Exploiting the 60 GHz Band for Local Wireless Multimedia Access: Prospects and Future Directions

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ABSTRACT

This article addresses basic issues regarding the design and development of wireless access and wireless LAN systems that will operate in the 60 GHz band as part of the fourth-generation (4G) system. The 60 GHz band is of much interest since this is the band in which a massive amount of spectral space (5 GHz) has been allocated worldwide for dense wireless local communications. The article gives an overview of 60 GHz channel characteristics and puts them in their true perspective. In addition, we discuss how to achieve the exploitation of the abundant bandwidth resource for all kinds of short-range communications. The main tenor is that an overall system architecture should be worked out that provides industry with plenty of scope for product differentiation. This architecture should feature affordability, scalability, modularity, extendibility, and interoperability. In addition, user convenience and easy and efficient network deployment are important prerequisites for market success. This article discusses these features and indicates a number of key research topics.

INTRODUCTION

There exists a multitude of multimedia applications calling for wireless transmission over short distances. Examples of applications, together with estimates of required data rates and cost requirements, are listed in Table 1. The data rate figures refer to individual connections rather than aggregate network capacity, which may be multiples of these figures. Table 1 illustrates that the required data rate for some applications may be hundreds of megabits per second and that the range of data rates is very wide. The large variety of applications indicates that the wireless infrastructure should support real-time traffic with largely varying delay constraints as well as non-real-time traffic with different reliability requirements. Flexible network solutions are required to accommodate the large number of communicating devices. In particular, the flexibility requirement is prominent in ad hoc network architectures that have multihop capabilities with many different operators in the same areas. Furthermore, Table 1 indicates that in many applications, information integrity plays a vital part and thus should be well secured. The significance of all this is that next to the network capacity required to accommodate the actual application, there is much additional transfer capacity needed for quality of service provisioning and key features such as dynamic resource allocation and routing and security protocols for data integrity and protection against unauthorized access. Table 1 also indicates that many applications require low-cost technology.

Third-generation cellular systems will not be based on low-cost technology and will not be able to cope with data rates in excess of 2 Mb/s. This is where wireless local area network (WLAN) systems come into the picture. Current WLAN products are proprietary systems or based on the IEEE 802.11b standard. These products operate in the industrial, scientific, and medical (ISM) 2400–2483.5 GHz band and provide a (gross) user capacity up to 11 Mb/s. In 1999 the IEEE ratified the WLAN standard IEEE 802.11a, which provides physical layer input data rates of 6, 9, 12, 18, 24, 36, and 54 Mb/s. In the United States these products operate in the 5.15–5.35 and 5.725–5.825 GHz Unlicensed National Information Infrastructure (UNII) band. High Performance Radio Local Area Network (HIPERLAN) Type 2, the standard specified by the European Telecommunications Standards Institute (ETSI) project Broadband Radio Access Networks (BRAN), defines the same physical layer with the exception that it provides one additional data rate, 27 Mb/s. In Europe, a license-exempt frequency band at 5.15–5.35 GHz and 5.470–5.725 GHz has been reserved for HIPERLAN. In the United States HIPERLAN products must operate in the

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Application	Capacity per user [Mb/s]	Low cost requirement
Wireless LAN bridge, e.g., for interconnecting GigaEthernet LANs in different buildings	100–1000	No
Wireless virtual reality allowing free body movements	450	Yes
Wireless IEEE 1394	100, 200, 400	Yes
Wireless TV high-resolution recording camera	150–270	No
Wireless trading terminal having multiple video channels that can be viewed simultaneously for monitoring world news next to stock quote information	50–100	No
Wireless news tablet, a very thin, possibly flexible device that provides the user with a newspaper, e.g., the possibility of activating images to see video impressions	50–100	Yes
Wireless (high-quality) videoconferencing	10–100	Yes
Wireless Internet download of lengthy files	10–100	Yes
Wireless ad hoc communications, i.e., direct communication between notebooks, between notebook and nearby printer, etc.	0.1–100	Yes
Wireless interactive design	20–40	Yes
Hospital bedside application allowing wireless retrieval of patient's status including X–ray pictures	10	Yes
Wireless surveillance cameras allowing face and number plate recognition at long distances	4–10	Yes
Patient monitoring (patients can walk freely around in the hospital or even at home) with devices that transmit ECG, blood pressure information, etc.	2	Yes
Wireless videophone	1.5	Yes
Wireless connection between domestic appliances and the Internet (e.g., a refrigerator scans its contents and orders the nearby supermarket to deliver what is missing	0.1	Yes
Wireless billing (e.g., automatic payment for petrol service via wireless connection between car and filling station)	0.1	Yes
Road pricing	0.1	Yes
Wireless burglar alarm (wireless window sensors, etc.)	0.01	Yes
Remote control (TV, lighting, door/window lock	0.01	Yes
Wireless embedded systems (e.g., in car between oil filter and dashboard)	0.01	Yes

