White Paper: Microcells – A Solution to the Data Traffic Growth in 3G Networks?

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May 2010

Microcells were used with great effect to enhance the capacity of GSM networks as the popularity of mobile services exploded in the mid-Nineties. The small cells allowed network operators to increase the frequency reuse and spectral efficiency of their networks dramatically and it was also easier to find sites for the smaller base stations, and their associated antennas, compared with traditional macrocell sites. Being a narrowband system, network operators were able to dedicate a small proportion of their radio carrier frequencies for microcell use in high traffic areas and effectively build hierarchical networks with the macrocells providing wide area coverage across the country and the microcells providing a high capacity overlay in areas where additional capacity was required.

Third Generation (3G) networks, such as those based on the UMTS and HSPA technologies, use wider band radio carriers and operators typically only have access to two or three of these. This means the idea of dedicating a radio carrier solely for use by microcells is often not possible, particularly for network operators who have only two radio carriers available. Because of the difficulties associated with accommodating cells of very different sizes operating on the same frequency, microcells have traditionally been ignored as a means of enhancing the capacity of a 3G network. When the 3G networks were lightly loaded and network operators could provide sufficient capacity simply by deploying new 3G macrocellular sites, or by adding the 3G technology to their existing macrocellular GSM sites, this did not represent a problem. However, the huge growth in data traffic over the last year or so has meant that 3G networks based on a traditional macrocell deployment no longer offer sufficient capacity to support the needs of their users. As a result, network operators are taking another look at microcells as a potential solution to their capacity headaches. In this paper we examine some of the issues associated with introducing microcells into a 3G network and the ways in which these issues can be addressed in practice.

Macrocellular Influence on the Size and Shape of the Microcells

In deployments where the microcells use the same carrier frequencies as the macrocells, the size and shape of the individual microcells is heavily influenced by their location with respect to the oversailing macrocell. In a CDMA network, the ideal boundary between two cells occurs at the point where the path loss to the two base stations is equal. If a mobile station remains served by a base station beyond the point where another base station offers a lower path loss, the amount of power transmitted on both the uplink and the downlink becomes greater than would be required if the mobile station switches to the other base station, thereby decreasing the overall capacity of the network compared with the case where the mobile station is always served by the base station offering the lowest path loss.

In a practical network with unequal cell loading, the situation is somewhat more complex in that a more lightly loaded base station may have more power available to serve a particular mobile station or its uplink noise rise may be lower, meaning that it can demand less power from a mobile station, even though the uplink path loss may be greater than for a neighbouring cell. However, the practical cell boundary will not deviate dramatically from the aforementioned equal-path loss boundary, and this provides a good reference point for the discussion presented in this white paper.

In a microcellular network without an oversailing macrocell, or where the macrocell layer uses a different carrier frequency, the size and shape of the microcells will be defined by the relative position of the microcellular base stations. In a simple hexagonal network of microcells, the coverage will be contiguous and each microcell will have broadly the same size and shape, as shown in Figure 1, where each colour represents a different cell's coverage area and the black dots show the locations of the base stations.

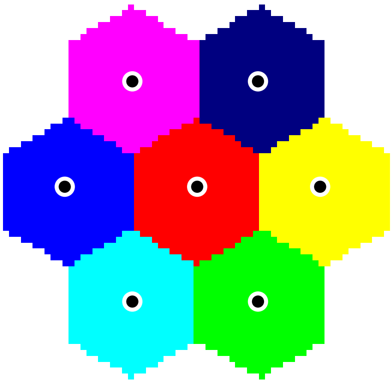


Figure 1 Size and shape of 'hexagonal' microcells without an oversailing macrocell on the same frequency

If we now introduce an oversailing macrocell at the same location as the central microcellular base station and examine the position of the equal-path loss boundaries, then the coverage of the microcells changes to that shown in Figure 2, with the pink area showing the coverage provided by the macrocell in the region of the microcells (note that the full coverage area of the macrocell would extend beyond the square shown in Figure 2). The first thing we notice is that the size of the central microcell has shrunk significantly, since the macrocell becomes dominant once a mobile station has moved a little way from the central microcellular base station. We also notice that the surrounding cells have shrunk to a lesser extent and their coverage is compressed on the side facing the macrocell and elongated on the other side (ie, the microcellular base station is no longer at the centre of the cell coverage area). This issue was addressed in Reference [1].

