# Integrated Dynamic Radio Resource Management

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*Abstract*— **Radio resource management techniques play a pivotal role in the quality and capacity of personal communications networks. For small cells with high user densities, future schemes will have to adapt dynamically to the rapidly changing traffic and interference. Existing systems perform several radio resource management tasks including admission control, channel assignment, power control, and handoff. This paper examines these processes simultaneously and adopts signal-to-interference ratio (SIR) as a decision criterion for handoff and admission control. Key results show that integrated radio resource management can increase system capacity within specified quality constraints. SIR is an appropriate criterion for it reflects the actual traffic conditions and channel usage patterns in the system. However, there are limitations to the use of SIR alone as an admission control criterion for reducing call dropping. The interaction of the power control and the SIR based handoff causes cell dragging and inhibits handoffs near geographical cell boundaries. This provides a motivation for future study of a handoff algorithm that is based on both SIR and transmitted power.**

## I. INTRODUCTION

In the current cellular system, a service area is covered by several base stations at known locations. The establishment and maintenance of calls between base stations and mobiles requires several resource allocation tasks such as base station assignment, channel allocation (carrier frequency/time slot etc), transmitted power adjustment (uplink/downlink), handoff and admission control.

Due to the time and space varying nature of the system, the radio resource management schemes have to adapt dynamically to instantaneous interference and traffic situations. Indeed, radio resource management becomes critical in designing a cellular network that offers high capacity, high quality (as reflected in achieved SIR or bit error rate), low blocking, and low dropping.

Existing work addresses these radio resource management tasks separately.

**Admission Control** A call admission policy is important to prevent the system from becoming overloaded and to ensure sufficient channels for handoff requests. A simple approach is to reserve a number of channels exclusively for handoffs. Prioritized handoffs have been proposed in [1–3].

**Channel Allocation** Fixed channel allocation with or without borrowing is controlled by reuse constraints while dynamic channel assignment adapts better to the time varying traffic patterns [8–12, 14].

**Power Control** Initial work on power control centered on maintaining a constant received power level. In [13], SIR balanced power control is proposed whereby individual terminal continuously performs power adjustments to attain a common SIR.

**Handoff** Base station and channel assignment are both necessary parts of a handoff algorithm. An obvious solution to base station assignment is to assign a mobile to the nearest base station. However, in the face of shadow fading, interference and other propagation losses, base assignment based on channel measurements have been proposed. Distance and received signal strengths are two major criteria adopted in current handoff algorithms [15]. Handoff algorithms based on relative signal strength were analyzed in [16, 17]. In the context of a CDMA system, base station assignment based on minimum power has been analyzed in [5–7].

This paper addresses these tasks with an integrated radio resource management scheme that offers better performance by making the necessary tradeoffs between the individual goals. With mobility, propagation loss and fading, it is crucial to understand the interplay and interdependence of all of these resource management tasks.

## II. INTEGRATED DYNAMIC RESOURCE MANAGEMENT

This work employs a resource allocation based on SIR thresholds. Such a scheme is able to adapt dynamically to the changing traffic conditions since SIR is an indicator of the link quality between the mobile and the base station. A total of 4 SIR thresholds, floor SIR $\gamma_{\text{drop}}$, target SIR $\gamma_t$, admission control SIR $\gamma_{\text{new}}$, and handoff criterion $\gamma_{\text{ho}}$ are introduced.

The floor SIR, $\gamma_{\text{drop}}$ is set to 16dB, and is considered the minimum tolerable ratio for sufficient service quality. A call will be dropped whenever SIR drops below $\gamma_{\text{drop}}$.

The target SIR, $\gamma_t$, is the ideal SIR level which each mobile is trying to attain through the SIR balanced power control scheme. To ensure that calls are not dropped and that speech quality is sufficient, $\gamma_t$ should always be greater than $\gamma_{\text{drop}}$. However, $\gamma_t$ should not be made unnecessarily large; otherwise it will lead to higher transmitted power levels and increased co-channel interference. We have chosen $\gamma_t$= 19dB for our simulations.

