International Telecommunication Union

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Recommendation ITU-R M.2091-0
(10/2015)

Methodology to calculate spectrum requirements within the frequency bands 1 545-1 555 MHz (space-to-Earth) and 1 646.5-1 656.5 MHz (Earth-to-space) for aeronautical mobile-satellite (R) service communications related to the priority categories 1 to 6 of Article 44 of the Radio Regulations

M Series

Mobile, radiodetermination, amateur and related satellite services

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Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R M.2091-0[1]

Methodology to calculate spectrum requirements within the frequency bands 1 545-1 555 MHz (space-to-Earth) and 1 646.5-1 656.5 MHz (Earth-to-space) for aeronautical mobile-satellite (R) service communications related to the priority categories 1 to 6 of Article 44 of the Radio Regulations

(2015)

Scope

This Recommendation provides a methodology to calculate aeronautical mobile-satellite (R) service spectrum requirements within the frequency bands 1 545-1 555 MHz (space-to-Earth) and 1 646.5-1 656.5 MHz (Earth-to-space). It is intended to be used to quantify the spectrum requirements related to the AMS(R)S priority categories 1 to 6 of RR Article **44**, for which the provisions of Resolution **222 (Rev.WRC-12)** apply.

Keywords

AMS(R)S; spectrum requirements; priority communications; methodology

Abbreviations/Glossary

AES	Aircraft Earth Station. As defined in RR No. **1.84** an AES is a mobile earth station in the aeronautical mobile satellite service located on board an aircraft
AES Count:	Number of actually operating AESs within the specified area of the satellite network and logged on to that satellite network under consideration in a defined period, in a particular area/beam. Note that the AES count should include only those AES which are expected to make use of the satellite network
AMS(R)S	Aeronautical Mobile-Satellite (route) Service. As defined in RR No. **1.36**, the AMS(R)S is an aeronautical mobile-satellite service reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes
AOC	Aeronautical Operational Control. AOC describes communications required for the exercise of authority over the initiation, continuation, diversion or termination of flight for safety, regularity and efficiency reasons
ATS	Air Traffic Service; ATS is a generic term meaning variously, flight information service, alerting service, air traffic advisory services, air traffic control service (area control service, approach control service or aerodrome control service)
CS	Circuit Switched
Erlang	A unit of traffic intensity. It is a dimensionless quantity expressing voice activity in units of time that would be seen in during some time interval, typically an hour. It is used to determine the number of circuits needed to satisfy circuit voice demand

[1] The Russian Federation had objected to the adoption of this Recommendation for the reasons indicated in the report of the SG 4 Chairman to RA-15, and declares that this Recommendation will be applied only among operators providing services relating to the transmission of AMS(R)S traffic with priorities 1-6 of RR Article **44**, contentious issues regarding the determination of spectrum requirements being resolved among the operators.

FEC	Forward Error Correction
GES	Ground Earth Station. The GES is the earth station used for the feeder links of the AMS(R)S system. This is equivalent to an aeronautical earth station, as defined in RR No. **1.82**
IP	Internet Protocol
ISDN	Integrated Services Digital Network

Related ITU Recommendations, Reports

Recommendation ITU-R M.1037-0	Bit error performance objectives for aeronautical mobile-satellite (R) service (AMS(R)S) radio link
Recommendation ITU-R M.1089-1	Technical considerations for the coordination of mobile-satellite systems relating to the aeronautical mobile satellite (R) service (AMS(R)S) in the bands 1 545 to 1 555 MHz and 1 646.5 to 1 656.5 MHz
Recommendation ITU-R M.1180-0	Availability of communication circuits in the aeronautical mobile-satellite (R) services (AMS(R)S)

The ITU Radiocommunication Assembly,

considering

a) that, in the frequency bands 1 525-1 559 MHz (space-to-Earth) and 1 626.5-1 660.5 MHz (Earth-to-space), geostationary mobile-satellite system operators currently use a capacity-planning approach at regional multilateral coordination meetings, under arrangements agreed between their administrations, to periodically coordinate access to the spectrum needed to accommodate their requirements, including the spectrum requirements of the AMS(R)S providing transmission of messages with priority 1 to 6 in RR Article **44**;

b) that the methodologies should first and foremost provide accurate results avoiding overestimation or underestimation of spectrum needs, should reflect as closely as possible the algorithms actually employed by the satellite system under study and should provide a simple, efficient and quick means for determining spectrum requirements;

c) that only AMS(R)S priority communications 1 through 6 per RR Article **44** supported by the satellite system beam under study should be included in these methodologies to determine the spectrum requirements;

d) that the methodologies should support the present AMS(R)S environment but take into consideration changes to the environment during the target period, including commencement of new AMS(R)S networks operation, changes in service offerings for the air traffic service (ATS) and aeronautical operational control (AOC), traffic, aircraft equipment, and technology;

e) that the methodologies should account for the characteristics of the aircraft equipment and the satellite network, and should consider only the services and transmission capabilities afforded by the communication equipment deployed on the aircraft, the ground earth station (GES) and satellite under study;

f) that the methodologies should avoid double counting of the bandwidth accommodating the communication traffic in areas with overlapping satellite network coverage;

g) that the information provided for each AMS(R)S satellite network, to be used as input parameters to the methodologies, should, to the extent possible, be independently verifiable;

h) that parameters used in the methodologies should have clear and adequate definition and/or description, as appropriate, avoiding the risk of misinterpretation, to ensure proper determination of AMS(R)S spectrum requirements priority communications 1 through 6 per RR Article **44** associated to each satellite beam;

i) that the methodologies should account for only that portion of the AMS(R)S client's airspace in which satellite communications would be employed such as by excluding airspace corresponding to areas in which VHF and HF communications are employed,

further considering

a) that spectrum needs of an AMS(R)S satellite network with multiple spot beams should be determined to the level of spectrum needs of each spot beam;

b) that proper measures should be taken into consideration where an AMS(R)S satellite system is capable of dynamically configuring its satellite network resources;

c) that proper measures should be taken into consideration where an AMS(R)S satellite network is capable of and support voice compression and/or data compression,

recognizing

a) that WRC-97 allocated the frequency bands 1 525-1 559 MHz (space-to-Earth) and 1 626.5-1 660.5 MHz (Earth-to-space) to the MSS to facilitate the assignment of spectrum to multiple MSS networks in a flexible and efficient manner;

b) that WRC-97 adopted RR No. **5.357A** giving priority to the accommodation of the spectrum requirements for the AMS(R)S providing transmission of messages with priority categories 1 to 6 in RR Article **44** in the frequency bands 1 545-1 555 MHz and 1 646.5-1 656.5 MHz;

c) that Resolution **222 (Rev.WRC-12)** relates to the use of the frequency bands 1 525-1 559 MHz and 1 626.5-1 660.5 MHz by the mobile-satellite service, and procedures to ensure long-term spectrum access for the aeronautical mobile-satellite (R) service;

d) that Resolution **422 (WRC-12)** invites ITU-R to conduct studies on, and develop in one or more ITU-R Recommendations, a methodology, including clear definitions of input parameters and assumptions to be used, to calculate spectrum requirements within the frequency bands 1 545-1 555 MHz (space-to-Earth) and 1 646.5-1 656.5 MHz (Earth-to-space) for AMS(R)S communications related to the priority categories 1 to 6 of RR Article **44**;

e) that systems providing broadband safety services have been developed, and are being considered by ICAO for incorporation into the aviation standards,

noting

a) that AMS(R)S systems are an essential element of the International Civil Aviation Organization standardized communications infrastructure used in air traffic management for the provision of safety and regularity of flight in civil aviation;

b) that, since spectrum resources are limited, there is a need to use them in the most efficient manner within and amongst various MSS networks,

recommends

1 that within the frequency bands 1 545-1 555 MHz (space-to-Earth) and 1 646.5-1 656.5 MHz (Earth-to-space), the spectrum requirements for AMS(R)S communications related to the priority categories 1 to 6 of RR Article **44** to be assigned by bilateral or multilateral frequency coordination meetings under Resolution **222 (Rev.WRC-12)** should be calculated using the methodology described in Annex 1;

2 that, when the methodology contained in Annex 1 is agreed to be used during a frequency coordination meeting, the participants to this meeting should also agree on arrangements regarding the input parameters required to use the methodology;

3 that, since relevant historical information for new AMS(R)S systems would not be available in advance of the commencement of their operation, established AMS(R)S operators should make available, in a timely manner, at frequency coordination meetings the relevant historical information applicable to the service area of the new AMS(R)S operator, required to determine spectrum requirements for the first year of operation of new systems, using the methodology contained in Annex 1;

4 that any ambiguity in specific parameters of the methodology contained in Annex 1 (e.g. whether messages are related to the priority categories 1 to 6 of RR Article **44**) should be resolved with mutual agreement on assumptions;

5 that any alternative methodologies to determine the spectrum requirements for AMS(R)S communications related to the priority categories 1 to 6 of RR Article **44** to be assigned by bilateral or multilateral frequency coordination meetings under Resolution **222 (Rev.WRC-12)** should be based on the principles and guidelines contained in *considering b)* to *i)* and *further considering a)* to *c)*.

Annex 1

Method of calculation of spectrum requirements for the AMS(R)S communications in the 1.5/1.6 GHz bands

1 General

1.1 Introduction

Through RR No. **5.357A**, priority shall be given to accommodating the spectrum requirements of the AMS(R)S satellite networks providing transmission of messages with priority 1 to 6 in RR Article **44**. This Annex contains a methodology which may be used to determine the AMS(R)S spectrum requirements per beam per satellite for AMS(R)S communications.

It should be noted that VHF air/ground/air links are used regularly to provide aeronautical communications services where available but for areas beyond line of sight (BLOS), designated HF channels or satellite communications must be employed. This methodology is intended for calculation of AMS(R)S spectrum requirements for areas where VHF links would not be available.

The methodology described in this Annex is based on the following steps:

1) determination of the number of AESs ("AES Count") within a beam;

2) calculation of the information volume generated by these AESs for each of a number of different voice and data carrier types;

3) calculation of the spectrum requirements for various types of carrier in each beam.

