Capacity of Broadband Communications in the Millimeter-Wave Band

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ABSTRACT

A cellular code-division multiple access (CDMA) system operating in the 63-64 GHz band for short-range communications is studied and analyzed. The system capacity, expressed as the maximum number of users per cell, is analytically derived and favorably compared with other CDMA schemes operating in conventional frequency bands (i.e. below 2 GHz). It turns out that the use of 63-64 GHz band significantly increases the capacity of a CDMA network, and proves to be suitable for cellular systems, personal communication networks (PCNs) and wireless broadband access.

1. INTRODUCTION

The capacity of Code Division Multiple Access (CDMA) systems is severely limited by the strong co-channel interference that calls for the adoption of some adequate countermeasures. An interesting mean to improve system capacity, with minimal complexity increase, is represented by the use of the 63-64 GHz band, in the vicinity of the oxygen absorption peak [1], where the effects of the adjacent interferers are significantly reduced. Such an approach promises substantial capacity gain due to the increased separation of users provided by natural atmospheric attenuation. Also, the large bandwidth available at those frequencies can be used for broadband services and permits the use of spread-spectrum (SS) transmission with large processing gains that considerably enhances system robustness against interference.

The goal of this work is to evaluate the capacity obtained by using the 63-64 GHz band for short-range CDMA communications.

2. SYSTEM OUTLINE

The cellular system analyzed is shown in (Fig. 1). For the sake of network management simplicity, the access technique is assumed asynchronous CDMA (A-CDMA) and the users are supposed uniformly distributed on the coverage area. The cell stations have azimuth-omnidirectional antennas, while mobile/portable units may have either omnidirectional or low-directional aerials.

In the forward-link, each station transmits N signals of equal power P to N active users inside the cell, while in the return-link, perferct power-control is assumed to eliminate the "near-far problem". In the following analysis we restrict our attention to the forward-link, and we assume the cell #1 as the reference cell, that is the cell transmitting the useful signal toward the receiver placed in a corner of the cell at distance R from the transmitter (Fig. 1).

Several CDMA interfering signals add to the useful signal at the receiver RF front-end, and considering a large number of transmitted channels, we can invoke a central-limit argument and model CDMA interference as additional Additive White Gaussian Noise (AWGN).

Now, denoting with E the average energy per bit received at distance R from the transmitter, the received signal power is $P(R)$. Also, denoting with $[C/I]_R$ the ratio between the useful signal carrier power and the total interfering power, comprehensive of both AWGN and CDMA interference with one-sided power spectral density (PSD) N_0 and $I_0(R)$, respectively, evaluated at distance R from the transmitter, we have

$$\left[\frac{C}{I}\right]_R \triangleq \frac{P(R)}{\left[N_0 + I_0(R)\right]B_{ss}} \tag{1}$$

In the practice, the value of $[C/I]_R$ is fixed by the BER required to achieve the desired signal quality. The required BER depends on the type of service provided. In practical voice communications, a maximum BER of 0.001 is often assumed. This value can be significantly smaller when dealing with data transmission.

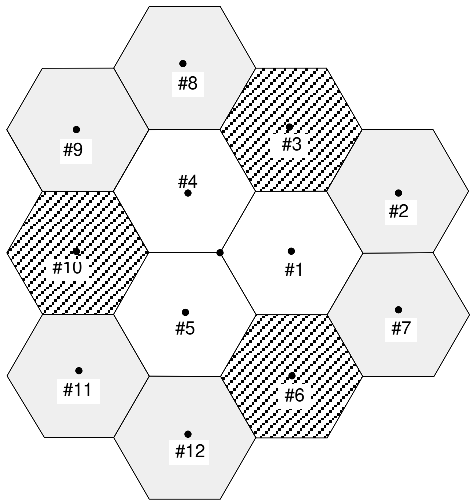

Figure 1: Cellular system model

3. PROPAGATION MODEL

In the following, the propagation model used to derive the main results of this study is outlined and discussed. The model is based on the study reported in [1]. The model was found to match remarkably well experimental data.

3.1 Atmospheric Attenuation

Atmospheric attenuation in the proximity of 60 GHz is mainly originated by two causes, namely rain and oxygen.

3.1.1 Rain
When using frequencies above 10 GHz rain attenuation affects radio propagation, depending upon the rain rate *r*, usually expressed in mm/h [2].

3.1.2 Oxygen
For carrier frequencies in the 63-64 GHz band the oxygen absorption introduces a further attenuation, whose specific value α_{OXY} is about 11 dB/km for f_c=63 GHz.

