

# OUTAGE PROBABILITY OF AN ADAPTIVE TDMA SATELLITE ACCESS SCHEME

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## Summary

Adaptive TDMA is a member of the "shared resource" branch of the fade countermeasure family. The throughput of a satellite channel is maximised by varying the data rate and the coding rate used by a number of transmitters according to the signal-to-noise ratio at the receiver. The highest possible transmission rate and the best coding rate (uncoded) is used on unfaded links. Faded links are assisted by choosing bit and coding rates according to the fade level to be countered. An adaptive method is considered to counteract rain attenuation effects in satellite links operating above 10 GHz, in particular in the 20/30 GHz band. The Monte Carlo method has been used to simulate the system in order to compute the outage probability which seems to achieve very low levels also when rain fades are severe. The experimental rain attenuation data measured at 11.6 GHz in two Italian stations with the Sirio satellite have been used.

The adaptive method (FODA/IBEA) has been already largely described<sup>1, 4, 5</sup> therefore only short outlines are made here.

## Introduction

A prototype of TDMA station has been developed by the Marconi Research Centre (UK) for use in a number of advanced communications 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<sup>(\*)</sup>, based on demand assignment of the channel capacity and able to simultaneously support both stream (isochronous) and datagram (anisochronous) traffic. 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 the service (COS) required by the sending application, independently of other packets within the same burst. The quality of the service required by the traffic is maintained, as much as possible, also in deep fade conditions by selecting a data bit rate and a coding rate suitable to gain a number of dB sufficient to counter the loss of dB due to the signal fade.

At the writing time, FODA/IBEA is going to be tested on the Olympus satellite in the framework of the Italian experiments in the 20/30 GHz band.

An adaptive method known in literature is BLC (Burst Length Control). It is the easiest form of adaptive coding to implement, applicable in time-division systems. BLC leaves at the end of the frame an empty space for use *exclusively* during the rain fade events. This space remains free in "normal conditions", i.e. when the power margin on each link is adequate to assure the required performances. When the power margin on a particular link becomes unable to overcome the rain attenuation, the transmission from/to the station in difficulty is increased in length H times, obtaining a multiplication by

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(\*) Fifo Ordered Demand Assignment/ Information Bit Energy Adaptive

H of its energy and the possibility to introducing a proper coding of the signal. As also using efficient coding schemes of reasonable complexity, the coding gain is bounded between 5 and 7 dB, BLC can be used when rain fades are not too severe (for an outage probability of  $10^{-3}$  or higher in a year). Moreover, the empty space devoted to be the shared common resource cannot be neither too large, otherwise the frame utilisation becomes too low, nor too small. The number of reserved slots necessary to maintain reliability of connections already in use when fade events occur depends on several factors, such as the number of stations, the traffic distribution among the stations, the geographical distribution of the ground stations relative to the profiles of high rain attenuation regions and the volume of traffic carried by ground stations in high rain-attenuation regions. Another factor to be kept into consideration is the relationship between the busy hour, when all the time slots not reserved for resource sharing might be expected to be in heavy demand, and the time of the day occurrence of significant rain attenuation events.

FODA/IBEA uses the *full frame* for simultaneous transmissions of stream and datagram traffic. In unfaded conditions, the stream traffic cannot overcome a fixed boundary in the frame, leaving the rest of the frame to the datagram transmissions. In faded conditions, data are sent with a redundancy chosen according to the fade level to be counteract. This redundancy is computed acting on both the data coding rate and, if necessary, on the data bit rate. It provokes an enlarging of the data in the frame, with the consequence that some data must wait a longer time inside the station before to be transmitted. By definition of isochronous traffic, the stream data must be sent at regular intervals of time; therefore their transmission cannot be delayed, while the transmission of the datagram traffic can be. Therefore, as the already active stream transmissions must be guaranteed as much as possible, the enlarging of the stream data sacrifices the datagram traffic. In very deep fade conditions, the datagram traffic may be suspended, leaving all the available space in the frame to support the already active stream transmissions. In faded conditions, new stream links are not accepted.

