Measurement-based Band Allocation in Multiband CDMA

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Abstract— **Multiband (or multi-carrier) CDMA is a promising approach to increasing the capacity of CDMA systems, while maintaining compatibility with existing systems. This paper proposes an algorithm for allocating new calls to bands based on measured path gains, or alternatively, on estimates of the mobile stations' positions. By separating strong and weak users into separate bands, this algorithm reduces the other-cell interference on the uplink. It is shown to provide significantly better performance than alternative algorithms when hard handoff is used. An additional benefit of this algorithm is a reduction in the dynamic range required for uplink power control.**

I. Introduction

Demand for increased capacity of code division multiple access (CDMA) systems is greater than can be supplied by simply increasing spectral efficiency. Greater spectral bandwidth must also be employed by CDMA systems, and in some places the necessary spectrum is already being allocated. It remains to be determined how best to use this increased spectrum. The most obvious approach, often called wideband CDMA, is simply to increase the spreading factor. However there are many other alternatives. Two promising approaches are a hybrid of orthogonal frequency division multiplexing (OFDM) and CDMA [1,2] and a hybrid of frequency division multiple access (FDMA) and CDMA [3–5]. Unfortunately, both are often called *multicarrier CDMA* although the approaches are entirely different. In OFDM systems, a connection employs many orthogonal carriers and divides the data among them. In classical OFDM, each bit is carried by a single carrier, so that an n carrier system will carry n bits simultaneously (assuming binary modulation). In OFDM/CDMA (or MC-CDMA as it is more often called) a bit is multiplied by a pseudonoise (PN) sequence as it is in DS-CDMA. However, each *chip* is then carried on a single carrier, but different chips from one bit are sent over many or all of the carriers. Thus a bit is spread over multiple carriers, providing the robustness normally associated with CDMA.

The other approach, which is variously called hybrid FDMA/CDMA, multi-narrowband or simply *multiband CDMA*, will be the focus of this paper. Like FDMA, multiband CDMA divides the available spectrum into distinct bands, and allocates each connection to a single band. However, several connections are spread over each band, so that each band is a miniature CDMA system. This hybrid retains many of the advantages of CDMA over FDMA. For example, frequency reuse of 1 can be used. Also, the guard bands separating the data bands can in principle be much smaller than for pure FDMA at the expense of increased background interference.

Typically the bands all have a bandwidth of 1.25 MHz for compatibility with the IS-95A standard [6], which has explicit provision for multiband operation. Indeed, it is because of this advantage of backwards compatibility that one of the competing proposals for third generation wireless proposes multiband CDMA rather than wideband CDMA or MC-CDMA.

Another key advantage of multiband CDMA over wideband CDMA is the ability to accommodate a non-contiguous spectrum allocation. Such an allocation is likely to result from the expansion of an existing system, where all of the adjacent spectrum has been allocated for other uses. As long as the RF sections of the transmitter and receiver can accommodate the spread of frequencies, any regions of spectrum can be used. This benefit is partially shared by MC-CDMA since its carrier frequencies can in principle be arbitrary (providing the orthogonality condition is retained). However, simple FFT implementations would become less practical if unevenly spaced carriers were used. Another benefit of multiband CDMA over wideband CDMA is that the chip rate is not increased to the full spread bandwidth. This keeps the handset hardware simple, and hence inexpensive. Indeed, multiband may be the only feasible CDMA option for very high data rate systems.

This paper will investigate the uplink performance of a multi-band system consisting of N bands of equal bandwidth, numbered 0 to $N-1$. It will generally be assumed that N is small (two to four), but the methods proposed are not limited to this case. The bands

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will be assumed to be closely spaced, so that they are identical with respect to issues such as propagation, but sufficiently widely spaced that there is no interference between bands.

