REPORT 918-1*

AVAILABILITY OF COMMUNICATIONS CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Question 85/8)

(1982-1990)

1. Introduction

The availability of communications circuits in the maritime mobile-satellite service needs to be defined in order to provide guidance to system planners and equipment manufacturers, and thus to provide an adequate standard of service to the user. In deriving a suggested philosophy for availability criteria, differences between the maritime mobile-satellite service and the fixed-satellite service are identified. However, it is considered that the concept of availability for the maritime mobile-satellite service should, as far as possible, be compatible with similar concepts adopted for the fixed-satellite service (Report 706) and for radio-relay systems (Report 445).

The approach adopted in this Report is to consider only those factors which can be accommodated by adequate system planning, equipment design and maintenance procedures. Examples of the INMARSAT system availability for general and distress communications are based on historic data obtained from actual operations.

2 General definitions and philosophy

2.1 *Definition of circuit availability*

The availability of communications circuits in the maritime mobile-satellite service will depend on the availability objectives set for each component part of the circuit. In this Report, consideration is given to availability objectives for the space sector, earth-station equipment and auxiliary functions, and for the radio paths between satellite and earth stations. The overall availability of the communications circuit is thus determined.

In the maritime mobile-satellite service, circuit availability (A) can be derived from the duration and rate of occurrence of interruptions to the component parts of the circuit, and can be defined as follows:

$$A = \frac{\text{(scheduled operating time)} - \text{(down-time)}}{\text{(scheduled operating time)}} \times 100 \ (\%)$$

where scheduled operating time is the time during which the circuit of interest is expected to perform its intended function, and down-time is the cumulative time of circuit interruptions within the scheduled operating time.

---

* The Director, CCIR, is also requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

When the concept of availability is applied to individual component parts of a circuit, and in particular to equipment at coast earth stations (CES) and ship earth stations (SES), the definition of availability for these component parts (A') may be written in terms of mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR), as follows:

$$A' = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100 \ (\%)$$

When considering the availability of telephone circuits, use can be made of the hypothetical reference circuit (Recommendation 546).

The time for which a communications circuit is said to be unavailable should include delays in setting up the call arising from failures in the satellite signalling system.* Failures in the shore-to-ship signalling channel, the ship-to-shore random access channel or the shore-to-shore signalling channel, due to adverse propagation conditions on the radio paths may result in a failed call.

It should be noted that in order to ensure continuous and reliable operation of the INMARSAT system, the following special measures have been implemented:

(a) to protect the system from possible interfering, e.g. signals resulting from malfunction of ship earth stations, coast earth station, satellite or other sources outside the system, contingency frequency plans and reserve frequencies both for signalling and communications circuits are provided in each ocean region;

(b) two common request channels are used;

(c) an operational and at least one spare satellite is provided in each ocean region. In the event of failure or degradation of service, traffic can be transferred to a spare satellite;

(d) the INMARSAT Operations Control Centre continuously monitors system performance and initiates appropriate actions as necessary to preserve system integrity; and

(e) equipment redundancy is provided at CESs to minimize risk of outage. In some cases, this extends to providing for access from spare antennas and RF equipment.

Calls lost due to congestion in the terrestrial network or the satellite network are not included in availability considerations as they relate to grade-of-service requirements rather than to availability.

* Note signalling channels should be designed to have a very high reliability such that signalling outage effects are insignificant compared to other possible causes of interruptions to communications circuits.

2.2 *Definitions of interruption*

The following sections give definitions of interruption for telephony and telegraphy. In view of the differing nature of these services, different availability criteria may be required for them, and this should be the subject of further study. Interruptions to data channels are also considered below.

