Frequency Reuse Impact on the Optimum Channel Allocation for a Hybrid Mobile System

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ABSTRACT

In this paper we study the effect of the frequency reuse constraints in both layers on the optimum channel allocation for a multi-cell/multi-spot- beam hybrid system. We adopt a specific multi-faceted cost function that incorporates call-dropping due to unsuccessful hand-off attempts, and blocking of new calls. The minimization of the cost function is attempted by choosing the optimal split of the total number of channels between the cellular and the satellite layers. This complex optimization problem is solved by means of standard clock simulation techniques along with the adaptive partitioned random search global optimization technique and the ordinal optimization approach.

I. INTRODUCTION

Future mobile communication systems are expected to use land mobile satellite systems to enhance terrestrial cellular service. Recent studies on integrated satellite-terrestrial networks emphasize using satellites to provide "out-of-area" coverage to mobile users. However, with recent developments in satellite technologies, such as narrow beam antennas and switchable spot-beams for LEO and GEO systems, satellites can be used effectively to off-load localized congestion within the underlying cells.

In pure cellular networks, earlier studies have shown that efficient use of the system bandwidth can be achieved by reuse partitioning [1] and using hierarchical cell layout [2],[3] with larger macrocells overlaying small microcells. In [2], the authors applied the concept of *cluster planning*, via which the proposed sectoring arrangement allows microcells to reuse macrocell frequencies. This in turn achieves higher system capacity. However, users' mobility and hand-offs were not considered in that model. The problem of finding the optimum partitioning of the frequency spectrum between microcells and macrocells was also addressed in [3]. This work differs from our work in two aspects. First, the call assignment policy was assumed to be speed dependent. Second, identical frequency reuse patterns in the microcells and macrocells are assumed. Performance analysis of a hybrid satellite-cellular system with the satellite foot-prints forming the highest layer in the hierarchy was also studied [4]. However, the reuse profile for the satellite system was assumed to be the same as that for the terrestrial system.

This work is along the same line of the work done in [5]. It builds upon our earlier work [6] in which the frequency reuse effect in both layers was not considered in the model, but rather, only the propagation delay effect was considered. More specifically, we introduce a multi-dimensional Markov chain-based model for a hybrid network consisting of multiple cells overlaid by multiple spot-beams. In [6], we focused on showing the trade-off and solving the problem for a simple system of just two cells overlaid by one spot-beam. Here, we are extending the model to a more realistic case of multiple cells and spot-beams. It is worth mentioning here that the solution approach developed in [6] still holds, assisted by the Adaptive Partitioned Random Search (APRS) global optimization technique[7]. Our prime concern is to show how the optimum channel partitioning between the cellular and the satellite layers is affected by the frequency reuse constraints.

The paper is thus organized as follows: In section II, system assumptions and the mathematical model are given. This is followed by the problem formulation in section III. In section IV, the optimization approach is illustrated. Simulation results are given and discussed in section V. In section VI, the study is extended to large hybrid systems. Finally, the conclusions are drawn in section VII.

II. SYSTEM DESCRIPTION

A. Assumptions and Definitions

In order to investigate the frequency reuse impact on the optimal channel partitioning policy, we first make the following assumptions and introduce appropriate notation. The network under consideration consists of 8 cells, namely C_1, C_2,..., and C_8. In addition, there is a satellite emitting 4 spot-beams S_1, S_2, S_3, and S_4 covering the same area, and supported by on-board switching as shown in Figure 1. New calls arrive at cell C_i according to a Poisson arrival process with rate λ calls/min. The duration of each call is assumed to be exponentially distributed with mean $1/\mu$ min.

