OUTAGE PROBABILITY
OF AN ADAPTIVE TDMA SATELLITE ACCESS SCHEME

Nedo Celandroni *, Erina Ferro *, Francesco Potorti *

* CNUCE, Institute of National Research Council
Via S. Maria 36 - 56126 Pisa - Italy
Phone: +39-50-593207/593132/593203
Fax: +39-50-589354 - Telex: 500371
Email: {nedo,erina}@VM.CNUCE.CNR.IT

* Telespazio S.p.A., Scholarship holder at CNUCE
Email: pot@CNUCE.CNR.IT

Abstract

An adaptive TDMA satellite access scheme able to counteract rain attenuation effects is sketched together with the employed prototypes of satellite controller and burst modem. The resulting system, based on the shared resource philosophy, is usable to support a multiplicity of applications in a LAN interconnection environment. Faded links are assisted by choosing the bit rate, the coding rate and the transmitting power level according to the fade level to be countered. A Monte Carlo simulation of the system behaviour has carried out to compute the outage probability of each link when operating in Ka band on the Olympus satellite. The shared resource occupancy has also been investigated. Comparisons are made with systems of the same capacity and without any fade countermeasure.

1. Introduction

A prototype of TDMA station has been developed by the Marconi Research Centre (UK) for use in a number of advanced communication experiments. The station consists of a processor based TDMA controller and a digitally-implemented multi-rate modem. The used satellite access scheme is FODA/IBEA(1), based on demand assignment of the channel capacity [5, 6] and able to simultaneously support both stream (isochronous) and datagram (anisochronous) traffic types. The system allows individual data packets inside a burst to be transmitted at a bit rate (in the range 1-8 Mbit/s) and at a coding rate chosen according to the class of service (COS) required by the sending application, independently of other packets within the same burst. The quality of service required by each application is maintained, as much as possible, even in deep fade conditions, by selecting a data bit rate and a coding rate suitable to compensate the loss of power due to the signal fading. In addition, the transmission power level is adjusted to compensate a certain amount of up-link attenuation, while keeping the satellite back-off at a suitable constant level. This allows the access of more carriers to the same transponder.

The adaptive method known in the literature as BLC ( Burst Length Control) [12] is the easiest form to implement adaptive coding in time-division systems. BLC leaves a spare space at the end of the frame (common resource) for use exclusively during the rain fade events. This space remains unused in clear sky conditions. When the received power level on a particular link is reduced by the rain attenuation, the transmission data bursts from/to the faded station are expanded in length by a factor of H, by acting on the coding rate and on the modulation scheme [2].

(e.g. by varying the number of levels in phase/amplitude modulation). The power margin is thus multiplied by the factor H and by the coding gain factor. The drawback of BLC is that the spare space devoted to the shared common resource cannot be too large, otherwise the frame utilisation becomes too low for most of the time.

FODA/IBEA uses the full frame for simultaneous transmissions of stream and datagram traffic. In unfaded conditions, the stream traffic cannot overcome a fixed amount of the frame, leaving the rest of the frame to the datagram transmissions. In faded conditions, data are sent with increased data redundancy, i.e. with varied bit and coding rates, according to the fade level to counteract. The consequent enlargement of the data frame occupancy is made possible by decrementing the capacity reserved for datagram. Indeed, datagram traffic can temporarily tolerate high delays or occasional interruptions. In these schemes the common resource is the frame space devoted to datagram traffic in clear sky conditions. It is sharable among the stream transmissions when they need to be assisted. In faded conditions, new stream links are not accepted. When the whole common resource is not sufficient to support the faded stream links at the requested class of service, the system tries to gain more space in the frame by requiring bandwidth compression to the applications supporting the compression feature, until the deep fade condition is overcome.

