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Optimization of Channel Sharing Strategies in Hierarchical Cellular Systems using Queuing

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Abstract

The primary goal of future cellular mobile communication networks is to provide efficient and cost effective services to mobile users under all environments. The major issues that affects the quality of service and performance in wireless communications systems is scarcity of resources. Hence, efficient resource allocation is prime concern in order to improve the performance of cellular networks. Two-Tier cellular system is considered to increase the channel utilization by sharing channels between two tiers. In this paper a Hybrid Channel Allocation (HCA) strategy for channel allocation and queuing technique is applied to hierarchical cellular network in order to enhance the performance of the system. The hierarchical cellular system helps better utilization of radio spectrum and application of queuing technique further increases efficiency of the system by reducing call blocking and dropping and by increasing number of users in the system.

Keywords: Hierarchical cellular system, hybrid channel allocation, microcell, macro cell, new call queuing, handoff call queuing.

1. Introduction

All wireless cellular mobile systems have been allocated a fixed set of radio spectrum. In order to increase the number of users supported by the network, efficient utilization of allocated radio spectrum is primary concern.

The third and future generation wireless communication networks will support heterogeneous traffic consisting of audio, video and data. Resource crunch is the main issue that needs to be fixed in such networks. The quality of service (QoS) is the complex problem due to the time varying characteristics of the channel and user mobility. Hierarchical structure of cellular mobile networks provides channel sharing in the overlapping region to reduce the probability of call blocking and call dropping. In this work a queuing technique is applied to a hierarchical cellular system to further enhance the efficiency by reducing call blocking and call dropping and hence increasing the number of users supported by the wireless cellular mobile network system.

Table 1: Notations

Symbol	Definition
P_b	Blocking & dropping probabilities of new calls & handoff calls (without queuing)
P_{nq}	Blocking probability of new calls (queuing applied only to new calls)
P_{nd}	Dropping probability of handoff calls (queuing applied only to new calls)
P_{hd}	Dropping probability of handoff calls (queuing applied only to handoff calls)
P_{hb}	Blocking probability of new calls (queuing applied only to handoff calls)
λ_{tf}^{M}	Aggregate traffic incurred in macro cell (by fast moving subscribers)
λ_{ts}^{M}	Aggregate traffic incurred in macro cell (by slow moving subscribers)
μ_{f}^{M}	Service rate in macro cell (for fast moving subscribers)

μ_s^M	Service rate in macro cell (for slow moving subscribers)
cM	Total number of channels in the macro cell
λ_f^M	New call arrival rate in macro cell (for fast moving subscribers)
λ_{fh}^M	Handoff call arrival rate in macro cell (for fast moving subscribers)

2. Overview of channel allocation of strategies

The channel or resource allocation strategies are developed to facilitate the optimum utilization of the available radio spectrum. The channel allocation strategy has a direct impact on the quality of service and hence user satisfaction. The basic channel allocation strategies are

2.1 Fixed Channel Allocation (FCA) Strategy

In this method, each cell is allotted a predefined fixed number of channels. If all the channels in the cell are busy then the call will be blocked and the customer is denied the service. The frequency reuse distance (D) and the co-channel interference (Q) are the factors that are considered while allocating set of channels to a particular cell. This is a very simple method of allocating channels. If the channel is available it is allocated very fast but if all channels are busy then no one will get service from the network till a ongoing call gets completed and vacates the busy channel.

Channel borrowing approach: This is one of the several variations of FCA scheme. In this method the cell is allowed to borrow the free channels from neighbouring cell, if all of its channels are already busy. The Mobile Switching Centre (MSC) supervises the channel borrowing process and ensures that the borrowing of channels does not interfere with any of the ongoing call in the donor cell.

2.2 Dynamic Channel Allocation (DCA) Strategy

In this method, no cell is allocated a predetermined set of channels. Whenever each time a call request is made the serving Base Transceiver Station (BTS) request a channel from the Mobile Switching Centre (MSC), if centralised control is used otherwise the BTS requests a channels from Base Station Controller (BSC) itself. The switch then allocates a channel to the requesting cell following an algorithm that takes into account cost functions such as future call blocking within cell, the frequency of use of candidate channel, the reuse distance of the channel and any other cost functions. Accordingly the MSC or BSC only allocates a given frequency or channel, if that frequency or channel not presently in use in the cell or any other which falls within the minimum restricted distance. The minimum restricted distance is given by $D/R=\sqrt{3k}$ and D / R= Q = $\sqrt{3K}$ is the co-channel interference reduction factor. Where R is the radius of the cell coverage and K is the frequency reuse pattern that is cluster size. DCA strategies will reduce the blocking probability that results in enhancing the user support capacity of the system. DCA strategies require the MSC or BSC to collect the real time information on channel occupancy, traffic distribution, and radio signal strength indicators (RSSI) of all channels on a continuous basis. This under heavy traffic load increases the storage and computational load on the system, and increases the delay time for allocating a channel for a particular mobile user but at the same, it gives the advantage of increased channel utilization and decreased probability of blocked calls.