The space in the frame devoted in clear sky conditions to the datagram traffic is the *common resource*, sharable in faded conditions among all of the stream transmissions which need to be assisted. When the whole common resource is insufficient to support the faded stream links at the requested class of service, the system tries to gain more space in the frame by requiring those applications which can work compressed, to compress themselves till when the deep fade condition is overcome.

## 2. The outage probability (using the Monte Carlo method)

The best way to show 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  $P_O$ ) that the BER over a link is higher than the target value. The complexity involved in deriving  $P_O$  in closed form is due to the huge number of the possible system states. In fact, for each COS, each station can be in one of the  $f$  possible fade levels. So the number of the mutually exclusive states in which the system can be, for  $n$  stations, is  $f^n$ , where  $f$  is a number between 6 and 10 (depending on the considered COS). The number of the system states is thus prohibitively high, even for a small  $n$ .

In Tab. 1 the fade ranges and the transmission parameters (bit and coding rates) are reported, as function of the BER range relevant to the COS requested by the application, and of the  $C/N_0$  (carrier power to noise density ratio) available at the receiver. Four classes of service are envisaged.

(a)-Class of service = 0 ( $BER < 10^{-8}$ )					
C/No range [dBHz]	Eb/No range [dB]	Fade range [dB]	Bit rate [Mbit/s]	Code rate	Data redundancy (+)
81	12	0	8	1	1
80.5 - 77	11.5 - 8	0.5 - 4	8	4/5	1.25
76.5 - 75	7.5 - 6	4.5 - 6	8	2/3	1.5
74.5 - 74	8.5 - 8	6.5 - 7	4	4/5	2.5
73.5 - 72	7.5 - 6	7.5 - 9	4	2/3	3
71.5 - 71	8.5 - 8	9.5 - 10	2	4/5	5
70.5 - 69	7.5 - 6	10.5 - 12	2	2/3	6
68.5 - 68	8.5 - 8	12.5 - 13	1	4/5	10
67.5 - 66	7.5 - 6	13.5 - 15	1	2/3	12

(b) - Class of service = 1 ( $10^{-8} < BER < 3 \times 10^{-7}$ )					
C/No range [dBHz]	Eb/No range [dB]	Fade range [dB]	Bit rate [Mbit/s]	Code rate	Data redundancy (+)
81 - 80.5	12 - 11.5	0 - 0.5	8	1	1
80. - 76.5	11 - 7.5	1 - 4.5	8	4/5	1.25
76. - 75	7 - 6	5 - 6	8	2/3	1.5
74.5 - 73.5	8.5 - 7.5	6.5- 7.5	4	4/5	2.5
73 - 72	7 - 6	8 - 9	4	2/3	3
71.5 - 70.5	8.5 - 7.5	9.5- 10.5	2	4/5	5
70 - 69	7 - 6	11 - 12	2	2/3	6
68.5 - 67.5	8.5 - 7.5	12.5- 13.5	1	4/5	10
67 - 66	7 - 6	14 - 15	1	2/3	12

(c)- Class of service = 2 ( $3 \times 10^{-7} < BER < 3 \times 10^{-5}$ )					
C/No range [dBHz]	Eb/No range [dB]	Fade range [dB]	Bit rate [Mbit/s]	Code rate	Data redundancy (+)
81 - 78	12 - 9	0 - 3	8	1	1
77.5 - 75	8.5 - 6	3.5 - 6	8	4/5	1.25
74.5 - 72	8.5 - 6	6.5 - 9	4	4/5	2.5
71.5 - 69	8.5 - 6	9.5 - 12	2	4/5	5
68.5 - 66	8.5 - 6	12.5 - 15	1	4/5	10

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(+) Data redundancy = (8/bit rate) x (1/code rate)

