Adaptive Channel Reservation Scheme for Satellite-Based Mobile Communication Systems

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Abstract: - Due to the high mobility of low earth orbit (LEO) satellites, there is a significant number of handover attempts in a LEO satellite mobile communication system, causing a high handover failure rate. This paper proposes an Adaptive Channel Reservation Scheme (ACRS) which gives an overall optimal success rate for both handover and new call initialisation. ACRS is able to adapt to the local traffic condition and makes the best decision on the timing of sending out a channel reservation request. A simulation model has been built and tested on uneven traffic density condition. Promising results have been obtained and they agree with theoretical expectation.

Key-Words: - Satellite mobile communications, Handover, Channel reservation

1. Introduction

Low earth orbit (LEO) satellites-based mobile communication systems play an important part in the International Mobile Telecommunications Systems – 2000 (IMT-2000) denoted by International Telecommunications Union (ITU), as they provide the convenience of connecting the users regardless of their geographical location. In terrestrial cellular communications, a service area is divided into multiple cells for frequency reuse purpose. Cellular concept is extended into mobile satellite communications with the assistance of the multiple-spotbeam antenna mounted on the satellites. A satellite's coverage area, or it's footprint, is divided into cells, each one of which is covered by one particular beam of the satellite's multiple spotbeams.

Due to the difference in the concept of coverage, two kinds of LEO satellite systems are defined:

- earth-fixed cell (EFC) systems, where each antenna beam is steered so as to point toward a given cell on Earth for a period of time
- satellite-fixed cell (SFC) systems, where their beams maintain a constant geometry with respect to the spacecraft, and the cells on the ground move along with the satellite [1].

In terms of implementation, it is easier to apply SFC technique than EFC technique because the assignment of carrier frequencies in SFC spotbeams is fixed and does not change as in EFC systems when the satellite moves along. This makes the design process of SFC systems simpler and faster. Furthermore, in order to implement EFC, it is necessary to predefine the location of cells covering all over the world and their respective communication frequencies. Beam steering mechanism, followed by cell switching is required in EFC [2] and thus increases the complexity of the satellite system, making it more prone to fault. And there is a lot of controlling and coordination are required among the spotbeam antennas (cells) and among satellites. In this sense SFC is simpler to implement. Moreover, most of the existing systems are SFC-based, for example Iridium, Globalstar and ICO. Future system can be expanded on them to avoid the high cost of building up a whole new system.

In SFC systems, when a mobile station (MS) leaves a satellite's footprint and enters into another, we say an intersatellite handover for its ongoing call occurs. On the other hand, the transfer of an ongoing call from one cell to the next one is named as interbeam handover. Since interbeam handover is much more frequent than intersatellite handover, only the former is given consideration in this paper. Due to the high velocity of LEO satellites (approximately 7.195 km/sec for the satellites in Globalstar system), the MS's speed on ground is neglected. Thus, all MS are assumed to be moving at the speed of satellite but in an opposite direction. In the Globalstar system, the length of a cell is 1000 km [1]. Therefore the time taken for a MS to leave a cell after entering it is only 2.825 min. Compared to the average call duration of 3 min, we can safely assume that in average a MS makes at least one handover attempt during its call lifetime. This contributes to a significant number of handover attempts in SFC systems.

A successful call establishment requires a communication channel to be allocated. When the call ends, the occupied channel is released and remains idle until it is taken up by another call. In a new call establishment attempt (NCEA), a MS sends a channel reservation request (CRR) to the cell where it is currently located. If there is a free channel in the cell, the new call will be allocated the channel and admitted to the cell. Oppositely, if all the channels are fully occupied, the attempt to establish a new call will be blocked. On the other hand, when a MS reaches the overlapping area between its current cell and the next destination cell, it initiates a handover attempt (HA) where a CRR is sent to the destination cell in order to secure a channel from it. If HA is granted, the handover process can be completed without a problem. On the contrary, if the HA is rejected, the call has to be terminated when the MS leaves the origin cell and we say the handover encounters a failure. Since the number of available channels in a cell is limited, it is not unusual that HA is blocked. A large number of HA in SFC systems causes proportionally a high handover failure probability (Phf) which is worth given serious consideration. If we can improve the performance of SFC systems by reducing its Phf, we can keep the competence of SFC systems over the EFC systems. In this paper, we propose a scheme which is not only capable in minimising the Phf, but also excel in other aspects.

