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Spectrum requirements for future SRS missions operating under a potential new SRS allocation in the band 22.55-23.15 GHz

SA Series

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REPORT ITU-R SA.2191

Spectrum requirements for future SRS missions operating under a potential new SRS allocation in the band 22.55-23.15 GHz

(2010)

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1 Introduction

WRC-12 Agenda item 1.11 proposes for consideration a companion band to the existing SRS space-to-Earth allocation in the band 25.5-27.0 GHz. This would enable the support of high data rate Earth-to-space links for SRS missions in near-Earth orbits, including missions in transit to the Moon, near the Moon and missions to Lagrangian points L1 and L2. Existing allocations near 2 and 8 GHz are becoming congested due to the increasing usage requirements of co-primary services and will not provide sufficient bandwidth for remote system management and updates, tele-operation, network management, mission data, high resolution imagery/video and maps, interactive management instructions, and command and control links for these future generation missions. Detailed description of spectrum usages, symbol rates and bandwidths is contained in Annex 1 for both unmanned and manned missions.

Multinational activities amongst space-faring nations have started in 2005 with the objective to coordinate future programmes for the exploration of the Moon. It is envisioned that these exploration missions will be robotic for the foreseeable future and manned in the long term. In the early phases, extensive robotic missions will be predominant, examining the lunar terrain, environment and potential landing sites. The use of SRS earth stations in this band will focus on support of lunar missions with antenna diameters of around 18 m. In addition, also Lagrangian point missions are planned to be supported by earth stations with antenna diameters of around 35 m. Low-Earth orbiting missions may also use this band and could generally be supported by antennas of around 10 m diameter.

It is anticipated that worldwide, over the next few decades, some 10-15 SRS earth stations of the various participating space agencies will use this band mainly for support of lunar and Lagrangian missions. The stations are almost exclusively deployed around mid-latitudes for mission specific reasons. Since several systems are expected to operate simultaneously in the vicinity of the Moon and their coincident appearance within an earth station antenna beam, frequency separation will be required between affected missions.

Earlier studies performed in the frame of the Space Frequency Coordination Group (SFCG) anticipated that a cumulative total net uplink bandwidth of up to 500 MHz will be needed for support of lunar missions only. In addition, this band will also be required for Lagrangian point (L1 and L2) missions. These missions will require less bandwidth than lunar missions but will also need exclusive frequencies as they will all be located within the main beams of antennas of the various space agencies.

Furthermore, detailed studies revealed that for reasons outlined below, it is not practicable to simply add one channel after the other. As explained, it would in practice not be feasible to assign the required channels in one contiguous band.

Annex 1 is taken from an SFCG Report and it presents details, based on the plans of the major space agencies worldwide, demonstrating the types of links that Lunar missions will use, their usage descriptions, the expected types of users, and the associated symbol rates and bandwidth requirements.

In summary, the indicated forward requirements of space agencies for their near-Earth, lunar and Lagrangian exploratory missions reveal that, even with global coordination within bodies such as the SFCG to achieve optimum efficiency in spectrum usage, their aggregate requirements will barely be accommodated in 600 MHz and will certainly require careful planning and extensive frequency coordination.

2 Assessment of spectrum requirements

A single space agency will typically have requirements for several frequency channels in order to simultaneously support different applications within an exploration venture such as low-Earth orbit check-out, manned or un-manned spacecraft support during transfer phase, crew lander, surface operations, habitat, etc. Frequency reuse is seldom possible as any spacecraft around the Moon will be in the antenna main-beam lobe of other space agencies supporting their own lunar missions. Despite large antennas with narrow main beams, the Moon is fully within the main lobe of any antenna pointing there from the Earth. A similar situation applies to Lagrangian points.

Bandwidth requirements can vary largely and depend on the mission objectives. Unmanned exploration missions to the lunar surface and Lagrangian points will involve large scale communication requirements such as transmission of detailed mission plans and instructions, highly detailed mapping and terrain updates for navigation, and software updates. In addition to the unmanned communication requirements, manned lunar exploration applications will involve communication requirements such as streaming high resolution video, video conferencing, high fidelity plans and maps, software updates, and other such detailed command and control transmissions. These communication requirements are standard practice in modern scientific work environments and will afford control personnel on Earth to effectively coordinate Lunar exploration activities.

