Introduction to Wireless USB - An embedded perspective

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Abstract

The growing amount of content and data creates the need for exploring new technologies that can cope with the huge amount of data traffic for example in the form of audio or video streams.

Wireless USB (WUSB) is one of the most promising, upcoming technologies for device interconnection. It continues the successful story of USB and will provide all features already known from recent USB implementations, plus the fact that no cables are needed anymore.

The whole existing USB infrastructure (i.e. device drivers, USB stack …) can be used just as it has been used up to now. That makes it much easier for developers to switch over to the new technology. The only thing that will change is the media transporting the data. With the concept of “Dual Role Devices”, which is similar to “USB on the go”, new application scenarios will be possible.

WUSB also provides a sophisticated power management mechanism. Hosts and devices implement smart algorithms to save power by switching off the radio and yet stay connected to each other. Host and device have to take care for power management by themselves.

The ultra wideband (UWB) technology is the physical basis of WUSB. It uses an extremely wide frequency spectrum at very low power radiation that works within the range of a few meters. MB-OFDM by the Multiband OFDM Alliance (MBOA) provides data rates of up to 480Mbps.

As with all wireless technologies, security is an important aspect, too. WUSB security will ensure the same level of security as wired USB. Connection-level security between devices will ensure that the appropriate device is associated and authenticated before operation of the device is permitted.

Wireless USB is a big leap in digital communication and will possibly become the ubiquitous connectivity interface. First products can be expected in 2006.

1 Introduction

1.1 What is Wireless USB

The Universal Serial bus (USB) is a mature, widely adopted and well known interconnection standard that has more and more proliferated from personal computers (PCs) into consumer electronics and mobile devices.
Wireless USB (WUSB) will continue the success of the wired Universal Serial Bus by providing the well known performance of its wired predecessor plus the fact that no more cables are required. In fact, it will be a one on one replacement of the wired USB bus.
This paper is a selection of information about Wireless USB, collected on the internet and several scientific databases.

The technical specification of Wireless USB is done by the WUSB Promoter Group [Introd].
It was founded at the Intel Developer Forum in spring 2004 and is comprised of 7 industry leaders, namely: Agere Systems, HP, Intel, Microsoft Corporation, NEC, Philips Semiconductors and Samsung Electronics.
The latest version of the WUSB specification has been released in May 2005 (version 1.0). There is also an erratum available that was released in July 2005.
Both documents can be downloaded at www.usb.org/developers/wusb

Physically, Wireless USB is based on an ultra wideband (UWB) radio standard, specified by the Multiband OFDM Alliance (MBOA) [MBOA].
A common Interface to UWB radios used by WUSB is standardized by the WiMedia Alliance.

1.2 Protocol Stack - WiMedia

WiMedia [WiMe] is a standard focussing on the Wireless Personal Area Network (WPAN) area. It provides a convergence layer for multiple applications to access a common UWB radio. WiMedia can be used to create ad-hoc, interoperable networks for audio, video, and computing devices such as MP3 players, camcorders, digital cameras, and home theatre systems.
WiMedia specifies a series of application profiles (e.g.: digital imaging device or video recorder) that are located on top of the transport, control, and service discovery protocols. These protocols in turn sit on top of the IEEE 802.15.3 Media Access and Physical layer definitions. The 802.15.3 MAC is important because it attempts to provide ease of use, quality of service, and a security framework for a high data-rate WPAN.