The rest of this paper is organised in the following manner: Section 2 describes the conventional methods addressing the problem of high Phf, whereas our idea is explained in the third section. Section 4 describes the simulation conditions and simulation results are presented in Section 5. Finally Section 6 concludes this paper.

2. Background

There have been some methods proposed to reduce handover failure. It is widely accepted that HA should be prioritised over NCEA, because dropping an ongoing call is less desirable than blocking the setup of a new call. As a result, HA and NCEA form a trade-off condition where if we give excessive emphasis to either one, the other will be compromised**.** In [3], there are guard channels specially allocated to HA. It is also proposed that the CRR of handover attempt (CRRHA) be queued up when there is no idle channel in the destination cell [3] [4]. This makes the CRRHA not only valid for an instant, but for a period of time where the respective MS remains in the overlapping area. Whenever there is a released channel in the destination cell, it will be exclusively reserved for the queued CRRHA. For NCEA, they are blocked immediately when there are no free channels to accommodate them.

Gerard Maral et al. has proposed a guaranteed handover scheme (GHS) where the CRRHA is made to the cell next to the one that the MS is entering [1]. With CRR being sent out much earlier, there is a greater chance in securing a channel. This is possible in SFC systems because of the following reason. Compared with the high velocity of satellite, random movement of MS is ignored that all of them move in the same direction with satellite speed. That makes the moment of which a MS enter into and leave from a cell is predictable.

Nevertheless, the GHS facilitates the handover at a great expense of NCEA. Yi Xu et al. proposed a more flexible scheme called Elastic Channel Locking Scheme (ECLS) where the instant of which a CRRHA being issued is not fixed only at the point when MS enters a cell, but it is made possible throughout the MS's stay in the cell [5]. We define the time from which a CRRHA is issued, until the MS reaches the joint boundary between the origin cell and destination cell, as channel reservation time (CRT). The larger is the CRT, the earlier is the CRRHA being sent. Yi Xu et al. has produced analytical results of both Phf and the new call blocking probability, Pb for every possible CRT. An optimum CRT has been found, but it is based on the assumption of uniform traffic distribution. We know that user population is unevenly distributed, leading to various traffic densities over the globe. Densely inhabited metropolitan area offers higher traffic load than hinterland. If we implement a scheme with the 'optimum' CRT in the real world, the scheme will fail to cope with the uneven traffic distribution pattern. The results of Phf and Pb will vary with the local traffic density, suggesting that it is not an optimum solution. An optimum scheme must be able to overcome the above condition.

3. Adaptive Channel Reservation Scheme

In this paper we come up with a practical solution called Adaptive Channel Reservation Scheme (ACRS) based on the ECLS theory and we actually implement it in a simulated SFC system. The scheme is supposed to know and then adapt to the current local traffic density.

In ACRS, CRT is a variable proportional to both the traffic density of the destination cell and the number of CRRHA from the current cell. In other words, the heavier is the traffic condition in the destination cell, the longer will be the CRT in our scheme so that there will be a greater chance of securing an available channel. Similarly, if many CRRHA have been made and queued, a MS will send out its one as soon as possible. In short, we have to observe two parameters: the 'supply' - how many idle channels are available in the destination cell, and the 'demand' - how many CRRHA have been issued and queued. The length of the CRRHA queue, QL, carries both the information of 'supply' and 'demand', making it a good measure of the actual traffic condition. The maximum possible QL is the number of channels allocated for a cell, or cell capacity. A short QL means 'supply' is much larger than 'demand'. A full QL means 'demand' is larger than 'supply'.

QL is periodically updated for each cell. CRT is proportional to the QL. The decision of when to send a CRRHA is decided based on the updated CRT. When a MS reaches a predefined distance away from the cell boundary, it checks the QL. By referring to Table 1, it gets to know the appropriate CRT, i.e. the time of which it should issue a CRRHA, calculated from the cell boundary.