2. Outage probability evaluation

The best way to evaluate the performance of a fade countermeasure system is to show how much the system is able to improve the outage probability of a link, i.e. the probability (denoted here by P0) that the BER over a link is higher than the target value. The complexity involved in deriving P0 in closed form is due to the huge number of possible system states. In fact, each station can be in one of the possible fade levels considered by the FODA/IBEA system. For each class of service (COS) a table relates the possible fade levels with appropriate bit and coding rates. Table 1 shows the COS tables for the two COS used in the simulation. Two more COS are supported by the system. The number of system states is m^n for n stations. Being m—the number of entries in the COS tables—equal to 9, a closed form analysis is prohibitively complex, even for a small n.

Monte Carlo techniques have thus been used to investigate the P0 dependence (relevant to the stream traffic only) on the amount of the common resource and/or on the compression factor of the application bandwidth. The analysis of the system has been made for the stationary case. The cumulative attenuation distributions of the stations are computed using the CCIR interpolation formula [8].

This work has been funded by ASST/ISPT in the framework of the Italian experiment on the Olympus satellite.

0-7803-0950-2/93 $1.00 © 1993 IEEE
where $A_p$ is the attenuation in dB exceeded for a $p$ percentage of the time and $A_{001}$ is the attenuation exceeded for 0.01% of the time.

All the tests were made for stations of intermediate climatic characteristics inside the Italian region. For these sites, the $A_{001}$ parameter at 11.6 GHz is available from the data of the SIRIO experiment at the Teleca Spazio Fucino station [10]. The $A_{001}$ parameter used in the simulation experiments has been obtained by frequency scaling these experimental results. In addition, some tests were made for stations like Lario ($A_{001}$ still derived from SIRIO), a site particularly heavy faded in the North of Italy. In Table 2 the value of the $A_{001}$ parameter used for the simulation is reported, for both types of stations and for both up and down-link frequencies, respectively.

The statistical cross dependence of the attenuation experienced by the stations has been taken into account by introducing a factor $h$, according to the model adopted by Carassa [12]. Denoting by $P_A$ the probability of exceeding a certain attenuation in a station, the joint probability $P_{A1}$ to exceed that attenuation at $n$ stations is

$$P_{A1} = n h^{-1} P_A^n$$

A value of $h = 1$ simulates statistical independence among the attenuations of the stations, while a value of $h = 20$ has been considered as the maximum stations dependence. This value of $h$ was measured between two stations rather close together [7] (Lario and Spino d’Adda, 85 Km apart) and with very similar climatic characteristics.

The following assumptions were made to simplify the Monte Carlo simulation:

- all the stations have the same cumulative attenuation distribution;
- all the stations have the same performance in terms of EIRP, G/T and the same geometric position with respect to the satellite;
- each station sends data over only one point-to-point link with one of the other stations;
- all the links have the same capacity;
- the factor $h$ is assumed the same for all the stations;
- only stream type links with guaranteed bandwidth are considered in the Po evaluation;
- the datagram capacity is seen as a common resource to be shared among the stream links, when faded, in the percentage indicated in the graph;
- no transponder intermodulation noise reduction, due to the

$$1450$$

The simulation program is written in C and has run on an IBM RISC 6000 machine. The most significant simulation parameters are:

- the number of stations;
- the throughput of each station [Kbit/s];
- the type of the station, i.e. Lario-like or Fucino-like station;

resource which can be used to assist the faded stream links;
- the up-link power control range [dB];
- the link budget margin [dB];
- the up-link and down-link nominal $C/N_0$ ratios [dBHz];
- the number of outage events to collect before stopping the run.

For each $P_0$ estimation a sample of 1000 favourable events was collected, thus getting a 99.5% confidence interval of ±10% for the mean value.

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>$A_{001}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>22.5</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
</tr>
</tbody>
</table>

**Table 2: Lario-like stations. Data frequency scaled from the 11.6 GHz values of the SIRIO experiment.**

The CPU cost of the outage analysis was roughly of 300 hours. Another simulation program, derived from the previous one, has been written to evaluate the probability that the common resource is used at a certain percentage. About 200 hours of CPU time were spent to evaluate such a cumulative distribution.