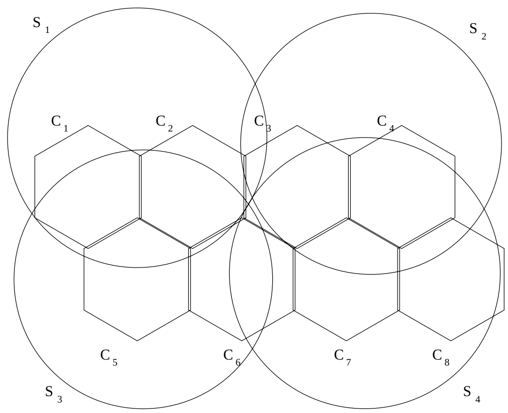

Figure 1. A Hybrid Mobile System of 8 Cells overlaid by 4 Spot-beams

We define K_s as the satellite reuse factor, that is the number of spot-beams per cluster, where all the spot-beams in a cluster use distinct frequency sets. Likewise, define K_c as the cellular reuse factor. Define K as the *relative reuse factor*, that is the ratio of the satellite reuse factor to the cellular reuse factor. The total number of *predesign* resources available to the system is M, where,

$$\mathrm{M} = \Sigma_{i=1}^{K_c}\mathrm{M}_i + \Sigma_{j=1}^{K_s}\mathrm{M}_{s_j}$$

and,
M_i = number of channels dedicated to cell C_i.
M_{s_j} = number of channels dedicated to spot-beam S_j.

Define P_{ij} as the probability of assigning a call with one of the parties in cell C_i and the other in cell C_j to the nearest cells. Also, define (1-P_{ij}) as the probability of assigning a call with one of the parties in cell C_i and the other in cell C_j to the overlaying spot-beam(s), where i,j = 1,2,....,8, i $\leq$ j. Using this assignment rule, we restrict call routes to pure terrestrial and pure satellite routes, i.e. no hybrid routes. Nevertheless, it is straightforward to extend this assignment rule in order to take hybrid routes into consideration. It contributes to more call types and hence increases the dimensionality of the problem. We assume that the base stations, namely BS_i, i=1,...,8, communicate via a terrestrial wireline infrastructure. According to this assumption, each mobile-to-mobile call needs 2 duplex channels. A mobile user can access the satellite directly, not through its BS, using a *dual mode* satellite/cellular mobile terminal. All call types have the same priority and all calls considered in this model are mobile-to-mobile calls. BSs and spot-beams are assumed to be stationary. We define f as the fraction of calls that originate in a cell and are destined to any other cell. The interhand-off time of a mobile from cell C_i to a neighboring cell C_j is assumed to be exponentially distributed with mean $1/\lambda_h$ min, i,j=1,2,...,8. Accordingly, the interhand-off time of a mobile from spot-beam S_l to spot-beam S_k is also exponentially distributed with mean $1/\lambda_{h_s}$ min, where the handoff-rate is assumed to be *inversely* proportional to the cell/spot-beam radius and l,k=1,2,3,4. It is worth mentioning that the additional resources provided by the overlapping spot-beams in Figure 1 is not considered in this model. Finally, we assume that blocked calls are cleared.

B. System Model

The state of the system can be defined by the vector $(n_{11}, n_{12}, n_{13}, ..., n_{ij}, ..., n_{88}, n_{s_{11}}, n_{s_{12}}, ..., n_{s_{kl}}, ..., n_{s_{44}})$, where i,j = 1,2,3,...,8, i $\leq$ j and l,k = 1,2,3,4, l $\leq$ k. n_{ij} is the number of active calls of type 'ij'; that is, calls served by BS_i and BS_j, where one of the parties is in C_i and the other is in C_j. On the other hand, $n_{s_{kl}}$ is the number of active calls of type 's_{kl}'; that is, calls served by spot-beams S_k and S_l, where one of the parties is within foot-print 'S_k' and the other is within foot-print 'S_l'.

