Australia's National
Science Agency

CSIRO submission to consultation on Satellite direct-to-mobile services: regulatory issues

CSIRO Submission 24/009

January 2024

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Introduction

CSIRO welcomes the opportunity to provide input to the Australian Communications and Media Authority (ACMA)'s consultation on Satellite direct-to-mobile services: regulatory issues, which is considering the use of terrestrial IMT frequency bands for direct-to-mobile services via satellite.

As Australia's national science agency, CSIRO is a world leader in radio astronomical research as well as developing astronomical receiver technology which is in use at many of the world's leading radio astronomy facilities.

Various organisations in the spectrum management community are referring to these services under different terms:

- direct to mobile (D2M)
- direct to handset (D2H)
- direct to device (D2D)
- direct to cell (D2C)
- supplemental coverage from space (SCS)

The operating principle relies on satellites in low earth orbit (LEO) being used as mobile phone service base stations, with the aim to provide connectivity in underserved and remote regions, using existing terrestrial mobile allocated spectrum.

There are a number of technical difficulties to consider with this approach:

- The link budget is limited, as the distance between the device and the base station can vary from (best case) about 500 km at zenith to (worst case) over 3000 km near the horizon.
- The geometry of the links varies rapidly, on tens of seconds timescales, due to the rapid motion of LEO satellites.
- The connections can only be maintained with an unobstructed line of sight. Even minimal signal attenuation through light vegetation such as tree cover results in loss of connectivity.
- Connectivity from inside a car or inside a building will not be possible for this reason.

Some mobile phones available today - such as Apple's iPhone 15 - have implemented emergency text messaging capabilities making use of existing mobile-satellite service (MSS) bands. The implementation of these new systems provides insight into the challenges encountered when trying to connect to a satellite from a device that is not equipped with a purpose built (and by necessity large), high gain antenna. They need to be manually pointed towards a passing satellite to establish and maintain a connection, in order for their built-in high gain patch antennas to point at the main beam of the satellite providing coverage. The use of such systems for emergencies could therefore be problematic when it is complicated and slow to establish and maintain a link.

These factors could place a high burden of operational difficulty on the usability of these systems, even for sending and receiving text messages. Enabling voice or data connections is likely to be even more difficult, with many issues unlikely to be solved in the near future, except for the special case of an unobstructed line of sight connection to the satellite.

In addition to the technical problems, it may be difficult to implement this technology, given the current regulatory environment. The bands in question are allocated for terrestrial mobile use and not (for the most part) for the mobile-satellite service (MSS). Some potential operators assume that if a company has a licence for terrestrial use, there is no barrier to using the spectrum from space. Other operators and regulators are proposing to allow use under Radio Regulations Article 4.4. Based on contextual interpretation of RR 4.4, CSIRO considers that RR 4.4 is not appropriate for long-term commercial operation for the following reasons:

- RR 4.4 prohibits interference to systems in other administrations operating in accordance with the Radio Regulations. It therefore implicitly provides no protection for systems operating in the same administration that is granting the RR 4.4 derogation. This could pose a significant risk for RAS in the bands under consideration, should ACMA authorise Australian providers to use their Australia wide terrestrial mobile allocations from space.
- For the mobile providers themselves, this is also problematic as RR 4.4 also removes the right to claim protection from interference from systems operating in accordance with the Radio Regulations in the same administration, creating new potential interference scenarios for systems being promoted for emergency communications that might then be incorrectly assumed to be usable as a safety of life application.

CSIRO response to the Questions

Impact on radio astronomy

CSIRO operates and hosts multiple radio astronomy facilities in Australia, including within the Australian Radio Quiet Zone Western Australia (ARQZWA). Each of the telescope facilities is protected from interference by coordination zones as described in RALI MS 31and RALI MS 32.

The Australian radio astronomy community has gone to great lengths and cost to build radio astronomy facilities as far away from civilisation as possible, to avoid terrestrial man-made radio signals and to prevent radio frequency interference (RFI) to observations of the universe made with these radio astronomical receivers. These receivers are many orders of magnitude more sensitive than commercial off the shelf (COTS) receiver equipment used in e.g. mobile phones and other small, connected devices.

Allowing satellites to use terrestrial mobile spectrum therefore will permanently illuminate radio astronomy facilities from space in frequency bands where they traditionally have been protected, both due to propagation effects by way of geographic separation, and through coordination with providers, making sure they do not point transmitters in the direction of radio telescopes.

Should these frequencies be permitted to transmit from satellites, vast swathes of spectrum would be rendered unusable for science. Furthermore, illuminating telescopes from space can potentially endanger the hardware integrity of the receiver's low noise amplifiers when a transmitting satellite crosses the main beam of the telescope. In that case, the signal is amplified by the full antenna gain of up to 85 dB in the case of the Parkes 64 m or Tidbinbilla 70 m antennas. Considering the orbital density of current and planned systems, such beam coupling has been shown in simulations to occur many times per day as shown below.

Current RAS receiver technology employs very wide band receivers, with up to several GHz of instantaneous bandwidth commonplace, and dozens of GHz of instantaneous bandwidth under development. While considerable effort has been expended to make these new systems resilient to interference through sidelobes, main beam coupling will inevitably result in the loss of the full integration cycle over the entire bandpass every time a satellite flies through the main beam.

