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Abstract - **In this paper we investigate downlink channel assignment scheme for multipoint communications and we propose a new Simulcast-based Dynamic Channel Assignment policy for both unicast and multicast connections in LEO satellite networks. In order to reduce co-channel interference power and to avoid Inter Symbol Interference problem, our policy is combined with a power control algorithm. Performance evaluations show that our policy compared to other policies achieve bandwidth optimization and improves the Quality of Service since it reduces call blocking probabilities for both unicast and multicast connections.**

I. Introduction

Recent advances in video, audio, data compression techniques and in network equipment have given rise to new multimedia multiparty applications. Some of these applications, such as Video-conferencing or Webcasting facilitate group communications and allow members of a group to work together or to share resources. We believe that there will be an increasing need for developing this kind of applications in the future and so, there will be an absolute necessity to provide multipoint communication services in networks.

Sending data to a huge number of geographically distributed recipients, in an efficient way is a complex problem. One interesting solution is the multicast service. In fact, multicast takes advantage of broadcast capability provided by some networks, such as Ethernet, or LEO networks to minimize the time between the sending of two data, and to optimize the bandwidth utilization.

Low Earth Orbital (LEO) satellite networks seem to be well adapted to support multimedia multiparty applications [1]. In fact, satellites use their radio interface to broadcast data to a large coverage area, and thus to a huge potential subscribers customers. Therefore, LEO satellite networks are designed to provide worldwide communications and to allow the support of heterogeneous traffics. One challenge is to provide the same capabilities for both unicast and multicast connections. However, the support of multicast in LEO networks leads to many problems that result from the combination of multicast problems (multicast routing, group management, error retransmission policies [2, 3] etc..) and LEO network problems (mobility management, bandwidth allocations, handoff policies [4, 5] etc.). Since resource management is a crucial issue for LEO networks and multipoint communications, we then address in this study the channel assignment question.

The rest of the paper is organized as follow, after a brief description of channel allocation schemes in section II, we present our S-DCA policy in section III. In section IV we detail the proposed power control algorithm. Performance evaluation and numerical results are exposed in section V. Finally, section VI summarizes the main contributions of this work.

II. Channel assignment schemes

A. Channel assignment overview for unicast communications

Channel assignment scheme is defined as the way to share radio resources between different cells requesting a channel. In our case study, radio resources are TDMA slots in a TDMA/FDMA system. Channel assignment schemes can be classified into three categories :

- Fixed Channel Assignment (FCA) : A set of nominal channels is permanently assigned to each cell. Howeover, each channel can be reassigned to co-channel cells according to the allowed reuse distance D. The number of nominal channels per cell is fixed and depends on the expected traffic. Therefore, FCA schemes are not adapted to changing traffic such as those expected for LEO networks and dynamic assignment schemes are more suitable for non-uniform traffic.
- Dynamic Channel Assignment (DCA) : All channels are kept in a central pool. A channel can be assigned to a cell if its Carrier to Interference Ratio

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(CIR) is above a given threshold Γ. When a call requests service, the controller checks to see in the central pool if there is any available channel. Control processing can be centralized or distributed. Depending on the way the satellite estimates the availability of a channel, DCA schemes can be subdivided into two categories: Cell-Based DCA schemes and Signal Strength Measurement-Based DCA schemes. In Cell-based schemes, the decision depends on the state of available channels in both current and adjacent cells. Therefore, a channel is assigned according to the allowed reuse distance, whereas, in the second category, the signal strength is measured and the CIR is estimated. Since more than one channel can satisfy the CIR criterion, the way a channel is selected from the pool will play an important role in the performance of the system. Therefore a wide range of channel selection strategies was proposed over the last years. [6] gives a good overview of the proposed DCA policies.

- Hybrid Channel Assignment (HCA): It is obvious that DCA overcomes the inefficiency of FCA schemes under non-uniform traffic conditions. However, under heavy traffic conditions, FCA performs better than DCA. Therefore, HCA is a compromising solution since some channels are permanently allocated to each cell, whereas the remaining channels are kept in the common pool and assigned according to a DCA strategy.