Accordingly, the system is modeled as a Continuous-time Markov Chain of 46 dimensions representing each call type. It is worth mentioning that all call types need 2 wireless channels/call. Therefore, the set of feasible states should satisfy the following state space constraints :

$$2n_{11} + n_{12} + n_{13} + n_{14} + ... + n_{18} \leq M_1$$

$$n_{12} + 2n_{22} + n_{23} + n_{24} + ... + n_{28} \leq M_2$$

$$n_{13} + n_{23} + 2n_{33} + n_{34} + ... + n_{38} \leq M_3$$

$$\vdots$$

$$n_{18} + n_{28} + n_{38} + n_{48} + ... + 2n_{88} \leq M_8$$

$$2n_{s_{11}} + n_{s_{12}} + n_{s_{13}} + n_{s_{14}} \leq M_{s_1}$$

$$\vdots$$

$$n_{s_{14}} + n_{s_{24}} + n_{s_{34}} + 2n_{s_{44}} \leq M_{s_4}$$

III. PROBLEM FORMULATION

The optimum channel allocation policy for a given call assignment rule and relative frequency reuse factor is obtained by solving the following minimization problem:

$$\min_{M_1, M_2, ..., M_8, M_{s_1}, M_{s_2}, ..., M_{s_4}} (P_b + \alpha . P_d) \quad (1)$$

s.t.

$$\mathrm{M} = \Sigma_{i=1}^{K_c}\mathrm{M}_i + \Sigma_{j=1}^{K_s}\mathrm{M}_{s_j}$$

where,

P_b = average new call blocking probability.
P_d = average call dropping probability.
α = weighting factor.

In the above formulation, the choice of the design parameter α is rather unguided, since there is no well-defined procedure for choosing it. The following formulation is equivalent and easier to implement. It consists of minimizing one component of the composite cost function above subject to the other component staying below a pre-determined acceptable threshold, namely,

$$\min_{M_1, M_2, \ldots, M_8, M_{s_1}, M_{s_2}, \ldots, M_{s_4}} P_b \tag{2}$$

s.t.

$$P_d \leq \beta$$
$$\mathrm{M} = \Sigma_{i=1}^{K_c} \mathrm{M}_i + \Sigma_{j=1}^{K_s} \mathrm{M}_{s_j}$$

The quantity β is the alternative (equivalent) parameter in a one-to-one correspondence to the value of α.

IV. OPTIMIZATION APPROACH

Due to the sheer complexity of jointly optimizing the channel allocation and the call assignment policy[6], we chose here to solve for the optimum channel split between the satellite and the cellular layers given a call assignment policy. The formulation of the problem given in section III can be solved via *Discrete Exhaustive Search*. This optimization approach is not only complex, but infeasible as well. This is due to the large dimensionality of the Markov Chain, which in turn leads to an extremely large pool of channel allocation policies.

The numerical solution was infeasible, too, due to the Markov Chain being of 46 dimensions. Consequently, we had to resort to simulation. A simulation process was developed using C++ and run on SUN-ULTRA 1/2 workstations. To increase the efficiency of the simulation, we employed the so-called standard clock (SC) simulation method. Its basic principles are explored in more details in [9]. The essence of SC simulation is that it allows the simultaneous measurement of performance of multiple different control policies with a single simulation run. Moreover, as we are more interested in the relative ranking of the channel allocation policies, rather than in their actual performance values, and to further speed up simulations, Ordinal Optimization was employed. Ordinal Optimization has been applied in the literature using several approaches, namely short simulation runs, crude analytical models, and simplified, but imprecise simulation models [8]. In [6], we concluded that ordinal optimization, based on short simulation runs, is applicable to our problem. Accordingly, it is employed in this paper in conjunction with SC simulation.

As indicated earlier, the search space for this problem is very large. Hence, it is infeasible to search for the optimum in one phase. Therefore, a tree-search type of algorithms is employed. According to [7], the search region of the objective function is to be partitioned into certain number of sub-regions. Then, using the sampled function values from each sub-region, determine how promising each sub-region is. The most promising sub-region is then further partitioned. This global optimization technique is called the *Adaptive Partitioned Random Search* (APRS). The simulation results show that, while the APRS does not necessarily reach a global optimum, it is guaranteed to reach a near-optimal solution quickly. This is achieved at a computational cost much lower than discrete exhaustive search.

V. RESULTS

The hybrid network shown in Figure 1 was analyzed assuming the numerical parameters given in Table 1. It should be pointed out here that the following results were obtained with no constraint enforced on P_d while minimizing P_b, i.e. β was assumed to be 1 in (2).

