Radio Coverage Planning with Small-Scale Fading

Dimitar G. Valchev

Abstract – **This paper describes an aspect not traditionally accounted for in the radio coverage planning methodology. It is shown that when the radio coverage is planned to ensure enough power, there are points in vicinity of the user's receiver that have essentially no power due to the multipath effects. Thus, the multipath channel modelling should play a significant role in the radio coverage planning process, where not only the landscape properties are taken into account, but also the spatial properties of the indoor propagation environment surrounding the antenna of the user's receiver.**

Keywords – **Fading channels, Propagation, Scattering.**

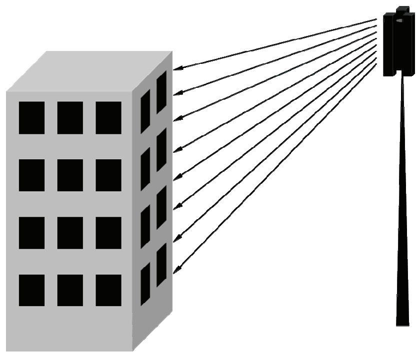
I. INTRODUCTION

Planning of the radio coverage is an important part of the wireless network design in wireless local area networks (WLANs) as well as in cellular networks. It ensures availability of radio signals to the terminal equipment within the area or volume covered by the corresponding access point or base station. Without loss of generality, the base station and the access point will be united in this paper in the common concept of base station (BS). The planning process ensures enough radio power in any point within the covered by the BS volume.

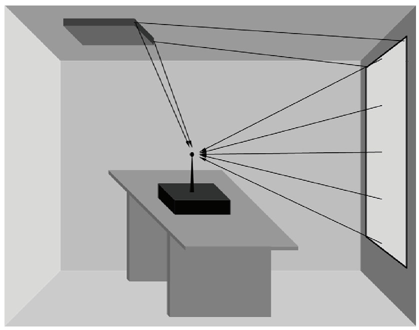
After the radio signal leaves the BS, power attenuation is in effect. It is caused mainly by three factors: path loss, shadowing and multipath fading [1]. The path loss determines the natural attenuation of the radio signal with distance from the transmitter. The dependence of the radio power on the distance is inversely proportional with some power factor depending on the properties of the propagation environment [1, 2]. The shadowing effect is caused by the presence of randomly placed obstacles within the volume covered by the transmitter of the BS. The shadowing effect causes power variation over distances comparable to the size of the surrounding blocking and reflecting objects.

The combined effect of path loss and shadowing forms the basis of the ray tracing models. The ray tracing models are particularly suited for computer aided radio coverage planning in various sites, by using geographical information systems (GIS) showing the corresponding landscape and buildings [2].

What is not accounted for in the ray tracing models forming the basis of the traditional radio coverage planning process, is the effect of multipath or small-scale fading. This effect is caused by multiple reflections and scattering of the radio signal in the vicinity of the receiving antenna, causing a standing wave interference pattern within the local volume of the user's receiver. Fig. 1 shows how different propagating radio waves can superimpose on the receiving antenna to create constructive and destructive interference



(a) Outdoor propagation



(b) Indoor propagation

Fig. 1. Radio signal propagation from the BS to the user's receiver

Even when the radio coverage is planned to deliver enough radio power to the receiver, the multipath fading itself might cause total absence of radio signal in particular points within the local volume! While the outdoor propagation is planned for a particular power level for the indoor users, the indoor propagation causes multipath by reflections of the radio signal. This paper stresses the importance of considering the multipath fading in the entire process of coverage planning.

The rest of the paper is organized as follows. Section II describes the multipath mitigation measures. Section III defines multipath shape factors, characterizing the local volume around the receiver. Upon them the fading signal coherence distance is defined. Section IV concludes the paper.

II. MULTIPATH FADING MITIGATION

The effects of multipath fading can be mitigated generally using a spatial diversity scheme in which multiple receiving antennas are combined. Two receiving antennas should be separated at least by the coherence distance of the fading signal for achieving maximum diversity gain [2]. If the multipath is concentrated around a relatively narrow beam, the coherence distance can be too large. Depending on the

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multipath angular power distribution (APD) around the user's receiver $p(\theta,\phi)$, with θ being the azimuth and ϕ being the elevation, the coherence distance has angular dependence [3]. In the spatial diversity system the multiple antennas should be placed such that the total occupied space is minimized and/or the diversity gain is maximized. Therefore, it is crucial for the system designer to get the APD around the receiver and based on it, to derive expressions that determine the angular dependence of the fading signal coherence distance within the particular indoor environment. The indoor environment itself determines the APD through the presence of scattering and reflecting objects. The coherence distance in different directions within the local volume is derived in terms of the so called multipath shape factors [3] that relate the APD around the receiver to the second-order fading statistics of the received radio signal. The next section will give approximate expression for the coherence distance that can be used in system design for the purposes of multipath fading mitigation.