B. Channel assignment for multipoint communications

Our aim is to propose a channel assignment solution that takes into account the non-uniformity of traffic demands in LEO network cells, and the sporadicity of multiparty multimedia flows. Under unicast non-uniform traffic conditions, several studies have proved that DCA algorithms outperform FCA ones. Since multicast services should save bandwidth, and DCA schemes should increase traffic capacity, it is reasonable to expect that DCA schemes for multicast communications will provide efficient use of radio resources. This should be the case, especially in the downlink sense where the satellite have to transmit simultaneously to several receivers. Multicasting in the upper link can be achieved by establishing a simple point to point connection between a sender and its corresponding satellite.

In our knowledge, most of DCA solutions in LEO networks or in cellular systems have been proposed for unicast communications. Other studies are related to broadcast channel assignment. In that case, multicast channel allocation was simply seen as a way to dynamically assign broadcast channels to multicast subscriber's cell. Therefore, DCA schemes for unicast connections are also proposed in the broadcast case. Nevertheless, due to interference reuse constraints, different channels are used to broadcast the same multicast data in adjacent multicast subscriber's cells. Although the use of broadcast channels achieves bandwidth optimization within a cell, we claim that multicell optimization can be obtained if the same channels are used to broadcast data in adjacent cells. This solution, which is called simulcast, is the one which is implemented in Satellite Digital Video Broadcasting (S-DVB) and Satellite Digital Audio Broadcasting (S-DAB) systems. These systems are also called Single Frequency Network (SFN), because the same frequency is used to simulcast each program in all subscriber's cells. The main advantages of simulcasting are:

- Since one channel is used in N cells instead of N broadcast channels, a high spectrum efficiency is achieved.
- Simulcating in two adjacent cells, may reduce handover blocking probability or data packet loss after a handover. In fact, dropping handover will not occur, if a broadcast channel is already transmitting in the destination cell or if simulcast is possible because a neighbor cell is transmitting the same multicast session.
- The signal received is a superposition of several signals transmitted by several satellites. Therefore, at the receiver standpoint the signal received is more robust than if it was emitted by a unique satellite.
- The total power emitted by several satellites simulcasting the same data can be much higher than the minimum power required to achieve Γ. Thus, power reduction can be applied to reduce the co-channel interference.

The main drawback with simulcasting is the Inter Symbol Interference (ISI) problem. In fact, it is well known that simulcast may create artificial multipath propagation environment. This problem is due to the fact that several satellites are transmitting in the same channel the same frame. Thus, because of different propagation delays, as many copies of the symbol as simulcast transmitters will arrive at different times. Few solutions were proposed to overcome this problem. Most researches suggest the use of a Time Guard Interval T_g to increase the time detection of the frame. Others propose new coding techniques such as COFDM. Both give partial solutions to ISI problem, however, in our case study, we adopt the first approach. We argue our choice by the fact that, in LEO networks, users are fixed compared to the speed of a satellite thus the delay spread of the signal can be bounded and T_g can be computed.

In spite of the fact that simulcast offers considerable advantages to multimedia multiparty applications, this technique is only applied, nowadays, for TV and Radio broadcast programs. Since each channel is permanently assigned in each cell to the same program, SFN can be

seen as an extension of FCA to the multicast case. However, as aforesaid, FCA schemes are not suitable for non-uniform traffic demands such as those which are expected for LEO networks and for multimedia multiparty applications. Therefore, our basic idea is to extend DCA algorithms for multicast traffic by using the simulcast technique. In the next section we detail our simulcast-based DCA scheme and its performance evaluation.

III. Proposed DCA for multicast in LEO networks

In order to optimize channel assignment for multicast traffic, the complete knowledge of assigned channels to a specific multicast session is required. In fact, the best strategy is the one that minimizes the number of allocated channels to a specific multicast session, the optimum is one channel per multicast group. Therefore, since a complete knowledge is required, we suggest that a Resource Manager (RM) in each satellite supervise the channel assignment task for a predefined set of spot-beams.

