INDOOR COVERAGE CONSIDERATIONS FOR HIGH-ELEVATION ANGLE SYSTEMS

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INTRODUCTION

It is increasingly the case that users of personal communications systems expect a seamless provision of coverage, whether in rural or urban areas, outdoors or indoors.

Existing 2G systems provide a fair degree of indoor coverage from existing micro- or macrocell base stations, though subscribers generally expect to have to co-operate by positioning themselves near windows. Such coverage is increasingly complemented by the addition of (public or private) picocells intended to provide connectivity over a room or a floor of a building.

For conventional, terrestrial, 3G networks, this situation will be largely unchanged. The increase in frequency (110% or 10%) will result in higher building penetration losses, and the link budget may be rather more constrained, but a similar degree of indoor coverage is likely to be available.

This will certainly not be the case for two types of 3G system that are currently proposed: services provided using satellites or high-altitude platforms will generally provide a high-elevation angle from receiver to transmitter, and in the case of the satellite option, a very constrained link budget. This paper examines the differences that might be anticipated between such systems in terms of the indoor coverage provided, and considers techniques by which the difficulties may be ameliorated.

BUILDING COVERAGE AND PENETRATION MODELS

Before considering the coverage problems presented by HAPS and MSS systems, it is necessary to review the techniques that have been developed for the prediction of building coverage and penetration.

The prediction of radio coverage within buildings received relatively little attention until the last decade or so. With the growth, not only in Personal Communications Systems (PCS) but also in Wireless LAN deployment, this has changed dramatically, with a large number of measurement campaigns and the development of a wide range of models.

Such models range from simple, empirical methods, requiring only minimal input data to very sophisticated deterministic methods requiring a detailed knowledge of the building in question. Historically, the primary application for these models has been in system design rather than in system planning, and a requirement for detailed input data has therefore not been a major problem. Increasingly, users are looking for models that will give practical information of use in the planning of network coverage within buildings.

The starting point for all RF coverage modelling is the Friis equation for free-space loss, in which path loss is proportional to the square of the path length. If 2-ray propagation is assumed, the path-loss slope will increase to 4.0. The simplest empirical indoor coverage models (1) simply modify the path-loss slope on the basis of measurements, giving the mean path loss as:

$$L = L_0 + 10n \cdot Log(d)$$

Where L_0 is the assumed field at 1 metre, and n is an empirically-derived slope value[1]. As this slope has implicitly to include the effects of all walls, floors and other obstructions, the standard deviation of prediction error can be expected to be very large. An illustrative comparison is shown below. Furthermore, as there is no reflection in the model of the underlying physical processes, such models generally give no information about the sensitivity of coverage to factors such as elevation angle.

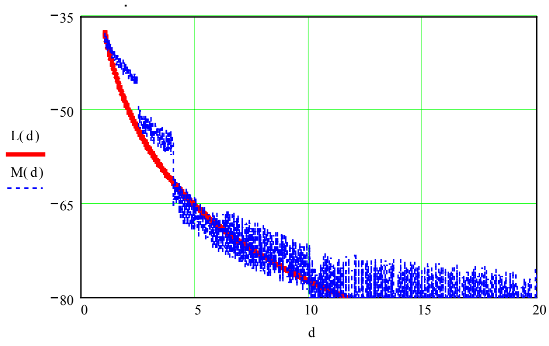

Figure 1: measured path loss vs. empirical prediction

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[1] If this form of model was to be used to model in-building coverage from an external transmitter, it would, of course, be necessary to change the reference point to refer to the field incident on the building.

A straightforward way to improve such predictions is to account explicitly for the excess losses of walls and floors, as in the model of Keenan and Motley (2). In these models, a bulk transmission loss is defined for all structures of interest (walls, windows, floors etc) and is added to the free-space loss for each structure passed. Thus:

$$L = L_0 + 10n \cdot Log(d) + L_W \cdot N_W + L_F \cdot N_F$$

where L_F and L_W are the losses associated with individual walls and N_F and N_W the number of such structures passed.

This allows a much more realistic assessment to be made of the coverage within a specific building.

