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Enhancement of Cellular Service via the Use of Satellite
Capacity

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ENHANCEMENT OF CELLULAR SERVICE VIA THE USE OF SATELLITE CAPACITY

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Abstract

In mobile communications, new services are being launched that provide extended geographical coverage of cellular service via the satellite. The additional satellite capacity can be shared among all the cells, thereby augmenting the dedicated cellular capacity available within the cells. This additional shared capacity has the inherent potential for increasing efficiency, as the extra channels can be assigned wherever they are needed rather than pre-allocating them. We considered the performance advantage the satellite offers in off-loading congestion within the cellular covered area. We propose a model for the hybrid network based on the recently proposed Multiple Service Multiple Resource concept. This model has been used in performing a detailed analysis that demonstrates the marked improvement in performance obtained by augmenting cellular capacity via the satellite and quantifies the gains achieved therein.

INTRODUCTION

With the rapid expansion of mobile communication services, the demand for more resources has grown correspondingly. New systems that are being launched augment the available cellular capacity via a satellite to meet this demand. The new service being launched by the American Mobile Satellite Corporation is a typical example of the hybrid networks that are thus emerging.

This growth has led to the chief resource, namely radio bandwidth, becoming increasingly scarce. Significant amounts of work are directed towards the best utilization of this resource for providing acceptable levels of performance. The integration of satellite and terrestrial resources in the newly emerging hybrid networks has given rise to a number of complex issues relating to utilization and resource allocation. The effect of shared capacity available via the satellite on the performance of the hybrid system is one such issue.

Cellular networks operate over a cell plan where the radio frequencies are allocated to individual cells in interference free patterns. The satellite is assumed to comprise of a number of spot beams that provide connectivity across all the cells in the cell plan. These beams may be fixed or switchable. The application of switchable spot beams has been noted (Ramseier et al. 1993).

An innovative concept called Multiple Service Multiple Resource (MSMR) systems has been recently proposed (Jordan et al. 1991). Services are being integrated onto a single network, comprised of different resources, rather than being offered on separate uncoordinated networks. MSMR models accurately model such systems. Since hybrid networks bring together terrestrial cellular resources as well as satellite resources to provide related services, they can be modelled as MSMR systems.

In the following, we first define the problem. We then propose the model for the hybrid network. This model is used to analyze an instance of the hybrid network and numerical results are presented for several key configurations of this network. The main idea of the analysis is to demonstrate the improvement in performance achieved by the use of shared capacity through the satellite rather than dedicated bandwidth allocated terrestrially to the cells.

Definition of the Problem

We have a cellular network with resources allocated and fixed in each cell. Resources refer to the number of channels which may be frequencies (as in FDMA systems) or time slots (as in TDMA systems). Shared capacity is made available via the satellite. The aim is to quantify the overall performance advantage gained by augmenting the cellular capacity with the incremental allocation of capacity to the satellite. This is equivalent to quantifying the performance when different fractions of the total system capacity are allocated as cellular channels and satellite channels.

The total system capacity is the sum of all satellite channels and the channels in every cell in the terrestrial cellular network. It is obvious that given the total capacity, we can allocate different number of channels to the satellite network and to the cellular network. A comparison of the performance for these different cases adequately quantifies the desired results.

THE MODEL

Assume a cell plan comprising of N cells. Calls arise in each of these N cells and their destination may be any one of the N cells. A call from cell 'i' to cell 'j' is defined as a call of service type (i,j) . It is thus obvious that we can have N^2 service types. These calls utilize two kinds of resources :

(1) satellite resources (2) cellular resources.

Assume that the total system capacity is M .

Satellite Resources

We assume there exists one uplink and one down link satellite beam focused over each cell. Thus we can simultaneously provide all the different source destination services.. The number of uplink and downlink channels are assumed to be equal on each beam. Let S represent the number of channels on each of the uplink and downlink beams. A call of any service type, using the satellite, utilizes one channel on an uplink beam and one channel on the downlink beam.

Cellular Resources

In each cell there are C channels available for allocation. For any given cell, these C channels are available to calls of $2N-1$ service types. A call from a user in cell i to another user in cell i uses just one channel in the cell. A call from a user in cell i to a user in cell j requires one channel in cell i and one channel in cell j .

We assume that service requests arrive as independent Poisson streams. Each call, once accepted, has a duration that is exponentially distributed and independent of other service times. The load of the service is defined as the ratio of the arrival rate to service rate. The system is modeled as a Markov chain. The state of the system is defined as the vector representing the number of calls of each service type that are currently in progress over the system. The state space of the system is constructed by individually considering the constraints upon the cellular component and the satellite component of the system. This is because the total number of calls of a given service type in the hybrid system is the sum of calls of that service type using cellular resources and calls of the same service type using satellite resources. Thus a given state is a component of the state space if it satisfies both cellular and satellite constraints.