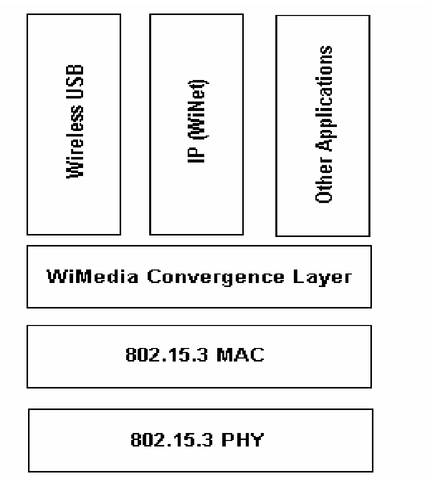

Figure 1:
WiMedia protocol stack layers [MBOA]

1.3 Topology

A WUSB system consists of a host and up to 127 devices connected to it. This structure is named “WUSB cluster”. The connections are point to point and directed between the WUSB host and a single device. Unlike wired USB, there are no hubs needed in this topology. The host initiates all the data traffic and assigns time slots and bandwidth to each device connected.
WUSB clusters co-exist within an overlapping spatial environment with minimum interference. This allows more WUSB clusters to be present within the same radio cell.

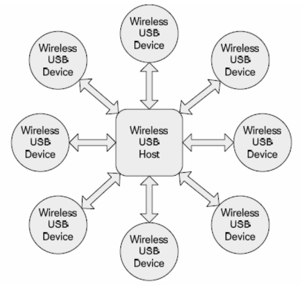

Figure 2: Bus Topology [WUSBWhi]

The bus protocol is time division multiple access- (TDMA) based.
WUSB will be backward compatible with wired USB and bridging to wired USB devices will be possible. Older USB devices can be “upgraded” to talk to wireless devices via a “Device Wire Adapter” (DWA). For hosts, this is the “Host Wire Adapter” (HWA).

Dual Role Devices
WUSB devices can provide device- and limited host-capabilities. If devices support this feature, they are called “dual role devices”.
This is similar to USB On-The-Go (OTG) for wired USB, which was an extension to the original standard. A dual role device (as well as an OTG device) can be connected to a PC as a normal USB device, but can also have USB devices connected to it and act as a host for these devices. For example: a camera (host) can connect directly to a printer (device) without the need for a PC.

Usage Scenarios
Many multimedia devices, like MP3 players, camcorders, PDAs, etc. provide the functionality of exchanging data with a PC or with other devices. USB has established itself to be a common interface for this purpose. Certainly, most devices would benefit from a wireless interconnection.
PDAs that need to be synchronised with the PC for example, would not have to be plugged into an adapter-station anymore. It would be enough to lay them near the PC.
Some consumer electronics applications also require high data throughput. A typical MPEG2 video stream’s bit rate ranges from 3 to 12 Mbps, HDTV requires 19 to 24 Mbps as MPEG2. With an effective bandwidth of 480Mbps, WUSB is capable of handling multiple audio / video streams simultaneously.

1.4 Power Management

Power management is an important aspect in the wireless world. Devices should meet the requirements of today’s mobile devices. A battery lifetime of 2-5 days is what customers expect from a frequently used device.
First of all, WUSB relies on Multiband OFDM radio’s power properties in the physical layer. The ambitious target for the beginning is to stay below 300mW for 480Mbps. This value should decrease to less than 100mW in the future.
A table with more detailed figures can be found in chapter 2.2.2.
Power Management in WUSB is done independently on the host side and on the device side. This means that hosts are unaware of the device‘s internal power management.

There are three ways for devices to save power:

- Power conservation during normal operation by shutting down the radio.The host is unaware of this.
- Device goes to sleep, which leads to extended periods of where the device won’t respond, but still stays connected. It only wakes up occasionally to tell the host that it is still around. The host recognises that and doesn‘t schedule traffic to the device, which saves bandwidth. Devices can go to sleep immediately or only if there is no work pending.
- Device disconnects explicitly and tells it to the host.

Hosts can save power by reducing the data rate or turning off the radio opportunistically. Devices aren‘t aware of this measures, they just see less activity.
Devices should hear something from the host at least every 4 seconds. It is also possible to shut down the radio completely and tell that to the devices.