It is generally accepted that there is a capacity penalty for using multiband CDMA due to effects such as the reduced multiplexing gain [3–5]. However, from an information theoretic point of view, the capacity of a multiband system is actually higher than an equivalent wideband system using a matched filter receiver due to the fact that users in different bands do not interfere with one another [7]. The challenge is thus to maximise the capacity of a multiband system, while maintaining its advantages of backwards compatibility and hardware simplicity.

One of the keys to getting good performance from a multiband system is the allocation of new calls to bands. In [5], new calls were allocated to the band with the fewest current connections. This was found to provide a significant improvement in the outage performance, bringing the performance of the multiband system close to that of a wideband system. Other approaches suggested in [8] are to use separate bands for macro- and micro-cells, which yields lower capacity, or to co-ordinate the allocation to macro- and micro-cells from a common set of bands, which yields improved capacity compared to random allocation.

This paper proposes a new approach to this problem, based on path gain measurements for the arriving call, or alternatively on the estimated distance of the user from the base station. (The required distance information will be available in many systems since the US government has ruled that mobile phones must be able to determine their location to within 125m 67% of the time to assist with e-911 emergency calls [9,10].) This path gain information is then combined with power control to improve the capacity of the system. This scheme will then be compared to alternative band allocation algorithms in terms of outage and blocking probability.

The rest of this paper is organised as follows. Section II describes the proposed band allocation approach in greater detail, and Section III-A uses a simple mathematical model of the system to investigate the potential performance gain of the approach in the case of hard handoff. The conclusions of this analysis are tested by simulation. The system being simulated is described in Section IV, and the results are presented in Section V. The impact of soft handoff on the system is then discussed briefly in Section VI.

II. MEASUREMENT BASED BAND ALLOCATION

A. *The near far effect*

CDMA systems typically use single-user matched filter receivers on the uplink. With such receivers, users other than the user being decoded are simply treated as background white noise. Thus a user near the base station, and hence with a strong received signal, can entirely mask a weaker user, even after the signal has been despread using the correct spreading sequence. This *near-far* problem is solved by using power control to ensure that all users in a given cell are received at the same power level, irrespective of their path gains [11–13]. However there are several drawbacks with this approach. Firstly, it requires the mobile transmitter to have a very large dynamic range, up to 80 dB [14], to counter the wide variety of fading conditions. Users with very low path gains will also suffer reduced battery life and the other adverse effects of excessive transmit power.

A second drawback is the significant increase in interference from neighbouring cells. The users with the lowest path gains, and hence highest transmit powers, are those near the boundary of the cell. However, these users are also those closest to the neighbouring base stations, and hence cause the greatest other-cell interference. This problem is alleviated by soft handoff [12,15,16] in which users connect to two or more base stations simultaneously, and are decoded by the base station currently having the highest path gain. This allows the mobile to be power-controlled to a lower level. However, multiband CDMA provides the opportunity to address this problem more directly by separating strong ("near") and weak ("far") users into separate bands. Thus weak users are not competing with strong users, and a lower received power is acceptable. This translates to a lower transmit power from the mobile. A group of users within a cell allocated to the same band will be called a "ring", since the geometric (r^{-4}) component of path loss causes them to lie approximately in concentric rings around the base station. The rings containing stronger users will similarly be referred to as the "inner" rings.

Power control aims to give all users the same signal to interference ratio (SIR). Since all users within a cell experience the same interference in the single-band case, this is equivalent to having equal received signal powers. However, for users in different cells or different bands, the two are not interchangeable. Separating near and far users is only beneficial if the different groups are allowed to be received at different power levels. This occurs automatically if power control equalises SIR directly, since the interference will be lower in the bands containing weaker users. However, if power control equalises received power levels then the received power for each band must be controlled to a different level, depending on whether the nominal path gain is "high" or "low". The optimal power levels will be discussed in Section III-A.