Table 1. *Examples of short–range wireless multimedia applications.*

UNII band. In Japan both systems have to use the 5.15–5.25 GHz band with sharing rules. HIPERACCESS is an extension that provides outdoor fixed radio access at 25 Mb/s to customer premises in various bands that are still to be determined. These throughput figures guarantee the support of an interesting subset of multimedia services. However, limitation to 25 Mb/s does not allow the support of many attractive but bandwidth-demanding services listed in (the upper part of) Table 1, particularly not if the wireless medium has to be shared with many users, which is typically the case in a LAN. Instead, an aggregate network capacity of many hundreds of megabits per second may be required. In principle, there are two ways to achieve such considerably higher network capacity: increasing the spectral efficiency and/or using more bandwidth.

Using higher order modulation methods such as M-ary quadrature amplitude modulation (M-QAM) can increase spectral efficiency. In practice, a bandwidth efficiency can be obtained on the order of 4–8 b/s/Hz. This has to be paid, however, with considerable transmit power; for example,, a doubling of the spectral efficiency requires 12 additional dBs in the link budget if a bit error ratio of 10^{-3} has to be maintained.

An alternative method of increasing spectral efficiency is to exploit space by using multiple transmit and receive antennas and transmitting different data streams on the different transmit antennas simultaneously. Various approaches can be followed. One method, known as space-time coding, is to encode the data by a channel code and split the encoded data into a number of parallel streams that are simultaneously transmitted on the different transmit antennas. Another technique is to properly exploit multipath scattering by using an appropriate processing architecture. It

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has been demonstrated that in such a way bandwidth efficiencies of 20–40 b/s/Hz can be reached [1]. This is not paid with transmit power but with complexity in terms of processing power (for channel estimation) and number of transceivers because each transmit/receive antenna stands for a complete transmitter/receiver.

A third method is to create spatially orthogonal channels with the help of high gain antennas aimed accurately at each other. This is particularly of interest for static interconnections such as HIPERLINK which is, as part of the HIPERLAN family, intended to provide static indoor links with a transport capacity of 155 Mb/s. HIPERLINK is planned to operate at 17 GHz in a band that spans a few hundred megahertz. For transmission schemes with moderate spectral efficiency, however, many hundreds of megahertz are required. In order to find that much spectral room, still higher frequencies have to be considered.

In the European Advanced Communications Technologies and Services (ACTS) program the 19, 40, and 60 GHz bands have been addressed by various research projects under which AWACS, SAMBA, and MEDIAN with target radio bit rates of 70, 2   64, and 150 Mb/s, respectively [2]. In Japan the Multimedia Mobile Access Communication (MMAC) committee is looking into the possibility of ultra-high-speed wireless indoor LANs supporting 156 Mb/s using 40 and 60 GHz. For dense local communications, the 60 GHz band is of special interest because of the specific attenuation characteristic due to atmospheric oxygen of 10–15 dB/km. The 10–15 dB/km regime makes the 60 GHz band unsuitable for long-range (> 2 km) communications, so it can be dedicated entirely to short-range (< 1 km) communications. For the small distances to be bridged in an indoor environment (<50 m) the 10–15 dB/km attenuation has no significant impact. The specific attenuation in excess of 10 dB/km occurs in a bandwidth of about 8 GHz centered around 60 GHz. Thus, in principle there is about 8 GHz bandwidth available for dense wireless local communications. This makes the 60 GHz band of utmost interest for all kinds of short-range wireless communications. In the United States, the Federal Communications Commission (FCC) set aside the 59–64 GHz frequency band for general unlicensed applications [3]. This is the largest contiguous block of radio spectrum ever allocated. FCC rules allow 10 W of equivalent isotropic radiated power (EIRP) in this band, which complies with a maximum power density of 9   W/cm2 at 3 m distance. This means that 20 dBm transmit power would be the legal power limit with an antenna having 20 dBi gain. Commercial power amplifier GaAs monolitic millimeter wave integrated circuits (MMICs) are now available that can produce 16 dBm of transmit power with good linearity. In Japan there was a new regulation in July 2000 for high-speed data communication. The frequency range is 59–66 GHz. The limitation of power to the feeder of the antenna is 10 dBm, whereas the antenna gain should be less than 47 dBi. In Europe two paired bands, 62–63 GHz and 65–66 GHz, have been provisionally allocated for mobile broadband systems. In addition, the 59–62 GHz band may be used for WLAN applications [4]. Thus, 5 GHz of spectral space has been assigned around 60 GHz with a worldwide overlap of 3 GHz (59–62 GHz band). The basic question that remains, however, is how to open up this large amount of bandwidth resource for the widest possible range of multimedia services.

