PROTOCOLS FOR HETEROGENEOUS MULTIHOP WIRELESS IPv6

IST-2001-37385 6HOP

D5.1

Standardization Report

Contractual Date of Delivery to the CEC:	**30.06.2004**
Actual Date of Delivery to the CEC:	**07.07.2004**
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Participant(s):	**Philips**
Workpackage/Activity:	**WP5/A.3**
Security:	**Pub.**
Nature:	**R**
Version:	2.0
Total number of pages:	22

Abstract:

This document summarizes the standardization activities of the project partners in WLAN (IEEE 802.11s) and WPAN (IEEE 802.15.3a)

Keyword list: standardization, 802.11, 802.15.3, UWB

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AP	Access Point
BSS	Basic Service Set
CP	Cyclic Prefix
CSM	Common Signalling Mode
DS-UWB	Direct Sequence UWB
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
LAN	Local Area Network
MAC	Medium Access Control
MBOA	Multi-band OFDM alliance
MB-OFDM	Multi-band OFDM alliance
MANET	Mobile Ad-hoc Network
Mbps	Megabits per second
MHz	Megahertz
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical
QoS	Quality of Service
RF	Radio Frequency
SG	Study Group

SSA	Soft Spectrum Adaptation
STA	Station
TFI	Time Frequency Interleaving
TG	Task Group
UWB	Ultra-wideband
WDS	Wireless Distribution System
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

1 INTRODUCTION

The success of any wireless technology depends on the availability of suitable and timely standards. Therefore, in 6HOP is an important task to follow and contribute to the different standardization bodies related to the project.

As already, shown in the “Exploitation and Dissemination plan” (D1.3 & D1.6), wireless local area networks (WLAN) and wireless personal area networks (WPAN) are two main areas of application of the 6HOP results. WLAN is based on the IEEE 802.11 standard. In this standard, there’s a study group (11s) currently working on distributed mesh networks, which is an important topic of the project.

On the other side, the IEEE 802.15 task group 3a is currently standardizing the Ultra-wide band (UWB) technology for high data rate WPAN. The two main applications are cable replacement and CE networking. UWB offers high data rates but with a very limited range (< 10m), so home networking will only be possible with multihop communications.

Since both IEEE 802.11s and IEEE 802.15.3a are directly related to multihop networking, Philips Research Germany has focused its standardization activities in these two groups. This document summarized the technical discussions and contributions to IEEE 802.11s and IEEE 802.15.3a. Due to the novelty of the UWB technology, the document includes also an introduction to the ultra-wideband modulation. The document is completed with a description of the Multiband OFDM and the WiMedia alliances, in which Philips is actively involved and which are related to IEEE 802.15.3a.

2 IEEE 802.11s: ESS Mesh Study Group

At the IEEE 802.11 meeting in Albuquerque in November 2003, the Mesh Networking Study Group (SG) was established. As the name of the SG already indicates, the group is interested in a future mesh network based on 802.11. Therefore the scope of the project is to define procedures that allow building an Extended Service Set (ESS) as a collection of Access Points (APs) interconnected with wireless links that enable automatic topology learning and dynamic path configuration. An ESS Mesh is functionally equivalent to a wired ESS, with respect to the STAs relationship with the BSS and ESS. Hence, the SG will define procedures for a wireless backbone only.

2.1 First meeting on January 2004 in Vancouver, Canada

In the first meeting, Steve Conner, Intel was chosen as the Interim Chair. Donald Eastlake, Motorola, has been approved, by unanimous consent, as Secretary.

In this meeting it has been discussed that the mesh capability shall be implemented in the driver or some daemon. No or minor changes to any firmware shall be needed. Existing devices shall be easily adopted to support a mesh network. The main task of ESS Mesh SG will be to define what a Wireless Distribution System is. The IEEE 802.11-1999 (2003 edition) standard provides a four-address frame format for exchanging data packets between APs for the purpose of creating a Wireless Distribution System (WDS), but does not define how to configure or use a WDS. The purpose of the project is to provide a protocol for auto-configuring paths between APs over self-configuring multi-hop topologies in a WDS to support both broadcast/multicast and unicast traffic in an ESS Mesh using the four-address frame format or an extension. What is being auto-configured, are the paths between APs. This means that there is interoperability at the AP level. To allow a sufficient efficiency of the mesh the amendment will allow the use of one or more transceivers in each Mesh AP.

The question of a definition of mesh was also discussed. Starting from "mesh" just meaning that all nodes are richly connected up to the interpretation of as mesh meaning a topology discovery and dynamic routing procedure different explanations have been given. It was concluded that an ESS mesh is an interconnected set of APs that can form a multi-hop WDS.

Further the ESS Mesh SG has decided to carefully extend the known 802.11 by methods to form a Wireless Distribution System. The WDS has been proposed in the original 802.11 standard, 1999, however, it has never been defined. Therefore first time ever multihop capability shall be introduced to 802.11 via the mesh network. This will allow setup of a wireless backbone.

