# 60GHz: Opportunity for Gigabit WPAN and WLAN Convergence

L. Lily Yang
Intel Corporation
lily.l.yang@intel.com

This article is an editorial note submitted to CCR. It has NOT been peer-reviewed. The author takes full responsibility for this article's technical content. Comments can be posted through CCR Online.

## ABSTRACT

60 GHz is considered the most promising technology to deliver gigabit wireless for indoor communications. We propose to integrate 60 GHz radio with the existing Wi-Fi radio in 2.4/5 GHz band to take advantage of the complementary nature of these different bands. This integration presents an opportunity to provide a unified technology for both gigabit Wireless Personal Area Networks (WPAN) and Wireless Local Area Networks (WLAN), thus further reinforcing the technology convergence that is already underway with the widespread adoption of Wi-Fi technology. Many open research questions remain to make this unified solution work seamlessly for WPAN and WLAN.

## Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

## General Terms: Design

**Keywords:** millimeter wave, mmWave, 60GHz, Gigabit Wireless Networks, Gigabit WPAN, Gigabit WLAN

## 1. WHY 60 GHZ?

Strong commercial interest in using the 57-66 GHz band (also known as the millimeter wave band, or mmWave band in short) for indoor wireless communications is evidenced by the recent industrial and standard development efforts in several international standard bodies including ECMA TC48, IEEE 802.15.3c and the proposed IEEE 802.11 VHT60 Task Group. See Section 5 later for details of these activities.

Why all the excitement about 60 GHz?

First of all, the abundance of the bandwidth in the unlicensed 60 GHz band is unmatched in any of the lower frequency bands. Figure 1 shows the available spectrum for indoor wireless communication around the world. The fact that this band is unlicensed and largely harmonized across most regulatory regions in the world is a big advantage, in contrast with the meager spectrum available in the lower frequency bands for existing technologies such as Wi-Fi. For example, there is only 70 MHz available in the 2.4 GHz band and 500 MHz in the 5 GHz band for Wi-Fi, compared to the multiple GHz available in 60 GHz. The current 11n draft allows channel bandwidth of 20 and 40 MHz. While MIMO (Multiple Input Multiple Output) technology such as spatial multiplexing has given 11n a huge boost in performance, there is a practical constraint in the number of antenna that can be packed onto the small form factor devices with reasonable cost. Theoretically, 11n using four antennas in the spatial multiplexing mode with 40 MHz channel bonding and short guard interval can reach 600 Mbps PHY data rate. However, there is not yet a commercial 11n product in the market that uses more than 3 antennas, and so increasing number of antenna is not a practical way to achieve gigabit data rate. Another obvious way to achieve higher data rate beyond 1 Gbps in the 2.4 and 5 GHz bands is to increase the channel bandwidth beyond 40 MHz. However, as the physical (PHY) data rate increases, the Media Access Control (MAC) overhead also increases at a faster rate, and so the effective MAC throughput does not scale linearly with the PHY rate. MAC efficiency analysis in [6, 10] shows that to reach 1 Gbps MAC throughput, the PHY rate has to be at least 2 Gbps when the Transmission Opportunity (TXOP) is 3ms, which requires at least 120 MHz of channel bandwidth. While there is not even enough bandwidth in 2.4 GHz to achieve that, practically, it is also very challenging to bond such a wide channel in 5 GHz band due to the co-existence issue with legacy devices that operate in 20 and 40 MHz channels.

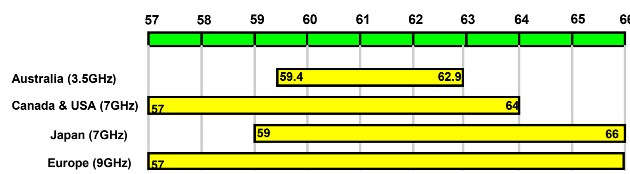


**Figure 1 Available spectrum in 60GHz band for indoor wireless communication around the world**

On the other hand, the 60 GHz band boasts a wide spectrum of up to 9 GHz that is typically divided into channels of roughly 2 GHz each. Both ECMA [1, 2] and 15.3c [3] drafts employ a similar channel plan that divides the 60 GHz spectrum into channels of 2.16 GHz each. Such wide channels make it easy to achieve gigabit data rate even with relatively simple modulation and coding schemes. For example, using relatively simple modulations such as QPSK (Quadrature Phase Shift Keying) or 16-QAM (Quadrature Amplitude Modulation), the SC (Single Carrier) PHY mode in 15.3c draft can achieve up to 2.664 or 4.965 Gbps of PHY rate, respectively [3]. Thus, it is clear that the abundance of bandwidth makes gigabit wireless feasible in the 60 GHz.

