Improvement of the Capacity of the LEO Mobile Satellite Systems Using Channel Reshuffling

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***Abstract*-This paper presents a Reshuffling technique which should ensure a more optimal usage of the available resources in a interference limited Low-Earth-Orbit (LEO) mobile satellite systems (MSS). The scheme is based on optimization of the interference situation in the system. After each blocking (new call or handover) it is attempted to reshuffle the channels in a way that a free carrier which is more favorable in interference terms replaces a carrier whose usage leads to the congestion in that part of the system.**

Firstly, the Reshuffling scheme has been combined with Hybrid Channel Allocation (HCA), where for a certain part of the resources fixed cell allocation is applied while the rest was allocated dynamically (DCA) to every cell. Later on, only the DCA has been used. Both capacity and interference limited systems have been investigated.

Simulation tests were carried out in order to evaluate the performance of these schemes. The results show that, in the interference limited LEO MSSs with non-uniform traffic the system performance parameters as call blocking, handover failure and Grade of Service (GoS) are significantly better using reshuffling. However, it was proven that the reshuffling technique doesn't bring much betterment to the capacity limited systems.

I INTRODUCTION

The first LEO MSSs in commercial use have very small capacity because of limited available spectrum and restricted power and the number of transceivers.

The first systems are defined as interference limited systems and the second are known as capacity limited systems. Today's generation of LEO MSSs are capacity limited mostly because of the problems with power supply on the satellites. Nevertheless, it is expected that the next generation will solve power supply problems which would lead to the extension of the traffic capacity. In that case the capacity limitation problems are on the spectrum side. Because of the scarcity of the spectrum, it is necessary to use bandwidth as efficiently as possible.

In this paper the new resource management strategy, partly known from terrestrial systems, has been proposed to be used in LEO MSSs. The after described Reshuffle scheme leads to the wanted optimization in the usage of the available traffic resources. This leads to the decrease of the new call as well as of the handover blocking probabilities. It is expected that the strategy brings betterment for interference limited systems.

Nearer description of the investigated LEO MSSs could be found in section 2 of this paper. The 3rd section enfolds clarification of the proposed Reshuffle scheme. In the section 4, simulation assumptions and results are presented and discussed. Finally, section 5 concludes the paper.

II SYSTEM DESCRIPTION

Area covered by each satellite, known as satellite footprint, is divided into spot-beams. They correspond to the cells in terrestrial cellular systems. As the LEO MSSs have been investigated, the spot-beams are constantly moving, often causing handovers. In order to reduce the difference of the carrier level between beams a passive power control scheme is used.

Considered LEO MSSs use for radio access the Frequency Division Multiple Access (FDMA) combined with Time Division Multiple Access (TDMA). The whole frequency band is divided into sub-bands and every one of them is assigned to one carrier frequency. Furthermore, each carrier sub-band consists of eight time slots: four for the up-link and four for the down-link connection.

Two channel allocation schemes have been applied and combined with channel reshuffling (Fig. 1):

- Hybrid Channel Allocation (HCA)
- Dynamic Channel Allocation (DCA)

HCA is the combination of Fixed and Dynamic Channel Allocation. In this strategy, the set of user-channels in a cell is divided into two sub-sets. One sub-set of channels is exclusively reserved for local use in spot-beams. The other sub-set of channels is allowed to be used by every cell, as long as the interference margins have not been violated. The partitioning of the set of user-channels into two sub-sets is fixed. The ratio, in which the set of channels is divided, is derived by estimating the expected traffic load to the corresponding cell. In this case, when a channel request arrives, it is better to try to allocate the channels fixed for local use before going in for a borrowable channel since fixed channels are optimally distributed in the system and dynamic channels could be seen as jokers which should be kept for the critical situations.

In DCA scheme the system allocates channels to cells on demand basis. The incoming requests (hand-over or new call)

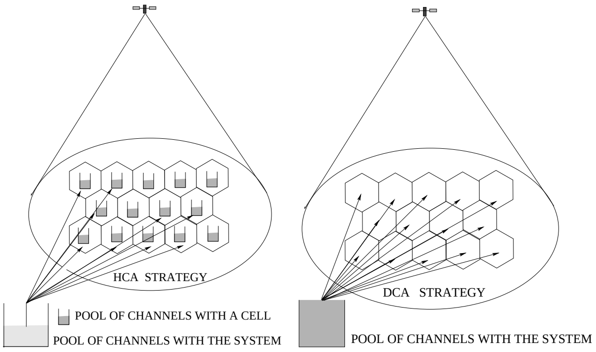

Figure 1: HCA and DCA schemes

are served by the system by a call-by-call optimisation of the system cost function. The cost function is optimised based upon the combination of any of the following inputs: blocking probability limits, channel occupancy distributions, re-use distance, current traffic measurements, radio channel measurements etc.