While the discussion came on the size of a mesh network, people argued that a mesh shall allow thousands of nodes to communicate. It was stated, that one needs to think differently with mesh. The more nodes there are, the more powerful the network and the better chance the data has of getting through. It was argued that the number of hops is what is important. It was stated that a mesh is being deployed across the city of Miami and 3 hops is the relevant limit. It was commented that it could be that in a few years every laptop in the room will be an AP. Maybe the limit should be the number of hops rather than the number of APs. Actually the SG will develop a layer-2 architecture but that should be extensible to allow vendor innovations, such as alternative metrics or protocols, on top of the core protocol.

On the opposite people argued that the SG should not look for the theoretically best solution but for a solution that is available tomorrow. There is desire to define a scope for a standard acceptable by the market that can be developed within a reasonable time. Hence it was pointed out that the motivation in coming up with a 32 AP target was to assure convergence of routing in a dynamic situation. The US Department of Defense Joint Tactical effort to do this for 1,600 to 2,000 nodes is having troubles. The ARPA goal was 10,000 nodes to work together in a mesh. It was also asserted that the MANET working group in the IETF, with a larger scope, is having a lot of trouble coming to a resolution.

A target configuration up to 32 devices participating as AP forwarders in the ESS Mesh was finally proposed. However, larger configurations may also be contemplated by the standard. It was asserted that people will read the letter of the “Project Authorization Request” (PAR) and think of 32 as a ceiling. It was stated that the real problem is in link stability, number of hops, etc. It was suggested that the PAR states up to 32 APs and up to 4 hops with no appreciable degradation of performance. Since a competition between IETF MANET and this SG is not desired, the scope shall be on a much smaller network.

2.2 MARCH 2004 MEETING IN ORLANDO, USA: DEFINITION OF ‘’MESH’

On Tuesday, 2004-03-16, Steven Connor (Intel) reviewed the meeting in Vancouver. His presentation discussed the benefits of mesh networks and questions: What is meant by a “mesh” network in terms of 802.11? The IBSS Ad hoc mode cannot be useful for mesh networks due to the assumption that all devices are in range of each other. Therefore and due to the fact that most of the WLANs use the infrastructure mode a mesh is considered to exist only between APs. Hence new security requirements will be needed: AP2AP authentication, key distribution, data forwarding.

The presentation from Janusys Networks (11-04-0342) discussed technical requirements. As one mesh network contains one or more mesh nodes traffic forwarding paths are calculated at each mesh node. Data frames are forwarded by bridging at mesh nodes. In addition to a hop count the path forwarding protocol may consider other metrics (link quality, data rate etc.) as well. It is proposed that the forwarding protocol should be resistant to temporary link quality instability. Mesh backbone control/management traffic should be protected by mutual authentication, which is to be specified in detail. Mesh nodes shall keep up-to-date association information to support roaming stations within the ESS mesh, regardless of correct re-association or not. QoS at the MAC layer, forwarding methods, multiple radios, access channel selection shall be considered by new proposals. Support for VLAN may be useful for L2.5.

Further on it was mentioned that multiple ESSIDs are problematic. Due to the necessary sharing of APs by different service providers TGs shall provide a solution for this issue. Frequency sharing, support for multiple frequency/radio solutions are considered to be less complicated. Issues regarding the Spanning Tree protocol were discussed, too.

A presentation by James P. Hauser was given during the 802.11 ESS Mesh session. He proposed that to a higher layer protocol all nodes in a LAN must appear to be one hop away from the vantage point. Hence, broadcast must be possible to all other nodes. Since station mobility must be supported he proposed a layer 2.5 routing scheme that supports all kinds of broadcast, multicast and unicast traffic. He mentioned that routing protocols may use proactive or reactive methods. Further on he mentioned issues regarding convergence (the ability of a protocol to form valid routes, affected by link dynamics) of the mesh network. New link metrics and link state advertisement procedures are needed as well. Different broadcast types (e.g. ESS-wide (all 1's), Mesh wide to all APs), have to be respected. Besides this broadcast traffic another procedure for non relayed broadcast might be needed. Regarding multicast traffic the APs have to be aware of buffering the traffic. A mesh network must be aware of synchronization, too. Therefore support for synchronous protocols might be useful. Support for QoS is mandatory. Further on beacon coordination may help to form a consistent mesh network. Hence a scheduled media access might be possible. The AP to AP message format is different from the one hop address format. Hence reserved message type/subtype field may be used. To support management information elements beacon frames may be used. The existing 802.11 WDS message format may be used for data encapsulation of frames within mesh frames. Therefore frame sequence numbers have to be considered in a mesh-wide scope.

User requirements to future mesh networks may address public safety as well as home networking. The project MESA provides detailed use cases on mesh networks, which are worth to study. Theses use cases are way beyond the capability of a 3G cellular system. Can 802.11 provide a solution? Today the New York City Department of Information Technology and Telecommunications (DoITT) already searches to establish a city wide broadband network, running at 4.9 GHz to support law enforcement and emergency troops. Therefore the city of New York has issued a Request for Information (RFI).