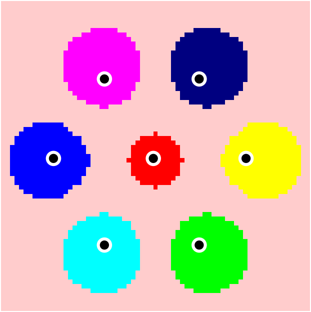


Figure 2 Size and shape of 'hexagonal' microcells with an oversailing macrocell on the same frequency

This simple example demonstrates that the size and shape of the microcells are clearly influenced by their location with respect to the oversailing macrocell and this must be taken into account when planning any microcellular deployment. Microcells that are located close to a macrocell will have a smaller coverage area and, as a result, they are likely to offload less traffic from the macrocell. Therefore, when choosing microcellular sites it is important to consider the degree of isolation between the macrocell and the microcell to ensure that the microcell will provide the desired network offload.

Figure 2 also shows that the microcellular coverage is no longer contiguous and a mobile station will need to hand over to the macrocell as an interim step as it moves between microcells. This will result in a significant increase in the signalling traffic between the network and the mobile station, compared with the case of contiguous microcellular coverage shown in Figure 1. This lack of contiguity is another factor that must be considered when microcell sites are chosen.

Interference Between Microcells

When considering the deployment of microcells, it is also important to take into account the specific propagation characteristics that exist within this type of cell and the impact of single-cell reuse on the network capacity. In broad terms, two distinct propagation scenarios exist within microcells, line-of-sight (LoS) propagation, whereby a mobile has a direct, unobstructed path between itself and a microcellular base station, and non-LoS, where the radio path between the mobile and the microcellular base station is obstructed.

In the non-LoS case, the signal travels between the mobile and the microcellular base station by means of reflections from and diffraction around obstacles. As a mobile moves towards a microcellular base station, the probability that it has a LoS path to the base station increases. This effect is captured in the International Telecommunication Union's model dealing with 'Propagation between terminals located below roof-top height at UHF', which is part of the ITU-R P.1411 Recommendation [2]. Using this model we can compute that, if a mobile is 276 metres from a microcellular base station it has a 10% probability of having a LoS path to that base station. This increases to a probability of 90% if the distance to the base station decreases to 16 metres.

The model also predicts that the radio signal decreases at 20 dB per decade increase in distance if a LoS path exists (ie, it follows a $1/r^2$ characteristic), whereas the signal roll-off for a non-LoS path is 40 dB per decade (ie, it follows a $1/r^4$ characteristic). The output of the model has been plotted in Figure 3 for different coverage probabilities. As an example, if a mobile is 800 m from its serving base station, the path loss will be less than 85 dB for 1% of locations and less than 173 dB for 99% of locations.

In GSM networks, co-channel microcells are generally separated from each other by at least one other cell (ie, co-channel cells are not direct neighbours). This means that the dual slope LoS/non-LoS propagation model described above can be exploited by arranging the microcellular base stations such that the propagation mechanism across much of the service area of a microcell is LoS, whereas the propagation path to each of the co-channel interfering base stations is non-LoS. In this way, the interference decays much more rapidly than the wanted signal, leading to reduced co-channel reuse distances and higher network capacity.

