Resource Allocation in GPRS Wireless Networks

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ABSTRACT

In this work, we have proposed two algorithms for the Fixed and the Dynamic Channel Allocation Schemes in GPRS. We started with a simple channel allocation problem in GPRS and showed that it is closely related to the One dimensional Standard Bin Packing Problem. We used two online bin packing algorithms, namely the First Fit (FF) and the Best Fit (BF) Algorithms, for channel allocation and obtained their performance for Single slot operation, Multislot operation and also for a realistic case with Multislot Class 21 MS. We have also analysed the Fixed Channel Allocation, Single slot operation case and analytical results are found to compare favourably with the results from simulations.

I. INTRODUCTION

The evolution of wireless communication has provided the ease and flexibility in the lifestyle of the people which was never before possible. Users have overwhelmingly appreciated the concept and this is justified with the spectacular growth of mobile users in the last two decades. In recent years, due to the increasing demand of information, anywhere and anytime, the use of *wireless data applications* is becoming more popular. Examples are wireless personal computing and Internet access, mobile offices and mobile business. All such applications produce *bursty* traffic.

The data services in present mobile radio systems (e.g. GSM) are based on *circuit-switched* radio transmission. For bursty traffic, this scheme is highly inefficient in terms of resource utilization. For bursty traffic, *packet-switched services* result in much better utilization of traffic-channels. This is because the radio resources will be used on the need basis *(Capacity on Demand)* and will be released immediately after the transmission of the packets. Owing to this, multiple users can share one physical channel at the same time.

General Packet Radio Service (GPRS) is a new bearer service for GSM. It uses packet switching principles to transfer the data packets in an efficient way between the mobile station supporting GPRS and external packet data networks. The detailed overview of the GPRS system architecture and functionality can be found in [1], [2] and [3].

Notice that GPRS is only meant for packet data services. It is not used to carry *voice traffic*. Current GSM techniques (circuit switching) are used for voice calls. In fact in a cell which supports GPRS, both GSM and GPRS systems operate in parallel.

The paper is organized as follows. The Channel Allocation Schemes in GPRS are presented in the section–2. Section–3 deals with the problem formulation of our channel allocation problem and its relation with the standard Bin Packing Problem. Some standard algorithms and results which we have used in the latter part of the paper, are presented in this section. In section–4, performance profiles of the channel allocation algorithms are presented which are obtained by simulations.

II. CHANNEL ALLOCATION SCHEMES IN GPRS

In this section, we shall briefly explain the 52– multiframe structure and Channel Allocation Schemes in GPRS. The reader can get a detailed description of it in [7] and [8].

A. Physical Resources

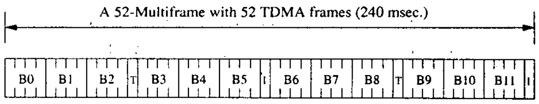
The radio spectrum allocated to the system as radio resource, is partitioned both in frequency and time. Frequency is partitioned into smaller frequency bands called *Radio Frequency Channels (RFCHs)*. These RFCHs are further partitioned in time using TDMA frames. Every TDMA frame is divided in eight timeslots and the duration of a timeslot is 577 μsec. The term *Burst* is used to represent the content of one timeslot. The sequence of four normal bursts carrying one RLC/MAC protocol data unit (PDU) is called a *Radio Block.*

A Physical Channel dedicated to packet data traffic is called Packet Data Physical Channel (PDCH). It represents one timeslot in a TDMA frame. One or more PDCHs can be allocated to the mobile station (MS) at a time on a need basis.

The physical connection used by the two Radio Resource (RR) Layer entitles to support the unidirectional transfer of Logical Link Control Protocol Data Units (LLC PDUs) on PDCHs is called a Temporary Block Flow (TBF). The TBF is temporary and maintained only for the duration of the data transfer.

B. 52–Multiframe Structure

The 52-Multiframe consists of 13 blocks of 4 consecutive TDMA frames. Out of these 52 TDMA frames, 48 TDMA frames (i.e., 12 blocks, B0 to B11) are used for the allocation of Packet Data Channels or Packet Control Channels. Two TDMA frames are idle and the rest two are used for Packet Timing Ad-



T represents the frame carrying PTCCH and I represents Idle frame
Fig. 1. 52–Multiframe Structure

vance Control Channel (PTCCH). The frame structure is shown in figure 1. A block allocated to a given logical channel comprises of one radio block and the type of channel may vary on a block-by-block basis (see [8]).

