Abstract

During the past few years, research covering propagation, channel characterization, and wireless system performance has yielded a substantial knowledge of the 60 GHz channel. The unlicensed 60 GHz frequency band presents many attractive properties for wireless communications. This paper addresses some wideband propagation characteristics for broadband wireless LANs (BWLANs). Important system-design characteristics, from measured results obtained from two wideband 60 GHz LOS radio links, are presented. Measurements were undertaken using the swept-frequency channel-sounding method. Analysis from the complex frequency responses in a worst-case scenario has yielded a lower-coherence-bandwidth value of 5 MHz. Minimum and maximum coherence bandwidths, obtained with a directional-horn transmitting antenna and an omnidirectional receiving antenna, were 1.10 MHz and 105.33 MHz, respectively. It was observed that the coherence bandwidth fluctuated significantly with the location of the receiver with respect to the base station. These results can be used for the modeling and design of future BWLANs.

Keywords: Local area networks; broadband communications; land mobile radio data communication; millimeter wave propagation; millimeter wave communication; communication channels; land mobile radio propagation factors; millimeter wave measurements; multimedia communication

1. Introduction

Broadband wireless LANs (BWLANs), earmarked for future wideband wireless services in the 60 GHz band, are envisaged with data-transmission rates up to 150 Mbit/s [1-13]. The 60 GHz band is of much interest, since this is the band in which massive amounts of spectral space (5 GHz) have been allocated worldwide for dense wireless local communications [2]. In addition, the 60 GHz front-end technology is emerging rapidly. There are a number of multimedia applications for short-range communications. Indoor applications are likely to include wireless access to local-area networks, the successful implementation of which requires a detailed knowledge of radio-propagation modes inside buildings. It is of great importance to determine exactly what information is required from the measurements and their consequent applications. Essentially, measurements should be capable of providing information pertinent to both accurate channel modeling (i.e., simulation), and the implementation of radio systems and networks. This paper deals with experimental results conducted at 62.4 GHz from measured responses taken in two indoor environments of a university building to characterize the channels' frequency-correlation function. Section 2 outlines some services, applications, and characteristics of broadband wireless systems. Section 3 explains the measurement setup, the environment, and
the procedure used for the experiments. The last section presents the concluding remarks and future work.

2. Services, Applications and Characteristics of Broadband Wireless Systems

The system concepts of a WLAN (wide-area local network), such as HIPERLAN, and of a broadband cellular system, such as a BWLAN, are different: they are directed toward services and applications that differ in many aspects. A comparison of several systems concerning two of the key features (mobility and data rate) is shown in Figure 1 [3], where it is clear that no overlap exists between the two approaches. The differences are more salient when other parameters are compared (Table 1 [3]).

3. 60 GHz Broadband Wireless LAN Environment and Measurement Setup

3.1 Transmitter

Figure 2 shows the block diagram of this system [14]. At the transmitter, the synthesized output of a vector network analyzer (VNA: HP8714C) is step-swept between 1-2 GHz. This is then up-converted (mixed) to a 62.4 GHz carrier, prior to transmission. The phase-locked oscillator (PLO) can be either synthesized from a 100 MHz internal oven-controlled crystal, or from an external reference. The up-converter has an IF bandwidth from dc to 6 GHz, and can also be used as a modulator. The output of the up-converter consists of two sidebands at a level approximately 6-7 dB below the swept-IF signal level. The upper sideband, with frequencies between 63.4 GHz and 64.4 GHz, is passed through a filter. The bandpass filter, with pass-band specified at 63.4 GHz and 65.4 GHz, also suppresses the lower sideband between 60.4 GHz and 61.4 GHz.

