ON BOARD RESOURCE SHARING IN FUTURE SATELLITE-BASED TV OR TLC SYSTEMS UTILIZING KA FREQUENCY BANDS

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ABSTRACT

The paper reviews some of the most relevant problems which are expected in realizing some of the satelllite-based Resource Sharing Systems envisaged in the next future. Important issues like the necessary input information, the dynamic properties the system must possess, the strategies and the needed margins are considered and some preliminary results coming from recent studies presented.

FOREWORD

Advanced satellite-based systems of the next future like point-to-multipoint-, broadcasting-, multicasting-systems or, more in general, systems providing many users with personalized services (as e.g. Internet via satellite) will probably became economically attractive to a large number of users within the end of the present decade. Owing to the enormous envisaged demand of capacity inherent in these systems, this will certainly imply resorting to higher and higher frequency bands and, as a consequence, exploiting the ka and V bands; this issue is indeed becoming an high priority subject of study in many research and development laboratories worldwide.

However, in order all this to come true, some problems related to the transfer channel, more severe than the ones faced in the past and in the present time, must be forwarded to a practical solution; among them, certainly in position of great relevance, there is the problem of the medium attenuation. The solution of this problem is an objective that appears today at hand but only by resorting to system philosophies (known as “fade mitigation techniques” or "fade countermeasures") totally different from the brute force approach substantially followed in the past and in the present.

Among these philosophies we find the Common Resource principle, a fade countermeasure known since more than 15 years [1] but that, in its practical implementation, became of practical interest only in the present time with the today’s perspectives of development.

It was clear since the beginning that the very limited margins allocable to satellite systems at high frequencies would be generally insufficient, in cost effective systems, for all the users simultaneously but, if used sparingly, could be sufficient for limited number of users really needing it, as it happens in adaptive systems able to allocate a resource only to the terminals undergoing bad weather conditions, i.e. in Resource Sharing Systems (RSS). Enabling technologies still remain however to be developed for the full realization of RSS: multiband systems, variable rate transreceivers, reconfigurable pattern antennas, beamforming networks, diplexing matrixes at mm waves, and, last but not least, enormously complex on-board processing for the real time treatment of the signals to be redirected.

Recent experiments and studies conducted in Europe, Japan and US have however demonstrated, even based on limited activity, the feasibility of such systems. Among the most significant we remind the following:

- the band-diversity experiment [2] which used dual-frequency data gathered with the ITALSAT satellite to simulate the behaviour of a ka system utilizing a back-up beacon in the ku band,
- the GEKO experiment [3] which used data gathered with the OLYMPUS and DFS KOPERNICUS satellites to simulate the behaviour of a network composed by four terminals experimenting a resource-sharing technique based on the burst length control,
- a power-sharing experiment operated in Japan where the behaviour of an antenna capable to contouring adaptively its directive pattern was simulated [4], and
- an experiment based on the ACTS satellite, conducted in the US [5], which showed, on the basis of real long-term BER measurements, the effectiveness of the adaptive code technique.

The continuation of these developments, on the other hand, is strongly conditioned by the perspectives of the real gain achievable: in other words, before embarking in very demanding and costly developments, the technology world wants to be reassured about the effectiveness of the RSS techniques, i.e. whether the costs and risks are balanced by real achievements in terms of reduced outage or improved quality of service.

All this leads to the necessity of complex studies on the impact of the meteorological conditions on the channel properties on a very wide variety of spatial scales (regarding both length and separation of the links) ranging from a few to thousands of kms. Some relevant studies have been supported in the recent past by the ESA which shared with some universities and research centres valuable expertise and data [6, 7]. For the next future also the Italian Space Agency (ASI) is developing an experimental programme aimed at providing a sound experimental basis to the models of multiple atmospheric channel transmission and at measuring directly the advantage obtainable from a real RSS serving a region whose dimension is of the order of the meteorological mesoscale (250 kms) [8].

The preliminary results from the past activities seem encouraging even if more statistical results are still required in order to enlarge the significance of the tests and to extend the validity of the conclusions up to the V band (particularly sensitive to the water vapour and clouds effects).