60 GHz Front-End Technology

The assignment of the large bandwidth around 60 GHz created new opportunities for 60 GHz front-end technology. In particular, gallium arsenide (GaAs) field effect transistor (FET) technology has evolved to the point where 60 GHz GaAs MMICs are production-ready [5]. GaAs-based 60 GHz devices such as low-noise amplifiers, high-power amplifiers, multipliers, and switches can nowadays be ordered in large quantities in die form at prices on the order of $10–20 apiece [6]. For application in WLAN equipment, however, this might still be too expensive. An alternative technology based on silicon germanium (SiGe) promises to provide truly low-cost millimeter-wave front-end MMICs while simultaneously maintaining the favorable performance of GaAs. Coplanar wirebond interconnects between chips could be low loss at 60 GHz, whereas multichip module technologies could well accommodate millimeter wave components along with intermediate frequency (IF) and baseband circuits [7]. The challenge will be to achieve high-volume production of high-performance compact 60 GHz transmitter/receiver modules (e.g., like those reported in [8]). A further improvement would be monolithic integration of antennas with MMIC chips in order to avoid significant interconnection losses.

Channel Properties

At 60 GHz there is much more free space loss than at 2 or 5 GHz since free space loss increases quadratically with frequency. In principle this higher free space loss can be compensated for by the use of antennas with more pattern directivity while maintaining small antenna dimensions. When such antennas are used, however, antenna obstruction (e.g., by a human body) and mispointing may easily cause a substantial drop of received power, which may nullify the gain provided by the antennas. This effect is typical for millimeter waves because the diffraction of millimeter waves (i.e., the ability to bend around edges of obstacles) is weak. Regarding blocking effects, omnidirectional antennas have an advantage in a reflective (e.g., indoor) environment since there they have the ability to still collect contributions of reflected power in the event of line of sight (LOS) obstruction.

Walls may considerably attenuate millimeter waves. The transmissivity strongly depends on material properties and thickness. At 60 GHz, transmissivity of glass may range from 3 to 7 dB, whereas transmission through a 15 cm thick concrete wall can be as high as 36 dB [9]. We may therefore expect concrete floors between stocks of a building to act as reliable cell boundaries. This helps to create small indoor cells for hot spot communications. A typical/moderate inner wall consisting of multiple partitions of different materials (e.g., windows and doors), on the other hand, may be considered neither a reliable cell boundary nor a transparent medium. Due to the possible significant attenuation of inner walls, it will generally be necessary to have at least one access point per indoor environment (room, hall, corridor, etc.) to create a reliable shared medium.

A consequence of the confinement to smaller cells is that channel dispersion is smaller than values encountered at lower frequencies because echo paths are shorter on average. Rms delay spread may range from a few to 100 ns. It is expected to be highest if omnidirectional antennas are used in large reflective indoor environments [9, 10]. When, instead, high gain antennas are used, rms delay spread may be limited to a few nanoseconds only [9, 11].

Movements of the portable station as well as movements of objects in the environment cause Doppler effects as frequency shift and spectrum broadening of the received signal. These Doppler effects are relatively severe at 60 GHz because they are proportional with frequency. If persons move at a speed of 1.5 m/s (walking speed), the Doppler spread that results at 60 GHz is 1200 Hz [9].

Application of OFDM

When low or medium gain antennas are used, a single-carrier channel equalization or multicarrier transmission scheme has to be applied to enable reliable high-speed transmission in an indoor environment. Probably the most suitable technique for high-speed transmission at 60 GHz is orthogonal frequency-division multiplex (OFDM). This technique partitions a highly frequency-selective wideband channel to a group of nonselective narrowband channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain. One of the attractive properties of OFDM is that, for a certain delay spread, the complexity of an OFDM modem vs. bit rate does not grow as fast as the complexity of a single-carrier system with an equalizer. The reason is that when the bit rate is doubled, an equalizer has to be made twice as long at twice the speed, so its complexity grows quadratically with the bit rate, whereas the complexity of OFDM grows only slightly faster than linear [12]. This makes it easier to implement modems, which have to handle more than 50 ns of rms delay spread at data rates exceeding 20 Mb/s. Another property of OFDM that makes it very attractive for our application is its easy scalability to different environments, bandwidths, or bit rates. This gives the possibility to use it for various applications simultaneously.

Due to Doppler spread the data rate per OFDM subcarrier must be above a certain minimum in order to avoid a coherent receiver experiencing significant loss of coherence over individual received symbols. For a Doppler shift of 1200 Hz, as may be expected in an indoor environment, the receiver performance is not significantly affected by Doppler shift as long as each subcarrier accommodates at least 30 ksym/s [9].