A study run by the Square Kilometre Array Observatory (SKAO) calculating main beam coupling statistics for the fully developed satellite constellations Starlink, OneWeb, and Guo Wang predicts a total of 15% data loss due to main beam coupling for a 2-degree beam averaged across telescope pointing elevations above 15 degrees. This is made up of the following data loss contributions:

- Starlink (phase 2): 3.8%
- OneWeb (phase 2): 3.7%
- Guo Wang: 5.4 %

A comparable CSIRO simulation using the ASKAP telescope characteristics (2.33 degres beam width at 750 MHz, and 1.25 degree beam width at 1400 MHz) shows the data loss to RAS observations for January 27 2024 and assessing only the Starlink constellation in its presently deployed state already would cause 0.96% data loss at 750 MHz and 0.28% data loss at 1400 MHz. Extrapolating from the SKAO study numbers for the fully developed constellations, data loss at ASKAP and 1400 MHz (due to harmonics) would amount to 5.1%. This data loss number exceeds the threshold inside the protected RAS band 1400 – 1427 MHz of 5% aggregate and 2% per system as described in ITU-R RA.1513-2.

Informal discussions with both potential operators of D2M systems and with regulators have indicated an expectation to mitigate interference to radioastronomy by implementing beam steering from the satellites. However, at the frequencies under consideration, the beam pattern on the ground is very large, and even in the far side lobes, the residual power from the satellite transmission exceeds the radio telescope protection levels by significant margins.

Radio astronomy facilities

We present a list of Australian radio astronomy facilities along with the frequencies of operation of the various receivers installed.

Radio astronomy has and always will be dependent on opportunistic observations in frequency bands not allocated to RAS due to the nature of radio emissions of cosmological origin. The radio frequencies at which physical processes such as excited molecules or matter being accelerated into a black hole are emitting radio waves are dictated by fundamental physics. Astronomical objects are observed at relative motion to us – the observer – that result in a significant doppler shift from their respective rest frequencies. For cosmologically distant objects, redshift due to cosmic expansion in addition can shift the frequencies of interest through much of the low frequency radio spectrum so that for example neutral hydrogen, with a rest frequency of 1.420 GHz, can be redshifted to as low as 50 MHz at the Epoch of Reionisation 13 billion years ago. To observe the universe's evolution, all frequencies must therefore remain observable.

Facility	Receiver	Applicable RALI	
		RALI MS 31	RALI MS 32
Parkes	UWB 704 - 4032 MHz	X	
	Methanol 5.9 - 7.0 GHz	X	
	Mars 8.0 - 9.0 GHz	X	
	K-band 16.0 - 26.0 GHz	X	
ATCA / Narrabri	16cm: 1100 - 3100 MHz	X	
	4cm: 3.9 - 12 GHz	X	
	15mm: 16.0 - 27.0 GHz	X	
	7mm: 30.0 - 50.0 GHz		
	3mm: 85.0 - 105.0 GHz		
Mopra / Coonabarabran	16cm: 1300 - 3000 MHz	X	
	4cm: 4.5 - 6.7 GHz	X	
	4cm: 8.0 - 9.2 GHz	X	
	15mm: 16.0 - 27.0 GHz	X	
	7mm: 30.0 - 50.0 GHz		
	3mm: 76.0 - 117.0 GHz		
Mt Pleasant / Hobart	16cm: 1100 - 3100 MHz	X	

	2.2 - 2.6 GHz	X	
	4.6 - 5.0 GHz	X	
	8.2 - 8.7 GHz	X	
	12.0 - 12.4 GHz		
	20 GHz	X	
	AuScope/VGOS 2 - 14 GHz	X	
Ceduna	1.2 - 1.8 GHz	X	
	2.2 - 2.6 GHz	X	
	4.6 - 5.0 GHz	X	
	8.2 - 8.7 GHz	X	
	12.0 - 12.4 GHz		
	20 GHz	X	
Tidbinbilla DSS-43 (70m)	L-band 1.4 - 1.9 GHz	X	
	S-band 2.2 - 2.3 GHz	X	
	X-band 8.2 - 8.6 GHz	X	
	K-band 17 - 27 GHz		
Tidbinbilla DSS-34 (34m)	S-band 2.2 - 2.3 GHz	X	
	X-band 8.2 - 8.6 GHz	X	
	K-band 25.5 - 27 GHz		
	Ka-band 31.8 - 32.3 GHz		
Tidbinbilla DSS-36 (34m)	S-band 2.2 - 2.3 GHz	X	
	X-band 8.2 - 8.6 GHz	X	
	K-band 25.5 - 27 GHz		
	Ka-band 31.8 - 32.3 GHz		
Tidbinbilla DSS-35 (34m)	X-band 8.2 - 8.6 GHz	X	
	Ka-band 31.8 - 32.3 GHz		
Katherine	AuScope/VGOS 2 - 14 GHz		
Yarragadee	AuScope/VGOS 2 - 14 GHz		

Facilities hosted inside the ARQZWA at Inyarrimanha Ilgari Bundara – CSIRO's Murchison Radio Observatory:

ASKAP	700 - 1800 MHz		X
MWA	50 - 270 MHz		X
SKA	50 - 350 MHz		X
Edges	70 MHz		X

RALIs applicable to the facilities:

RALI MS 31 protected bands	1250 - 1780 MHz
	2200 - 2550 MHz
	4350 - 6700 MHz
	8.0 - 9.2 GHz
	16.0 - 26 GHZ
RALI MS 32 protected band	70 MHz - 25.25 GHz

Analysis of spectrum under consideration

The Australia wide spectrum licenses currently under consideration for D2M include the 700 MHz, 800 MHz, 850/900 MHz, and 2.5 GHz bands.