Data reported in Table 3 were assumed as the link budget parameters. The Ka band Olympus transponder [1] is assumed to be accessed by three carriers. Each carrier may support a FODA/IEEE system, working alone or as an element of a multifrequency system, e.g. the one proposed in [3].

The FODA/IEEE system implements both the up-power-control (UPC) and the variable bit and coding rate (VBCR) features. Comparison is made with systems without UPC and/or without VBCR. Systems without VBCR are assumed to send permanently reduced data. Their bandwidth is assumed equal to the sum of the stream plus the common resource bandwidth of the systems working with VBCR. It must be emphasised that the common resource used by FODA/IEEE is available for datagram traffic for most of the time (as shown later on), while a system without VBCR has no space at all available for datagram, even in no-fade conditions.
The minimum Eb/N0 net value is fixed at 6 dB because of the poor performance of the modem burst acquisition at lower values. This poses a limitation on the used coding rates. Indeed, even for COS 0, the minimum usable coding rate is 2/3. The comparison with systems without VBCR was made by considering the coding rates: 7/8, 4/5, 3/4 and 2/3, with redundancy ranging from 1.14 to 1.5 respectively. When a higher redundancy was needed (e.g. a factor of 2, equivalent to

<table>
<thead>
<tr>
<th>Up-link freq. [GHz] (CH1)</th>
<th>28.0725555</th>
<th>Total IPFD [dB/W/m²]</th>
<th>-101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down-link freq. [GHz] (CH3)</td>
<td>19.475</td>
<td>Input Back-off [dB]</td>
<td>8</td>
</tr>
<tr>
<td>E/S EIRP [dBW]</td>
<td>73</td>
<td>Satellite EIRP [dBW]</td>
<td>55.5</td>
</tr>
<tr>
<td>Up-power Control Margin [dB]</td>
<td>12</td>
<td>E/S G/T [dB/K]</td>
<td>27.3</td>
</tr>
<tr>
<td>Satellite G/T [dBK]</td>
<td>14</td>
<td>Down-link C/N0 [dB]</td>
<td>90</td>
</tr>
<tr>
<td>C/N0 at satellite input [dBW/K]</td>
<td>-142.5</td>
<td>C/N0 at E/S receiver [dBHz]</td>
<td>83.2</td>
</tr>
<tr>
<td>Intermodulation G/T [dBW/K]</td>
<td>-140</td>
<td>Eb/N0 at 8 Mbit/s [dB]</td>
<td>14</td>
</tr>
<tr>
<td>Total Up-link G/T [dBW/K]</td>
<td>-145</td>
<td>Modern impl margin [dB]</td>
<td>1</td>
</tr>
<tr>
<td>Up-link C/N0 [dB]</td>
<td>-145</td>
<td>Eb/N0 in clear sky conditions</td>
<td>12</td>
</tr>
<tr>
<td>Number of carriers</td>
<td>84</td>
<td>Link budget margin [dB]</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Link budget for the Olympus Ka transponder. Three carriers at 8 Mbit/s access the transponder in FDMA. The 2.5 m E/S is equipped with a 70 W HPA and with tracking feature.

100% of the common resource) an appropriate change was introduced on the bit rate of both the preamble and the data. The sum of the contributions given by the UPC, the coding gain and the bit rate redundancy was taken into account as an increment of the link budget margin (LBM). The simulation program was run with equivalent LBM values and without any common resource availability to obtain P0 relevant to systems without VBCR.

In the simulation the transponder is employed without automatic gain control (AGC) and the up-link C/N0 of 84.2 dB is relative to a transponder gain close to the minimum. The LBM reported in Tab. 3 is 1 dB. This value is assumed in all the simulation runs, unless different values are expressly indicated. In order to increase LBM in the present environment it is necessary to increase the up-link C/N0 by reducing the satellite input backoff. This fact may force us to reduce the number of carriers on the transponder.

