Simulation of Broadband FWA Networks in High-rise Cities with Linear Antenna Polarisation

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Abstract — A ray-tracing algorithm is used to simulate broadband radio propagation at 3.5GHz for a FWA network in a high-rise city environment. Both coverage and uplink interference are investigated, with linear antenna polarisation. It is shown that some rooftop locations are unsuitable positions for SU’s, due to the existence of single or multiple-bounce reflected rays causing uplink interference. It is usually possible to find a SU position just a few metres away on the same rooftop which gives much lower uplink interference.

I. INTRODUCTION

In Point-to-Multipoint (P-MP) broadband Fixed Wireless Access (FWA) networks, a number of terminals or subscriber units (SU’s) communicate with a single base station or access point (AP). In countries experiencing rapid urban growth such as China, there is a demand for FWA networks to provide broadband radio links in high-rise cities, both for cellular backhaul and business data. The broadband radio channel is characterised by multipath propagation due to reflection, shadowing, and diffraction from buildings, which often have a high content of steel and glass in their outer walls. One result of radio signal reflections is increased interference, especially in the upstream direction. The SU’s in a FWA network typically have narrow-beam antennas, pointing directly at the AP, but the AP antennas may have wider beamwidths, for example 90° to 120°. Due to a limited amount of spectrum being available for FWA networks, (especially below 10GH2), a 4-sector AP may need to re-use the same frequency in opposite sectors. In this case, the presence of high-rise buildings may result in uplink cochannel interference from a SU in one sector to the opposite sector of the AP, as shown in Fig.1: SU(1) in the south sector boosts its transmit signal level to overcome shadowing and multipath interference in its own sector, but some of the signal bounces off a building behind the AP, and causes upstream interference into the north sector, thus degrading the received signal from SU(2).

Previous FWA interference studies usually consider line-of-sight (LOS) interference from a neighbouring cell [1],[2],[3]. In a dense urban environment, shadowing, reflections and diffraction from buildings may produce significantly different interference levels from the LOS case [4]. This paper describes the use of a ray-tracing algorithm to model radio propagation for a FWA system deployed in a high-rise city, and investigates the effect of building reflections on uplink interference (linear polarisation only).

II. HIGH-RISE CITY DATABASE

An algorithm was developed to randomly generate a dense high-rise city database. Adjustable parameters include the distribution of building heights, (using a Rayleigh distribution [5]), and the placing of buildings along a grid of roads and rivers. The parameters were adjusted to generate a city profile representative of big cities, as found in South-East Asia. For other random city generators, see [6], [7]. Candidate SU locations on each rooftop higher than 50 metres were identified for analysis in the ray-tracing algorithm.

III. RAY-TRACING MODEL

The model is optimised for FWA scenarios: the AP antenna is well above the height of ground clutter. The model works with raster terrain as well as 3D vector and terrain databases, for example [8], and it considers reflections off building walls, off-axis rooftop and terrain diffractions, and foliage attenuation. Outputs include received power and channel impulse response, permitting a detailed and realistic assessment of FWA systems. Ray-tracing models have been used extensively for modelling of propagation in small-cells [9], which may also be used in conjunction with large-cell models [10]. In microcellular environments, the dominant propagation mechanisms are reflection and corner diffraction. For FWA systems with SU’s below rooftop, 2-D models may be sufficient, but for high-rise buildings with antennas above the rooftop, a 3-D model is more accurate [11]. Ray-tracing models for medium-size cells [12] still only support rooftop diffraction after the reflection points. In this ray-tracing model, rooftop diffraction is calculated both before and after the reflection points, since this is the dominant propagation mechanism when antennas are positioned on rooftops, or high on outside walls. The model takes as input a
city database file, which lists terrain contours, and co-
ordinates and heights of all buildings. For a chosen AP
position, image trees are constructed for all building
walls, taking into account size and orientation of each
wall, to get an accurate picture of the reflected rays.
When the geometry of each ray has been found, the
angles of arrival (both azimuth and elevation) at the
AP and SU are calculated and the antenna patterns
included. The model computes the diffraction and re-
fection coefficients along each path, using the Uniform
Theory of Diffraction (UTD) and Geometrical Optics.
Depolarisation of reflected rays is also modelled.

IV. SIMULATION STUDY

A TDMA FWA system in a high-rise city (building
height $\gamma = 70m$ [5]) was simulated. The AP
has 4 sectors, each antenna having a 90° half-power
beamwidth and gain 11.1dBi. The SU antennas point
directly towards the facing sector of the AP, and have
20° beamwidth, gain 15.6dBi. Various different com-
binations of vertical and horizontal polarisation at the
AP and SU are used. The AP transmit power is set
to 1W (+30dBm) into the antenna. The uplink power
control on each SU is adjusted to achieve a setpoint
AP receive power of $-72dBm$ for QPSK, and $-63dBm$
for 64QAM signals. These power levels are calculated
from the maximum power required to achieve a BER
of $10^{-6}$ as listed in ETSI Standard EN301021 [13], plus
a fade margin of 5dB. A 2-frequency reuse scheme is
used so that opposite sectors transmit on the same fre-
quency. The carrier frequencies range between 3.4GHz
and 3.6GHz, with a 14MHz channel bandwidth, and
frequency-division duplex (FDD) mode. Separate ray-
tracing simulations were performed for each city map,
taking into account 0, 1 and 2 reflections, respectively,
for each ray. Grid resolution used was 5m, so that a
number of positions on each rooftop were simulated.