1.5 Security and Device Association

With wired USB, the user can be pretty sure his data is secure against eavesdropping or manipulation by external instances. An attacker would have to tap the wire to get access to critical data. Naturally, in wireless systems more effort has do be put in securing the communications channel, as it is available for everyone in the proximity of the transmitter.
Security is an issue that is being treated in several layers of the WUSB system. The 802.15.3 MAC, for instance, already includes a security framework and also upper layer parts of the software will have mechanisms like verification during authentication, message integrity codes or cryptography to grant a secure communication.

For establishing a secure connection, WUSB devices and hosts initially have to exchange a so called connection-context (CC). This includes a globally unique host ID, a host-unique device ID and a 128 bit symmetric connection key that is changed periodically.
The CC is always generated on the host and downloaded to the device.
The procedure of device association is to get the CC from the host to the device. This can be a challenge, as it must use a secure transmission channel.
Possible ways to achieve this are:

- Use a cable
- Use UWB radio with encryption and user authorisation
- Use Near Field Communication (NFC)

2 Ultra Wideband (UWB)

2.1 What is UWB

Per definition of the US Federal Communications Commission (FCC), any communications technology that occupies a signal bandwidth greater than 20 percent of the center frequency, or a 10dB bandwidth of more than 500MHz, is called an Ultra Wideband technology [UWB].
UWB allows very high data rates, as it occupies a frequency band of 7.5 GHz (3.1 – 10.6 GHz). It operates on extremely low power at ranges of a few meters.
Development on UWB for consumer applications started in 2002, when in the US the 7.5GHz band was approved for this use by the FCC.
To allow such a large signal bandwidth, the FCC put in place severe power restrictions: maximum -41dBm/MHz effective isotropic radiated power (EIRP), which is below noise emission limits. UWB devices use an extremely wide frequency band, while not emitting enough power to be recognised by other narrow band devices. The wide use of spectrum allows very high data throughput, but devices must be in close proximity.
UWB is based on the efforts of the IEEE 802.15 task group 3a (TG3a).
Today there are two competing proposals: orthogonal-frequency-division-multiplex-UWB (OFDM-UWB) proposed by the MBOA [MBOA] and direct-sequence-UWB (DS-UWB) by the UWB Forum [For]. Because of its robustness to multipath dispersion, to interferers and the ability to sculpt the transmit spectrum [Design], the OFDM approach is the solution selected by the Wireless USB alliance.

2.2 Multiband OFDM

Traditionally, UWB communication systems were designed using very narrow time-domain pulses which occupied a very large frequency spectrum [Approach]. For the hardware design, it was a challenging task to build RF- and analog circuits with large bandwidths and analog to digital converters (ADCs) to process such extreme wideband signals.
The multiband approach alleviates the need of processing such a large bandwidth by dividing the frequency spectrum into smaller sub bands.
The MBOA specified five channels, whereas every device must at least support the first one. Each Channel contains three sub bands that are 528 MHz wide. The fifth channel only contains two sub bands [MBOA] (see also: figure 3).

Dividing the spectrum into sub-bands provides 1.7 GHz of the spectrum to be utilized while the digital signal processing only needs to process a signal bandwidth of approximately 500 MHz. By interleaving the symbols across sub-bands, UWB systems can still maintain the same transmit power as if they were using the entire bandwidth. This results in reduced costs and power consumption at transmitter and receiver side.

Multi-band systems use orthogonal frequency division multiplexing (OFDM) techniques to transmit signals in the sub-bands. OFDM has high spectral efficiency, inherent resilience to RF interference, robustness to multi-path, and the ability to efficiently capture multi-path energy. It is mature and has been proven in other commercial technologies (e.g.: IEEE 802.11a/g).
Initial devices will use the frequency band from 3.1 GHz to 4.8 GHz, because it has been shown that using an upper frequency beyond 4.8 GHz improves the link margin only slightly using current RF CMOS technology. Indeed, limiting the upper frequency has several advantages, like shortening time to market, simplifying the design of the RF and analogue front-end circuits (low noise amplifiers and mixers) and avoiding interference from the 5GHz U-NII band, where IEEE 802.11a signals reside. Of course, as RF technology improves, utilising the entire bandwidth will become more attractive.