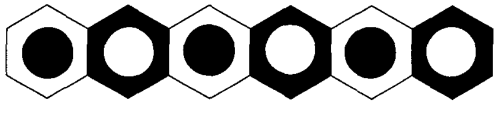

Fig. 1. Alternating bands

B. Coordinating cells

In a two band system, if band 0 is always assigned to the strong users and band 1 is always assigned to the weak users, then the ratio of the signal to other cell interference will not be helped in the outer band. The interference from neighbouring outer rings transmitting on the same band will be reduced by some factor, k_{int}, because those users are no longer competing with stronger users, but the user's own signal will be reduced by exactly the same factor, $k_{\text{sig}} = k_{\text{int}}$. To obtain maximum benefit, there must be two types of cells; type 0 with band 0 as the inner ring , and type 1 with band 1 as the inner ring. Cells of the two types can then be alternated, as shown in Fig. 1 for the one dimensional case. This way, the weaker users in the outer ring need only combat the weaker interference from the inner ring users in the neighbouring cells. These interferers are generally further from the user's base station, resulting in a lower path gain for the interfering signal. More importantly, they (by definition) have a higher path gain to their own base stations, and thus have substantially lower transmit powers than outer ring users. The stronger outer ring interferers are then left to be combatted by the inner ring users. These users by definition have high path gains to their target base station, and can thus tolerate substantial interference.

The situation is slightly more complicated in two dimensions, since cells cannot simply alternate, but the principle is the same. The best arrangement for two bands is to have four neighbours of the opposite type, and two neighbours of the same type, as shown in Fig. 2. A symmetric arrangement is possible for three bands in two dimensions (Fig. 3), but there are many other possibile configurations. It is not clear that the symmetric arrangement is optimal, although it is intuitively appealing, and gives very good performance. In general, there are $N!$ types of cells, corresponding to all of the different permutations of N bands. In this study, only the N cyclic permutations of bands have been used to simplify the arrangement of cells, but further work is required to find the optimal way to allocate frequency bands to spatial groups. This problem has many similarities with the frequency planning problem [17], [18]. The principal difference is that each cell uses *all* of the bands, and it is only their order which changes. Thus the capacity reduction associated with frequency reuse factors greater than 1 is avoided, although the design effort may still be substantial.

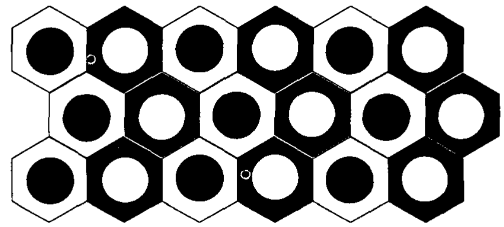

Fig. 2. Alternating bands in two dimensions

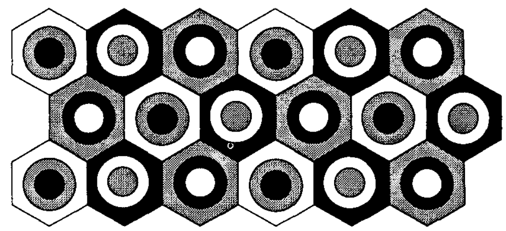

Fig. 3. Three bands in two dimensions

C. Distance vs. path gain

In the absence of log-normal shadowing, grouping mobile stations by distance from the base station is equivalent to grouping them in order of average path gain. However, with log-normal shadowing, a choice between the two approaches must be made. Grouping users by distance has two principal benefits. First, users close to one base station are known to be far from the others, and so their transmit power can be raised without causing excessive interference. With log-normal shadowing, it is possible for a single user to have a high path gain to multiple base stations. The second benefit arises if the spatial correlation between fading is low, such as in a region with many small obstructions, and the average mobility is low. The user's position at call setup may then be a better predictor of the path gain over the lifetime of the call than the actual path gain at call setup is. This is because the r^{-4} component of the path gain is almost invariant to small movements, while the log-normal component can vary considerably. It is thus possible for a user to have very high path gain at setup, and be placed in a "strong" band, but in fact have a low path gain for the majority of the call.