(d) - Class of service = 3 ( $3 \times 10^{-6} < \text{BER} < 10^{-3}$ )					
C/No range [dBHz]	Eb/No range [dB]	Fade range [dB]	Bit rate [Mbit/s]	Code rate	Data redundancy (+)
81 - 76	12 - 7	0 - 5	8	1	1
75.5 - 75	6.5 - 6	5.5 - 6	8	4/5	1.25
74.5 - 73	8.5 - 7	6.5 - 8	4	1	2
72.5 - 72	6.5 - 6	8.5 - 9	4	4/5	2.5
71.5 - 70	8.5 - 7	9.5 - 11	2	1	4
69.5 - 69	6.5 - 6	11.5 - 12	2	4/5	5
68.5 - 67	8.5 - 7	12.5 - 14	1	1	8
66.5 - 66	6.5 - 6	14.5 - 15	1	4/5	10

Tab. 1 - Transmission characteristics for various classes of services

A Monte Carlo analysis has thus been developed to investigate the  $P_0$  variation (relative 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. Preliminary investigations of joint attenuation distributions have been carried out in Italy as part of the Sirio programme, using the three stations of Lario (North Italy), Spino d' Adda (North Italy) and Fucino (Centre-Sud Italy). The attenuation distributions at 11.6 GHz obtained over the total five years period during which Sirio was maintained at the longitude of  $15^\circ$  W have been taken as reference. Frequency scaling extrapolations of the above distributions at 20/30 GHz for Fucino and Lario stations<sup>11</sup> have been used in the Monte Carlo simulation. From the rain attenuation point of view, Lario is the worst station among the ones experimented in the Sirio programme; however locations having still worse behaviour may be found in Italy. The cumulative attenuation distributions of the stations are computed using the CCIR interpolation formula<sup>8</sup>:

$$A_p = A_{001} 0.12 p^{-(0.546 - 0.0043 \log p)}$$

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, like the Fucino station. In addition, some tests were made for stations like Lario ( $A_{001}$  still derived from Sirio). In Tab. 2 the parameters  $A_{001}$  used for the simulation are reported, for both types of stations and for both up and down-link frequencies, respectively.

Frequency [GHz]	$A_{001}$ [dB]	$A_{001}$ [dB]
	Fucino-like stations	Lario-like stations
30	22.5	59
20	12	29

Table 2: Attenuation exceeded for 0,01% of the time ( $A_{001}$ ) for Fucino and Lario-like stations. Data frequency scaled from the 11.6 GHz values of the SIRIO experiment.

The Sirio experiment also allowed to investigate on the statistical dependence among the attenuations at the various stations. The statistical 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<sup>12</sup>. Denoting the probability to exceed a certain attenuation at each station by  $P_A$ , the joint probability  $P_{A_j}$  to exceed that attenuation at  $n$  stations is

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

A value of  $h = 1$  simulates the statistical independence among the attenuations of the stations, while a value of  $h = 20$  has been considered as the maximum station dependence. This value of  $h$  was measured between two stations rather close together<sup>11</sup> (Lario and Spino d'Adda, 85 Km apart) and with very similar climatic characteristics.

The simulation program (outage.c) is written in C and it runs on an IBM RISC 6000 machine. The simulation parameters are contained in an input file which can be modified by the user according to the type of run. They are:

- the number of stations,
- the throughput of each station [Kbit/s],
- the type of the station, i.e. Lario-like station or Fucino-like station,
- the type of the up-link (as previous),
- the required class of service,
- the percentage of the common resource which can be used to assist the faded stream links,
- the usable compression factor,
- the up-link power control value [dB],
- the link budget margin [dB],
- the number of outages to collect before stopping the run.

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

The CPU cost of the outage analysis was roughly of 300 hours. Another simulation program, derived from outage.c, has been written in order to evaluate the probability that the common resource is used at a certain percentage (datagram.c). About 200 hours of CPU time were spent to evaluate such a probability.