While UWB (Ultra-wideband) technology leverages a much wider channel (each band is 528 MHz), its maximum power is severely limited by regulation (Equivalent Isotropically Radiated Power, or EIRP for short, cannot exceed -41.3 dBm under FCC regulations) comparing to 60GHz (EIRP 40 dBm), and so is its performance.

Another important factor that contributes to (industry) excitement in the 60 GHz space is the recent advances [12, 17] of using

CMOS (Complementary metal–oxide–semiconductor) technology to build inexpensive and low power 60 GHz transceiver components. This advance makes it feasible to use the 60 GHz radio for mass market applications.

## 2. 60 GHZ CHANNEL PROPERTIES

Before we examine the applications and usages that may be feasible for 60 GHz, we should first understand the channel properties of this band.

First of all, 60 GHz band comes with a large free space propagation loss (about 20 dB more than that in 5 GHz band) which must be compensated for by high gain directional antennas in order to reach decent range, such as more than 1 meter. Fortunately, high gain directional antennas are feasible to implement even for small form factor devices due to the relatively short wavelengths of about 5 mm. Such directional antennas can be implemented either with a sector antenna that can be switched from sector to sector or an adaptive antenna array that can be configured into different radiation patterns.

Secondly, 60GHz channel generally exhibits quasi-optical properties, meaning the strongest components tend to be Line of Sight (LOS). Non Line of Sight (NLOS) components do exist, but mostly in the form of reflection. However, the short wavelengths in this band impose some serious challenges such as greater signal diffusion and difficulty diffracting around obstacles. 60 GHz band measurements [13] show that in general, the strongest reflected components are at least 10 dB below the line of sight (LOS) component. Even more challenging are the problems caused by obstructions. A human body walking into the path between the transmitter and the receiver can attenuate the signal by 15 dB or more and easily break the link. Common objects such as furniture, walls, doors and floors found in indoor environments can also be problematic. As a result, the practical indoor operation range at 60 GHz is likely to be limited by penetration loss instead of free space propagation loss and therefore mostly confined to a single room. In comparison, the link characteristics are very different in the lower frequency bands such as 2.4/5 GHz, where penetration loss is less, rich multi-path exists to provide diversity, and the range can reach up to hundreds of meters.

## 3. WPAN and WLAN CONVERGENCE

What are the main applications or usages for the 60 GHz indoor wireless communications? The usages for the 60 GHz span the Wireless Personal Area Networks (WPAN) and the Wireless Local Area Networks (WLAN). The main difference between the WPAN and the WLAN is the traffic pattern. The primary purpose of WLAN is to provide backhaul connectivity to the devices so all the traffic are routed to and from the AP (Access Point), with a star or tree topology traffic pattern. On the other hand, the WPAN traffic is mostly peer to peer traffic between two or more devices. As we examine the usages carefully below, it becomes clear that other than the difference in traffic pattern, there is really no significant difference in any other measure between WPAN and WLAN (data rate, range, channel condition, data type, power requirement, etc.). Therefore, the boundary between WPAN and WLAN usages has already blurred in terms of the requirements.

### 3.1 WPAN Usages

Three main usages fall into the category of the WPAN applications.

#### *3.1.1 Sync-n-go*

Sync-n-go rapidly transfers data from one device to another. It may be downloading a multimedia file like HD (High Definition) movie from a Kiosk to a handheld device; it may also be exchanging data such as photos between two peer to peer devices such as cell phones. The speed is the key to make this usage compelling, especially when the amount of data is huge. Sync-n-go typically does not involve a range beyond 1 meter, and so LOS channel is generally available. However, some usages such as sync-n-go with a device in the pocket would require it to operate with NLOS condition.

#### *3.1.2 Wireless Display*

Wireless Display replaces the video cable such as HDMI (High-Definition Multimedia Interface) or Display Port cable for both consumer electronic applications such as wireless TV in the living room, and for productivity applications such as wireless projector in a conference room or a wireless computer display in an office. The key enabler for such usages is the pristine video quality that people associate with wired display. HD resolutions generally require gigabit performance, even with light compression. Wireless Display generally requires in-room coverage, and the exact range depends on the specific environment. For example, 1-2 meter may be sufficient for desk top display, but a range of 5-10 meters may be needed for the projector in a conference room or for the TV in a living room. It is impractical to guarantee LOS due to the clutter commonly found in the home or office environment, and so NLOS is generally required.

