates in the 3.1 – 10.6 GHz band

Long range is a welcome facet of TVWS devices and it is as yet undetermined whether the next RF standards to be adopted will use low-frequency TVWS based solutions as a means for achieving long range, or whether they will attempt to leverage coding gain instead.

Summary

The market for unlicensed RF devices continues to develop across the globe, with healthy competition in the marketplace, and fast-moving specifications being developed to facilitate new use cases. The end user should expect to see the emergence of support for higher bandwidth, longer range, and lower power devices.

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