Overview of PCS Unlicensed Wireless Standards in the US

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Abstract

The demand for wireless services is growing rapidly. The extension of service into the in-building environments and in public pedestrian areas further enhance this trend. This trend is no exception in the United States. With the availability of spectrum in the PCS Unlicense band it becomes apparent that standardization is required to provide cost-effective solutions for in-building business applications. This paper discuss the three user premise equipment wireless standards developed in TIA (Telecommunications Industry Association) The main purpose of this organization was to develop the standards for inter- vendor operability for operation in the US PCS Unlicense band. The three user premise equipment wireless standards are PWT (Personal Wireless Terminal), PCI (Personal Communication Interface) and PACS (Personal Access Communication System).

Operation in the unlicense band is first discussed. Both voice or isochronous type services and data or asynchronous services are accommodated in the PCS unlicense band. Different rules of access governs each service type. A process of channel monitoring with a listen-before-transmit protocol is provided to allow for sharing of channels in the band. This process also better know as the "etiquette rule" or "spectrum etiquette" together with standardization of the three over-the-air protocols in TIA provides a significant new opportunity for the extension of personal communications for the in-building business applications.

Introduction

With the emergence of digital cordless telephony standards, cordless systems with enhanced functionality such as CT2, CT2Plus, DECT, and PHS have been developed for wireless private branch exchanges (WPBXs). But these standards are developed for European, Japanese or Canadian deployment with possible adapation to some Asian and Latin American countries. These standards without changes however will not work in the US spectrum.

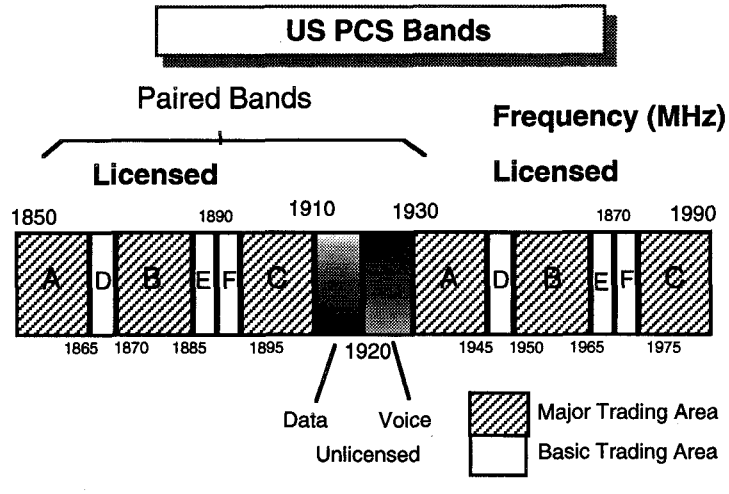
CT2 and CT2Plus are FDMA digital standards developed for specific geographical area. CT2 is currently deployed in Europe and Asia, CT2Plus is an enhancement to the CT2 standard and it is currently deployed in Canada.

DECT and PHS however are FDMA/TDMA digital standards designed for high capacity in-building usage. DECT is currently deployed in Europe,

Currently, PWT (Personal Wireless Terminal), PCI (Personal Communications Interface) and PACS (Personal Access Communication system) wireless protocol standards has been standardized in TIA (Telecommunications Industry Association) TR41.6, with the aim of achieving industry wide interoperability for customer premise equipment for operation in the US PCS unlicense band.

Operation in the PCS Unlicensed Band

The band 1850 - 1990 MHz in the lower 2 GHz has been designated for PCS operations. This band section between 1910 to 1930 MHz has been designated for the unlicensed PCS services. This is the middle band between the go and return channels of the licensed PCS assignments on either side. The main advantage of operating in the unlicense band over the license band is "it is free", or "almost free". So long as the equipment is FCC certified the equipment can be deployed and turned on. But during the initial days of spectrum clearing an organization call UTAM (Unlicensed PCS ad-hoc committee for 2 GHz microwave Transition and Management) may require a small fee before deployment can take place. Depending on the spectrum congestion in some areas, deployment may not even be possible.