Summarised, these bands span the following frequencies:

703 – 748 MHz

758 – 803 MHz

814 – 825 MHz

825 – 845 MHz

859 – 869 MHz

870 – 890 MHz

890 – 915 MHz

935 – 960 MHz

2.55 – 2.63 GHz

Further to this, footnote 5.320 in the Radio Regulations would permit the following bands to be used for MSS use in Region 3 subject to agreement under No. 9.21:

806 – 890 MHz

942 – 960 MHz

A visualisation of the current band plan from 500 MHz to 2.7 GHz is shown in

Figure 3 of the Appendix. This aligns well with the observed occupancy spectrum shown in Figure 4. A visualisation of the current band plan along with the proposed D2M bands is shown in Figure 5.

In addition to the proposed bands, the 600 MHz band is under consideration in the USA and was proposed by some respondents to the Five Year Spectrum Outlook 2023-2028. This is the only band where D2M – at its fundamental frequency - would not impact heavily on RAS as long as 608 – 614 MHz (5.149 applies) can be avoided. The Parkes UWB receiver system as well as ASKAP, which currently has a largely unencumbered swath of spectrum between 700 MHz to 1020 MHz, would not be affected directly by a 600 MHz allocation. The cleanliness of that part of the spectrum at the Western Australia site is a globally unique and precious resource, and it is therefore important to preserve.

To illustrate this, a 24h waterfall plot from 500 MHz to 1000 MHz taken on January 5 2024 shows the cleanliness of this portion of the spectrum at the Western Australian site:

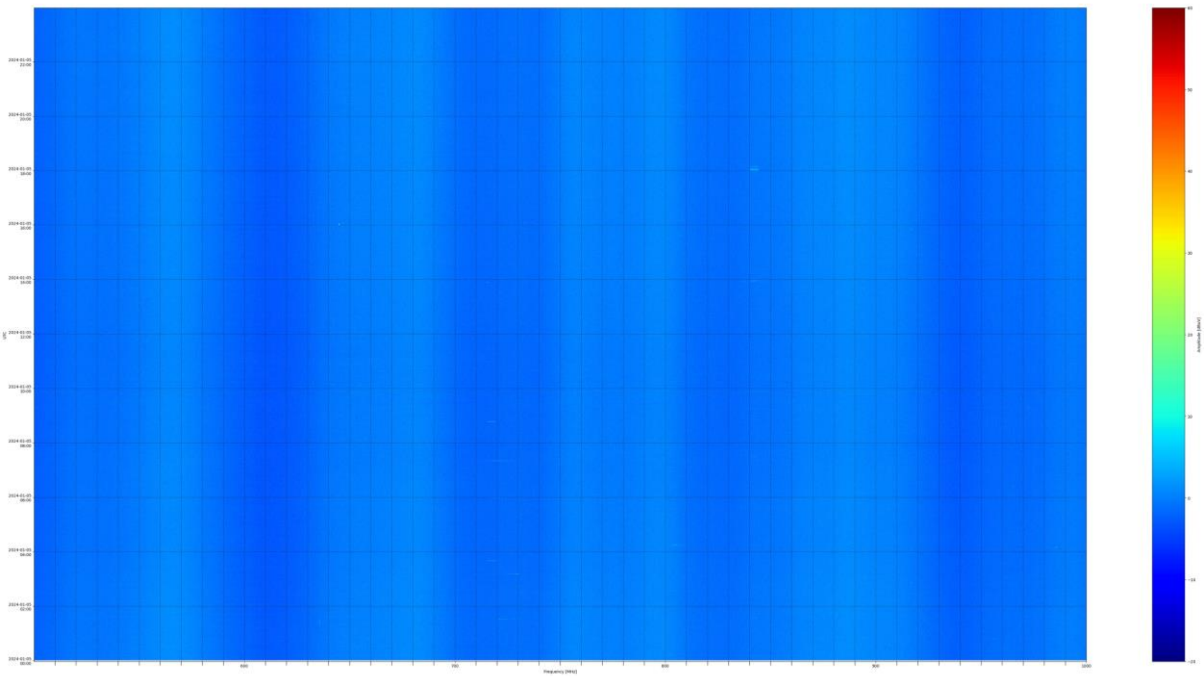

Figure 1 24h waterfall plot from 500 - 1000 MHz at Inyarrimanha Ilgari Bundara - CSIRO's Murchison Radio Observatory

Comparing the plot above to data taken during a severe tropospheric ducting event on November 24 2023, shows what this part of the spectrum could look like permanently, if D2M was enabled on the proposed frequencies. The following waterfall plot shows ducted interference from mobile system base stations between 700 MHz – 960 MHz. In this particular instance, the base stations received at the MRO were as far away as Cape Naturaliste and Busselton (850km) to the south-west, and Exmouth to the north-west (580km away). It is important to acknowledge that what is now very intermittent interference, would be permanent due to high-powered signals from satellites above the radio horizon. The normal frequency occupancy for this portion of the spectrum is shown in Figure 6, and in Figure 7 the occupancy during the severe ducting event is shown.

