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SYSTEM DESIGN FOR CONTIGUOUS CELL COVERAGE IN HIGH DENSITY MICROCELLULAR NETWORKS

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ABSTRACT

This paper examines whether microcellular networks can be designed to provide contiguous cell coverage for a given proportion of mobile terminals. Simulation results using a general microcellular interference model show that contiguous cell coverage may not be possible for an acceptable proportion of mobile terminals even if the call loss rate is low.

1. INTRODUCTION

System design methodologies for conventional (large cell) cellular networks have matured through a mix of theory and operational experience since the first systems were developed in the 1970s [1]–[2], but the applicability of these design techniques to the microcellular case is questionable [3]–[6].

The wide scale deployment of an extensive, high grade, wireless telephone system will require engineering tools and techniques that allow rapid and accurate system design [7]. The fundamental problem that needs to be addressed is of modelling the end result of multiple users propagating in a congested area [7],[8].

Some of the factors which affect the performance of microcells include adjacent channel interference, the distribution of user terminals, the close spacing of fixed stations, and spatial traffic variability [3]–[19].

One of the important system design issues for microcellular networks is the radio coverage quality. Users will increasingly demand wireline call quality [8] throughout the network and this will require reliable, contiguous radio coverage.

2. CELL COVERAGE MODEL

A general interference model has been developed that enables microcell coverage and cell radius distributions to be analysed in terms of the system design parameters [3]–[6].

The model takes a spatial approach to analysing the interference effects on a wanted link of an arbitrary number of interfering mobile terminals communicating with an arbitrary number of fixed stations.

An important aspect of the model is that it incorporates channel spill interference from all other users regardless of the magnitude of the interference at the source. Theoretical analysis and simulation results have demonstrated that even in the absence of cochannel and immediately adjacent channel interferers, interference from other users can be significant [6].

The model can be used to analyse cell coverage performance via a parameter called the 'interference to noise ratio' or INR, given the symbol η [3]. The INR is the total interference power at the input to a receiver divided by the receiver noise power and describes the extent of noise or interference dominance of the wanted link. Using this parameter, the maximum possible range *r* of a mobile terminal from its fixed station is given by a simple expression of the form [4]:

$$r^{\gamma} = \psi\left[\frac{1}{\eta_F + 1}\right] \quad (1)$$

where η_F is the uplink INR (i.e. the INR at the fixed station receiver). The parameter ψ is a system constant for a particular mobile technology and is a function of frequency, transmitter power, cochannel protection ratio and the receiver noise floor. γ is the path loss exponent in a simple distance–dependent path loss propagation model.

In a noise limited system, $\eta_F \ll 0.1$ and $1/(\eta_F+1) \approx 1$, thus the maximum terminal range *r* is relatively stable. As a system becomes interference limited, $\eta_F \gg 10$, $1/(\eta_F+1) \approx 1/\eta_F$, and the maximum terminal range *r* becomes sensitive to η_F and the arrangement of the interferers. The INR provides a means of computing cell radius distributions and thus the proportion of mobile terminals which meet some cell coverage criterion.

Previous papers [5]–[6] have examined the uplink INR and cell radius statistics in cellular and microcellular networks for example scenarios, both through Monte Carlo simulations and theoretical analysis. The next step is to consider how these statistics are affected by varying the user load and fixed station separation.

If a microcell network is to provide reliable, contiguous coverage, then a system design methodology needs to be developed so that the required proportion of mobile terminals continues to meet coverage targets as the user density increases.

3. CELL COVERAGE SIMULATION

The microcell simulation program used in [4]–[6] can be used to investigate cell size distributions as a function of user density. The program performs Monte Carlo simulations in accordance with the microcell interference model described in the previous section. The simulation provides call blocking and dropout estimates and Probability Density Functions (PDFs) and Cumulative Distribution Functions (CDFs) for the resultant INR and cell radii statistics.

The simulation was loaded with the technical specifications, call set up and channel allocation procedures for CT2 (an existing microcellular system). In each simulation 10 000 call attempts were made within a regular hexagonal arrangement of 19 CT2 fixed base stations, each 173.2 metres apart, so that the mobile terminal range required for contiguous coverage was 100 metres. A fixed number of mobile terminals were placed in random locations but with a uniform distribution in each cell. Transmitter power control was not used.

Call attempts in the simulation proceeded in a random sequence. A mobile terminal's call attempt would fail if it didn't meet the required S/[N+I] at both the fixed and mobile ends of the link. An initially successful mobile terminal could also drop out if the success of other mobiles led to an increase in interference, causing its S/[N+I] to fall below threshold. Channel reassignments and retries were allowed in accordance with the CT2 specifications. All calls were cleared and the process repeated after every terminal had completed a call attempt. The propagation exponent γ was set to 3 for both signal and interference.