The unlicensed PCS band is surrounded by the licensed bands (see figure above). This is an important consideration in the design of the unlicensed radio equipment as the unlicensed devices must coexist with a high level of activity and transmitter powers in the immediately adjacent bands.

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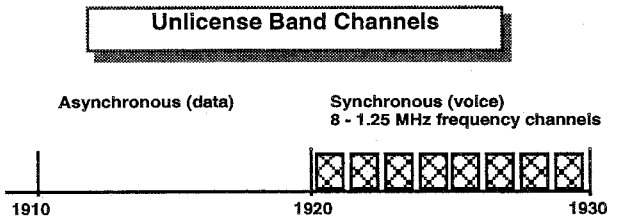
The unlicensed band has been divided into two parts to accommodate two classes of device operation. These are for the isochronous (voice) and the asynchronous (data) devices. Isochronous devices require a regular repeated transmissions as typified by TDMA/TDD voice systems. The asynchronous devices are those with no regular transmission pattern but which send high speed bursts of information when needed and can tolerate a delay before sending a burst.



The asynchronous devices have been assigned the sub-band between 1910 and 1920 MHz while the isochronous devices are assigned the segment from 1920 - 1930 MHz (see figure above). There is no channel assignment in the asynchronous band while in the synchronous band, the band is divided into eight 1.25 MHz segments.

The etiquette uses the concept of an "emission bandwidth" to set the transmitter power level and emission limits for the devices. The basic concept is to limit the transmitter power, to limit the duration of transmissions and to provide a "listen before transmit" protocol so that new transmitters defer to established traffic. This set of rules has been called an "etiquette" or "spectrum etiquette". The concept is that an existing user of the radio spectrum should be protected from interference from a new device. Thus all devices must listen on a channel to be sure it is free before beginning transmissions.

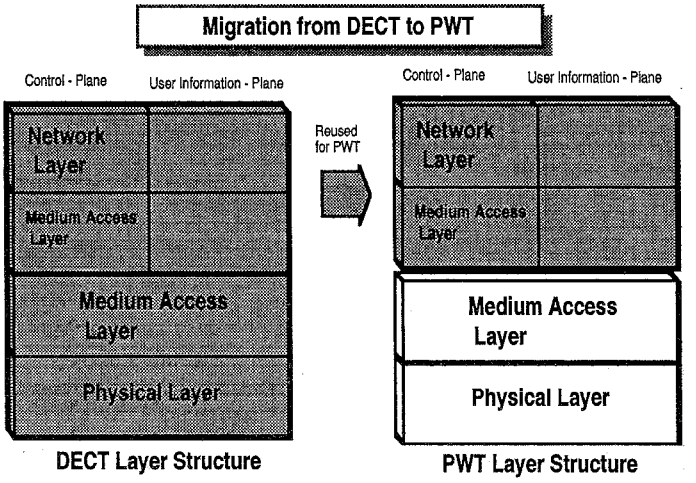
PWT

PWT (Personal Wireless Terminal Interoperability Standard) is essentially the same as DECT in the higher layers. The lower layers are adapted for usage in the US unlicensed PCS band (1920 - 1930 MHz).

PWT is a micro-cell radio communication system that provides low - power radio (cordless) access between portable parts and (PWT) fixed parts at ranges up to a few hundred meters. The range maybe extended through the use of in-band repeaters to distances of a few kilometers for applications such as fixed wireless access (FWA). The basic technical characteristics are as follows:

Frequency band:	1920 - 1930 MHz; unlicensed 1910 - 1920 MHz optional unlicensed; PWT-E (licensed) 1850-1990 MHz
Number of carriers:	8 (1920-1930 MHz) 16 (if implemented from 1910 - 1930 MHz)
Carrier spacing:	1.250 MHz, 1910 - 30 MHz;
Peak transmit power:	90 mW
Carrier multiplex:	TDMA; 24 slots per frame;
Frame length:	10 ms;
Basic duplexing:	TDD using 2 slots on same RF carrier;
Gross bit rate:	1152 kb/s;
Symbol rate:	576 kb/s;
Net channel rates:	32 kb/s B - field (traffic)) per slot; 6.4 kb/s A - field (control/signaling) per slot.