Consider the problem of finding the optimum static channel split for a given call assignment policy and frequency reuse pattern. The optimum was determined for the frequency reuse factors given in Table 2 and the following call assignment probabilities:

$$P_{ij} = 0.5, \qquad \text{i,j} = 1,2,\ldots,8,\ \text{i} \leq \text{j}$$

For the first frequency reuse pair, i.e. $K_c = 4$, $K_s = 1$, the frequency reuse in the satellite layer was optimistic in the sense that neighboring, or even overlapping footprints, may use the same frequencies. This assumption is supported by the different satellite propagation characteristics which may permit a much denser frequency reuse pattern in the space segment.

Table 1. System Parameters

Total System Bandwidth (M)	40 channels
Call Arrival Rate per Cell (λ)	0.6 calls/min
Call Service Rate (μ)	0.6 calls/min
Call Hand-off Rate (λ_h)	0.5 calls/min
Fraction of calls originated in a cell and destined to any other cell (f)	0.125

Table 2. Frequency Reuse Factors

K_c	K_s	K = $\frac{K_s}{K_c}$
4	1	0.25
4	2	0.5
3	2	0.666
3	4	1.333

The development in antenna technology and careful evaluation of the propagation effects support this idea. On the other hand, the frequency reuse in the cellular layer was, relatively, conservative by assuming that each cell cluster has 4 cells. For this set of frequency reuse factors, the shared satellite resources assisted by the denser frequency reuse pattern in the space segment, give the superiority to the satellite layer. The pool of channel allocation policies is generally huge to search for the optimum in one phase, so the APRS global optimization technique was recommended to speed-up the search process as will be explained later. However, the spatial symmetry of the call arrival rates, service rates, and hand-off rates among the cells and spot-beams can be noticed from Table 1. Therefore, the search space was restricted to those policies having equal shares among cells and equal shares among spot-beams, i.e. $M_{c_i} = M_c$, i=1,2,...,8, $M_{s_j} = M_s$, j=1,2,3,4. The simulation results shown in Table 3 indicate that the optimum policy (shown in bold font) is to assign all the resources to the satellite.

Table 3. Blocking and Dropping Performance of Channel Allocation Policies ($K_c = 4$, $K_s = 1$)

$(M_1, M_2, M_5, M_6, M_{s_1})$	P_b	P_d
(0,0,0,0,40)	**0.000007**	**0.000009**
(1,1,1,1,36)	0.000031	0.000020
(2,2,2,2,32)	0.000046	0.000027
(3,3,3,3,28)	0.000052	0.000036
(4,4,4,4,24)	0.000079	0.000057
(5,5,5,5,20)	0.000090	0.000070
(6,6,6,6,16)	0.000174	0.000080
(7,7,7,7,12)	0.000279	0.000183
(8,8,8,8,8)	0.001485	0.003517
(9,9,9,9,4)	0.019534	0.030689
(10,10,10,10,0)	0.080307	0.125289

Consider next the hybrid system having the second frequency reuse pair in Table 2, i.e. $K_c = 4$, $K_s = 2$. In this case, both layers have good, but not the best achievable frequency reuse patterns. Again, the shared capacity advantage of the space segment still wins and the *"All-Channels-to-Satellite"* allocation policy achieves the minimum blocking probability as shown in Table 4.

Table 4. Blocking and Dropping Performance of Channel Allocation Policies ($K_c = 4$, $K_s = 2$)

$(M_1, M_2, M_5, M_6, M_{s_1}, M_{s_2})$	P_b	P_d
(0,0,0,0,20,20)	**0.000029**	**0.000016**
(1,1,1,1,18,18)	0.000040	0.000028
(2,2,2,2,16,16)	0.000053	0.000044
(3,3,3,3,14,14)	0.000090	0.000053
(4,4,4,4,12,12)	0.000119	0.000061
(5,5,5,5,10,10)	0.000596	0.000708
(6,6,6,6,8,8)	0.002138	0.003385
(7,7,7,7,6,6)	0.007791	0.013216
(8,8,8,8,4,4)	0.020592	0.024475
(9,9,9,9,2,2)	0.052548	0.079817
(10,10,10,10,0,0)	0.081292	0.126263