Control signals as described above for communications to these unmanned and manned exploration terminals can be transmitted in a multiplexed fashion and distributed to the individual surface elements by way of a communications terminal on the lunar surface. The communications terminal will relay mission data to the specified surface element. Annex 1 contains specific requirements and data/information rates for both unmanned and manned missions, as well as explains the data/information rates that need to be supported.

The expected information rates as listed in Table 1 of Annex 1, for a user, per channel, is estimated to be 10-20 MSps (Million Symbols per second) for Earth to Lunar orbit communications and 20-25 MSps for Earth-to-Lunar surface communication terminal transmissions. These high data rates are required to support the large scale requirements of lunar scientific exploration. Therefore, typical channel bandwidths as listed in Table 1 of Annex 1, for lunar missions are expected to range between 10 and 25 MHz. For one space agency's lunar exploration program, a requirement of typically 2 × 25 MHz channels plus one or 2 channels between 10 and 20 MHz, will result in an aggregate requirement of 60-90 MHz for Earth-to-space support of the various lunar mission applications. At least for one of these channels, it is desirable to have the same centre frequency as a Data Relay System (DRS) channel as explained below. Such channels may be reused in low-Earth orbits but the direct links towards the Moon could not be reused and have to be exclusive.

Support of Lagrangian missions is also expected to typically utilize around 2 or 3 channels, each with a bandwidth of several MHz, so that another 10 MHz of exclusive (non-reusable) bandwidth may be added per space agency. Spectrum for low-Earth orbiting missions can in all likelihood be reused in view of low probabilities of interference so that such requirements would not have to be added to the non-reusable spectrum requirements.

There are current plans by at least six space agencies for manned Lunar exploration missions and at least eight space agencies for unmanned Lunar exploration missions. Due to the large distances between SRS earth stations and Lunar and Lagrangian exploration activities, the footprints of even very narrow antenna beams from multiple space agencies will intersect. Since individual missions of one space agency will potentially fall within the beam of another space agency, each individual space agency will require exclusive channels to communicate with their respective missions.

To mitigate the potential of interference between multiple transmissions among space agencies, guardbands between the various channels will be required which will increase the total spectrum requirement by around 20%. Therefore, a total net requirement of 70-100 MHz of spectrum per space agency will in total require around 85-120 MHz per space agency taking into account guard bands. Due to excessive interference, re-use of the guardbands by means of interleaved channels is not possible for missions requiring exclusive bandwidths but can, and actually would be applied for conventional near Earth missions.

This would mean that, if 600 MHz is allocated at WRC-12 in the band 22.55-23.15 GHz, hypothetically a total of some 5 to 7 space agencies may be accommodated in the midterm if frequency channels could be freely selected from a contiguous band. However, several factors will limit the choice of available spectrum as explained below.

Sharing among Lunar and Lagrange missions is not possible (although sharing between each of these types of missions and low-Earth orbit missions is possible) due to geometric configurations that would cause missions to be within the main lobe of antennas of other missions. This is also further described in Annex 1.

3 Factors limiting the choice of available channels

3.1 Data relay satellite compatibility

The 22.55-23.55 GHz band is already used by Data Relay Satellite (DRS) systems to communicate with user satellites (forward links) via an existing primary inter-satellite service allocation. These forward links are paired with inter-satellite return links in the band 25.25-27.5 GHz. It is therefore desirable to select frequencies for support of mission phases in the vicinity of the Earth in accordance with the internationally agreed DRS channels in order to enable global support either via an earth station or via a DRS satellite. This provides a degree of redundancy and flexibility of increased coverage to space agencies by not limiting their communications to direct visibility from an earth station. This ability to achieve global coverage by any one space agency may prove vital for future missions.

The DRS channels are spaced at 60 MHz intervals and are part of international cross-support agreements. Even if a bandwidth for a specific mission is typically around 25 MHz, its centre frequency will have to match a DRS channel centre frequency as otherwise no support via a DRS will be feasible. Re-use of DRS channels for conventional uplinks to low Earth orbiting satellites, as well as for other DRS forward links, is expected to be feasible in view of an allowed interference percentage of 0.1% as contained in Recommendations ITU-R SA.609 and ITU-R SA.1155.