Future digital home networks will incorporate today's PCs as an AP. Thus multi hop connectivity is a key requirement in most homes. To further support usage of WLAN technology in a home environment self forming and healing procedures are required. They enable consumer applications to use mesh networks. Support for QoS and fast route discovery is another must. An even faster route switching technology which is highly scalable has to be supported, too. Coexistence support regarding neighboring networks and addressing security issues will be needed. Still the use case for 802.11 mesh networks will be different than for 802.15 mesh networks. To support these future mesh network "hooks into the MAC for link quality metrics" will be needed.

After the mid plenary session, more presentations in the ESS Mesh group were given. Document 11-04-0383 discusses indoor and outdoor scenarios using fixed and/or mobile mesh networks using directed/omnidirected antennas.

Document 11-04-0354 (Nortel Networks) proposes some standardization process specific details.

In document 11-04-257 a prioritized MAC access mechanism of routing related frames is proposed for usage in ESS mesh networks. Since ESS Mesh networks shall support services like “instant messaging” or “push to talk over WLAN (POW)” QoS requirements for ad hoc mesh networks are needed. These address throughput, latency, security, reliability and coverage of the mesh.

Mesh Dynamics gave a software presentation (11-04-272) of their solutions for multiple radio support in mesh networks nodes. Multiple transceivers are managed by the hierarchical structure of the system. Thus a switched stack (802.1d) is built. Each node has a radio that is child to other nodes and another radio which is parent to other nodes/APs. Hence a tree is set up. Thus a root bridge exists. An adaptive control layer talking to the MAC is used to automatically configure this system. Since hardware demonstration has not been allowed by IEEE (due to IEEE own WLAN network), a software demonstration was presented. The distributed procedures calculate in each node the least interfered frequencies. Based on high throughput or low latency needs the topology is set up. In the discussion concerns about the presented hierarchy were asked. Since the TG shall set up mesh networks, but not trees or hierarchical networks some attendees did not agree with Mesh Dynamics approach. Due to military projects mesh dynamics cannot present 3 or 4 radio solutions which are able to setup real mesh networks, not only trees configurations.

It was further proposed to focus on usage models during the next meeting. A straw poll “should usage model documentation and prioritization be a major objective for the May 802.11 Mesh Study Group meeting” has been decided by Yes-No-Abstain: 42-2-3.

The next straw poll on “Should ESS Mesh definition and possible high-level discussions be an objective for the May 802.11 Mesh Study Group meeting?” has been decided by Yes-No-Abstain: 56-1-9.

Cisco argued that a main goal of the whole group should be to learn from .11n where they keep on searching for a usage model for more than more year.

2.3 MAY 2004 MEETING IN ORANGE GROVE, USA: USAGE SCENARIOS

As decided on March 2004, this meeting focused mainly on usage scenarios and usage cases.

Philips Research gave 2 presentations regarding usage scenario and MAC for mesh networks:

- "Mesh networks for home entertainment", Guido R. Hiertz, Yunpeng Zang, ComNets; Jörg Habetha, Philips Research, 04/530
- "Is the 802.11 MAC sufficient for wireless high speed mesh LANs?", Guido R. Hiertz, Lothar Stibor, ComNets; Jörg Habetha, Philips Research, 04/558r2

An Ad hoc group regarding definitions and usage scenarios has been formed and Philips Research is participating in this group. After the meeting Philips and RWTH Aachen have set up a server with web-interface for the 802.11s group, which serves for exchanging documents and contributions and which is currently the main forum of the group.

A probable date for a call for proposals for 802.11s is November.

Few presentations regarded definition questions were given. Some members of the group are concerned about finding the right words, especially there is a misunderstanding about words used in the original 802.11 and how to map that to the ESS mesh world Other presentations explained problems regarding the 802.11 MAC and mesh networks, Philips presentation regarding this issue was backed up by Intel.

Other Documents presented:

- "Defining Usage Models for 802.11 ESS Mesh", Steven Conner, Intel Corp, 11-04/528r1
- "A rationale for security (mis)use cases", Jasmeet Chhabra, Intel Corp. 11-04/586
- "Usage Models for ESS Mesh", Kevin Dick, Kue Wong, Nortel Networks, 04/568r0
- "ESS Mesh Deployment Usage Model", Ted Kuo, Tyan-Shu Jou, Ming Sheu, Janusys Networks, 04/590
- "Usage scenario for ESS mesh network", Hidenori Aoki, Koji Omae and Yoichi Matsumoto, NTT DoCoMo, 04/600
- "Suggested Clarification of 802.11s ESS Mesh Terminology", Steven Conner, Intel Corp, 04/529r1
- "ESS-Mesh: Things That Make Me Go Hmm" Thomas Maufer, Nvidia, 04/602r4
- "Need Clarification on The Definition of ESS Mesh", Tricci So, Radiant Zone, 04/500r1
- "Consideration on WDS Addressing", Tricci So, Radiant Zone,4/501r1