The methodology also includes steps for the calculation of the total AMS(R)S spectrum requirements for a network.

For the established networks, a methodology based on historical traffic records should provide the most accurate results. Also, where historical information is available, the average traffic per aircraft within each satellite beam can be estimated from call and data records. This allows any geographic variability in the average traffic per aircraft to be readily estimated. In addition, since relevant historical information for new AMS(R)S systems would not be available in advance of commencement of their operation, established AMS(R)S operators should make available, in a timely manner, at frequency coordination meetings the relevant historical information applicable to the service area of the new AMS(R)S operator, required to determine spectrum requirements for the first year of operation of new systems, using the methodology contained in this Annex 1.

The procedures in this Annex for the calculation of the spectrum requirements of the AMS(R)S communications are illustrated in the flow chart of Fig. 1.

It is generally necessary to determine the spectrum requirements considering a particular time period when traffic is expected to be at its highest. Typically, traffic is assessed for the busy hour of a day and, if there is significant day-to-day variation, it may be necessary to consider the traffic expected on the busiest day of the year.

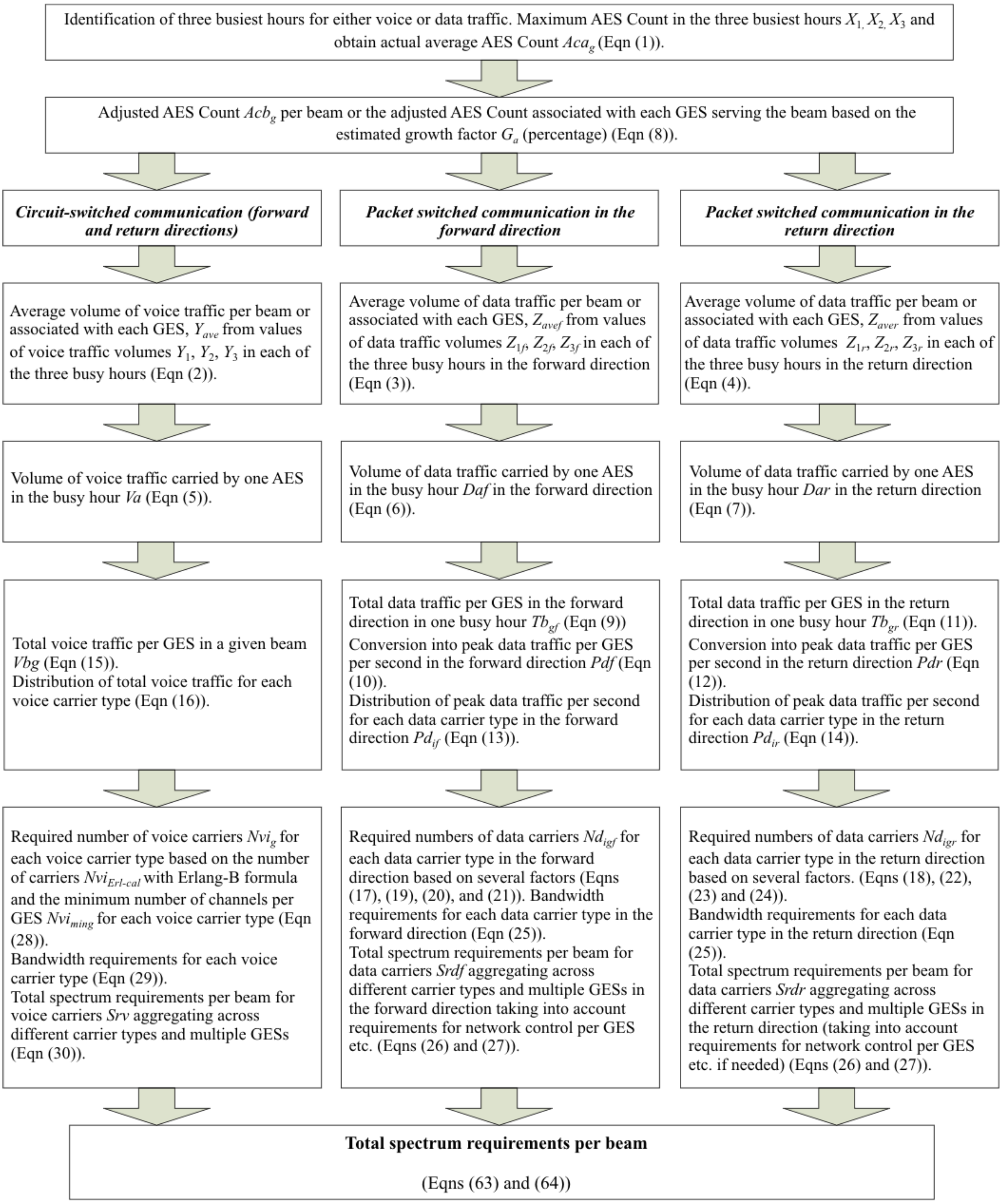
Calculations are based on the input information of total data/voice traffic of the AMS(R)S communications for all aircraft earth stations (AESs) which are actually operating AMS(R)S applications within the specified service area of the satellite network under consideration.

In some satellite networks, there can be more than one ground earth station (GES) providing AMS(R)S services in a given service link beam. As the service link carriers typically cannot be shared by the GESs, in such a case it is necessary to determine traffic and spectrum requirements of each GES separately. In this case, it is important that the AES count associated with each GES includes only those AESs which operate via that GES.

The total spectrum requirements for a beam served by multiple GESs are determined by summing up the calculated spectrum requirements of the GESs serving that beam.

FIGURE 1

Flowchart illustrating general method to calculate AMS(R)S spectrum requirements



M.2091-01

1.2 Parameters

The following notation is used in the parameter names for the hierarchy and suffixes, for the most part:

– Ground earth station – "*g*"

– Airspace or service area – "*a*"

– Beam for spectrum calculation –"*b*"

– Type of traffic – data: "*d*"; voice: "*v*"; circuit switched voice: "*CS-voice*"; circuit switched ISDN: "*CS-ISDN*"; standard IP: "*StdIP*"; streaming IP: "*StrIP*"

– Requirements or capacity for a specific carrier – "*c*"

– Type of carrier – voice carrier type: "*j*"; data carrier type: "*d*"; circuit switched voice sub-carrier type or circuit switched ISDN sub-carrier type: "*j*"; standard IP sub carrier type or streaming IP sub-carrier type: "*k*"

– Forward and return link – "*f*", or "*r*".

The parameters used in the methodology in Annex 1 are shown in Attachment 1.

2 Estimation of AES count and volume of information per AES to be handled with the satellite system under consideration

From an operational and economical point of view, it is generally desired that normal traffic in a wide area be handled by the global beam, and high traffic in congested airspace be handled by spot beams. The advantage of the global beam is that it covers areas that would otherwise not be covered by the spot beams. In a typical deployment scenario a cluster of spot beams may be activated to serve aircraft along the high traffic air routes with the outlying aircraft served by the global beam. Although it is possible for the global beam to provide many of the same services as the spot beams the global beam is likely to be used additionally for broadcast messages, signalling, and logging aircraft on to the network. The spacecraft design may include the adoption of spot beams to provide services where it is more spectrally efficient or power efficient to do so. It is important to know how many AESs are being served by spot beams and global beams during the peak period. As discussed above, the number of AESs (AES Count) within a specified beam to be handled within the satellite system under consideration should be determined. The AES Count is defined as number of actually operating AESs within the specified area of the satellite network and logged on to that satellite network under consideration within a given period and in a particular area/beam. Note that the AES Count should include only those AES which are expected to make use of the satellite network.

The AES Count is a fundamental parameter required for the estimation of the spectrum requirement for the AMS(R)S communications. The approach used to determine this number is based on the assumption that historical data for the total number of logged-on AESs within each beam of the AMS(R)S system within the three highest busy hour periods in a given year is available, and estimates of future requirements may be made based on this historical data, with a suitable adjustment to account for increasing or decreasing demand in the future.

This approach is applicable to established systems and should provide the most accurate estimate of AMS(R)S spectrum requirements.

An AMS(R)S system may consist of several GSO satellites, which may have overlapping beams in some areas. The spectrum requirements are determined separately for each beam within each satellite, and in areas of overlap there is a risk that AESs are double-counted, i.e. assigned to two satellites at the same time. Hence, when determining the AES Count in areas of overlapping coverage, it is necessary to ensure that the number of AESs is suitably apportioned between the satellites. Such consideration does not apply to situations where one satellite is a backup or hot-standby satellite.

The traffic data for both circuit switched traffic and the packet switched data traffic is typically processed on an hourly basis based on the raw call data records. In such as case, it is possible to gather the following information on an hourly basis for each calendar day of any given month.

– Satellite network/associated GES
– Beam: Global/spot within the satellite
– Calendar day
– Hour (0-23 hours) (NOTE – 1st hour recorded as "0 hour", 24th hour recorded "23rd hour")
– AES identification number communicated with satellite network/associated GES
– Time of start and end of the communication.

The following should also be used to estimate the volume of traffic information, where the traffic consists of the user information and does not include the overheads associated with transmission of the information:

– Traffic unit (kbit/s for packet switched data traffic (forward and return directions) and minutes for circuit switched traffic).
– Volume of traffic (kbit/s or mins).

Based on the above information it is possible to identify three busy hours within a given year for each category of voice and packet data traffic in each beam of satellite network by analysing the call records gathered in the GES serving such a beam. There are occasions where a beam could be served by more than one GES, in which case the busy hour traffic should be determined separately for each GES. Having identified the three busy hours, the AES Count is determined for each of those busy hours and the average value of the AES Count for those three busy hours is used in the further analysis. These steps are undertaken separately for the voice and data traffic so that two values for the AES Count are determined-one applicable to voice traffic and the other applicable to the data traffic. An underlying assumption here is that there is not a significant difference in volume of traffic associated with each of the three busy hours.