C. *Channel Allocation Schemes*

There are three channel allocation schemes used in GPRS. These are:

1. Fixed Channel Allocation
2. Dynamic Channel Allocation
3. Extended Dynamic Channel Allocation

We have presented algorithms for Fixed Allocation and Dynamic allocation schemes. We shall now discuss these two schemes one by one. The detailed procedures are given in [7].

Fixed Channel Allocation:
In Fixed Allocation Scheme, the resources allocated to a particular MS are fixed for the allocation period. The network indicates the MS about the starting frame of the TBF, timeslot assignment and the corresponding ALLOCATION_BITMAP in the Packet Uplink Assignment message (see [7]). The MS uses those blocks for radio block transmission which are indicated in the ALLOCATION_BITMAP. A unique Temporary Flow Identity (TFI) is assigned to each ongoing TBF and is thereafter included in each RLC data and control blocks related to that TBF. Because each radio block contains TFI, all received radio blocks are correctly associated with a particular LLC frame and a particular MS.

Dynamic Channel Allocation:
In this case, the Packet Uplink Assignment message includes the list of PDCHs allocated to the MS and the corresponding Uplink State Flag (USF) values per PDCH. The MS monitors the USFs on the allocated PDCHs and transmits radio blocks on those which currently bear the USF value reserved for the usage of the MS. It is evident that in Dynamic Allocation, the possibility of wastage of radio resource is very less as compared to the Fixed Allocation case.

III. THE PROBLEM OF CHANNEL ALLOCATION AND ITS RELATION TO BIN PACKING

The problem of channel allocation in GPRS is quite different from that in contemporary GSM services. In GSM, a single channel is dedicated to a particular mobile user, whereas in GPRS multiple TDM channels (timeslots) can be dynamically allocated to a single mobile station on a block-by-block basis in a 52–multiframe. The Base Station Subsystem (BSS), has to now follow many constraints for proper operation.

It would have been unnecessary and cumbersome as well if we had formulated the problem with all these constraints right from the beginning. So we took a simplified problem of channel allocation. We also made the following assumptions to further simplify the problem.

- We considered only a single cell and no hand-overs are considered.
- We considered only GPRS Traffic in the cell.
- We do not buffer (or queue) Packet Channel Requests. A request that can not be allocated the required amount of resources (minimum QoS requirement, i.e., minimum number of blocks allocated in a multiframe) is immediately blocked.

A. *Our Problem*

For the sake of convenience in problem formulation, we now consider only *single-slot operation*. Multislot case will be an extension of this.

Let us consider the problem of channel allocation in a cell which is supporting GPRS traffic. Assume we have N PDCHs in this cell which are allocated to the different MSs in the cell as per their demand and availability of resources. This allocation is done on the basis of the number of blocks which are given to an MS in a 52–multiframe. Let us assume that the i^{th} Packet Channel Request is allocated r_i blocks per multiframe of resources on one of the N PDCHs. Suppose there are n such users who are in the system and are getting service. Then the *necessary condition* to support all these n users can be expressed as,

$$\sum_{i=1}^{n} r_i \leq 12N.$$

We want to allocate the resources so that the utilization of resources is maximized and more and more users can be accommodated.

B. *Relation to Bin Packing*

We can also look at the problem stated in the previous section from a different point of view. Suppose we have N bins, each of capacity 12. We want to pack some items, say n, into these bins. Items are such that no item can be distributed in two or more bins. Items are of sizes $r_i \leq 12$, $i = 1, 2, \ldots, n$, and these sizes are not apriori known. It is as if we are given items one-by-one. The items which can not be packed are thrown away immediately and are not reconsidered for packing. The *necessary condition* that these n items can be packed in N bins is,

$$\sum_{i=1}^{n} r_i \leq 12N.$$

After taking a close look at both the allocation and bin packing problems, we can see that both the problems are *online* and closely related to each other,

- N channels are equivalent to N bins.
- Resource allocated to user i (r_i) is equivalent to size of item i (r_i).

For the multislot case, a request is allocated more than one PDCH simultaneously on a Radio Frequency Channel (RFCH). At most eight PDCHs can be allocated to an MS. It is as if items of different sizes (≤ 12) arrive in a batch for packing and are allocated different bins for packing.