The following assumptions were made in order 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  $P_O$  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 graphs. No investigation has been made on the available datagram capacity in order to evaluate the datagram links outage probability.
- no transponder intermodulation noise reduction, due to one attenuated carrier, is taken into account;

- data reported in Tab. 3 were assumed as the link budget parameters.

Up-link freq. [GHz] (CH1)	28.072255	Total IPFD [dBW/n <sup>2</sup> ]	-101
Down-link freq. [GHz] (CH3)	19.475	Input Back-off [dB]	8
E/S EIRP [dBW]	73	Satellite EIRP [dBW]	55.5
E/S HPA Back-off [dB]	3	Output Back-off [dB]	4.5
Up-power Control Margin [dB]	12	E/S G/T [dB/K]	27.3
Satellite G/T [dBK]	14	Down-link C/No [dB]	90
C/T at satellite input [dBW/K]	-142.5	C/No at E/S receiver [dBHz]	83.2
Intermodulation C/T [dBW/K]	-140	Eb/No at 8Mbit/s [dB]	14
Total Up-link C/T [dBW/K]	-145	Modem impl. margin [dB]	1
Up-link C/(No+Io) [dBHz]	84.2	Eb/No in clear sky conditions	12
Number of carriers	3	Link budget margin [dB]	1

Table 3. Link budget for the Olympus  $K_a$  transponder.

Three carriers at 8Mbit/s access the transponder in FDMA.

The 2.5 m E/S is equipped with a 70 W HPA.

The FODA/IBEA system implements both the up-power-control (UPC) and the variable bit and coding rate (VBCR) features. Comparisons are made with systems without UPC and/or without VBCR. Systems without VBCR are assumed to send permanently redundant data, in such a way as to occupy a bandwidth equivalent to the sum of the stream plus the common resource bandwidth occupied by the systems working with VBCR. It must be emphasized that the common resource used by FODA/IBEA is available for datagram traffic (as shown later on) for most of the time, while a system without VBCR has no space available for datagram, even under low fade conditions.

The minimum Eb/No net value is fixed at 6 dB because, for lower values, the modem burst acquisition performance is poor. This poses a limitation on the utilised coding rates. In fact, even for the  $\text{COS} = 0$ , 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 from 1.14 to 1.5 respectively. For higher redundancy (e. g. 2, equivalent to 100% of the common resource) a suitable redundancy 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 no common resource to obtain  $P_o$  relative to systems without VBCR.

In the simulation the transponder is employed without automatic gain control (AGC) and the up-link C/No 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/No by reducing the satellite input back-off. This fact may force us to reduce the number of carriers on the transponder.

### 3. Simulation results

In Tab. 4 a summary of the most significant parameters relevant to the various simulations is reported. All of the simulations were made for the h parameter equal to 1, 5 and 20, respectively.

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 confidence interval  $\pm 10\%$ .

number of stations	link capacity [Kbit/s]	total stream capacity [Kbit/s]	capacity for datagram [Kbit/s]	system overhead(*) [Kbit/s]
48	64	3072	3326	1794
10	384	3840	3858	494
2	1920	3840	4131	221

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

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

Runs with 48 stations were made considering 64 Kbit/s links with  $\text{COS} = 0$ . In Fig. 1  $P_O$  is reported, for Fucino-like stations, as a function of the amount of the used common resource and the station dependence factor. Four systems are compared with all the combinations of the UPC and VBCR features. It is evident that the full FCM system needs only 50% of the common resource to give the maximum improvement of  $P_O$ , 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  $P_O$  on the factor  $h$  is higher if the common resource is smaller.