3. Simulation model

We shortly explain the basic ideas on which the Monte Carlo simulation programs are based.

In the case of the outage probability of one link, for each event the up-link and the down-link attenuations are drawn according to the cumulative distribution of the attenuation of the sending and the receiving stations, respectively. The factor h is also taken into account. The possible residual up-link attenuation, after the UPC adjustment, together with the down-link attenuation is used to compute the total attenuation of the link using the following formula:

\[ A_a = \rho_{up} \cdot \rho_{down} \cdot A_u + A_d \]

\[ + 10 \log_{10}(10^{\rho_{up} 10} + 10^{\rho_{down} 10}) \]

where: \( \rho_{up} \) is the total C/N0 in clear sky conditions\n
\( \rho_{down} \) is the up-link C/N0\n
\( \rho_{down} \) is the down-link C/N0\n
\( A_u \) is the up-link attenuation\n
\( A_d \) is the down-link attenuation.

The resulting Eb/N0 is then:

\[ Eb/N0 = Eb/N0_{net} + LBM - A_a \]

where \( Eb/N0_{net} \) is Eb/N0 in clear sky conditions.

If the total attenuation is lower than the LBM, the link is considered not in fade and the analysis on that event is over. Otherwise, for each of the other links, an attenuation is drawn and, for the faded links, the common resource occupancy is computed. If the total common resource needed is greater than the available, one or more of the faded links will be in outage. A further draw is then made to decide if the originally considered link is in outage.

When the use of the common resource (shared resource occupancy) is studied, for each event all the links must be investigated to verify that no outage is due to the insufficiency of the common resource. This does not save further investigations when the first examined link is not in fade (most of the cases), as in the previous case.

4. Simulation results

In table 4 a summary of the most significant parameters relevant to the various simulations is reported. All the simulations were made with the h parameter assuming the values 1, 5 and 20. Large scale irregularities in the graphs are due to the threshold effects produced by the discrete nature of the COS tables. Small scale irregularities are due to the ±10% confidence interval.

Depending on the number of stations, different aspects of the system performance are shown.

Runs with 48 stations were made considering 64 Kbit/s links with COS 0. In fig. 1 P0 is plotted, for Fucino-like stations, as a function of the amount of the used common resource and the h factor. Four systems are compared with all the combinations of the UPC and VBCR features. The results show that the full fade countermeasure (FCM) system needs only 50% of the common resource to give the maximum improvement of P0, while the same system without UPC would need a common resource greater than the allowable one to reach the maximum gain. This tendency is even more obvious in the case of Lario-like stations (fig. 2). As expected, the dependence of P0 on the factor h is higher if the common resource is smaller.

<table>
<thead>
<tr>
<th>number of stations</th>
<th>link capacity [Kbit/s]</th>
<th>total stream capacity [Kbit/s]</th>
<th>capacity for datagram [Kbit/s]</th>
<th>system overhead (1) [Kbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>84</td>
<td>3072</td>
<td>3268</td>
<td>1794</td>
</tr>
<tr>
<td>10</td>
<td>384</td>
<td>3840</td>
<td>3858</td>
<td>494</td>
</tr>
<tr>
<td>2</td>
<td>1292</td>
<td>3840</td>
<td>4131</td>
<td>221</td>
</tr>
</tbody>
</table>

Table 4. Simulation parameters. Channel capacity = 8192 Kbit/s

In fig. 3 P0 is plotted versus LBM for Fucino-like stations, for an availability of 50% of the common resource. This graph allows an evaluation of how big the LBM must be, once a certain P0 is required. The comparison among the four systems is straightforward. For a Po of 10^-4 the UPC+VBCR system gains about 10 dB on the UPC system and 18 dB on the system

(1) reference burst + two control slots + stream slot preamble + control sub-burst
without any FCM. The comparison with the VBCR system would be more fair only allowing a higher amount of the common resource.