- "Mesh in CAPWAP and AP Functional Definitions", Lily L. Yang, Intel; Tyan-Shu Jou,
- Janusys Networks, 04/595r3
- "Performance Implications of the 802.11 MAC on Multi-Hop Mesh Networks", Xingang Guo, W. Steven Conner, Lily Yang, Intel Corp.
- "Is Spanning Tree Protocol Right for ESS Mesh", Tyan-Shu Jou, Ted Kuo, Ming Sheu, Janusys
- Networks, 04/598
- "On ESS Mesh Device Discovery", Tyan-Shu Jou, Ted Kuo, and Ming Sheu, Janusys Networks, 04/599

3 IEEE 802.15.3a: High Data Rate WPAN

3.1 INTRODUCTION TO ULTRA-WIDEBAND (UWB)

The UWB wireless technology is revolutionary in that it allows data to be sent faster than 802.11a speeds of 54 Mbps and consumes less power than Bluetooth. Transmissions typically consist of rapid bursts of low power RF energy (pico-seconds to nano-seconds) with resulting waveforms covering a broad band of spectrum. High data rate communication with up to 500 Mbps over short distances up to 10 m can be achieved. However, beyond pure high data rate communications (e.g., high speed WLANs, ad-hoc wireless networks, intra-home and intra-office communication), UWB radio can also be used in applications requiring only medium- to low data rates (e.g. in sensor networks for high-resolution indoor positioning and tracking of assets and people, intrusion detection in security systems, obstacle avoidance and motion sensing).

Based on the definition given by the Federal Communication Commission (FCC), UWB waveforms occupy a minimum of 500 MHz of spectrum or the minimal fractional bandwidth should be 0.2, referred to the -10 dB points. The fractional bandwidth is the quotient between the used bandwidth (*B*) and the central frequency (F_c). This is shown in the next equation whereby the power spectrum density at f_h and f_l is 10dB under the maximum. $B_f = \frac{B}{F_c} = \frac{f_h - f_l}{(f_h + f_l)/2} > 0.2$

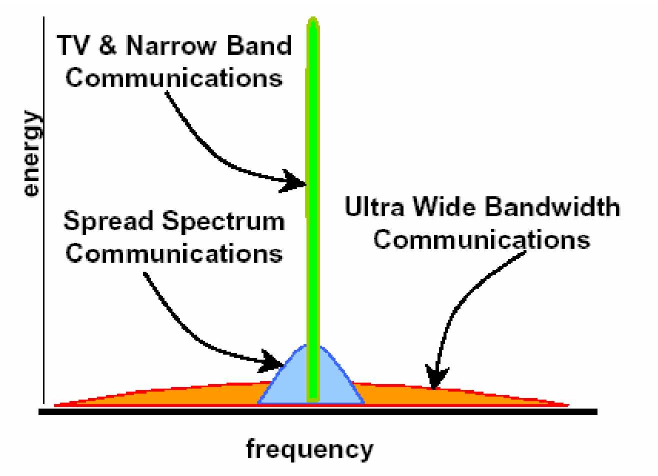

Figure 1 UWB in relation to narrow band and spread spectrum

Figure 1 shows the spectrum width of UWB compared to conventional wireless communication techniques. Because the power of an UWB transmitter is spread across a very wide frequency spectrum, the power spectral density is very low.

Due to the high bandwidth UWB is potentially able to transmit very high data rates. Due to transmission of very short duration pulses over a wide frequency range in impulse radio UWB, UWB systems offer, in contrast to many traditional narrow-bandwidth RF systems, an excellent immunity to multi-path interference. Therefore, the requirement for a margin in the RF link budget is substantially less. Additionally, UWB receivers offer an excellent immunity to interference from other radio systems due to a very high spreading and processing gain. However, it is important to note that UWB may provide a significant increase in channel capacity, but only at limited distance. For this reason, it is an attractive technology for high-rate Wireless Personal Area Networks. (WPAN).

3.2 UWB REGULATION FOR CONSUMER PRODUCTS

UWB has been traditionally used in the military area. However, its interest by the consumer market grew on February 2002, when the FCC decided to permit the use of this technology in certain types of new products, such as short-range, high-speed wireless data transmissions or ground penetrating radar.

For communication and measurement systems, such as networking devices as well as storage tank measurement devices, the rules state that devices must operate in the frequency band 3.1-10.6 GHz and be designed to ensure that operation can only occur indoors, or must be hand-held devices that may be employed for such activities as peer-to-peer operation. Additional frequency and allowable-use restrictions are given for ground penetrating radar, vehicle radar systems, in-wall imaging systems, through-wall imaging systems, medical systems and surveillance systems. The FCC said it was taking a "cautious first step" in allowing the use of UWB in order to ensure the integrity of existing and planned radio services, particularly safety services

According to the FCC Part 90 or Part 15 rules, UWB operation is likely to be contained to the 3.1 – 10.6 GHz band, where transmitted power levels will be required to remain below 41 dBm in that band. To provide better protection for GPS applications, as well as aviation and military frequencies, the spectral density is likely to be limited to a much lower level in the 960 MHz to 3.1 GHz band (see Figure 2).