It is evident from this discussion that our channel allocation problem is equivalent to a *One–Dimensional Bin Packing Problem*. Therefore we can modify and use standard online bin packing algorithms for the channel allocation problem.

C. Standard Bin Packing Problem

In classical *One-dimensional Bin Packing problem*, we are given a sequence $L = \langle a_1, a_2, \ldots, a_n \rangle$ of items, each with size $s(a_i) \in (0, 1]$ and are asked to pack them into a number of unit capacity bins, i.e., partition them into a minimum number of subsets $B_1, B_2, \ldots, B_m$ such that $\sum_{a_i \in B_j} s(a_i) \leq 1, 1 \leq j \leq m$.

D. Standard Bin Packing Algorithms

The Bin Packing Problem is *NP-Hard* (see [4]). Therefore we attempt approximate solutions of the problem. There are various online bin-packing algorithms discussed in [4]. We shall discuss some of them here which we shall use in our channel allocation problem.

1. First Fit (FF): In *First Fit algorithm* we place an item in the first (lowest indexed) bin into which it will fit, i.e., if there is any partially filled bin B_j with $level(B_j) + s(a_i) \leq 1$, we place a_i in the lowest indexed bin having this property. Otherwise we start a new bin with a_i as the first item.

2. Best Fit (BF): Here, we place item a_i in the partially filled bin B_j with the highest level $level(B_j) \leq 1 - s(a_i)$. Ties are broken in favour of the bin with lower index.

Best Fit and First Fit can give strikingly different packings for individual list.

K–Bounded Space Algorithms : An online bin packing algorithm uses K–bounded space if at no time during its operation does the number of open bins exceed K.

Johnson and Csirik showed (see [4]) that K–Bounded Space Best Fit algorithm (BBF_K) performs *better* than its First Fit counterpart.

IV. SIMULATION RESULTS

In this section, we present the simulated performance of the First Fit (FF) and the Best Fit (BF) algorithms for Fixed and Dynamic Channel Allocation schemes.

We shall consider Single slot operation, Multislot operation and a realistic case with Multislot Class 21 MS for Fixed and Dynamic Channel Allocation schemes in our simulations.

In addition to the assumptions given in section–3, we took the following assumptions for the simulation purpose. For every case, the case specific assumptions will be mentioned before presenting the results for that case.

A. Assumptions

- We have not considered any retransmission of RLC blocks.
- We considered only unidirectional transmission of data packets, either in the Uplink direction or in the Downlink direction.
- The Packet Channel Request arrival process is *Poisson*.
- Every Packet Channel Request brings in a Data Packet for transmission, the length of which is *Geometrically distributed* with mean packet length = 75 blocks. This is equivalent to 4 KB of encoded data (a typical e-mail message size).

The simulated performance of the FF and the BF Algorithms is obtained for different numbers of RFCHs for all the three cases. This is done to get a better interpretation about the performance.

We now present the results for different cases one by one.

B. Single slot Operation

In this case every incoming Packet Channel Request is allocated one PDCH, i.e., one timeslot on a given RFCH. Every request brings in a minimum requirement of radio resources and depending on the availability of resources, a TBF is established between the network and the MS. In the Fixed Allocation scheme, the number of blocks allocated to a Packet Channel Request in a multiframe is fixed throughout the packet transfer period and is equal to the minimum QoS requirement of the Packet Channel Request. Whereas in the Dynamic Channel Allocation scheme, in addition to the minimum QoS requirement of Packet Channel Requests, extra blocks on the same PDCH (which are not currently allocated to any other request) are allocated to them *fairly* in a dynamic manner. In our simulations, we have used *Max-Min Fairness* concept to allocate the resources to the TBFs on a PDCH. Therefore in the Dynamic Channel Allocation scheme, the resource utilization is maximized by using unused resources.

We first present the assumption which we have made for the Single slot operation case.

Assumption:

- Minimum number of blocks that are requested by a Packet Channel Request in a multiframe is *Uniformly distributed* (U[1,12]). We assume it as the minimum QoS requirement of that Packet Channel Request.