For the third frequency reuse set, i.e. $K_c = 3, K_s = 2$, we assume an optimistic reuse pattern for the terrestrial layer. On the other hand, a good reuse pattern (but not the best) is assumed for the satellite. We expect that the best frequency reuse in the terrestrial layer might overcome the shared capacity advantage of the satellite, and this what actually happens. The simulation results, see Table 5, show that the optimum allocation policy, in terms of minimizing the blocking probability, is $M_1 = 2$, $M_2 = 2$, $M_3 = 2$, $M_{s_1} = 17$, $M_{s_2} = 17$.

Table 5. Blocking and Dropping Performance of Channel Allocation Policies ($K_c = 3$, $K_s = 2$)

$(M_1, M_2, M_3, M_{s_1}, M_{s_2})$	P_b	P_d
(0,0,0,20,20)	0.000029	0.000016
(1,1,1,18,19)	0.000026	**0.000011**
(2,2,2,17,17)	**0.000023**	0.000020
(3,3,3,15,16)	0.000034	0.000027
(4,4,4,14,14)	0.000068	0.000037
(5,5,5,13,12)	0.000080	0.000051
(6,6,6,11,11)	0.000104	0.000091
(7,7,7,10,9)	0.000537	0.000310
(8,8,8,8,8)	0.001812	0.004610
(9,9,9,6,7)	0.005413	0.008814
(10,10,10,5,5)	0.008635	0.016808
(11,11,11,4,3)	0.017908	0.0042381
(12,12,12,2,2)	0.036162	0.073978
(13,13,13,1,0)	0.051285	0.125041

Table 6. Blocking and Dropping Performance of Channel Allocation Policies ($K_c = 3$, $K_s = 4$)

$(M_1, M_2, M_3, M_{s_1}, M_{s_2}, M_{s_3}, M_{s_4})$	P_b	P_d
(0,0,0,10,10,10,10)	0.017	0.011
(1,1,1,9,9,9,10)	0.009	0.012
(2,2,2,8,9,9,8)	0.008	**0.005**
(3,3,3,7,8,8,8)	0.006	0.0053
(4,4,4,7,7,7,7)	**0.0058**	0.006
(5,5,5,6,7,6,6)	0.009	0.011
(6,6,6,5,6,6,5)	0.011	0.016
(7,7,7,5,4,5,5)	0.015	0.023
(8,8,8,4,4,4,4)	0.019	0.027
(9,9,9,3,3,4,3)	0.031	0.051
(10,10,10,2,3,3,2)	0.038	0.067
(11,11,11,2,1,2,2)	0.044	0.086
(12,12,12,1,1,1,1)	0.055	0.11
(13,13,13,1,0,0,0)	0.063	0.136

Finally, the last set of frequency reuse factors, $K_c = 3, K_s = 4$, indicates that bandwidth partitioning will be the optimum allocation policy since the terrestrial network has the best achievable frequency reuse factor, while the satellite layer has the worst one. The simulation results for this case are given in Table 6. It can be noticed that the optimum channel allocation policy in this case is $M_1 = 4$, $M_2 = 4$, $M_3 = 4$, $M_{s_1} = 7$, $M_{s_2} = 7$, $M_{s_3} = 7$, $M_{s_4} = 7$.

In order to reach the previous results, we made use of the spatial symmetry of the call arrival rates, call service rates, and call hand-off rates in limiting the search space. We restricted the search process to those policies having equal shares among cells and equal shares among spot-beams. For the general case, the search space will be extremely large and it would be impossible to search for the optimum in one phase. Therefore, we recommend employing a tree search type of algorithms, like the APRS global optimization technique. We applied this optimization technique on our system with $K_c = 4, K_s = 2$, and the same numerical parameters given in Table 1. To verify our earlier results, shown in Table 4, we resolved the optimization problem without taking into account the spatial symmetry. Instead, we searched for the optimum in the whole space of 1,221,759 policies. In this case, the space of channel allocation policies was 6-dimensional. The search space was partitioned to 12 regions in each phase and a sample policy was picked randomly from each partition according to a uniform distribution. The partitioning was performed using hyperplanes parallel to the space axes. In each search phase, we marked the partition having the policy that gave the minimum bloking rate as the *"most promising"* partition, and it was partitioned further in the next phase. Tables 7 through 10 show the blocking and dropping performance of the sample policies in the four search phases performed. It should be pointed out that, in each phase, the *"most promising"* partition is shown in bold font.