The actual average AES Count per beam associated with a given GES is obtained from the following equation:

$$ACa_g = (X_1+X_2+X_3)/3 \quad (1)$$

where X_1, X_2 and X_3 are the number of AESs in each of the three busy hours generating either the highest voice or data traffic in a given year.

Average volume of voice traffic per GES in a given beam in the busy hour:

$$Y_{ave} = (Y_1+Y_2+Y_3)/3 \quad (2)$$

where Y_1, Y_2 and Y_3 are the values of voice traffic volume in each of the three busy hours corresponding to X_1, X_2 and X_3.

For the established AMS(R)S satellite networks it is possible to obtain the data traffic information volumes separately in the forward and return directions from the historical traffic data.

The average volume of data traffic per GES in a given beam in the busy hour in the forward direction is given by:

$$Z_{avef} = (Z_{1f} + Z_{2f} + Z_{3f})/3 \quad (3)$$

where Z_{1f}, Z_{2f} and Z_{3f} are the values of data traffic volume in the forward direction in each of the three busy hours corresponding to X_1, X_2 and X_3.

Similarly, the average volume of data traffic per GES in a given beam in the busy hour in the return direction is given by:

$$Z_{aver} = (Z_{1r} + Z_{2r} + Z_{3r})/3 \quad (4)$$

where Z_{1r}, Z_{2r} and Z_{3r} are the values of data traffic volume in the return direction in each of the three busy hours corresponding to X_1, X_2 and X_3.

The volume of voice traffic carried by one AES in the busy hour is given by:

$$Va = Y_{ave} / ACa_g \text{ min} \quad (5)$$

The volume of data traffic carried by one AES in the forward direction in the busy hour is given by:

$$Daf = Z_{avef} / ACa_g \text{ kbit} \quad (6)$$

The volume of data traffic carried by one AES in the return direction in the busy hour is given by:

$$Dar = Z_{aver} / ACa_g \text{ kbit} \quad (7)$$

Based on the above procedure it is possible to arrive at the AES count in a given beam for each type of voice and data service and the associated traffic volume carried per typical AES.

To account for short-term growth or decrease of traffic activity, the adjusted AES Count ACb_g per beam associated with a given GES is obtained from the following equation:

$$ACb_g = ACa_g \times (1+G_a/100) \quad (8)$$

where G_a is the estimated percentage of change in the number of aircraft served by satellite network of interest for the year in question.

3 Calculation of information volume for each type of traffic

The calculation of information volume may be conducted separately for each of a number of different traffic types. In the sub-sections below, a method to determine the information volume for each of the following traffic types is considered:

– packet switched communication (including packetized voice);

– circuit-switched communication (voice and possibly data).

The information volume for each type of traffic in the beam should be obtained by considering only the portion of the AES Count supporting a particular traffic type.

3.1 Packet switched communication (including packetized voice)

Peak data rate for the addressed data carriers to be handled by each type of carrier can be calculated by the following process. Total data traffics per GES in a given beam (Tb_{gf} (kbit)) in the forward direction in the busy hour can be obtained as:

In case of forward link traffic provided in kbit/hour:

$$Tb_{gf} = Daf \times ACb_g \quad (9)$$

and required peak data rate per beam in forward direction (Pdf (kbit/s)) is calculated as:

$$Pdf = (hs \times Tb_{gf}/3600) \quad (10)$$

where:

Daf: averaged unit data traffic information to be handled by an AES (kbit/hour) in the forward direction

hs: conversion factor from the average data rate in kbit/s to the required peak data rate in kbit/s in the forward direction.

The parameter *hs* accounts for potential fluctuations in aggregate data transmission rate during the three highest busy hour periods. If the generated data volume (e.g. data arrival rate) is uniformly distributed across the target period, value of *hs* would be 1. However, when the generated data volume is of sporadic nature, then it would be required to determine an *hs* value of larger than 1. At present, there is no known model that could closely represent data generation and arrival rates on AMS(R)S systems. Thus, it would be the responsibility of the system operators to suggest a proper value for *hs*, representing/modelling their system's behaviour, with sufficient justification.

Total data traffics per GES in a given beam (Tb_{gr} (kbit)) in the return direction in the busy hour can be obtained as:

In case of return link traffic provided in kbit/hour:

$$Tb_{gr} = Dar \times ACb_g \tag{11}$$

and required peak data rate per beam in return direction (*Pdr* (kbit/s)) is calculated as:

$$Pdr = (hs \times Tb_{gr}/3\,600) \tag{12}$$

where:

Dar: averaged unit data traffic information to be handled by an AES (kbit/hour) in the return direction

hs: conversion factor from the average data rate in kbit/hour to the required peak data rate in kbit/s, in the return direction.

If there are different types of packet data carrier operating within a beam, the peak information data rate per GES in a given beam to be supported in the forward and return directions can be divided for each type of carrier as:

$$Pd_{if} = rd_i \times Pd_f \tag{13}$$

$$Pd_{ir} = rd_i \times Pdr \tag{14}$$

where:

rd_i: data carrier type (*i*) ratio.

In this case, rd_i would be ratio of data traffic volume associated with each carrier type (*i*) relative to total data traffic volume (*Tb*).

3.2 Circuit-switched communication

Circuit-switched communication is typically used to support some voice and some data applications (such as ISDN). Circuit-switched traffic is measured in minutes.

Total voice traffic per GES in a given beam in the busy hour (Vb_g (Erlang)) can be obtained as:

$$Vb_g = (Va \times ACb_g)/60 \tag{15}$$

where *Va* is the averaged voice traffic in minutes obtained from equation (5) in § 2.

Averaged unit information volume for voice signal to be handled by a satellite system (Va) can be obtained by aggregating the amount of voice traffic over a given period of time tp (i.e. the busy hour).

Where several different carrier types are used to carry the circuit-switched traffic, the total voice traffic (Vb_g) can be divided for each type of carrier as:

$$Vb_{g\,j} = rv_j \times Vb_g \tag{16}$$

where:

rv_j: ratio of traffic volume for voice carrier type (j) to total traffic volume.

4 Calculation of required bandwidth for each beam and type of carrier

4.1 Packet switched communication (including packetized voice)

The required number of specified circuits per beam and GES (Nd_{igf}) in the forward direction and (Nd_{igr}) in the return direction can be calculated by the following formulas:

$$Nd_{igf} = \text{Maximum (Roundup(}Pd_{if}/Cd_{if}\text{)}, Nd_{imingf}) \tag{17}$$

$$Nd_{igr} = \text{Maximum (Roundup(}Pd_{ir}/Cd_{ir}\text{)}, Nd_{imingr}) \tag{18}$$

where:

Pd_{if}: peak information data rate to be supported (kbit/s) in the forward direction

Pd_{ir}: peak information data rate to be supported (kbit/s) in the return direction

Cd_{if}: effective information transmission rate, i.e. the transmission capacity of the normalized data carriers in kbit/s taking into account the channel overhead in the forward direction

Cd_{ir}: effective information transmission rate, i.e. the transmission capacity of the normalized data carriers in kbit/s taking into account the channel overhead in the return direction

Nd_{imingf}: minimum number of circuits per GES required for each forward direction data carrier type

Nd_{imingr}: minimum number of circuits per GES required for each return direction data carrier type.

A minimum number of channels would be required for the operation of AMS(R)S systems for the purpose of achieving the availability requirements defined by ICAO standards documents. It would be the responsibility of the system operator to provide the minimum number of channels for their system, with sufficient technical justification.

One approach to calculate Cd_{if} and Cd_{ir} is given below.

The effective carrier transmission rate (Cd_{if}) that is available to deliver the service data in the forward direction (ground-to-aircraft) may be determined from the following equations:

$$R_{iracf} = (R_{Ti} - R_d - R_{frm} - R_f) \tag{19}$$

$$R_{irbcf} = R_{iracf} \times CR \tag{20}$$

$$Cd_{if} = R_{irbcf} \times (1 - r_{rf}) \tag{21}$$

where:

R_{Ti}: carrier transmission rate (kbit/s)

R_d: dummy bit rate (kbits/s)

R_{frm}: format identification and multi-frame rate (kbit/s)

R_f : framing rate (kbit/s)

R_{iracf} : information rate after coding in the forward direction (kbit/s)

R_{irbcf} : information rate before coding in the forward direction (kbit/s)

CR: Forward error correction rate (numerical ratio)

r_{rf} : ratio of retransmissions due to fading and, interference, in the forward direction (a number between 0 and 1). Note that broadcast channels would repeat messages at certain intervals, and therefore there should be no retransmission factor in the broadcast case.

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

The effective carrier transmission rate (Cd_{ir}) that is available to deliver the service data in the return direction (aircraft-to-ground) may be determined from the following equations:

$$R_{iracr} = (R_{Ti} - R_{uwf} - R_p) \quad (22)$$

$$R_{irbcr} = R_{iracr} \times CR \quad (23)$$

$$Cd_{ir} = R_{irbcr} \times (1 - r_{rr}) \quad (24)$$

where:

R_{Ti}: carrier transmission rate (kbit/s)

R_{uwf}: unique word and flush bit rate (kbit/s)

R_{iracr}: information rate after coding in the return direction (kbit/s)

R_{irbcr}: information rate before coding in the return direction (kbit/s)

CR: forward error correction rate (numerical ratio)

R_p: preamble bit rate (kbit/s)

r_{rr}: ratio of retransmissions due to fading, interference, collisions in the return direction (a number between 0 and 1).

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

NOTE 1 – The above items are normalized with respect to frame duration or burst duration in order to have consistency with the other parameters in terms of units (kbit/s).

The parameters r_{rf} and r_{rr} are required in systems where retransmission of packets may occur. This may occur for a number of reasons. One potential reason, particularly relevant for the return link is due to the use of random access protocols such as “slotted ALOHA”. In such protocols, packet collisions can occur at the receiver, preventing the correct reception of the desired packets. As a consequence, retransmission of the failed packets is required. Another potential reason for retransmission of a packet is due to failed reception of the packet due to propagation issues such as obstruction of the AES antenna and fading. To determine values for r_{rf} and r_{rr} requires careful analysis based on the characteristics of the specific AMS(R)S system and may be dependent on the traffic statistics during the busy hours. Therefore generally applicable values cannot be provided, and proposed values will require careful analysis and explanation.