C. *Results for Single slot Operation*

Discussion:

From the performance curves of Single slot case, we have three key observations:

- The Dynamic Channel Allocation scheme performs better than the Fixed Channel Allocation scheme.
- The BF Algorithm performs better than the FF Algorithm when Fixed Allocation scheme is used. This effect dominates when the number of Radio Channels is large.
- In case of Dynamic Channel Allocation, both the FF and the BF Algorithms perform almost equally well.

The better performance of the Dynamic Channel Allocation scheme for Single slot operation as compared to the Fixed Channel Allocation scheme is based on the better utilization of resources on every PDCH. In case of Dynamic Channel Allocation, whenever some resources are free on a PDCH, these are distributed *fairly* to all the TBFs on that PDCH. When a new Packet Channel Request comes in and there is a lack of resources, these extra resources are released to provide space for the new request.

Observation 2 can be explained on the basis of the result given in the previous section, where we stated that K-Bounded Space BF Algorithm performs *better* than its FF counterpart. The K-Bounded Space constraint in our case is the limited number (K) of channels. As the number of channels increases, the new Packet Channel Request has better options for allocation in the case of BF Algorithm and hence with the increase in the number of channels, the separation between the curves representing the FF and the BF increases.

To explain observation 3, let us reconsider the Dynamic Channel Allocation scheme. In the beginning, when the number of ongoing TBFs in the system is small and some PDCHs are free, if a new Packet Channel Request comes, it will be allocated a new PDCH without following the FF or the BF rule. Thus the Dynamic Allocation scheme works as a *greedy* scheme. Whenever such a situation occurs, the FF and the BF rules are violated for better utilization of resources. This leads to nearly same performance of both the algorithms in the case of Dynamic Channel Allocation.

D. *Multislot Operation*

In Multislot operation, more than one PDCH (upto 8) on the same RFCH can be allocated to a single MS. Now a Packet Channel Request brings in a request with the minimum number of PDCHs required to establish the TBF and also the number of blocks allocated in each of the multiframes carried on these PDCHs, depending on the minimum QoS requirement of the Packet Channel Request. For example, in the Fixed Channel Allocation scheme, we select the RFCH for the allocation depending on the FF or the BF Algorithm and allocate the minimum requested resources. In case of the Dynamic Channel Allocation scheme, the FF or the BF Algorithm is overruled when

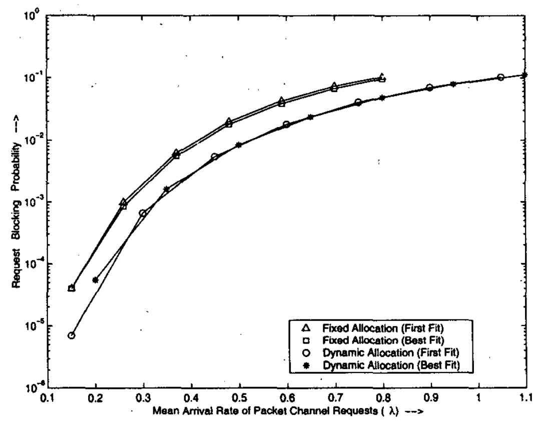


Fig. 2. Single slot operation with 1 Radio Frequency Channel (8 PDCHs) where one PDCH is dedicated to carry Control Information

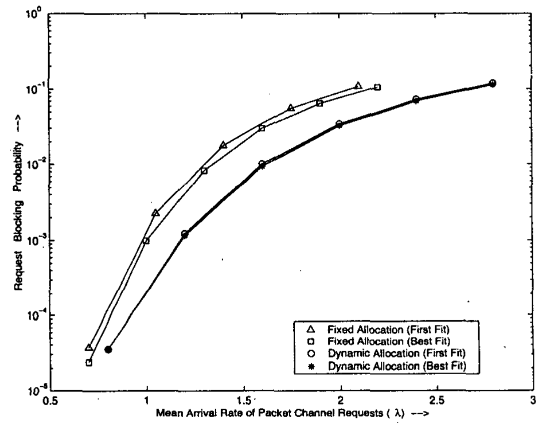


Fig. 3. Single slot operation with 2 Radio Frequency Channels (16 PDCHs) where one PDCH is dedicated to carry Control Information