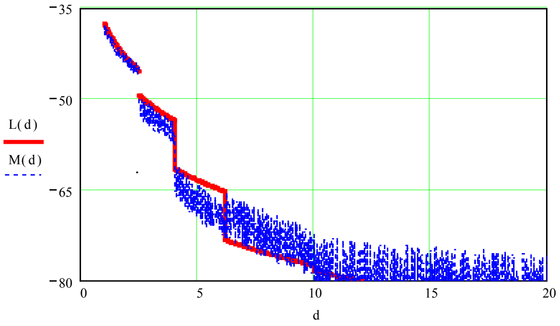

Figure 2: measured path loss vs. 'multi-wall' prediction

A major potential problem with such models is that path-loss into, or within, buildings is not simply proportional to the number of structures crossed. As the excess loss on the direct path increases, so other (reflected or diffracted) paths become more significant. Some of these models therefore include a simple modifier which, effectively, set an asymptote (determined experimentally) to which the path loss declines.

A representative model of this type (3), in which the non-linear attenuation due to multiple floors is modelled, is:

$$L = L_{FS} + L_W \cdot N_W + L_F \cdot N_F^{\left[\frac{L_F+2}{L_F+2}-b\right]}$$

Another improvement is to determine the Fresnel transmission co-efficients at each material interface, though this will require a detailed knowledge of the electrical characteristics of the materials. This is the form of model from which the results in this paper have been generated.

If such detail is available, however, a more fundamental improvement to the modelling involves an attempt to reflect all underlying physical processes and interactions between the EM wave and the building. This is most commonly by way of ray-tracing models, using either simple geometrical optics (GO) or the geometrical theory of diffraction (GTD) (4,5).

INDOOR COVERAGE FROM HIGH-ELEVATION SYSTEMS

While GSM standards have only been deployed in the form of terrestrial networks, the IMT-2000 / UMTS vision has always included an integrated satellite component. More recently, the use of so-called High Altitude Platform Systems (HAPS) has been sanctioned at 2 GHz for the delivery of 3G services.

The majority of proposed satellite systems operate in Low- or Medium Earth orbit, giving rise to a continually-variable azimuth and elevation angle of the satellite at the user terminal. The elevatio statistics of some typical systems are indicated below.

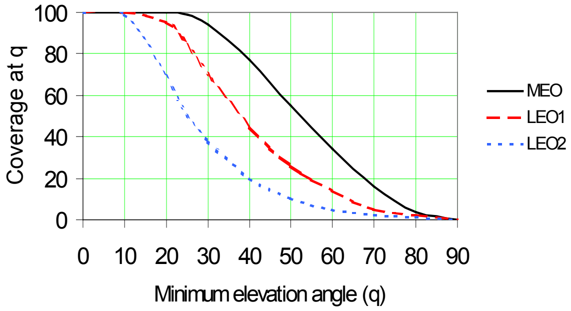

Figure 3: Elevation statistics for NGSO MSS

One of the foremost HAPS proposals involves the use of stratospheric balloons at an altitude of some 20 km. The system is intended to be located over an urban area, providing primary coverage out to around 36 km from nadir. The elevation angle of the HAPS, at the user terminal, will therefore lie in the range 30-90 degrees.

For both these system types, then, the elevation angles expected at the UT will be much greater than that expected from a terrestrial network. In most situations, this is a great advantage, reducing clutter losses. However, it seems intuitively likely that penetration into buildings will be reduced: as the angle increases, so it is to be expected that the slant path from the platform will intersect a larger number of walls and floors. Such reduced coverage will have implications for user acceptance of such systems.

Some simulations have been undertaken to attempt to quantify the differences in building penetration that might be expected, and some results are illustrated below for different elevation angles.

In all cases, the median excess loss suffered to a receiver on the ground floor of the building is calculated The transmitter providing coverage (terrestrial BS, HAPS or MSS) is assumed to be situated to the South East of the building being modelled.

Figure 4: predicted 1st floor coverage from terrestrial microcell

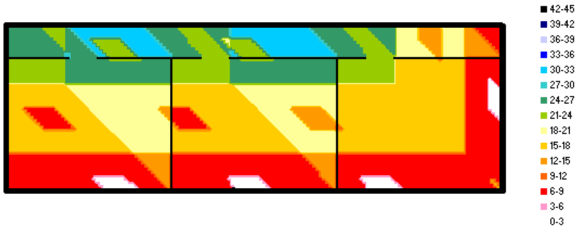

Figure 5: predicted 1st floor coverage from MSS at 45 degrees

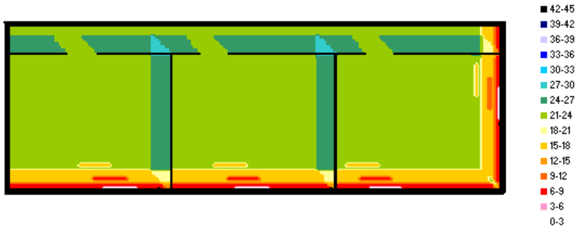

Figure 6: predicted 1st floor coverage from HAPS at 90 degrees

Figures 4-6, above, indicate the area coverage achieved, but for planning purposes, the statistics of coverage are more relevant, and these are compared in Figure 7.