The required bandwidth per beam and GES (SRd_g) can be calculated by the following formulas:

SRdg is determined by multiplying the bandwidth allocated to each carrier type (*Ddi*) and the required number of carriers by accumulating all type of carriers as follows:

$$BWdi_g = Nd_{ig} \times Ddi \text{ (kHz)} \tag{25}$$

where:

- $BWdi_g$: calculated bandwidth for specific type of carrier (i)
- *Ddi*: bandwidth allocated to each data carrier type in kHz.

$$SRd_g = \Sigma\,(BWdi_g) + SRxi_g \tag{26}$$

where:

- $\Sigma\,(BWdi_g)$: is the summation of the bandwidth for each data carrier type
- $SRxi_g$: spectrum requirement for the network control carriers per GES (e.g. pilot carriers).

Then, total spectrum requirement for data carriers in a beam (*SRd*) can be obtained as:

$$SRd = \Sigma\,(SRd_g) \tag{27}$$

where $\Sigma\,(SRd_g)$ is the summation of the bandwidth for each GES.

NOTE 2 – In the above discussion, forward and return link requirements may be calculated separately, i.e. *SRdf* and *SRdr*, as these links may have different characteristics and traffic loading.

4.2 Circuit-switched communication

Circuit-switched communication is typically used for voice services, but may also be used for some data applications, such as ISDN. The number of circuits required for circuit-switched communications (*Nv*) can be obtained by the Erlang-B formula to satisfy V_{bgj} (Erlang). The detailed description of the method to obtain the number of circuits is given in § 7.5 of the ITU-D SG 2 publication "Handbook, Teletraffic Engineering", Jan. 2005[2].

The goal of the Erlang traffic theory is to determine how many service-providing elements should be provided in order to meet the specified grade of service (GoS). For example, in a system where there is no queuing, the GoS may be that no more than 1 call in 100 is blocked (i.e. rejected) due to all circuits being in use (a GoS of 0.01), which becomes the target probability of call blocking, P_b, when using the Erlang-B formula. The relevant ICAO standard for grade of service is given in Annex 10 to the Convention on International Civil Aviation, Volume III, 4.6.5.1.3.1, which states that: "The system shall have sufficient available voice traffic channel resources such that an AES- or GES-originated AMS(R)S voice call presented to the system shall experience a probability of blockage of no more than 10^{-2}."

In some established satellite networks it is common to allocate certain minimum number of channels Nvg_{min} for each GES serving a given beam. For each voice carrier type, the required number of channels is calculated as per the Erlang-B formula for a given grade of service (GoS). Then the maximum of the numbers is taken, i.e.:

$$Nvi_g = \max\,(Nvi_{ming}, Nvi_{Erl\text{-}Bcal}) \tag{28}$$

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[2] ITU–D Study Group 2, Question 16/2, "Handbook, Teletraffic Engineering", Geneva, January 2005, First edition of the Teletraffic Engineering Handbook worked out as a joint venture between the ITU – International Telecommunication Union, and the ITC – International Teletraffic Congress, http://www.itu.int/en/ITU-D/Emergency-Telecommunications/Pages/Publications.aspx.

where:

Nvi_{ming}: minimum number of channels per GES required for each voice carrier type

$Nvi_{Erl\text{-}Bcal}$: number of channels based on Erlang-B formula calculations for each voice carrier type, as a function of V_{bgj}.

In situations where there is very low traffic volume it is necessary to provide certain minimum number of channels per GES for each voice carrier type. However, this number is to be chosen very carefully in order not to increase the channel numbers and hence push up the spectrum requirements unnecessarily.

The required bandwidth (*SRv*) can be calculated by multiplying the allocated bandwidth per voice carrier type (*Dvi*) and the required number of voice channels and then summing up the calculated required bandwidth values for all types of voice carrier.

$$BWv_{i,g} = Nvi_g \times Dvi \text{ (kHz)} \tag{29}$$

where:

$BWv_{i,g}$: spectrum required for one specific carrier type in kHz

Nvi: number of carriers of type (*i*)

Dvi: bandwidth per voice carrier type (*i*) in kHz.

The total spectrum requirement for voice carriers in a beam (*SRv*) can be obtained as:

$$SRv = \Sigma_{\,(i=1 \text{ to } n)}\, \Sigma_{\,(g=1 \text{ to } m)}\, (BWv_{i,g}) \tag{30}$$

where:

n: total number of carrier types supported

m: total number of GES serving the beam.

In general the spectrum requirements for circuit-switched voice in the forward and reverse directions are equivalent.

4.3 Broadband safety services

Broadband safety systems within the AMS(R)S are being developed. The applicability of this section would depend on completion of ICAO review of this service. The characteristics of broadband safety services differ fundamentally from those of traditional aero classic services in that calls or “sessions” may share the same channel simultaneously. This contrasts with the current AMS(R)S voice services which can accommodate a single call in each channel. The broadband safety system will do this by allocating unique time slots that define the channel access for every requested session. In so doing, the same channel (subject to its inherent capacity) may be shared between simultaneous sessions without conflict occurring.

The sharing of a channel is made possible by the fact that the time slot allocated typically lasts 5 or 20 milliseconds and is dependent on the service type. The allocated time slots must be sufficiently long and frequent to provide the data throughputs or bit rates that are required.

Broadband safety services are able to provide greater capacity than the current AMS(R)S services. This means that more sessions can be accommodated in the same block of spectrum. This is possible at the expense of an increase in the complexity of the design of the satellite payload, the terminals, and of the systems managing broadband safety services.

The following types of services will be offered in the broadband safety services.

Circuit switched (CS) services

1) Circuit switched voice for voice only communications

2) Circuit switched ISDN service used for voice and some data communications

The bandwidth and duration of the time slot required for circuit switched traffic is fixed and is dependent on specific AES type.

Packet switched services

3) Streaming IP (Internet protocol) service providing guaranteed user data rates

Under the same link conditions, the maximum data rate available to a user is based on the AES terminal type. The channel occupancy is dynamically controlled in order to provide the required data at all times.

4) Standard IP service also known as background IP and providing data rates in relation to the availability capacity within a channel

The standard IP service will attempt to fill as much of the allocated channel as possible. This means that peak data rates higher than streaming IP are possible but are not guaranteed. All of the above services will be used to transport AMS(R)S communications with priority 1-6 as defined in RR Article **44**. The methodology in this section assumes that all traffic considered is AMS(R)S communications with priority 1-6 and that there is no mixing of such traffic with lower priority or non AMS(R)S traffic.

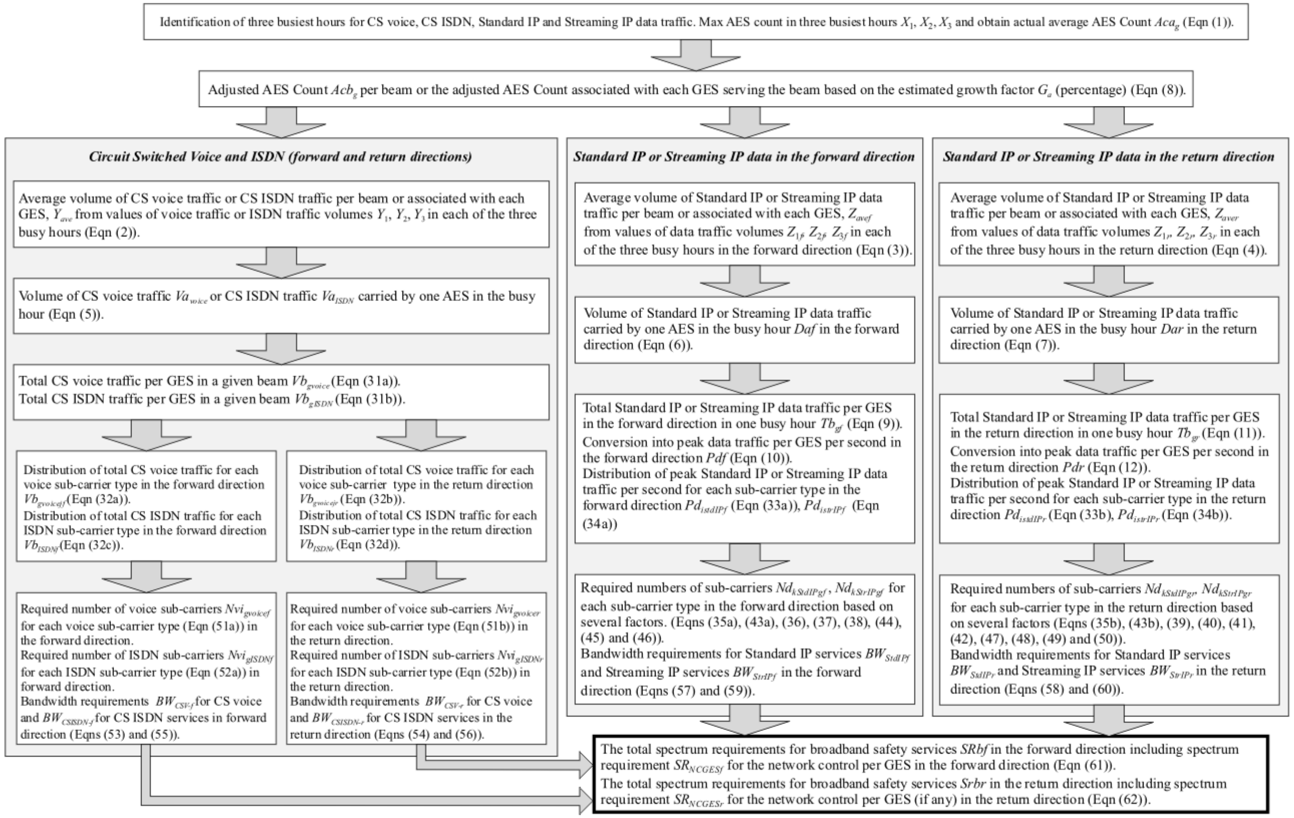
The satellite payload is typically divided up into a number of carriers (one example could be 200 kHz) which contain one or more sub-carriers used for signalling or carrying the broadband safety traffic. The traffic-carrying carriers may accommodate a number of sessions from one or more users and including a number of the different service types listed above. At least one carrier is allocated to each of the satellite narrow beams with an additional carrier being allocated to a beam when the carrier capacity is filled as a result of traffic demands, subject to availability. The capacity available to provide safety services is two-dimensional, with not only a frequency domain but a time as well to consider.

