Implications of power control and successive interference cancellation on indoor DS-CDMA system deployment and performance

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Implications of Power Control and Successive Interference Cancellation on Indoor DS-CDMA System Deployment and Performance

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***Abstract*— We investigate the optimal combination of power control and successive interference cancellation to yield performance gains in a multi-floor indoor DS-CDMA system. Using measured indoor propagation data and a Monte Carlo simulation, it is shown that the performance gains achieved are significantly influenced by the base station deployment strategy chosen.**

***Index Terms*— Direct sequence code division multiple access (DS-CDMA), indoor wireless systems, multiuser detection, successive interference cancellation (SIC), power control.**

I. INTRODUCTION

SUCCESSIVE interference cancellation (SIC) is a multiuser detection technique that cancels intra-cell interference on the uplink of a DS-CDMA system by sequentially decoding and cancelling mobiles' signals from the strongest to the weakest [1-3]. As this technique inherently enables better detection of mobiles that have weak received signals, an indirect benefit of SIC is that it combats the near/far effect, which would otherwise occur when mobiles near a base station (having strong received signals) degrade the performance of mobiles further away (having weaker received signals) [1-3].

However, in conventional DS-CDMA systems that operate without SIC, the near/far effect is combatted by using power control (PC) to regulate the transmitting powers of mobiles so that their signals are received at the base station with approximately the same mean power [1,2]. Because both PC and SIC combat the near/far effect, it is important to understand their individual and joint implications on system performance. In [1,2], it is shown that a multi-cell DS-CDMA system employing SIC receivers with path loss based received power disparities has better performance than a power-controlled DS-CDMA system employing conventional receivers. However, [1,2] only considered an *outdoor* DS-CDMA system with lognormal shadowing.

To the authors' knowledge, the joint influence of PC and SIC on multi-floor *indoor* DS-CDMA system performance has not been previously reported in the literature. In the future it is likely that wireless operators will have the option of implementing SIC in multi-floor indoor environments that have more hostile propagation conditions than outdoor environments. The performance of an indoor DS-CDMA system is particularly sensitive to base station positioning. For example, it is shown in [4] that a power-controlled multifloor indoor DS-CDMA system has better performance if base stations are positioned in a vertically aligned arrangement than if they are positioned in an offset arrangement.

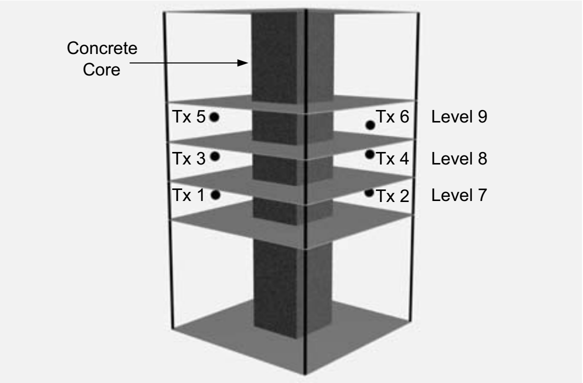

Fig. 1. Three-dimensional view of The University of Auckland's School of Engineering building. Positions of transmitters indicated by '•'s.

The purpose of this Letter is to investigate the optimal combination of PC and SIC to yield performance gains in a multi-floor indoor DS-CDMA system for different deployment strategies. A propagation study has been conducted in a multi-floor indoor environment (Section II) and the results of this study have been used in a Monte Carlo simulation which estimates DS-CDMA system performance (Section III).

II. PROPAGATION MEASUREMENT STUDY

A programme of 1.8 GHz narrowband mean path loss propagation measurements was conducted in The University of Auckland's School of Engineering building. This building is a 12-level reinforced-concrete office block with horizontal dimensions 18.5m by 18.5m, and has a central square-shaped concrete core which houses two lifts, a stairwell and services. Surrounding this concrete core are a corridor and offices. Six transmitters were deployed on Levels 7, 8 and 9 of the building, as shown in Fig. 1. Mean path losses from each of these transmitters were determined at 52 locations across Level 8 of the building by rotating the receiving antenna around a

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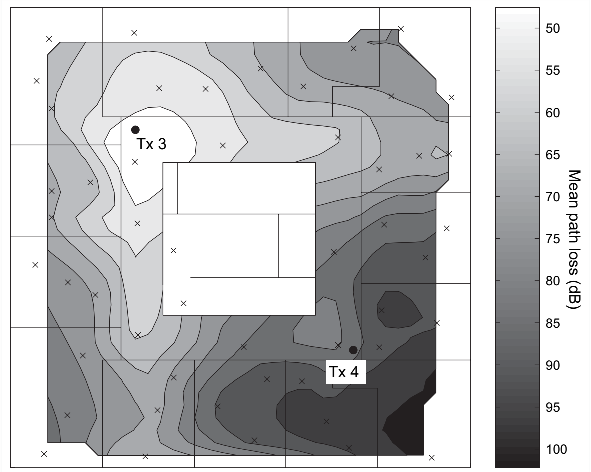

Fig. 2. Contour map[1] of the mean path loss on Level 8 from Tx 3. Positions of Tx 3 and Tx 4 indicated by '•'s. Measurement locations indicated by '×'s.