RM decisions are based on an Augmented Channel Occupancy matrix (ACO). The ACO contains the state of the channels that are managed by the RM and those which are allocated to its neighbors satellites. To update their information, neighbors' satellites regularly exchange their tables. The ACO indicates the cells which are currentely using a channel. Hence, in our DCA policy, the RM dynamically assigns channels to spot-beams according to the ACO with respect to the interference reuse constraints. Therefore, a channel j is considered as free in cell i if the ACO indicates that it is not being used in all the cells that are within j' minimum reuse distance.

When a unicast call request arrives, the satellite searchs for an available channel in the ACO with respect to the interference reuse distance, if a free channel is found then it is assigned to that call, otherwise the call is blocked.

When a multicast request arrives, the satellite uses ACO to see if a broadcast channel for the same multicast session has been allocated to the current spot-beam. In this case, the customer identifier is added to the receivers of the broadcast channel and the join request is accepted. Otherwise, the satellite tries to do a simulcast. Hence, if a broadcast channel has been assigned in neighbor cell to the same multicast session, the satellite allocates the same channel. However, if this channel is occupied in the current cell by a unicast call, the satellite tries an intra-handover and switches the unicast channel to a free one. To avoid the instability of our algorithm, such channel rearrangements are not allowed when the channel is occupied by another multicast session. In this case, as well as when there is not any neighbor cell transmitting the multicast session, the station looks for a free channel to start the broadcast.

When allocating a free channel to a unicast call or a multicast group, more than one channel can be idle. The choice of the best candidate must follow a strategy. A simplistic approach would be to search sequentially in the ACO for a free channel, another one could be to select randomly a channel among the idle ones. However, [6] indicates that these strategies are not optimal. Moreover, in our case study, a unicast channel must be selected carefully in order to reduce the intra-handover requests that may arrive when the RM performs a channel rearrangement. Similarly, a broadcast channel have to be chosen in such a way that the number of channels assigned to its multicast session is minimized. Hence, without explicitly reserving a number of channels for each connection class, the RM must distinguish between channels that are suitable for unicast calls and those who are adapted for each multicast session.

One interesting solution to that problem is the Channel Segregation (CS) technique [7]. The basic idea of CS is to associate for each channel i a priority value v_i.

To allocate a channel, the RM finds the channel with the highest v level between all free channels according to the channel reuse constraints. Let n_i denotes the numbers of times that channel i have been considered for use. Each time a channel i is assigned to a cell, v_i increases according to eq. 1, otherwise if the selection fails, v_i decreases following eq. 2.

$$v_i = (v_i n_i + 1) / (n_i + 1), \; n_i = n_i + 1 \qquad (1)$$

$$v_i = (v_i n_i) / (n_i + 1), \; n_i = n_i + 1 \qquad (2)$$

In our strategy, each channel has a different CS priority values, a v_i^u for a possible unicast selection, and as many v_i^m values as multicast sessions in the satellite coverage area. Each time a channel is assigned to a unicast new call, a unicast handover or a unicast intra-handover request, v_i^u in the corresponding cell increases. Else, if the allocation fails or if a channel that was originally used by a unicast call has to be reassigned to a multicast call after an intra-handover rearrangement request done by the RM then its v_i^u in the corresponding cell decreases. Whenever a channel is successfully assigned to a multicast new call demand or a multicast handover request m its v_i^m increases in all cells that are managed by the RM. Otherwise, if the assignment fails the value decreases.

Depending on the connection request type, the RM chooses a free channel that has the highest v for that connection class. When a multicast request arrives while the multicast session is not active in the coverage area of the RM, the RM selects the one with highest unicast v_i^u and initializes its corresponding CS priority value. Hence, this strategy achieves dynamic partition between channels which are suitable to unicast calls and those which have to be assigned to multicast calls in order to support the use of the simulcast transmission.

