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The Impact of Spreading Bandwidth on DS-CDMA Power Control Requirements

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Abstract

Direct Sequence Code Division Multiple Access (DS-CDMA) techniques have received a great deal of attention for current and future communication systems. One of the major considerations in implementing a DS-CDMA system is the necessity for accurate power control to ensure adequate quality-of-service and capacity. This paper investigates the power control errors that occur in a real microcellular environment for a variety of architectures. Furthermore, the mitigation of the effect of power control errors with varying spreading bandwidth is quantified.

1. Introduction

Direct Sequence Code Division Multiple Access systems have been proposed for Universal Mobile Telecommunications System (UMTS) and International Mobile Telecommunications for the year 2000 (IMT-2000). Proposed systems employ a larger bandwidth than currently deployed narrowband CDMA techniques [1]. Consequently, the technique is often referred to as Wideband Code Division Multiple Access (W-CDMA).

It is widely acknowledged that power control is of major importance in DS-CDMA cellular systems to combat the near-far effect [2]. If power control is insufficient, quality-of-service is degraded, and overall capacity is reduced.

In this paper, the reduction in DS-CDMA capacity due to power control errors is quantified employing real propagation data, obtained from microcellular environments in the city of Bristol. Propagation measurements are employed to establish the performance of both narrowband and wideband DS-CDMA systems. In particular, the impact of spreading bandwidth on power control error is characterised. It is proposed that the more deterministic envelope fading characteristic associated with a large spreading bandwidth will ease the stringent requirements for power control, due to the less rapid variation of the wideband signal envelope.

Since the same propagation data can be employed in each case, and merely the spreading bandwidth altered, a direct comparison of power control errors is possible. The power control error can then be averaged over a number of measurements and environments to determine a realistic value. Employing this method, it is possible to determine power control error in each configuration in a series of real environments, without the need for channel simulation techniques. System simulation analysis is then employed to characterise the cellular capacity improvement associated with a given spreading bandwidth, employing standard power control algorithms. Consequently, the analysis quantifies the mitigation of power control errors associated with W-CDMA.

2. Analysis of Power Control

A large dynamic range is required in the uplink power-control to compensate for path-loss variability and the near-far effect [3]. The uplink analysed comprises both open and closed-loop power control. The open-loop power control estimates the path loss and shadowing from the desired base station using the pilot signal strength.

If the architecture is Frequency Division Duplex, multipath fading on the uplink and downlink will be uncorrelated. Consequently, closed-loop power control information is transmitted by the base station, which adjusts mobile station power such that, ideally, the received power of all the links is at the same level.

2.1 Power Control Algorithms

Power control is generally performed by estimating the received signal-to-interference ratio (SIR) [4]. The estimated SIR is then compared to a control threshold. If the estimated value exceeds the threshold, the mobile station is requested to reduce its power by a particular increment; otherwise, the power is increased by the same increment.

Three power control algorithms were employed in this analysis, as shown in table 1. Scheme 1 employs the same command rate as IS95 [3], with a fixed step size of 0.5dB. Scheme 2 utilises the same command rate, with a step size twice as large. This approach trades-off power control error due to increased quantisation with faster tracking of rapidly changing multipath fading.

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Finally, scheme 3, proposed in FRAMES multiple access mode 2 [1] is also employed. The FRAMES approach is slightly more complex, with both adaptive update rate and adaptive step size. In all cases open loop power control with a dynamic range of 80dB is assumed to remove the effects of shadowing.

Table 1: Power Control Algorithms

	Command Rate	*Step Size*
1	800Hz	0.5dB
2	800Hz	1dB
3	0.5-2kHz	0.5-2dB

2.2 Modelling Interference

If interferers are joining or leaving the network during the period under test, variations in the interference level will be observed. To model this effect accurately, it is necessary to know the loading level, call duration mean and variance. These variables will be affected by a number of factors including environment type and traffic demand cycle. Consequently, in preliminary propagation analysis it is assumed that interferers are not joining or leaving the network during the period of a single measurement run.

In a conventional DS-CDMA architecture, intra-cell interference will dominate inter-cell contributions. Therefore, the main variation in interference level on the uplink is due to imperfections in the power control of the other users within the cell. Application of the central limit theorem shows that, for a large number of interferers, the variance of total interference from the other users will be small compared to the variance in the desired link. Therefore, in the initial analysis presented here, the interference power is assumed to be constant over the propagation run [4]. This assumption will result in somewhat less severe power control errors than would be expected in a more realistic scenario.

Whilst it has been necessary to make a number of assumptions in the simulation and propagation studies, the different CDMA configurations are analysed under the same conditions. Thus, the results still provide a meaningful comparison between narrowband and wideband CDMA.