Availability of sufficient DRS channels below 23.15 GHz would also allow for minimal usage of those DRS channels which currently overlap with HIBLEO-2 channels in the range 23.18-23.38 GHz. Despite meeting generally recognized protection criteria in co-channel operations, use of DRS channels below 23.15 GHz would result in even further reduced interference potential for the HIBLEO-2 system.

3.2 Sharing with other services

Protection of radio astronomy service (RAS) stations from in-band emissions needs to be taken into account for the bands 22.81-22.86 GHz and 23.07-23.12 GHz in accordance with RR No. 5.149. This has been shown to be feasible by geographic separation between SRS and RAS stations on the order of 150 km, and by avoiding use of DRS forward channels which could illuminate a radio astronomy site. The unavailability of a DRS forward channel allows the SRS to fit several other Earth-to-space channels into these 2 sub-bands.

Depending on the location of the SRS earth stations with respect to radio astronomy stations, some frequency sub-bands will not be available on a global basis. Specific examples are Cebreros and Robledo which are both relatively close to the radio astronomy station Yebes. As a consequence, frequencies in the range 22.81-22.86 GHz and 23.07-23.12 GHz cannot be used without causing potentially harmful interference to the radio astronomy observatory.

While studies have shown that sharing with fixed service installations is generally feasible with large margins, there may be a few locations in the world where separation distances could be insufficient. In such cases, some frequencies within the 600 MHz band might not be usable and alternative frequencies need to be available.

3.3 Coherency requirements for ranging purposes

Position determination by means of ranging requires a fixed turn-around ratio between the Earth-to-space link around 23 GHz and the space-to-Earth link around 26 GHz. On top of the already identified reasons above, the choice of available frequencies for those mission applications requiring position determination by means of ranging is further limited due to established usage of some of the companion frequencies in the SRS 26 GHz receive band.

4 Potential frequency plan taking into account limiting effects

The above considerations show that frequency planning and coordination will be a very complex task. Taking into account the above factors, at least 600 MHz of bandwidth is required to meet the projected requirements of space agencies worldwide. This is why the original European Common Proposal for WRC-07 covered the entire band 22.55-23.55 GHz. However, during WRC-07, compatibility concerns with respect to the HIBLEO-2 system operating above 23.18 GHz led to the SRS community electing to limit their allocation to 23.15 GHz as a means of alleviating this HIBLEO-2 concern. In the meantime, several studies have shown ample compatibility with potential future HIBLEO-Ka ISS links.

Figure 1 illustrates an example of a potential frequency plan. The figure presents the requirements for these types of SRS missions grouped together as it is useful to present them in a single, consolidated channel plan. The figure represents a spectrum usage plan by multiple space agencies worldwide. As previously stated, sharing among Lunar and Lagrange missions between multiple space agencies or even within a single space agency is not possible (although sharing between each of these types of missions and low-Earth orbit missions is possible) due to geometric configurations that would cause missions to be within the main lobe of antennas of other missions. This is also further described in Annex 1.

Referring to Fig. 1, in sub-bands used by the RAS, the non-globally available channels are shown with lower amplitude. The following arrangement of channels may constitute a practical approach:

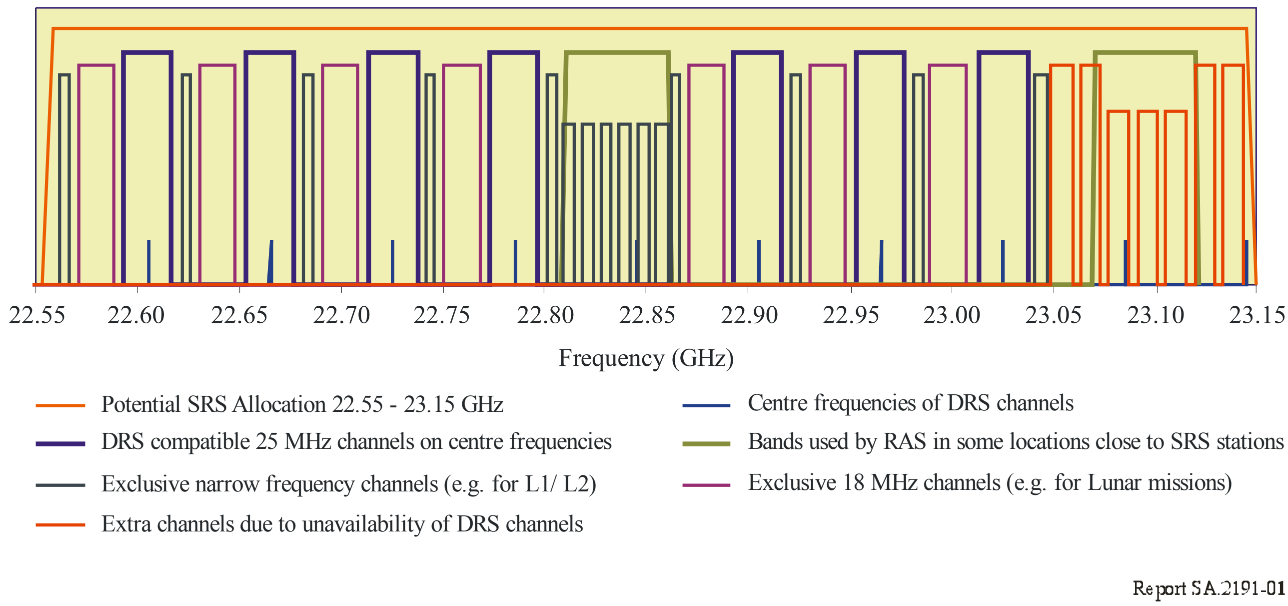
– 7 channels of 25 MHz centred on a DRS channel allowing for DRS cross support;
– 7 exclusive 18 MHz channels globally available for support of lunar missions;
– 4 exclusive 10 MHz channels globally available for support of lunar missions;
– 3 exclusive 10 MHz channels not globally available due to the need to protect the RAS;
– 9 exclusive 5 MHz channels globally available for support of Lagrangian point missions;
– 6 exclusive 5 MHz channels not globally available due to the need to protect the RAS.

The above channelling arrangements provide the minimum net aggregate requirements among multiple space agencies, that, when taken in the context of the practical application within the 22.55-23.15 GHz range, result in a minimum requirement of 600 MHz. This comprises the net bandwidths for the channels listed above that results in a total net required channel width aggregate of 446 MHz. Added to this will be guardbands between the various channels. An illustration of the projected communication system architecture and requisite channel and bandwidth requirements as described above in § 2, are presented in Annex 1.

For the narrower channels, around 2-4 MHz may be sufficient, while wideband channels may require significantly higher guardbands on the order of 4-8 MHz. On average, it is assumed that approximately 4 MHz of guardband is needed between any 2 channels. Consequently, an additional 140 MHz of bandwidth is needed based on the above identified 36 channels. This results in a total required bandwidth of 586 MHz for this example and leaves around 7 MHz of guard band at each end of the potential allocation to increase protection of adjacent services. Not factored into these calculations are the added overhead that 60 MHz will not be usable in areas where the separation distance to RAS stations is not sufficient. Also, in some locations, additional spectrum may be unavailable due to the need to protect fixed service stations.

FIGURE 1

Example for a channel plan to support Lunar and Lagrangian missions



The above example shows that even with an allocation of 600 MHz, the requirements identified in § 2 can hardly be met to the desirable extent.

5 Conclusions

A contiguous bandwidth of 600 MHz would be required to accommodate minimum bandwidth demands identified for space agencies worldwide. Efficient use of this bandwidth will require very careful planning and coordination at an early stage to enable the accommodation of all mission requirements in the longer term. This is notwithstanding that a number of practical constraints such as DRS channel plan compatibility, protection of other services and ranging coherency requirements may limit the choice of available frequencies within the band.

An allocation to the SRS in the range 22.55-23.15 GHz is therefore essential to satisfy a minimum of expected spectrum requirements for planned SRS missions.

Annex 1

Estimated data rate and spectrum requirements per space agency

Over the past couple of years, multiple orbiting and impactor spacecrafts from several agencies have been sent to the Moon with missions to obtain high resolution lunar terrain maps, ascertain chemical composition of the Moon's surface, examine lunar soil layers and probe/record the environment on the Moon, such as its electromagnetic features and solar wind, which are crucial for future landings. These precursor missions are integral steps in the lunar exploration roadmaps for these agencies. These planned robotics and manned missions include a variety of spacecraft/vehicles on the lunar surface and orbits such as orbiters, landers, experiment packages/terminals, rovers, robotic assistants, extravehicular activities (EVAs), communications terminals, and relay satellites.

