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Fig. 3 shows the circuit parameters of a series L-C network that reproduce the $n = 2$ susceptance characteristic in Fig. 2. The magnitude of the adaptive change in the L-C parameters has been reduced (compared to the single IS solution in Fig. 3). The absolute values are also more practical for high-frequency circuits.

Practical considerations concerning adaptive Salisbury screen: The physical structure of the adaptive IS will depend on the frequency band over which it is to operate. At radio frequencies, the IS (being an active two-dimensional version of an impedance string [6]) will comprise discrete circuit components. At microwave frequencies, an adaptive, possibly fractal, frequency selective surface (FSS) becomes more appropriate. A fractal FSS geometry has advantages owing to its multiband impedance characteristic. The adaptive network may comprise an electronic or optical switch to effect a step change in the L-C parameters of an IS. Smaller yet continuous change may be achieved through the use of varactor circuit elements. The use of semiconductor switching elements results in switching time constants of the order of 10^{-9} seconds, so that for most applications the absorber will have the electromagnetic characteristics of a broadband material.

The condition that $Y = 0$ at the resistive card is necessary for all incident angles and polarisations. Since the apparent electrical depth of the absorber changes with incidence angle, the IS susceptance that produces $Y = 0$ also changes. Nonetheless, the same physical structures that yield broadband absorption at normal incidence can be retained for broadband absorption at other incidence angles and polarisations (with appropriate scaling of R in (2)). However, if the angle of incidence is arbitrary, R must also be adaptive.

Conclusions: Adaptive absorbers circumvent the fundamental limitations that limit the absorption bandwidth of thin low-frequency absorbers. An adaptive ultra-broadband Salisbury screen can be designed for perfect absorption at normal or oblique incidence angles, though if the incident wave arrives at an arbitrary angle, the resistive card and the IS must have, respectively, adaptive resistive and adaptive reactance properties.

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Application of five-sector beam antenna for 60 GHz indoor wireless communications

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

The application of a switched five-sector beam antenna in high-speed indoor wireless LAN systems operating in the 60 GHz band is investigated. The effects of line-of-sight obstruction as well as the influence of the access-point antenna height are experimentally studied in a typical small-sized office room. The results are compared with those obtained with classical antenna configurations.

Introduction: The 60 GHz band is of much interest since this is the band in which a massive amount of spectral space has been allocated world-wide for unlicensed dense wireless local communications [1]. An ongoing key research issue is to find adequate antenna solutions for 60 GHz wireless LAN applications. A major hurdle to be overcome is that diffraction is relatively low at 60 GHz. Consequently, antenna obstruction by an object or person may easily result in a substantial drop in received power.

The application of fan-beam antennas, as proposed in [2], yields considerable received power under line-of-sight (LOS) conditions. The effect of LOS path obstruction is, however, about 11 dB. This raises the question whether alternative antenna solutions could alleviate the shadowing problem, e.g. by introducing and exploiting path diversity. A well-known method is to apply a sector antenna at the portable station (PS) with the possibility to switch between the different sectors, as proposed in [3]. This ability to switch to another sector at the access point (AP) is especially advantageous in case other access points can be selected to communicate with when the communication path becomes blocked by shadowing. In this Letter, however, we consider the diversity gain that can be achieved by applying a sector antenna in case there is only one AP for the PS to communicate with. This is likely be the case in a small sized office room or living room.

Experimental setup, location and antennas used: The measurement setup used for the study was built around an 8510C network analyser [4]. The (complex) channel impulse responses have been measured in the 58 to 59 GHz band with 401 data points.

The measurements have been conducted in an office room at Eindhoven University of Technology. A plan view of the room is shown in Fig. 1. The size of the room is $8.75 \times 4.90 \times 3.10\ m^3$. Sides 1 and 2 are smoothly plastered concrete walls. Side 3 consists of glass window from a height of 1 m to the ceiling and a metal heating radiator below. Side 4 is a concrete wall covered with wood and the floor is linoleum on concrete. The ceiling consists of aluminium plates and light holders.