The SIR threshold $\gamma_{\text{new}}$ is used as an admission control criterion. A new call is accepted only if there is a channel that can offer an SIR better than $\gamma_{\text{new}}$. This avoids packing the system too tightly, which could result in dropped calls when terminals move since it will be difficult to find free channels for handoff. On the other hand, this admission control also ensures that the new call, once admitted, will not cause severe interference to other ongoing calls by transmitting with very high power in an effort to achieve target SIR. Therefore,

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$\gamma_{\text{new}}$ should be higher than $\gamma_t$.

The handoff criterion $\gamma_{\text{ho}}$ is used in the SIR based handoff algorithm that we consider. In this case, handoff requests are made whenever the SIR falls below the threshold $\gamma_{\text{ho}}$.

To summarize, these four thresholds should satisfy

$$\gamma_{\text{drop}} < \gamma_{\text{ho}} < \gamma_t < \gamma_{\text{new}} \tag{1}$$

Detailed discussion of these four thresholds follows.

### *A. SIR Balanced Power Control*

The transmitted power at both the base stations and mobiles (uplink and downlink) are controlled so that all terminals attain a target SIR $\gamma_t$. We describe this approach for the uplink. This scheme is implemented in a distributed way whereby each terminal measures its uplink SIR based on its own path loss and total cochannel interference in the system at that particular instant. The interference contribution of other mobiles will depend on the uplink gain factors $G_{ij}$ due to path loss and fading between a mobile $i$ and a base station $j$. The uplink SIR of mobile $i$ at base station $j$ on channel $k$ is

$$\gamma_{ij}^{(k)} = \frac{p_i G_{ij}}{I_{ij}^{(k)}} \tag{2}$$

where $I_{ij}^{(k)}$ is the interference seen by mobile $i$ on channel $k$ measured at base station $j$. Note that the interference on a particular channel includes both interference from other mobiles as well as receiver noise. Using $M_i$ to denote the set of mobiles that share the same channel as mobile $i$, we can write

$$I_{ij}^{(k)} = \sum_{i' \in M_i} p_{i'} G_{i'j} + \eta \tag{3}$$

where $\eta$ is the base station receiver noise. When mobile $i$ is assigned to base $k$, its transmitter power $p_i$ is adjusted asynchronously every second via

$$p_i = \min\{p_{\max}, \gamma_t I_{ij}^{(k)} / G_{ij}\} \tag{4}$$

The maximum transmitter power $p_{\max}$ is determined by hardware constraints. We consider $p_{\max} = 1$ W in our model.

### *B. Call Admission*

We assume that each base station $j$ transmits a beacon signal (pilot tone) at a constant power level $P_j$ at all times. The mobile measures and compares the signal strength of all neighbouring base stations. Each mobile $i$ is assigned to the base station with the strongest signal. That is, mobile $i$ is assigned to a base station $j^*$ such that

$$P_{j^*} G_{ij^*} = \max_j \{P_j G_{ij}\} \tag{5}$$

The channel assignment scheme considered here is the minimum interference (MI) scheme in which after a mobile is assigned to a base station $j$, the best channel $k^*$ is chosen such that

$$I_{ij}^{(k^*)} = \min_{k \in C_j} \{I_{ij}^{(k)}\} \tag{6}$$

where $C_j$ is the set of channels at base $j$ that are not previously assigned to other mobiles. Given the channel $k^*$, an additional constraint has to be satisfied: the estimated SIR that can be achieved with maximum power level on channel $k^*$ cannot be less than $\gamma_{\text{new}}$. That is, the call of mobile $i$ is accepted at base $j$ on channel $k^*$ only if

$$p_{\max} G_{ij} / I_{ij}^{(k^*)} \geq \gamma_{\text{new}} \tag{7}$$

We note that $p_{\max} G_{ij} / I_{ij}^{(k)}$ is only an estimate of the SIR that mobile $i$ would attain using power $p_{\max}$. In particular, this estimate neglects the response of other mobiles to the maximum power transmission of user $i$.

