SPECTRAL EFFICIENCY OF MQAM USING DIVERSITY TECHNIQUES

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Abstract: The performance of Time Division Multiple Access (TDMA) is affected by various factors. Accurate coverage prediction, modulation and coverage control techniques can significantly improve the capacity. Spectrum efficiency and good coverage are the main objectives of radio system planning. The capacity of a cellular system is directly related to spectrum efficiency and is directly proportional to the cluster size, so that any decrease in the size indicates that co-channel cells are located much closer together. This allows more frequency channels to be reused taking into account minimum co-channel interference (CCI). The above factors have an impact on the capacity, it is therefore crucial to include them in the evaluation to minimize the assumptions made. This paper shows development of a Monte Carlo simulation model which accurately assesses the performance of cellular systems.

Keywords: Modulation, Efficiency, Diversity, Co-channel, Interference, Spectrum

1 INTRODUCTION

The radio spectrum is a finite resource and it is important that it is exploited efficiently by all users. Accordingly modulation scheme used for mobile environment should utilise the RF channel bandwidth and the transmitted power as efficiently as possible. This is due to the fact that the mobile radio channel is power and bandwidth limited, which implies the need to investigate different digital modulation, schemes under different propagation channels. A typical application of such results would be the choice of modulation technique for a digital mobile radio system in a specific environment.

This paper discusses the impact of the choice of a modulation scheme on the reuse distance. Since the value of the reuse distance has a decisive effect on the performance of the spectral Efficiency, a relation is set between the chosen modulation level and the spectral efficiency. Assuming the downlink case, the power at the mobile receiver from the desired base station (BS) and the co-channel BS's was calculated according to the propagation model used.

The CCI associated with a certain bit error rate (BER) for a particular modulation scheme will define the reuse distance, D. The value of D is the maximum value that complies with the constraint set by CCI ratio.

As detailed in [Parsons, 1992], selected propagation model for both desired and interfering signals are applied. It is acceptable that frequencies are reused at distance D, therefore the area covered by the service of one set of these reused frequencies is roughly covered by, $\pi(D/2)^2$. The relation of the reuse distance D with radius R is given by the reuse distance factor, Ru = D/R as shown in Figure 0.

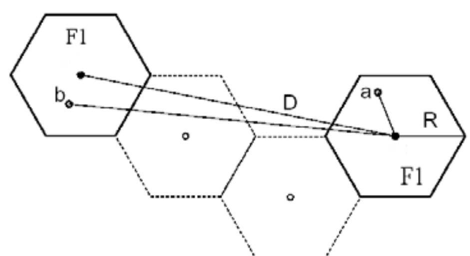

Figure 0: The relation of reuse distance D and radius R where a and b are mobile

Manhattan microcell, Cost231-Hata and Lee models were used to assess the capacity potential for high-level modulation schemes. In order to provide a comparative capacity evaluation, diversity vs. omni directional configurations where applied in different propagation models. These coverage control schemes are used to increase capacity by reducing the co-channel interference, thus the reuse distance D.

The spectrum efficiency evaluation technique described studies the effective area of each cell in a co-channel interference limited environment. By

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specifying the BER performance, the corresponding carrier-to-interference ratio (CIR) can be obtained for a specific modulation scheme, thus the reuse distance is evaluated.

The following sections describe the capacity evaluation method and the simulation results obtained using different propagation models.

2 CHANNEL AND SYSTEM MODELS

Spectral efficiency is evaluated so that minimum assumptions are made. In this section, the propagation and interference models are explained.

2.1 Propagation models

Cell radius and path loss exponent are critical parameters, derived from the propagation model. These are assessed from the received signal in a specific environment.

The work done here describes three cells:

2 Macrocell, R>1km, S_{th}=65 dBm
3 Microcell, 300m>R>1 km, S_{th}=115 dBm.
4 Microcell, R<300m, S_{th}=115 dBm.

Using different propagation models, the cell radius is determined by the predefined system threshold, S_{th}, below which the mobile receiver may not be able to detect the desired signal from noise [Holma and Toskala, 2000]. The path loss exponent 20 dB/dec can also be easily derived.