Table 1. A comparison of HIPERLAN and BWLAN characteristics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HIPERLAN</th>
<th>BWLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner/Operator</td>
<td>Private system, owned by the user</td>
<td>Public and private system</td>
</tr>
<tr>
<td>Objective</td>
<td>Extension or replacement of fixed LANs</td>
<td>Mobile and wireless extension to or</td>
</tr>
<tr>
<td>Applications</td>
<td>Primarily indoor and on-premises computer</td>
<td>replacement of fixed B-ISPDN</td>
</tr>
<tr>
<td>Services/Data Rates</td>
<td>MAC layer (bearer) service rates: &lt;20 Mb/s for asynchronous services 64 kb/s up to 2.048 Mb/s for time-bounded services</td>
<td>ATM cell transfer capability; up to 150 Mb/s</td>
</tr>
<tr>
<td>Communication</td>
<td>Connectionless</td>
<td>Connectionless and connection-oriented</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>No, only HIPERLAN nodes with functions for transmitting and receiving, and optionally for forwarding, bridging, and internetworking</td>
<td>Yes, cellular system consisting of mobile stations, base stations comprising transceivers, controller, and interworking units</td>
</tr>
<tr>
<td>Configurations</td>
<td>Standalone, ad-hoc networking, integration or MAC-level bridging with other LANs, internetworking with other networks</td>
<td>Stand-alone, integration with B-ISPDN, internetworking with other networks</td>
</tr>
<tr>
<td>Mobility</td>
<td>Up to 36 km/h</td>
<td>Up to 100 km/h</td>
</tr>
<tr>
<td>Coverage</td>
<td>Locally &quot;unlimited&quot; due to forwarding of active nodes</td>
<td>&quot;Unlimited&quot; due to cellular infrastructure and handover</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 50 m at 20 Mb/s and up to 800 m at 1 Mb/s</td>
<td>Up to 1 km, depending on antenna and frequency</td>
</tr>
<tr>
<td>Channel Access</td>
<td>FDMA/TDMA, variable data packets (up to 24322 bit), no frame structure, contention mode with priority</td>
<td>FDMA/TDMA, frame structure with fixed time slots and transmission bursts (356 symbols)</td>
</tr>
<tr>
<td>Frequency Bands</td>
<td>5.15-5.30 GHz, 17.1-17.3 GHz</td>
<td>39.5-40.5 GHz and 42.5-43.5 GHz, 62.0-63.0 and 65.0-66.0 GHz</td>
</tr>
<tr>
<td>Duplexing</td>
<td>1 frequency TDD</td>
<td>2 frequencies FDD, up to 4 carriers in parallel</td>
</tr>
<tr>
<td>Physical Channel Access</td>
<td>23.5 Mb/s</td>
<td>40 to 150 Mb/s</td>
</tr>
<tr>
<td>Modulation</td>
<td>GMSK</td>
<td>4- and 16-OQAM</td>
</tr>
</tbody>
</table>

3.2 Receiver

At the receiver, a 62.4 GHz phase-locked oscillator is synthesized from the same 100 MHz oven-controlled crystal by connecting a 50 m Sucoflex flexible coaxial cable (very low loss: 0.23-0.73 dB/m) from the transmitter to the receiver. The 1-2 GHz signal is coherently detected, amplified by an LNA (low-noise amplifier), with bandwidth of 900-2000 MHz and 32 dB gain. It then is fed back through a second 50 m Sucoflex flexible coaxial cable to the receiving port of the vector network analyzer, to measure the channel’s transfer function. The channel-sounding system was calibrated in an anechoic chamber.

3.3 Antennas

Two antenna configurations were used in the measurements. Two standard horns were used at the transmitter and receiver in the first configuration. In the second configuration, a standard horn and an omnidirectional antenna were used as transmitting and receiving antennas, respectively. The standard horn, with a gain of 10 dBi, had 3 dB beamwidths of 69° and 55° in the E and H planes, respectively. The omnidirectional antenna had 6 dBi of gain, and full azimuth coverage with a 6.5° E-plane (elevation) beamwidth [15]. It consisted of two reflector plates supported by a hollow plastic cylinder, as shown in Figure 3.