In Fig. 3  $P_O$  is reported, for Fucino-like stations, as function of LBM, for an availability of 50% of the common resource. This graph allows an evaluation of how big the LBM must be, once a certain  $P_O$  is required. The comparison among the four systems is straightforward. For a  $P_O$  of  $10^{-4}$  the UPC+VBCR system gains about 10 dB on the UPC system and 18 dB on the system 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 two stations runs (Figs. 4-6), H.261 videoconference applications are considered, with  $\text{COS} = 1$  (high quality video) and rates of 384 and 1920 Kbit/s, respectively. Such applications are supposed to be compressible in bandwidth, for the VBCR systems, by a factor between 1 and 6 in the 384 Kbit/s case and by a factor between 1 and 15 in the 1920 Kbit/s case, respectively. The results of these runs are reported in Figs. 7 to 9. In general it can be seen that by increasing the compression factor of the applications the common resource occupancy is saved for a higher percentage of the time. In fact, 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, once the percentage of the common resource made available is fixed.

Finally, the use of the common resource is shown in Figs. 10 and 11.. ??????????????????????

## Conclusions

FODA/IBEA allows both stream and packet traffic to be accommodated in the same network. In addition stations can operate with reduced power margins since the system adapts the transmitted bit energy in real time to counteract fade conditions. Such a system will allow the use of smaller earth stations and so will improve the economics of user-located satellite communications networks.

(\*) reference burst + two control slots + stream slot preamble + control sub-burst

The system performance analysis has been made using a Monte Carlo simulation. This study shows that, using the FODA/IBEA system, the outage probability of a link can be reduced to acceptable values even in Ka band, when transponders with good performances (i.e. with spot coverages), such as Olympus, are employed. The common resource, i.e. the capacity allocated for datagram is scarcely used by the faded stream links.

## Acknowledgements

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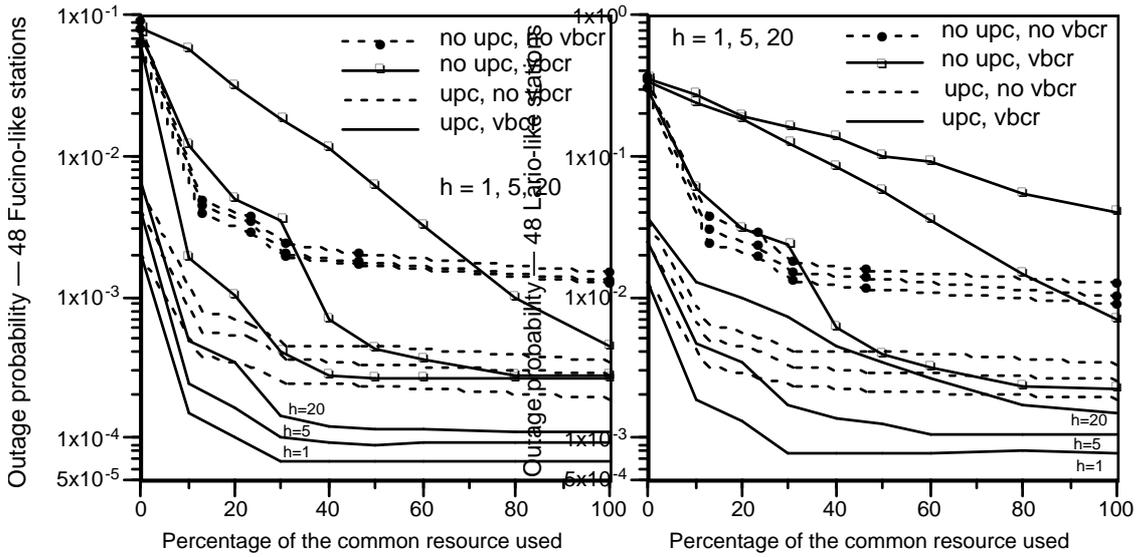


Figure 1. Four systems are compared: with and without VBCR, with and without UPC. 48 Fucino-like stations are considered.