An example city is shown in 3-D in Fig.2. The AP
is located on the rooftop of a high-rise building near
the city centre, and all rooftops higher than 50 metres
are considered as potential SU locations for modelling
purposes. Fig.3 shows a SU in the north sector, which
is producing uplink interference into the south sector of
the AP due to multiple reflections off buildings. Fig.4
shows the same phenomenon in 3-D, emphasising the
usefulness of the ray-tracing model for investigating
building reflections which are not usually considered
in statistical interference studies. The following results
are for a single city map, but are representative of a
number of runs of cities using the same building distri-
bution. Downstream coverage is shown as a cumulative
distribution function (cdf) plot in Fig.5. It is seen that
for 3 of the sectors, approximately 85% of rooftop lo-
cations above 50m receive sufficient power ($-72dBm$)
to support QPSK transmission, and 70% can support
64QAM. It should be noted that even though a par-
ticular rooftop location may be in shadow, a nearby location on the same rooftop may receive significantly higher power, see Fig.8.

Upstream interference is also modelled. Adjacent channel interference is easily rejected by the receive filter, but cochannel interference is a more difficult problem. The minimum tolerable cochannel interference is listed in ETSI EN301021 [13] as being an interfering signal level of $-23\,dB$ (QPSK) or $-37\,dB$ (64QAM) below the wanted signal, which causes an increase in BER from $10^{-6}$ to no more than $10^{-5}$ (although a well-designed radio receiver may have better cochannel rejection capability than this). For a QPSK signal level with sensitivity of $-72\,dBm$, a cochannel interferer down by $23\,dB$ gives a maximum allowable interference level of $-95\,dBm$. We consider only a single high-power interferer, although it is known that the combination of many interferers at lower signal levels is also very detrimental [14]. Each rooftop SU location is examined for its potential to cause an upstream interference level of more than $-95\,dBm$ into the opposite sector of the AP. These calculations are performed for 0, 1 and 2 reflections, respectively, along each path; firstly for all sectors of the AP having vertical polarisation, and then for opposite sectors having opposite polarisations (for example, vertical polarisation in the south sector, horizontal in the north). The results are shown in Fig.6, each large dark spot indicates an interfering SU location: graphs (a) and (d) show that with no reflections from buildings, SU’s from the opposite sector do not cause any cochannel interference. Graph (a) relies on the front-to-back isolation of the opposite-facing AP antenna. If necessary, this isolation may be increased by placing a small metallic screen immediately behind each AP sector antenna, but for the antennas used in this simulation, it appears that the front-to-back isolation is sufficient. Graph (d) is expected to be even better because it has the additional benefit of the AP antenna cross-polar isolation. Graphs (b) and (c) show that when 1 and 2 reflections are considered per ray, with vertical polarisation on both AP and SU, a number of SU rooftop locations cause upstream interference with the opposite sector. Graphs (e) and (f) show that when opposite polarisation is used in opposite sectors, the upstream interference is reduced.

Fig.7 shows the cdf of upstream interference power received at the AP from SU’s in the opposite sector. An interference noise floor of $-120\,dBm$ is assumed. It is seen that for V-H polarisation (that is, vertical polarisation at the SU, horizontal at the opposite AP sector),
Fig. 6. Top view of Rooftop locations which cause high upstream interference to the opposite sector, AP marked “+.”

The cdf increases only slowly as the interference power reduces, until the interference noise floor is reached. This illustrates the improvement due to the cross-polar isolation of the antennas, but also shows that some upstream reflections still cause interference because their polarisation is altered at the reflection point (so they are no longer completely vertically polarised). Circular polarisation would both reduce uplink interference, and also reduce the multipath distortion in the wanted signal (both upstream and downstream), since single-bounce echoes from buildings undergo a change in direction of their circular polarisation, and are rejected at the receiver. Fig.8 shows a number of locations on each rooftop, classed as either: (a) Good coverage, (b) High interference, or (c) Poor coverage. It is seen that on the same rooftop, different physical locations have different received coverage and upstream interference levels [15]. It may be possible to reduce upstream interference simply by moving the SU to a different location on the same rooftop whilst still maintaining sufficient signal coverage. Fig.9 shows the proportion of buildings which have both good coverage and high interference locations on
to prevent reflections into the opposite sector of the AP. Therefore, careful SU installation may be needed to keep interference to a minimum. It has been shown that vertical-horizontal polarisation on opposite sectors also helps to reduce the uplink interference, but this linear polarisation discrimination does not help with the downlink multipath problem. Radio trials are currently under way [16], and will investigate the use of circular polarisation for reducing both multipath and cochannel interference.

V. Conclusions & Further Work

Uplink cochannel interference may cause some difficulties with deployment of broadband FWA systems in dense high-rise cities. However, the uplink interference can usually be reduced by moving the interfering SU to a different location on the same rooftop, so as to prevent reflections into the opposite sector of the AP. Therefore, careful SU installation may be needed to keep interference to a minimum. It has been shown that vertical-horizontal polarisation on opposite sectors also helps to reduce the uplink interference, but this linear polarisation discrimination does not help with the downlink multipath problem. Radio trials are currently under way [16], and will investigate the use of circular polarisation for reducing both multipath and cochannel interference.

References