2.2.1 *Telephony*

The following definition for interruption to telephony circuits in the maritime mobile-satellite service is consistent with that proposed for the fixed-satellite service (Report 706):

A telephone circuit in the maritime mobile-satellite service should be considered to be interrupted if a channel experiences one of the following conditions for more than 10 consecutive seconds:

- the wanted signal entering one end of the channel is not received at the other end,
- for analogue transmission, the unweighted subjectively equivalent noise power in the telephone channel exceeds 10^6 pW0p.
- **for digital transmissions, a channel Bit Error Rate (BER) worse than 10^{-2} (for 99% time) occurs.**

Further information on the availability of telephony circuits can be found in CCITT Recommendation G.821.

2.2.2 *Telegraphy*

The following definition for interruption to telegraphy circuits has also been suggested:

A telex circuit in the maritime mobile-satellite service should be considered to be interrupted if N character errors are detected in a time interval less than 1.5 N s, where N is between 10 and 20.

This definition is considered to provide for sufficient measurement time and accuracy, and to take account of character error rates of the order of one error in 10 characters.

In practice, a fade of 5 to 6 dB above AFC level in the radio path is considered by coast earth station operators to represent an interruption. Persistent occurrences of such an interruption will cause the CES operator to shift the traffic to a reserve carrier.

2.2.3 Data

The definition of interruption will depend on the bit rate adopted for the service, the required error rate and the distribution of the errors. The availability of data channels requires further study.

2.2.4 System element outages

The following are definitions of system element outages that may result in interruption of a service:

(i) Space Segment Outage

Any interruption of more than ten consecutive seconds directly attributable to the operational satellite.

(ii) Network Coordination Station Outage

Any interruption of the vital network coordination functions, such as loss of call processing capability, of more than ten consecutive seconds, affecting the collocated coast earth station or coast earth stations.

(iii) Network Outage

Any interruption of services of more than ten consecutive seconds affecting all coast earth stations in an ocean region caused by adverse propagation phenomena or interfering signals on any of the AFC channels, request channels, Coast Earth Station TDM frequencies or on the common TDM frequency.

(iv) Coast Earth Station Outage

Any complete loss of all telephone channels, or all telex channels, or of both, of more than ten consecutive seconds, or a corresponding loss of call processing capability of more than one minute that is directly attributable to the coast earth station.

2.3 *Scheduled operating time*

Availability criteria proposed for the fixed-satellite service apply to the availability of full-time circuits (telephony and television), where the scheduled operating time is the same as the calender time. In the maritime mobile-satellite service the shore-to-ship telegraphy/signalling channels will be operated on a full-time basis in that the carriers will be permanently activated, but telephony channels (shore-to-ship and ship-to-shore) and the telegraphy/signalling channels transmitted by ships will only be activated for the duration of the call.

Equipment availability at coast earth stations and ship earth stations is not affected significantly by the inherently demand-assigned nature of the maritime service (compared to the availability of essentially the same equipment operating with permanently activated carriers). Hence the scheduled operating time is equated to calendar time for all equipment.

2.4 *Factors affecting availability*

The overall availability of circuits in the maritime mobile-satellite service will depend on the availability criteria adopted for the following:

- *Space sector*, including satellite equipment, the effects of satellite manœuvres and the provision of spare satellites;
- *Coast earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and natural disasters), and the effects of human error;
- *Ship earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and environmental conditions), and the effects of human error;
- *Auxiliary functions*, such as might be performed by control coast earth stations (e.g. frequency control, power control and channel assignment);
- *Shore/satellite and ship/satellite RF links*, in particular the effects of attenuation and excess noise due to precipitation, the effects of multipath fading and the effects of interference such as might arise from terrestrial and space services.

Despite this, in determining realistic availability objectives, it would not be practicable to take account of all the above eventualities.

2.5 Influence of natural or extreme phenomena

For the purpose of this Report interruptions are classified as follows:

- Predicted interruptions: either interruptions to correct non-catastrophic failures which may be planned to occur at some time and which can be tolerated for relatively short periods (e.g. equipment faults, propagation fading), or scheduled interruptions which are known to occur at specific times (e.g. certain types of preventive maintenance on equipment, sun interference at coast earth stations);
- Unpredicted *interruptions:* those interruptions whose occurrence or duration cannot be predicted and which could cause prolonged outages (e.g. natural disasters such as earthquakes, high winds or exceptionally severe sea conditions, and natural blockage effect such as shielding by mountains).