#### *3.1.3 Wireless Docking*

Wireless Docking replaces the wired connector or cable between mobile computing devices such as laptops or Mobile Internet Devices (MIDs) and their peripheral devices. The wireless docking station may be embedded into a display or monitor, or it may be a fixed standalone device. Mobile devices such as laptops or MID are connected wirelessly to the docking station when in the office. Other fixed devices such as keyboard, mouse, printer, and storage device (e.g., a hard drive) may be plugged into the docking station either via a wired interface (e.g., USB) or wirelessly. As wired interfaces strive toward multiple Gbps link rate (for example, PCIe2 and USB3 at 5 Gbps, and PCIe3 toward 8 Gbps), wireless IO would need to keep up with such increasing demand of the performance as well. A range of a few meters would be needed for wireless docking with NLOS channel in a room.

### 3.2 WLAN Usages

WLAN is all about providing Internet connectivity wirelessly to mobile and nomadic devices at home, enterprise and hot spots. Even though Wi-Fi 11n can provide capacity up to multiple hundreds of Mbps, it can still be challenging to meet the requirement of bandwidth-intensive usages such as enterprise backup service in WLAN because the capacity is shared among many users. As wired Ethernet already reaches 10 Gbps, it is natural to look for the next performance enhancement to push WLAN beyond Gbps. The 60 GHz radio can potentially provide the performance boost for WLAN users. One may question whether the 60 GHz radio can deliver the similar range that is being delivered with the existing WLAN Access Points (AP). Indeed the 60 GHz radio cannot match the maximum range (up to several hundred meters) that can be delivered by the 2.4 or even 5 GHz radio. However, the actual operational range for many of the WLAN deployments is already in the order of 10s of meters, which is not too much bigger than the range the 60 GHz can deliver. Because many of the current WLAN deployments are performance limited, not range limited, APs already tend to be deployed rather densely today in order to achieve higher link throughput and higher network capacity. 60 GHz is the next evolutionary step for WLAN to provide higher data rate, though at a shorter range, as it has been the evolutionary path of 802.11 technology, from 802.11b to 802.11g/a, then to 802.11n.

### 3.3 A Unified Technology for WPAN and WLAN

Given that WPAN and WLAN already look very similar from the usage requirement's point of view, there is really no reason to believe that these usages require different wireless technology. We believe technology convergence for WPAN and WLAN is already underway. Wi-Fi has clearly become the technology of choice in the WLAN market, providing Internet connectivity for homes, enterprises and hot spots. We have also started to see Wi-Fi being used beyond WLAN into WPAN spaces. There have been multiple efforts to make IEEE 802.11 technology more friendly to peer to peer usages, including first the ad hoc mode and then 11s mesh networking amendment [18] that is still in its draft development stage. Even though ad hoc mode was not used widely and successfully in the market, 802.11s promises to enable single hop and multi-hop peer to peer usages for Wi-Fi devices. Most recently, Wi-Fi Alliance Group (WFA) [19] has also started a Peer to Peer Task Group to enable Wi-Fi technology development, certification and market adoption for peer to peer usages.

If Wi-Fi is considered the unified technology of choice today for WLAN and WPAN usages, we believe 60 GHz represents an opportunity to further reinforce this technology convergence by boosting the performance of WPAN and WLAN to gigabit level in the near future.

As pointed out in Section 2, 60 GHz channel can be challenging to work with in real world environments such as offices and homes, due to obstructions from common objects like furniture and people moving around. In particular, wireless display, wireless docking and WLAN usages demand NLOS channels, but the quantity and quality of such NLOS channels vary greatly from one room to another, depending on many factors such as construction material, wall surface, furniture and fixture material, fabrics, and people's activities. Robustness may be a big challenge, especially in situations when many people may be moving around. On the other hand, the Wi-Fi solution in lower frequency band (2.4/5 GHz) is already proven to be much more robust in the indoor environments with better range and excellent NLOS channels due to rich scatters.

The complementary nature of 60 GHz band and the lower 2.4/5 GHz band makes multi-band solutions a very appealing approach to address the future need of WPAN and WLAN usages. This means the Wi-Fi devices that need a boost of gigabit performance will be upgraded by replacing their 2.4 or 5 GHz radio to multi-band radio(s) that can operate in 2.4/5 GHz and 60 GHz bands. Such multi-band devices can leverage 60 GHz to provide the gigabit wireless performance when it is needed the most and when it is feasible to obtain. On the other hand, when the range or channel condition causes link outage in the 60 GHz band, e.g., when the range is beyond the range of the 60 GHz in a WLAN deployment, or when a LOS link for wireless display is temporarily blocked by someone walking by, it has the choice to fall back to lower frequency bands so that the application is not severely disrupted.