III. MULTIPATH SHAPE FACTORS

In [3] the concept of three-dimensional multipath shape factors is developed to derive the important fading statistics in non-omnidirectional wireless channels. The definitions of the shape factors are based on the *l*-th degree, *m*-th order spherical harmonic coefficients S_l^m of the APD $p(\theta,\phi)$ as follows:

Angular Spread, ranging from 0 to 1:

$$\Upsilon = \sqrt{1 - \frac{{S_1^0}^2 + \left|S_1^1\right|^2}{{S_0^0}^2}}, \quad (1)$$

Elevational Constriction, ranging from –0.5 to 1:

$$\xi = \frac{1.5 S_2^0 S_0^0 - \left({S_1^0}^2 - 0.5\left|S_1^1\right|^2\right)}{{S_0^0}^2 - \left({S_1^0}^2 + \left|S_1^1\right|^2\right)}, \quad (2)$$

45°-*Inclined Constriction*, ranging from 0 to 1:

$$\chi = \frac{2\left|S_2^1 S_0^0 - S_1^0 S_1^1\right|}{{S_0^0}^2 - \left({S_1^0}^2 + \left|S_1^1\right|^2\right)}, \quad (3)$$

Azimuthal Constriction, ranging from 0 to 1:

$$\chi = \frac{\left|S_2^2 S_0^0 - {S_1^1}^2\right|}{{S_0^0}^2 - \left({S_1^0}^2 + \left|S_1^1\right|^2\right)}, \quad (4)$$

Azimuthal Direction of Maximum Fading at 45° *Elevation*:

$$\theta_{\phi 45}^{\max} = \arg\left\{S_2^1 S_0^0 - S_1^0 S_1^1\right\}, \quad (5)$$

Azimuthal Direction of Maximum Fading at Zero Elevation:

$$\theta_{\phi 0}^{\max} = \arg\left\{S_2^2 S_0^0 - {S_1^1}^2\right\}. \quad (6)$$

The spherical harmonic coefficients are calculated by the following integrations [4]:

$$S_0^0 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\cos\phi\, d\phi\, d\theta, \quad (7)$$

$$S_1^0 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\sin\phi\cos\phi\, d\phi\, d\theta, \quad (8)$$

$$S_1^1 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\cos\phi\, e^{j\theta}\cos\phi\, d\phi\, d\theta, \quad (9)$$

$$S_2^0 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\left(\sin^2\phi - 1/3\right)\cos\phi\, d\phi\, d\theta, \quad (10)$$

$$S_2^1 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\cos\phi\sin\phi\, e^{j\theta}\cos\phi\, d\phi\, d\theta, \quad (11)$$

$$S_2^2 = \int_0^{2\pi}\int_{-\pi/2}^{\pi/2} p(\theta,\phi)\cos^2\phi\, e^{j2\theta}\cos\phi\, d\phi\, d\theta, \quad (12)$$

The coherence distance by which the multiple antennas should be separated in the spatial diversity scheme is given in terms of the multipath shape factors as [3]:

$$d_c = \frac{\lambda}{\Upsilon}\left\{15.33\left[1 + 1.5\left(\xi\left(2\sin^2\phi - 0.67\right) + \chi\sin 2\phi\cos\left(\theta - \theta_{\phi 45}^{\max}\right) + \zeta\cos^2\phi\cos 2\left(\theta - \theta_{\phi 0}^{\max}\right)\right)\right]\right\}^{-\frac{1}{2}}. \quad (13)$$

It is seen that the coherence distance is a function of the azimuth and elevation and therefore has a minimum at a particular direction. This is the direction at which the multiple elements of the receiver diversity scheme should be aligned in order to achieve minimum occupied space and/or maximum diversity gain for the received signal.

IV. CONCLUSION

This paper augments the traditional radio coverage planning methodology by introducing the small-scale fading into the designing process. It is shown that even when the radio coverage is planned for a sufficient power level, there are points within the local volume in vicinity of receiver antenna where the signal is absent. Therefore, a spatial diversity scheme at the receiver is needed in order to ensure a reliable communication link. The paper shows the importance of analyzing the environment around the user's receiver in order to optimally plan the radio coverage.

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