Regarding the regulation of UWB emissions outside the USA, Europe seems to follow more or less the development of the regulation process. In particular, CEPT/SE24 and ETSI study groups are investigating how to accommodate UWB radio devices within the 1 to 40 GHz frequency range with other radio services.

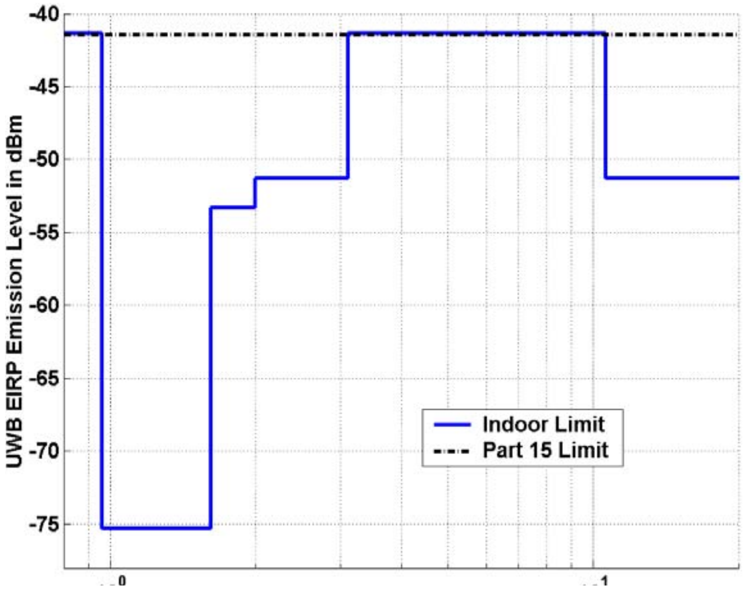

Figure 2 UWB Emission Limit for Indoor Systems

3.3 THE IEEE 802.15 TASK GROUP 3A (http://www.ieee802.org/15/pub/TG3a.html)

The IEEE 802.15 High Rate Alternative PHY Task Group (TG3a) for Wireless Personal Area Networks (WPANs) is currently working on a higher speed PHY enhancement amendment to 802.15.3 for applications which involve imaging and multimedia. For example, users may expect from future ad-hoc PANs support of multimedia services within the following classes of quality-of-service (QoS): conversational (voice), streaming (video/audio), interactive (Web), background data transfer (FTP, etc.). For example, the IEEE study group (SG3a) considers the following system requirements:

- Coexistence with all IEEE 802 wireless PHYs
- Target aggregate data rate of 110 Mb/s and support of 3 to 4 parallel links at up to 10m range for embeddable consumer applications; possible extension to 200 Mb/s (up to 4 m range)
- Robust multipath performance
- Location awareness enabling applications such as range-dependent authentication
- Anticipation of using additional unlicensed spectrum for high-rate WPANs to relieve possible spectrum congestion.

It is evident that these requirements can be met almost only if the alternative PHY system incorporates the principles of UWB. Further applications envisaged under this future standard are very high data rate links replacing short-range cable connections (e.g., up to 480 Mb/s data rate as in IEEE1394 or USB2.0) keeping as much as possible from the MAC as defined in the IEEE 802.15.3 standard.

Since IEEE 802.15.3 standardizes the PHY and MAC layers, the WiMedia alliance will implement a certification and interoperability program for use by all upper layer protocols, in much the same fashion as the Wi-Fi Alliance develops interoperability specifications for wireless LANs based on 802.11

Currently, the Physical Layer that should be adopted as basis for the IEEE's 802.15.3a standard is still under discussion. There are two main proposals, the proposal of the so-called ‘Multiband OFDM Alliance’ (MBOA) and the proposal from XtremeSpectrum and Motorola known as ‘Direct Sequence UWB’ (DS-UWB). The MBOA alliance comprises most of the big Semiconductor manufacturers, among them Philips. MBOA’s is the most voted proposal but it hasn’t reached the 75 percent of votes required to be adopeted as PHY standard. On the other side, the WiMedia Alliance has officially announced its support for the MultiBand OFDM Alliance UWB Specifications

To better understand the ongoing discussions in the IEEE 802.15 TG3a, we will introduce first the Multiband OFDM alliance and the WiMedia alliance.

3.4 MULTIBAND OFDM ALLIANCE (www.multibandofdm.org)

In support of developing the best overall solution for the emerging market in ultrawideband-based technology, the Multiband OFDM Alliance (MBOA) was formed in June 2003 and now numbers over 150 member companies. These companies support a UWB specification that is based on an OFDM approach, originally introduced by Texas Instruments in March 2003, which will enable the broadest possible range of applications and satisfy the requirements of consumers and regulatory agencies worldwide.

The MBOA has been working closely to leverage its collective expertise in the creation and publication of a Multiband OFDM specification for UWB PHY technology and will work in harmony with other UWB standards bodies such as IEEE, WiMedia, Wireless USB Promoter Group, 1394 TA, CEA, and others as appropriate.