Despite the above arguments in favour of distance base band allocation, using measured path gain will generally be the better option. The final objective of the proposed scheme is to equalise the path gain to the receiving base station, and thereby to minimise the need for power control. In addition, the path gain is usually already known, as it is needed for existing power control, whereas the location may not be. Both of these are compelling reasons to use the actual path gain rather than the estimated position to select a band for a new call.

III. Other-Cell Interference

A. Analytic model

Following [19], the other cell interference can be approximated by determining the ratio of other cell to same cell interference, f, under the assumption that users are spread uniformly over the entire plane, rather than being located at discrete points. This fluid limit corresponds to a very large number of users and a commensurately high spreading factor. It also assumes that users are evenly distributed, and there are no "hotspots" in the network. With the proposed band allocation algorithm, each ring has a substantially different level of interference, and this ratio must be evaluated separately for each ring. For simplicity, the area (and hence number of users) of each ring will be assumed to be equal, at $3\sqrt{3}/2N$ units of area. For notational convenience, and without loss of generality, the rings will be numbered so that in the cell of interest, ring i uses band i. It will also be assumed that band allocation is performed based on the user's location, rather than path gain. In the case of hard handoff with equal received power in each band, the other- to same-cell interference ratio for band i may then be expressed as

$$f_i = e^{b^2(\beta\sigma)^2}\left[\frac{2N}{3\sqrt{3}}\iint_{\overline{S}_{0,i}} R_1^m(x,y)dA(x,y)\right], \tag{1}$$

where $b \approx 1/\sqrt{2}$ is the fraction of the fading variance not attributable to the near field of the mobile, $\beta = \ln(10)/10$, σ is the variance of the log-normal shadowing expressed in dB. The exponent $m \approx -4$ is the exponent of the geometric component of the path gain, so that the path gain is r^m times the log-normal shadowing. The quantity $R_1(x,y)$ is the ratio of the distance from the base station of interest, $r_0(x,y)$, to the distance from the base station nearest the mobile, $r_1(x,y)$. The region $\overline{S}_{0,i}$ is the region outside the cell of interest in which users connect on band i. In the single band case, this is clearly the entire region outside the cell of interest. However, when there are multiple bands, $\overline{S}_{0,i}$ depends on the spatial arrangements of the different cell types, as discussed in Section II. For example, for the two band system of Fig. 2, $\overline{S}_{0,0}$ is the union of $\overline{S}_{0,0,0}$ and $\overline{S}_{0,0,1}$ in Fig. 4.

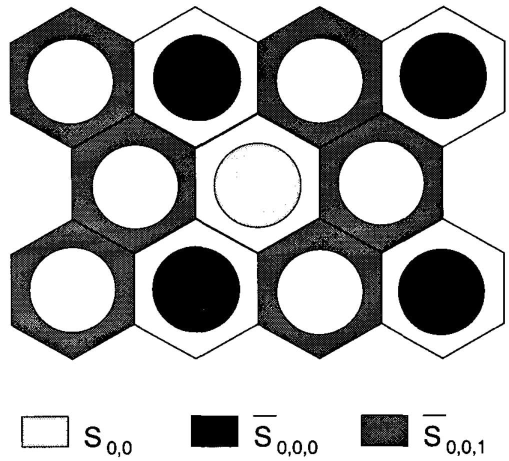

Fig. 4. Regions $S_{0,0}$, $\overline{S}_{0,0,0}$and $\overline{S}_{0,0,1}$ for two-band case.

