Modelling Interference for Indoor Wireless Systems using the FDTD Method

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Abstract

A 2D TM_z implementation of the Finite-Difference Time-Domain algorithm is used to model radio-wave propagation from multiple transmitter locations in an eight storey building. From the steady-state field data, the Signal-to-Interference Ratio (SIR) is calculated for down-link scenarios. One transmitter is located on each floor and two base-station configurations are examined: aligned and staggered. Vertically-aligned transmitters are found to have better SIR performance — 9% of the sectors in the aligned configuration and 23% in the staggered configuration have SIRs less than 5 dB. The central services core significantly reduces the SIR, however this effect can be alleivi-ated by including another set of vertically-aligned transmitters.

1 Introduction

The increased deployment of wireless systems in buildings has necessitated the reuse of frequencies on multiple floors. Indoor environments are primarily interference limited, as all transmitters are usually in close physical proximity. Independent systems (particularly WLAN's) operating on adjacent (or nearly adjacent) floors in a building can potentially interfere with each other, reducing performance, capacity and reliability. To accurately predict parameters characterizing system performance (such as the Bit Error Rate (BER) and outage probability) reliable propagation models to estimate signal strengths (and, therefore the levels of interference) are required. However, indoor propagation modelling is complicated by the large variability in building styles, construction materials and general inhomogeneity.

Numerous propagation studies have attempted to statistically characterise and model the indoor radio channel with experimental measurements (for example, [1, 2]). However, these models do not explain the physical observations and are thus hard to generalise. When used in practice, statistical models were found to result in pessimistic estimates of system performance [3]. More accurate findings were reported when the statistical analysis was complemented with physical factors, such as correlated shadowing [4]. Although *mechanistic* propagation models, derived from a numerical analysis of the indoor radio channel, can provide the physical basis for many of the hitherto unexplained physical phenomena [5, 6], there remains a trade-off between model complexity and local accuracy [7]. Site-specific ray-tracing methods must be applied to the indoor propagation problem with caution as many of the assumptions and approximations used in their derivation are generally not valid for typical indoor environments.

Therefore, the approach taken in this paper is to estimate the Signal-to-Interference Ratio (SIR) directly from a numerical analysis of the propagation environment using the Finite-Difference Time-Domain (FDTD) method. The findings related to optimal base-station deployment can be applied to other buildings in the form of heuristic design rules.

2 FDTD Modelling

The building under investigation is the School of Engineering office tower at The University of Auckland, Auckland, New Zealand. Two internal geometries for this building have been considered: A) multiple concrete floors and B) multiple concrete floors and the hollow central services core (this has been modelled as empty, though in reality it contains two elevators and a stairwell). The geometries are shown in Fig. 1(a) and (c); these consider 2D vertical slices through the building, consisting of concrete floors with metal reinforcing bars, glass windows and external hanging panels. The floors are 0.30 m thick, the reinforcing bars are 5 cm square and spaced 0.5 m apart and the 1 cm thick glass windows extend from floor to ceiling. The concrete has been modelled with $\epsilon_r = 4$ and $\sigma = 50$ mS/m [5] and the reinforcing bars with $\sigma = 10^7$ S/m. The floor-ceiling height is 2.7 m and the floors are 18.5 m wide. Eight floors are considered, and the problem geometry (terminated with a uniaxial perfectly matched layer [8]) extends 4.0 m out from the edge to fully capture the Fresnel diffraction zone created by the floor edges [5]. Two transmitter locations per floor are considered—located 1.5 m in from the windows.

The TM_z lattice is excited with a modulated Gaussian pulse $p(t) = e^{-((t-t_0)/t_w)^2} \sin(2\pi f_0 t)$ with centre frequency 1.0 GHz and a 150 MHz 3 dB bandwidth; numerical dispersion is minimised by ensuring the lattice density is at least 12 cells/λ_{min} [8]. The steady-state fields are extracted by multiplying the time-series with a 1.0 GHz cissoid. At this stage, only 2D TM_z FDTD simulations have been implemented, due to the unrealistically high computational requirements necessary for a full 3D characterization of the geometry. However, the 2D FDTD simulation results are extended to 3D by assuming isotropic spreading in the third dimension. An additional divergence term of $\frac{1}{\sqrt{d}}$ is applied to the electric field, where d is estimated from the total elapsed time $d = c_0 t$. This correction has been observed to over-estimate the distance travelled (and thus the attenuation) in the concrete — however, as this distance is small compared to the free-space distance, the maximum error is 0.9 dB/floor [7].

3 Modelling SIR

Although multiple transmitter locations per floor have been simulated, the SIR is modelled assuming a single transmitter operates on each floor. This analysis only considers the down-link portion of the system; previous experimental studies report a difference between the up-link and down-link [3]. Users operating in the building are assumed to connect to the transmitter with the strongest signal — therefore, others transmitters operating at the same frequency appear as interference. The electric fields are spatially averaged over $3\lambda \times 3\lambda$ sectors to remove small scale fading and the SIR is computed for each sector by dividing the power from the strongest transmitter by the sum of the power produced by transmitters on the other seven floors, as described by

$$\mathrm{SIR}_{i,j} = \left[\frac{\max\{E_{i,j} \in x\}}{\sum_x E_{i,j} - \max\{E_{i,j} \in x\}} \right]^2$$

where i and j identify the sector and x represents the set of transmitter locations. Two deployment strategies are examined — the first considers offset transmitters aligned vertically down the left side of the building; the second staggers the transmitters locations between the left and right sides of the building. Surface plots of the SIR (in dB) for both deployment strategies and problem geometries are shown in Fig. 1. The location of the transmitters are marked with $\bullet$. By examining the proportion of internal sectors with SIR lower than a fixed protection ratio (5 dB in this case), a quantitative assessment for each configuration can be obtained. These findings are summarized in Table 1.