2.3 System Architecture

A network level and link level simulation of DS-CDMA were adopted to translate the power control errors calculated from the real environment onto capacity of a network deployed in that area. The uplink simulation model employed is based on previous work on DS-CDMA capacity [2,3]. The Monte-Carlo simulation of the network employs hexagonal omnidirectional cells, in a 5 tier pattern, with at least 10,000 mobile links analysed for each instance of loading level.

Table 2: Link and Network Configuration

Parameter	*Specification*
Path Loss Coefficient (α)	2 (<100m) 3.5 (>100m)
Cell radius	200m
Shadowing St. Dev. (α_{log})	8dB
Voice Activity Factor (δ)	0.5
Handover Margin (Δ_{HO})	0dB
Spreading Bandwidth	1.25-20MHz
User Bit Rate (R)	8kbps
Modulation	D-QPSK
Coding	1/3 rate convolutional
Eb/No for BER $\leq 10^{-3}$	7dB [2]
Acceptable Outage	1%

The configuration considered supports voice traffic only. Expansion of the analysis to a multi-rate and multi-service network will require more complex analysis to support a variety of quality-of-service criteria.

2.4 The Problem of Power Control

Due to the susceptibility of DS-CDMA to the near-far effect, a slight variation in the power of other users in the cell will dramatically impact on the quality of the desired link. Figure 1 shows the significant effect of imperfect power control on the outage probability of a CDMA system.

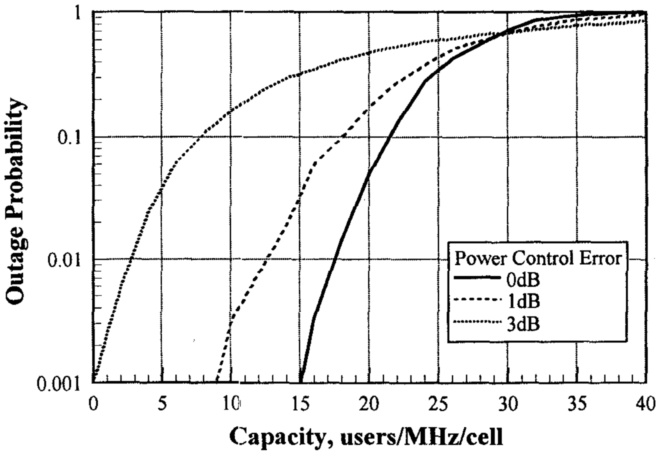

Figure 1: Link Outage Probability with Imperfect Power Control

Assuming that an acceptable link outage probability is 1%, the degradation of capacity can be quantified.

Figure 2 shows a significant reduction in capacity with a log-normal distribution of power control error. For example a 1dB error in power control results in approximately 30% capacity reduction. From these results it is obvious that even a small error in power control can produce in considerable degradation in performance.

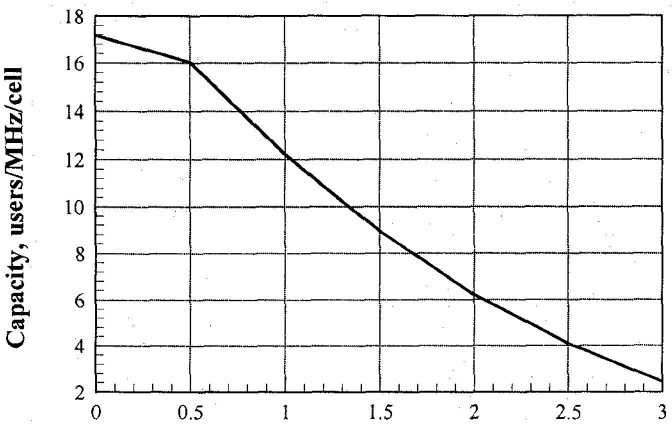

Figure 2: Capacity Degradation with Imperfect Power Control

3. Propagation Measurements

3.1 System Configuration

The data used to quantify the power control error that occurs in a real microcellular environment was obtained from a series of propagation trials undertaken in the city of Bristol. The system employed was a correlation sounder with a bandwidth of 68MHz, operating in the ISM band at 2.4GHz [5]. Consequently, a path resolution of 14.7ns was achieved. A variety of microcellular-type environments were studied, and a number of runs taken to characterise each location.

3.2 Analysis of propagation data

3.2.1 Envelope Statistics

Post-processing was employed to resolve the environments for a range of spreading bandwidths, in this case 1.25 - 20MHz, and the fading statistics were analysed.

Figure 3 shows the cumulative density function of the received envelope, demonstrating that the envelope variation reduces significantly with increased spreading bandwidth. Employing a larger spreading bandwidth will result in a more deterministic fading envelope, thus reducing the requirement for the power control to track rapidly changing magnitude levels in the multipath environment.