The broadband safety services will use different frame/burst durations, modulation schemes and coding rates depending upon the type of service and link conditions.

Due to the different characteristics of such broadband safety services, some changes are required to the general methodology used in §§ 4.1 and 4.2 above. The methodology for such services is illustrated in Fig. 2 and is described in the sub-sections below.

FIGURE 2

Flowchart illustrating the method to calculate AMS(R)S spectrum requirements for broadband safety services



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4.3.1 Estimation of AES count and the volume of traffic per AES to be handled

The methodology given in § 2 for the estimation of AES count and the volume of traffic per AES to be handled is also applicable for the different types of services being considered in broadband safety services (equations (1) to (8)).

Equation (5) for estimation of volume of voice traffic is valid for both circuit switched voice and circuit switched ISDN services. Similarly, equations (6) and (7) for estimation of packet data traffic in forward and return directions respectively are also valid for both streaming IP data and standard IP services in the forward and return directions.

4.3.2 Calculation of circuit switched voice and ISDN traffic volumes

Total circuit switched voice traffic per GES in a given beam Vb_{gvoice} in Erlangs can be obtained as:

$$Vb_{gvoice} = (Va_{voice} \times ACb_{gv})/60 \tag{31a}$$

where Va_{voice} is the averaged voice traffic in minutes based on equation (5) and ACb_{gv} is the adjusted AES count per beam or the adjusted AES count associated with each GES serving the beam for circuit switched voice traffic.

Total circuit switched ISDN traffic per GES in a given beam Vb_{gISDN} in Erlangs can be obtained as:

$$Vb_{gISDN} = (Va_{ISDN} \times ACb_{gISDN})/60 \tag{31b}$$

where Va_{ISDN} is the averaged voice traffic in minutes based on equation (5) and ACb_{gISDN} is the adjusted AES Count per beam or the adjusted AES Count associated with each GES serving the beam for circuit switched ISDN traffic.

Here it is assumed that 100% of the total circuit voice traffic or total circuit switched ISDN traffic is used in each direction similar to the classic AMS(R)S voice services.

Total circuit switched voice traffic $Vb_{gvoicejf}$ for voice sub-carrier type (j) in the forward direction can be obtained from the following formula:

$$Vb_{gvoicejf} = brv_{jf} \times Vb_{gvoice} \tag{32a}$$

where:

brv_{jf}: ratio of traffic volume for voice sub-carrier type (j) to total circuit switched voice traffic volume in the forward direction.

Total circuit switched voice traffic $Vb_{gvoicejr}$ for voice sub-carrier type (j) in the return direction can be obtained from the following formula:

$$Vb_{gvoicejr} = brv_{jr} \times Vb_{gvoice} \tag{32b}$$

where:

brv_{jr}: ratio of traffic volume for voice sub-carrier type (j) to total circuit switched voice traffic volume in the return direction.

Total circuit switched ISDN traffic Vbg_{ISDNjf} for ISDN sub-carrier type (j) in the forward direction can be obtained from the following formula:

$$Vb_{gISDNjf} = br_{ISDNjf} \times Vb_{gISDN} \tag{32c}$$

where:

br_{ISDNjf}: ratio of traffic volume for ISDN sub-carrier type (j) to total circuit switched ISDN traffic volume in the forward direction.

Total circuit switched ISDN traffic Vbg_{ISDNjr} for ISDN sub-carrier type (j) in the return direction can be obtained from the following formula:

$$Vb_{gISDNjr} = br_{ISDNjr} \times Vb_{gISDN} \quad (32d)$$

where:

br_{ISDNjr}: ratio of traffic volume for ISDN sub-carrier type (j) to total circuit switched ISDN traffic volume in the return direction.

4.3.3 Calculation of streaming IP data and standard IP data traffic volumes

Part of the methodology given in § 3.1 is also applicable to streaming IP and standard IP types of service for the calculation of traffic volumes (equations (9) to (12)). However, for the purpose of easy understanding and convenience, the description and the equations are repeated with specific notations for the streaming IP and standard IP services in the forward and return directions.

Standard IP data traffic volumes

As the broadband safety standard IP traffic is carried by different types of sub-carriers, the peak information data rate per beam in the forward and return directions can be obtained for each type of sub-carrier as:

$$Pd_{kStdIPf} = brd_{kStdIP} \times Pd_{StdIPf} \quad (33a)$$

$$Pd_{kStdIPr} = brd_{kStdIP} \times Pd_{StdIPr} \quad (33b)$$

where:

Pd_{StdIPf}: peak information data rate per beam for standard IP traffic in the forward direction

Pd_{StdIPr}: peak information data rate per beam for standard IP traffic in the return direction

$Pd_{kStdIPf}$: peak information data rate per beam corresponding to specific sub-carrier type for standard IP traffic in the forward direction

$Pd_{kStdIPr}$: peak information data rate per beam corresponding to specific sub-carrier type for standard IP traffic in the return direction

brd_{kStdIP}: standard IP data sub-carrier type (k) ratio.

In this case, brd_{kStdIP} would be ratio of standard IP traffic volume associated with sub-carrier type (k) relative to total standard IP data traffic volume (Tb_{StdIP}).

Streaming IP data traffic volumes

As the broadband safety streaming IP traffic is carried by different types of sub-carriers, the peak information data rate per beam in the forward and return directions can be obtained for each type of sub-carrier as:

$$Pd_{kStrIPf} = brd_{kStrIP} \times Pd_{StrIPf} \quad (34a)$$

$$Pd_{kStrIPr} = brd_{kStrIP} \times Pd_{StrIPr} \quad (34b)$$

where:

Pd_{StrIPf}: peak information data rate per beam for streaming IP traffic in the forward direction

Pd_{StdIPr}: peak information data rate per beam for streaming IP traffic in the return direction

$Pd_{kStrIPf}$: peak information data rate per beam corresponding to specific sub-carrier type for streaming IP traffic in the forward direction

$Pd_{kStrIPr}$: peak information data rate per beam corresponding to specific sub-carrier type for streaming IP traffic in the return direction

brd_{kStrIP}: streaming IP data sub-carrier type (k) ratio.

In this case, brd_{kStrIP} would be ratio of streaming IP traffic volume associated with sub-carrier type (k) relative to total streaming IP data traffic volume (Tb_{StrIP}).

4.3.4 Calculation of required number of sub-carriers for standard IP and streaming IP types of services

Again, for the purpose of easy understanding and convenience, the description and the equations to calculate the required number of sub-carriers are repeated with specific notations for the streaming IP and standard IP services in the forward and return directions.

Standard IP traffic

The required number of specified sub-carriers per beam and GES ($Nd_{kStdIPgf}$) in the forward direction and ($Nd_{kStdIPgr}$) in the return direction can be calculated by the following formulas:

$$Nd_{kStdIPgf} = \text{Roundup}(Pd_{kStdIPf}/Cd_{kStdIPf}) \quad (35a)$$

$$Nd_{kStdIPgr} = \text{Roundup}(Pd_{kStdIPr}/Cd_{kStdIPr}) \quad (35b)$$

where:

$Pd_{kStdIPf}$: peak information data rate to be supported by sub-carrier type k (kbit/s) in the forward direction

$Pd_{kStdIPr}$: peak information data rate to be supported by sub-carrier type k (kbit/s) in the return direction

$Cd_{kStdIPf}$: effective information transmission rate, i.e. the transmission capacity of the normalized data sub-carriers in kbit/s taking into account the channel overhead and other relevant factors in the forward direction

$Cd_{kStdIPr}$: effective information transmission rate, i.e. the transmission capacity of the normalized data sub-carriers in kbit/s taking into account the channel overhead and other relevant factors in the return direction.

One approach to calculate $Cd_{kStdIPf}$ and $Cd_{kStdIPr}$ is given below.

The effective carrier transmission rate (Cd_{kf}) that is available to deliver the standard IP service data in the forward direction may be determined from the following equations:

$$R_{iracf} = (R_{Tk} - R_{uw} - R_{pi}) \quad (36)$$

$$R_{irbcf} = R_{iracf} \times CR \quad (37)$$

$$Cd_{kStdIPf} = R_{irbcf} \times (1 - r_{rf}) \quad (38)$$

where:

R_{Tk}: sub-carrier transmission rate (kbit/s)

R_{uw}: unique word bit rate (kbits/s)

R_{pi}: pilot bit rate (kbit/s)

R_{iracf}: information rate after coding in the forward direction (kbit/s)

R_{irbcf}: information rate before coding in the forward direction (kbit/s)

CR: Forward Error Correction (FEC) coding rate (numerical ratio)

r_{rf}: ratio of retransmissions due to fading and interference (a number between 0 and 1) in the forward direction.