For the 10 and the 2 stations runs (figs. 4-6), videoconference applications are considered, following the H.261 protocol, with COS 1 (high quality video) and rates of 384 and 192 Kbit/s, respectively. In other runs the same applications are supposed to be compressible in bandwidth, for the VBCR systems, by a factor in the range from 1 to 6 in the 384 Kbit/s case and by a factor in the range from 1 to 15 in the 192 Kbit/s case, respectively. The results of these runs are plotted in figs. 7 to 9. It can be seen that a higher compression factor of the applications affects favourably the common resource occupancy. Indeed, for a certain compression factor, the gain increases only up to a certain percentage of the common resource occupancy. Conversely the graphs allow an evaluation of the percentage of time during which the application is compressed at the various levels, for a fixed percentage of the common resource.

Finally, the use of the common resource is shown in figs. 10 and 11, where the probability that a percentage of the common resource is exceeded is plotted for 48 Fucino-like and 48 Lario-like stations, respectively. Probability values lower than 10^-4 have a lower accuracy then the ones relative to the collection of 1000 favourable events. This is because the simulation program was stopped after 10^6 total events, regardless of the number of the favourable events, to save the huge amount of CPU time that would have been otherwise required.

Conclusions

The performance analysis of the FODA/IBEA system has been made using a Monte Carlo simulation. This study shows that the outage probability of a link can be reduced to acceptable values even in Ka band, when transponders with good performance (i.e., with spot coverages), such as Olympus, are employed. The common resource, i.e., the capacity allocated for datagram, is scarcely used on average by the faded stream links. It must be outlined that the performance shown by the figures is relative to a full occupation of the capacity reserved for stream (about half of the nominal channel capacity). In the practice, due to the demand assignment philosophy of the channel capacity, the system is not generally loaded at its maximum with stream traffic. In this case, the system offers a higher performance, in terms of the stream links outage and/or in terms of the availability of the capacity reserved for datagram.

Acknowledgements

The authors thank Mr. N. James, Mr. A. Baslington, Mr. A. Brown, Mr. M. Williams and Mr. R. Wilden, from Marconi R.C. (U.K.), who were involved in the realisation of the flexible TDMA station, and Mr. A. Marzoli and Mr. M. Neri from Telespazio (I) for their precious collaboration.

References

[10] Programma Sirio - "I principali risultati dell'esperimento di propagazione di onde elettromagnetiche a frequenza superiore ai 10 GHz" (3 volumes), CNR-CSTTS - Centro di Studio per le Telecomunicazioni Spaziali, Roma, 1983.
Figure 1. Four systems are compared: with and without VBCR, with and without UPC. 48 Fucino-like stations are considered.

Figure 2. Four systems are compared: with and without VBCR, with and without UPC. 48 Lario-like stations are considered.

Figure 3. Four systems are compared: with and without VBCR, with and without UPC. 48 Fucino-like stations are considered. The availability of the common resource is 50%.

Figure 4. The FODA/BEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. 10 Fucino-like stations are considered.

Figure 5. The FODA/BEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. 10 Lario-like stations are considered.

Figure 6. The FODA/BEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. 2 Fucino-like stations are considered.
Figure 7. Performance of the FODA/BEA system loaded with applications allowing different compression factors. 2 Fucino-like stations are considered.

Figure 8. Performance of the FODA/BEA system loaded with applications allowing different compression factors. 10 Lario-like stations are considered.

Figure 9. Performance of the FODA/BEA system loaded with applications allowing different compression factors. 10 Lario-like stations are considered.

Figure 10. Probability that a percentage of the common resource is exceeded for various values of the h factor. 48 Fucino-like stations are considered. Both VBCR and APC features are used.

Figure 11. Probability that a percentage of the common resource is exceeded for various values of the h factor. 48 Lario-like stations are considered. Both VBCR and APC features are used.