It can be noticed from Table 10 that the partitioning process is approaching the optimum policy (0,0,0,0,20,20) given in Table 4. Therefore, we conclude that the APRS algorithm reaches a near-optimal solution quite fast as compared to exhaustive search. Hence, it is suitable for solving our complex optimization problem.

Table 7. Phase #1 ($K_c = 4$, $K_s = 2$)

Partition	P_b	P_d
(0-13,0-13,0-13,0-13,0-13,26-40)	0.016	0.035
(0-13,0-13,0-13,0-13,13-26,13-26)	**0.003**	**0.002**
(0-13,0-13,0-13,0-13,26-40,0-13)	0.117	0.095
(0-13,0-13,0-13,13-26,0-13,0-13)	0.036	0.029
(0-13,0-13,0-13,13-26,13-26,0-13)	0.215	0.184
(0-13,0-13,13-26,0-13,0-13,0-13)	0.013	0.012
(0-13,0-13,13-26,13-26,0-13,0-13)	0.054	0.054
(0-13,0-13,26-40,0-13,0-13,0-13)	0.222	0.530
(0-13,13-26,0-13,0-13,0-13,0-13)	0.069	0.122
(13-26,0-13,0-13,0-13,0-13,13-26)	0.012	0.020
(13-26,0-13,13-26,0-13,0-13,26-40)	0.050	0.140
(26-40,0-13,0-13,0-13,0-13,0-13)	0.070	0.174

Table 8. Phase #2 ($K_c = 4$, $K_s = 2$)

Partition	P_b	P_d
(0-6,0-6,0-6,0-6,13-19,13-19)	**0.000023**	**0.000017**
(0-6,0-6,0-6,0-6,19-26,13-19)	0.086920	0.051897
(0-6,6-13,0-6,0-6,19-26,19-26)	0.055596	0.037105
(0-6,0-6,0-6,6-13,13-19,13-19)	0.001575	0.001456
(0-6,0-6,6-13,0-6,13-19,19-26)	0.035220	0.041223
(0-6,0-6,6-13,0-6,19-26,19-26)	0.066947	0.067648
(0-6,6-13,0-6,0-6,13-19,13-19)	0.011133	0.015620
(0-6,6-13,0-6,6-13,13-19,13-19)	0.041521	0.064385
(6-13,0-6,0-6,0-6,13-19,19-26)	0.007141	0.013065
(6-13,0-6,0-6,0-6,13-19,19-26)	0.034991	0.069517
(6-13,0-6,0-6,6-13,19-26,13-19)	0.036735	0.107833
(6-13,0-6,0-6,6-13,13-19,13-19)	0.013944	0.032950

Table 9. Phase #3 ($K_c = 4$, $K_s = 2$)

Partition	P_b	P_d
(0-3,0-3,0-3,0-3,13-16,16-19)	0.000239	0.000111
(0-3,0-3,0-3,0-3,16-19,16-19)	**0.000019**	**0.000021**
(0-3,0-3,0-3,3-6,13-16,16-19)	0.000089	0.000037
(0-3,0-3,3-6,0-3,16-19,13-16)	0.000526	0.000638
(0-3,0-3,3-6,3-6,13-16,3-6)	0.000308	0.000160
(0-3,3-6,0-3,3-6,16-19,13-16)	0.000698	0.000765
(0-3,3-6,3-6,3-6,13-16,13-16)	0.002556	0.003067
(0-3,3-6,3-6,3-6,16-19,3-6)	0.024001	0.048456
(3-6,0-3,3-6,0-3,13-16,16-19)	0.000182	0.000369
(3-6,0-3,3-6,3-6,13-16,3-6)	0.007087	0.011455
(3-6,3-6,0-3,0-3,16-19,13-16)	0.003145	0.007962
(3-6,3-6,3-6,3-6,13-16,13-16)	0.001834	0.002189