2.1.1 Lee Model

Lee's empirical propagation model is considered accurate enough and simple to use for macrocellular systems [Lee, 1990a]. Since this model is a semi statistical model, the results are also considered statistical. The model is used to predict the field strength of the received signal P_r which can be expressed as

$$P_r = P_o - \beta \log\left(\frac{d}{d_o}\right) - \eta \log\left(\frac{f_c}{900}\right) + \alpha_o$$

where f_c is the carrier frequency, P_o and η are the parameters found from empirical measurements at a 1.6 km point of interception , -64 dBm and -43.1 dBm respectively.

In this paper, these were taken for an urban area (Newark, USA), where β is the path loss exponent, d is distance in km from the transmitter, d_o is 1.6 km, and α_o is the correction factor for a different set of conditions.

2.1.2 Cost-231 Hata Model

This model can distinguish between three different environmental types. The model is expressed in terms of the carrier frequency f_c (in MHz), the base station antenna height h_b (between 30 and 200 meters), the mobile station antenna height h_m (between 1 and 10 meters), and the distance d (between 1 and 20 km) between transmitter and receiver. The urban path loss LU is given as $A + B \log_{10} d$, for urban areas with some correction factors for suburban areas *(LSU)= LU -15.11* and for open areas *(LO) = LU - 30.23*. The terms A and B are expressed as follows [6]:

$$A = 46.3 + 33.9 \log(f_c) - 13.2 \log(h_b) - a(h_m),$$
$$B = 44.9 + 6.55 \log(h_b),$$

where $a(h_m)$ depends on the city type; for small and medium cities:

$$a(h_m) = 1.1 \log_{10}(f_c - 0.7) * h_m - 1.56 \log_{10}(f_c - 0.8),$$

for large cities:

$$a(h_m) = 3.2(\log_{10}(11.75 * h_m))^2 - 7.97,$$

In our simulation, environment only large cities and urban areas is considered.

2.1.3 Manhattan Model

The line of sight path loss L_{LOS} is defined using this model for the microcell scenario, for a distance *d= 300* [Holma and Toskala, 2000],

$$L_{LOS} = 82 + 40 \log_{10} \frac{d}{300}$$

From the previously described models, Table 1 shows the derived path loss exponent and radius.

Table 1: Path loss exponents and cell radius.

Propagation model	S_{th} (dBm)	Radius	Path loss exponent
Lee model	65	2.5 km	4.31
Cost231-hata	115	780 m	3.0647
manhattan	115	213 m	2.028

2.2 Interference Models

To simplify the analysis only first tier co-channel interference is taken into account. The desired user CIR is as follows,

$$CIR = \frac{S_d}{S_i} = \frac{S_d(r)}{\sum_{i=1}^{n_i} S_i(r_i)} \qquad (1)$$

Where S_d (r) is the desired power level from the desired mobile at a distance r from its BS, S_i is the total received interfering power level from the i^{th} interfering mobile at a distance r_i from the desired mobiles BS, and n_i is the number of active interferences, for the case of non-sectorized cellular systems n_i =6.

3 AREA SPECTRAL EFFICIENCY

The performance measure used in this paper is the area spectral efficiency, η_{area}, as defined by Alouini [Alouini and Goldsmith, 1999b] for FDMA/TDMA systems and is given by,

$$\eta_{area} = \frac{4}{\pi D^2} \int_{R_0}^{R} \log_2(1+\gamma)\, p_r(r)\, dr \qquad (2)$$

where D is the reuse distance at which the frequency are reused, R_0 corresponds to the closest distance the mobile can be from the BS antenna and R is the cell radius. The average area spectral efficiency $\overline{\eta}_{area}$ measured in [bits/s/Hz/km^2] is defined as the sum of the maximum average data rates/Hz/Unit area for the system derived from Shannon capacity,

$$C = W \log(1+CIR)$$

where W is the total allocated bandwidth /cell [Lee, 1990b].