For the coast earth stations and ship earth stations, it is considered that interruptions due to unforeseen circumstances should be excluded from availability considerations, and account should be taken only of foreseen interruptions. In addition, for ship earth station equipment, the following foreseen interruptions should be ignored:

2.5.1 *Interruptions due to sun interference*

With fixed earth stations, outages due to excessive noise on the down-path when the sun passes through the antenna beam can be predicted; durations of outages will depend on individual station locations, but degradations will be encountered for about 30 min for 3-4 days twice a year. Adverse effects on the service can, therefore, be minimised by arranging to pass traffic via alternative routes. With mobile stations, such as ship earth stations, the occurrence of sun interference will depend on the ship's route, which will vary from ship to ship, and this phenomenon could therefore be encountered several times in the course of a year by particular ships. The duration of the interference would be longer than for shore stations because of the relatively broad beamwidth of the ship-borne antenna, although the degradation in receiver noise temperature would be less severe.

2.5.2 *Interruptions due to severe weather conditions*

Current ship earth station equipment is designed to withstand severe environmental conditions such as temperature variations, humidity, precipitation, wind and vessel motions; typical conditions are given in the document "Technical Requirements for INMARSAT Standard-A ship earth stations" [INMARSAT, 1988, issue 3].

Additional protection to the above-deck equipment is provided by a radome, but at some time most ships will encounter weather conditions which will render the equipment inoperable, e.g. inability to maintain antenna-pointing due to high sea state conditions. It is therefore considered that such interruptions should not be included in the assessment of ship terminal availability, although equipment manufacturers and system planners should not be discouraged from investigating means of maintaining ship terminal operation under extreme conditions.

2.5.3 *Interruptions due to antenna blockage effects*

Although ship owners and manufacturers should be encouraged to install ship earth stations in locations which minimize the probability of antenna blockage, such locations may not be available in all cases. It is therefore proposed that these outages be excluded from availability criteria.

2.6 *Measurement of circuit availability*

Taking account of the exceptions outlined in § 2.5 above, the following expression should be used for the measurement of communications circuit availability in the maritime mobile-satellite service:

$$A = \frac{T_s - (T_{sat} + T_1 + T_2 + T_{shore} + T_{ship} + T_{aux})}{T_s} \times 100 \qquad (\%)$$

where:

T_s: scheduled operating time;

T_{sat}: cumulative time of circuit interruptions caused by failures of the satellite;

T_1: cumulative time of circuit interruptions attributable to factors on the shore-to-ship radio path (i.e. $T_1 = T_{shore\ sat} + T_{sat\ ship}$, where $T_{shore\ sat}$ refers to the shore-to-satellite link, and $T_{sat\ ship}$ refers to the satellite-to-ship link);

T_2: cumulative time of circuit interruptions attributable to factors on the ship-to-shore radio path (i.e. $= T_2 = T_{ship\ sat} + T_{sat\ shore}$, where $T_{ship\ sat}$ refers to the ship-to-satellite link, and $T_{sat\ shore}$ refers to the satellite-to-shore link);

T_{shore}: cumulative time of circuit interruptions caused by failures of shore station equipment and communications capability;

T_{ship}: cumulative time of circuit interruptions caused by failures of ship terminal equipment and communications capability;

T_{aux}: cumulative time of circuit interruptions caused by failures of auxiliary functions at separate control earth stations.

In the event of two or more items occurring simultaneously, only the duration of the longest interruption should be taken into account.