As mentioned previously, current CDMA systems equalise the received SIR of all users. However, the above analysis, based on that in [19], assumes all users are received with equal power. Because the other cell interference differs from ring to ring, this will result in unequal SIR in the multiband case. This can be rectified by using a different nominal received power, p_i, for each ring. Clearly the interference from a user will be directly proportional to its transmit power, and hence to its receive power. The total other cell to same cell interference ratio, f_i, is thus given by

$$p_i f_i = \sum_{j=0}^{N-1} p_j f_{i,j}, \tag{2}$$

where $f_{i,j}$ is the relative interference to band i in the cell of interest caused by users in region $\overline{S}_{0,i,j}$, the region in other cells in which users communicate on band i and are in ring j. The regions $\overline{S}_{0,0,0}$ and $\overline{S}_{0,0,1}$ are illustrated for the case of two bands in Fig. 4. Thus

$$f_{i,j} = e^{b^2(\beta\sigma)^2}\left[\frac{2N}{3\sqrt{3}}\iint_{\overline{S}_{0,i,j}} R_1^m(x,y)dA(x,y)\right]. \tag{3}$$

The SIR in band i is then

$$\begin{aligned}\alpha_i &= \frac{p_i G}{(k_u-1)p_i + k_u p_i f_i}\\ &= \frac{p_i G}{(k_u-1)p_i + k_u \sum_{j=0}^{N-1} p_j f_{i,j}},\end{aligned} \tag{4}$$

where k_u is the number of users per ring and G is the processing gain per band. Rearranging (4) indicates that the SIR for all users will be equal if

$$\left(\frac{G}{\alpha k_u} - \frac{k_u - 1}{k_u}\right) P = FP, \quad (5)$$

where α is the common SIR, $P = (p_0, \ldots, p_{N-1})^T$ is the vector of nominal received powers, and $F = (f_{i,j})$ is the (non-negative) matrix of other-cell interference. Thus P is an eigenvector of the matrix F.

Let us first consider the case where F is irreducible, as for the cyclic permutations used in this study. Perron-Frobenius theory [20] then guarantees the existence of a unique positive eigenvector of F, corresponding to a dominant real eigenvalue, λ. Equation (5) also says that the maximum number of users which can be accommodated per cell with SIR at least α is given by

$$(G + \alpha)/\alpha(1 + \lambda), \quad (6)$$

Thus λ corresponds to f in [19].

Cases where F is reducible arise when the rings can be partitioned into subsets such that each subset has its own set of bands, disjoint from those of the other subsets. Because interference between bands is reciprocal, the sparsity of F is symmetric, meaning $f_{i,j} = 0 \Leftrightarrow f_{j,i} = 0$. Thus if F is reducible, it can be transformed by a permutation into a block diagonal matrix with irreducible square blocks on the diagonal, $F = \text{diag}(F_1, \ldots F_n)$. Each of these blocks corresponds to a disjoint set of bands which create mutual interference, but do not interfere with bands from other sets. In this case, it is not generally possible to ensure that bands in different blocks have the same SIR. However, the above analysis applies to each irreducible component, and thus the capacity of the ith subset of bands is determined by the dominant eigenvalue of F_i. The capacity of the cell (in users per unit area) is then at least the smallest capacity of any of these subsets of bands. This is obtained by substituting the largest eigenvalue of any of the F_is in (6). (Note that largest eigenvalue of any of the F_is is simply the largest eigenvalue of F.)

B. Numerical results

The potential performance improvement achievable by the proposed scheme can be calculated by solving (3) and (5) numerically. Fig. 5 shows the normalised SIR, $\alpha k_u/G \approx 1/(1+\lambda)$, for $N = 1, 2, 3, 4$ and 7 bands, for both two dimensional and one dimensional grids of cells. The proposed approach of separating strong and weak users clearly provides a worthwhile gain in the two-dimensional case, and quite a significant gain in the one-dimensional case. It is worthwhile noting that the normalised SIR initially increases as the number of bands increases, but then peaks and begins

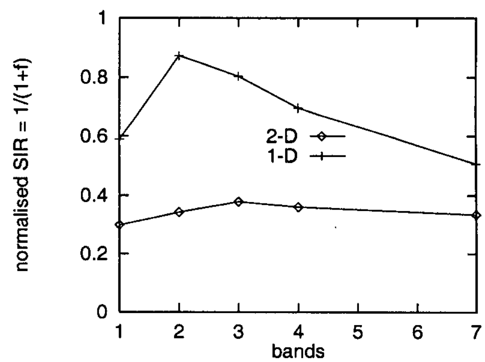

Fig. 5. Normalised SIR for different numbers of bands, in both one and two dimensional layouts.

to reduce. (Note that the total capacity continues to increase as more bands are added, but the capacity per band begins to drop.) This effect is due to the cyclic band allocation, and is the subject of further study.