3.4 Environment and Analysis of Measured Results

Frequency-response measurements were obtained in two indoor line-of-sight (LOS) channels. The first environment comprised a corridor (4.00 × 1.91 × 2.68 m; see Figure 4), located on the second floor corridor of a four-story building. The corridor had windows in alcoves, a fixed metallic heater, wooden doors to various rooms, and plasterboard sidewalls covered with a thin metal sheet. The floor was covered with vinyl plastic tiles, and the ceiling was covered with polystyrene tiles to which neon lamps were attached over the length of the corridor. The above scenario is considered to be the worst-case scenario for a typical 60 GHz system.

The second environment (12.80 × 6.92 × 2.60 m) was a lecture room, with thick walls made of bricks and concrete blocks, and with a carpeted floor and a ceiling made of polystyrene tiles. Cubic-shaped electric metallic heaters and windows were present on one wall. There was also a metallic fire door with two white boards. The tables and chairs were arranged in order to simulate an office environment. Two measurement links were set up, one with the room empty and another with furniture.

In the corridor, the transmitter was mounted on a box and kept stationary at one end. The receiver was displaced to different loca-

Figure 3. The millimeter-wave band omnidirectional antenna.

Figure 4a. The lecture room 60 GHz broadband wireless LAN environment.

Figure 4b. The corridor 60 GHz broadband wireless LAN environment.
Figure 5. The frequency-correlation functions obtained in the corridor. Curve a (the upper, thicker line on the left) is for a separation of 1.5 m (probe), curve b (the lighter, central line) is for a separation of 18.09 m, and curve c (the lower line) is for a separation of 37.80 m.

Table 2. The statistics of the coherence-bandwidth function for the 0.9 correlation level for the corridor and the room, for the cases investigated.

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Min</th>
<th>Max</th>
<th>S/D</th>
<th>Mean</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horn-Horn</td>
<td>1.3</td>
<td>84.5</td>
<td>16.0</td>
<td>14.1</td>
<td>38.0</td>
</tr>
<tr>
<td>Horn-Omni</td>
<td>1.1</td>
<td>105.3</td>
<td>16.4</td>
<td>11.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Room</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furniture</td>
<td>5.8</td>
<td>75.6</td>
<td>21.5</td>
<td>31.3</td>
<td>62.8</td>
</tr>
<tr>
<td>Empty</td>
<td>6.8</td>
<td>82.6</td>
<td>23.3</td>
<td>23.3</td>
<td>72.0</td>
</tr>
</tbody>
</table>

A rapid decrease of the frequency-correlation function with respect to the frequency separation and, also, as the receiver moved away from the base station, were observed. The decrease of the frequency-correlation function was not monotonic, and this was due to the presence of multipath echoes in the mm-wave radio channel. The 90th percentile of the coherence bandwidth at a correlation level of 0.9 for the corridor values stayed below 38 MHz. The minimum and maximum $B_{0.9}$ coherence bandwidths, obtained with a directional-horn transmitting antenna and an omnidirectional receiving antenna, were 1.10 MHz and 105.3 MHz, respectively (Table 2). The coherence-bandwidth function for the 0.9 correlation level as a function of the receiver position for the corridor is shown in Figure 6. It can be observed that the coherence bandwidth was highly variable with changes in the location of the receiver with respect to the base station [16, 17]. Strictly speaking, the highly fluctuating coherence bandwidth means that the system designer can only rely on the lower values of this parameter in such an environment. From Figure 6, this is about 5 MHz.

4. Conclusions and Future work

The huge amount of transmission capacity required for broadband wireless LANs can only be accommodated in the 60 GHz frequency band. The mm-wave bands are of special interest for indoor applications, because of the potential for frequency reuse. There is a massive amount of spectral space allocated worldwide for dense wireless local communications. It is extremely important to determine exactly what information is required from the measurements, and what are the applications. Measurements should be capable of providing information pertinent to both accurate channel modeling, and to the design evaluation of radio services. The 90th percentile of the coherence bandwidth at a correlation level of 0.9 for the corridor values stayed below 38 MHz. The minimum and maximum $B_{0.9}$ coherence bandwidths obtained with a directional-horn transmitting antenna and an omnidirectional receiving antenna were 1.10 MHz and 105.33 MHz, respectively. The lower coherence bandwidth value obtained in a worst-case 60 GHz scenario was 5 MHz. It was observed that the coherence bandwidth fluctuated significantly with the location of the receiver with respect to the base station. The reasons for the fluctuations were shown to be due to the presence or absence of frequency selectivity in the channel response, which varied significantly with small displacements in the position of the receiver. The measurement results presented in this paper can be used to refine the existing 60 GHz channel models, and to assist in the development of new models.