3. Assessment of availability objectives

3.1 Space Sector

The actual availability of the INMARSAT space segment for the maritime mobile-satellite service can be assessed from past experience with operational and spare satellites in-orbit performance. Over 1988, the INMARSAT space segment availability in each of the three ocean regions (Atlantic (AOR), Pacific (POR) and Indian (IOR)) was 100%. For the operational period from 1982 to 1988 the overall three region availability was 99.995%, in the AOR - 99.990, in the IOR - 99.995, in the POR - 99.998. The high level of availability was maintained mainly due to the measures described in § 2.1 and rapid corrective actions by the Operations Control Centre.

3.2 *Earth station equipment*

Availability criteria for coast earth stations can be derived from experience gained with earth stations in the fixed-satellite service, and may therefore be readily defined. The derivation of availability criteria for ship earth stations, however, cannot be obtained so precisely, for the following reasons:

- the performance of INMARSAT ship earth stations is not under the direct control of operating administrations, and cannot be easily monitored full-time on a long-term basis;
- compared to INMARSAT coast earth stations environmental conditions for ship earth station operation are more severe, and facilitites available on ships at sea for repair and maintenance purposes are limited; furthermore, both the environmental conditions and the maintenance facilities will vary from ship to ship.

Account should be taken of the respective roles of coast earth station operators and ship earth station users: an outage at a coast earth station would result in loss of service to a considerable number of ships, whereas an outage of a ship earth station would generally affect only that ship. Hence, in theory, the availability objectives for shore stations should be higher than for ship earth stations.

Auxiliary functions provided by control stations will affect all coast earth stations and ships in the coverage area, and hence an outage could lead to complete system disruption. Availability objectives for these functions will therefore need to be high.

3.2.1 *Coast earth stations*

Twenty coast earth stations are operating in the INMARSAT system and their availabilities for the provision of satellite circuits during 1988 ranged from 98.43% to 100%.

3.2.2 *Ship earth stations*

Faults on ship terminal equipment can occur at any time, and it would be unreasonable to assume that ships will carry sufficient spare components and maintenance expertise to cope with all eventualities at sea. Availability criteria should, therefore, take account of the prolongation of outages caused by a ship having to make port in order to effect repairs and an estimate of the average down-time, including the time taken to make port, would be about 3 days. (It should be recognized that this figure is strongly dependent upon the maintenance organization.) This figure may then be equated to MTTR in the expression for A' in § 2.1.

The above considerations apply to Standard-A ship earth station complying with the requirements of the document "Technical Requirements for INMARSAT Standard-A ship earth stations" [INMARSAT, 1988, Issue 3]. Data for performance of other INMARSAT standards is not yet available.

Some studies made by shipping companies indicate that during 12-month trials the actual MTBF figures of old model ship earth stations were between 4,000 and 9,000 hours. A group of newer ship earth station models demonstrated MTBF's in the range of 11,000-13,000 hours.

A target objective of 10000 h for an SES MTBF would appear to be reasonable, and is compatible with current and future equipment designs. The corresponding availability objective would be maintained at a level higher than 99%.

3.2.3 Network Coordination Stations

The maritime mobile-satellite service requires the provision of auxiliary functions for network coordination purposes, such as power control, frequency control and channel assignment functions. These functions are provided at the network coordination stations in all ocean regions. For any essential function, the loss of which would adversely affect operation of the total network, a very high availability objective must be established e.g., 99.999%. Such an objective may be achieved by making a high redundancy provision, with at least 2 stations per coverage area being capable of performing the critical auxiliary functions and each station having an availability of the order of 99.95%.

For 1988 the availability of NCS performing vital coordinating and distress priority processing functions in the INMARSAT system was:

- in the Atlantic ocean region - 99.977%
- in the Pacific ocean region - 99.979%
- in the Indian ocean region - 99.982%

The high availability objectives achieved are necessary to avoid a complete system disruption which could result in a loss of service to a considerable number of ships.

3.3 Satellite network

For telephony, in order to render the channel unavailable, 10^6 pW0p of noise would be required (see § 2.2.1), which from Report 752 would require a fade on the radio path of 5 to 6 dB.

Similar considerations would apply to telegraphy.