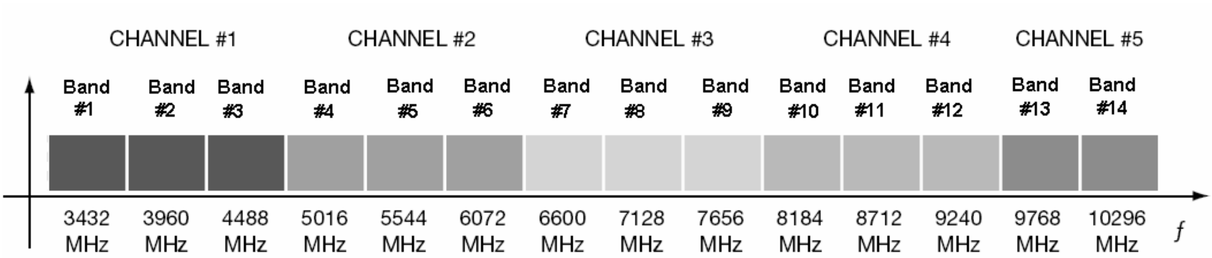

Figure 3: Frequency allocation of sub-bands for a multi-band OFDM system. [UWB]

Figure 4 provides an example of an OFDM symbol-transmission in a multi-band OFDM system. This figure shows that the OFDM symbols are transmitted one by one in consecutive channels. It is also apparent, that a cyclic prefix (CP) is inserted at the beginning of each symbol and a guard interval of 9,5ns is appended. The first is responsible for robustness to multipath distortion. The latter ensures that there is sufficient time for the transmitter and receiver to switch to the next band [Approach].

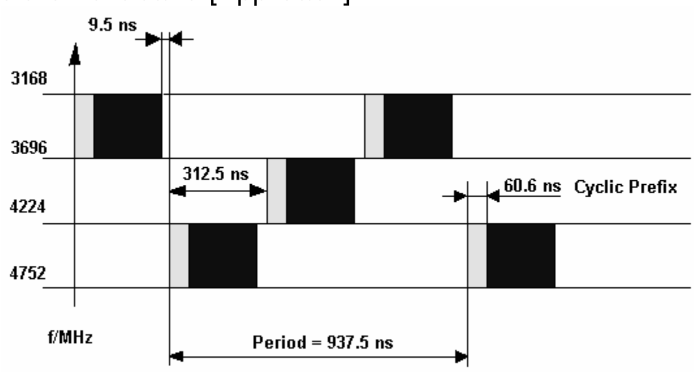

Figure 4: An example of time-frequency interleaving for the multi-band OFDM system. [Approach]

2.2.1 Spectral Flexibility

UWB devices must be able to co-exist together with other transmitting devices that share the same frequency spectrum. Multiband OFDM is robust to narrow-band interferers.
To be more specific about potential interferers, the device must be capable of receiving data from a transmitter at a distance of 10 meters, whereas e.g.: a WLAN transmitter is also sending out signals. This means, a -70 dBm UWB signal must be received in the presence of a nearby +23 dBm transmitter operating at a frequency only a few hundreds of MHz away. Hence a receiver must meet strict noise and distortion requirements over a very large bandwidth.
Additionally, the spectral allocation will differ from country to country. For example, the Japanese government has encouraged wireless system developers to avoid several narrow bands within the UWB spectrum that have been allocated for radio astronomy. Multiband OFDM can comply with local regulations by dynamically turning off certain tones or channels in software. This capability will help with the worldwide adoption of multi-band OFDM systems.

2.2.2 Power Consumption and Complexity

By limiting the transmitted symbols to a quadrature phase-shift keying (QPSK) constellation, the resolution of the DAC/ADC and the internal precision in the digital base band, especially the FFT, can be lowered.