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

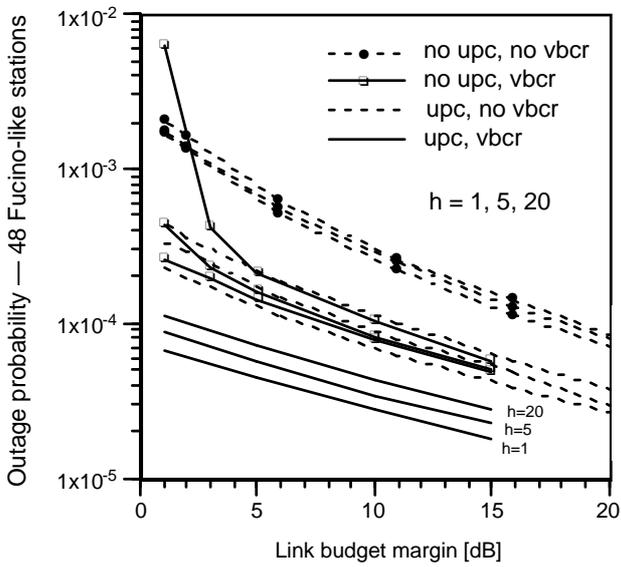


Figure 3. Four systems are compared: with and without VBCR, with and without UPC. 48 Fucino-like stations are considered.

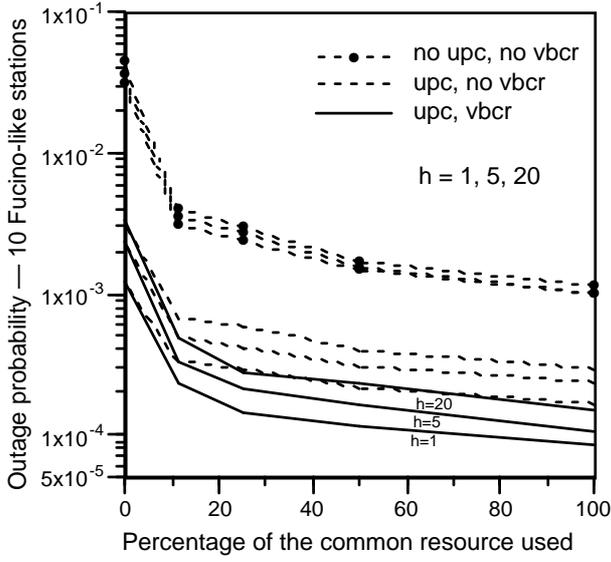


Figure 4. The FODA/IBEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. 10 Fucino-like stations are considered.

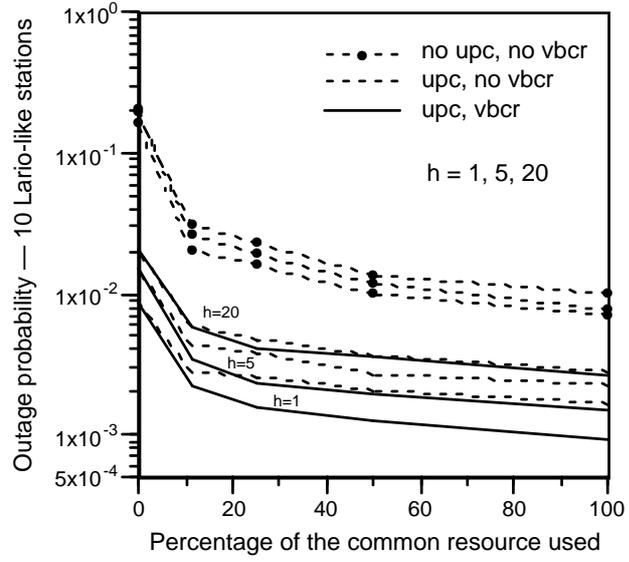


Figure 5. The FODA/IBEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. 10 Lario-like stations are considered.