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

The effective carrier transmission rate ($Cd_{kStdIPr}$) that is available to deliver the standard IP service data in the return direction may be determined from the following equations:

$$R_{iracr} = (R_{Tk} - R_{gr} - R_{uw}) \quad (39)$$

$$R_{irbcr\text{-}weuw} = R_{iracr} \times CR \quad (40)$$

$$R_{irbcr} = R_{irbcr\text{-}weuw} - R_{euw} \quad (41)$$

$$Cd_{kStdIPr} = R_{irbcr} \times (1 - r_{rr}) \quad (42)$$

where:

R_{Tk}: sub-carrier transmission rate (kbit/s)

R_{gr}: guard time and ramp up CW time bit rate (kbits/s)

R_{uw}: unique word bit rate (kbits/s)

R_{iracr}: information rate after coding in the return direction (kbit/s)

$R_{irbcr\text{-}weuw}$: information rate before coding with embedded unique word in the return direction (kbit/s)

R_{irbcr}: information rate before coding in the return direction (kbit/s)

CR: FEC coding rate (numerical ratio)

R_{euw}: embedded UW bit rate (kbit/s)

r_{rr}: ratio of retransmissions due to fading, interference, collisions (a number between 0 and 1) in the return direction.

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

NOTE – Above items are normalized with respect to slot duration or burst duration in order to have consistency with the other parameters in terms of units (kbit/s).

Streaming IP traffic

The required number of specified sub-carriers per beam and GES ($Nd_{kStrIPgf}$) in the forward direction and ($Nd_{kStdIPgr}$) in the return direction can be calculated by the following formulas:

$$Nd_{kStrIPgf} = \text{Roundup}(Pd_{kStrIPf}/Cd_{kStrIPf}) \quad (43a)$$

$$Nd_{kStrIPgr} = \text{Roundup}(Pd_{kStrIPr}/Cd_{kStrIPr}) \quad (43b)$$

where:

$Pd_{kStrIPf}$: peak information data rate to be supported by sub-carrier type *k* (kbit/s) in the forward direction

$Pd_{kStrIPr}$: peak information data rate to be supported by sub-carrier type *k* (kbit/s) in the return direction

$Cd_{kStrIPf}$: effective information transmission rate, i.e. the transmission capacity of the normalized data sub-carriers in kbit/s taking into account the channel overhead and other relevant factors in the forward direction

$Cd_{kStrIPr}$: effective information transmission rate, i.e. the transmission capacity of the normalized data sub-carriers in kbit/s taking into account the channel overhead and other relevant factors in the return direction.

One approach to calculate $Cd_{kStrIPf}$ and $Cd_{kStrIPr}$ is given below.

The effective carrier transmission rate (Cd_{kf}) that is available to deliver the streaming IP service data in the forward direction may be determined from the following equations:

$$R_{iracf} = (R_{Tk} - R_{uw} - R_{pi}) \tag{44}$$

$$R_{irbcf} = R_{iracf} \times CR \tag{45}$$

$$Cd_{kStrIPf} = R_{irbcf} \times (1 - r_{rf}) \tag{46}$$

where:

- R_{Tk}: sub-carrier transmission rate (kbit/s)
- R_{uw}: unique word bit rate (kbits/s)
- R_{pi}: pilot bit rate (kbit/s)
- R_{iracf}: information rate after coding in the forward direction (kbit/s)
- R_{irbcf}: information rate before coding in the forward direction (kbit/s)
- CR: Forward Error Correction (FEC) coding rate (numerical ratio)
- r_{rf}: ratio of retransmissions due to fading and interference (a number between 0 and 1) in the forward direction.

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

The effective carrier transmission rate ($Cd_{kStrIPr}$) that is available to deliver the streaming IP service data in the return direction may be determined from the following equations:

$$R_{iracr} = (R_{Tk} - R_{gr} - R_{uw}) \tag{47}$$

$$R_{irbcr\text{-}weuw} = R_{iracr} \times CR \tag{48}$$

$$R_{irbcr} = R_{irbcr\text{-}weuw} - R_{euw} \tag{49}$$

$$Cd_{kStrIPr} = R_{irbcr} \times (1 - r_{rr}) \tag{50}$$

where:

- R_{Tk}: sub-carrier transmission rate (kbit/s)
- R_{gr}: guard time and ramp up CW time bit rate (kbits/s)
- R_{uw}: unique word bit rate (kbits/s)
- R_{iracr}: information rate after coding in the return direction (kbit/s)
- $R_{irbcr\text{-}weuw}$: information rate before coding with embedded unique word in the return direction (kbit/s)
- R_{irbcr}: information rate before coding in the return direction (kbit/s)
- CR: FEC coding Rate (numerical ratio)
- R_{euw}: embedded UW bit rate (kbit/s)
- r_{rr}: ratio of retransmissions due to fading, interference, collisions (a number between 0 and 1) in the return direction.

Provision of values for the above parameters and ratios would be the responsibility of the system operator. Sufficient technical justifications should be provided in support of such values.

NOTE – Above items are normalized with respect to slot duration or burst duration in order to have consistency with the other parameters in terms of units (kbit/s).

4.3.5 Calculation of required number of sub-carriers for circuit switched voice and ISDN types of services

Here it is proposed to use the Erlang-B formula explained in § 4.2 to calculate the number of sub-carriers required to support circuit switched voice and ISDN traffic in the forward and return directions.

Circuit switched (CS) voice traffic

The number of voice bearers required to carry the CS voice traffic in the forward direction:

$$Nvi_{gvoicef} = \max\left(N\,vi_{\ voice\_min\ gf},\ N\,vi_{\ voice\ Erl\text{-}Bcalf}\right) \qquad (51a)$$

where:

$N\,vi_{\ voice\_min\ gf}$: minimum number of sub-carriers per GES required for each voice sub-carrier type in the forward direction

$N\,vi_{\ voice\ Erl\text{-}Bcalf}$: number of sub-carriers based on Erlang-B formula calculations for each voice sub-carrier type as a function of $Vb_{gvoicejf}$ in the forward direction.

The number of voice sub-carriers required to carry the CS voice traffic in the return direction:

$$Nvi_{gvoicer} = \max\left(N\,vi_{\ voice\_min\ gr},\ N\,vi_{\ voice\ Erl\text{-}Bcalr}\right) \qquad (51b)$$

where:

$N\,vi_{\ voice\_min\ gr}$: minimum number of sub-carriers per GES required for each voice sub-carrier type in the return direction

$N\,vi_{\ voice\ Erl\text{-}Bcalr}$: number of sub-carriers based on Erlang-B formula calculations for each voice sub-carrier type as a function of $Vb_{gvoicejr}$ in the return direction.

Circuit switched (CS) ISDN traffic

The number of ISDN sub-carriers required to carry the CS ISDN traffic in the forward direction:

$$Nvi_{gISDNf} = \max\left(N\,vi_{\ ISDN\_min\ gf},\ N\,vi_{\ ISDN\ Erl\text{-}Bcalf}\right) \qquad (52a)$$

where:

$N\,vi_{\ ISDN\_min\ gf}$: minimum number of sub-carriers per GES required for each ISDN sub-carrier type in the forward direction

$N\,vi_{\ ISDN\ Erl\text{-}Bcalf}$: number of sub-carriers based on Erlang-B formula calculations for each ISDN sub-carrier type as a function of $Vb_{gISDNjf}$ in the forward direction.

The number of ISDN sub-carriers required to carry the CS ISDN traffic in the return direction:

$$Nvi_{gISDNr} = \max\left(N\,vi_{\ ISDN\_min\ gr},\ N\,vi_{\ ISDN\ Erl\text{-}Bcalr}\right) \qquad (52b)$$

where:

$N\,vi_{\ ISDN\_min\ gr}$: minimum number of sub-carriers per GES required for each ISDN sub-carrier type in the return direction

$N\,vi_{\ ISDN\ Erl\text{-}Bcalr}$: number of sub-carriers based on Erlang-B formula calculations for ISDN each sub-carrier type as a function of $Vb_{gISDNjr}$ in the return direction.

4.3.6 Calculation of required bandwidth for different sub-carriers and overall spectrum requirements for broadband safety services

The allocated bandwidth for different individual sub-carriers depends on the modulation scheme, coding rate and the terminal types. The different sub-carriers within the carriers carry different types of traffic – a mix of circuit switched voice, ISDN, streaming IP and background IP traffic each with different bandwidths.

The required bandwidth for each type of sub-carrier is evaluated separately for both forward and return directions and then aggregated by summing up the bandwidth requirements for circuit switched voice, circuit switched ISDN, standard IP and streaming IP services.

4.3.6.1 The bandwidth requirements for the circuit switched voice services

In the forward direction:

$$BW_{cs\text{-}voicef} = \Sigma\ Nv_{igvoicef} \times Dd_{CS\text{-}voiceif} \quad (53)$$

where:

- $Dd_{CS\text{-}voiceif}$: bandwidth allocated to each voice sub-carrier type (i) in the forward direction in kHz
- $Nv_{igvoicef}$: number of sub-carriers required for the CS voice service in the forward direction.

In the return direction:

$$BW_{CS\text{-}voicer} = \Sigma\ Nv_{igvoicer} \times Dd_{CS\text{-}voiceir} \quad (54)$$

where:

- $Dd_{CS\text{-}voiceir}$: bandwidth allocated to each voice sub-carrier type (i) in the return direction in kHz
- $Nv_{igvoicer}$: number of sub-carriers required for the CS voice service in the return direction.

4.3.6.2 The bandwidth requirements for the circuit switched ISDN services

In the forward direction:

$$BW_{CS\text{-}ISDNf} = \Sigma\ Nv_{ig\ ISDNf} \times Dd_{CS\text{-}ISDNif} \quad (55)$$

where:

- $Dd_{CS\text{-}ISDNif}$: bandwidth allocated to each ISDN sub-carrier type (i) in the forward direction in kHz
- $Nv_{igISDNf}$: number of sub-carriers required for the CS ISDN service in the forward direction.

In the return direction:

$$BW_{CS\text{-}ISDNr} = \Sigma\ Nv_{igISDNr} \times Dd_{CS\text{-}ISDNir} \quad (56)$$

where:

- $Dd_{CS\text{-}ISDNir}$: bandwidth allocated to each ISDN sub-carrier type (i) in the return direction in kHz
- $Nv_{igISDNr}$: number of sub-carriers required for the CS ISDN service in the return direction.