ACRS is compared with the some fixed channel reservation schemes (FCRS) where their CRT is not adjustable. All the schemes are tested in both uneven and even traffic distribution conditions and the results show a good agreement with the theoretical expectation.

4. Implementation

A Globalstar-like system has been simulated. There are 16 spotbeams in one satellite footprint. For simplicity we assume a 4 X 4 cells arrangement in the footprint (Fig. 1). Each cell is modeled as a rectangle bounded by the segments joining intersection points of adjacent circular cells belonging to the same street of coverage [2]. Overlapping area of two cells has been removed for simplicity. The Globalstar satellite is estimated to be moving at a velocity of 7.195 km/sec relative to ground. Cell crossing time (CCT), the time taken for a MS to leave a cell after entering it, is taken as 170 sec since the cell length is 1000 km. Cell capacity is 20. Call duration is assumed to be exponentially distributed at an average of 180 sec. We also assume that the moving direction of every MS is exactly perpendicular to the joint boundary of two cells. Total simulation time is 3600 sec or 1 hour.

Three new call arrival rates have been chosen to represent three different traffic density conditions. The new call arrival rate is assumed to be Poisson distributed with an average of {0.0278, 0.0584, 0.0889} calls/sec/cell or {5, 10.5, 16} erlangs [1], each representing {light, medium, heavy} traffic density condition in a cell. A traffic distribution pattern describes the changes in traffic density over a footprint. Various traffic distribution patterns have been created for testing purpose. These patterns are categorised into two: uneven and even (uniform). In an uneven traffic distribution pattern, the mean new call arrival rate per cell (CAPC) of one cell can be different from that of its neighbouring cells. Conversely, CAPC in each cell is the same in an even traffic distribution pattern. There are five uneven traffic distribution patterns each with different average CAPC over the footprint (CAPCF). An example is shown in Fig. 2. An even traffic distribution pattern is also created corresponding to each uneven traffic distribution pattern with the same CAPCF for comparison purpose.

The following table shows the corresponding CRT to various QL in ACRS.

QL	CRT (sec)
0 to 4	5
5 to 9	10
10 to 14	15
15 to 20	20

Table 1. CRT value selected for different QL

Three fixed channel reservation schemes (FCRS) have been used for comparison, each with a fixed CRT of {0, 10, 20} sec and they are denoted as {FCRS0, FCRS1, FCRS2} respectively. FCRS0 is a reference scheme where HA is treated the same as NCEA, as it has a CRT of 0 sec, which means that CRRHA is only issued when the MS reaches the boundary and rejected CRRHA is not queued up for another attempt.

5. Results

Simulation results of Phf and Pb for various CAPCF values are shown in Fig. 3 and Fig. 4, for uneven and even traffic distribution patterns respectively. The general trend is that Phf and Pb go up when the traffic density becomes higher (higher CAPCF). The performance of ACRS and FCRS does not differ from each other much at low traffic density. Significant difference can only be observed at high traffic density condition. Generally, all the schemes perform slightly poorer under uneven traffic distribution condition because it is a harder condition to deal with. Phf and Pb of FCRS0 are almost the same because the HA receives the same treatment as the NCEA does. ACRS, FCRS1 and FCRS2 all have a lower Phf, but a higher Pb compared to FCRS0, since they give priority to HA over NCEA.

From both figures, we can see that ACRS gives the lowest Pb among the schemes which prioritise HA, at an expense of slightly higher Phf. However, the amount of increment over Phf is much less compared to the amount of reduction over Pb. For example, for an uneven traffic distribution pattern with CAPCF 0.0736 calls/sec/cell, Pb of ACRS is 0.0311 smaller than that of FCRS2, whereas Phf of ACRS is only 0.0053 larger than that of FCRS2. Similar situation goes for even traffic distribution pattern with same CAPCF value: for ACRS, its Pb is 0.0269 smaller while its Phf is only 0.0060 larger compared to the respective value of FCRS2. We conclude that ACRS is a more balanced scheme giving fairer treatment towards both HA and NCEA by keeping both Phf and Pb low.