3.2 Overall Attenuation
The resulting specific attenuation factor due to atmospheric causes is therefore the sum of both the contributions (in dB/km). Also, the received power varies as the squared inverse of the distance from the transmitter. This holds true for free-space propagation only and does not apply to urban areas where different propagation models must be used.

Further details about millimeter-wave radio propagation in urban areas an be found in Ref. [3].

4. NUMERICAL RESULTS
Let us evaluate first the capacity of a simple A-CDMA system for mobile communications at low data rate, suited for cellular and IVHS (Intelligent Vehicle-Highway System) applications. The "asynchronous" multiplexing approach selected here guarantees reduced complexity at both modem architecture and system management levels. The modulation scheme is QPSK. The activity factor v is set to 0.5. Also, we set the processing gain $G_p = 750$, that allows the transmission of a bit rate $R_b = 8$ kb/s within a bandwidth $B_{ss} = 6$ MHz. Recalling that forward-link and return-link operate in different frequency bands, the overall bandwidth occupancy of this CDMA cellular/IVHS service amounts to 12 MHz.

Figure 2 shows the number of users per cell (*N*) versus the cell radius (*R*) for a target bit error rate (BER) $\left[P_b\right]_R = 10^{-2}$. In the numerical derivation of the system capacity we assumed $\gamma = 2$.

Such an assumption is quite reasonable for an IVHS scenario while in the case of urban propagation it represents a sort of "worst-case" condition, because it implies a strong adjacent-cell interference. The curves are plotted from equation (5) for a fixed value of $\left[C/I\right]_R$ (determined by the required BER) and in the absence of thermal noise. Thick line corresponds to 63 GHz and the thin one to 1 GHz. From Fig. 2 it is apparent that the use of 63-64 GHz band improves the performance of the A-CDMA system over the use of 1-2 GHz and that beyond 1 km the capacity gain is approximately zero. Therefore, in the following, unless otherwise specified, we consider $R = 1$ km.

As a case study, we consider now a wideband access provided by means of a wireless "last mile" connection at 63 GHz between customer premises and some radio base stations that serve as gateways with the cable/optical fiber network backbone, thus avoiding the costly operation of wiring offices and houses.

The users' terminals are supposed to be portable (e.g. laptop computers), but conceived to operate from a fixed position. This permits the use, of a low-directional antenna, that helps in getting rid of undesired signals coming from surrounding gateway stations.

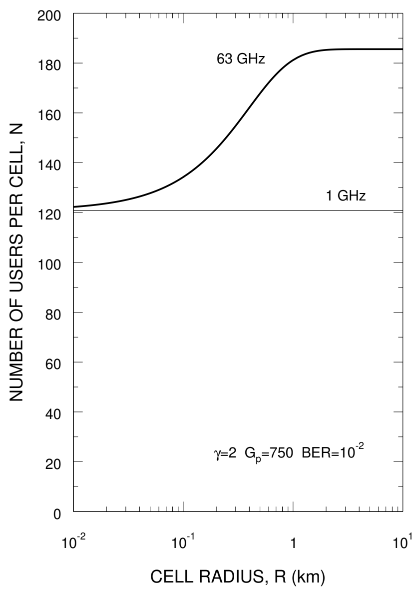

Figure 2: Cell capacity vs. cell radius

For the sake of simplicity we will assume that every terminal is equipped with an antenna having an ideal radiation pattern 100°-wide. It follows that a user in the worst-case location of Fig. 1, having the antenna with the center of its radiation lobe aimed at station #1, will not receive any interference from stations #4, 5, 8, 9, 10, 11 and 12.

5. SUMMARY AND CONCLUSIONS
Based on a simple propagation model for the 63-64 GHz band, the capacity of a cellular A-CDMA system has been derived. It turned out that the use of 63-64 GHz significantly increases the overall system capacity compared to conventional bands. For a given *R*, the capacity gain depends only on the propagation exponent γ, and the gain is remarkable if the propagation conditions cause strong interference from other cells. In this case the oxygen absorption is effective in reducing the interference coming from distant cells, but not from the interferers having the same distance from the receiver as the reference cell station (near-in region). In any case, for the example considered, no further capacity increase is obtained for *R* greater than 1 km.

ACKNOWLEDGEMENTS
The author wishes to thank Prof. P.J. Parker of the Central University, Sidney, for his invaluable help.

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