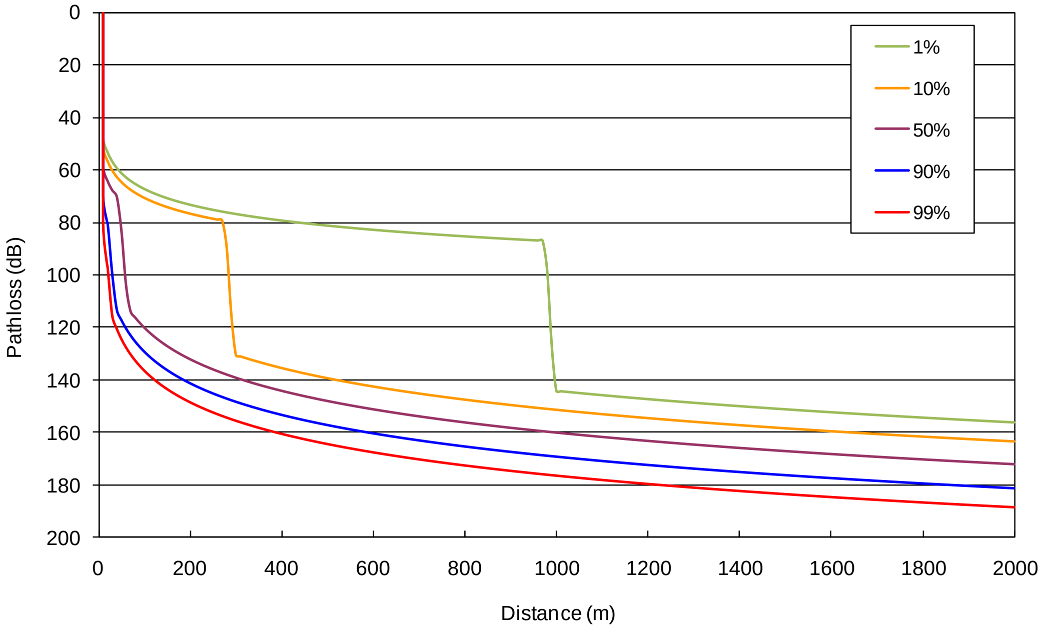


Figure 3 Low antenna height propagation model (frequency = 2 GHz)

In a CDMA network with single-cell frequency reuse, the neighbouring cells will also be co-channel interferers and this means that the propagation characteristics for the wanted signal and for the interfering signals will be more similar than in GSM networks. In the case of a very dense microcell layer, the probability of having a LoS propagation path to one or more neighbouring, co-channel microcellular base stations becomes much greater. In order to investigate this effect on the capacity of a CDMA network, a simple simulation has been developed to examine the manner in which the ratio of the total uplink interference experienced at a base station to the uplink interference from users within the same cell varies with microcell density. This ratio, known as the geometry factor, indicates the relative size of the intracellular interference (ie, interference from users within the same cell) and the intercellular interference (ie, the interference from users in surrounding cells) and it has a direct impact on the capacity of a CDMA network.

The simulation involves placing users randomly within a network of hexagonal microcells, adjusting their transmit power based on the path loss to their serving cell and calculating the interference they generate at surrounding cells. The results of the simulation are shown in Figure 4 and this demonstrates that the total-to-intracell interference ratio increases significantly as the base station spacing is decreased from 200 m to 25 m. This variation is a result of the dual slope propagation model that we have used, since as the microcell density increases, a mobile station is more likely to have a LoS path to its surrounding (non-serving) base stations and, thereby, suffer significantly more intercell interference.