2.3 Hybrid Channel Allocation (HCA) Strategy

The HCA strategy is combination of FCA and DCA strategies. In HCA strategy, the total available set of channels is divided into two subsets. First subset is assigned to a cell according to FCA strategy where as second subset is kept in a central pool and assigned dynamically to a cell whenever there is a need. Hence HCA combines simplicity, efficiency of FCA and flexibility of DCA strategy.

3 Related works

In order to bridge the gap between bandwidth required and available, we use two-tier cellular structure. In our hierarchical system, there are two layers of cells namely (a) bigger macrocells (top layer) serving fast moving subscribers and smaller microcells (bottom layer) supporting slow moving subscribers. Macro cells micro cells can overlap with each other in the service area and hence can use this overlapping area to share load, optimizing the performance. A great deal of work has been done in this field. In [1, 2, 3, 7] subscribers are assigned to microcell and macrocell based on their mobility. In [4] to direct call termination and paging on the same tier is proposed to reduce paging cost. In [5], calls are classified into various categories depending on their velocities, and different handoff threshold are used for them. The velocity threshold to choose tiers is dynamically selected [6]. It was proposed in [8], a new/handoff call would be directed to the appropriate tier based on its previous speed. If there is no free channel on the preferred tier then the call would be directed to other (un-preferred) tier. This is called overflow. In [9], only overflow from low tier to high is allowed. While in [10], overflow from low tier to high tier is restricted to only handoffs. In [11], mobile subscribers travelling on the low tier may borrow channels from a pool of reserved handoff channels provided by the high tier. In [12], two-way overflows between both tiers are considered. Also, a take back scheme is introduced so as to redirect a call from an un-preferred tier to a preferred tier at the occasions of handoffs. In [13] a channel rearrangement scheme by forcing a handset in the overlapping area to take an early handoff prematurely, if the signal quality in the next cell is acceptable, is proposed.

In [14], a vertical channel sharing (between macrocell and microcell) and horizontal channel sharing (between macrocell and macrocell) is considered.

4 Proposed HCA strategies

Hybrid Channel Allocation (HCA) is the combination of Fixed Channel Allocation (FCA) and Dynamic Channel Allocation (DCA). Here proposed HCA with queuing technique is considered. Whenever a slow moving subscriber initiates a new call, channels are allocated using FCA method from microcell whereas for fast moving subscriber the allocation of channel is done DCA method from macrocell. Handoff calls will also be allocated to microcell or macrocell depending on their speed. All the new and handoff calls are queued before the actual channel allocation is done. Queuing of new and handoff calls is an effective way to reduce new call blocking and handoff call dropping only if they come in bundles. For a uniform traffic queuing is not effective. Generally, in real world scenario, during peak hours calls do come in bundles. Hence, queuing is essential for enhancing the performance of the cellular mobile network by reducing new call blocking and handoff call dropping.

Consider λ_1 and λ_2 are arrival rates of new calls per second for slow moving and fast moving subscribers respectively. Take M_1 and M_2 are the queue size of new calls for slow moving subscribers and fast moving subscribers respectively. Assume the total number of channels in a cell is N. Queuing analysis of for new calls for slow moving subscribers and fast moving subscribers is shown below.

4.1 Queuing of calls not applied to new calls and handoff calls

In this case, the blocking probability of new calls and dropping probability of handoff calls (P_b) is given by

$$P_b = \frac{\left(\frac{\lambda_{tf}^M}{\mu_f^M} + \frac{\lambda_{ts}^M}{\mu_s^M} \right)^{cM}}{cM!} P(o) \text{K K K} \; (1)$$

$$where$$

$$P(o) = \left(\sum_{n=0}^{cM} \frac{\left(\frac{\lambda_{tf}^M}{\mu_f^M} + \frac{\lambda_{ts}^M}{\mu_s^M} \right)^{cM}}{n!} \right)^{-1}$$

This is an erlang 'B' formula to calculate the blocking and dropping probability of new and handoff calls.