This multi-band solution will provide a unified technology that can effectively address the needs of both WPAN and WLAN usages and hence further the technology convergence that is already underway today.

## 4. RESEARCH CHALLENGES

In this section we will outline the potential benefits, requirements and some of the design issues we need to address in multi-band design. Many of these issues are still open areas that require further exploration.

### 4.1 Integration Benefits and Challenges

We have discussed the benefit of improved robustness by leveraging the *band diversity* that is provided by the different bands. Multi-band integration can potentially provide other benefits in addition to improved robustness. For example, if a link is already established in one band, it may facilitate faster link establishment in the other band. More specifically, device discovery in 60 GHz can be time-consuming due to the directivity of 60 GHz link. One 60 GHz device looking for other 60 GHz devices needs to employ some kind of omni-communication because there is no prior knowledge of the existence and the direction of the other devices. Having a link already established in 2.4 or 5 GHz enables, some information about the other multi-band devices to be communicated more quickly in 2.4 or 5 GHz band to speed up the discovery process in the 60 GHz band.

It is also possible to leverage channels in both the 60 GHz band and the lower band(s) to further improve the performance for multi-band devices. For example, throughput can be aggregated for the devices by using simultaneous communication channels in both the 60 GHz band and the 2.4 or 5 GHz band.

Many open questions and challenges remain to realize such integration. For example, where would be the ideal integration point in this multi-band architectural framework? The answer partly depends on how similar or different we believe the radio stack (antenna, PHY, MAC, etc.) would look like across the bands. We believe the MAC for 60 GHz would be quite different from the existing one in Wi-Fi lower bands, and Section 4.2 will detail the reasoning behind it. In Section 4.3 and 4.4 we will list some of the requirements, such as interoperability of mixed devices in one network, and the need to participate in multiple networks. Section 5 explores the concept of band switching and radio concurrency.

### 4.2 Media Access Mechanisms

Given the very different channel properties of the 60 GHz band, the antenna, RFIC and baseband design for the 60 GHz would be quite different from that of 2.4 or 5 GHz band [17]. We also have strong reasons to believe that the media access mechanism for 60 GHz would be quite different from the CSMA/CA based media access mechanism for Wi-Fi in the 2.4 and 5 GHz bands.

First and foremost, the current design of CSMA/CA assumes that devices in the same physical proximity can carrier sense and overhear each other because omni-directional antenna is mostly used in 2.4 and 5 GHz bands and so all communications can be assumed to be broadcast at the physical level. This is no longer the case in 60 GHz, because high gain directional antenna would be employed in order to reach decent range. This directivity fundamentally violates the assumption of CSMA/CA and so direct reuse does not make sense.

Another reason that we may want to modify the MAC is that current 802.11 MAC does not provide strong QoS guarantee, which may be acceptable for Internet connectivity type of applications but not acceptable for high performance media application such as wireless display. Media access such as TDMA (Time Division Multiplex Access) that can provide better QoS assurance is probably needed. While TDMA typically is used successfully for licensed band applications such as cellular networks, it is relatively unproven for unlicensed band applications such as 60 GHz. The main difficulty with TDMA in unlicensed band is to cope with the interference from independent overlapping networks without causing instability in the networks. The fact that networks in 60 GHz may typically employ directional communication between devices can somewhat mitigate such a problem as directional communication helps lesson the probability of interference and hence improves space reuse [11][14].

For these reasons, we believe media access mechanism for 60 GHz would be quite different from that of existing Wi-Fi at 2.4 and 5 GHz. This begs the question of how these different media access mechanisms be reconciled or integrated in the multi-band framework. Such reconciliation needs to be investigated carefully.

## 4.3 Devices of Mixed Capabilities

Some devices would have multi-band capability; that is, these devices would be able to operate in both the 60 GHz and the lower band(s) (such as the 2.4 or 5 GHz band). But not all devices would be dual-band or tri-band capable; some devices may operate only in the 60 GHz bands, and some devices may operate only in the 2.4 or 5 GHz band only. Obviously any two devices that want to communicate with each other must find a common band to operate in, but it is possible to have a WLAN or a WPAN that includes devices of mixed capabilities, as shown in Figure 2.