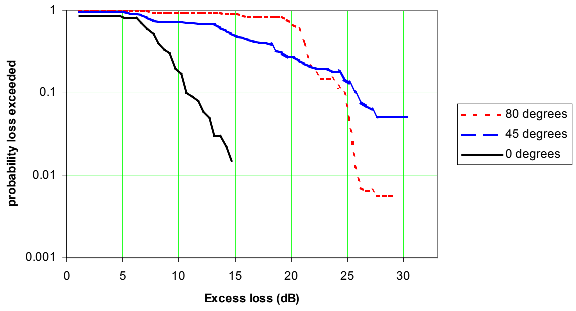

Figure 7: comparison of coverage statistics

It can be seen that, as expected, the high-elevation systems suffer considerably greater excess losses than does the terrestrial system. While only 20% of the floor area suffers an excess loss greater than 10dB in the terrestrial case, this increases to some 80% and 90% at 45° and 80° respectively. While the HAPS system may be able to allow a considerable additional margin in the link budget, this will not be the case for the MSS. Furthermore, inter- and intra- service interference considerations will demand that system EIRP be minimised in each case.

TECHNIQUES FOR THE EXTENSION OF INDOOR COVERAGE

Given the relative difficulty of providing a useful degree of indoor coverage from high elevation angle systems, it is necessary to consider the ways in which the impact of this may be overcome.

The most obvious option is, perhaps, not to attempt to provide a direct link to the user using these technologies, but rather to use the satellite or stratospheric platform as a means of implementing infrastructure links to conventional local microcells and picocells.

While such infrastructure arrangements seem likely to be implemented at the higher frequencies available for use by these platforms (Ku- and Ka-bands for the satellite case, and Ka-band for HAPS), the lower available frequency are too limited in bandwidth and too attractive for mobile applications to be considered for this role.

Attention must therefore be directed to methods for enhancing indoor coverage at these frequencies. Short of re-engineering specific buildings for greater electromagnetic transparency, this will involve some form of ‘repeater’ concept.

An attractively straightforward method would involve the use of a passive repeater, which would offer simple installation at low cost, and inherent bi-directionality. Unfortunately the link-budget improvement by such means is minimal.

A greater link budget improvement results from the use of an active, non translating repeater, though this will demand a pair or reciprocal transmission paths, filtering and a power supply. Such techniques are commonly used to improve the coverage of terrestrial networks, where the traffic levels justify the engineering costs associated with a permanently installed system. If such systems were to be deployed on a temporary, ad-hoc, basis they would, however, be vulnerable to unintentional feedback resulting in oscillation or instability. This can be avoided by careful positioning of antennas to ensure sufficient screening, but this will contravene the requirement for operational simplicity.

Frequency-translating repeaters avoid this problem, but ‘in-band’ spectrum is extremely limited at 2GHz (for both terrestrial and MSS applications). The likelihood of interference being caused to other systems users in adjacent cells will probably rule out such an approach.

The most likely approach will involve the use of entirely separate parts of the spectrum, ideally licence exempt, where capacity is available. Though this will obviously add complexity to the design of user terminals it also brings the possibility of allowing ad-hoc connectivity to other existing networks (wireline domestic phone, office LAN) as well as to the HAPS/MSS 'repeater'. The simplest such concept would involve the use of low-cost, readily available technologies such as DECT or Bluetooth (6), which seem likely to be incorporated in a growing number of personal terminals in any case.

One potential pitfall associated with this approach concerns EM compatibility. With an MSS downlink operating at 2.2 or 2.5 GHz, and a Bluetooth transmitter at 2.4 GHz, the possibility exists of desensitisation of the MSS receiver by the noise sidebands of the Bluetooth device, which may itself suffer from overload by the MSS transmitter. If equipment was barely compliant with the current (V1.0) Bluetooth specification, separation distances of many metres are implied without additional filtering. The problem is, however, minimal for the case of a HAPS terminal operating in the slightly lower terrestrial allocations. The potential for EMC problems could, of course, be avoided altogether by the use of infra-red techniques (7).

CONCLUSIONS

Some approaches to the prediction of indoor coverage of personal communications systems have been reviewed and the relative difficulty of providing a useful degree of in-building coverage from systems operating at a high elevation angle as seen by the user highlighted.

Possible methods for improving the in-building coverage, and thus the competitiveness, of these systems have been briefly considered.

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