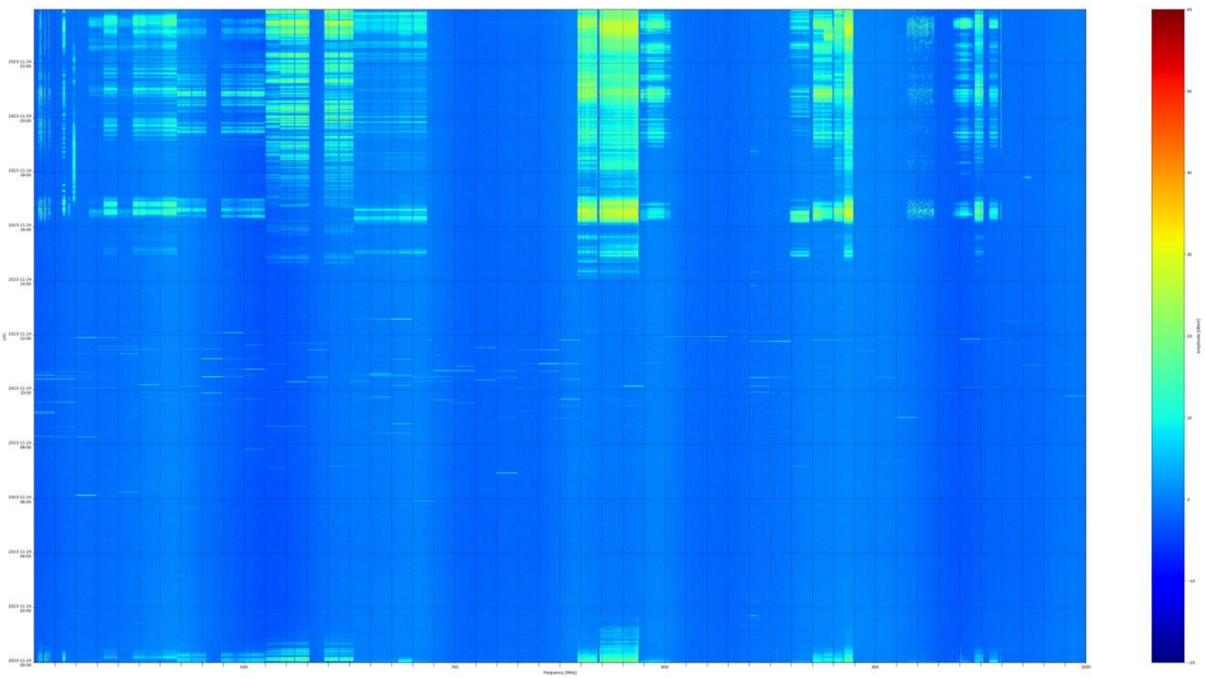

Figure 2 24h waterfall plot from 500 - 1000 MHz at Inyarrimanha Ilgari Bundara - CSIRO's Murchison Radio Observatory taken on November 24, 2023, during a severe tropospheric ducting event.

Harmonics

In addition to the concerns regarding the fundamental frequencies of the bands proposed for D2M, CSIRO notes the second and third harmonics will encroach on protected RAS bands. Under normal (terrestrial) conditions, harmonics are rarely a problem for RAS because they are lower (by order of magnitude 60 dB) than the fundamental, and terrestrial shielding limits the propagation of these signals. With transmitters in space, there is nothing but free space loss between the transmitters, their harmonics, and the telescopes.

Specifically, the following protected RAS primary allocations would be affected by harmonics:

- 1400 – 1427 MHz (5.340 applies) affected by
    - 2nd harmonics of 700 MHz band
- 1610.6 – 1613.8 MHz (5.149 and 5.341 apply) affected by
    - 2nd harmonics of 806-890 MHz 5.320 band
- 1660.5 – 1668 MHz and
  1668.0 – 1668.4 MHz and
  1668.4 – 1670 MHz (5.149 and 5.341 apply, also affects METEOROLOGICAL AIDS)
    - 2nd harmonic of 806-890 MHz 5.320 band
    - 2nd harmonic of 850/900 MHz band
    - 2nd harmonic of 800 MHz band
- 1718.8 – 1722.2 MHz (5.149 applies)
    - 2nd harmonic of 850/900 MHz band
- 2690 – 2700 MHz (5.340 applies)
    - 3rd harmonic of 850/900 MHz band
- 4990 – 5000 MHz (5.149 applies)
    - 2nd harmonic of 2.5 GHz band is directly adjacent from 5000 MHz.

The following RAS secondary allocations and other secondary science allocations for EESS (passive) and SRS (passive) would be affected by harmonics:

- 2655 – 2670 MHz and
  2670 – 2690 MHz (5.149 applies)
    - 3rd harmonic of 850/900 MHz band

None of the proposed bands in the 700 – 960 MHz range are therefore acceptable under the ITU-R's Radio Regulations, owing to their harmonics impinging on protected RAS primary allocated bands.

Higher frequencies

Frequencies above 2 GHz are problematic given the entire band from 2 GHz to 14 GHz is in use for geodetic very long baseline interferometry (VLBI) observations. As mentioned above, frequency bands solely allocated to RAS are not sufficient to obtain solutions that are of adequate quality.

VLBI is a radio-astronomical technique that connects telescopes around the continent and even around the world to achieve highest measurement precision.

The VLBI Global Observing System (VGOS) is the global effort to use the VLBI technique to measure the Earth. It is one of three crucial techniques to accurately measure the Earth's shape, rotation, and orientation in space and as such is underpinning all positioning and navigation applications. It is also needed to measure the most accurate coordinate and reference system of the Earth as well as in space.