### *C. SIR Based Handoff Algorithm*

A handoff occurs whenever the SIR falls below the handoff threshold $\gamma_{\text{ho}}$. In order to avoid unnecessary handoffs, a hysteresis level, $T_{\text{hy}}$ is specified. During each resource reassignment, a mobile $i$ assigned to channel $k$ at base $j$ executes the following algorithm:

```
adjust the transmitter power $p_i$;
evaluate SIR $\gamma$;
if ($\gamma < \gamma_{\text{ho}}$) {
   find destination base $j^*$ from equation 5;
   if ($j^* \neq j$) { (intercell handoff)
      find the quietest channel $k^*$ from equation 6
      if ($\gamma_{ij}^{(k^*)} - \gamma > T_{\text{hy}}$)
         handoff to channel $k^*$ at base $j^*$;}
   else { (intracell handoff)
      find the quietest channel $k^*$;
      perform the handoff to $k^*$ if $k^* \neq k$;}}
```

If all handoff attempts fail, the call continues to be served by the old base station although it may be dropped if its SIR falls below $\gamma_{\text{drop}}$.

## III. SYSTEM MODEL

In this section, we describe the simulation scenario, the assumptions made and the performance measures. For the cell layout, 20 base stations are spaced uniformly on a closed loop to avoid edge effects. All cells are 2 km in length with base stations located at the center of each cell. A total of 40 channels are considered. The speed distribution of the terminals is modeled using a truncated Gaussian Distribution with mean value of 90km/hr and standard deviation of 15km/hr, truncated at a minimum speed of 60km/hr and a maximum speed of 120km/hr. The "clockwise" and "counterclockwise" directions are equally likely. It is assumed that both the speed and direction of the terminal remain constant throughout the duration of the call.

The call arrival rate in each cell is an independent Poisson process of intensity $\lambda$ calls/sec. Call durations are exponentially distributed with mean $1/\mu = 120$ s. Given $M = 40$ as the size of channel set for the whole system, $B = 20$ base stations, the normalized traffic load is $\rho = \lambda/(\mu M B)$ erlangs/channel/cell.

The received signal strength in dB is calculated as the emitted power minus the path loss between the base and the mobile. The path loss is modelled as a sum of two terms, one due to the distance and the other due to lognormal (shadow) fading. Rayleigh fading is neglected and is assumed to be averaged out in power measurements due to short correlation distance. In this simulation, the uplink gain is given by

$$G_{ij} = \frac{1}{d_{ij}^{\alpha}} U_j(d_{ij}) \tag{8}$$

where $d_{ij}$ is the distance between mobile $i$ and base station $j$ and $U_j(d_{ij})$ is the lognormal fading factor. We use $\alpha = 4.0$ throughout our simulations, which is typical of urban radio links. If the power transmitted is $p_i$, the power received, $r_i$ will be $r_i = G_{ij} p_i$. In units of dB,

$$10 \log r_i = 10 \log p_i - 10\alpha \log d_{ij} + 10 \log U_j(d_{ij}) \tag{9}$$

The lognormal shadow fading term $S_j(d_{ij}) = 10 \log U_j(d_{ij})$, is modeled as a gaussian random variable with mean zero and standard deviation of $\sigma = 6$ dB. The shadow fading processes $S_j(d)$ and $S_{j'}(d')$ for distinct base stations $j$ and $j'$ are assumed to be independent. To account for the correlation over distance of the shadow fading, we use a first order autoregession model. In the simulations, a shadow fading pattern is generated first by applying the autoregressive model over the 40 km length of the system. The correlation distance, $d_0$, is 45m and shadow fading measurements are obtained at $\delta = 5$ m intervals. This produces a distance autocorrelation function

$$\rho(d) = E\left\{S_j(d')S_j(d'+d)\right\} = e^{-|d|/d_0} \tag{10}$$

If signal strength measurements are taken at equally spaced locations, $\delta, 2\delta, \ldots$, we have $S_j(n\delta) = \rho(\delta) S_j((n-1)\delta) + V_i$, where the $V_i$ are independent identically distributed normal random variables with $E[V_i^2] = \rho^2(\delta)(1-\sigma^2)$.

The performance of the system is evaluated in terms service quality, service denials and handoff statistics. We use the SIR as a measure of the service quality of a link. Service denials are measured in terms of the new call blocking probability $P_b$ and forced termination probability $P_d$. From the simulation, $P_b$ and $P_d$ are estimated using

$$P_b = \frac{\text{total new calls blocked}}{\text{total call arrivals}} \tag{11}$$

$$P_d = \frac{\text{total dropped calls}}{\text{total admitted calls}} \tag{12}$$

The performance of the handoff algorithm is described by $E[H]$, the mean number of handoffs/mobile/call, and $E[D_{ho}]$, the average handoff crossover distance. The crossover distance is the distance from the old base station to the point where a successful handoff is performed. It does not provide information about where the handoff requests are made, which may be at some distance less than the crossover point.