The constraints in both systems arise from the simple principle: Sum of calls of all service types using a particular resource should be less than or equal to the amount of that resource available. We have the following definitions:

X_i = Number of calls of service type i in the hybrid system

C_i = Number of calls of service type i using cellular resources

S_i =Number of calls of service type i using satellite resources

$$X_i = C_i + S_i \quad (1)$$

Therefore the state vector $\bar{x} = [x_1 \dots x_i \dots x_p]$ where $p = N^2$, decomposes to two vectors, \bar{c} and \bar{s} , each comprising N^2 elements. The constraints on the cellular resource based calls are:

$$\sum_{j=1}^N C_{j+(i-1)N} + \sum_{j=1, j \neq i}^N C_{i+(j-1)N} \leq C \quad (2)$$

and the constraints on the calls using satellite resources are:

$$\max_{i=1 \dots N} \{ \max \{ \sum_{j=1}^N S_{j+(i-1)N}, \sum_{j=1, j \neq i}^N S_{i+(j-1)N} \} \} \leq S \quad (3)$$

where $i=1,2,\dots,N^2$. In equations 2 and 3 the c_i and the s_j refer to those elements of the vectors \bar{c} and \bar{s} which utilize the same set of channels i.e cellular channels within the same cell and channels on the same satellite beam respectively. A state vector x is a vector in the state space if there exists vectors c and s which satisfy the equations from 1 to 3. The steady state probabilities of this Markov chain can be obtained by a simple product form solution mentioned in literature (Aein,1978). A call request is considered blocked if it cannot be supported given the present utilization of the system resources. The sum of the steady state probabilities of all those states which are the blocking states for a given service type gives the blocking probability for that service type. This blocking probability is a function of the load on the system.

RESULTS

We use the model defined above in our analysis of a two cell hybrid system. We assume each cell has C cellular channels. The hybrid system also comprises of 1 uplink and 1 downlink beam on each of the 2 cells, Each beam has S channels. The total capacity of the system would thus be $M = 2C + 2S$ channels. The number of service types available is $N^2=4$. ρ_i represents the load of service type i . We compute the blocking probability for each service type according to the procedure outlined. The average blocking probabilities are used as a measure of performance. The average blocking probability is given by,

$$\text{Average Blocking Probability} = \sum_{i=1}^4 (\rho_i \times \text{Prob. Blocking(Service } i)) / (\rho_1 + \rho_2 + \rho_3 + \rho_4) \quad (4)$$

The following results show the performance of the network, for configurations where the total available capacity is progressively shifted from a totally dedicated allocation within the cells to a totally shared allocation on the satellite. The total capacity M and the allocations C and S determine the number of states in the state space. For example, with $M=16$, $C=0$, $S=8$ results in a state space with 1365 states. Thus, even for low values of M , the problem becomes computationally intense.

Firstly, we obtain results that show the variation of average blocking probability with load for different allocations, given the total system capacity to be some M channels. These probabilities are computed under the assumption that all 4 different service types have the same load. We present a graphical representation of the results for the case where M is specified to be 10 and 22 channels (Figures 1a and 1b). In both these cases, the curves represent the performance of the system as the total available resources are allocated, in different fractions, to the dedicated cellular capacity and the shared satellite capacity.

In both the cases shown, it is seen that the performance of the system improved drastically as more resources were allocated to the satellite system rather than to the cellular system. The average blocking probabilities, as expected,

increased with the load . However , for a given load, the configuration that experienced the highest blocking probabilities had all the resources dedicated to the terrestrial cellular network. The lowest blocking probabilities were obtained for the configuration where all the resources were made available as shared capacity on the satellite.

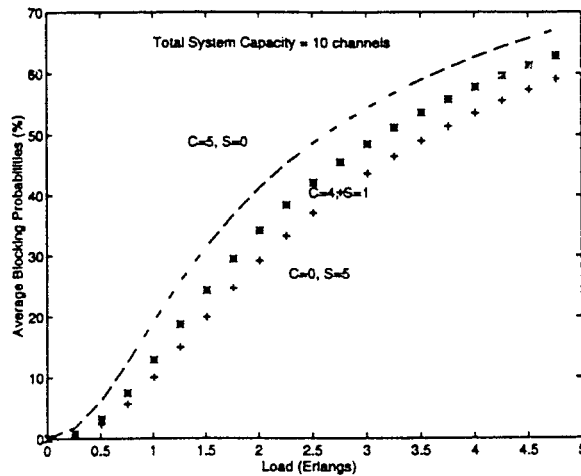


FIGURE 1 a. Average Blocking Probability versus Load (Total Capacity =10 channels).