Table 1 shows the estimated power consumption of a multi-band OFDM implementation in 90 nm CMOS technology.

Data Rate	Transmit Power	Receive Power	Deep Sleep Power
110 Mbps	93 mW	155 mW	15 µW
200 Mbps	93 mW	169 mW	15 µW
480 Mbps	145 mW	236 mW	15 µW

Table 1: Estimated power consumption for the multi-band OFDM system in a 90 nm CMOS process [MBOA]

2.2.3 Global Regulations

While spectrum allocation policies around the globe will continue to evolve, proposals from the European Commission and the Japanese Ministry are important definitive steps towards UWB deployment, although the European Commission stated that it's unlikely the EC rules — expected before June 2006 — will be the same as the FCC's [EET]. Tightening or blocking out spectrum bands are easy changes to handle, but if they bring the power levels way down it could scrap some planned applications.
Other countries in Europe and Asia are in the process of allocating UWB spectrum, with several decisions expected this year. South Korea has already issued test licenses for UWB products. Other Asian governments will hopefully move forward by the midyear 2006. Systems based on the WiMedia Alliance specifications will be able to meet Japanese and European requirements with minor changes, and the specification has the flexibility needed to adapt to the requirements of other countries.
Although worldwide harmonization of spectrum policy may be overly optimistic, standardization among the companies leading the UWB charge will enable interoperability, leading to worldwide adoption and widespread commercialization of WiMedia-based UWB technology and products.

3 Certification

Certification, compliance testing and logo licensing will be done by the USB Implementers Forum (USB IF). The only standard supported by WUSB will be WiMedia, which provides a test suite for the USB IF for PHY, MAC and WiMedia conformance.
The USB Implementers Forum provides a one stop compliance testing and certification.

For Companies developing WUSB devices, a Peripheral Development Kit (PDK) for Certified Wireless USB is available from Intel [Intel]. It provides a host-side certified wireless UWB radio solution and consists of a PCI board with an Altera® Excalibur™ FPGA and some simple tools to enhance early debugging. The PDK is used in conjunction with a PHY and a host software stack, both of which must be obtained separately by the customer. The PDK will be compatible with PHYs from the three leading UWB PHY vendors: Alereon, Staccato, and Wisair. The PDK costs $5,000 and does not include the PHY.

4 Chip Vendors

Companies that want to deploy WUSB products in 2006 have started to design their own MACs one year ago. The first chips were all based on a 0.9 version of the WiMedia MAC and PHY specs, and are implemented in FPGAs [EET].
Several hurdles have still to be taken, as standard compliant chip sets must pass several interoperability tests, costs need to come down from expected initial levels of about $10 per node, and regulations in Europe and Asia need to open the door for designs approved by the FCC. The biggest issue in fact will be getting to interoperability [EET].

Alereon	Single Chip WiMedia MAC PHY (also available separately), Antennas, Software Development Kit, Development boards
Artimi	Single Chip PHY, MAC and IO-Controller
Philips Semiconductors	90-nm WUSB end-device MAC based on ARM7; third-party PHY
NEC	MAC with third-party PHY; own PHY in development
Intel	MAC and PHY chips, NFC for device association
Staccato	Single chip solution MAC / PHY, RF processor, memory, IO, Development Kits
Wisair	UWB chipset integrated RF transceiver MAC / PHY Reference designs Development kits
Wipro	Generic UWB MAC supporting Advanced encrypting standard, AES -128 ;plans a WUSB end-device MAC early 2006
Freescale	DS-UWB chipset

5 Summary

Wireless USB will definitely bring convenience into our lives, allowing quick and uncomplicated exchange of data. It is supposed to be a replacement of wired USB.
Implementing this ultra wideband-based technology is a challenge for embedded systems design. First silicon is already available and also developer kits can be obtained. First products are stated to be released in early 2006, but as long as the UWB standard is not established worldwide, use is limited to US.

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