## IV. SIMULATION RESULTS

The results are obtained using the model outlined in the previous section. Table 1 summarizes various parameters used in our simulations. Discussion of the effect of the four thresholds on call blocking, call dropping, handoff crossover distance, and mean number of handoffs follows.

TABLE I
SIMULATION PARAMETERS

| | | |
|---|---|---|
| $B$ | Number of base stations | 20 |
| $C$ | Number of channels in system | 40 |
| $D$ | Distance between 2 base stations | 2000m |
| $\alpha$ | Propagation exponent | 4 |
| $\sigma$ | Std. deviation of lognormal fading | 6dB |
| $d_0$ | Shadow fading correlation distance | 45m |
| $\delta$ | Sampling distance | 5m |
| $v_{\text{min}}$ | Minimum speed | 60km/hr |
| $v_{\text{max}}$ | Maximum speed | 120km/hr |
| $E\{V\}$ | Mean speed | 90km/hr |
| $\eta$ | Receiver noise power | -150dBw |
| $p_{\text{max}}$ | Maximum transmitter power | 0dBw |
| $\gamma_{\text{drop}}$ | Floor SIR | 16dB |
| $\gamma_t$ | Target SIR | 19dB |
| $\gamma_{\text{ho}}$ | Handoff SIR Threshold | 18dB |
| $\gamma_{\text{new}}$ | New Call SIR Threshold | 21dB |

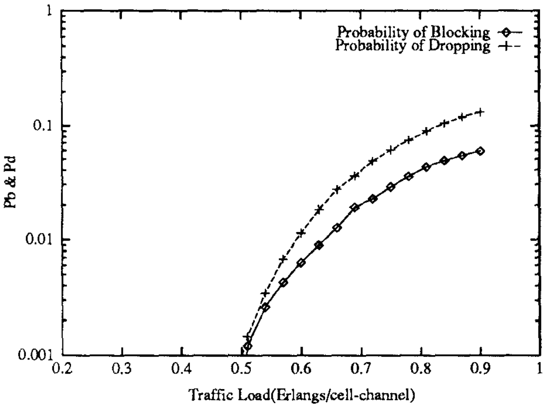

Fig. 1. Service Denial at Different Load ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB, $T_{\text{hy}}$=0dB)

### A. Call Blocking and Dropping

In Fig. 1, the load is 0.63 erlang/channel/cell at $P_b = 0.01$ and 0.57 erlang/channel/cell at $P_d = 0.01$. We can deduce that the system can support a capacity of 0.57 erlang/cell-channel with the condition that both $P_b$ and $P_d$ are less than 1%. However, the probability of call dropping is slightly higher than blocking probability. This result is not favorable since forced termination of on-going calls is much less desirable than blocking of new calls. Therefore, it is essential to choose the threshold values more carefully and consider the use of an admission control policy.

### B. Handoff Performance

From Fig. 2, we found that the crossover distance at a mean load of 0.45 erlang/cell-channel is 1580m from the old base station, which is 580m past the nominal cell boundary.

This result indicates that the interaction of the power control and handoff algorithms tends to keep a call with the old base station when the terminal travels into the adjacent cell. In particular, the mobile transmitter power will continue to increase to maintain the target SIR $\gamma_t$ until $p_{\max}$ is reached. This finding helps explain why the probability of dropping is higher than expected. A terminal that enters a new cell but still connected to the original base station must transmit with higher power to achieve $\gamma_t$, causing additional co-channel interference and increased call dropping.