IV. Power control

In this study, we have assumed that simulcast can be achieved if satellites are perfectly synchronized and transmit simultaneously the same frame. However, even if satellites are synchronized, ISI problems may arise. As we have already mentioned before, ISI is due to the transmission of the same symbols in two co-channels. This point is critical in large propagation delays environment such as LEO satellite networks and may create an artificial multipath propagation environment. However, to overcome ISI problem, a guard interval could be added to increase the symbol detection time. In fact, since in LEO networks the delay spread of a signal can be bounded then T_g can be deduced. Nevertheless, the delay spread of the signal form the satellite to the terminal must be smaller than T_g, otherwise the signal will contribute to the interference power part. In this study, to avoid ISI problem, we suggest the use of a power control algorithm.

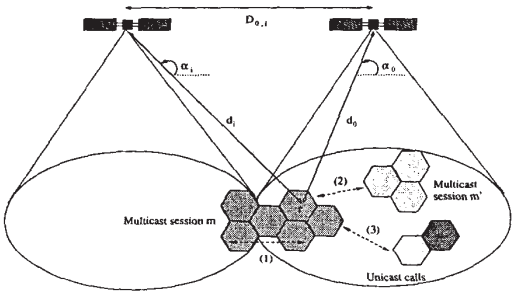

Fig. 1: Artificial multipath problem

It is clear that useful simulcast signals are transmitted by the closed satellite, while the interfering ones are those which are transmitted by far satellites. Thus, the best power control strategy will be to reduce the power of interfering signal and to upgrade useful ones. Note that applying our power control algorithm to a multicast session m may reduce co-channel interference with other unicast or multicast connections, improving thus their target CIR. In fact, as aforesaid in section II, thanks to simulcast, the power of several superposed signals can be much more higher than the power required to achieve the target CIR. Thus, power reduction can be applied by using our power control algorithm.

The CIR for a multicast session m can be obtained by computing the power of useful part of co-channel signals that participate to the simulcast transmission and dividing it by the power of the noise added to the interfering signals. The interfering signals are due to other co-channel transmissions such as those of other multicast sessions (e.g. interference 2 on Fig. 1) or unicast calls (e.g. interference 3 on Fig. 1). Interference is also due to another channel participating in the simulcast transmission but with a signal delay spread higher than the T_g (e.g. interference 1 on Fig. 1). Therefore a signal may participate depending on its delay spread fully or partially to the useful power of the symbol. Thus, we use the weighting function $w(.)$ of [8] to indicate whether the signal contribute to the useful part of the signal or to the interference. $w(.)$ is time dependant. However, [8] shows that time criterion can be translated into space parameters. Hence, let c denotes the speed of light, T_u the time interval of the symbol useful part, $T_f = T_u + T_g$, and let $D_{0,i}, d_i, d_0, \alpha_i$ and α_0 defines the relative distance Δd_i between the nearest satellite transmitter 0 and the satellite transmitter i (see Fig. 1), then :

$$w(\Delta d_i) = \begin{cases} 1 & ,0 \leq \Delta d_i \leq d_g \\ \left[\frac{d_u + d_g - \Delta d_i}{d_u}\right]^2 & ,d_g \leq \Delta d_i < d_f \\ 0 & ,otherwise, \end{cases} \quad (3)$$

with $\Delta d_i = \sqrt{D_{0,i}^2 - 2 d_i d_0 (1 - \cos(\alpha_0 - \alpha_i))}$.

and $d_g = cT_g, d_f = cT_f, d_u = cT_u$

Let S_M be the set of co-channel transmitters sending data by simulcast to a multicast session m, $S_{UM'}$ the set of co-channel transmitters emitting data to unicast calls or to other multicast sessions $m' \neq m$. Denotes $g_{i,k}$ the downlink gain between satellite i and receiver r in spot-beam k, $p_{i,k}$ the power transmitted by satellite i to terminal r in cell k and N_r the received noise power by terminal r in cell k. The carrier to interference ratio $\gamma_{r,k}$ for terminal r in cell k is given by [8]:

$$\gamma_{r,k} = \frac{\sum_{i \in S_M} g_{i,k}\, p_{i,k}\, w(\Delta d_i)}{\sum_{j \in S_M} g_{j,k}\, p_{j,k}\, (1 - w(\Delta d_j)) + \sum_{j \in S_{UM'}} g_{j,k}\, p_{j,k} + N_r} \quad (4)$$