It should be noted that as spectral efficiency increases the constellation lattice becomes denser, hence, detection at the receiver becomes more difficult and BER may rise significantly. For this reason, greater power transmission is needed in order to maintain a specific quality of service. The higher transmitted power would raise the interference level in the system, which suggests larger reuse distance. Therefore by letting the CIR obtained from the modulation scheme for a certain BER to determine the size of the cell, will lead to optimum results.

In cellular systems, modulation has a significant impact on the system capacity. The capacity can be obtained by estimating for each required CIR level which is determined by the BER requirement. In this paper all the simulation is performed for a BER performance of 0.001, the required co-channel interference ratio is obtained by using Figure 1 .

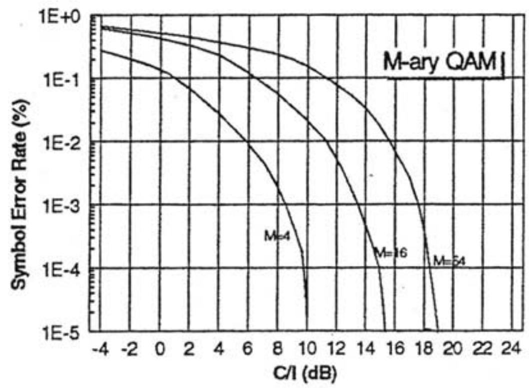

Figure 1: C/I required to meet BER requirement for different M.

The total bandwidth is determined from the following equation,

$$B_w = \frac{R_b(1+\alpha)}{\beta}$$

where R_b is the bit rate, α is the excessive bandwidth often assumed 0.35 and β is the bandwidth efficiency measured in bits/sec/Hz.

With reference to the required signal to interference ratio, the six co-channel cells are moved towards the centre cell. The minimum reuse distance, *D*, corresponds to the point where the co-channel interference ratio is satisfied.

Using the evaluated cell radius, *R*, the reuse distance is obtained by estimating for each required co-channel interference level determined by the (BER) requirement.

The optimal reuse distance is based on the worst case configuration, where r_i=*D-R.* The simulated model also takes into account the effect of users' random location in their respective cells, the impact of propagation parameters, cell size, and cell sectorization is also considered. The spectral efficiency is computed for the practical case where the user and the interferer are randomly allocated.

4 ADAPTIVE MQAM AND DIVERSITY

The radio channels in a wireless mobile communication system are affected by different types of fading (multipath, shadowing, etc), therefore, they will have negative effect on signals carried on these channels.

To compensate for these channel impairments imposed by fading, adaptive modulation scheme is used. In adaptive MQAM, information about the channel conditions at the receiver is fed back to the transmitter so that it will adjust its transmitted modulation level (constellation size) accordingly. This channel information is usually acquired by using a pilot signal or inserting a training sequence into the stream of MQAM data symbol to extract the channel induced attenuation and phase shift [Alouini and Golsmith, 1999a].

In this work, the adaptive rate fixed-power MQAM system is combined with a well-known diversity combining techniques. In particular we use the maximal ratio combining (MRC) and selection combining (SC) of the received signal. The former requires the M signals to be weighted proportionately to their CIR and then summed coherently. Perfect knowledge of the branch amplitudes and phase is assumed. The disadvantage of MRC is that it requires knowledge of the branch parameters and independent processing of each branch. The PDF of the received CIR at the output of a perfect M-branch MRC is derived in in [Alouini and Goldsmith, 2000] to be:

$$P^{mrc}(\gamma) = \gamma^{M-1} e^{-\gamma/\bar{\gamma}} / (M-1)\bar{\gamma}^{M} \qquad (3)$$

In the SC technique only one of the M receivers having the highest baseband CIR is connected to the output. Unlike the MRC it does not require coherent reception.