3.3.1 *Shore-to-ship path*

3.3.1.1 *General*

The shore-to-ship radio path comprises a shore-to-satellite link (assumed here to be in the 6 GHz frequency band) and a satellite-to-ship link (1.5 GHz). The more critical of these is the 1.5 GHz link to ships, where satellite power is likely to be at a premium and hence a large allowance for fading is not feasible.

3.3.1.2 *Up link*

On the 6 GHz up link, a margin of around 2 dB would enable the required performance objective under fading conditions to be achieved for 99.99% of the time at 5° elevation angle; the actual margin for up-path fading required at each coast earth station will depend on local climatic conditions. In order to render the circuit unavailable, a fade of 5 to 6 dB would be required on the up link; the corresponding percentage time for which such a fade would apply is estimated at less than 0.005%, even under the most unfavourable propagation conditions i.e. corresponding to an availability figure of 99.995%. The use of up-path power control at shore stations would improve link performance and the availability.

3.3.1.3 *Down link*

On the satellite-to-ship link at 1.5 GHz, fading is caused primarily by multipath reflections. In the worst case, which is defined here as occurring at the edge of the satellite service area (i.e., at a ship earth station elevation angle of 5°, see [INMARSAT, 1978]), fading statistics indicate that a fade of 4 to 5 dB would be encountered for 1% of the time, and hence the percentage time applicable to a 5 to 6 dB fade would be somewhat less than 1%.

3.3.1.4 *Worst case* (case of a ship at 5° elevation angle).

Bearing in mind the small contribution from the 6 GHz shore-to-satellite link, and taking account of interference effects on both the shore-to-satellite and the satellite-to-ship links an objective availability of 99% would be reasonable.

3.3.1.5 *General case* (case of a ship travelling in regions where multipath effects are insignificant). The down-time due to fading is negligible in this case.

3.3.2 *Ship-to-shore path*

The ship-to-shore radio path comprises a ship-to-satellite link (1.6 GHz) and a satellite-to-shore link (assumed here to be at 4 GHz). Multipath fading will again be the dominant effect, and hence from considerations in § 3.3.1 the availability under worst-case conditions will be of the order of 99%, but for the general case the down-time will be negligible.

To improve availability in the telegraph mode the NCS/CES is provided with the capability of using a second TDM to which traffic is shifted from TDM-1 when interruptions of services are judged to be excessive. This improvement would not be available to SES models which have a limited TDM tuning capability. However, there are only a small number of such models in service.

3.4 Circuit availability objective

The expression indicated in § 2.6 for communications circuit availability (A) in the maritime mobile-satellite service can be written in terms of percentage down-time ($D = 100 - A$), as follows:

$$A = \frac{T_s - (T_{sat} + T_{ship} + T_{shore} + T_{aux} + T_1 + T_2)}{T_s} \times 100 \quad (\%)$$

$$= 100 - D_{sat} - D_{ship} - D_{shore} - D_{aux} - D_1 - D_2 \quad (\%)$$

Concerning D_1 and D_2, it is shown in § 3.3 that these outages are due predominantly to multipath fading effects on the satellite-to-ship and ship-to-satellite links respectively. Fading on these links at 1.5/1.6 GHz will be correlated i.e. the effects will occur simultaneously and hence only the outage of longest duration should be considered. This may be denoted by $D_{1,2}$.

From considerations in this and previous sections, down-time values for the various component parts of the communications circuit may be assumed to be as shown in Table I. The overall circuit availability is then about 99% in the general case and 98% in the worst case. If account is taken of the time for which ships are in port and are not permitted to transmit, the availability would be considerably improved.