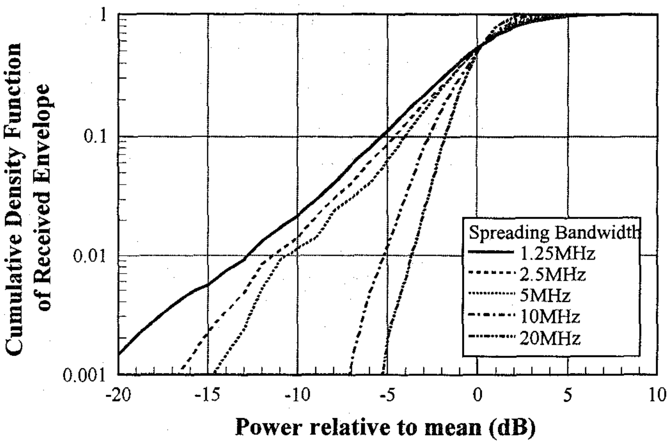

Figure 3: CDF with Increasing Spreading Bandwidth

3.2.2 Power Control Errors

The power control algorithms specified in section 2.1 were applied to the measured data obtained during the propagation trials. Figure 4 shows the probability density function of power control errors in these environments when a simple sigma-delta power control algorithm (scheme 2, table 1) was employed. As expected, the higher values of spreading bandwidth result in less significant power control error.

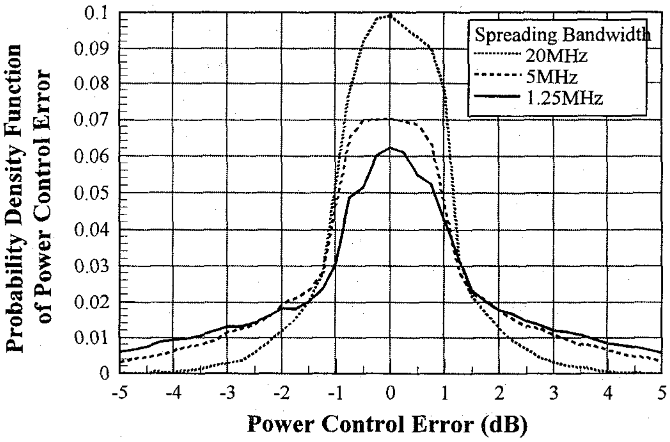

Figure 4: PDF of Power Control Errors at 120km/h

These results are calculated at a velocity of 120km/h, specified as the maximum level in a microcellular environment for UMTS [6]. More significant power control error occurs at higher velocities, due to the increasing requirement for the closed loop power control to track rapid envelope variations. However, the degradation present at high velocities is mitigated by the improvement in coding efficiency associated with the more random nature of the errors that occur.

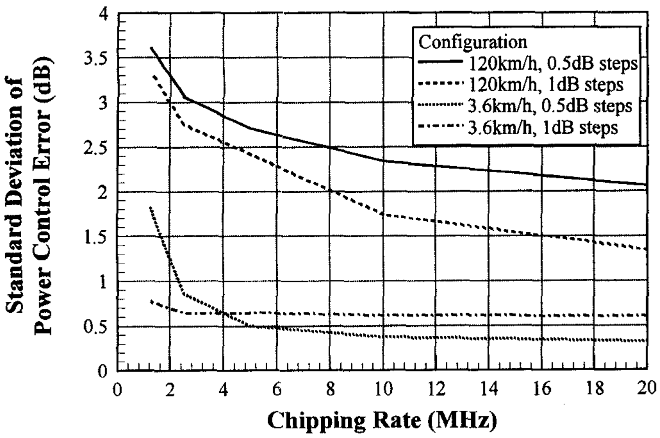

Figure 5: Improvement in Mean Power Control Error with Increasing Spreading Bandwidth

Figure 5 indicates the improvement in mean power control error associated with variable velocity and spreading bandwidth, employing simple power control algorithms (schemes 1 and 2 in table 1). It can be seen that the performance enhancement associated with spreading bandwidth becomes more significant at higher velocities. At lower velocities, the command rate of the power control algorithm can adequately track the variation in C/I, and errors occur due to the quantisation of power control steps.

At the lowest velocity shown (3.6km/h), the performance of the algorithm with a step size of 0.5dB is superior when the spreading bandwidth exceeds approximately 4MHz. This result occurs as the increase in spreading bandwidth reduces the SIR variations that must be tracked. Consequently, it can be seen that more accurate, but slower tracking algorithms can be employed at high spreading bandwidth to reduce the power control error. As expected, the larger step size produces better performance at higher velocities, due to the rapid fluctuations in SIR that require compensation.