4.3.6.3 The bandwidth requirements for the standard IP services

In the forward direction:

$$BW_{StdIPf} = \Sigma\ Nd_{kg\ StdIPgf} \times Dd_{StdIPkf} \quad (57)$$

where:

- $Dd_{StdIPkf}$: bandwidth allocated to each standard IP sub-carrier type (k) in the forward direction in kHz
- $Nd_{kgStdIPgf}$: number of sub-carriers required for the standard IP service in the forward direction.

In the return direction:

$$BW_{StdIPr} = \Sigma\, Nd_{kgStdIPgr} \times Dd_{StdIPkr} \quad (58)$$

where:

$Dd_{StdIPkr}$: bandwidth allocated to each standard IP sub-carrier type (k) in the return direction in kHz

$Nd_{kgStdIPgr}$: number of sub-carriers required for the standard IP service in the return direction.

4.3.6.4 The bandwidth requirements for the streaming IP services

In the forward direction:

$$BW_{StrIPf} = \Sigma\, Nd_{kgStrIPgf} \times Dd_{StrIPkf} \quad (59)$$

where:

$Dd_{StrIPkf}$: bandwidth allocated to each streaming IP sub-carrier type (k) in the forward direction in kHz

$Nd_{kgStrIPgf}$: number sub-carriers required for the streaming IP service in the forward direction.

In the return direction:

$$BW_{StrIPr} = \Sigma\, Nd_{kgStrIPgr} \times Dd_{StrIPkr} \quad (60)$$

where:

$Dd_{StrIPkr}$: bandwidth allocated to each streaming IP sub-carrier type (k) in the return direction in kHz

$Nd_{kgStrIPgr}$: number of sub-carriers required for the streaming IP service in the return direction.

4.3.6.5 Overall spectrum requirements in the forward and return directions

The total spectrum requirements for broadband safety services *SRbf* in the forward direction depends on the number of carriers required to accommodate the required number of sub-carriers and is obtained from the following formula:

$$SRbf = \{\text{Roundup}\ ((BW_{cs\text{-}voicef} + BW_{CS\text{-}ISDNf} + BW_{StdIPf} + BW_{StrIPf} + SR_{NCGESf})/Xf)\} \times Xf \quad (61)$$

where:

SR_{NCGESf} : spectrum requirement for the network control per GES in kHz in the forward direction

Xf : the bandwidth of one carrier in the forward direction (kHz).

Roundup (x) gives the value of x rounded up to the next integer value.

The total spectrum requirements for broadband safety services *SRbr* in the return direction depends on the number of carriers required to accommodate the required number of sub-carriers and is obtained from the following formula:

$$SRbr = \{\text{Roundup}\ ((BW_{cs\text{-}voicer} + BW_{CS\text{-}ISDNr} + BW_{StdIPr} + BW_{StrIPr} + SR_{NCGESr})/Xr)\} \times Xr \quad (62)$$

where:

SR_{NCGESr}: spectrum requirement for the network control per GES (if any) in kHz in the return direction

Xr: the bandwidth of one carrier in the return direction (kHz).

Roundup (x) gives the value of x rounded up to the next integer value.

5 Spectrum requirements for a beam within the network under consideration

Total forward and return spectrum requirements per beam can be obtained as:

$$SRf = SRdf + SRvf + SRbf \tag{63}$$

$$SRr = SRdr + SRvr + SRbr \tag{64}$$

where:

- $SRdf$: required spectrum for data traffic per beam in the forward direction
- $SRvf$: required spectrum for voice traffic per beam in the forward direction
- $SRbf$: required spectrum for broadband safety traffic per beam in the forward direction
- $SRdr$: required spectrum for data traffic per beam in the return direction
- $SRvr$: required spectrum for voice traffic per beam in the return direction
- $SRbr$: required spectrum for broadband safety traffic per beam in the return direction
- SRf : required forward spectrum per beam
- SRr: required return spectrum per beam.

During the frequency coordination discussions, the spectrum assigned per beam should take into account further constraints such as those from the satellite transponder channelization.

6 Example calculations

Examples of calculations using the above methodology are shown in Attachment 2.

Attachment 1 to Annex 1

Parameters used in the methodology

TABLE A1

Parameters used in the methodology in Annex 1

Parameter	Description	Unit assumed in the methodology
ACa_g	The actual AES Count per beam associated with a given GES	Number
X_1, X_2, X_3	Number of AESs in each of the three busiest hours generating either the highest voice or data traffic in a given year	Number
G_a	Estimated growth in the number of aircraft for the year in question as a percentage	%

TABLE A1 (*continued*)

Parameter	Description	Unit assumed in the methodology
ACb_g	Adjusted AES Count per beam associated with a given GES	Number
Y_1, Y_2, Y_3	Values of voice traffic volumes in each of the three busy hours corresponding to X_1, X_2, X_3	Minutes
Y_{ave}	Average volume of voice traffic per GES in a given beam in the busy hour	Minutes
Z_{1f}, Z_{2f}, Z_{3f}	Values of data traffic volumes in the forward direction in each of the three busy hours corresponding to X_1, X_2, X_3	kbit
Z_{avef}	Average volume of data traffic per GES in a given beam in the busy hour in the forward direction	kbit
Z_{1r}, Z_{2r}, Z_{3r}	Values of data traffic volumes in the return direction in each of the three busy hours corresponding to X_1, X_2, X_3	kbit
Z_{aver}	Average volume of data traffic per GES in a given beam in the busy hour in the return direction	kbit
Va	Volume of voice traffic carried by one AES in the busy hour	Minutes
Daf	Volume of data traffic carried by one AES in the forward direction in the busy hour	kbit
Dar	Volume of data traffic carried by one AES in the return direction in the busy hour	kbit
Tb_{gf}	Total data traffic per GES in a given beam in the forward direction in the busy hour	kbit
Pdf	Required peak data rate per beam in the forward direction	kbit/s
hs	Conversion factor from the average data rate in kbit/s to the peak data rate in kbit/s	Number
Tb_{gr}	Total data traffic per GES in a given beam in the return direction in the busy hour	kbit
Pdr	Required peak data rate per beam in the return direction	kbit/s
rd_i	Data carrier type ratio for different data carrier types. Ratio of data traffic volume associated with carrier type (*i*) relative to the total data traffic volume	Number
Pd_{if}	Peak information data rate per beam to be supported in the forward direction for each type of carrier	kbit/s
Pd_{ir}	Peak information data rate per beam to be supported in the return direction for each type of carrier	kbit/s
Vb_g	Total voice traffic per GES in a given beam in the busy hour	Erlangs
rv_j	Voice carrier type ratio for different voice carrier types. Ratio of traffic volume for voice carrier type (*j*) to the total traffic volume	Number
Cd_{if}	Effective information transmission rate i.e. the transmission capacity of the normalized data carriers taking into account the channel overhead in the forward direction	kbit/s
Cd_{ir}	Effective information transmission rate i.e. the transmission capacity of the normalized data carriers taking into account the channel overhead in the return direction	kbit/s

TABLE A1 (*continued*)

Parameter	Description	Unit assumed in the methodology
Nd_{igf}	The required number of specified circuits per beam per GES in the forward direction	Integer
Nd_{igr}	The required number of specified circuits per beam per GES in the return direction	Integer
Nd_{ig}	The required number of specified circuits per beam per GES in any direction	Integer
Nd_{imingf}	Minimum number of circuits per GES required for each forward direction data carrier type	Integer
Nd_{imingr}	Minimum number of circuits per GES required for each return direction data carrier type	Integer
R_{Ti}	Carrier transmission rate	kbit/s
R_d	Dummy bit rate	kbit/s
R_{frm}	Format identification and multi-frame rate	kbit/s
R_f	Framing rate	kbit/s
R_{iracf}	Information rate after coding in the forward direction	kbit/s
R_{irbcf}	Information rate before coding in the forward direction	kbit/s
CR	Forward Error Correction Rate (numerical ratio)	Number
r_{rf}	Ratio of retransmissions due to fading, interference in the forward direction (a number between 0 and 1)	Number
R_{uwf}	Unique word and flush bit rate	kbit/s
R_{iracr}	Information rate after coding in the return direction	kbit/s
R_{irbcr}	Information rate before coding in the return direction	kbit/s
CR	Forward Error Correction Rate (numerical ratio)	Number
R_p	Preamble bit rate	kbit/s
r_{rr}	Ratio of retransmissions due to fading, interference in the return direction (a number between 0 and 1)	Number
$BWdi_g$	Calculated bandwidth for specific type of carrier (i)	kHz
Ddi	Bandwidth allocated to each data carrier type	kHz
$SRxig$	Spectrum requirement for the network control per GES and etc.	kHz
SRd_g	The required bandwidth per beam and GES	kHz
SRd	Total spectrum requirements for data carriers in a beam	kHz
Nvi_{ming}	Minimum number of channels per GES required for each voice carrier type	Integer
$Nvi_{Erl\text{-}Bcal}$	Number of channels per GES based on Erlang-B formula for each voice carrier type	Integer
Nvi_g	Maximum number of channels per GES required for each voice carrier type	Integer
Dvi	Bandwidth per voice carrier type	kHz
Va_{voice}	Volume of CS voice traffic carried by one AES in the busy hour	Minutes
Va_{ISDN}	Volume of CS ISDN traffic carried by one AES in the busy hour	Minutes

TABLE A1 (*continued*)