The frequency plan for the lunar region will revolve around communications from Earth to the lunar region, lunar region to Earth, lunar surface to orbit communications, lunar communications between several points on the surface, and lunar orbit to lunar orbit communications. Multiple simultaneous communications links are expected to operate in the vicinity of the Moon to control/command equipment operation, communicate with on-orbit crew, stream video, update/modify/verify software uploads, enable health diagnosis, execute detailed fault detection/isolation/recovery procedures and adjust mission plans based on science and telemetry data with precise and high resolution instructions and graphics. Figure 2 provides an overview of the types of links typically supported simultaneously via an earth station.

These links will mainly be used for a wide range of bandwidth intensive applications, such as video and data transmissions. Some of the links to the surface of the moon can be a multiplex of several applications which are described in Table 1. For the modulation techniques, filtered QPSK has been assumed. Regarding channel coding, coding rates vary between 1/2 and 7/8, depending on the specific mission application.

FIGURE 2

A conceptual scenario representing space agency lunar orbit and surface communication elements

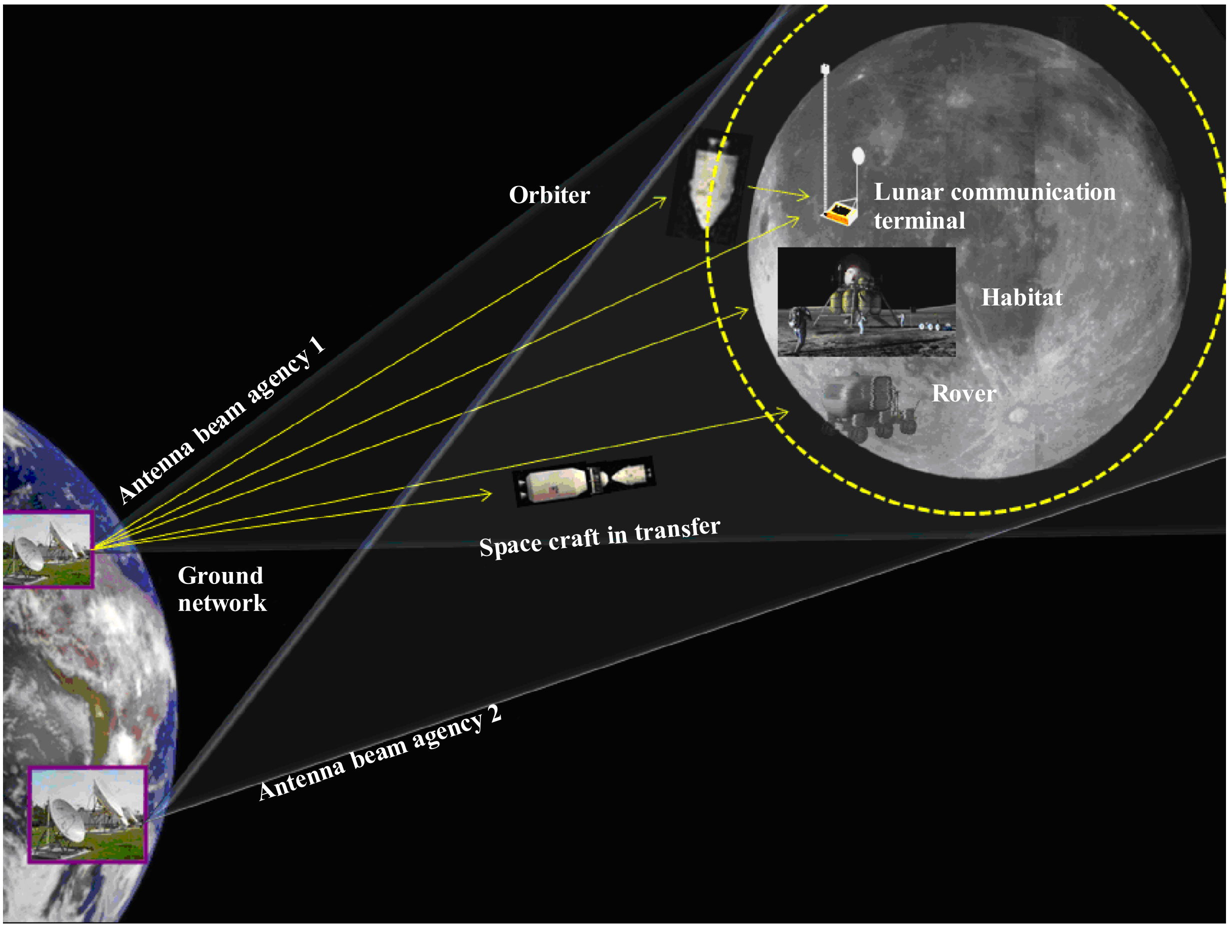


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TABLE 1

Communications requirements matrix

Link type	Usage description	Users	Estimated symbol rates (per channel/ per user) (MSps)	Estimated BW (per channel/ per user) (MHz)
Earth-to-lunar orbit	Direct high rate communications from the Mission Control Centre (through an earth station) to orbiter in low lunar orbit. Contents of link include composite/multiplex data stream such as spacecraft system management controls, software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, in-flight maintenance procedures, voice with onboard crew, navigation updates, video conferencing and streaming video.	Orbiter/ manned and unmanned	10-20	10-20

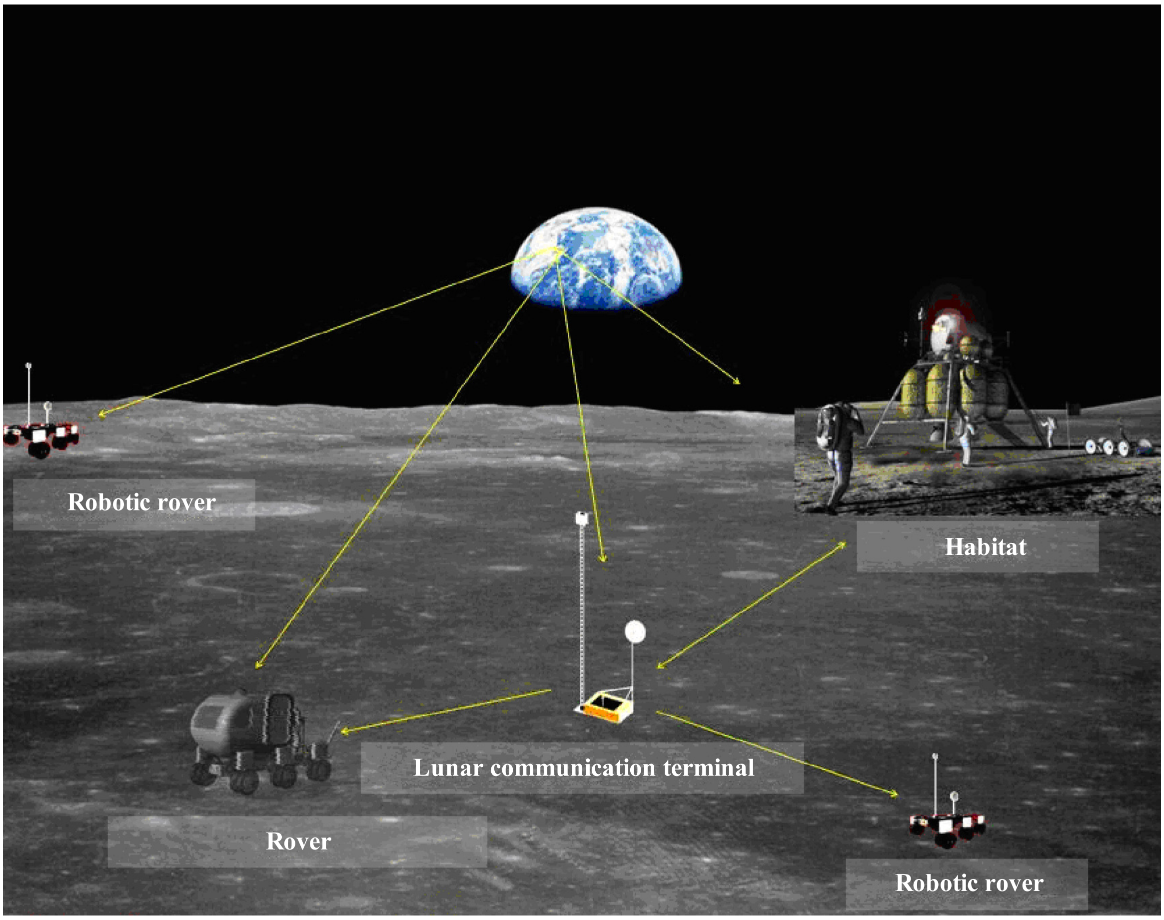
TABLE 1 (*end*)