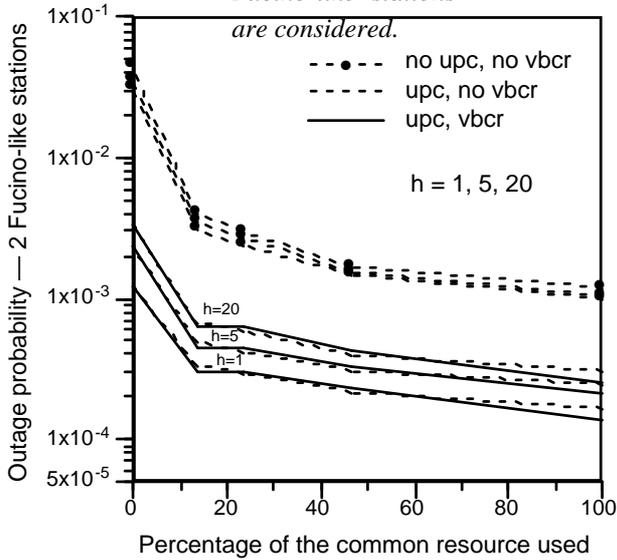


Figure 6. The FODA/IBEA system is compared with two systems with fixed bit and coding rate, one of them with UPC. Two Fucino-like stations are considered.

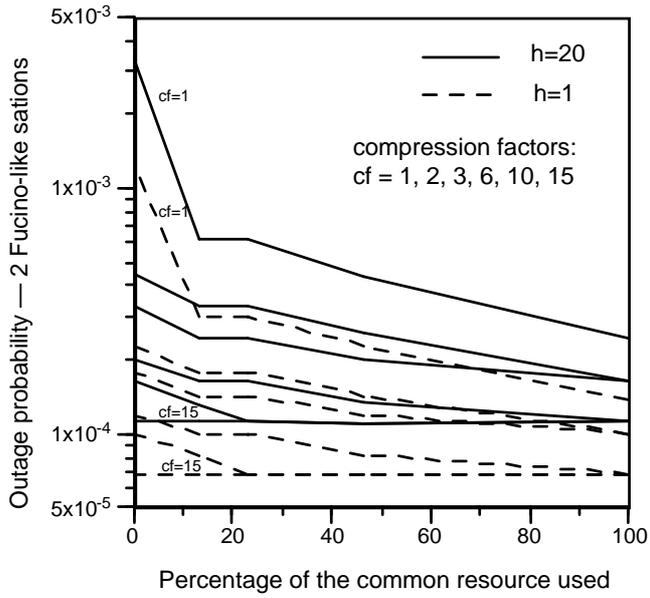


Figure 7. Performance of the FODA/IBEA system loaded with applications allowing different compression factors. Two Fucino-like stations are considered.

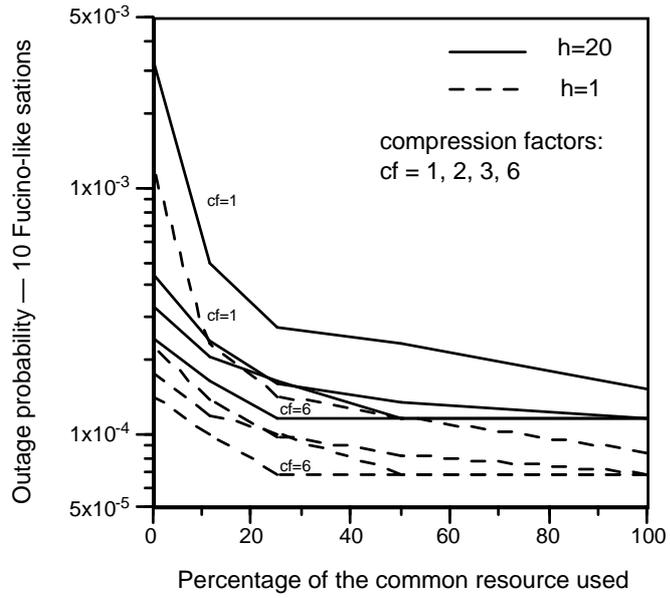


Figure 8. Performance of the FODA/IBEA system loaded with application allowing different compression factors. 10 Fucino-like stations are considered.