Let Γ_m be the CIR threshold for session m, then for each multicast session m $\gamma_{r,k}$ must be greater or equal to Γ_m. A unicast call can be seen as a special case of a multicast session where only one channel is used. Therefore our power control algorithm applies also for unicast traffic. Since the downlink power control algorithm is centralized and done by the RM, then finding the optimal power vector P leads to solve the following Linear Program using known LP methods such as the Simplex:

LP: minimize $\sum_k \sum_i p_{i,k}$
subject to $\forall m$,

$$\sum_{i \in S_M} g_{i,k} p_{i,k} \left(w(\Delta d_i)(1 + \Gamma_m) - 1\right) + \sum_{j \in S_{UM'}} \Gamma_m g_{j,k} p_{j,k} \geq \Gamma_m N_r$$

V. Performance evaluation

In order to evaluate the benefits of our dynamic channel allocation (S-DCA), discret even simulations were run. A scenario has been considered. Calls of both unicast and multicast traffics, arrive according to a Poisson process. Call holding times for both unicast and multicast traffic are supposed to be exponentially distributed, with a mean call duration equal to 2 minutes. Mean call inter-arrival time for unicast and multicast are computed to reach the several input load factors. We have simulated a Satellite-Fixed Cell system with 60 channels and 30 spot-beams.

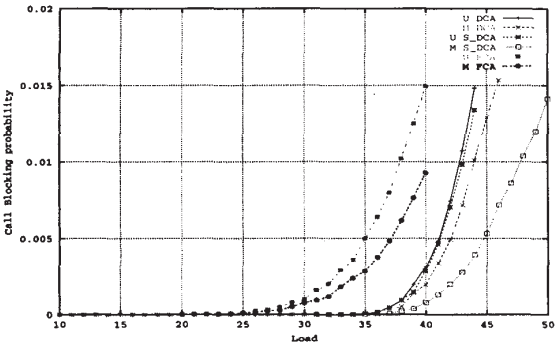

Fig. 2: Call blocking

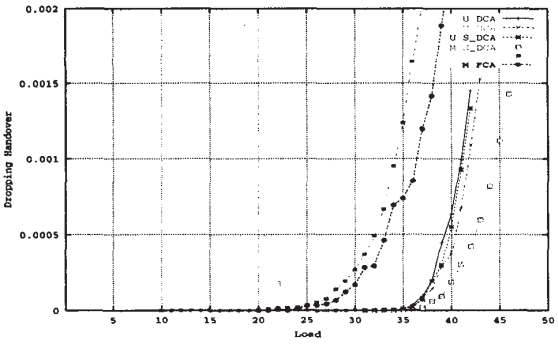

Fig. 3: Dropping handover

Two other policies have been simulated. The first one uses only DCA for both unicast and broadcast channels. The second one uses FCA for both broadcast and unicast connections. Results show clearly that our policy compared with the two others ones decreases call blocking probabilities and dropping handovers for multicast connections (see Fig. 2 and Fig. 3). Moreover, the curves show that our S-DCA policy improve the QoS of multicast connections without degradating unicast QoS. In fact, S-DCA reduces the number of call blocking and intra-handover of unicast connections. The improvement should be much more important if we had assumed that multicast connections required more than one channel unit. We also find out that the impact of our channel selection, using the modified version of CS and the use of our power control in the radio interface, are significant since they reduce the number of intra-handovers of unicast connections.

VI. Conclusion

Efficient multicasting is a fundamental issue for the success of LEO satellite networks. In this paper we have presented a new Simulcast-based DCA scheme which is combined with a new power control algorithm that minimizes the interference effects. The resulted scheme improves significantly the QoS for both unicast and multicast connections and optimizes the use of the bandwidth. Our future investigations will concern the integration into our S-DCA scheme of a call admission policy that takes into account reservation mechanisms such as Trunk Reservation in order to protect traffic classes against high load traffics such as those of multimedia multiparty applications.

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