Future research work is recommended in the following directions:

- Performance evaluation of 60 GHz indoor radio channels, to include data transmission and BER measurements. This evaluation can be based on directly measurement results.
- The application of various diversity, equalization, modulation.
tion, and coding techniques for wideband 60 GHz multi-
path channels represents a challenging area for future re-
search.

- Deterministic modeling using ray-tracing of 60 GHz indoor
radio channels.

- Statistical propagation modeling might be considered, based
on an extensive measurement data pool.

- Indoor-outdoor mobile characterization in various 60 GHz
environments, to include second-order channel statistics,
e.g., Doppler spectra, angles of arrival, and average fade
statistics.

- Determination of an asynchronous transfer method, tailored
to handle broadband information traffic in a wireless LAN.
Items such as transfer mode, duplex method, error control,
multi-access control, and OFDM could be investigated.

- Biological effects on human tissues and SAR in the human
operators exposed to 60 GHz EM radiation in environments
likely to occur in WLAN applications.

- Design of low-cost antenna solutions operating at 60 GHz.

- Charting out everything that should be done to pave the way
towards affordable high-voltage production of 60 GHz
front-end MMICs.

5. References

Reuse and System Capacity in Mobile Broadband Systems: Com-
parison between 40 and 60 GHz Bands,” Wireless Personal Com-

2. P. F. M Smulders, “Exploiting the 60 GHz Band for Local
Wireless Multimedia Access: Prospects and Future Directions,”

band Communications,” IEEE Communications Magazine, 34, 1,

4. L. Fernandes and L. M. Correia, “Project R2067-MBS,” Pro-
cedings of the Joint COST 227/231 Workshop on Mobile Com-
munications, September 1993, pp. 156-171.

Communications,” International Workshop on Telecommunica-

Study, PhD thesis, Eindhoven University of Technology, The

7. Jay E. Fadgett, Christoph G. Gunther, and Takeshi Hattori,
“Overview of Wireless Personal Communications,” IEEE Commu-

8. Jose J. G. Fernandes, Peter A. Watson, and Jose C. Neves,
MmW Systems,” IEEE Communications Magazine, 32, 8, August
1994, pp. 68-73.

9. Walter Honcharenko, Jan P. Kruys, David Y. Lee, and Nitin J.


105 GHz and Associated European Table of Frequency Alloca-

Characterization of Fading in LOS Wireless Channels with a Finite
Number of Dominant Paths. Application in Millimeter Frequen-
cies,” International Journal of Infrared and Millimeter Waves, 20,

Broadband Wireless Indoor Networks at Millimeter Waves,”
International Journal of Infrared and Millimeter Waves, 21, 2,

broad Characterisation and Measurements at 62.4 GHz,” PhD the-
esis, University of Glamorgan, United Kingdom, June, 2001.

15. H. B. Abdullah, “Microwave and Millimeter-Wave Omni-
directional Antennas in the Azimuth Plane for Mobile Communica-

Measurements for Future Millimeter 60 GHz Wireless LANs,”
Electronics Letters, 38, 16, August 2002, pp. 918-920, ISSN 0013-
5194.

17. M. O. Al-Nuaimi and A. G. Siamarou, “Coherence Bandwidth
Characterization and Estimation for Indoor Rican Multihop Wire-
less Channels Using Measurements at 62.4 GHz,” IEE Proceed-
ings on Microwaves, Antennas and Propagation, 149, 5, June

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