The global geodetic reference frame (GGRF) has been identified by the United Nations to underpin its UN Sustainable Development Goals (UN-SDGs) and identified to be fundamental for Earth science missions and climate adaptation.

The Commonwealth of Australia supports the GGRF through its Positioning Australia Initiative, executed by Geoscience Australia. Specifically, Geoscience Australia maintains a research collaboration with the University of Tasmania (AuScope VLBI project), operating a network of three 12-m radio telescopes (in Hobart-TAS, Katherine-NT, and Yarragadee-WA) that are dedicated to GGRF work as part of a global network.

Modern VGOS observations record signals from extragalactic radio sources over the wide frequency range of 2 - 14 GHz and operate about 50% of the time.

One of the most important products of global VLBI are daily dUT1 measurements which vary due to the everchanging real rotational speed of the Earth. If VLBI were to cease measuring this, it would quickly be noticeable due to degradation of high precision positioning and navigation in all applications using GNSS.

Site analysis

Limited information is available about specific frequency bands and power levels of proposed D2M systems. However, one system is proposing to use 2.5 GHz with a power flux density of -80 dBm/m^2/MHz within the service area and -99 dBm/m^2/MHz outside the service area. The latter value equates to -158 dBm/Hz. The RALI MS 31 threshold at 2.5 GHz (and at 5 GHz) is between -204 and -237 dBm/Hz, and the RALI MS 32 threshold is -232 dBm/Hz. Therefore, even if the beam is not directed at the telescope sites, the power spectral density exceeds the RAS thresholds by 46 to 79 dB. Even if harmonics are suppressed by about 60 dB, the power in the second harmonic is likely to exceed the thresholds.

While values are not immediately available for systems proposed at UHF frequencies, they are not expected to be so different that the thresholds described in RALI MS 31 and 32 can be met.

Conclusion

CSIRO has outlined problems that will arise should terrestrial mobile spectrum between 700 MHz to 960 MHz be permitted to be used from space at their fundamental frequencies, including:

- the relatively clean spectrum we have currently becomes encumbered by permanently visible emissions from satellites
- the second and third harmonics of the fundamental frequencies of the proposed bands which will emit inside protected and RAS primary spectrum allocations.

This will negatively impact scientific discovery and could jeopardise the major investments Australia has made into radio astronomical facilities of national importance. It will also negatively impact other science services with allocations in affected bands such as EESS (passive), SRS (passive), and METAIDS (passive).

Using extended swathes of spectrum above 2 GHz for D2M services could cause significant problems for essential reference frame observations executed by an international network including AuScope/VGOS telescopes.

The use of Article 4.4 for permanent service allocations, and specifically for satellite allocations, may not be appropriate.

Australia wide spectrum licenses issued for terrestrial use should not be converted to satellite use at the discretion of the license holders. ACMA could consider issuing the appropriate licenses for these services and avoid leaving this to the discretion of the mobile providers, as this could result in regulatory uncertainty and place the burden to coordinate on the affected parties.

CSIRO considers the 600 MHz band (excluding 608 – 614 MHz assigned to RAS by RR footnote 5.149), and recognising that this would affect the broadcasting service, the appropriate band for D2M. CSIRO considers that a narrow portion of the 2.5 GHz band could be used, as a temporary measure, until the 600 MHz band can be enabled for D2M.