A second cause of spectrum broadening is phase noise produced by the local oscillators (LOs) in the transceivers. In practice, an LO signal generated by a voltage-controlled oscillator (VCO) operating at a relatively low frequency is multiplied to obtain a reference signal at a frequency near the carrier frequency. As a result, the phase noise produced by the original source is proportionally magnified. The phase noise encountered at 60 GHz, for instance, is $10\log(60/5)^2 = 21.6$ dB higher than the phase noise at 5 GHz originating from the same source. The influence of phase noise becomes most critical when OFDM is combined with higher order modulation formats such as 16- and 64-QAM [12]. In order to alleviate oscillator noise problems to a minimum, the OFDM subcarrier spacing should be taken as high as possible (i.e., as high as delay spread allows). This approach also yields a number of side benefits; the required number of subcarriers reduces for a given data rate target, and with that the processing complexity and interference problems due to nonlinear amplification. In addition, problems due to Doppler effects are reduced.

Feasible Link Performance

A consequence of the low wall penetration of millimeter waves is that in many cases, at least one access point per indoor environment is required. From a coverage point of view the best place for the access point antenna would be somewhere near the center of the room at a high position near the ceiling. From a network deployment viewpoint, however, the need to mount antennas in the ceiling in each and every room is tiresome, and cables would probably have to run over the ceiling, which would be unaesthetical.

An attractive alternative option would be the possibility to place a small access point in each room, with its small antenna(s) mounted on a wall where it can readily be connected to the existing LAN cabling already installed, just as is the case with today's WLAN access points.

In order to allow flexible terminal use, the low position of the access point (antenna) necessitates measures to cope with the drop in received power due to LOS obstruction by a person or object. One measure is to apply macro diversity by switching to another access point as soon as the received signal drops below a certain threshold. However, this requires the use of more than one access point per room, which may increase the costs significantly, particularly when many small rooms have to be covered. A more attractive solution may be found in another direction, namely that of applying particular antenna patterns that may be adaptive to some extent (e.g., by applying beam switching). Low- or medium-gain antennas may be preferred to high-gain antennas in order to avoid stringent antenna pointing and tracking requirements. Experimental work on 60 GHz antenna pattern optimization has been carried out by the Radiocommunication Group at the Eindhoven University of Technology. Measurements have been conducted in many indoor environments. Figure 1a shows the received power normalized on the transmitted power (NRP) in dB measured in the 58–59 GHz band as function of the separation distance between transmitter and receiver. These

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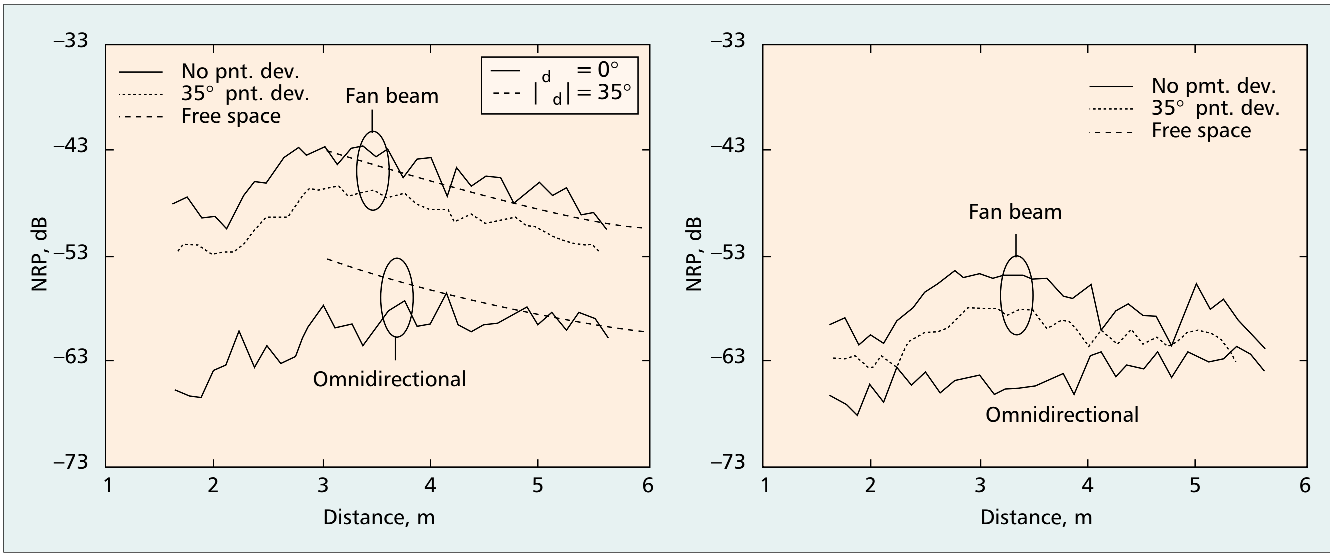