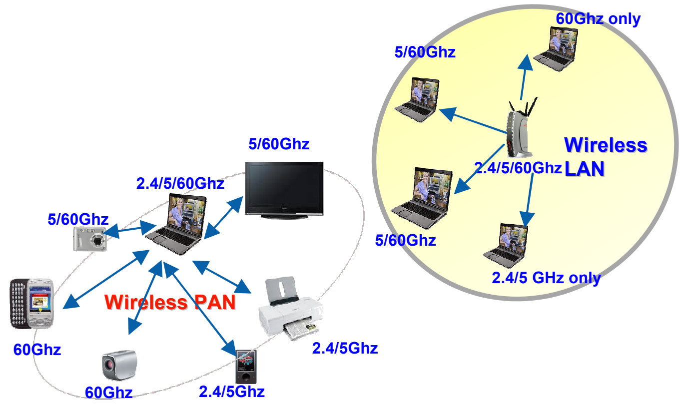


Figure 2 Examples of WPAN and WLAN that include devices of mixed capabilities

## 4.4 Participating in Multiple Networks


Figure 3 A usage scenario where a device may desire to participate in more than one network at a time

Another interesting usage scenario that needs to be supported is for a mobile device to be actively participating in more than one network at a time; for example, a laptop user may want to connect to the Internet via WLAN AP while at the same time it also wants to participate in wireless docking in a WPAN, as shown in Figure 3. This may impose some special requirements as the device that participates in multiple networks has to find a mechanism to time share the radio resources among different networks. It also requires the networks to be tolerant of such "intermittent devices" [16] because the device may not be able to connect to any network all the time and so it appears to be "intermittent" in its connectivity to any given network. How to maintain satisfactory performance in each network that it participates in is also an interesting research topic.

## 4.5 Radio Concurrency and Band Switching

Depending on how tightly the 60 GHz radio and 2.4/5 GHz radio are integrated, a multi-band device may or may not be able to have both radios operating concurrently. Therefore it is important to have the flexibility of allowing both configurations to function in the network. If two radios can be used concurrently, it opens up the possibility of using both bands to further optimize the performance for the device and the network beyond what a single radio can provide. On the other hand, full concurrent operations may consume too much power for the mobile devices. If we don't want to have two radios operate simultaneously for a long period of time, then how and when to switch from one band to another is also an interesting question to consider.

Another general requirement that needs to be satisfied is co-existence with other systems in the proximity that may operate in the same operational bands as these devices.

It is clear that there are many open research and design challenges to address in order to achieve the benefits of multi-band integration. This research requires clear definition of the usages and the objective of integration in terms of both performance and power.

## 5. 60GHZ STANDARD ACTIVITIES

ECMA TC48 [1, 2] is developing a 60 GHz PHY and MAC standard to provide high rate WPAN transport. The usage cases are high definition (uncompressed or lightly compressed) AV streaming, wireless docking station and short range sync-n-go. The IEEE 802.15.3c Task Group [3] is also developing a millimeter-wave-based alternative PHY for the existing 802.15.3 WPAN Standard 802.15.3-2003. This mmWave WPAN will support at least 1 Gbps and optionally 2 Gbps for applications such as high speed internet access, streaming content download, multiple real time HDTV video streams and wireless data bus for cable replacement.

In 2007, the IEEE 802.11 working group also began a new "Very High Throughput" study group (VHT SG) [4] to investigate technologies that can support performance beyond 802.11n for WLAN. The Wi-Fi Alliance (WFA) was consulted to develop usages for VHT. The six categories of usages envisioned [5] include wireless display, in home distribution of video, rapid upload and download to and from a remote server, mesh or point-to-point backhaul traffic, campus or auditorium deployments, and manufacturing floor automation. The VHT SG has been exploring possible solutions in both the microwave and mmWave bands, acknowledging that each band presents unique challenges and opportunities. The intention of the VHT SG is to pursue two parallel efforts in two separate task groups. One of them, called VHTL6 Task Group, is chartered to develop enhancements in microwave bands that are below 6 GHz. The other task group is called VHT60 Task Group with the charter to develop a solution that leverages 60 GHz band to achieve higher link throughput.