The PDF of the received CIR at the output of M-branch is again derived in [Alouini and Goldsmith, 2000] and it is given by:

$$P^{SC}(\gamma) = \frac{M}{\bar{\gamma}}(1 - e^{\gamma/\bar{\gamma}})^{M-1} e^{-\gamma/\bar{\gamma}} \qquad (4)$$

Assuming perfect coherent detection, thus the only source of error is noise and interference from the channel BER is approximated by [Goldsmith and Chua, 1997]

$$BER(M,\gamma) \approx 0.2\exp(-\frac{3\gamma}{2(M-1)}) \qquad (5)$$

where γ is the CIR.

For given CIR and assuming ideal Nyquist pulses the spectral efficiency of a continuous rate MQAM can be approximated by inverting Eqn. 5 giving;

$$\eta = \log 2(M) = \log 2(1 + \frac{3\gamma}{2K}) \qquad (6)$$

Where K= -ln (5BER)

In practice the CIR is not fixed, it is rather fluctuating due to channel impairments. Therefore the area spectral efficiency is calculated by integrating the above equation over the distribution of CIR and substituting in Eqn. 2. In this case we integrate over MRC distribution function to yield the following:

$$\eta_{area}^{mrc} \approx \frac{4}{\pi D^2 \log_2(2)} \times \mathrm{P}_M(\frac{-1}{\overline{\gamma_o}})\left(-E + \ln\overline{\gamma_o} + \frac{1}{\overline{\gamma_o}}\right) + \sum_{k=1}^{M-1} \frac{\mathrm{P}_k(\frac{-1}{\overline{\gamma_o}}) - \mathrm{P}_{M-k}(\frac{-1}{\overline{\gamma_o}})}{k} \qquad (7)$$

Where $\overline{\gamma_o} = \frac{3}{2K}\bar{\gamma}$, and $\bar{\gamma}$ is the average received CIR.

In the case of SC diversity, an alternative diversity combining technique, we integrate for a selection combining distribution function to yield the following approximation [Alouini and Goldsmith, 2000]

$$\eta_{area}^{SC} \approx \frac{4M}{\pi D^2 \log_2(2)} \sum_{k=0}^{M-1} \frac{(-1)^k}{1+k} \binom{M-1}{k} \times e^{(1+k)/\bar{\gamma}} \left[E + \ln(\frac{1+k}{\bar{\gamma}}) - (\frac{1+k}{\bar{\gamma}}) \right] \qquad (8)$$

Where the binomial coefficient is given as,

$$\binom{M-1}{k} = \frac{(M-1)!}{(M-k-1)!k!}$$

The results have shown a significant increase when using diversity combining technique; these will be shown in details in the following section.

5 SIMULATION SETUP AND RESULTS

In this section, the effects of the different propagation parameters, cell size and modulation level is computed on the spectral efficiency.

Monte Carlo method is applied to determine the rates for the user. The user position is randomly picked and the CIR is evaluated accordingly. After 30,000 repetitions, the average spectral efficiency is evaluated. In the case of MRC and SC diversity, number of branches assumed is 4.

Figure 3-5 depicts the effect of MRC and SC diversity on macrocells and microcells. For all cell sizes, the best performance can be seen using MRC diversity technique. It should also be noted that higher modulation level reduces the performance since they require higher CIR values. This will lead to larger sizes to mitigate the increased interference.

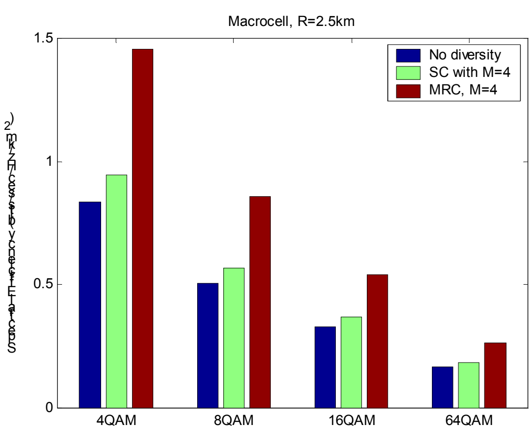

Figure 3: Modulation and diversity effects on system capacity in macrocell environment.