1m diameter circular locus and averaging the instantaneous power measurements to remove multipath fading.

To illustrate typical propagation behavior, Fig. 2 is a contour map of the measured mean path loss on Level 8 from Tx 3. Superimposed on Fig. 2 is a floor plan of Level 8, the positions of Tx 3 and Tx 4, and the 52 measurement locations.

III. SYSTEM MODEL AND ANALYSIS

A. System Assumptions

We assume that a DS-CDMA system with BPSK modulation operates on Levels 7, 8 and 9 of the building described in Section II, with one base station per floor. A processing gain of 511 and a voice activity factor of 0.5 are used. The system may operate with either PC, SIC, or both methods. If PC is used, it is assumed to be perfect. If PC is not used, it is assumed that all mobiles have the same mean transmitting power. A mobile is assumed to connect to the base station to which it has the lowest mean path loss. Signals are assumed to experience short-term variations due to multipath fading.

B. Model for BER Performance without SIC

Assuming that the interference is approximately Gaussian distributed, it can be shown that the instantaneous uplink bit-error-rate (BER) for the $(j+1)^{\text{th}}$ mobile in an interference-limited DS-CDMA system operating without SIC is

$$BER_{j+1} = Q\left(\frac{P_{j+1}^{\text{ic}}}{\frac{\alpha}{3N}\left(\sum\limits_{k=1,k\neq j+1}^{K} P_k^{\text{ic}} + \sum\limits_{m=1}^{M} P_m^{\text{oc}}\right)}\right), \quad (1)$$

where α is the voice activity factor, N is the processing gain, P_{j+1}^{ic} is the power of the $(j+1)^{\text{th}}$ mobile, $\sum\limits_{k=1,k\neq j+1}^{K} P_k^{\text{ic}}$ is the total intra-cell interference emanating from $K-1$ intra-cell interferers and $\sum\limits_{m=1}^{M} P_m^{\text{oc}}$ is the total inter-cell interference emanating from M inter-cell interferers [5].

C. Model for BER Performance with SIC

SIC is performed at the base station by ranking mobiles' signals in decreasing order of strength and detecting each of them in succession. After a particular mobile is detected, its signal is regenerated and subtracted from the overall received signal so that subsequent mobiles (of weaker strength) can be detected with less interference presented to them [3]. Using the Gaussian approximation, (1) can be modified to show that the instantaneous uplink BER in an interference-limited DS-CDMA system employing SIC is

$$BER_{j+1} = Q\left(\frac{P_{j+1}^{\text{ic}}}{\frac{\alpha}{3N}\left(\sum\limits_{k=j+2}^{K} P_k^{\text{ic}} + \sum\limits_{m=1}^{M} P_m^{\text{oc}} + \sum\limits_{i=1}^{j} \eta_i\right)}\right), \quad (2)$$

where

$$\eta_{j+1} = \frac{\alpha}{3N}\left(\sum_{k=j+2}^{K} P_k^{\text{ic}} + \sum_{m=1}^{M} P_m^{\text{oc}} + \sum_{i=1}^{j} \eta_i\right). \quad (3)$$

In (2), $\sum\limits_{k=j+2}^{K} P_k^{\text{ic}}$ is the total intra-cell interference emanating from the weakest $K-(j+2)+1$ intra-cell interferers and $\sum\limits_{i=1}^{j} \eta_i$ is residual interference which results from the detections of the previous j mobiles [3].

D. Monte-Carlo Simulation

A Monte-Carlo simulation has been conducted to obtain estimates of the uplink performance for indoor system deployments that employ either PC, SIC, or both methods. Uplink performance is quantified in terms of an outage probability. An outage occurs at a mobile location if the instantaneous BER exceeds 10^{-2}. In each iteration of the simulation, a given number of mobiles are randomly placed on each floor and the number of outages is determined using either (1) or (2), depending on whether or not SIC is employed. Exponential random variables and the mean path loss data obtained from the propagation measurement study (Section II) are used to model short-, medium-, and long-term signal strength variability. At the end of all iterations, the average uplink outage probability is calculated from the total number of outages and connections to the 'desired' base station.

IV. PERFORMANCE RESULTS AND COMPARISONS

The influence of PC and SIC on uplink performance is demonstrated using two deployment strategies:

- an aligned deployment that uses Tx 1, 3, and 5, and
- an offset deployment that uses Tx 2, 3, and 6.