The MBOA has developed a specification for the UWB PHY that has been proposed in 802.15.3a and is currently working on the development of a new MAC specification based on the OFDM PHY. The reason for working on a new MAC protocol was that some deficiencies of the 802.15.3 in ad hoc networking scenarios were discovered. The latter are mainly due to the centralized, piconet-based character of the 802.15.3 MAC.

3.4.1 PHY proposal

The multiband OFDM system divides the UWB spectrum (3.1 to 10.6 GHz) into 528-MHz-wide sub-bands and uses OFDM modulation to transmit the information in each subband. The OFDM symbols are then interleaved over three contiguous sub-bands across both time and frequency to provide a robust link and maximum range to support multiple access between piconets. Currently, the multiband

OFDM proposal defines data rates from 55 up to 480 Mbits/s and restricts the constellation size to quadrature phase-shift keying (QPSK).

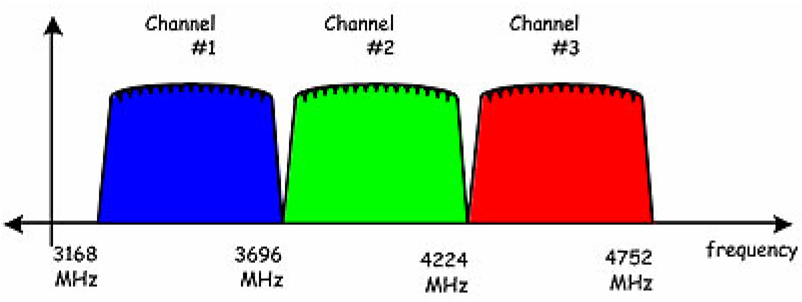

Figure 3 Frequency allocation of sub-bands for a multi-band OFDM system.

Even though the FCC has allocated the entire spectrum from 3.1 GHz and 10.6 GHz for UWB, it has been shown that using an upper frequency beyond 4.8 GHz leads to an improvement in the overall link margin of only 1 dB with current RF CMOS technology. This comes at the expense of higher complexity, and higher power consumption.

The minimal gains in the link budget and the increase in complexity and power consumption lead one to conclude that the bandwidth between 3.1 and 4.8 GHz will provide the most effective bandwidth for initial deployments of UWB devices. Indeed, limiting the upper frequency to 4.8 GHz also has several decided advantages, including shortening time to market, simplifying the design of the RF and analog front-end circuits (low noise amplifiers and mixers), making it more amenable to CMOS technology, and avoiding interference from the U-NII band, where IEEE 802.11a signals reside.

Given the frequency band from 3.1 GHz to 4.8 GHz and the FCC requirement that UWB signals have to be at least 500 MHz, only three sub-bands can be used in the initial deployment of multi-band OFDM systems. Figure 3 illustrates one way to allocate the three sub-bands with the given frequency allocation.

The advantage of using sub-bands of 528 MHz is that the information can be processed over a much smaller bandwidth, thereby reducing the complexity of the design, reducing the power consumption, lowering the cost, and improving spectral flexibility and worldwide compliance. Other advantages of this approach include using lower-rate ADCs and simplifying the digital complexity. Systems built using this type of approach are often referred to as multi-band systems.

OFDM has several nice properties, including high spectral efficiency, inherent resilience to RF interference, robustness to multi-path, and the ability to efficiently capture multi-path energy. It is also well understood and has been proven in other commercial technologies (ex. IEEE 802.11a/g).

The main advantages are that it is easier to collect multi-path energy using a single RF chain, relaxed switching times, insensitivity to group delay variations, and ability to deal with narrowband interference at the receiver without having to sacrifice sub-bands or data rate. The only drawback of this type of system is that the transmitter is slightly more complex because it requires an IFFT and the peak-to-average ratio may be slightly higher than that of the pulse-based multi-band approaches.

The frequency planning shown in Figure 3 was chosen for two reasons. First it allows sufficient guard band on the lower side of channel number 1 and the upper side of channel number 3 to simplify the pre-select filter's design. Second it ensures that both the transmitter and receive can switch to the next center frequency within a few nanoseconds.

Figure 4 provides an example of how the OFDM symbols are transmitted in a multi-band OFDM system. This figure shows that the first OFDM symbol is transmitted on channel number 1, the second OFDM symbol is transmitted on channel number 3, the third OFDM symbol is transmitted on channel number 2, the fourth OFDM symbol is transmitted on channel number 1, and so on.