Table 10. Phase #4 ($K_c = 4$, $K_s = 2$)

Partition	P_b	P_d
(0-2,0-2,0-2,0-2,18-19,18-19)	**0.000068**	**0.000027**
(0-2,0-2,0-2,2-3,16-18,18-19)	0.000093	0.000053
(0-2,0-2,0-2,2-3,18-19,18-19)	0.000117	0.000083
(0-2,0-2,2-3,0-2,18-19,18-19)	0.000250	0.000176
(0-2,0-2,2-3,2-3,18-19,16-18)	0.000430	0.000389
(2-3,2-3,0-2,2-3,16-18,18-19)	0.000749	0.000531
(0-2,2-3,2-3,2-3,18-19,16-18)	0.000081	0.000058
(0-2,2-3,2-3,2-3,16-18,16-18)	0.000641	0.001064
(2-3,0-2,0-2,2-3,16-18,18-19)	0.000085	0.000047
(2-3,0-2,2-3,2-3,16-18,16-18)	0.000102	0.000079
(2-3,2-3,2-3,0-2,18-19,16-18)	0.000096	0.000080
(2-3,2-3,2-3,2-3,18-19,16-18)	0.000101	0.000064

VI. LARGE HYBRID SYSTEMS

In this section, our objective is to emphasize the significance of the relative frequency reuse effect on the optimal channel allocation policy for hybrid networks reflecting practical environment. Therefore, we consider a network of 4 spot-beams overlaying 100 terrestrial cells and assume the numerical parameters given in Table 11. Our major concern is to demonstrate that partitioning the channels between the satellite and the cellular layers outperforms, under certain frequency reuse conditions, the *"All-Channels-to-Satellite"* allocation policy. This is due to the denser cellular frequency reuse factor, as compared to the satellite reuse factor, which in turn overcomes the shared capacity advantage of the space segment. For this large system, discrete event simulation is the only feasible performance evaluation approach. Therefore, simulation studies were conducted on the Object Oriented Hybrid Network Simulation (OOHNS)[11] testbed developed at the University of Maryland.

Table 11. Large Hybrid Network Parameters

Number of Cells	100
Number of Spot-beams	4
Total System Bandwidth (M)	100 channels
Call Arrival Rate	0.333 calls/min
Call Service Rate	0.333 calls/min
Cellular Frequency Reuse Factor (K_c)	3
Satellite Frequency Reuse Factor (K_s)	2

We compared the performance of two policies, namely policy π which allocates all the channels to the satellite and policy $\tilde{\pi}$ which partitions the total number of channels equally between the satellite and the cellular layers. For the numerical parameters given in Table 11, the blocking and dropping probabilities for policy π turned out to be 0.052 and 0.06 respectively. On the other hand, the blocking and dropping probabilities for policy $\tilde{\pi}$ are 0.009 and 0.006. From these results, we emphasize the major role the relative frequency reuse factor plays in the design of real hybrid systems.

VII. CONCLUSIONS

In this paper we studied the effect of the relative frequency reuse factor on the optimal static channel split for a multi-cell/multi-spot-beam hybrid network. The objective was to show how the optimal channel allocation policy is affected by varying the frequency reuse factors in both layers. This was achieved via minimizing a multi-faceted cost function composed of the call blocking and dropping probabilities for a given set of frequency reuse factors in both layers. We have shown, via simulations, that the optimal channel allocation policy is the *"All-Channels-to-Satellite"* policy if the terrestrial frequency reuse pattern is not dense enough to overcome the shared capacity advantage of the space segment. On the other hand, when the terrestrial reuse pattern is denser than the satellite reuse pattern, partitioning the channels between the two layers turns out to be the optimum policy. Therefore, it can be concluded that the relative frequency reuse factor plays a major role in the design of hybrid systems. Finally, we found out that our results carry for large hybrid networks reflecting practical environment.

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