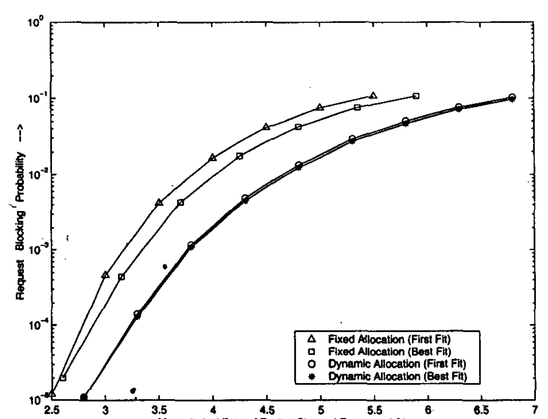


Fig. 4. Single slot operation with 5 Radio Frequency Channels (40 PDCHs) where five PDCHs are dedicated to carry Control Information

an RFCH with more resources as compared to the requested resources, is found unused. All the extra resources on an RFCH are distributed fairly to the TBFs on that RFCH. Therefore the Dynamic Channel Allocation scheme is *more greedy* now in contrast with the Dynamic Allocation scheme for Single slot operation.

The assumptions for the Multislot case are as follows:

Assumptions:

- Minimum number of timeslots (PDCHs) requested by a Packet Channel Request in a TDMA frame (i.e., on an RFCH) is *Uniformly distributed* (U[1,8]).
- Every PDCH, which is allocated to the Packet Channel Request, carries 12 blocks in a multiframe. The minimum number of blocks that are requested by the Packet Channel Request in each of these multiframe is *Uniformly distributed* (U[1,12]).

E. Results for Multislot Operation

Discussion:

By observing the performance curves of Multislot case, we find the following major differences in the performances of the Single slot and the Multislot operations:

- The Dynamic Channel Allocation scheme performs better than the Fixed Channel Allocation scheme when the arrival rate of the Packet Channel Requests is high.
- The Fixed Channel Allocation scheme performs better than the Dynamic Channel Allocation scheme for low arrival rate of the Packet Channel Requests.

This behaviour of the two channel allocation schemes can be explained using a simple example. Let us assume we have two RFCHs (i.e., 16 PDCHs) in our system and assume the system is empty (i.e., no TBF is going on). Assume two Packet Channel Requests, each with a request of minimum 4 PDCHs, enter the system. In case of Dynamic Allocation, both of these requests will be allocated different RFCHs. Now if a new request with five or more PDCHs arrive, it will be blocked. It would not be the case if the Fixed Channel Allocation scheme is used. Due to the *greediness* of the Dynamic Channel Allocation scheme, it performs poorly at low arrival rates. When the arrival rate is high, the system is almost full and a new request is allocated the resources mostly following the First Fit and the Best Fit algorithms. Now the effect of better utilization of resources and faster service rate dominates and therefore the Dynamic Channel Allocation scheme performs better than the Fixed Channel Allocation scheme.

F. A Realistic Case with Multislot Class 21 MSs

In this section, we are going to present the performance of the FF and the BF Algorithms for a real situation. One such example for the Fixed Allocation case is illustrated in [7]. We consider a cell in which all the mobiles that support GPRS be-

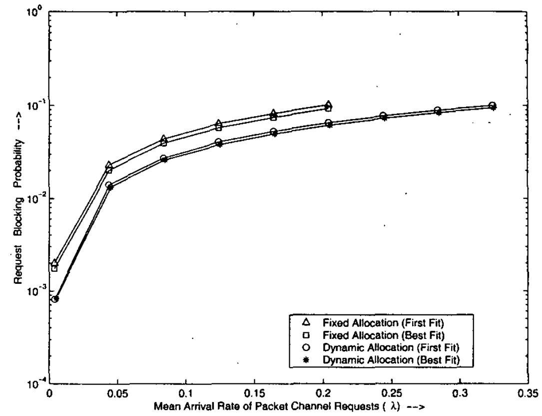


Fig. 5. Multislot operation with 1 Radio Frequency Channel (8 PDCHs) and no PDCH is dedicated to carry Control Information