Figure 1. *a) Normalized received power under LOS conditions; b) normalized received power under NLOS conditions.*

measurements have been performed in a room with dimensions 7.2 6 3.1 m^3. The sides of the room consist of glass windows and smoothly plastered concrete walls, whereas the floor is linoleum on concrete. The ceiling consists of aluminum plates and light holders. The transmitting antenna was located in a corner of the room at a height of 2.5 m. This antenna has an antenna gain of 16.5 dBi and produces a fan beam that is wide in azimuth and narrow in elevation. Its beam was aiming toward the middle of the room. A similar fan beam antenna was applied at the receiving station, which was positioned at various places in the room 1.4 m above the ground. The upper solid curve in Fig. 1a shows the NRP when the beam of the receiving antenna is pointing exactly toward the transmitting antenna. The dotted curve represents the situation in which the fan beam at the receiver has an azimuth pointing deviation of 35°. The lower solid curve represents the situation in which the fan beam antenna at the receiver is replaced by an antenna that has an antenna gain of 6.5 dBi and radiates omnidirectionally in the horizontal plane. As a reference, dashed curves are added that represent the respective theoretical results according to the free-space law of Friss (i.e., a 6 dB decrease per doubling of distance). The curvature of both solid NRP curves is typical of indoor situations in which antenna patterns are not well pointed toward each other at short distances. In that area, the NRP increases with distance. This is because the increased free space loss is more than compensated for by antenna gain since the antennas are better directed toward each other. If the separation distance is increased further, these curves tend to become higher than the free-space curves because the reflections from walls and so on contribute effectively to the received power. The dotted curve remains lower because of the fixed 35° antenna mispointing at all distances.

All curves in Fig. 1a refer to the situation of an LOS path between transmitter and receiver. Figure 1b shows the curves for non-LOS (NLOS) conditions. On applying the fan beam antenna the average drop of NRP due to LOS path obstruction is about 11 dB for 0° as well as 35° pointing deviation. With the omnidirectional antenna this drop is about 4 dB.

The results in Fig. 1 are representative for other indoor environments in the sense that the free-space law can be considered a reliable lower bound of NRP at relatively large distances. Hence, we can estimate the feasible link performance on the basis of the free space loss. Let us, for instance, consider the antenna setup as described but in a larger room. The transmitted power is 7 dBm (5 mW), which is well feasible with today's 60 GHz MMIC amplifiers operating in their linear region. According to the Friss formula, the received power is –58 dBm. If only thermal noise is encountered, the noise power at the receiver is $10\log kTBF$ with k is Boltzmann's constant ($1.38 \cdot 10^{-23}$ J/K), T is equivalent noise temperature of the receiver (room temperature = 290° K), B is noise bandwidth, and F is receiver noise figure. With a receiver noise figure of 10 dB and a noise bandwidth of 100 MHz the received noise power amounts to –84 dBm. This yields a signal-to-noise ratio (SNR) of 26 dB. Within 100 MHz bandwidth, a data rate of 100 Mb/s can be accommodated by using OFDM in combination with quadrature phase shift keying (QPSK) and 3/4 rate convolutional coding. For sufficient performance in terms of bit error ratio ($< 10^{-6}$) an SNR of about 10 dB is required. This implies that 16 dB margin is left to cope with shadowing and performance degrading factors occurring in the transceiver such as phase noise and frequency shift. As shown by Fig. 1 this margin can be improved 16.5 – 6.5 – 11 + 4 = 3 dB by applying fan beam antennas instead of omnidirectional antennas. In order to avoid cumbersome pointing, a fan beam antenna can be used in the form of a sector antenna as presented in [13].

Now let us compare the SNR performance at 60 GHz with what we may expect at a much lower frequency, say 5 GHz. Since, according to the Friss formula, the free-space path loss is proportional to the square of the frequency, the