Appendix

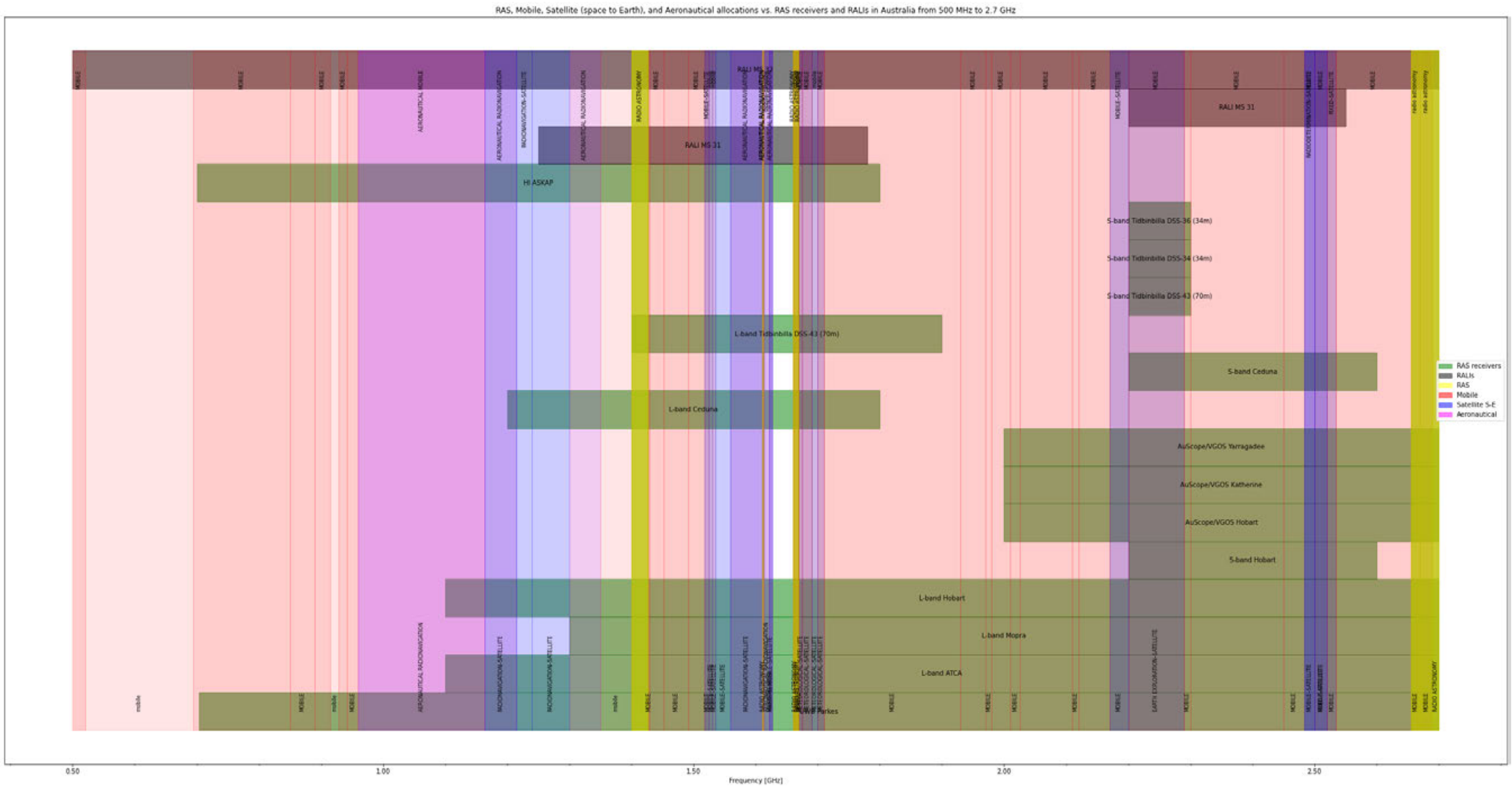

Figure 3 Relevant spectrum allocations from 0.5 – 2.7 GHz with the receiver fleet of all Australian radio astronomy receivers overlaid.