Algorithm for channel sharing between microcell and macrocell when no queuing is applied and a call is initiated in microcell m_i, $1 < i < n$.

```
If there is free channel in $m_i$ then
        (a) Assign this channel to the request
Else
        (a) If there is free channel in M then assign the channel to the request
Else
        (a) Pick any call in M such that corresponding microcell $m_j$ has a free channel.
        (b) Transfer the call to $m_j$ to vacate a channel in M
```

```
            (c) Then overflow channel
                request to M
    Else
            (a) Block the call

    End
```

Algorithm for channel sharing between macrocell and microcell when no queuing is applied and a call is initiated in microcell M.

```
If there is free channel in M the
    (a) Assign this channel to the request
Else
    (a) Overflow to the corresponding
        microcell if the microcell has the
        free channel
Else
    (a) Pick any call in M such that the
        call's corresponding microcell, say
        $m_{j,}$ has a free channel.
    (b) Transfer the call to $m_j$ to vacate a
        channel in M,
    (c) Assign the vacated channel to the
        request
Else
    Block the call
End
```

4.2 Queuing of calls applied only to new calls and not on handoff calls

In this case, the blocking probability of new call (P_{nq}) is given by

$$P_{nq} = \left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)^{M1} P_q(o) \text{KKK} \, (2)$$

where

$$P_q(o) = \frac{1}{cM! \sum_{n=0}^{cM-1} \frac{\left(\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}} + \frac{\lambda_{ts}^{M}}{\mu_{s}^{M}} \right)^{n-cM}}{n!} + \frac{1 - \left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)^{M_1+1}}{\left(1 - \frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)}}$$

Now the dropping probability (P_{nd}) of handoff call is given by

$$P_{nd} = \frac{1 - \left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)^{M_1+1}}{\left(1 - \frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)} x \frac{1}{cM \sum_{n=0}^{cM-1} \frac{\left(\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}} + \frac{\lambda_{ts}^{M}}{\mu_{s}^{M}} \right)^{n-cM}}{n!} + \frac{1 - \left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)^{M_1+1}}{\left(1 - \frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM} \right)}} \text{KKK}(3)$$

Algorithm for channel sharing between microcell and macrocell when queuing is applied new calls but not on handoff calls and a channel request in microcell $m_{i,}$ $1 < i < n$.

```
    If there is free channel in $m_i$ then
```

```
        (a) Assign this channel to the request
    Else
        (b) If there is free channel in M then assign the channel to the request
    Else
        (c) Pick any call in M such that corresponding microcell $m_j$ has a free channel.
        (d) Transfer the call to $m_j$ to vacate a channel in M
        (e) Then overflow channel request to M
    Else
        If initiated call is new then
         (a) Queue the call for a predefined time T and till a channel gets free
         (b) Assign the channel to the call
         Else
         (a) Block the call

    End
```

Algorithm for channel sharing between macrocell and microcell when queuing is applied new calls but not on handoff calls and a channel request in microcell M.

```
If there is free channel in M the
    (a) Assign this channel to the request
Else
    (b) Overflow to the corresponding microcell if the microcell has the free channel
Else
    (d) Pick any call in M such that the call's corresponding microcell, say $m_j$, has a free channel.
    (e) Transfer the call to $m_j$ to vacate a channel in M,
    (f) Assign the vacated channel to the request
Else
    If initiated call is new then
        (a) Queue the call for a predefined time T and till a channel gets free
        (b) Assign the channel to the call
    Else
        (a) Block the call
End
```

4.3 Queuing of calls applied only to handoff calls and not on new calls

Here the call dropping probability (P_{nd}) of the handoff call is given by

$$P_{hd}=\left(\frac{\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}}}{cM}\right)^{M_2} x \frac{1}{N!\sum_{n=0}^{cM-1}\frac{a^{n-cM}}{n!}+\frac{1-\left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{N}\right)^{M_1+1}}{\left(1-\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM}\right)}} \ldots\ldots(4)$$

and the blocking probability (P_{hb}) of the handoff call is given by

$$P_{hb}=\frac{1-\left(\frac{\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}}}{cM}\right)^{M_2+1}}{1-\left(\frac{\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}}}{cM}\right)} x \frac{1}{cM\sum_{n=0}^{cM-1}\frac{\left(\frac{\lambda_{tf}^{M}}{\mu_{f}^{M}}+\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}\right)^{n-cM}}{n!}+\frac{1-\left(\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM}\right)^{M_1+1}}{\left(1-\frac{\frac{\lambda_{ts}^{M}}{\mu_{s}^{M}}}{cM}\right)}} \ldots\ldots(5)$$