The PWT is designed for use in the US PCS unlicense band and is designed as a flexible interface to provide cost-effective communication services to high user density in picocells. The standard is intended for wireless PBX, cordless telephony or wireless local loop. It does support multiple bearer channels for speech and data transmission, handover, location registration, and paging. Extensions to PWT allow it to be used in the licensed PCS bands for such applications as FWA. These extensions are known as PWT-E (Enhanced).

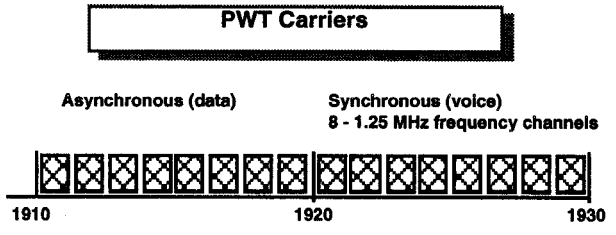


PWT like DECT uses TDMA and TDD, with 12 slots per carrier in each direction. A PWT base station can support multiple handsets simultaneously with a single transceiver. It can also allocate several bearers for a single call to provide high bandwidth communication. The channel spacing in PWT is decreased to 1.25 MHz from the 1.728 MHz used in DECT. This is done to adhere to the FCC rules for channel spacing. This change forced a change in the modulation scheme, from GFSK to a more narrow-band $\pi/4$ DQPSK. The PWT provides 8 carriers in the 10 MHz band between 1920 - 1930 MHz. A further 8 carriers may also be used in the 1910 - 1920 MHz sub-band, however, a different MAC layer access etiquette must be used for this sub-band. The

details of the MAC layer procedures to comply with the FCC etiquette for either sub-band are not given in the standard and must be developed by the manufacturers for compliance to the FCC rules. PWT, like DECT, uses 32 kb/s ADPCM speech coding.

Standard	PWT	DECT
Frequency Band (MHz)	1920 - 1930	1880 - 1900
Duplexing	TDD	TDD
Carrier spacing (kHz)	1250	1728
Number of carriers	8; 16 if 1910 - 30	10
Bearer channels/carrier	12	12
Channel bit rate (kb/s)	1152; 576 kbaud/s	1152
Modulation	$\pi/4$ DQPSK	GFSK
Speech Coding (kb/s)	32	32
Frame duration (msec)	10	10
Peak handset TX power (mW)	90	250

The basic structure of DECT is maintained in PWT. The Physical Layer has been modified to suit the isochronous unlicensed band FCC rules and adaptation for the 1.25 MHz channel spacing. The Medium Access Layer has also been modified to adhere to the "etiquette rule". The other parts of PWT, however, are identical to DECT.



In summary, PWT is very similar to DECT, except at the physical and MAC layers where changes have been introduced for operation in the 1910 - 1930 MHz band rather than the 1880 - 1900 MHz band. The modulation is $\pi/4$ DQPSK rather than the GFSK used in DECT. The FCC "etiquette rules" make the channel selection algorithm slightly altered in the Medium Access Layer. The GAP (Generic Access Profile), where feature definitions and access to system features are defined, were also slightly changed for operation in the US. With 8 carriers available in the 1920 -1930 MHz sub-band for PWT, instead of the 10 available in DECT, the large system peak traffic capacity maybe slightly lower. However, as the DECT capacity capability is so very large, this is not significant.

In conclusion, the PWT standard is an attractive option for wireless communication in the US especially for picocell and highly densed populated applications. Its capability in multi-bearer is especially attractive for multimedia applications. Its layered protocol structure allows easy migration to PWT for manufacturers with DECT products. DECT is also attractive because it has defined interworking with GSM/PCS1900 and provides a variety of defined data services with rates up to about 500 kb/s.