Table 1 gives a summary of the call failure statistics, uplink INR (η_F) statistics, and contiguous coverage results as the traffic load was increased from 1 to 4 *simultaneous* users per CT2 cell. The cumulative η_F statistics for the *successful* calls are plotted on a lognormal probability scale (which amplifies the tails of the distribution) in figure 1. The cumulative cell radius statistics, computed from the η_F CDF using equation (1), are plotted on a log probability scale in figure 2.

Table 1 – Simulation Results for CT2 Network

PARAMETER	1 user/ cell	2 users/ cell	3 users/ cell	4 users/ cell
Call Blocking (%)	0.00	0.63	1.74	3.08
Call Dropping (%)	0.02	0.51	1.54	3.54
Total Call Loss (%)	0.02	1.14	3.28	6.62
Log Average η_F	0.050	0.375	0.869	1.410
Std Deviation log η_F	1.180	0.802	0.622	0.527
Terminals with contiguous coverage (%)	95.2	88.5	80.9	74.1

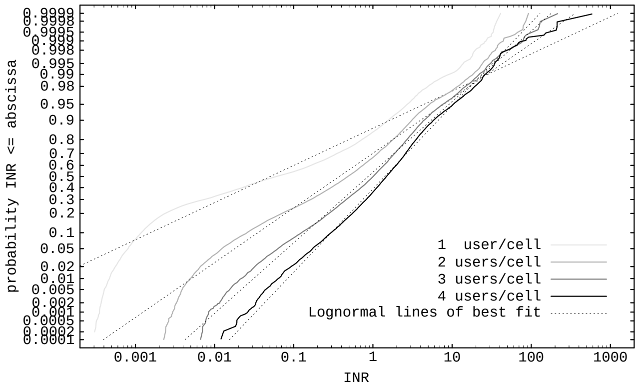

Figure 1 – η_F CDF vs cell load

Figure 1 shows that as the user loading per cell increased, the INR distribution approached a lognormal distribution, its log weighted average increased, but the standard deviation decreased (the dotted lines in figure 1 show the lognormal line of best fit to each simulated data). These results are consistent with the results presented in [6] for interferer ensembles.

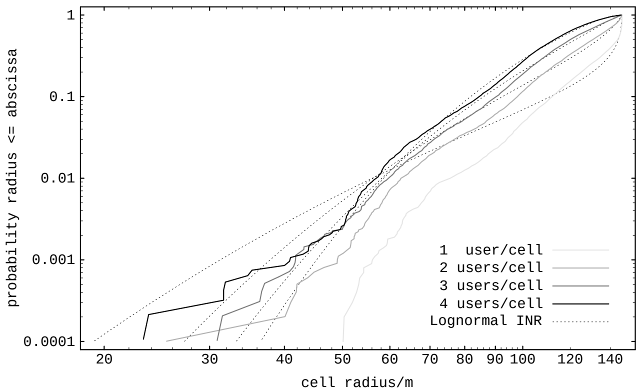

Figure 2 – Cell radius CDF vs cell load

The cell radius CDF (figure 2), derived from the η_F CDF using equation (1), shows that as the cell loading was increased, the proportion of terminals enjoying a cell radius sufficient to provide contiguous coverage (i.e. 100 m) reduced from 95% at 1 user/cell to an unacceptable 74% at 4 users/cell, even though the total call loss rate stayed well under 10% (see table 1).

The dotted lines in figure 2 show the cell radius CDF based upon the lognormal lines of best fit as shown in figure 1. The shape of these CDF curves varies substantially as a function of the mean and standard deviation of the lognormal estimate.

The question that needed to be answered was whether the coverage with 4 simultaneous users/cell could be improved by reducing the fixed station separation. Say a target is set that 90% of terminals should have contiguous coverage as determined by the fixed station layout. An iterative design strategy could then involve determining the 90% terminal range, reducing the fixed station separation in accordance with this range, and performing the simulation again to establish whether the coverage target had been met.

In the above simulation, 90% of terminals had a cell radius of 84.5 metres or more. The fixed station separation was reduced so that contiguous coverage would have required a cell radius of 84.5 metres, and the simulation was performed again. Note that this also increased the user density as a fixed number of users made call attempts in each cell.

This simulation indicated that 90% of terminals had a cell radius of 72.7 metres or more, again insufficient for the coverage target. The fixed station separation was reduced again so that contiguous coverage would have required a cell radius of 72.7 metres, and the simulation repeated. This process was continued and the results are shown in figures 3 and 4.

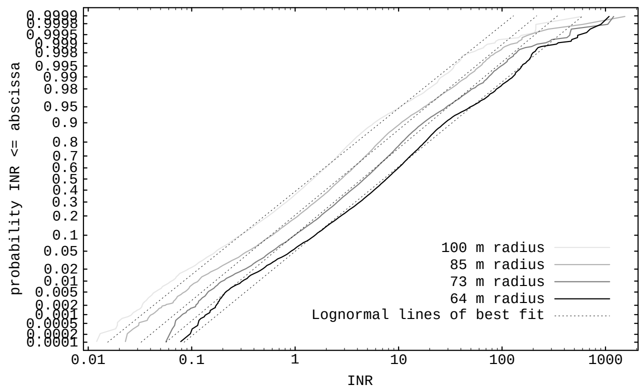

Figure 3 – η_F CDF vs cell spacing

Figure 3 shows that as the fixed stations were placed closer and closer together, the average uplink INR increased approximately in inverse proportion to the fixed station separation but the standard deviation of the INR samples essentially remained unchanged.