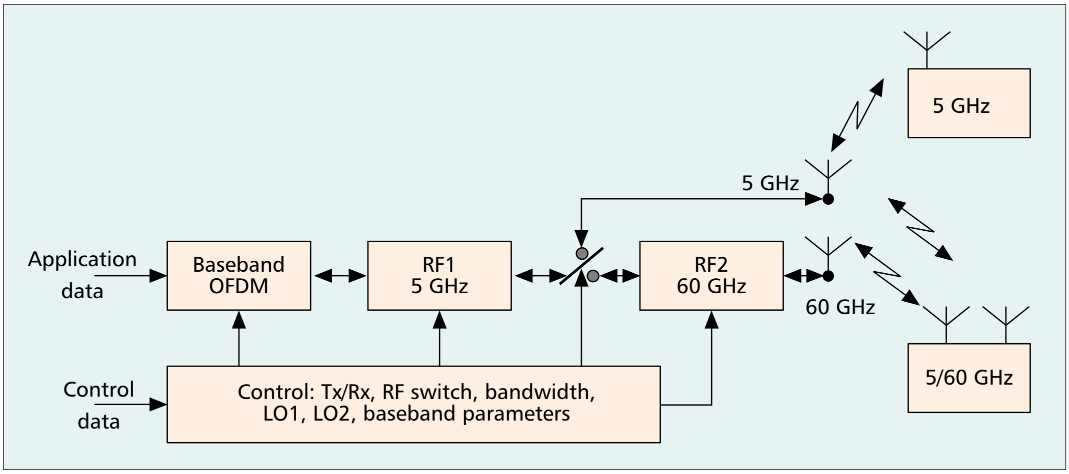

Figure 2. *5/60 GHz radio.*

An essential prerequisite for low fabrication cost is that the required MMIC technology is produced in high volumes and with high yields and short turn-around times, short time to market and quick return on investments.

link budget at 60 GHz is 21 dB less than the link budget at 5 GHz under equal conditions (same antenna patterns, separation distances, etc.). Thus, at first sight there seems to be a substantial disadvantage of 60 GHz transmission. It should be realized, however, that any successful commercial system is essentially limited by co-channel interference, which will also be 21 dB lower at 60 GHz as far as it concerns free-space loss. As a matter of fact, the signal-to-interference ratio of an interference-limited system is commonly modeled as independent of the operating frequency [14]. If we also take into account the attenuation due to oxygen absorption as well as the extra severe wall attenuation at 60 GHz, we may even expect better signal-to-interference figures.

Dual-Band Operation

An additional measure against coverage limitations due to wall attenuation, but also against severe shadowing, is to operate the 60 GHz system in combination with a system that works at a much lower frequency. An obvious option to combine with is the 5 GHz WLAN system. As a matter of fact, this should be done in any case to achieve interoperability with the legacy 5 GHz WLAN. Figure 2 shows the option of 60 GHz radio combined with the 5 GHz system. In this multimode scenario the system always tries first to reach users at 60 GHz. Under nominal propagation conditions the user can exploit the resources of the 60 GHz system. As soon as the channel conditions worsen, say, as a result of (severe) shadowing or when the user walks in an area not covered by the 60 GHz system, the connection switches to the 5 GHz band. In this way the 5 GHz band serves as a fallback option and umbrella cell for 60 GHz cells.

The radio frequency (RF) select can be based on channel conditions, channel availability, user preferences, and connection parameters. Note that the WLAN RF of 5 GHz is also utilized as intermediate frequency (IF) for the 60 GHz system. In order to minimize complexity of the baseband, functions are as much as possible the same for both systems. For instance, the 60 GHz system may utilize (multiples of) 64-subcarrier units.

Cost Reduction and Product Differentiation

According to Table 1, cost reduction to an acceptable level is of primary concern for a successful takeup of 60 GHz wireless products. An essential prerequisite for low fabrication cost is that the required MMIC technology be produced in high volumes and with high yields and short turnaround times, short time to market, and quick return on investments. Consequently, there should be clear incentives for the semiconductor industry to invest in the new generation of ICs required. A clear incentive would be the promise of a mass market on top of an interesting niche. Therefore, a set of protocols should be developed and standardized, supporting not only typical WLAN configurations but a whole family, including ad hoc networking, remote access/wireless local loop (WLL), point-to-point, consumer business standards like FireWire (IEEE 1394), and all kinds of low-cost, short-range communication between all kinds of appliances as listed in Table 1. Thus, *an extended family of configurations should be addressed covering the broadest possible range from low-speed, low-bandwidth, low-cost products to high-speed, high-bandwidth products that can be produced at reasonable cost*. These products should support flexible multiple access for a broad mix of multimedia traffic.

A scenario of a 5/60 GHz dual-band system for professional applications is shown in Fig. 3a. There is, however, no reason to restrict the application field to particular environments; many probable uses can also be found in indoor areas such as residential environments (Fig. 3b), but also in outdoor environments such as outdoor factory sites, ship yards, and air bases.

For the sake of cost reduction, processing efficiency and power efficiency it should be avoided having to temporarily operate terminals intended for the support of a certain (maximum) data rate at a very much higher air interface rate. Let us consider, for instance, a 60 GHz portable videophone that supports 2-way videophony with 1.5 Mb/s upstream and 1.5 Mb/s downstream where the air interface is based on packet transmission in a time-division multiple access (TDMA) frame with a (net)