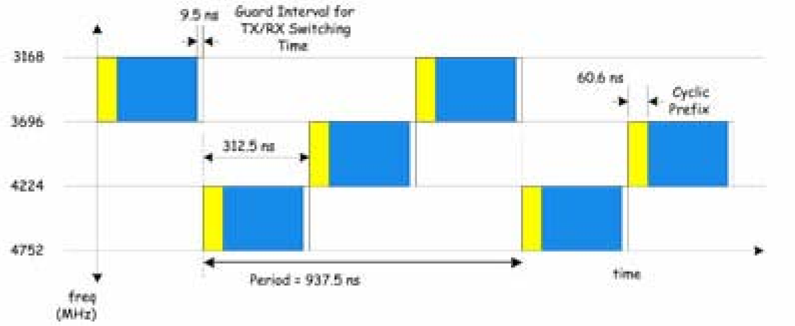

Figure 4 An example of time-frequency interleaving for the multi-band OFDM system

In Figure 4, it is assumed that time-frequency interleaving (TFI) is performed across just three OFDM symbols. In practice, the TFI period can be much longer. The exact length and pattern of the TFI may differ from superframe to superframe and piconet to piconet.

From this Figure, it is also apparent that a cyclic prefix (CP) is inserted at the beginning of each OFDM symbol and a guard interval (9.5 ns) is appended to each OFDM symbol. The guard interval has been inserted to ensure that only a single RF transmitter and RF receiver chain are needed for all channel environments and all data rates and that there is sufficient time for the transmitter and receiver to switch to the next channel.

To provide the best trade-off between the CP overhead and FFT complexity, the multiband OFDM system uses 128 tones. To be compliant with FCC regulation, the 10-dB bandwidth of an UWB signal ought to be at least 500 MHz. This implies the use of at least 122 tones. Hence, the 128 tones are partitioned into 100 data tones, 22 pilot tones and 6 null tones.

Among the 22 pilot tones, 12 would be standard-defined pilot tones and 10 would be user-defined pilot tones. The 12 standard-defined pilot tones are sufficient to estimate/track phase variations due to carrier/timing frequency mismatch. To relax the specifications on the channel select filter, the tones at the edge of the spectrum are either null tones or user-defined pilot tones.

3.4.2 MAC proposal

The present IEEE 802.15.3 MAC, which is based on a centralised MAC protocol, is unable to solve all the mobility and CE requirements and issues as well as the needs of all the isochronous and asynchronous applications and related issues for UWB systems. There are certain features the 802.15.3 MAC doesn't have, mostly mobility centric such as mesh and roaming and the ability to handle dynamically varying environments.

For this reason, the MBOA is developing a new MAC that combines proposals made by Philips, Sony and Alereon, and was unanimously approved by 54 participants representing 24 companies. This MAC allows for the reservation of timeslots for 802.15.3-like time-division multiple access for high priority connections requiring determinism while assigning contention-based, best-effort access periods. The two main access mechanisms of the MBOA MAC have been proposed and specified by Philips Research.

A key requirement for the MAC is decentralization, along with the notion that every node will announce its connections and with whom its exchanging data. Along with facilitating roaming and reducing dropped connections, the mesh capability also provides a spatial frequency reuse capability so devices that are out of range of each other can communicate independently.

3.5 THE WIMEDIA ALLIANCE (www.wimedia.org)

The WiMedia Alliance is a not-for-profit open industry association formed to promote personal area wireless connectivity and interoperability among multimedia devices in a networked environment. The Alliance develops and adopts standards-based specifications for connecting wireless multimedia devices including application, transport, and control profiles; test suites; and a certification program to accelerate widespread consumer adoption of "wire-free" imaging and multimedia solutions.

WiMedia's founding members also included XtremeSpectrum Inc., the developer of DS-UWB. XSI was bought last year by lead investor Motorola. Also some MBOA members like Intel, Texas Instruments, Alereon, Appairent Technologies, Hewlett-Packard, Philips, Samsung, Sharp and STMicroelectronics-on the WiMedia board of directors.

Since the incorporation of Intel and Texas Instruments as directors, the WiMedia Alliance board has endorsed the Multiband-OFDM Alliance's ultrawideband media-access control and physical layers as the foundation for its common radio platform for personal-area networking

Now that WiMedia has a clearer idea of what the media-access control and physical layer may look like, the group will proceed to develop a convergence layer. Work on that crucial layer has been in limbo since the alliance's formation in 2002 because its characteristics depend to a large degree upon the MAC and PHY.

One important aspect of this convergence platform is Wireless USB (W-USB), which is a protocol adaptation layer that will make USB links compatible with UWB. The alliance is also looking to adapt 1394 and UPnP links over UWB.

3.6 TG3A UPDATE

3.6.1 November 2003 meeting in Alburquerque, USA

Different papers discussing PHY layer details were presented at TG3a. A ballot was won by OFDM against UWB. Still it was discussed whether UWB is the better approach. Regulatory issues were a main reason. All voters against OFDM were given a chance to state their opinion on an OFDM solution.