Fig. 3 shows the average uplink outage probability against the number of mobiles per floor for the aligned and offset

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[1] Contours are not shown within the central concrete core because only two measurements were taken in this area.

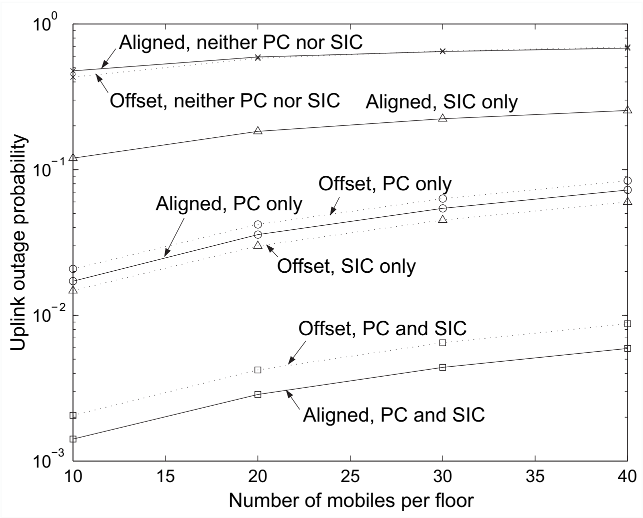

Fig. 3. Uplink outage probability versus the number of mobiles per floor for the two deployments employing PC and/or SIC.

TABLE I

E_b/N_o MEAN (μ) AND STANDARD DEVIATION (σ) FOR 10 MOBILES PER FLOOR IN THE TWO DEPLOYMENTS EMPLOYING PC AND/OR SIC.

	E_b/I_o — Aligned (dB)		E_b/I_o — Offset (dB)	
	μ	σ	μ	σ
Neither PC nor SIC	1.42	17.27	3.45	14.87
PC only	14.90	5.73	14.28	5.73
SIC only	15.74	12.90	20.74	8.67
PC and SIC	21.34	3.34	20.24	3.55

deployments if either PC, SIC, or both methods are used. The following observations are made:

1) If neither PC nor SIC are used, both deployments have similar performance.
2) If only PC is implemented, the aligned deployment has marginally better performance than the offset deployment. This confirms the findings in [4].
3) If only SIC is implemented, the offset deployment outperforms the aligned deployment by an order-of-magnitude.
4) For the offset deployment, implementing SIC is more beneficial than implementing PC, whereas for the aligned deployment this relationship is reversed.
5) For both deployments, the best performance is attained when PC and SIC are jointly implemented.

To explain these differences in performance, the mean and standard deviation of the energy per bit to interference density ratio (E_b/I_o) have been extracted from the system for ten mobiles per floor, as shown in Table 1. It is evident that a high E_b/I_o mean and low E_b/I_o variability are beneficial for system performance. For both deployments, SIC increases the E_b/I_o mean more significantly than PC does, whereas PC reduces the E_b/I_o variability more significantly than SIC does.

The results suggest that the deployment strategy chosen has a profound impact on the effectiveness of SIC to yield performance gains. For example, the offset deployment has an order-of-magnitude better performance than the aligned deployment if SIC is implemented alone, whereas the aligned deployment has marginally better performance than the offset deployment if PC and SIC are jointly implemented.

These differences can be explained by using the F-factor, which is defined as the ratio of the intra-cell interference to the total interference in the system. As SIC cancels only intra-cell interference, a high F-factor *before* the implementation of SIC is desirable because it enables a greater proportion of the total interference to be cancelled. In the aligned (offset) deployment operating with *neither PC nor SIC* the mean F-factor is 0.93 (0.97), whereas in the aligned (offset) deployment operating with *PC only* the mean F-factor is 0.91 (0.89). If SIC is implemented in either of these cases, the deployment with the higher F-factor yields better performance. These statistics show that the F-factor is related to whether or not PC is used. Further analysis shows that the F-factor is also related to the distribution of mobiles in the system, which is in turn governed by the base station deployment strategy chosen.

The same trends are observed for the other aligned deployment (Tx 2, 4 and 6) and offset deployment (Tx 1, 4 and 5). As the results are based on propagation measurements, they are strictly applicable to the building under consideration. However, it is expected that the trends reported here would be similar in many other buildings of similar construction.

V. CONCLUSION

This Letter has shown that PC and SIC can yield significant performance gains in indoor DS-CDMA systems. The performance gain achieved is likely to be influenced by the deployment strategy chosen. For example, PC (SIC) provides a greater performance gain for an aligned (offset) deployment than an offset (aligned) deployment. Both deployments yield the highest performance gains if PC and SIC are jointly implemented, which is approximately an order-of-magnitude better performance than if PC is implemented alone. Clearly, the availability of SIC has the potential to influence conventional indoor DS-CDMA system deployment strategies.

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