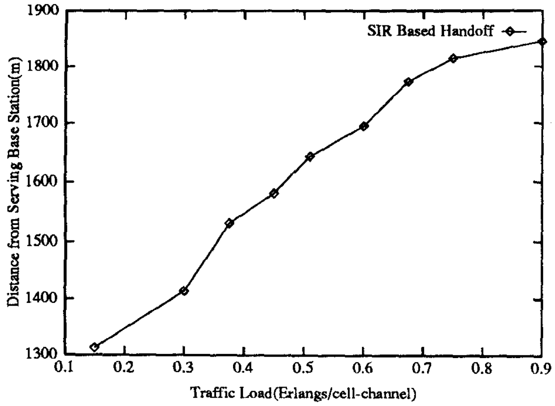

Fig. 2. Mean Distance from Base Station where Handoff Takes Place ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB, $T_{\text{hy}}$=0dB)

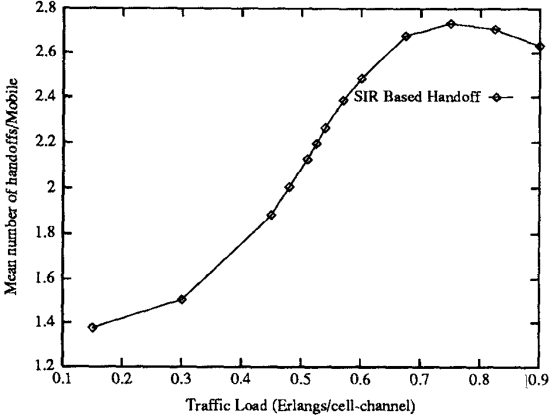

Fig. 3. Mean Number of Handoffs/Mobile at Varying Load ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB, $T_{\text{hy}}$=0dB)

In addition, the crossover distance increases when the traffic load increases. As the system becomes more heavily loaded, it becomes more difficult for the terminal to find a free channel for handoff. and the call must remain connected to the old base station. In this case, the transmitter power stays at maximum until either a free channel is found or until the SIR drops below $\gamma_{\text{drop}}$ and the call is dropped.

The mean number of handoffs per call generally increases with the offered load. In Fig. 3, mean number of handoffs increases from 1.4 to 2.6 as the traffic load is increased from 0.2 to 0.7 erlang/channel/cell. At an average velocity of 25m/s, a call which lasts 120s (mean duration) will result in average travel distance of 3000 m/call or 3km/call. With a cell size of 2km, the average number of cells visited per call be 1.5. Hence, under high load, the average handoffs/call is significantly greater than what travel distances would suggest is needed.

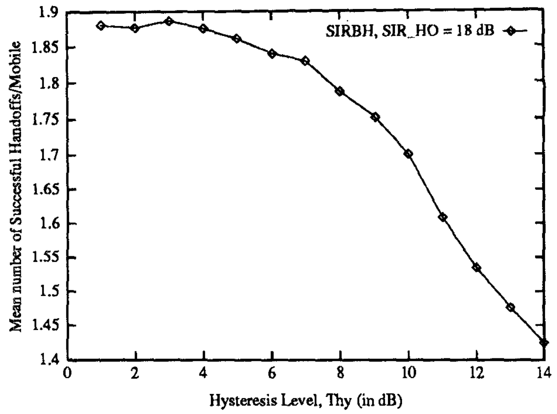

Fig. 4. Mean Number of Handoffs/Mobile vs Hysteresis Level at Load= 0.45 Erlang/cell-channel ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB)

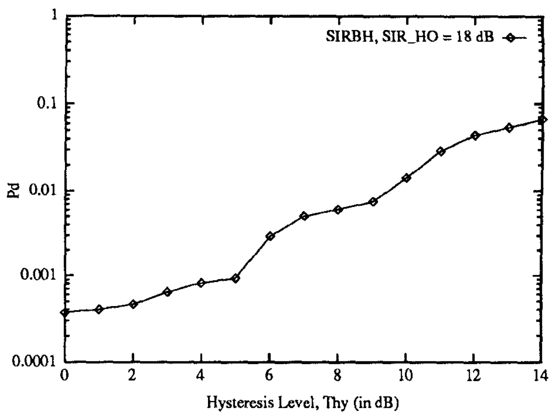

Fig. 5. Probability of Call Dropping vs Hysteresis Level at Load= 0.45 Erlang/cell-channel ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB)

As the handoff hysteresis $T_{\text{hy}}$ increases, the mean number of handoffs per mobile is reduced (Fig. 4) while the number of dropped calls increases (Fig. 5). The SIR based handoff scheme inhibits handoff at the cell boundary, resulting in channels being used outside the planned cell area, therefore creating unnecessary co-channel interference. If the terminal waits longer to handoff, the chances of the call being terminated is increasing. Fig. 6 shows the trade off between the average number of handoffs/call and probability of dropping at the load of 0.45 erlang/cell-channel.