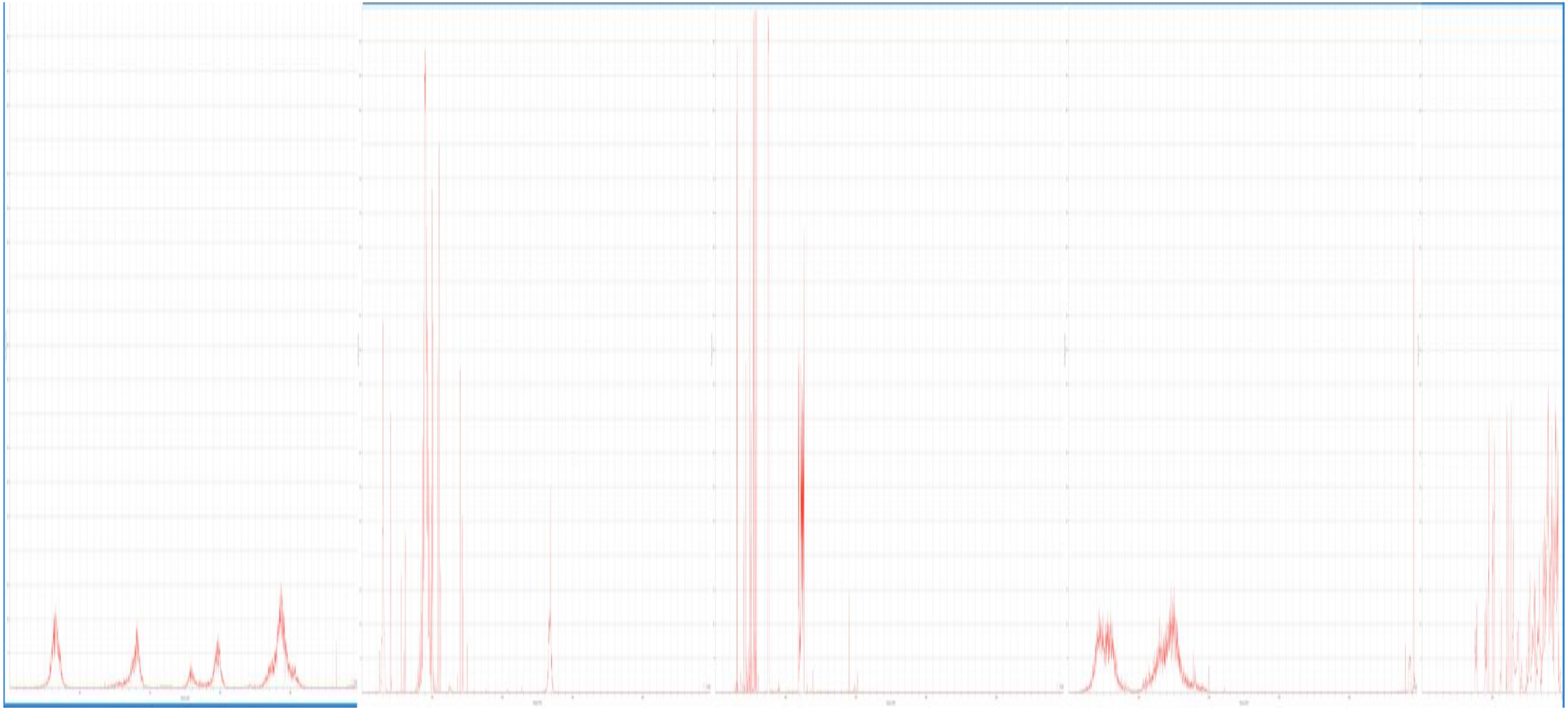

Figure 4 Occupancy spectrum for a 24h period from the RFI monitoring equipment at the Inyarrimanha Ilgari Bundara – the CSIRO Murchison Radio Observatory site from 500 MHz to 2.7 GHz. The vertical scale of this plot is from 0% to 100% occupancy over a 24h period on January 5 2024. Note the small humps from 500 MHz to 1 GHz and from 2 GHz – 2.5 GHz are caused by standing waves in the RF over fiber link of the RFI antenna and have not been calibrated out, i.e. they are not real signals seen by the telescopes and should be ignored.

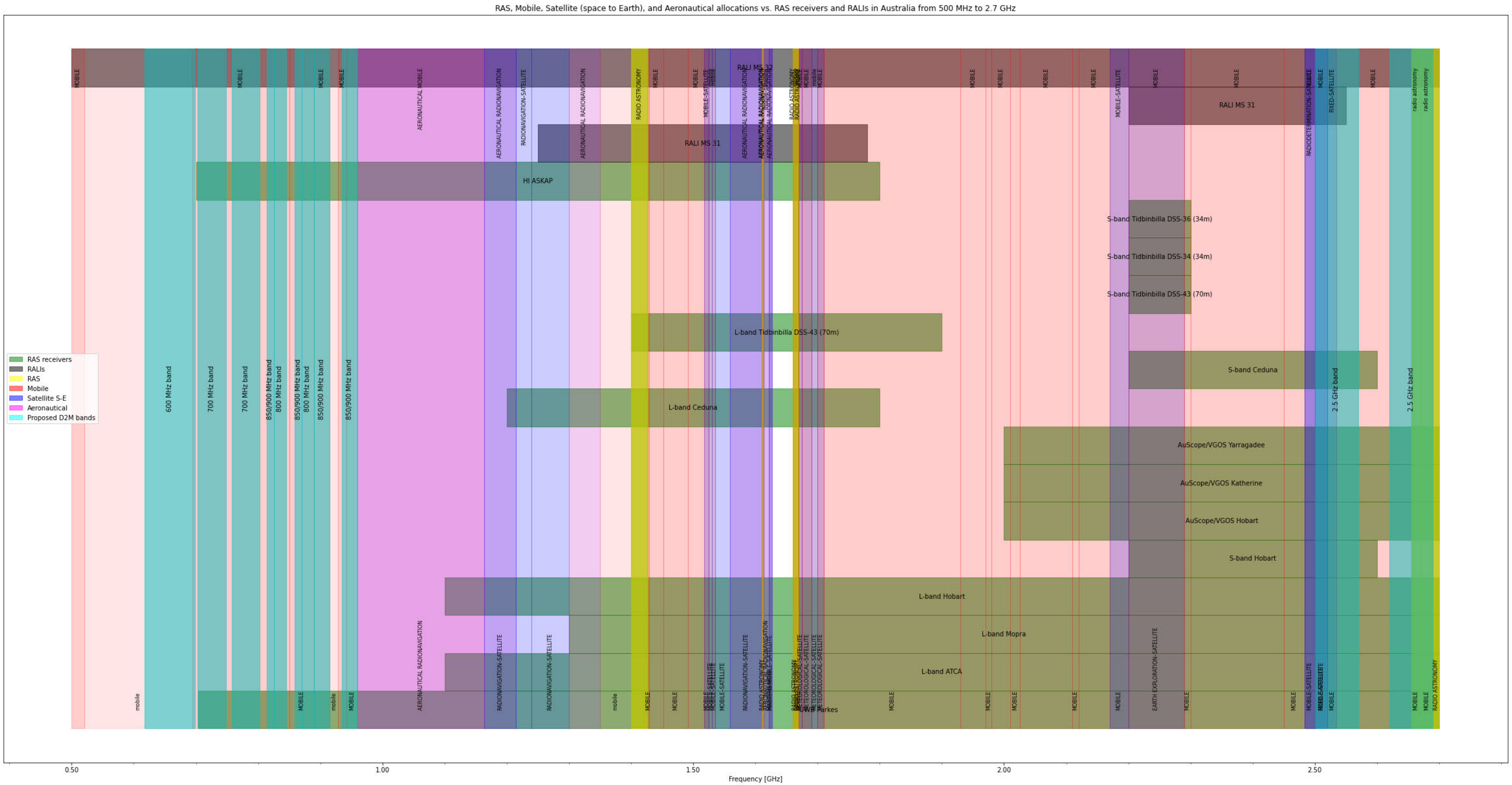

Figure 5 Relevant spectrum allocations from 0.5 – 2.7 GHz with the receiver fleet of all Australian radio astronomy receivers overlaid along with the proposed D2M bands.