The actual power allocations, P, are shown in Fig. 6 for $N = 2, 3, 4$ and 7 bands in the two dimensional case. The powers have been normalised so that the innermost ring has a received power $p_0 = 1$. Clearly, there is a substantial difference in the powers in the different rings, with the outermost ring being received at a power approximately half of that of the innermost ring. Notice also that there is a strong correlation between the performance gain shown in Fig. 5, and the reduction in received power of the outermost ring. This is to be expected since the majority of the interference comes from the users in the neigbouring cells with the lowest path gains to their own base stations, and hence the highest transmit powers.

The corresponding powers for a one dimension grid of cells do not show the same monotonic decrease. Instead, for four and seven bands, the powers are quite irregular. This is because the cyclic band allocation uses the same band for the innermost and outermost rings in adjacent cells, which breaks the symmetry of the arrangement.

IV. Experimental Scenario

The above analysis made many simplifying assumptions, and only provided information about the average interference. This does not necessarily give an accurate indication of the actual performance experienced by users, in terms of outage and blocking probabilities. In order to evaluate the proposed scheme more thoroughly, it was simulated with discrete calls for the case of two bands. The results were compared with those from a single-band system with twice the spreading ("wideband"), two bands with random allocation of calls to bands ("random"), and two bands with calls allocated to the band with the fewest current calls ("least

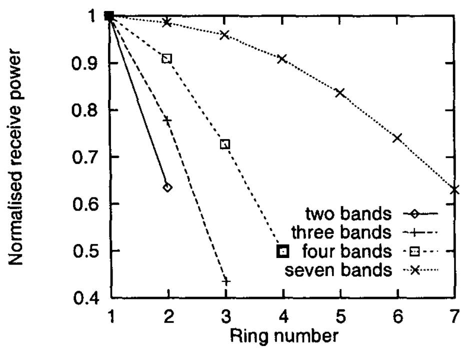

Fig. 6. Normalised received power for each ring , for 2, 3, 4 and 7 bands

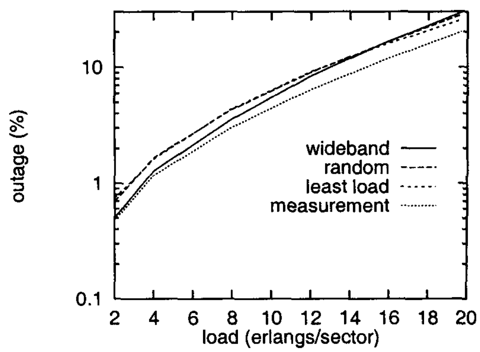

Fig. 7. Comparison of band allocation strategies without CAC

loaded") [5].

An 8×8 toroidal grid of hexagonal cells was used. Call attempts were made according to a Poisson process in time and space, with a uniform distribution of users over the entire grid. Call times had a negative exponential distribution, and established calls were never dropped due to outage.

A call was deemed to be in outage if the average received SIR, after log-normal shadowing, was less than 6 dB. Fast fading was averaged over. Log-normal shadowing with a standard deviation of 8 dB was used, of which 4 dB was considered to be caused by the near field of the user, and was cancelled out by the power control. Power control was assumed to be ideal; there was no limit imposed on the maximum transmit power of a mobile, and there was no tracking error in the power control loop. For computational simplicity, transmit powers were controlled to a fixed receive power at the nearest base station, rather than to a fixed SIR. This can be expected to provide an upper bound on the actual outage probability, since some users may be received at a higher SIR than they require. For the proposed measurement based approach, the nominal received powers were set according to Fig. 6. The system was assumed to be interference limited, and thermal noise was ignored. Since only the uplink was considered in this investigation, there was no interference from a pilot signal.