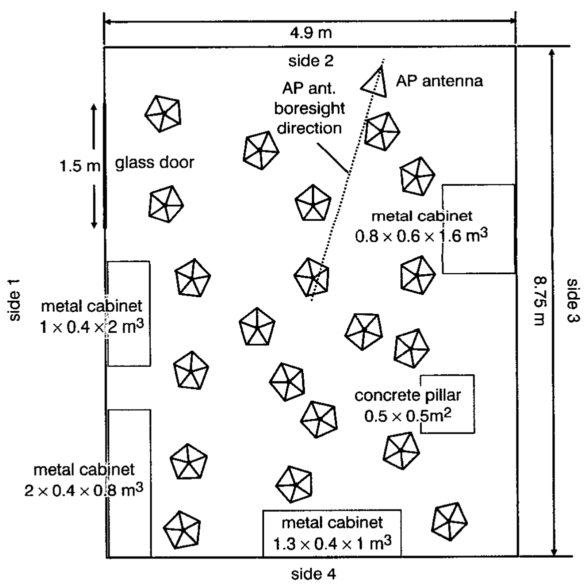
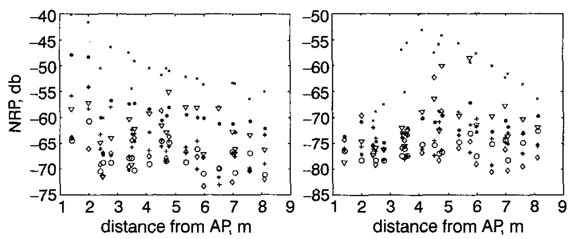


Fig. 1 *Plan view of office room*

A vertically polarised E-plane sectoral horn, representing the AP antenna was located as indicated in Fig. 1. This antenna produces a fan-beam with a −3 dB beamwidth of 140° in azimuth and 24° in elevation. Its beam was aimed towards the middle of the room. Generally, placement of the antenna in a corner provides relatively easy installation compared with mounting the antenna on the ceiling as proposed in many publications.

A similar fan-beam antenna was applied at the PS to represent the individual sectors of a five-sector antenna. Channel impulse responses have been measured at 20 randomly chosen PS positions, all indicated in Fig. 1. At each measurement position, the antenna was pointed with 0°, 72°, 144°, 216° and 288° azimuth deviation from the boresight direction of the AP antenna beam. The height of the PS antenna at each measurement position was fixed at 1.4 m above the ground. In addition, the PS antenna beam was elevated towards the AP antenna. Furthermore, an omnidirectional antenna having a −3 dB beamwidth of 18° (biconical horn with pancake-shaped beam as described in [5]) was applied at the PS for comparison. As opposed to the fan-beam antennas, the beam of the omnidirectional antenna was not elevated but always kept in the horizontal direction.

Measurement results and discussion: Figs. 2*a* and *b* show the normalised received power (NRP), i.e. the total received power within the measurement bandwidth normalised on the transmitted power against the separation distance between the AP and PS antennas, for AP antenna heights of 1.4 and 2.4 m, respectively. Also included are the results obtained with the omnidirectional antenna under unobstructed LOS (dots) as well as obstructed LOS (circles) conditions. These values for the obstructed (OBS) case have been derived from the measurement results obtained under LOS conditions by mathematical removal of the LOS component in the received impulse responses. The highest NRP values (indicated as crosses) all correspond with the most ideal situation of (unobstructed) LOS between the AP antenna and the PS antenna sector that aims towards the PS antenna, as expected.