In this work the DCA has been implemented in the way that transceiver assignment to an user should not be time, frequency, beam or antenna limited.

III RESHUFFLE STRATEGY DESCRIPTION

The Reshuffle strategy is not itself a complete channel allocation scheme but only an algorithm, which when used in addition to existing strategies, enhances the system efficiency by better management of the system bandwidth. The parameters which determine the Reshuffle strategy are used in the following scheme description defined as follows:

- SB1, SB2 : Identities of spot-beams
- A, B : Identities of users
- CH1, CH2 : Identities of user-channels
- N : Total number of user channels in the system
- I(SBx) : Set of beams interfering with beam 'SBx'
- OUC(SBx) : Set of channels used only once in the interference zone of beam 'SBx' along with the information of the cell-identity where the user-channel is in use
- F(SBx) : Set of free channels in beam 'SBx'
- INTERFERENCE ZONE: The area around a cell, where a user-channel being used in the cell, cannot be re-used in order to avoid co-channel interference
- RE-USE DISTANCE : This is the minimum distance between the cells for which the use of the same channel gives rise to an acceptable co-channel interference level.

A The Algorithm

This algorithm (Fig. 2) starts when no channel is available for a new call or for a handover request arrival. Let us consider a channel request arrival 'A' in a particular spot-beam 'SB1', which is about to be blocked due to non-availability of a free user-channel. The cell 'SB1' starts the Reshuffle algorithm. Firstly, the beam 'SB1' refers to the set OUC(SB1). If this is non-empty, it takes the first element of the set OUC(SB1) into consideration and sends a request to the corresponding cell, asking if it can shuffle the user occupying the corresponding user-channel to any other free user-channel. Let the 'once used channel' be 'CH1', the identity of beam be 'SB2' and the identity of the user be 'B' (Fig. 3). Cell 'SB2', in response to the request of cell 'SB1', refers to the set F(y). If F(y) is non-empty, it makes an intra-beam handover i.e. allocates the user 'B' a new user-channel (let it be 'C2') and lets the user-channel 'C1' free making it available for beam 'SB1' to use. This channel 'C1' is now allocated by beam 'SB1' to the user 'A'.

If there is no free channel in beam 'SB2' to shuffle the user, it conveys its inability spot-beam 'SB1'. Upon this the cell 'SB1' follows the same procedure with the other elements of set OUC(SB1). Only if the set OUC(SB1) of the cell 'SB1' is empty or if no channel of set OUC(SB1) could be reassigned, the Reshuffle algorithm fails and the call-attempt will be blocked and terminated.

The Reshuffle strategy could improve the performance of the system significantly by making a way for a new call or

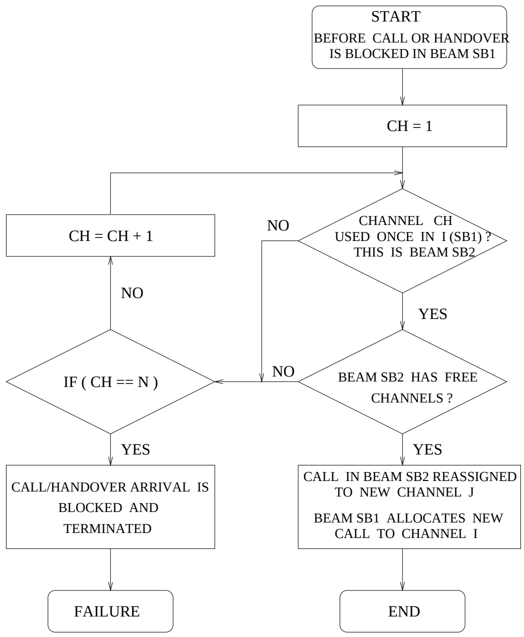

Figure 2: The algorithm of the Reshuffle strategy

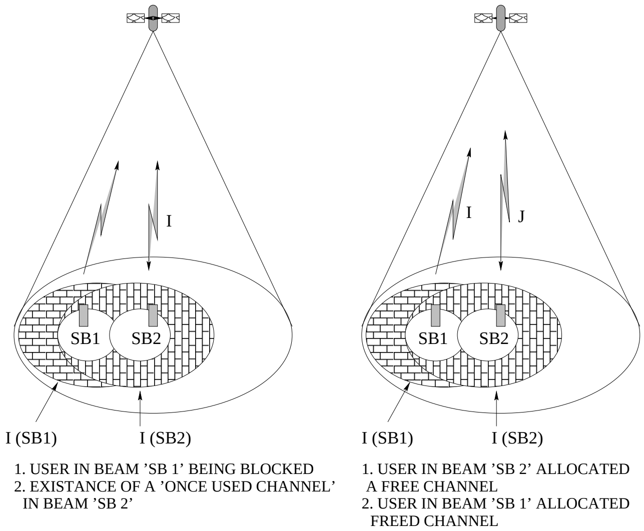

Figure 3. Finding of the 'once used channel'