PCI

PCI (Personal Communications Interface) Interoperability Standard is an enhancement to the original CT2 standard which is designed for operation in the US unlicensed PCS band.

PCI is defined to operate in the sub-band 1920 - 1930 MHz. The channel center frequencies for both the portable and fixed parts are defined by the following:

1920.0 + 0.1 n MHz where n is an integer between 1 and 99.

The first channel will be at 1920.10 MHz;

The last channel will be at 1929.90 MHz;

Frequency band:	1920 - 1930 MHz; US unlicensed PCS band
Number of carriers:	99; only 76 available for use because of FCC rules
Carrier spacing:	.100 MHz, 1910 - 30 MHz;
Peak transmit power:	30 mW
Carrier multiplex:	FDMA; 2 slots per frame;
Frame length:	2 ms;
Basic duplexing:	TDD using 2 slots on same RF carrier;
Modulation:	2-level FSK;
Gross bit rate:	76 kb/s;
Net channel rates:	32 kb/s (traffic) per slot; 2 kb/s (control/signaling) per slot.

The most noteworthy features of this standard are the digital transmission format and the use of time division duplexing (TDD). With PCI, speech is first digitized using a 32 kb/s adaptive differential pulse code modulation (ADPCM) encoder. The time-compressed digitized speech and control data are modulated onto a carrier at a rate of 72 kb/s using Gaussian filtered FSK (GFSK) and are transmitted in 2-ms frames. Each frame includes one base-to-handset and one handset-to-base burst. This mode of duplexing (TDD) has significant advantages: no duplex filter is required in either the handset or the base station; both transmission and reception antenna diversity can be used; and the system is easily adapted to other frequency bands.

The PCI standard provides for 99 nominal carrier locations

with 100 kHz spacing throughout the band. Only about 76 of these are usable in practice due to restrictions in the FCC rules. The maximum transmit power is 30 mW. Two-level power control, with a 16 dB step, is used to prevent the desensitization of base station receivers, and as a by-product, to contribute to improved frequency reuse.

PCI also supports the transmission of data, up to 2.4 kb/s through the speech codec (4.8 kb/s under some circumstances). No other data services are supported except through the use of the signaling channel.

Standard	PCI	CT2
Frequency Band (MHz)	1920 - 1930	864 - 868
Duplexing	TDD	TDD
Carrier spacing (kHz)	100	100
Number of carriers	99	40
Bearer channels/carrier	1	1
Channel bit rate (kb/s)	72	72
Modulation	2 level - FSK	GFSK
Speech Coding (kb/s)	32	32
Frame duration (msec)	2	10
Peak handset TX power (mW)	30	10

In summary, PCI is much like CT2, with operation in the 1920 - 1930 MHz band rather than the 864 - 868 MHz band. With 10 MHz to work with the number of available channels for PCI is much enhanced over CT2. The modulation is exactly the same. But with "Part 15.D etiquette rule" operation, paging, the channel selection algorithm and the call set-up procedures are slightly altered.

Nortel today is marketing PCI with the Companion brand name in the US with their PBX and wireless adjunct products. In conclusion, the PCI standard is an attractive option for wireless communication and has been optimized with respect to cost. It is a low-cost and attractive standard to use in microcell in the mid-tier density for voice and low data rate (in band) applications.

PACS

Like PWT, the PACS standard uses TDMA and TDD. But each carrier only carries 4 duplex bearer channels rather than 12 in PWT. Since PACS only has 4 full-duplex channels per carrier verses 12 full duplex channels per carrier for PWT, each PACS base station does not have the same traffic carrying capacity as a PWT base station. The total number of traffic channels available in the band, however, is about the same between PWT and PACS (and also PCI).