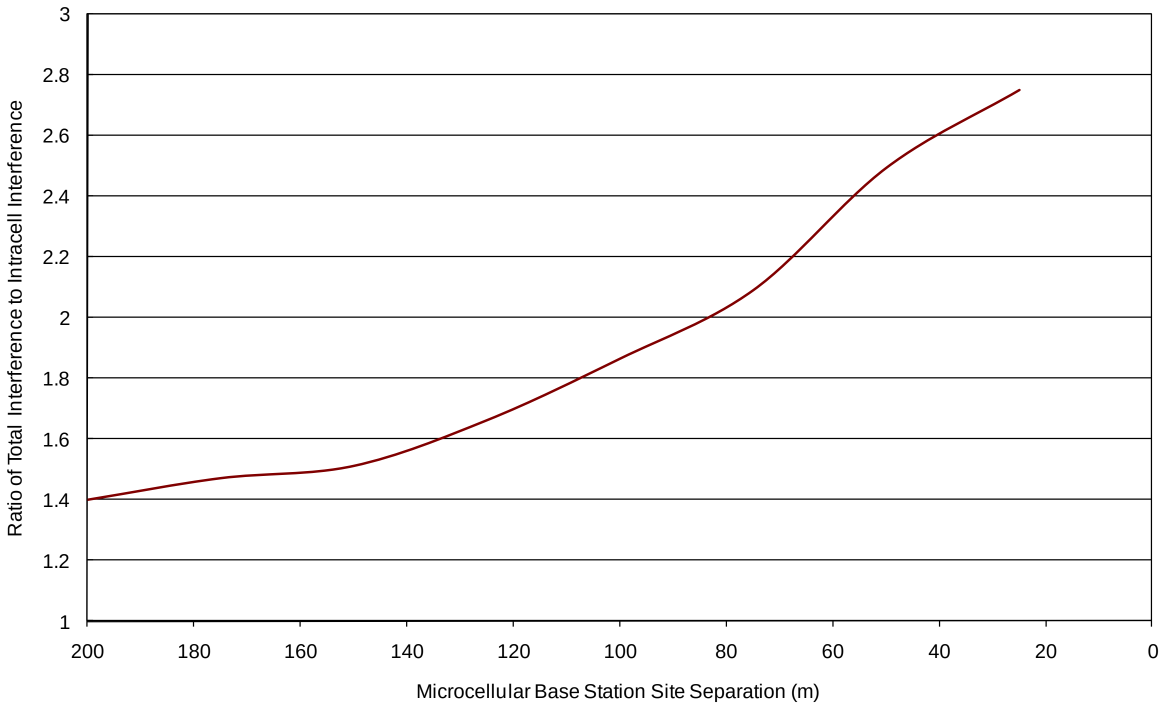


Figure 4 Variation in total-to-intracell interference ratio with base station separation

In order to understand the impact of this variation in geometry factor on the overall capacity of the network, we need to examine the basic CDMA equation, which is given below

$$\frac{E_b}{I_0} = \frac{S/R_b}{N_t/W + S\,(N-1)\,\alpha\, f} \tag{1}$$

where E_b/I_0 is the ratio of the energy per bit to the power spectral density of the noise and interference required for a particular service, S is the uplink power received from a user that is being served by the base station, R_b is the data rate of the service, N_t is the thermal noise power at the receiver, W is the CDMA chip rate (ie, the spread bandwidth) , α is the transmission duty cycle (ie, the proportion of time a mobile station transmits during a connection), N is the number of users served within a cell and f is the geometry factor, which has been discussed above.

By solving this equation for N, the number of users served within a cell, we can examine the impact of the geometry factor on the uplink cell capacity and the results are shown in Figure 5, where the cell capacity has been shown relative to the cell capacity at a site separation of 200 m.