## 6. CONCLUSIONS

The industry is positioning 60 GHz radio as a high performance radio that is capable of delivering gigabit performance in a wide range of usage scenarios. We propose to integrate 60 GHz radio with the existing Wi-Fi radio in 2.4/5 GHz band to take advantage of the complementary nature of these different bands and hence provide a unified technology for both gigabit WPAN and WLAN. This integration would give the industry an opportunity to further reinforce the technology convergence that is already underway with the widespread adoption of Wi-Fi technology. There are still many open research and design questions that need to be answered in order to realize this technology vision.

## 7. Glossary

WPAN: Wireless Personal Area Networks

WLAN: Wireless Local Area Networks

PHY: Physical Layer

MAC: Media Access Control

MIMO: Multiple Input Multiple Output

QPSK: Quadrature Phase Shift Keying

QAM: Quadrature Amplitude Modulation

SC: Single Carrier

LOS: Line of Sight

NLOS: Non Line of Sight

HD: High Definition

HDMI: High Definition Multimedia Interface

MID: Mobile Internet Device

WFA: Wi-Fi Alliance Group

TDMA: Time Division Multiplex Access

CSMA/CA: Carrier Sense Multiplex Access with Collision Avoidance

## 8. REFERENCES


[1] ECMA TC48 – High Rate Short Range Wireless Communications, http://www.ecma-international.org/memento/TC48-M.htm

[2] ECMA TC48 draft standard for high rate 60 GHz WPANs White Paper", http://www.ECMA-international.org/activities/Communications/tc48-2008-024-Rev1.doc, Feb 2008.

[3] IEEE 802.15 WPAN Millimeter Wave Alternative PHY Task Group 3c (TG3c), http://www.ieee802.org/15/pub/TG3c.html

[4] IEEE 802.11 Very High Throughput Study Group (VHT SG), http://grouper.ieee.org/groups/802/11/Reports/vht_update.htm

[5] A. Myles, R. de Vegt, "Wi-Fi (WFA) VHT Study Group Usage Models", IEEE 802.11-07/2988r4, 2007

[6] M. Park, C. Cordeiro, E. Perahia, and L. L. Yang, "Millimeter-Wave Multi-Gigabit WLAN: Challenges and Feasibility", Invited paper for IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), September 2008.

[7] C. Park, T. S. Rappaport, "Short-Range Wireless Communicaitons for Next-Generation Networks: UWB, 60 GHz Millimeter-Wave WPAN, and ZigBee", IEEE Wireless Communications, August 2007

[8] N. Guo, R. C. Qiu, S. S. Mo, K. Takahashi, "60-GHz Millimeter-Wave Radio: Principle, Technology and New Results", EURASIP Journal on Wireless Communications and Networking, 2007

[9] P. Smulders, "Exploiting the 60 GHz Band for Local Wireless Multimedia Access: Prospects and Future Directions", IEEE Communications Magazine, Jan. 2002

[10] M. Park, "Analysis on IEEE 802.11n MAC Efficiency," IEEE 802.11-07/2431r0

[11] L. Yang, "60GHz for Gigabit WPAN and WLAN: Opportunities and Challenges", Intel Developer Forum, San Francisco, Aug 2008, http://intel.wingateweb.com/US08/published/sessions/FUTS006/SF08_FUTS006_100p.pdf

[12] S. K. Moore, "Cheap chips for next wireless frontier," *IEEE Spectrum*, vol. 43, 2006.

[13] H. Xu, V. Kukshya, and T. Rappaport, "Spatial and Temporal Characteristics of 60 GHz Indoor Channels," *IEEE Journal in Selected Areas in Communications*, April 2002.

[14] L. L. Yang, M. Park, "Applications and Challenges of Multi-band Gigabit Mesh Networks", Mesh 2008 (Best paper award), Cap Estera, France, August 2008

[15] J. Kivinen, "60-GHz Wideband Radio Channel Sounder," IEEE Trans. on Instrumentation and Measurement, vol. 56, no. 5, Oct. 2007

[16] X. Yang, J. Zhu and X, Guo,"Study on Intermitten WLAN Consisting of Heterogeneous Multi-radio Devices", 13th IFIP International Conference on Personal Wireless Communications (PWC 2008), Oct 2008, Toulouse, France (Best paper award).

[17] C. H. Doan, S. Emami, D. A. Sobel, A. M. Niknejad, and R. W. Brodersen, "Design Considerations for 60 GHz CMOS Radios", IEEE Communications Magazine, December.

[18] IEEE 802.11s Mesh Networking Task Group, http://grouper.ieee.org/groups/802/11/Reports/tgs_update.htm

[19] Wi-Fi Alliance Group, http://wi-fi.org/