handover even when it is going to be blocked due to non-availability of resources. The Reshuffle strategy could be used over HCA or DCA schemes (HCAR, DCAR). The difference between these both cases is only in the number of channels that are available for reshuffling.

B An Ideal Channel Allocation Scheme

The described Reshuffle strategy is one step to an ideal scheme which makes the maximum use of the available system resources, without considering the complexity of implementation. When a request for a user channel is received by the system, the system tries to serve the request using the DCA algorithm. If the system fails in this attempt, it rearranges all the active connections in the system by applying the Reshuffle strategy to all the cells in order to create a free channel for the request. The system blocks the call only if it fails to accommodate the request even after the rearrangement.

It can be easily observed that the successful allocation to a new request is possible if there is a cell in the system, in whose interference zone, the whole of the available system bandwidth is not in use i.e., if there are less than 'N' active users in the interference zone of a cell in the system. Due to its high computational complexity this scheme has not been here implemented and further investigated.

IV SIMULATION AND RESULTS

A System Model

The performance of the investigated resource management schemes of the capacity limited LEO MSSs has been evaluated by event driven simulations using the in-house-developed simulation tool. Most of the system parameters have been chosen similarly to IRIDIUM system, implying a constellation of 66 LEO satellites. They are divided into six orbits, in each orbit 11 satellites. Satellite foot-print is divided into 48 spot-beams.

During the simulation process following assumptions related to the traffic model have been made:

- generated users are uniformly distributed over the rectangular simulation area;
- the disposed frequency band is divided in 24 reusable carriers;
- call duration is exponentially distributed (mean 180 s);
- the guaranteed elevation angle is $\varepsilon = 8°$;

The uniform user distribution is not in contradiction with the assumption that offered traffic is non-uniform. Due to the satellite movement and limited simulated area traffic load varies from 0, when the satellite is not serving the simulation area, to the max value when the satellite foot-print maximally covers the simulated area. Thus, this traffic should be characterized as highly non-uniform from the satellite point of view.

In order to validate the performance of the proposed scheme following system parameters have been determined: new call blocking probability, handover blocking probability and GoS.

The *new call blocking probability*, P_{new}, is defined as the ratio of the number of (new call) connect rejects and the number of connect requests.

The *handover blocking probability* P_{ho} is defined as the ratio of the number of rejected handovers and the number of requested handovers.

From users point of view, lost connections (caused by rejecting handover attempt) are worse then new call rejects. Since the GoS criteria takes both new call and handover blocking probabilities into account, weighted with the appropriate factors, this parameter has been used for the evaluation of the system performance:

$$GoS = \frac{rejected\_connections + 10 \cdot rejected\_handovers}{requested\_connections - rejected\_connections} \quad (9)$$

B Results and Discussion

The following assumptions are made for the system:

- The satellites in the network are capable of communicating with each other.
- The neighbouring satellite has the information regarding the beams to be considered for reshuffle based on the identities of the source satellite and its beam.

It is an obvious observation that a cell cannot accommodate a request (new arrival or handover), if the number of active users in its interference zone is equal to the total number of user channels in the system. The interference zone has been determined empirically through the simulations. It has been noticed that one 'cell-ring' around the observed cell determines the interference zone. This represents just an estimation, but it includes the worst case.

The Reshuffle strategy has been investigated as improvement of HCA as well as DCA schemes. New call and handover blocking probabilities as well as GoS have been used as validation parameters.

B.1 Capacity Limited System

In this case analysis and simulations have been performed for different traffic densities, which went from 30 Erlang/Mkm², representing systems with low traffic loads, to 55 E/Mkm², for the very busy systems. Only 96 transceivers with maximal 96 power units were on the disposal per satellite. This transceiver number is not sufficient for all wanted connections and the most of blocking occurrences happen due to the transceiver shortage. Since the constraint is power and not bandwidth, whose utilisation is optimised by Reshuffle strategy, the improvement in the efficiency of the system is not significant.