Link type	Usage description	Users	Estimated symbol rates (per channel/ per user) (MSps)	Estimated BW (per channel/ per user) (MHz)
Earth-to-lunar surface	Direct high rate communications from both the Mission Control Centre and Payload Control Centre (through an earth station) to communications terminal on lunar surface for redistribution to both mobile and fixed elements on the surface of the Moon. The communications terminal serves as a "cell tower" to relay mission and system updates to multiple surface experiments and interactive capability for individual principle investigators with experiments they are responsible for. Contents of link include experiment system management controls, software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, high fidelity/resolution maps, etc.	Communica-tions terminal/ manned and unmanned	20-25	20-25
Earth-to-lunar surface	Direct high rate communications from the Mission Control Centre (through an earth station) to the lunar Surface Habitat. Contents of link include composite/multiplex data streams such as Habitat system management controls, Habitat software maintenance updates, data encryption/authentication protocol, network security protocol, detail mission plans/instructions, in-flight maintenance procedures, voice with crew, video conferencing and streaming video.	Habitat/ manned	10-20	10-20
Earth-to-lunar surface	Direct high rate communications from the Mission Control Centre (through an earth station) to rovers or landers on the lunar surface. Contents of link include spacecraft system management controls, detailed mission plan updates/revisions, software maintenance updates, data encryption/authentication protocol, network security protocol, high fidelity/resolution maps, video instructions, direct voice with MCC to Extra Vehicular Activity (EVA) astronauts.	Rovers/ landers/ manned and unmanned	10-20	10-20
Earth-to-transfer spacecraft	Direct high rate communications from the earth station to the transfer spacecraft. Contents of link include composite/multiplex data stream such as spacecraft system management controls, software maintenance updates, detail mission plans/instructions, in-flight maintenance procedures, voice with onboard crew, navigation updates, video conferencing and streaming video.	Spacecraft manned and unmanned	10-25	10-25

Figure 3 shows a conceptual scenario of Earth-to-lunar surface links.

FIGURE 3

A conceptual scenario representing Earth-to-lunar surface communication elements



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Each agency can operate lunar missions with multiple carriers of the nature discussed above, and potentially anywhere on the surface of the Moon. The interference caused by the intersection of their respective beams would preclude co-frequency sharing among lunar missions. The same holds true for co-frequency operations of Lagrangian missions.

Additionally, co-frequency sharing between lunar and Lagrangian mission's carriers from separate earth stations is also not possible, as the geometry discussed above results in small off-axis angles between carriers. However, co-frequency sharing is possible between other combinations of carriers. The specific compatibility of these various scenarios is shown in Table 2.

TABLE 2

Compatibility matrix for SRS mission types

	Victim mission type			
Interfering mission type	Lunar	Lagrangian	LEO	DRS
Lunar	N	N	Y	Y
Lagrangian	N	N	Y	Y
LEO	Y	Y	Y	Y
DRS	Y	Y	Y	Y

It should be noted that these 23 GHz links in support of LEO missions, will not be able to be used in the same manner as links in the 7 GHz band due to increased atmospheric attenuation and other physical constraints effecting in particular omnidirectional antenna design.

There is a need for a guardband between each channel, since, due to the in-beam geometry and significant spectral densities of near side lobes, some out-of-band roll-off attenuation is required. Using Recommendation ITU-R SM.1541, for the 12 MHz lunar links a 5 MHz guardband results in out-of-band attenuation of 12.5 dB, and for the 3 MHz Lagrangian links a 1 MHz guardband results in out-of-band attenuation of 10.0 dB. Achieving an attenuation of 12.5 dB for a 24 MHz channel will require a guardband of around 10 MHz. Depending on the actual channel bandwidths, guardbands between 1 and 10 MHz are therefore expected to be required.