ACRS's performance becomes more distinguished in uneven traffic distribution condition than in even traffic distribution condition. There was an increment of 0.0110 in the Pb of FCRS2 where the scheme was first tested under even traffic distribution pattern, and then under the uneven one, with the same CAPCF of 0.0736 calls/sec/cell. But the increment was only 0.0068 for ACRS under the same sequence of tests. It is the same condition for Phf: its increment was 0.0013 for FCRS2, and only 0.0007 for ACRS when they were tested in similar sequence.

6. Conclusion

We have shown that our proposed idea of ACRS gives much smaller value of Pb compared to the conventional FCRS, at the same time keeping the Phf low. ACRS outperforms FCRS more significantly in an uneven traffic distribution condition compared to an even one. Balanced improvement on Phf and Pb introduced by ACRS could help keeping the competence of SFC systems against the more complicated EFC systems.

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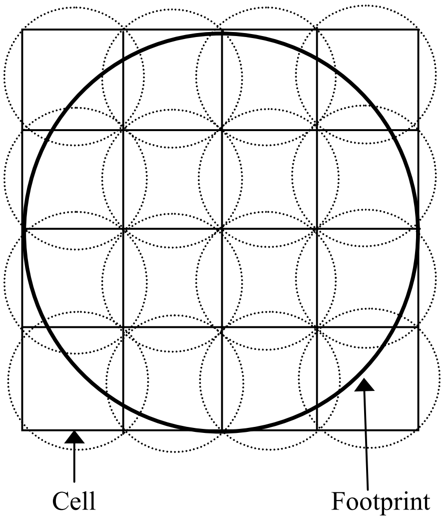

Fig. 1 Footprint model

H	H	M	L
M	M	M	M
L	L	M	H
L	L	M	H

H (heavy traffic density) - 0.0889 calls/sec/cell
M (medium traffic density) - 0.0584 calls/sec/cell
L (light traffic density) - 0.0278 calls/sec/cell

Fig. 2 Example of traffic distribution pattern

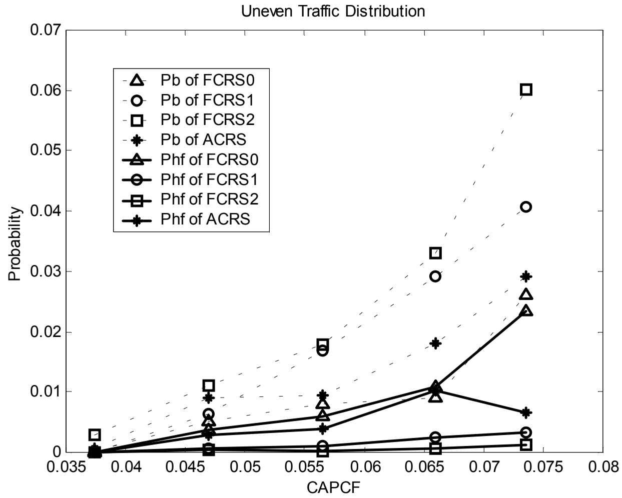

Fig. 3 Phf and Pb vs. CAPCF for uneven traffic distribution patterns

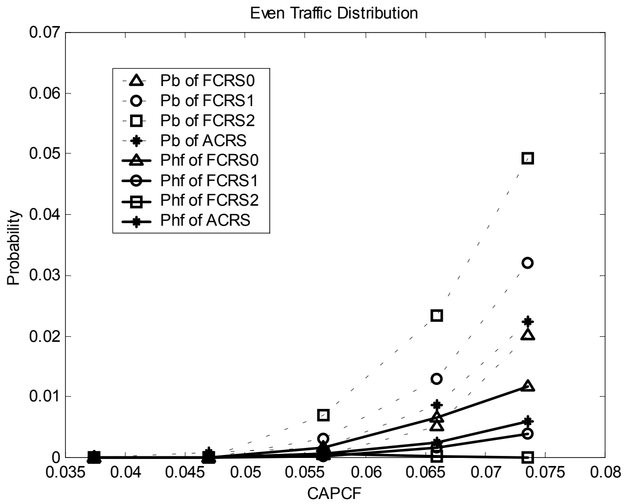

Fig. 4 Phf and Pb vs. CAPCF for even traffic distribution patterns