Once a call was set up, mobiles were fixed in space, and there were thus no handovers. Mobility effects were modelled by periodically recalculating the log-normal shadowing. At intervals of $0.01/\mu$, where $1/\mu$ is the mean call holding time, the fading of all users to all base stations was recalculated, and transmit powers were recalculated. The fading for each mobile to base station link was drawn from a first-order autoregressive process. The correlation between samples separated by time $1/\mu$ was 0.5. Band allocation was based on the mobile's position, which was assumed to be known exactly, rather than the path gain.

A spreading factor of 128 was used for the two band case, and 256 for the single-band case. This corresponds to two IS-95 bands being used for each of the schemes. Voice activity was assumed to be 100% in all cases, and antenna sectorisation of 1 was used.

For each of the four band assignment schemes, two cases were considered. In the first, there was no call admission control (CAC). Any call arriving was allowed to transmit, even if it was in outage, or would cause other calls to go into outage. This is the simplified scenario implicit in "snapshot" simulations, which place users according to a Poisson process and then calculate the outage. In the second, more realistic case, a call was only admitted into the system if its SIR was at least 6 dB, so that it would not be in outage when the connection is established. In all of the multiband systems, when a call arrived, a band was selected according to the specified allocation algorithm. If the SIR in this band was insufficient, the other band would be tried. A call would be blocked only if neither band had sufficient SIR. The CAC did not consider the impact of the new call on existing calls in other cells, and so could cause them to go into outage. The other possible reason for outage with CAC is that the fading conditions can change during the course of a call.

V. Simulation Results

Fig. 7 shows the results of several band allocation strategies for two bands without call admission control (CAC). Note that the actual figures for load and outage indicate very low performance since soft handoff was not used, and voice activity was assumed to be 100%. Voice activity is not expected to make a qualitative difference to the results, but the use of soft handoff requires further investigation.

From this figure, it can be seen that the proposed measurement based strategy provides the best outage performance. If an outage rate of 5% is considered acceptable, it increases the capacity from 8.5 to 10.5 Er-

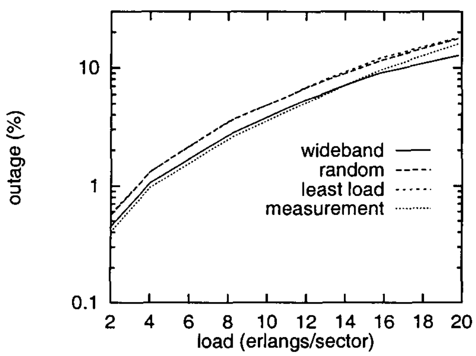

Fig. 8. Comparison of band allocation strategies with CAC

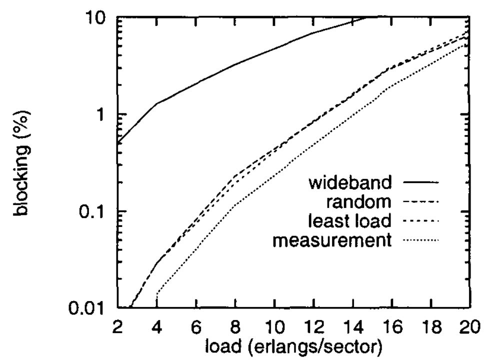

Fig. 9. Blocking for different band allocation strategies with CAC

langs per cell compared to the least load strategy, an improvement of 23%.

It is also worth noting that these results do not show the benefit of least load over random assignment that was found in [5]. This is due to a combination of the use of hard handoff and the fact that the power control used equalised received power, rather than SIR. In soft handoff, the majority of the interference (60%) comes from within the user's cell, and so there is a substantial benefit in equalising the load on each band within the cell. However, with hard handoff, the majority of the interference (70%) comes from neighbouring cells [19]. Thus allocating the user to a band based on the current calls within the its own cell is of limited benefit. (Note that this would be overcome if the measure equalised were the total received power in the band, rather than the number of call in this cell in the band. This alternative is mentioned briefly in [5].)