As indicated in Table 1 and Fig. 1(a) and (c), increased SIR is obtained when the transmitting antennas are vertically aligned. The SIR is highest around the transmitters and

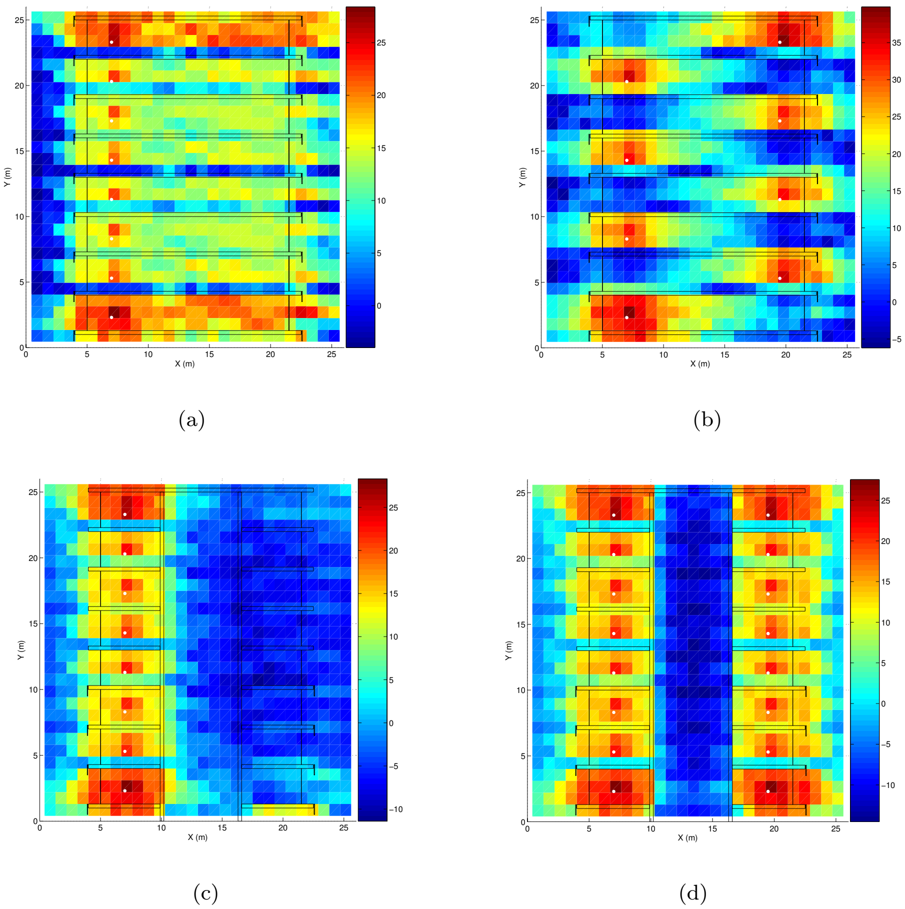

Figure 1: Signal to interference ratio in dB for (a) Multiple floors, vertically aligned transmitters and (b) Multiple floors, vertically staggered transmitters, (c) Multiple floors and core, vertically aligned transmitters and (d) Multiple floors and core, two-sets of vertically aligned transmitters.

generally decreases as the user moves further across a floor. As shown in Fig. 1(c), the SIR decreases significantly in regions across the core — this strongly suggests the core supports additional mechanisms allowing RF energy to propagate between the floors. However, as demonstrated in Fig. 1(d) this can be overcome by placing another set of vertically aligned transmitters down the right side of the building; the SIR within the core is low, but remains high in regions where users typically operate. When the transmitters are staggered (as shown in Fig. 1(b)) an increased number of sectors have low or negative SIR. This result agrees well with findings based on experimental measurements [3]. Correlated shadowing in the indoor environment has been proposed as the mechanism that causes this effect [4]. When the transmitters are vertically aligned, the signal and interference paths are largely the same and hence they are positively correlated, that is, if the desired signal increases so does the interference and vice-versa. However, when the transmitters are staggered, the desired signal and interference operate on quite different propagation paths: the desired signal is still propagating a distance across the floor; while the interference has a much shorter path. Obstacles such as the central services core can shadow the desired signal and interference channels, such that a negative correlation can sometimes exist between them [4].

Table 1: Percentage of internal sectors below the 5 dB protection ratio.

Configuration		Percentage
Multiple Floors	*Aligned*	9.1%
	Staggered	23.2%
Multiple Floors and Core	*Aligned-left*	65.3%
	Left and Right	43.6%

4 Conclusions

A 2D implementation of the FDTD algorithm has been used to predict the signal strengths from multiple transmitter locations in an eight storey office building. The electric fields were spatially averaged to remove the effects of multi-path fading and the SIR calculated by dividing the strongest signal with the power sum of the interference from the other transmitters. These preliminary results show that the SIR is strongly dependent on the deployment of the base-stations and confirm some of the experimental findings concerning optimal base-station placement in multi-storey buildings. The percentage of sectors below a 5 dB protection ratio increases from 9% to 23% when the transmitter configuration is changed from aligned to staggered. Including the central services core introduces other propagation mechanisms to transfer power between the floors and consequently reduces the SIR. Future work will extend this analysis to predict the outage probability within multi-storey buildings, including the impacts of RF-shielding on system performance.

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