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Application of fan-beam antennas for 60GHz indoor wireless communication

J. George, P.F.M. Smulders and M.H.A.J. Herben

The application of fan-beam antennas in high-speed indoor wireless communication systems operating in the 60GHz band is investigated. The effects of line-of-sight obstruction as well as antenna pointing deviation on the power link budget are experimentally studied in a typical laboratory environment. The results are contrasted with those obtained with alternative antenna configurations.

Introduction: Antenna solutions for high-speed indoor wireless communication in the millimetre-wave region have been the interest of many researchers recently [1 – 5]. Most of them address problems associated with the occurrence of multipath and/or shadowing. They have come up with a variety of antenna configurations capable of mitigating at least one of the mentioned impairments [2 – 5]. A configuration with omnidirectional antennas, as proposed in [3, 4], features considerable flexibility in moving portable stations (PSs) without the need of a complex antenna tracking mechanism. This flexibility is paid for, however, with a rather poor link budget. In addition, considerable channel dispersion occurs. The latter can be handled, and even exploited, by implementing sophisticated signal processing algorithms in the transceivers. Hence, the problem that remains is the poor link budget. This problem is of particular significance when the transmission takes place in the millimetre-wave frequency band owing to the performance of millimetre-wave RF components being relatively poor and free-space loss at high frequencies being relatively high. A solution for the tight link budget could be the use of high-gain pencil-beam antennas. However, this makes the antenna setup rigid and severe shadowing will easily occur. The challenge is therefore to find an antenna configuration that provides an optimal compromise between link budget and flexibility in moving the PSs around.

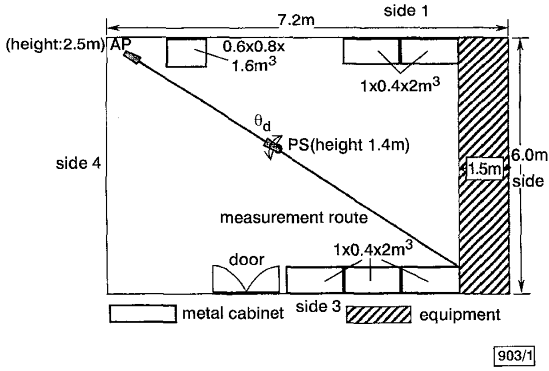

Fig. 1 *Plan view of laboratory room*

Table 1: Antenna parameters

Type of PS antenna	Half power beamwidth		Gain
	E-plane	H-plane	
	deg	deg	dBi
Fan-beam antenna*	12.0	70.0	16.5
Pencil-beam antenna	8.3	8.3	24.4
Omnidirectional antenna	9.0	Omnidirectional	6.5

*Similar E-plane sectoral horn antenna used as transmitter

Experimental setup, location and antennas used: The measurement setup used for the study was built around an 8510C-network analyser [6]. The (complex) channel impulse responses have been measured in the 58 to 59GHz band with 401 data points. A Kaiser window was applied with a sidelobe level of –44dB. With this window a time domain resolution of 2ns is achieved.

The measurements have been conducted in the network analyser laboratory of Eindhoven University of Technology. A plan view of the room is shown in Fig. 1. The dimensions of the room are 7.2 × 6 × 3.1m. Sides 1 and 2 consist of glass window from a height of 1m to the ceiling and a metal heating radiator below. Sides 3 and 4 are smoothly plastered concrete walls and the floor is linoleum on concrete. The ceiling consists of aluminium plates and light holders.

A vertically polarised E-plane sectoral horn was located in a corner of the room at a height of 2.5m, representing the access point (AP) antenna (see Fig. 1). This antenna produces a fan-beam that is wide in azimuth and narrow in elevation. Its beam was aimed towards the middle of the room. In general, the placement of the antenna in a corner provides relative ease of installation when compared with mounting the antenna on the ceiling as proposed in many publications.