The role of the power control is a little more subtle. The aim of equalising the load in each band is to reduce the variance in the interference a call receives. Outage events are caused by interference values in the "tail" of the probability distribution, and so reducing the variance reduces the outage probability. However, power controlling to equal SIR increases the variance. That is because users suffering high interference will have to increase their powers, which increases the interference they themselves cause. This positive feedback amplifies the variance in interference. If users are power controlled to a fixed received power, this positive feedback does not occur, and reducing the variance in cell occupancy becomes less important.

Fig. 8 shows the results corresponding to those of Fig. 7 when CAC is used. The capacity at 5% outage now rises from 10.3 Erlangs per cell for least load to 11.8, an improvement of 15%. Once again, there is minimal improvement due to least load rather than random allocation.

When CAC is used, outage figures are of limited meaning without considering the blocking performance. The blocking performance is shown in Fig. 9. The blocking is slightly lower for the measurement based scheme than least load or random. However, the most striking fact is that the blocking is very much lower for all of the multiband algorithms than for the wideband system. The reason for this is not clear and is the subject of continuing investigation. It seems to result from the heavy-tailed distribution of interferences when hard handover is used, as the effect is not observed when soft handover is used. It is essentially because the call is blocked only when *both* of the bands are blocked. If the correlation between the load in the two bands is not too high, and the blocking probability on each is low, this probability will be of the order of the square of the probability of being blocked on either one of the bands. This is a much lower value than the probability of being blocked on a single band if the interference is heavy-tailed. The probability of being blocked in the wideband case will also be less than the probability of being blocked on a single narrow band, since the average load and the spreading are both twice as large, giving greater trunking efficiency. However for low blocking probabilities, the former effect is dominant, resulting in the observed lower blocking for the multiband systems.

The fact that the blocking is much higher in the wideband case means that it is very difficult to make a fair comparison between the performance of multiband and wideband based only on outage probabilities in the absence of CAC, as is often done. It also means that the wideband results in Fig. 8 are not directly comparable with those for the multiband systems. Another point to note is that the improvement in blocking performance for multiband systems is contributed to by the imperfect correlation between the occupancy of the bands, and so anything which increases this correlation increases the blocking. For example, the least load allocation strategy aims to equalise the load in each band. Thus the performance improvement of least load over random assignment may be overestimated by outage measurements alone. However, for reasons discussed above, this phenomenon does not occur to a great extent for the hard handoff scenario considered here.

VI. Soft Handoff

So far, this study has concentrated on systems employing hard handoff. The benefits of soft handoff make it mandatory for a practical CDMA system. As pointed out in Section V, soft handoff can make a qualitative difference to the behaviour of different band allocation schemes. One effect of soft handoff is to reduce the other cell interference greatly. Because the aim of the proposed band allocation scheme is to reduce the other cell interference, the potential improvement is reduced in a system already employing soft handoff. However, the use of soft handoff does not preclude the use of the proposed algorithm. Handoff between bands must be hard, but transmissions on the given band may still be decoded by two or more base stations, and the one giving the lowest frame error rate used. Thus soft handoff can co-exist with measurement based band allocation. The interaction between the proposed band allocation and soft handoff is the topic of continued research.

VII. Conclusion

This paper has proposed a new approach to the task of assigning new calls to bands in a multiband CDMA system, based on measured propagation conditions. By separating strong and weak users into different bands, the near-far problem can be attacked directly, reducing the amount of power control needed, and improving the system capacity. In two dimensions, the potential benefit of this approach is maximised for three-band systems. Even greater improvement is possible for one-dimensional cell layouts, such as are found along railway lines. The predicted benefits have been demonstrated by simulation, and the proposed scheme has been found to reduce both outage and blocking compared to both random and least load assignment algorithms.

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