Parameter	Description	Unit assumed in the methodology
ACb_{gv}	Adjusted AES Count per beam or the adjusted AES count associated with each serving the beam for circuit switched voice traffic	Number
ACb_{gISDN}	Adjusted AES Count per beam or the adjusted AES count associated with each serving the beam for circuit switched ISDN traffic	Number
Vb_{gvoice}	Total circuit switched voice traffic per GES in a given beam in the busy hour	Erlangs
Vb_{gISDN}	Total circuit switched ISDN traffic per GES in a given beam in the busy hour	Erlangs
$Vb_{gvoicejf}$	Total circuit switched voice traffic for voice sub-carrier type (*j*) in the forward direction	Erlangs
$Vb_{gvoicejr}$	Total circuit switched voice traffic for voice sub-carrier type (*j*) in the return direction	Erlangs
$Vb_{gISDNjf}$	Total circuit switched ISDN traffic for ISDN sub-carrier type (*j*) in the forward direction	Erlangs
$Vb_{gISDNjr}$	Total circuit switched ISDN traffic for ISDN sub-carrier type (*j*) in the return direction	Erlangs
Brv_{jf}	Ratio of traffic volume for voice sub-carrier type (*j*) to total switched voice traffic volume in the forward direction	Number
Brv_{jr}	Ratio of traffic volume for voice sub-carrier type (*j*) to total switched voice traffic volume in the return direction	Number
br_{ISDNjf}	Ratio of traffic volume for ISDN sub-carrier type (*j*) to total switched ISDN traffic volume in the forward direction	Number
br_{ISDNjr}	Ratio of traffic volume for ISDN sub-carrier type (*j*) to total switched ISDN traffic volume in the return direction	Number
Pd_{StdIPf}	Peak information data rate per beam for standard IP traffic in the forward direction	kbit/s
Pd_{StdIPr}	Peak information data rate per beam for standard IP traffic in the return direction	kbit/s
$Pd_{kStdIPf}$	Peak information data rate per beam corresponding to specific sub-carrier type (*k*) for Standard IP traffic in the forward direction	kbit/s
$Pd_{kStdIPr}$	Peak information data rate per beam corresponding to specific sub-carrier type (*k*) for standard IP traffic in the return direction	kbit/s
brd_{kStdIP}	standard IP data sub-carrier type (*k*) ratio	Number
Pd_{StrIPf}	Peak information data rate per beam for streaming IP traffic in the forward direction	kbit/s
Pd_{StrIPr}	Peak information data rate per beam for streaming IP traffic in the return direction	kbit/s
$Pd_{kStrIPf}$	Peak information data rate per beam corresponding to specific sub-carrier type (*k*) for streaming IP traffic in the forward direction	kbit/s
$Pd_{kStrIPr}$	Peak information data rate per beam corresponding to specific sub-carrier type (*k*) for streaming IP traffic in the return direction	kbit/s
brd_{kStrIP}	Streaming IP data sub-carrier type (*k*) ratio	Number

TABLE A1 (*continued*)

Parameter	Description	Unit assumed in the methodology
Tb_{StdIP}	Total standard IP data traffic volume	kbit
Tb_{StrIP}	Total streaming IP data traffic volume	kbit
$Nd_{kStdIPgf}$	The required number of specified standard IP sub-carriers per beam and GES in the forward direction	Integer
$Nd_{kStdIPgr}$	The required number of specified standard IP sub-carriers per beam and GES in the return direction	Integer
$Pd_{kStdIPf}$	Peak information data rate to be supported by standard IP sub-carrier type *k* in the forward direction	kbit/s
$Pd_{kStdIPr}$	Peak information data rate to be supported by standard IP sub-carrier type *k* in the return direction	kbit/s
$Cd_{kStdIPf}$	Effective information transmission rate, i.e. the transmission capacity of the normalized standard IP data sub-carriers taking into account the channel overhead and other relevant factors in the forward direction	kbit/s
$Cd_{kStdIPr}$	Effective information transmission rate, i.e. the transmission capacity of the normalized standard IP data sub-carriers taking into account the channel overhead and other relevant factors in the return direction	kbit/s
$Nd_{kStrIPgf}$	The required number of specified streaming IP sub-carriers per beam and GES in the forward direction	Integer
$Nd_{kStrIPgr}$	The required number of specified streaming IP sub-carriers per beam and GES in the return direction	Integer
$Pd_{kStrIPf}$	Peak information data rate to be supported by streaming IP sub-carrier type (*k*) in the forward direction	kbit/s
$Pd_{kStrIPr}$	Peak information data rate to be supported by streaming IP sub-carrier type (*k*) in the return direction	kbit/s
$Cd_{kStrIPf}$	Effective information transmission rate, i.e. the transmission capacity of the normalized streaming IP data sub-carriers taking into account the channel overhead and other relevant factors in the forward direction	kbit/s
$Cd_{kStrIPr}$	Effective information transmission rate, i.e. the transmission capacity of the normalized streaming IP data sub-carriers taking into account the channel overhead and other relevant factors in the return direction	kbit/s
R_{Tk}	Sub-carrier transmission rate	kbit/s
R_{uw}	Unique word bit rate	kbit/s
R_{pi}	Pilot bit rate	kbit/s
R_{gr}	Guard time and ramp up CW time bit rate	kbit/s
$R_{irbcr\text{-}weuw}$	Information rate before coding with embedded unique word in the return direction	kbit/s
R_{euw}	Embedded unique word rate	kbit/s
$Nvi_{gvoicef}$	The number of voice sub-carriers required to carry the CS voice traffic in the forward direction	Integer
$N\,vi_{\,voice\_min\,gf}$	Minimum number of sub-carriers per GES required for each voice sub-carrier type in the forward direction	Integer

TABLE A1 (*continued*)

Parameter	Description	Unit assumed in the methodology
$N\,vi_{voice\ Erl\text{-}Bcalf}$	Number of sub-carriers based on Erlang-B formula calculations for each voice sub-carrier type in the forward direction	Integer
$Nvi_{gvoicer}$	The number of voice sub-carriers required to carry the CS voice traffic in the return direction	Integer
$N\,vi_{voice\_min\ gr}$	Minimum number of sub-carriers per GES required for each voice sub-carrier type in the return direction	Integer
$N\,vi_{voice\ Erl\text{-}Bcalr}$	Number of sub-carriers based on Erlang-B formula calculations for each voice sub-carrier type in the return direction	Integer
Nvi_{gISDNf}	The number of ISDN sub-carriers required to carry the CS ISDN traffic in the forward direction	Integer
$N\,vi_{ISDN\_min\ gf}$	Minimum number of sub-carriers per GES required for each ISDN sub-carrier type in the forward direction	Integer
$N\,vi_{ISDN\ Erl\text{-}Bcalf}$	Number of sub-carriers based on Erlang-B formula calculations for ISDN sub-carrier type in the forward direction	Number
Nvi_{gISDNr}	The number of ISDN sub-carriers required to carry the CS ISDN traffic in the return direction	Integer
$N\,vi_{ISDN\_min\ gr}$	Minimum number of sub-carriers per GES required for each ISDN sub-carrier type in the return direction	Integer
$N\,vi_{ISDN\ Erl\text{-}Bcalr}$	Number of sub-carriers based on Erlang-B formula calculations for ISDN sub-carrier type in the return direction	Integer
$Dd_{CS\text{-}voiceif}$	Bandwidth allocated to each voice sub-carrier type (*i*) in the forward direction	kHz
$BW_{cs\text{-}voicef}$	Bandwidth requirements for CS voice services in the forward direction	kHz
$Dd_{CS\text{-}voiceir}$	Bandwidth allocated to each voice sub-carrier type (*i*) in the return direction	kHz
$BW_{CS\text{-}voicer}$	Bandwidth requirements for CS voice services in the return direction	kHz
$Dd_{CS\text{-}ISDNif}$	Bandwidth allocated to each ISDN sub-carrier type (*i*) in the forward direction	kHz
$BW_{CS\text{-}ISDNf}$	Bandwidth requirements for CS ISDN services in the forward direction	kHz
$Dd_{CS\text{-}ISDNir}$	Bandwidth allocated to each ISDN sub-carrier type (*i*) in the return direction	kHz
$BW_{CS\text{-}ISDNr}$	Bandwidth requirements for CS ISDN services in the return direction	kHz
$Dd_{StdIPkf}$	Bandwidth allocated to each standard IP sub-carrier type (*k*) in the forward direction	kHz
BW_{StdIPf}	Bandwidth requirements for standard IP services in the forward direction	kHz
$Dd_{StdIPkr}$	Bandwidth allocated to each standard IP sub-carrier type (*k*) in the return direction	kHz
BW_{StdIPr}	Bandwidth requirements for standard IP services in the return direction	kHz
$Dd_{StrIPkf}$	Bandwidth allocated to each streaming IP sub-carrier type (*k*) in the forward direction	kHz
BW_{StrIPf}	Bandwidth requirements for streaming IP services in the forward direction	kHz
$Dd_{StrIPkr}$	Bandwidth allocated to each streaming IP sub-carrier type (*k*) in the return direction	kHz

TABLE A1 (*end*)

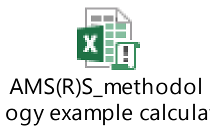
Parameter	**Description**	**Unit assumed in the methodology**
BW_{StrIPr}	Bandwidth requirements for streaming IP services in the return direction	kHz
Xf	The bandwidth of one carrier in the forward direction	kHz
Xr	The bandwidth of one carrier in the return direction	kHz
SR_{NCGESf}	Spectrum requirement for the network control per GES in the forward direction	kHz
SR_{NCGESr}	Spectrum requirement for the network control per GES (if any) in the return direction	kHz
SRdf	Required spectrum for data traffic per beam in the forward direction	kHz
SRvf	Required spectrum for voice traffic per beam in the forward direction	kHz
SRbf	Required spectrum for broadband safety traffic per beam in the forward direction	kHz
SRdr	Required spectrum for data traffic per beam in the return direction	kHz
SRvr	Required spectrum for voice traffic per beam in the return direction	kHz
SRbr	Required spectrum for broadband safety traffic per beam in the return direction	kHz
SRf	Required forward spectrum per beam	kHz
SRr	Required return spectrum per beam.	kHz

Attachment 2
to Annex 1

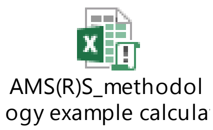
Example calculations of AMS(R)S spectrum requirements

This Attachment contains example calculations, and explanatory notes, based on the approach presented in Annex 1. The first spreadsheet gives an example calculation applicable for systems without the broadband safety services and the second spreadsheet gives an example calculation applicable for systems employing broadband safety services only.

Example calculation applicable for systems without the broadband safety services



Example calculation applicable for systems employing broadband safety services only



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