A similar fan-beam antenna was applied at the portable station (PS), with its beam elevated towards the AP antenna. In addition, a pencil-beam antenna (conical horn) with elevated beam was applied at the PS for comparison. Furthermore, an omnidirectional antenna (bi-conical horn with pancake shaped beam as described in [3]) was applied at the PS for comparison. As opposed to the other two antennas, the beam of the omnidirectional antenna was not elevated but always kept in a horizontal direction. The different characteristics of the applied antennas are given in Table 1.

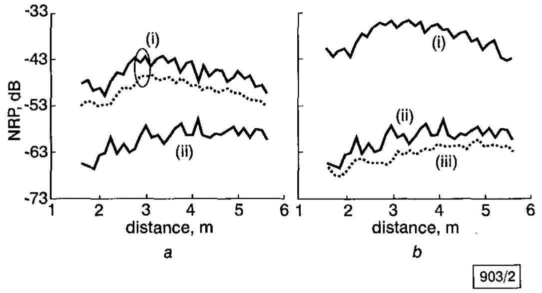

Fig. 2 *NRP performance of different antennas used in study under LOS conditions*

a Fan-beam antenna
(i) fan-beam
(ii) omnidirectional
b Pencil-beam antenna
(i) pencil-beam
(ii) omnidirectional
(iii) pencil-beam
——— $\theta_d = 0°$
·········· $|\theta_d| = 35°$

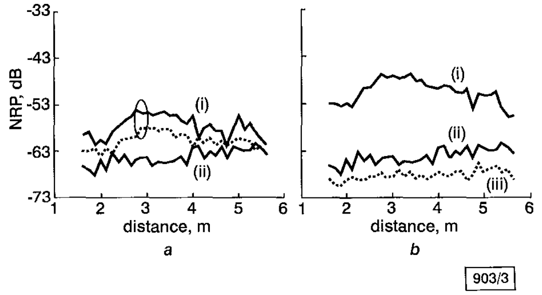

Fig. 3 *NRP performance of different antennas used in study under NLOS conditions*

a Fan-beam antenna
(i) fan-beam
(ii) omnidirectional
b Pencil-beam antenna
(i) pencil-beam
(ii) omnidirectional
(iii) pencil-beam
——— $\theta_d = 0°$
·········· $|\theta_d| = 35°$

Measurements, results and discussions: To evaluate/demonstrate the merits and limitations of the fan-beam antenna combination, channel impulse responses were measured along the diagonal of the room shown in Fig. 1. The measurements have been performed along this route with a step size of 12.5cm. The height of the PS antenna in each measurement was fixed at 1.4m above the ground.

Figs. 2*a* and *b* depict the normalised received power (NRP), i.e. the total received power within the measurement bandwidth normalised on the transmitted power, of the three kind of antennas, viz. fan-beam, pencil-beam and omnidirectional under line-of-sight (LOS) conditions. Figs. 2*a* and *b* include the average NRP performance with the fan-beam and pencil-beam antennas in boresight direction as well as at an azimuth pointing deviation $\theta_d = \pm 35°$. The test case for maximum pointing error is chosen at $\theta_d = \pm 35°$ as the 3dB beamwidth of the fan-beam antenna in the horizontal plane is 70°. Fig. 2*a* shows that with a fan-beam antenna the NRP is only ~4dB lower at ±35° pointing deviation when contrasted with the values at 0°. With the pencil-beam antenna, the average difference in NRP in the entire pointing deviation range between +35° and –35° amounts to 26dB. The NRP values observed with the fan-beam antenna are ~11dB above those observed with the omnidirectional antenna and ~14dB above those obtained with the pencil-beam antenna at ±35° pointing deviation.

The effects of the LOS path obstruction have been obtained by mathematical removal of the first ray in each measured impulse response. Since the applied resolution is 2ns and the sample spacing is 1ns, this ray is represented by those two neighbouring samples that are most close to the LOS ray position. It should be noted that this is a somewhat pessimistic approach since some part of the diffracted rays that arrive immediately after the LOS ray are also represented by one of these removed samples.