### *C. Call Admission Performance*

Fig. 7 depicts the tradeoff curves between the blocking and dropping probability, $P_b$ and $P_d$, at different traffic loads as a function of the call admission SIR threshold $\gamma_{\text{new}}$. Probability of blocking increases as $\gamma_{\text{new}}$ is increased as it becomes more difficult for new calls to satisfy the admission constraint set by $\gamma_{\text{new}}$. In this case, more free channels become available for handoffs and the probability of call dropping decreases slightly.

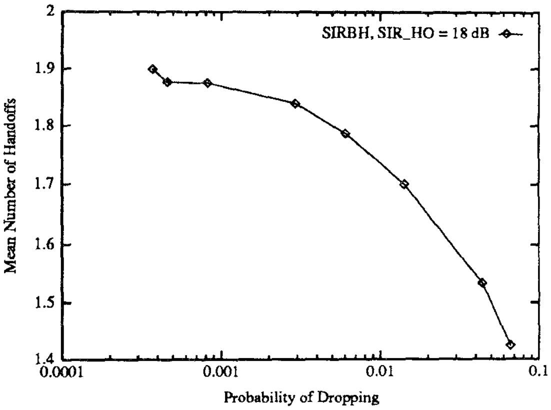

Fig. 6. Mean Number of Handoffs/Mobile vs Probability of Dropping at Load = 0.45 Erlang/cell-channel ($\gamma_{\text{new}}$=21dB, $\gamma_{\text{ho}}$=18dB, $T_{\text{hy}}$ varies from 1 to 14dB)

For a desired grade of service (as indicated by the corresponding $P_b$ and $P_d$) at a specific load, we can choose the appropriate $\gamma_{\text{new}}$ as the admission control parameter. However, we observe from Fig. 7, that the tradeoff between call blocking and call dropping provided by $\gamma_{\text{new}}$ is not very favorable.

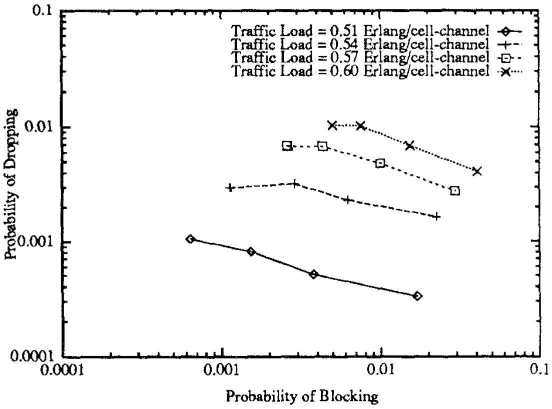

Fig. 7. Tradeoff Curve Between Dropping and Blocking Probability as a function of $\gamma_{\text{new}}$ (SIR_NEW) and Traffic Load ($\gamma_{\text{ho}}$=18dB, $\gamma_{\text{new}}$=19, 22, 25, 28dB, $T_{\text{hy}}$=0dB)

## V. CONCLUSIONS

The performance of an integrated radio resource algorithm using Signal-to-Interference-Ratio (SIR) information is studied. The algorithm performs a handoff only when the maximum achievable SIR is less than the threshold $\gamma_{\text{ho}}$. Similarly a new call is accepted if the achievable SIR is greater than $\gamma_{\text{new}}$. Dynamic channel allocation, signal strength base assignment and asynchronous power control are integrated into the system model.

For the simulation model considered, the results show that the coupling of $\gamma_{\text{new}}$ and $\gamma_{\text{ho}}$ provides a reasonable number of handoffs while keeping the blocking and dropping probability below 1%. Higher hysteresis cause a larger delay in handoff, and reduces the number of handoffs at the expense of increased call dropping. Although we would like to minimize the number of handoffs, there is a limit of improvement constrained by the desired grade of service.

Results also show that SIR balanced power control can inhibit handoffs at a geographical cell boundary, and allow a call to remain served by the old base station even when the terminal has traveled far into the adjacent cell. Such cell dragging delays the dropping of a call in a densely packed system, but causes unnecessary interference in the case of low traffic load.

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