GENERAL

Among the many envisaged RSS, the most promising ones on the stage today are the ones based on the possibility of reconfiguring the antenna directivity pattern at any instant in order to distribute the EIRP in a time-variant optimized way by allocating the resource to those links of the served region which are the most unfavoured due to bad weather condition. This form of RSS is particularly well applicable to the case of broadcasting; on the opposite, the form of band- or time-assignment will be favoured in the case of telecommunications (this case however can also utilize the reconfigured antenna directivity as an additional countermeasure to increase the RSS effectiveness). Fig. 1 shows a set of spots projected on Europe by a multibeam antenna created in the frame of an activity of the European Community (SECOMS project [9]). Antenna systems like that can create adaptively contoured patterns for broadcasting applications or, alternatively, separate cells for the frequency band re-use like in the terrestrial mobile systems as in the IRIDIUM system.

INFORMATION NECESSARY FOR THE SYSTEM CONTROL

The assessment of the C/N relative to all, or a significant sub-set of receivers is obviously a prerequisite for the system control; for TLC systems assigning dynamically bandwidth or time (variable rate or burst-length control) the C/N ratio measurement can be performed by each receiver individually by measuring its BER (Channel Bit Error Rate) and transmitting this information to the system controller which provides to allocate the resource in optimum way [6]. A serious problem in the case of ka bands or of higher frequencies, could be constituted by the dynamic range of attenuation ranging from a few to more than 15 dB (excluding the worst few hours per year); in this situation the error count could be hampered by the opposite problems of too little number of errors (too much time needed) or, oppositely, difficult syncronisms recovering. In the case of broadcasting (TV-sat etc.), owing to the high number of users, it will be probably unfeasible to take into account all the channels individually and an estimate of the statistical distribution of the attenuation over an area of a certain extension (say 200 ÷ 300 km diameter) at a given instant could be the only utilizable information (from METEOSAT or ECMWF). It has been recently shown [6]] that, by combining data from these two sources, any sub region of the covered area can be characterized by a curve of the type shown in Fig. 2 which gives, at any given instant, the number of the users in a given sub-area (e.g. the area of a spot) which are lost owing to the bad weather conditions as a function of the margin provided by the satellite to that particular sub-area. From the figure it can be seen that a certain amount of power must be set apart to counteract wide-scale phenomena like humidity and clouds and that, in addition, some further dB's are necessary to “recover” the users undergoing rain attenuation (increasing margin to progressively reduce the Number of Non Served users).

DYNAMIC PROPERTIES

The reassignment of the resource is an operation which could require a certain time to be implemented: the design of the countermeasure requires information about the rate of change of attenuation: the inverse of this quantity, i.e. the time to cross two consecutive thresholds 1 dB apart can be preferable for the natural filtering it introduces by excluding eventual variations due to small signal envelope oscillations, even if very rapid. The probability density of this quantity seems constant in the range 0 to 1 min at 50 GHz, as demonstrated by the cumulative distribution of fig 3 which exhibits an extremely linear behaviour.

Another issue related to the optimum control of the RSS is the updating of the measurements for the case of adaptive antenna directivity: pending the need of more refined analysis, what can be said is that this adjourning interval must be related to the time required by a meteorological front to cross a spot like the ones of fig.1. It is taught that, with spot dimensions of the order of 100 km, adjourning times of the order of one hour could be adequate.

STRATEGIES

Different control strategies can be needed for different systems; a first differentiation can be made by distinguishing between TV-broadcasting and TLC cases. In the first case, owing to the high number of users, it will be probably impossible to optimize the resource allocation taking into account the needs of the single users; in these cases the state of the links in a particular area could be “guessed” from meteorological indicators (ECMWF or meteosat data) and the optimization could be performed on the basis of best estimates of the state of the channels instead of deterministic assessment. Naturally the case of TLC will be different as the individual measurements can be taken into account separately.

Further differentiations could be made considering the case in which not all the needs can be satisfied due to shortage of resource: these situations can be solved in different ways depending on the type of service (services which can be delayed or not) or on the importance of the transmission (excluding first the less privileged users or similar). Strategic issues are also the ones related to the non-uniform spatial density of the users: indeed where big concentrations of users exists, any system trained to minimize the number of non served users will inevitably exclude the users in less populated regions: such a behaviour could discourage the subscription of users living in country regions.