Algorithm for channel sharing between microcell and macrocell when queuing is applied handoff calls but not on new calls and a channel request in microcell m_i, $1 < i < n$.

```
        If there is free channel in $m_i$ then
```

```
        (a) Assign this channel to the request
    Else
        (c) If there is free channel in M then assign the channel to the request
    Else
        (f) Pick any call in M such that corresponding microcell $m_j$ has a free channel.
        (g) Transfer the call to $m_j$ to vacate a channel in M
        (h) Then overflow channel request to M
    Else
        If initiated call is handoff then
         (c) Queue the call for a predefined time T and till a channel gets free
         (d) Assign the channel to the call
         Else
         (b) Block the call

    End
```

Algorithm for channel sharing between macro cell and micro cell when queuing is applied handoff calls but not on new calls and a channel request in microcell M.

```
If there is free channel in M the
        (b) Assign this channel to the request
Else
        (c) Overflow to the corresponding microcell if the microcell has the free channel
Else
        (g) Pick any call in M such that the call's corresponding microcell, say $m_j$, has a free channel.
        (h) Transfer the call to $m_j$ to vacate a channel in M,
        (i) Assign the vacated channel to the request
Else
        If initiated call is handoff then
                (c) Queue the call for a predefined time T and till a channel gets free
                (d) Assign the channel to the call
        Else
                (b) Block the call
End
```

5. Simulation and results

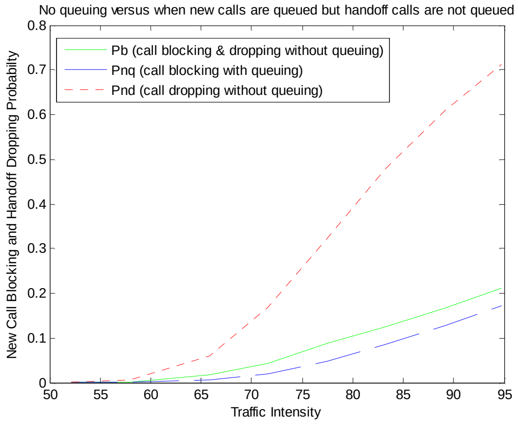

Figure 1: No queuing versus new calls are queued but handoff calls are not queued with varying traffic intensity

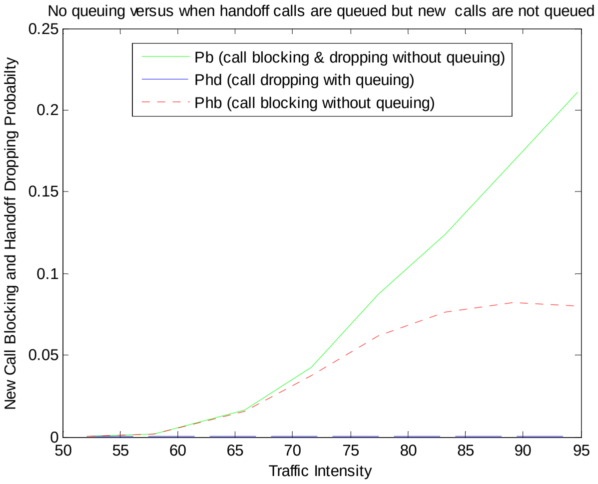

Figure 2: No queuing versus handoff calls are queued but new calls are not queued with varying traffic intensity

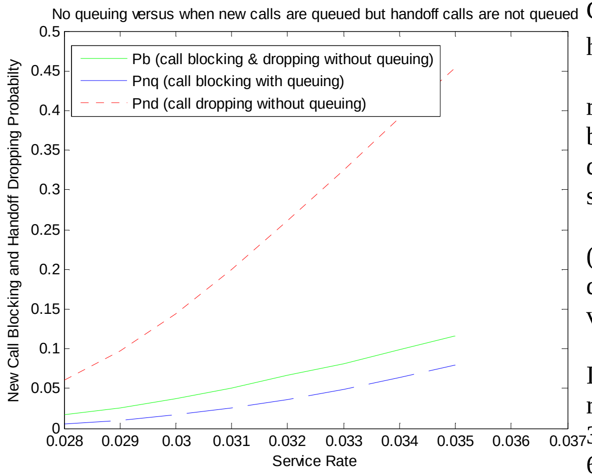

Figure 3: No queuing versus new calls are queued but handoff calls are not queued with varying service rate