For HCA there is almost no change (HCA and HCAR are represented with only one curve on Fig. 4 and 5). By DCA techniques, the reshuffling brings very small betterment for the new call blocking probability, while the handover blocking probability has, on the contrary, slightly increased (Fig. 4-5). Using GoS (Fig. 6) as parameter for estimation of the system goodness it could be concluded that, as expected, the reshuffling is not applicable for capacity limited systems.

B.2 Interference Limited System

The number of transceivers in this case was 384 which is enough to avoid any blocking because of the transceiver shortage. The blocking occurs because of an inadequate interference situation. So, the system is endowed with sufficient power, the constraint being the bandwidth. Analysed traffic range was from 60 E/Mkm² to the 100 E/Mkm². The Reshuffle strategy coupled with DCA, improves the performance of the system significantly, noted by the Fig. 7-9. Both new call and handover blocking have been improved and consequently also the GoS. It could be noticed that the improvement of all parameters is up to 100%!

If using Reshuffle with HCA the large betterment of a new call blocking has been reached, which has been improved for up to 500%!!! On the other side the handover blocking probability deteriorates up to 30%.

The reason is the improvement in the strategy for the new calls. They are now in position to occupy more resources then before. When a handover request comes, the situation is worse since lot of channels, which in the previous strategy were left free due to the new call blocking, are now occupied. The betterment brought by reshuffling has been lost due the mentioned implicit prioritisation of new call attempts. As stated in the Fig. 9, the GoS is also worse then in HCA

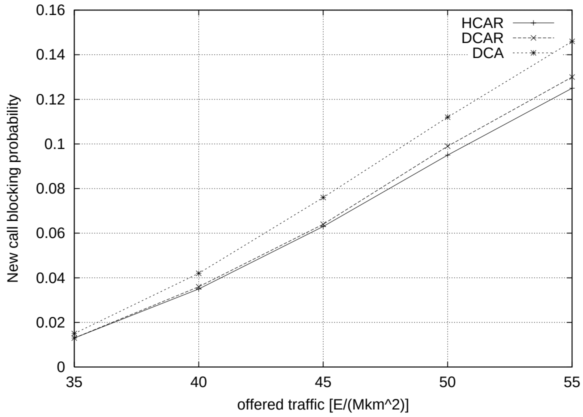

Figure 4: New call blocking in capacity limited systems

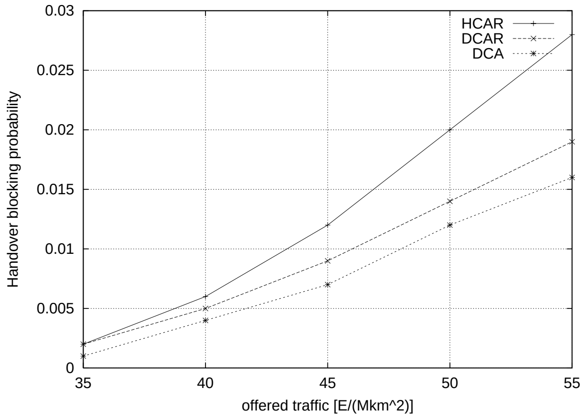

Figure 5: Handover blocking in capacity limited systems

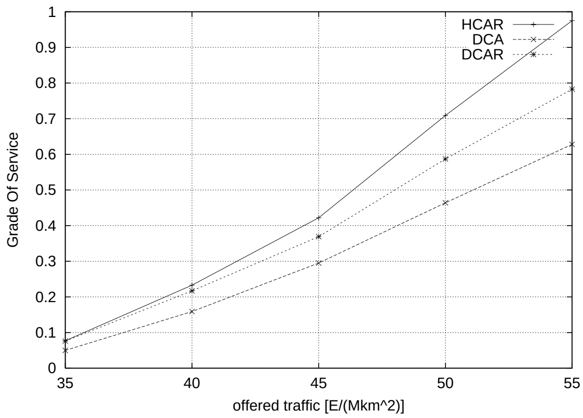

Figure 6: GoS in capacity limited systems

without the Reshuffle scheme. The message is clear: for the HCA systems, where the GoS is used for the validating of the system performances, the Reshuffle strategy could not be recommended. If the aim is only a significant improvement of the new call blocking, regardless if the handover blocking is slightly deteriorated, reshuffling should be used. The last is the case of the modified GoS formula, in the sense that the handover rejects are multiplied with some smaller number then ten.

In this last case as well as in some other situation it could be better to apply the modified Reshuffle scheme. The modification is in its application only for handover requests and not for the new calls. In that way the handovers are prioritised which is commonly requested by communication networks. It could be expected that the new call blocking rises but it is covered by the substantial improvement in the handover blocking rate. The implementation of this scheme is out of the scope of this paper.