The PACS (unlicensed) standard has been developed from the PHS (PBX) Japanese standard largely by NEC and Panasonic. PHS is designed for low tier public outdoor service, FWA, residential cordless and PBX applications. The PACS as proposed in TIA is adapted to be used for US unlicensed PCS operation. The differences with PHS are primarily in Layer 1 due to the constraints required by the spectrum etiquette rules and channel allocation required by the FCC. Note that the unlicensed version of PACS standardized in the TR41.6 sub-committee is not the same as the licensed and unlicensed versions of PACS (PACS UA and PACS UB) standardized in the JTC. These three versions are reported to be not interoperable.

The PHS allocation consists of 77 channels, 300 kHz in carrier spacing, in the band 1895 - 1918.1 MHz for Japan. This 300 kHz carrier spacing fits well into the required channel spacing for United States isochronous PCS sub-bands 1920 - 1930 MHz. The asynchronous sub-band 1910 - 1920 MHz is not specified for use by PACS.

PACS utilize time division duplex and time division multiple access. Access to radio channels is performed in accordance to the FCC's described etiquette for operation in the unlicensed PCS frequency band (1920 MHz - 1930 MHz). PACS uses dynamic channel assignment.

The modulation used for PACS is $\pi/4$ DQPSK which is the same as PHS. The maximum transmit power per channel is 53 mW. The frame duration is 5 ms. Like the other protocols discussed, PACS and PHS uses 32 kb/s ADPCM speech coding. Unlike DECT/PWT, PACS provides dedicated control channels. The following are some technical details of the PACS air interface :

Frequency band:	1920 - 1930 MHz; US unlicensed PCS band
Number of carriers:	32;
Peak transmit power:	53 mW peak
Carrier multiplex:	TDMA; 4 full-duplex channels;
Frame length:	5 ms;
Basic duplexing:	TDD using 2 slots on same RF carrier;
Channel bit rate:	384 kbps;
Voice encoding:	32 kbps ADPCM;
Radio access/duplex	TDMA - TDD
Number of TDMA multiplexed circuits	4 (when full rate CODEC is used)
Carrier frequency spacing	300 KHz (100 KHz interleaving)
Modulation	$\pi/4$ shifted DQPSK (roll-off rate = 0.5)

PACS protocol structure is divided into three protocol stages with easy adaptation from PHS. In conclusion, the PACS standard is an attractive option for wireless communication in the US, especially for microcell and medium density applications. Its layered protocol structure allows easy migration to PACS for manufacturers with products in PHS. The proximity of the frequency bands between Japan and the USA would permit manufacturers to produce handsets capable of operation in either domain.

Standard	PCI	PWT	PACS
Frequency Band (MHz)	1920 - 1930	1920 - 1930	1920 - 1930
Duplexing	TDD	TDD	TDD
Carrier spacing (kHz)	100	1250	300
Number of carriers	99	8; 16 if 1910 -30	32
Bearer channels/carrier	1	12	4
Channel bit rate (kb/s)	72	1152; 576 kbaud/s	384
Modulation	2 level - FSK	$\pi/4$ DQPSK	$\pi/4$ DQPSK
Speech Coding (kb/s)	32	32	32
Frame duration (msec)	2	10	5
Peak handset TX power (mW)	30	90	53

Closing

This paper has reviewed the three user premise wireless standards for US PCS unlicense band operation. The "etiquette rule" for operation in the PCS unlicense band was also briefly described. PWT offers the highest density microcell operation (8 with option to upgrade to 16 carriers, each carrier supporting 12 full-duplex channels) and with PACS and PCI placing below PWT in traffic carrying capacity.

Three existing working air-interface standards has been adopted from Europe and Japan for operation in the new US PCS unlicense band for fast market deployment. Only extensive changes are necessary in the Physical Layer and slightly modification in the Medium Access Layer are needed to meet the "etiquette rule". The expense of further modification in the higher layers are carefully avoided in the standards committee. This strategy is especially attractive and were supported by manufacturers that already have products for the existing protcols.

Acknowledgments

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