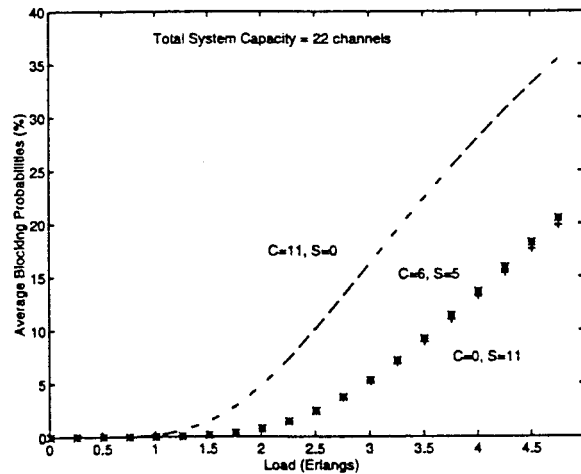


FIGURE 1b. Average Blocking Probability versus Load (Total capacity=22 channels)

Figure 2 shows the magnitude of improvement obtained by allocation of resources as shared capacity . The figure shows three different comparisons between configurations which vary by a unit value in their cellular and satellite capacities. We see that the maximum improvement is observed when then total capacity of 16 channels is allocated as C=8 S=0 and C=7 S=1. This would imply that the most dramatic improvements in performance can be expected when the total available capacity is predominantly dedicated in the cells and we provide incremental shared capacity on the satellite network. The loads are assumed to be equal for all service types. The graphs show the performance enhancement. for a unit transfer of capacity from the terrestrial network capacity in Configuration (2) to the shared satellite capacity in Configuration (1).

Figure 3 shows the performance of the system when the loads of the intercellular traffic and intra cellular traffic are no longer equal, but vary independently. In Figure 3 we analyze the system with capacity M=16 channels. We compare two configurations (1) C=5 S=3 and (2) C=4 S=4. Figure 3 shows the magnitude of improvement in performance obtained in configuration (2), which has a higher shared capacity, over configuration (1) which has a higher dedicated capacity, as a function of the variation in the values of both inter cellular traffic load (ICL)

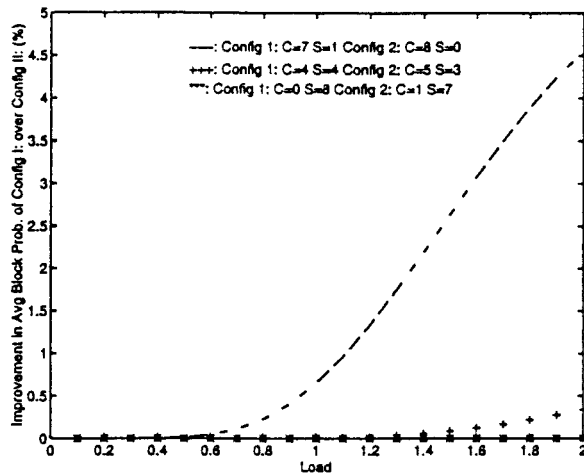


FIGURE 2. Improvement in Average Blocking Probability versus Load.

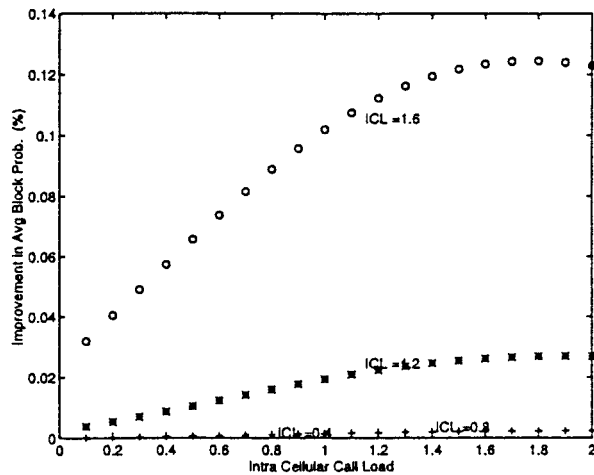


FIGURE 3. Effect of Different Inter Cellular and Intra Cellular Traffic Loads on Performance.

cellular traffic load. It is observed that the presence of shared capacity provides an improvement in performance in the case of inter cellular traffic as well as intra cellular traffic. However, the improvement obtained in the situation where inter cellular traffic dominates over intra cellular traffic, is greater than when the intra cellular traffic is higher. This shows that the presence of shared capacity assists the servicing of intercellular traffic more than it improves intracellular services.

Analysis of various network configurations for different capacities, under different loading conditions, indicated trends identical to those that have been outlined by the few typical cases described above.

Conclusions

Having proposed an appropriate model for the hybrid network, we have demonstrated, within the framework of that model, the clear performance advantages obtained by the provision of shared incremental bandwidth on the satellite

as compared to investemnt of the resource as dedicated bandwith within the cellular network. The performance improvement was quantified over a wide range of network configurations.

Acknowledgments

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