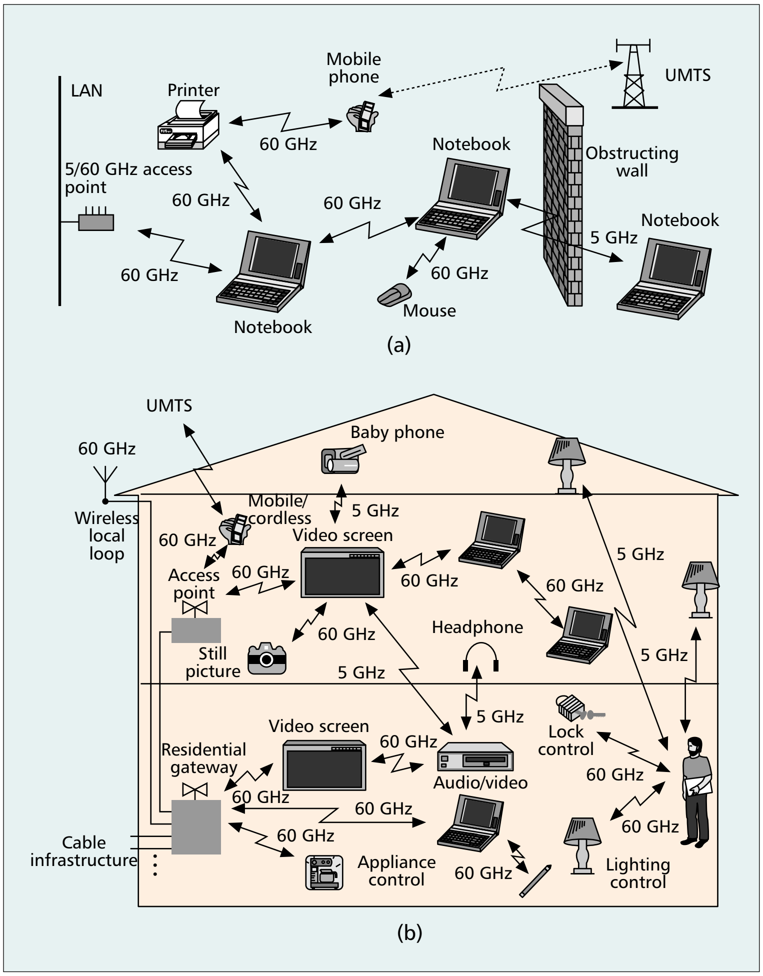

Figure 3. *a) 5/60 GHz system scenario in office environment; b) 5/60 GHz system scenario in home environment.*

TDMA rate of 150 Mb/s. The transmission of each such packet would require 50 times as much peak transmit power and processing speed as strictly necessary. It would be much better to exploit the scalability feature of OFDM, which allows a terminal to process only a small subset of available subcarriers of that single unit (scalable bit rate). This approach is also supported by the fact that the requirement for a terminal to be able to reach the total transmission capacity of the access point is unreasonable because such a requirement would lead to serious overdesign. All this is significant for the partitioning of the transmission band in small OFDM units, which can be dedicated to individual terminals. A suitable choice may be to take the 64-carrier OFDM units of IEEE802.11a/HIPERLAN as basic building blocks. This would facilitate reutilization of baseband hardware in a dual-mode 5/60 GHz radio. It should be possible to extend the capacity of the access point at will by plugging in additional PC cards containing one or more of those basic modules. Extension of terminal capacity should be possible in a similar way. A high-definition television (HDTV) studio camera could be an example of a high-capacity terminal with many PC cards plugged in. For initial 60 GHz systems the capacity of such an OFDM building block may be limited to 18 Mb/s, which is the highest bit rate supported by IEEE802.11a and HIPERLAN Type 2 based on QPSK. These standards also support higher bit rates, but these are achieved by using higher order modulation formats (16- and 64-QAM), which are relatively susceptible to oscillator phase noise.

STANDARDIZATION

Figure 4 shows a reference model indicating how standardization could take place. The proposed reference model is in line with the basic approach taken for HIPERLAN Type 2 standardization by ETSI BRAN, which is to standardize only the radio access network and some of the interworking functions to different core networks. The core network specific functions will be left to the corresponding fora (e.g., ATM Forum, Internet Engineering Task Force, and other ETSI projects).

The scope of the HIPERLAN Type 2 Technical Specification is limited to the 5 GHz air interface, the service interfaces of the wireless subsystems, the interworking functions, and supporting capabilities to realize the services. The scope of the 60 GHz extension, as proposed herewith, concerns 5/60 GHz dual-band operation including RF selection and OFDM subcarrier selection.

It may be expected that the service interfaces, interworking functions, and supporting capabilities for the 60 GHz extension are essentially similar to those defined within the HIPERLAN Type 2 technical specification. This will considerably reduce the time needed to develop the necessary technical specifications as far as the higher-layer functionalities. However, a review of these functionalities is required to identify and standardize the adaptations required.