4. System Capacity Implications

The power control error calculated in section 3.2.2 is applied to the Monte Carlo simulation studies described in section 2.2 to provide a measure of the network capacity in each instance. Hence, it is possible to predict the capacity achieved with each value of spreading bandwidth and quantify the improvement gained in power control when comparing narrowband and wideband CDMA. Furthermore, it is unnecessary to make assumptions concerning the nature of the power control random variable, as real error statistics are employed.

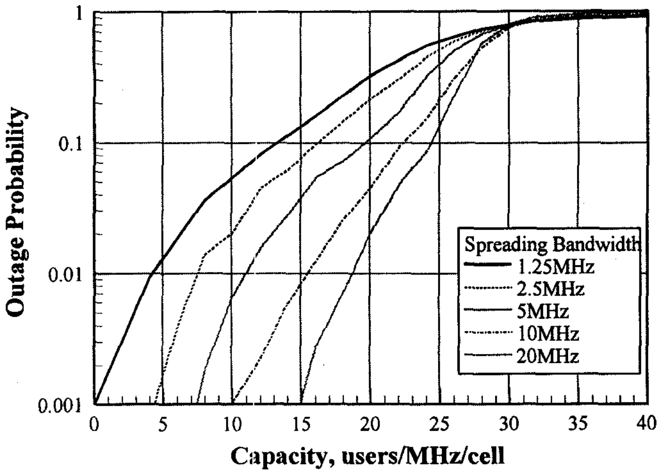

Figure 6: Capacity Degradation for Different Spreading Bandwidths

Figure 6 shows the outage probability for the FRAMES power control algorithm (scheme 3, table 1), employing a variety of spreading bandwidths. The graph indicates that as the spreading bandwidth is increased, the outage probability for a given loading level decreases, corresponding to an increase in quality-of-service.

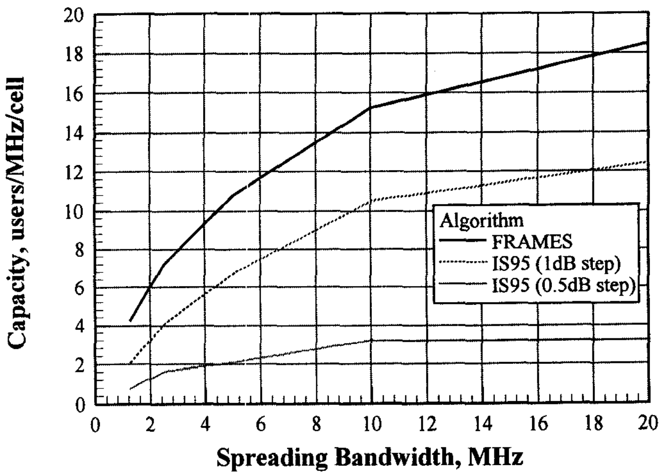

Figure 7: Comparison of Power Control Algorithms

Figure 7 shows the improvement in capacity with spreading bandwidth for a 1% outage probability in the voice network with a velocity of 120km/h. These results represent a worse case scenario, as it is unlikely that a significant number of users within the cell will be travelling at high velocity.

The analysis presented here indicates that the capacity improves with increasing spreading bandwidth, although with higher spreading bandwidths the improvements are small. For example, doubling the bandwidth from 2 to 4MHz improves capacity by approximately 50%, whereas an increase from 4 to 6MHz results in 15% higher capacity. Furthermore, the comparison of simple power control algorithms indicates that the adaptive scheme has the best performance, as expected. Interestingly, the scheme with a step size of 1dB outperforms the smaller step sized algorithm, due to the high velocity employed in this analysis.

5. Conclusions and Future Work

The effect of power control accuracy on the capacity of a DS-CDMA system has been evaluated with actual microcellular wideband propagation data. Propagation analysis and simulation studies were combined to analyse the statistics of the power control schemes, as well as the impact on system capacity.

Results confirm that system performance is heavily dependent on power control error [3]. Analysis of high spreading bandwidth systems demonstrates that power control is considerably simplified by the inherent fading characteristics. Consequently, when considering the effects of realistic power control in the network, employing a high spreading bandwidth will improve quality-of-service and capacity. For example, employing 5MHz bandwidth with a FRAMES II power control algorithm results in a capacity of approximately 150% greater than the same system with 1.25MHz spreading bandwidth.

The results presented are an initial analysis of CDMA power control using a combination of real propagation data and simulations. Further work will expand the study to incorporate the different power control requirements for a multi-rate multi-service network. Furthermore, it is important to include a more realistic interference model, which takes account of users arriving and leaving the network and interfererer power control errors. The likely distribution of mobile velocities will impact on the capacity degradation associated with imperfect power control. The available data can also be used to extract the necessary information to design a power control algorithm, rather than postulate it.

6. Acknowledgements

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