3.6.2 March 2004 meeting in Orlando, USA

On Monday, 2004-03-15, the Document 15-04-085r0 presented an UWB coexistence study. It was proposed to introduce a Common Signaling Mode (CSM). A CSM may use one common mode for all multiple PHYs, e.g. BPSK. Here it is proposed that the CSM shall work in MB-OFDM band 2 using BPSK modulation. Hence, CSM may be used for coexistence of MB-OFDM and DS-UWB, since the CSM information can be easily understood by DS-UWB and MB-OFDM systems. The CSM shall allow time slot requests and allocations. It may further be used to support a global synchronization of all participating stations. The CSM presentation was followed by a heavy discussion. Pros and cons of such a “separate” MAC were discussed. Some attendees feared the CSM may be used to rule out the existing 802.15.3 MAC proposal. Another concern is that the CSM may only be motivated to satisfy both opposed industry camps and that for technical reasons it makes no sense to allow both MB-OFDM and DS-UWB coordinated by the CSM.

On Tuesday, 2004-03-16, the Document 15-04-099 presented DS-UWB responses to MB-OFDM no voter comments. Again it was stressed that a coexistence solution for OFDM DS-UWB and MB-OFDM called Common Signaling Mode (CSM) was available. People were encouraged to contribute to a Soft Spectrum Adaptation (SSA) to ensure world-wide compliance with different regulations. Furthermore, the system performance and complexity of DS-UWB was analyzed. Another part of the presentation was spent on narrow band interference and forward error correction. The presentation closed comparing multi path robustness and complexity of both approaches. The last topic regarded the clear channel assessment in the MB-OFDM approach. The presentation was followed by a fierce discussion regarding the technical merits of the two proposals MB-OFDM and DS-UWB.

On Thursday, 2004-03-18, the concerns of the “No-voters” to the MBOA proposal were discussed (see 15-04-099). The DS-UWB supporters argued that regulatory items might not be met. They claimed that the DS-UWB proposal offered higher data rates and less interference. It was argued that the DS-UWB proposal was more scalable and less complex. Further on it was argued that the signaling tones in MBOA caused broadcasting noise. To overcome incompatibility between both approaches the DS-UWB supporters proposed once again the common signalling mode (CSM). It has to be noted that the DS-UWB camp has by far the minority of votes (around 40%), which are only coming from a relatively small set of companies. This is why the DS-UWB camp is attacking the MB-OFDM proposal heavily and why at the same time they are trying to preserve their solution with the Common

Signalling Mode. Document 15-04-163 discussed harmonizing of the MB-ODFM and the DS-UWB approach. Of course the Common Signaling Mode (CSM) is a key element. According to the DS-UWB camp this mode should be a mandatory base mode required to be implemented in all devices. The CSM shall be used for control signaling & data traffic (e.g. Beacons, 9.2Mb/s data rate). Compliant devices can implement either DS-UWB or MB-OFDM for higher rates. The common frequency plan for all modes allows using a cheap 26MHz cell phone XO to implement the CSM. Hence the CSM center frequency is 3978 MHz, which is the same as the band #2 center frequency for both MBOA and DS-UWB.

Document 15-04-164 presented a study on scaling for higher rates of DS-UWB and MB-OFDM.

Soft Spectrum Adaptation (SSA) regarding DS-UWB implementations is discussed in document 15-04-0130. SSA provides the ability to generate multi band pulses of 3-3.8 ns duration. Thus it provides a possible implementation in software which is very flexible. SSA may be used for future UWB standards. It is adaptive to regulatory items. Dynamic pulse waveform shaping proposed here can satisfy the FCC spectral mask.

3.6.3 May 2004 meeting in Orange Grove, USA

There was still no consensus in the PHY and the MBOA was not very interested in more technical discussions, since the outcome was unlikely to change in any case.

Compromise discussions have been taking place between MBOA and the DS-UWB leadership teams. Talks are also taking place between the MBOA and Motorola to reach a common position on the international regulatory issues facing UWB.

It can be expected that both camps continue to work out their solutions independently of the IEEE and go to the market. As mentioned before, the MBOA has gained a huge momentum with over 150 member companies and it can be expected to become a de facto standard similar to Bluetooth, which was also originally specified by a Special Interest Group (SIG) like MBOA.

4 CONCLUSIONS

In this report the participation of 6HOP members in the relevant international standardization bodies was summarized. Among the 6HOP partners, Philips was the one to attend the standardization meetings. Philips as a whole is present in many different standardization groups. However, in this report only those working groups were reported, in which members of the 6HOP project participated. 6HOP decided to participate in IEEE 802.11s, as it is the working group, which is working on mesh networking for 802.11 and thereby of great relevance for 6HOP. The group is still in the discussion phase. No technical proposals are to be submitted yet. However, Philips participated in the discussion intensively and made several contributions regarding current problems of 802.11 as well as potential usage scenarios and terminology. The second standardization group in which 6HOP, respectively Philips participated was IEEE 802.15.3 and the Multi-band OFDM alliance. This group was selected because 6HOP was considering heterogeneous networks consisting of WLAN as well as WPAN links. 802.15.3 and the MBOA are standardizing the next generation WPAN system based on UWB, which will be the successor of the Bluetooth system. Even though the system is standardized on layers below the 6HOP focus, it was of great importance to 6HOP to be aware of the possibilities and limitations of the new technology. In summary, the participation in standardization was very helpful to understand the current developments and to promote the work of the 6HOP project.