THE RESOURCE DIMENSIONING

On the case of broadcasting systems, the analysis of the rain distribution shows that the total area covered by convective rain is very limited: e.g. a rain rate of 10 mm/h is probably exceeded in an average fractional area less than 10^{-3} in Europe: on the other hand the spatial scales of such phenomena are of the order of 10 to 50 km; counteracting the strong attenuation created by such a rain by means of the antenna directivity while avoiding to radiate power outside these limited areas would imply, from 36000 km, an antenna with many hundreds of beamlets. In this case a very limited amount of power would be actually necessary on board (a margin of about 2 dB has been evaluated as the theoretical limit to radiate the minimum needed power flux density all over the Europe). It seems logical to conclude that any improvement of the antenna size would provide an unlimited increasing advantage in terms of needed power. However such highly sophisticated antennas are probably unfeasible or uneconomic; a better compromise could be the one of assuming as horizontal space detail the one of the stratiform rain which is one order of magnitude greater (in linear term) than the one of convective rain.

Preliminary analyses conducted using an antenna with a beam clustering such as the one of Fig.1 demonstrated that an advantage of a factor 4 in terms of reduction of non served users (with a fixed on-board power) is obtainable by resorting to adaptivity (i.e. an optimized set of excitation coefficients adjourned every hour) as shown in fig. 4 which compares the optimized with the non-optimized cases. An advantage of more then 6 seems obtainable with about 200 beams.

A FUTURE EXPERIMENT IN ITALY

In the TLC case the benefit obtainable by utilizing the adaptive properties of the antenna can be increased by exploiting possibilities enabled by modern technologies like the variable rate, adaptive coding or burst length control. The italian resource sharing experiment to be performed with the DAVID satellite (launch foreseen in the early 2004) has been conceived with the aim of demonstrating the advantage of the burst-length-control technique in the 22 GHz band. Up to 16 stations located in a region of 250 km diameter around the space-station of Spino d’ Adda will share the resource (i.e. the extra burst length) trying to minimize the number of terminals undergoing outage due to bad weather conditions.

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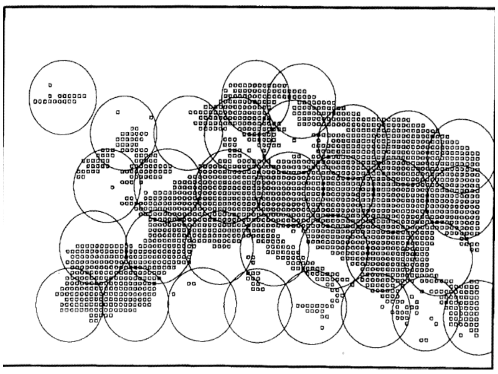

Fig.1: Coverage of Europe with a cluster of 32 feeds

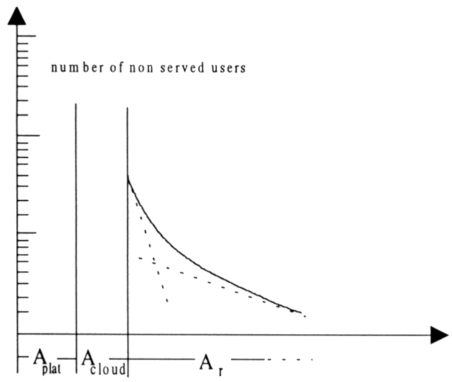

Fig.2: Number of non served users (due to bad weather conditiontions) in a sub-area as a function of the margin over free space

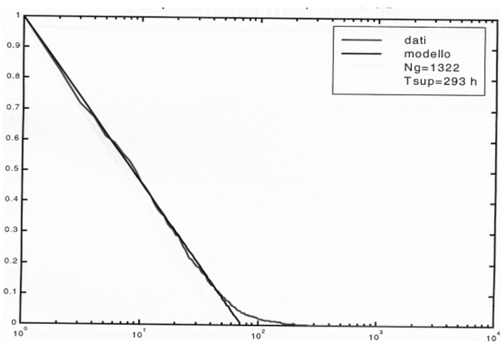

Fig.3: Cumulative distribution function of the time interval between the instants in which two attenuation levels separated by 1 dB are crossed. F=50 GHz

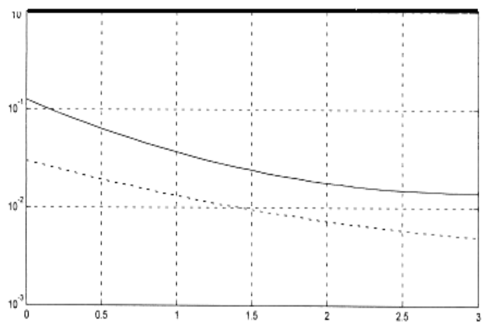

Fig. 4: Average number of non served users (due to bad weather conditions) as a function of the overall system margin. The two curves refer to the non-optimized case (upper curve) and optimized case (lower curve)