TABLE I — *Down-time for component parts of a communication circuit in the maritime mobile-satellite service*

Symbol	Component part	Down-time (%)	Notes
D_{sat}	Space sector	0.001	
D_{shore}	Coast earth station equipment	0.1	
D_{ship}	Ship earth station equipment	1	(1)(2)(3)
D_{aux}	Auxiliary functions	0.05	(4)
$D_{1,2}$	Radio paths	General case: 0 Worst case: 1	
D_{total}	Total circuit down-time	General case: 1.15 Worst case: 2.15	

(1) Assumes ship terminal antenna pointing can be maintained.
(2) No consideration given to times when ship is in port in a territory where its use may be prohibited.
(3) Assumes standard A ship earth station G/T of -4 dB (K^{-1}).
(4) If two NCSs are available in one coverage area the effective down time will be 0.001%, see § 3.2.3.

3.5 Availability of the INMARSAT Priority Three System for Distress Alerting

The availability of uninterrupted access to the Rescue Services to transmit a ship-to-shore distress message over INMARSAT Standard-A Priority 3 system during a calendar year (1986) is calculated as follows :

$$A_{da}(\%) = A_{rcc}(\%) + A_{ses}(\%) + A_{inm}(\%) - 200(\%)$$

where

$A_{rcc}(\%)$- availability of a land line and its end terminal at the Rescue Coordination Centre

$A_{ses}(\%)$- availability of a shipborne distress function unit at the ship earth station

$A_{inm}(\%)$ - availability of the INMARSAT Priority 3 system

Each of this component parts availability is calculated per formula :

$$A(\%) = \frac{T_s - T_o}{T_s} \times 100(\%), \quad \text{where}$$

T_s - 31,536,000 seconds, scheduled operational time of one year;

T_o - outage time, probably causing an interruption of access from ships to Rescue Services.

3.5.1 Rescue services component part

The Rescue Co-ordination Centres (RCC) associated with the CES have dedicated lines and dedicated end terminals, providing nearly 100% availability for access.

In the unlikely event of the need to handle two or more simultaneous Priority 3 ship-to-RCC calls the additional Priority 3 calls are routed to the RCC via alternative lines, and if all these terrestrial facilities fail to provide connections the Distress Call and Message is routed to the personnel at the CES. The loss of a distress alert which is being processed by a CES is therefore highly improbable.

3.5.2 SES component part

Part A of the INMARSAT Design and Installation Guidelines based on the IMO requirements for the GMDSS shipborne equipment implies that it should have highly reliable performance, providing near 100% availability for distress alerting.

3.5.3 INMARSAT component part

$$A(\%)_{inm} = \frac{T_s - T_{sp.s} - T_{ncs} - T_{net}}{T_s} \times 100(\%)$$

where

T_s - scheduled operational time of one calendar year;

$T_{sp.s}$ - total outages of space segment;

T_{ncs} - total outages of network co-ordination and its collocated coast earth station;

T_{net} - total outages of satellite channels.

As shown earlier component parts availability is affected by many factors varying in time and locations.

For 1988 the availability of the component parts stood as follows :

	$A_{SP.S}(\%)$	$A_{NCS}(\%)$	$A_{NET}(\%)$	$A_{INM}(\%)$
AOR	100	99.977	99.997	99.974
IOR	100	99.982	100	99.982
POR	100	99.979	100	99.979

Overall three-regions average system availability - 99.978

For the period from 1982 to 1988 the availability of the component parts stood as follows :

	$A_{SP.S}(\%)$	$A_{NCS}(\%)$	$A_{NET}(\%)$	$A_{INM}(\%)$
AOR	99.990	99.977	99.961	99.928
IOR	99.995	99.982	99.984	99.961
POR	99.998	99.979	99.987	99.964

Overall average three-regions system availability - 99.951

CONCLUSIONS

This Report has considered the engineering and operational measures taken by INMARSAT to ensure a high availability of communications circuits in the Maritime Mobile Satellite Service. Example results for the period 1982 to 1988 have been used to support these considerations. For general communications, availability objectives of 99.90% for CESs, 99.95% for NCSs, 99.99% for space segment and 99% for SESs would seem achievable. For ship-to-shore distress alerting in telex an availability objective of 99.99% has been consistently achieved in practice, a figure significantly higher than was suggested by earlier theoretical considerations.