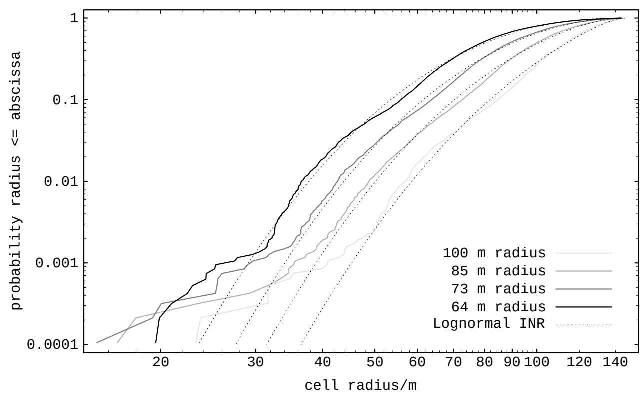

Figure 4 – Cell radius CDF vs cell spacing

This had the effect, as can be seen in figure 4, of increasing the spread of cell sizes. This only served to compete against the cell coverage improvement being attempted by this process.

Thus contiguous coverage was not achieved simply by reducing the fixed station separation, but it is not clear from figure 4 whether reducing the fixed station separation actually improved or reduced the proportion of terminals with contiguous coverage.

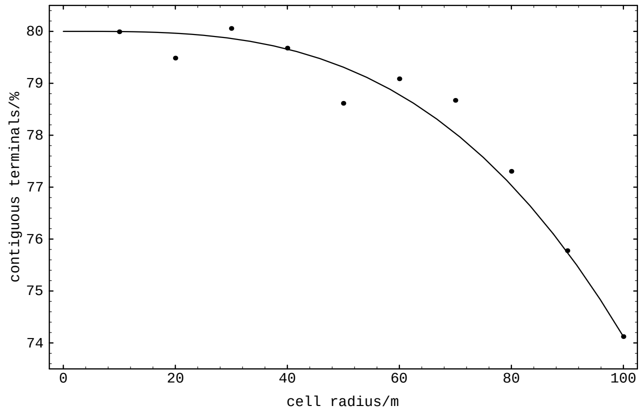

Figure 5 – Proportion of mobile terminals with contiguous coverage vs cell spacing

Figure 5 shows the proportion of mobile terminals which achieved contiguous coverage (as defined by the fixed station layout) versus the fixed station separation. With 4 simultaneous users/cell, the proportion of terminals with contiguous coverage increased slightly as the fixed station separation was reduced, but the proportion of terminals with contiguous coverage flattened out at approximately 80% at very small fixed station separations.

However, the total call loss rate improved slightly, from around 6.6% to 5.6%, as the fixed station separation was reduced. The rates for both call blocking and call dropping reduced as part of this reduction in total call loss.

Hence even with a low call loss rate and a very small fixed station separation contiguous coverage was not achieved. It would appear that the coverage quality limit is a function of the user load, the terminal distribution, and the cumulative off–adjacent channel spill from interfering users.

Cochannel and immediately adjacent channel interferers can largely be discounted from causing this limit because such interferers cause horizontal jumps in the INR and cell radius CDF traces. Examining figure 4, such jumps only occur in the last 0.5% of samples, thus coverage for the last 10% of terminals would mostly be determined by the effect of off–adjacent channel interference.

Overcoming a coverage limit may be difficult. Solutions could include a hard limit on the system capacity (i.e. controlling the number of fixed network trunks available per cell), or imposing stricter limits on system channel spill specifications. A better solution may be to develop new terminal admission controls that monitor and tailor the INR (and thus cell radius) statistics in order to maintain some coverage target.

4. CONCLUSION

Cell sizes experienced by individual mobile terminals in a cellular system are a function of the uplink "interference to noise ratio" or INR. The extent of contiguous coverage, or the proportion of terminals meeting a coverage target in a cellular or microcellular system, can be deduced from the INR statistics.

Simulations have shown that the proportion of mobile terminals meeting a contiguous coverage requirement in a microcell environment decreases as the per–cell load increases. Further, when the proportion of terminals with contiguous coverage drops below the target level, reducing the fixed station separation improves the proportion only slightly.

Hence contiguous cell coverage may not be possible for an acceptable proportion of mobile terminals in a microcell system even if the call loss rate is low. This coverage limit appears to be a function of the accumulated interference from off–adjacent channel spills of other users.

These results suggest that a system–wide microcellular design methodology will need to address the INR statistics in a system, and possibly tailor them through terminal admission controls, if contiguous coverage is required for a certain proportion of mobile terminals.

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