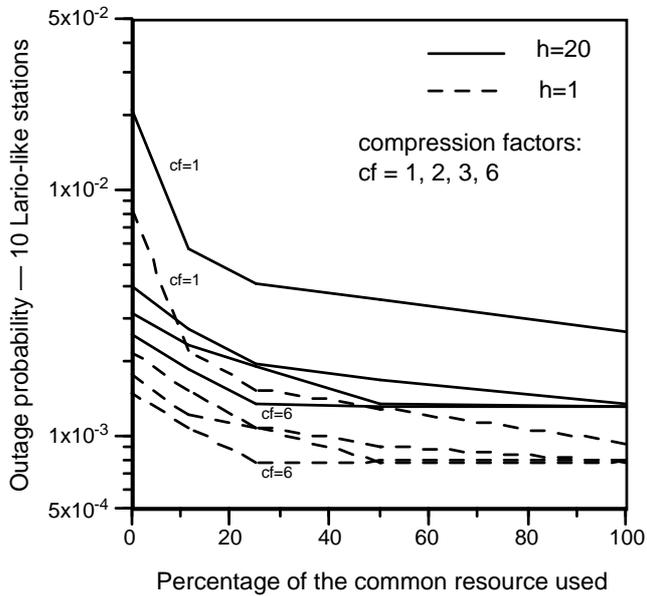


Figure 9. Performance of the FODA/IBEA system loaded with applications allowing different compression factors. 10 Lario-like stations are considered.

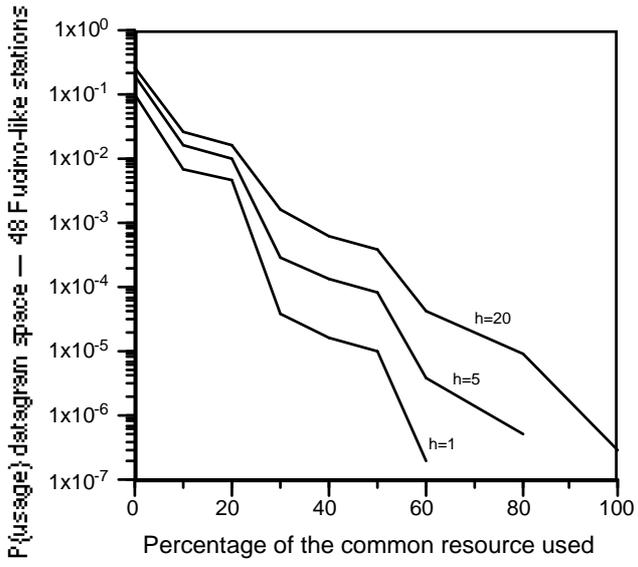


Figure 10. Didascalia 10.

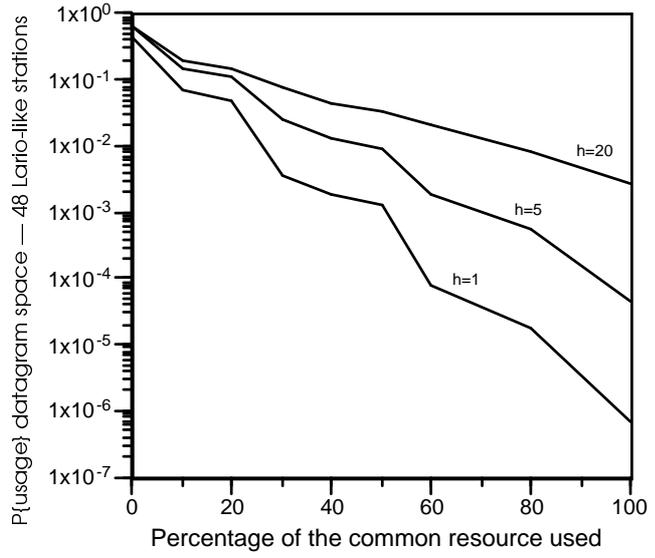


Figure 11 Didascalia 11.