It is important to notice that all inter-beam handovers have been taken into account for statistic. This handover art has very high success rate in DCA systems since it is not necessary that user changes any of his connection parameters (carrier frequency, time slot,…). An another beam takes only formal control of the user. As consequence, again some advantage has been brought to DCA strategy compared with HCA, which has less dynamic channels that could profit from mentioned betterment.

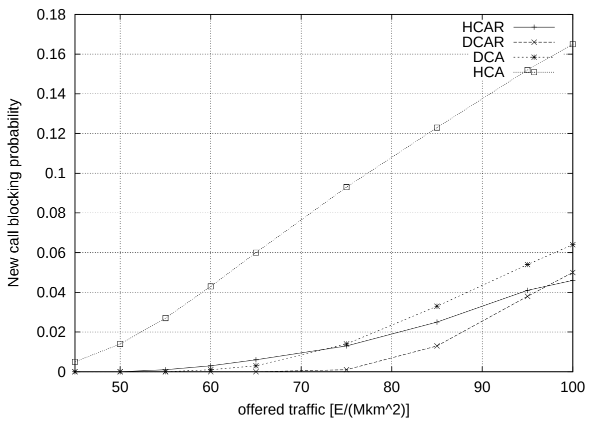

Figure 7: New call blocking in interference limited systems

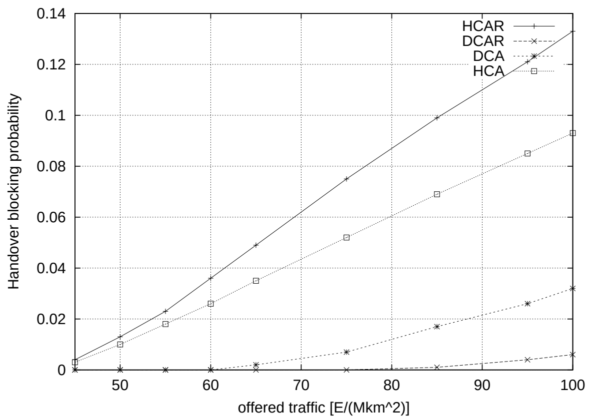

Figure 8: Handover blocking in interference limited systems

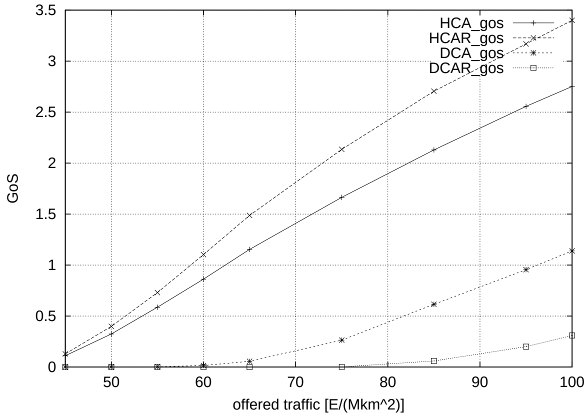

Figure 9: GoS in interference limited systems

V CONCLUSIONS

This paper presented an upgrade of known LEO MSSs resource management schemes with dynamic component. The upgrade is based on the reshuffling of the occupied channels with the idea of getting a better interference situation. This leads to the acceptance of the new call or handover request which would be normally blocked.

Both interference and capacity limited LEO MSSs have been investigated. The Reshuffling scheme has been combined with HCA and DCA strategies. The evaluation criteria used for testing the scheme were the new call and handover blocking probabilities as well as GoS. All evaluations have been made by simulations.

It has been noticed that no significant betterment has been achieved by capacity limited systems for all combinations of strategies. This was expected, considering that, in this kind of MSSs, the blocking occurs due to the limited power and not because of the bandwidth, on which the improvement was focused. On the contrary, by the interference limited systems a significant improvement has been reached, especially by combining the Reshuffle and DCA schemes. However, the combining of Reshuffle and HCA brings only a system dependant betterment.

VI REFERENCES

[1] B. Bjelajac, “Modeling and evaluation of the mobile satellite systems with DCA” (“Modellierung und Leistungsbewertung von mobilen Satellitensystemen mit dynamischer Kanalvergabe”), PhD Thesis, RWTH Aachen, July 98

[2] A. Löhner and A.H. Aghvami, “Performance evaluation of channel allocation algorithms with the new reshuffle technique”, IEEE 0-7803-3002-1/95

[3] V. Obradovic, S. Cigoj, “Improvement of the Performances of the Mobile Satellite Systems by Sophisticated Handover Management”, Proceedings European Wireless (EW‘99), Munich, Germany, October 99