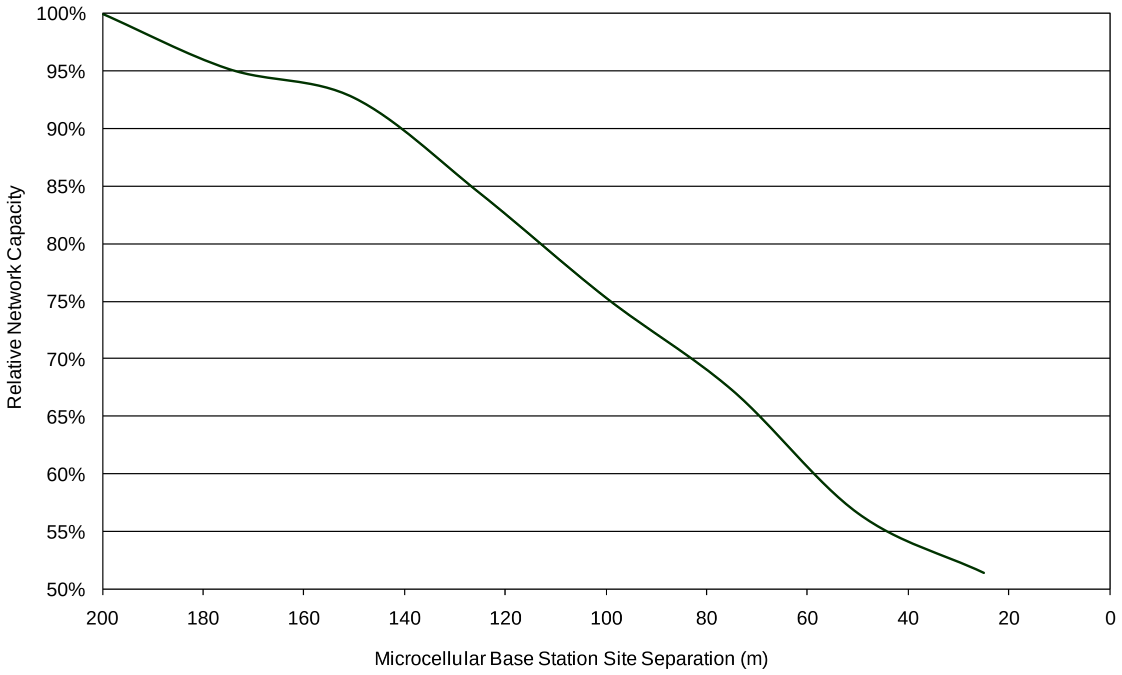


Figure 5 Variation in network capacity with base station separation

This shows that the capacity of a cell will fall to around 60% at a site separation of 60 m, compared with the cell capacity at a 200 m separation. Of course, the overall network capacity will still increase if the cell density is increased in this way, since the 11-fold reduction in cell area more than compensates for the loss of capacity at each individual cell. However, the important message here is that the capacity benefit of each individual microcell will decrease significantly as the microcell density is increased in a way that was not seen in GSM networks. This effect must be taken into account when assessing the number of microcells required to deliver a particular capacity increase and also when assessing the cost and benefits of introducing a particular microcell.

Microcells Limit the Capacity of an Oversailing Macrocell

When deploying a microcellular overlay on the same carrier frequencies that are used in the macrocellular layer, it is also important to understand the impact of the microcellular users on the capacity of the oversailing macrocells. In the case of GSM networks, the microcellular base stations operate on a different set of frequencies and once a mobile is served by a microcell, it no longer generates any significant interference to the oversailing macrocell. As a result, it has no impact on the macrocellular base station's capacity. In CDMA networks, on the other hand, mobiles that are served by the microcellular base stations will still generate interference at the oversailing macrocellular base station, thereby decreasing its overall capacity. In other words, a mobile that is served by a microcellular base station is not completely offloaded from the macrocellular base station in a CDMA network and will continue to consume some of the macrocellular base station's radio interface capacity.

To demonstrate this effect, the hexagonal simulator has been used to investigate the impact on the geometry factor at a macrocellular base station when a number of microcells are introduced into its coverage area. A 19-cell network of hexagonal microcells, with a site spacing of 100 m, was overlaid onto a

19-cell network of hexagonal macrocells, with a site spacing of 250 m, and the geometry factor at the central macrocellular base station was measured. In general, the geometry factor for a macrocellular base station in a uniform hexagonal cellular network is assumed to be 1.5. In our simulation, this value increases to around 5 when the microcells are introduced. Based on Equation (1), this change in geometry factor will result in the capacity of the macrocellular base station decreasing to 30% of its capacity in the macrocell-only network.

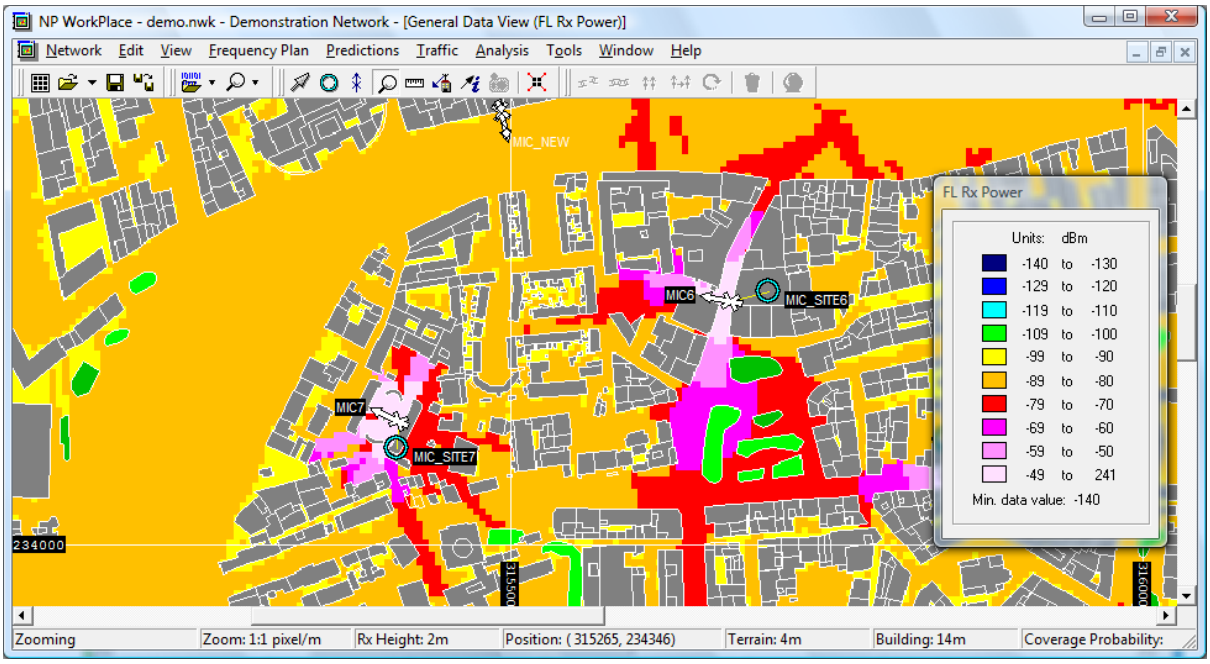
This example shows that, although microcells can be used to increase the available network capacity within a particular area, the mobiles that are served by the microcellular base stations continue to have an impact on the capacity of the oversailing macrocells and this effect must be taken into account when determining the amount of traffic that can be served by the macrocellular base stations.