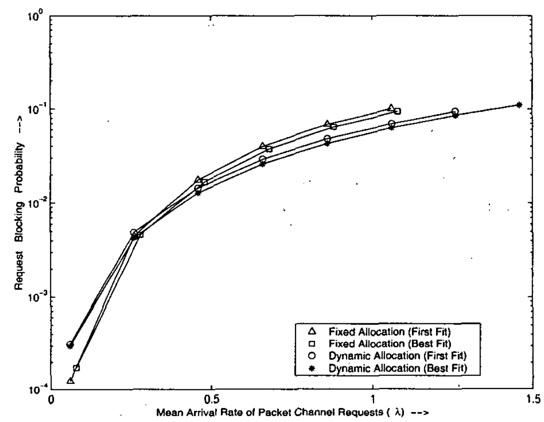


Fig. 6. Multislot operation with 2 Radio Frequency Channels (16 PDCHs) where one PDCH is dedicated to carry Control Information

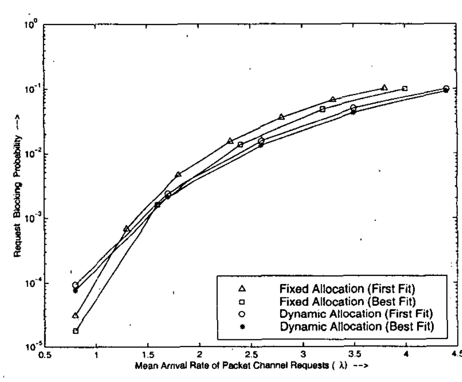


Fig. 7. Multislot operation with 5 Radio Frequency Channels (40 PDCHs) where five PDCHs are dedicated to carry Control Information

long to Multislot Class 21. We consider only downlink traffic (network originated) in this example. We obtain the performance curves after adding some practical constraints. These are as follows:

- The PBCCH is allocated on one PDCH (Timeslot 0) on a given RFCH and it has allocated four blocks in a multiframe. This is the maximum number of blocks that PBCCH can be allocated.
- The allocation of PCCCH (PPCH and PAGCH for the downlink case, see [7]) is dynamic and is done on the same RFCH on which PBCCH is allocated. For the network originated packet transfer, the MS is first paged on PPCH. For every new request arrival, we are allocating one radio block on timeslot 1 (PPCH allocation). After receiving the paging message, the MS switches to PRACH to send Packet Channel Request and comes back on PAGCH to receive Packet Downlink Assignment message or Packet Access Reject message. To provide sufficient switching time to MS, we allocate PAGCH on timeslot 7 (again one radio block in a multiframe).
- We are assuming that the network orders the MS for neighbouring cell power measurements and allocates the required resources. The maximum repetition rate for the measurements (see [7]) is after the reception of every radio block MS takes the measurements. The slowest rate is after the reception of every 32 blocks, MS has to make measurements. In our case the MS makes measurements after the reception of every 16 blocks and a gap of two timeslots (for two block periods) is provided by the network to the MS.

G. *Performance Curves for the Example*

For the above mentioned example, the performance plots are given in figures 8, 9 and 10. We can easily observe that the performance is nearly identical to the Multislot case. From this observation, it is clear that the performance evaluation of these algorithms can be done without imposing the practical constraints like neighbouring cell power measurements, and the obtained performance is nearly identical in both the cases.

V. COMPARISION WITH ANALYTICAL RESULTS

The system of Radio Channels, in which *Packet Channel Requests* are arriving and are being served, can be modeled as a *Multidimensional Markov Chain*. Only the service procedure of ongoing TBFs will depend on the type of algorithm used by the Base Station Subsystem (BSS) for resource allocation (e.g. Fixed Allocation (FF), Fixed Allocation (BF), Dynamic Allocation (FF) or Dynamic Allocation (BF)). Though the case of Dynamic Allocation will be quite cumbersome to model, the Fixed Allocation case *without multislot class* can be easily modeled.

We modeled and analysed the Fixed Channel Allocation scheme without considering the *multislot operation* for Single and Two Channel cases. The detailed analysis can be obtained in [5].