a *b*

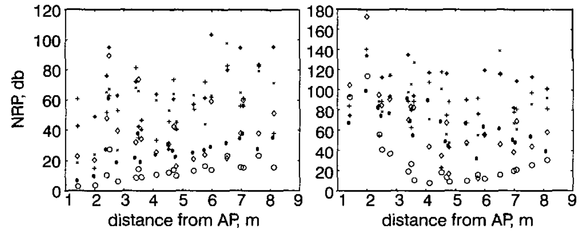
Fig. 2 *Normalised received power performance*

a AP antenna height 1.4 m
b AP antenna height 2.4 m
• BICON-LOS
○ BICON OBS
× FAN BEAM-0 deg
+ FAN BEAM-72 deg
* FAN BEAM-144 deg
◇ FAN BEAM-216 deg
▽ FAN BEAM-288 deg

Let us now assume that, as soon as obstruction occurs, the AP switches to the sector that provides the best alternative, i.e. the highest NRP. From Figs. 2*a* and *b* we can conclude that a drop in NRP of ~9 dB (on average) will result. According to [2] the drop in NRP due to LOS path obstruction is ~11 dB in the case where one single fan-beam antenna is used at the PS. This indicates that the gain in link budget provided by the considered switched five-sector antenna is only ~2 dB. This can be explained by the fact that the 'best' alternative sector has to rely on relatively weak reflected power when compared with the power that comes via the direct path. When compared with the case of an obstructed omnidirectional PS antenna (circles), the switched five-sector antenna provides ~7 dB more link budget, on average.

Furthermore, Figs. 2*a* and *b* show an interesting relationship between the height of the AP antenna and the (absolute) values of NRP. When we compare both Figures, we see that NRP values obtained with an AP antenna height of 1.4 m are significantly higher than the corresponding values for AP antenna height of 2.4 m. The average difference amounts to ~9 dB! A factor that contributes to this difference is the misalignment of both antennas in elevation which commensurates with their height difference. The misalignment occurred because the AP antenna beam was always aimed at the centre of the room for all considered positions of the PS.

Figs. 3*a* and *b* show the rms delay spread (RDS) against separation distance between the AP and PS antennas, again for AP antenna heights of 1.4 and 2.4 m, respectively. Also included are the results obtained with the omnidirectional antenna under unobstructed LOS (dots) conditions. The lowest RDS values (indicated as circles) correspond with the most ideal situation of (unobstructed) LOS between the AP antenna and the PS antenna sector that aims towards the PS antenna, as expected.



a *b*

Fig. 3 *Rms delay spread performance*

a AP antenna height 1.4 m
b AP antenna height 2.4 m
• BICON-LOS
○ FAN BEAM-0 deg
× FAN BEAM-72 deg
+ FAN BEAM-144 deg
* FAN BEAM-216 deg
◇ FAN BEAM-288 deg

From Figs. 3*a* and *b* we can conclude that switching to another antenna section almost always results in a considerably, about a factor 3, higher RDS value. These Figures also show a clear relationship between the height of the AP antenna and the (absolute) values of RDS. When we compare both figures we see that RDS values obtained with an AP antenna height of 1.4 m are about a factor 2 lower than the corresponding values for AP antenna height of 2.4 m. This indicates, that the antenna misalignment makes the reflective environment a more prevalent factor.

Conclusions: The results indicate that application of the considered sector antenna at the PS yields a link-budget advantage of a few dBs at maximum when compared with the use of a single fan-beam antenna. When compared with an omnidirectional antenna, the advantage is about 7 dB. This advantage must be paid with increased system complexity regarding antenna switching and additional measures to increase multipath robustness.

It also occurs that the height of the AP antenna has a substantial influence on NRP as well as RDS. If the AP antenna height equals the height of the PS antenna (i.e. 1.4 m) then NRP values are in the order of 9 dB higher than those obtained with the AP antenna at 2.4 m. In addition, the RDS values are, on average, a factor 2 lower. Hence, the AP fan-beam antenna can be placed slightly above table height. This is a favourable result since table height is in many cases the place where the AP can be readily connected to the fixed backbone network.

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