CONCLUSIONS

The principal reason for focusing on the 60 GHz band is the huge amount of allocated bandwidth around 60 GHz, which can be used to accommodate all kinds of short-range (< 1 km) wireless communication. In addition, 60 GHz front-end technology is emerging rapidly. In order to exploit the 60 GHz band efficiently, an overall network architecture should be worked out that gives the industry wide scope for product differentiation. Guiding criteria such as affordability, modularity, scalability, expandability, interoperability, and ergonomics should form the guidelines along which 60 GHz system design should evolve. By taking these principles into account we arrive at the following conclusions:

- Probably the most attractive transmission scheme for wireless high-speed transmission is OFDM.
- For interconnection of access points the already existing LAN cabling has to be used as much as possible.
- It should be possible to mount access points/antennas on the walls rather than on the ceiling.
- Antennas have to be optimized for alleviating the effects of LOS blocking.
- The 60 GHz system must operate in combination with the 5 GHz system, not only to achieve interoperability with legacy 5 GHz systems but also to use it as a fallback

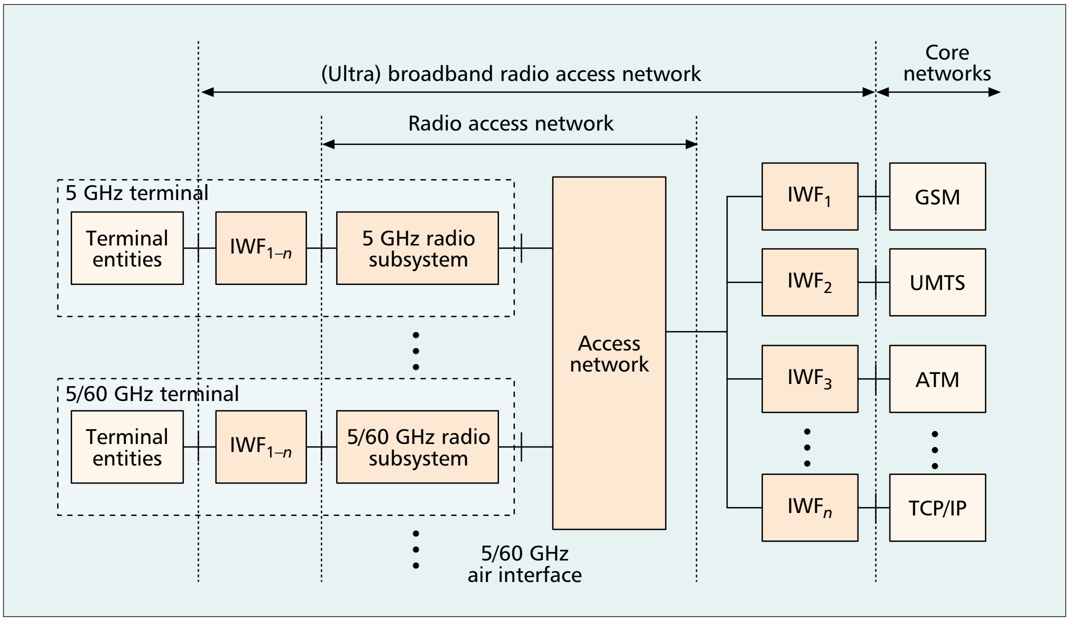

Figure 4. *The standardization reference model.*

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option in case the received power at 60 GHz becomes insufficient.
- It must be possible to readily extend the capacity of the access point (e.g., by plugging in additional PC cards). Extensions of portable capacity should be possible in a similar way.

Research effort should be directed toward the development and optimization of techniques that can cope with the particular properties of the 60 GHz channel. Considerable research will be needed in order to:
- Refine existing and develop new 60 GHz channel models
- Determine low-cost antenna solutions
- Chart out everything that should be done to pave the way towards affordable high volume production of 60 GHz front-end MMIC's
- Develop a system architecture that optimally utilizes the existing cabling infrastructure in offices allowing access points to be readily connected with the backbone
- Develop a system architecture that gives the industry the widest possible degree of freedom for product differentiation

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Biography

Peter Smulders [SM] (P.F.M.Smulders@tue.nl) graduated from Eindhoven University of Technology in 1985. In 1985 he joined the Propagation and Electromagnetic Compatibility Department of the Research Neher Laboratories of the Netherlands PTT (currently KPN research). During that time he was doing research in the field of compromising emanation from civil data processing equipment. In 1988 he moved to the Eindhoven University of Technology as a staff member of the Telecommunications Division. Next to his lecturing duties he performed a Ph.D. research in the field of broadband wireless LANs. He has been involved in the ACTS project MEDIAN-Wireless Broadband CPN/WLAN for Professional and Residential Multimedia Applications, during which he contributed to the conceptual design of the MEDIAN system architecture. His current work addresses the feasibility of a low-cost, low-power, small-sized wireless LAN technology operating in the 60 GHz band. His field of interest, covering 60 GHz channel properties, 60 GHz RF/IF technology including antennas, modulation, and coding, and MAC and higher-layer issues, is reflected in numerous IEEE publications. His future research activities will include low-cost antenna and front-end technology and tailor-made modulation and channel coding solutions.