Practical Microcellular Planning

Of course, the analyses presented in this paper have been based on relatively simple models in order to convey the general principles of CDMA network design. The models have also been based around the uplink. Since the effects of introducing microcells on the downlink capacity of a CDMA network will not necessarily be the same, different models are required to investigate the impact on the downlink.

In practice, the size, shape and capacity of an individual microcell will be governed by its surroundings, the exact location of its neighbours, including the macrocellular base stations, and the loading on each cell. Microcells will be far from hexagonal and their coverage will tend to follow the shape of the streets in which they are placed. Therefore, more sophisticated tools are required to determine the impact of introducing microcells into a CDMA network and a screenshot from such a tool is shown in Figure 6. This shows the downlink (or forward link) received power for two microcells deployed within a city (MIC6 and MIC7) and clearly demonstrates the manner in which the size and the shape of microcells is governed by the surrounding buildings.

The tool used to produce the screenshot in Figure 6 comprises a microcellular propagation prediction component, known as the NP WorkPlace, which allows a network designer to position the proposed microcells with a high degree of accuracy based on a high resolution map of the urban area. Propagation prediction models that have been tailored specifically to the microcellular propagation environment are then used to determine the path loss to each macrocellular and microcellular base station across the coverage area. Figure 6 shows the received downlink power within the coverage area based on these propagation models. A CDMA simulation component, known as MACcdma, can then be used to populate the network with active users and calculate the probability of a service being available across the coverage area. Other parameters can also be collected from the simulation, such as the number of mobile stations served by each base station, so that the network designer can judge the ‘quality’ of each new potential microcellular site, the benefit of deploying a base station at that location and the impact on the capacity of the oversailing macrocell.



Units: dBm

■	-140	to	-130
■	-129	to	-120
■	-119	to	-110
■	-109	to	-100
■	-99	to	-90
■	-89	to	-80
■	-79	to	-70
■	-69	to	-60
■	-59	to	-50
■	-49	to	241

Min. data value: -140

Zooming | Zoom: 1:1 pixel/m | Rx Height: 2m | Position: (315265, 234346) | Terrain: 4m | Building: 14m | Coverage Probability:

Figure 6 Screenshot from MAC Ltd's radio network planning tool, NP WorkPlace, and CDMA simulation tool, MACcdma

Conclusions

Microcells can offer significant capacity benefits in a 3G CDMA network and provide an effective solution to the current capacity crunch. However, microcellular site selection is far more important in a CDMA network compared with a GSM network and poor site selection can make the addition of a new CDMA microcell pointless in terms of providing a capacity uplift, or worse still, the addition of the site could be detrimental to the overall network performance. Although simple rules can be developed to help site acquisition teams locate sites that could potentially bring benefit to the network, the final decision as to the suitability of a site can only be made using sophisticated planning tools that can take into account the precise location of the other base stations within the network and the surrounding environment.

References

1 Gould P R, 'Radio Planning of Third Generation Networks in Urban Areas', IEE Third International Conference on Mobile Communication Technologies (3G 2002) , London, 8-10 May 2002,

2 International Telecommunications Union, 'Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz', Recommendation ITU-R P.1411-5 (10/2009).