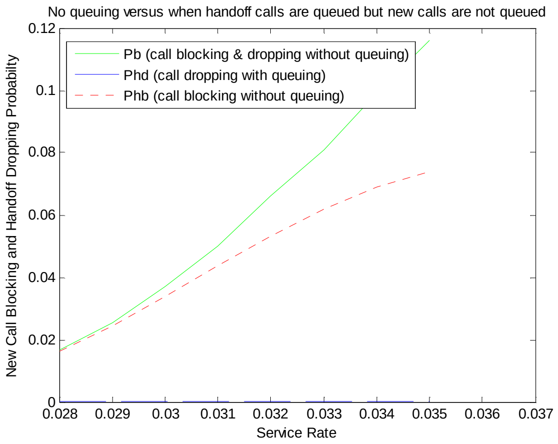

Figure 4: No queuing versus handoff calls are queued but new calls are not queued with varying service rate

6. Sensibility Analysis

The sensibility analysis is of our proposed hybrid channel allocation with queuing of new calls and handoff calls with following data. Each cell has 78 channels (N).

(i) No queuing versus when new calls are queued but handoff calls are not queued with varying traffic intensity.

In figure 1, we use following the data: arrival rate per hour of new calls λ_1 is from 1800 to 3270 (slow moving subscribers) and λ_2 is from 63 to 115 (fast moving subscribers) respectively. Call holding time (μm) is 101 seconds=.028 hour.

The probability of new call blocking (P_{nq}) reduced considerably as compared to call blocking and call dropping (P_b) in without queuing but call dropping (P_{nd}) increases significantly.

(ii) No queuing versus when handoff calls are queued but new calls are not queued with varying traffic intensity

In figure 2, we use following the data: arrival rate per hour of new calls λ_1 is from 1800 to 3270 (slow moving subscribers) and λ_2 is from 63 to 115 (fast moving subscribers) respectively. Call holding time (μm) is 101 seconds=.028 hour. The probability of new call blocking (P_{hb}) as well as (P_{hd}) reduced considerably as compared to call blocking and call dropping (P_b) in without queuing.

(iii) No queuing versus when new calls are queued but handoff calls are not queued with varying service rates

In figure 3, we use following the data: arrival rate per hour of new calls λ_1 is 2270 (slow moving subscribers) and λ_2 is 80 (fast moving subscribers) respectively. Call holding time (μm) range from 101 seconds (.028 hour) to 126 seconds (.035 hour). Queue size for new calls (M1) and Queue size for handoff calls (M2) is 5. The probability of new call blocking (Pnq) is reduced considerably as compared to call blocking and call dropping (P_b) but call dropping (P_{nd}) increases significantly.

(iv) No queuing versus when handoff calls are queued but new calls are not queued with varying service rates

In figure 4, we use following data: arrival rate per hour of new calls λ_1 is 2270 (slow moving subscribers) and λ_2 is 80 (fast moving subscribers) respectively. Call holding time (μm) range from 101 seconds (.028 hour) to 126 seconds (.035 hour). Queue size for new calls (M1) and Queue size for handoff calls (M2) is 5. The probability of new call blocking (P_{hb}) as well as (P_{hd}) reduced considerably as compared to call blocking and call dropping (P_b) without queuing.

7. Conclusions

We have investigated the effect of queuing in hierarchical cellular system

(a) With varying traffic intensity
  I. When queuing is applied only to new calls but not to handoff calls then there is reduction in call blocking but there is significant increase in call dropping which is not suitable for customers as dropping of ongoing call is more annoying then blocking a new call.
  II. When queuing is applied only to handoff calls but not to new calls then there is considerable reduction in call blocking as well as call dropping. This is will result in increased traffic carrying capacity and enhanced quality of service for customers.

(b) With varying service rate
  I. When queuing is applied only to new calls but not to handoff calls then there is reduction in call blocking but there is significant increase in call dropping which is not suitable for customers as dropping of ongoing call is more annoying then blocking a new call.
  II. When queuing is applied only to handoff calls but not to new calls then there is considerable reduction in call blocking as well as call dropping. This is will result in increased traffic carrying capacity and enhanced quality of service for customers.

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