The NRP performance of the antennas under non-line-of-sight (NLOS) conditions is shown in Figs. 3*a* and *b*. With application of the fan-beam antenna, the average drop of NRP due to the LOS path obstruction is ~11dB for 0° as well as ±35° pointing deviation. For comparison: with the pencil-beam antenna the drop of NRP due to LOS obstruction ranges from 5dB at ±35° pointing deviation to ~12dB in boresight direction. With the omnidirectional antenna this drop is ~4dB. At ±35° pointing deviation and LOS obstruction, the fan-beam PS antenna yields ~4 and 7dB better link budget when contrasted with that obtained with omnidirectional PS antenna and pencil-beam PS antenna, respectively.

In all considered configurations the AP antenna has a fan-beam. This yields a link-budget advantage of ~10dB when contrasted with the link budget that is obtainable with an omnidirectional AP antenna. This follows from a comparison of NRP results with those presented in [4].

Conclusion: The results indicate that application of a fan-beam antenna at the AP yields a significant link-budget advantage of ~10dB. This 10dB is gained along with ease of installation of the AP in the corner of the room. The application of a fan-beam antenna at the PS yields an additional gain of 4dB as well as good immunity to azimuth pointing deviation. This gain, however, has to be paid for with the complexity associated with the required antenna tracking mechanism.

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Maximising directivity of array antennas mounted over complex environments with near-field null constraints

L. Landesa and F. Obelleiro

A technique is presented which allows array antennas to be synthesised under the constraint of optimum directivity, taking into account the fact that the antenna is embedded in a complex environment, and near-field null conditions to be imposed at a set of given points.

Introduction: Array antennas used to be synthesised under free-space conditions, without account being taken of their real operating environments. However, the real performance of any antenna is significantly affected by its location over a complex platform. Thus, it is of great importance to develop synthesis techniques accounting for the real-world conditions under which antennas operate. This problem has been addressed in different ways in recent years [1 – 6]. In [1], a two-dimensional (2D) linear array antenna is optimised to provide a prescribed radiation pattern; this is accomplished by imposing near-field nulls inside electrically small near-field obstacles, in an attempt to minimise their contribution to the scattered field. This method is generalised in [2], where it is extended to take into account large scatters (of dimensions comparable to the wavelength), by imposing low array radiation over the surface of the obstacles. An alternative is developed in [3], where the idea of minimising the scattering from the structure is replaced by the idea of incorporating its effects into the synthesis procedure. In this way, it is possible to take advantage of the surrounding radiation, obtaining better results in the synthesis of a prescribed radiation pattern. This technique has been shown to be valid for very large structures and has already been extended to general three-dimensional (3D) problems [4]. Variations on these techniques have been presented in [5] for dielectric structures.

In all the above works, the optimisation procedure is applied in order to obtain a prescribed radiation pattern. In [6], the authors present an alternative method to maximise the directivity of an array antenna in a prescribed direction, obviously also accounting for the presence of obstacles in the near-field region. This synthesis procedure may be useful in applications involving high gain antennas.

In this Letter, we present a new synthesis procedure which allows us to synthesise array antennas under the constraint of optimum directivity, taking into account real-world antenna operating conditions. The main difference between this and the above-mentioned method presented in [6] is that the proposed method also allows the possibility of imposing additional near-field null conditions at a set of given points. This feature is of great interest because it allows us to control the electromagnetic interference with other electronic devices or to avoid the presence of dangerous levels of radiation in zones with persons or sensitive weapon systems, etc.

Electromagnetic model: Consider the problem of a two-dimensional array antenna embedded in a complex environment. The antenna array has N_a elements, and their excitations are expressed by the vector $\mathbf{x}$ of dimensions $N_a \times 1$.

We define a vector $\mathbf{S}_{ff,\theta_o}$ of dimensions $1 \times N_a$, which contains the far-field radiation of each array element in a prescribed direction θ_o, namely the direction in which we want to obtain the maximum directivity. The presence of the structure was taken into account when deriving the components of $\mathbf{S}_{ff,\theta_o}$. A simple way to calculate these components is presented in [6]. Thus, the far-field radiation in the direction θ_o can be obtained as

$$e_{\theta_o} = \mathbf{S}_{ff,\theta_o} \cdot \mathbf{x} \qquad (1)$$