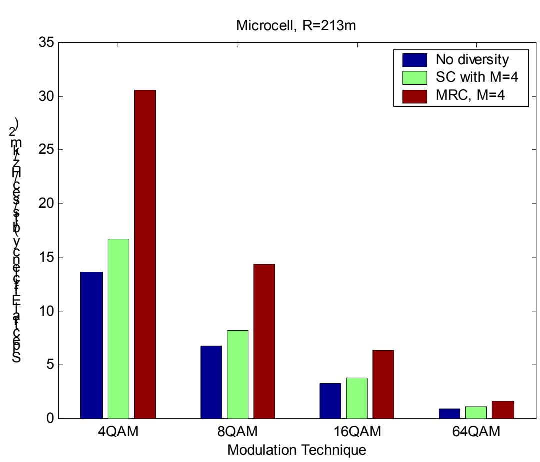

Figure 4: Modulation and diversity effects on system capacity in microcell environment.

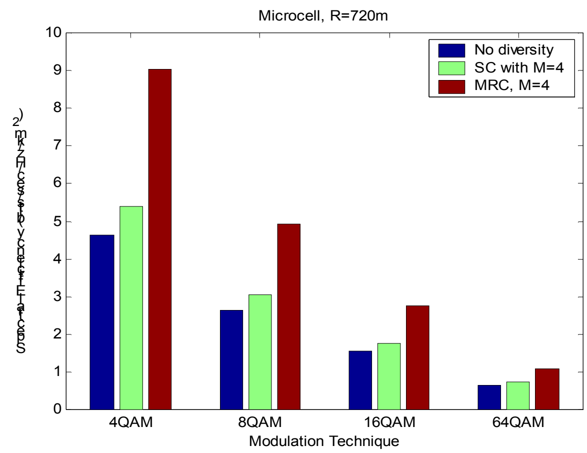

Figure 5: Modulation and diversity effects on system capacity in microcell environment.

6 CONCLUSION

Higher modulation and different antenna pattern using diversity were investigated using the developed capacity evaluation technique. In order, to improve system capacity, the factors, which are limiting the system performance, must be identified. It is also evident, that the best performance was obtained when a microcell is considered. Thus, the radius of the cell is inversely proportional to the spectral efficiency.

In a microcell, the performance of M-QAM degrades as the level increases. Despite better bandwidth efficiency at higher level modulation, more power is needed to maintain energy to noise, E_b/N_o, ratio to achieve a fixed BER at the receiver. The increase in power will require larger cell sizes to mitigate the increased interference level, thus reducing the spectral efficiency of the system. Consequently, 4-QAM=QPSK is the best modulation scheme to achieve high capacity, nonetheless if the modulation level is controlled according to the CIR very high spectral efficiency can be expected. MRC significantly increased the performance of the system when using M=4.

In a macrocell, a higher level modulation scheme may be used to take advantage of higher transmitted power around the base site. A lower level modulation can be accommodated when the receiving power level is low. According to distance from the base station, different modulation schemes are adapted to site coverage, thus improving the system performance.

Finally, the improvement on the factors mentioned in this paper and the investigation of different parameters, results in an overall capacity improvement.

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In September 1999, Professor Marwan Al-Akaidi appointed as a Chairman for the IEEE UKRI Signal Processing Society and March 2000 the IEEE UKRI Conferences chair and in December 2000 appointed to join the board of IEEE Industrial relation. He has won the award of the IEEE UKRI in Recognition of Outstanding Leadership as a chapter chair for Year 2001 & 2002.

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