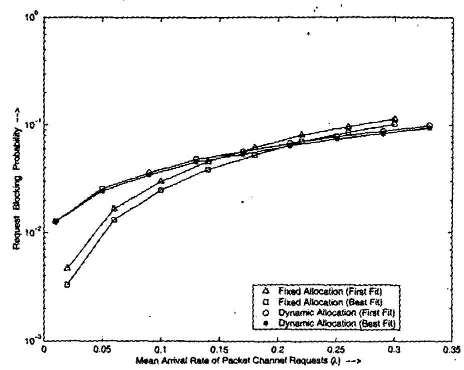


Fig. 8. Performance with one Radio Frequency Channel (8 PDCHs) with Multislot Class 21 MSs

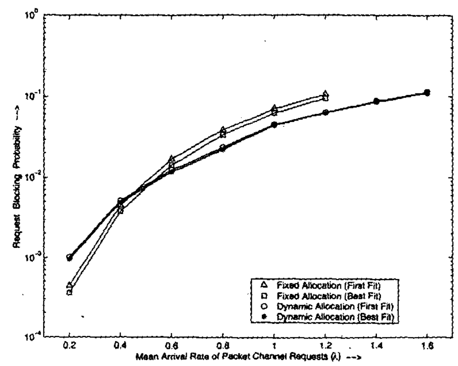


Fig. 9. Performance with two Radio Frequency Channels (16 PDCHs) with Multislot Class 21 MSs

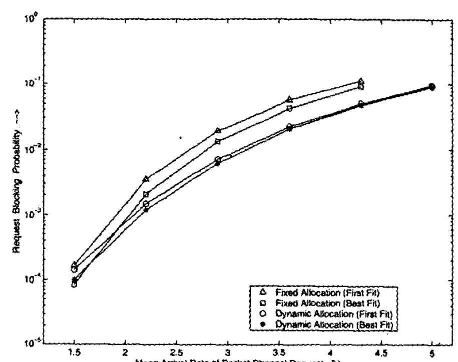


Fig. 10. Performance with five Radio Frequency Channels (40 PDCHs) with Multislot Class 21 MSs

For both the cases, we see that simulation results closely follow the analytical ones. This verifies the correctness of our simulations for the Fixed Channel Allocation case. Notice that for the single channel case *First Fit* and *Best Fit* algorithms perform identically.

VI. CONCLUSIONS

In this work, we have presented algorithms for the Fixed and Dynamic Channel Allocation Schemes used in GPRS. We started with a basic problem of channel allocation in GPRS and showed the relation between our problem and the standard Bin Packing problem. We used two online Bin Packing algorithms, First Fit and Best Fit, for the Fixed and the Dynamic Channel Allocation schemes and obtained the performance curves for various cases. We also compared the performance obtained using simulations with analytically obtained performance for the Fixed Allocation, Single slot operation case.

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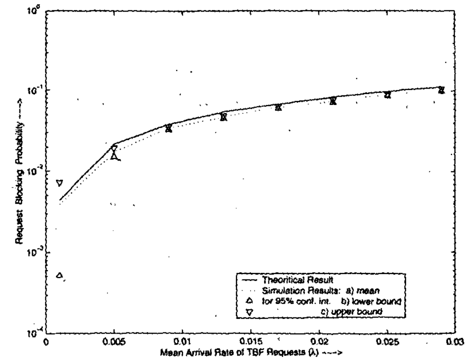

Fig. 11. Comparison of results for the Single Channel case when First Fit algorithm is used. In this case First Fit and Best Fit perform the same.

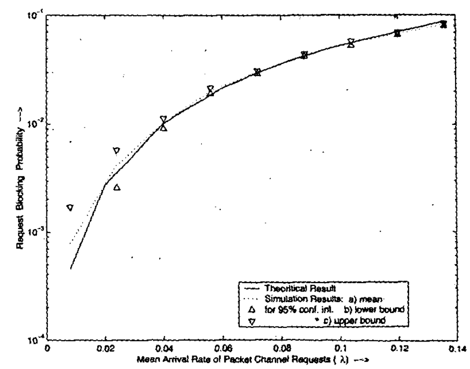

Fig. 12. Comparison of results for the Two Channel case when First Fit algorithm is used.

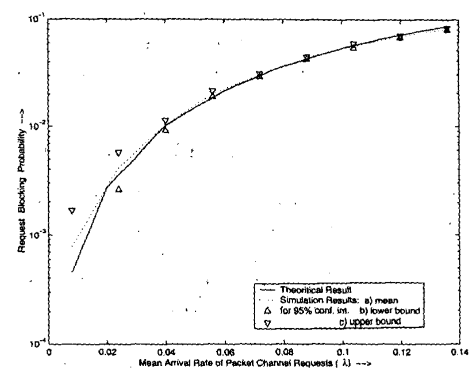

Fig. 13. Comparison of results for the Two channel case when Best Fit algorithm is used.