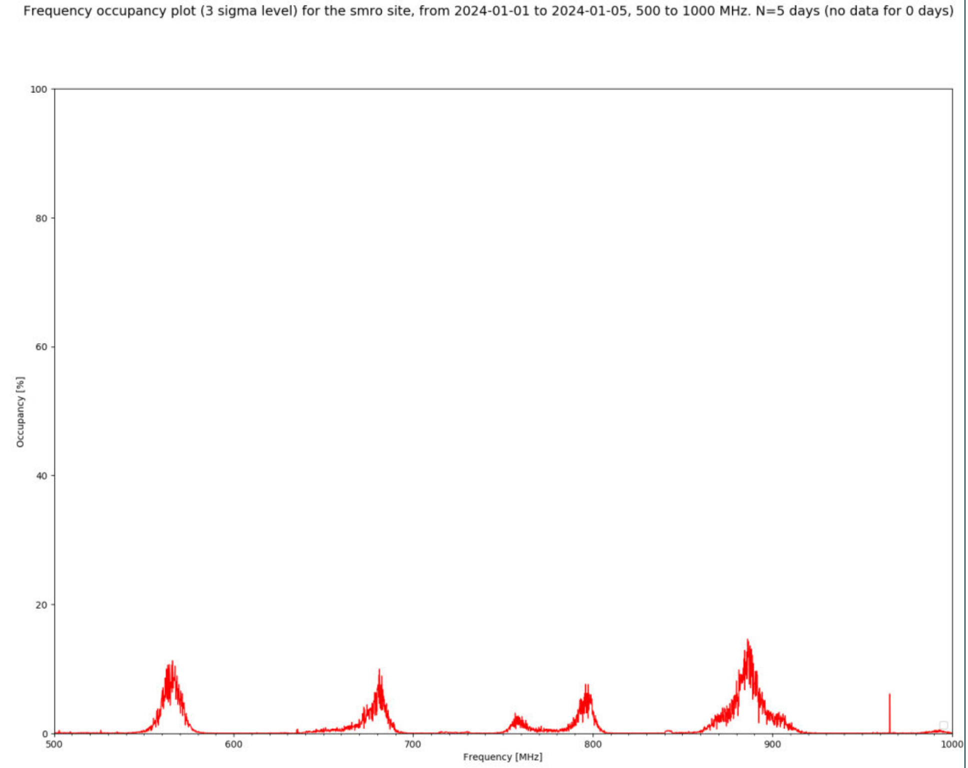

Figure 6 Occupancy spectrum for a 5 day period from the RFI monitoring equipment at the Inyarrimanha Ilgari Bundara – the CSIRO Murchison Radio Observatory site from 500 MHz to 1000 MHz. The vertical scale of this plot is from 0% to 100% occupancy over the full 5 day period. Note the small humps are caused by standing waves in the RF over fiber link of the RFI antenna and have not been calibrated out, i.e. they are not real signals seen by the telescopes and should be ignored.

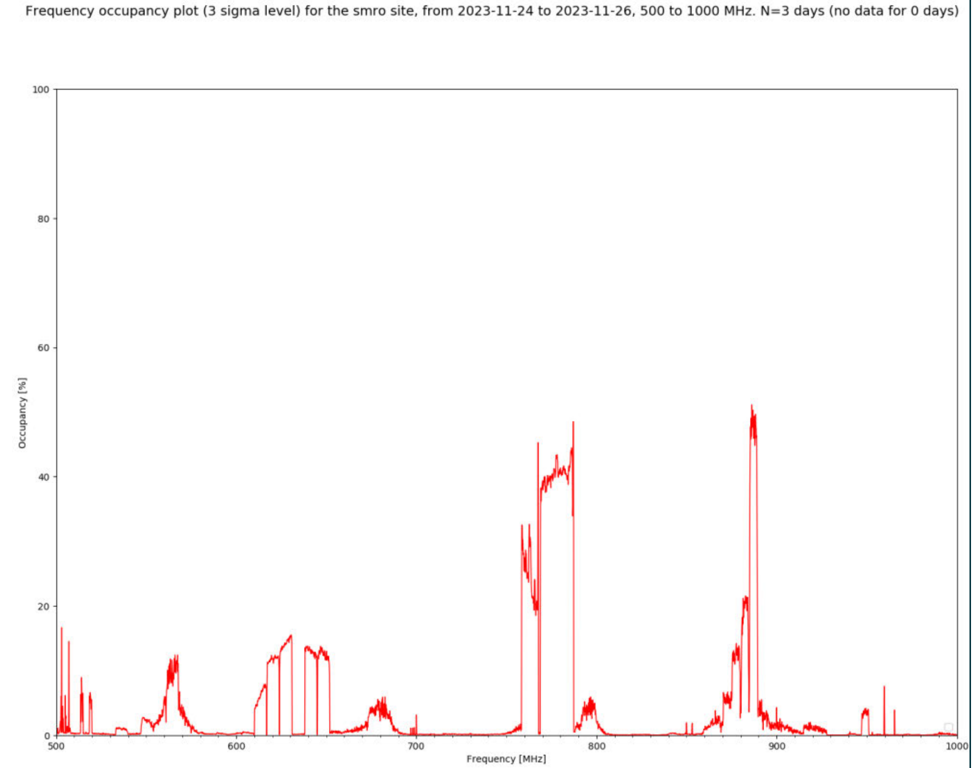

Figure 7 Occupancy spectrum for a 3 day period during which severe nighttime ducting events were taking place. Data taken from the RFI monitoring equipment at the Inyarrimanha Ilgari Bundara – the CSIRO Murchison Radio Observatory site from 500 MHz to 1000 MHz. The vertical scale of this plot is from 0% to 100% occupancy over the full 3 day period. The mobile service signals visible in this plot would indicate 100% occupancy if they were emitted from satellites.

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