17 CALCULATIONS: SATELLITE NETWORK COORDINATION

17.1 INTRODUCTION

The Satellite Network Coordination tool is used to determine if there is a need to coordinate frequencies for earth stations and geostationary satellites with other earth stations and geostationary satellites. The method for this is defined in the ITU Radio Regulations Appendix 8, **[B06]**.

The ITU in this context defines a complete *Satellite network* to comprise two earth stations being linked over one satellite that either has a frequency-shift transponder (considered as a linear amplifier with a transponder gain) or a type of transponder that performs on-board signal processing. The basic interference calculations are performed by considering all interfering signals to produce an increase in the receiver noise temperatures equivalent to the interference power. This results in a worst-case calculation, which subsequently should be refined by considering the real transmitter spectrum masks and receiver selectivities to calculate the signal-to-noise (S/I, or as an equivalent term the C/I – carrier-to-interference ratio). The latter is done in the Interference tool.

The relative increase due to interference in the receiver noise temperature is expressed as a percentage. The noise increase is translated to the receiving earth stations for the frequency-shift transponder types. The noise increase is referred to each receiver in the system for the other types of transponders.

It is important to note that the percentage noise increase relates to the complete noise temperature in the non-interfered case. The noise temperature at an earth station comprises the sum of the local noise temperature at the earth station receiver (given as an earth station specific information in the *Edit Station* window) and the noise temperature of the associated satellite for the frequency-shift case, as transferred to the earth station receiver by the transmission gain (see 17.2 for definition).

WRAP accounts for the following in this implementation:

- Earth station locations, antenna patterns and gains, radiated power, receiver noise temperature and frequencies. The earth station antennas point with the maximum radiation towards the associated satellite.

- Satellite locations on the geo-stationary orbit, antenna patterns and gains, radiated power, receiver noise temperature, transponder gain and frequencies. The satellite antennas point with the maximum radiation towards the defined coordinates for the aim point of the antenna beam.

Antenna patterns use the WRAP standard definitions of the attenuation (referenced to the maximum antenna gain) in the horizontal plane and in the vertical plane in the direction of maximum radiation. A three-dimensional antenna pattern is derived from these two two-dimensional patterns.

Free-space propagation is assumed as defined by the ITU. Space stations and earth stations that are beyond radio-optical visibility are not considered as potential interferers. The same holds for space stations that are beyond radio-optical visibility. For detailed calculations in the Interference tool other models can be selected, for instance the ITU-R P.619 earth-space method or the ITU P.526 method to account for the terrain mask as identified by the terrain database.

17.2 PREPARATION OF INPUT DATA

The Satellite Network Coordination tool needs valid satellite networks as input data. Such a network contains the following:

- Earth station(s)
- Satellite stations: This is a normal station, with transmitter, receiver, transmitter antenna, receiver antenna
- Satellite: Contains one or more satellite stations
- Satellite network: This defines the association of satellites and earth stations, so that point-to-point links are formed. The azimuth and elevation angles for the earth stations are automatically calculated upon forming the satellite links.

The transmission gain of the satellite link is important in the calculation. This is defined as the total gain in dB between the output of the receiving antenna of the satellite, through the transponder and the transmitting antenna of the satellite, the space-to-earth transmission loss and through the receiving earth station antenna to the input of the earth station receiver. A calculator exists for this purpose in the *Edit Group/Satellite Network* tab, see **Figure 17.1.**

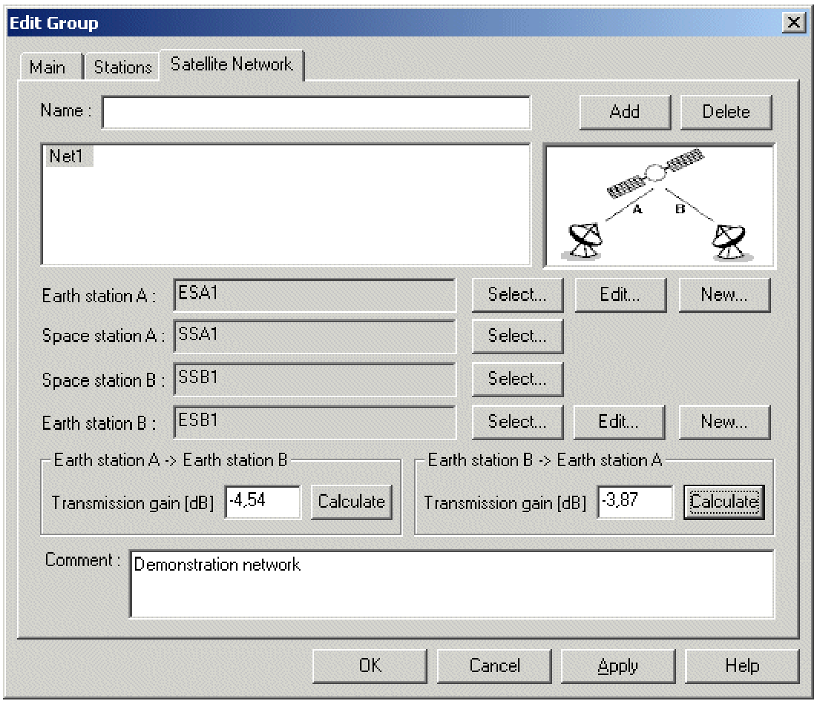

Figure 17.1: *Window for creation of satellite networks.*

17.3 RESULTS

Results are presented as can be seen in **Figure 17.2**. The total increases in noise temperature, expressed as percentages with reference to the non-interfered case, are presented at the bottom of the window. One value is given for each existing direction of the links. In addition each individual contribution is given, identified to the relevant receiver and which transmitter that gives the interference.

Total values that are above the set threshold are identified in bold typeface. The complete result can be printed.

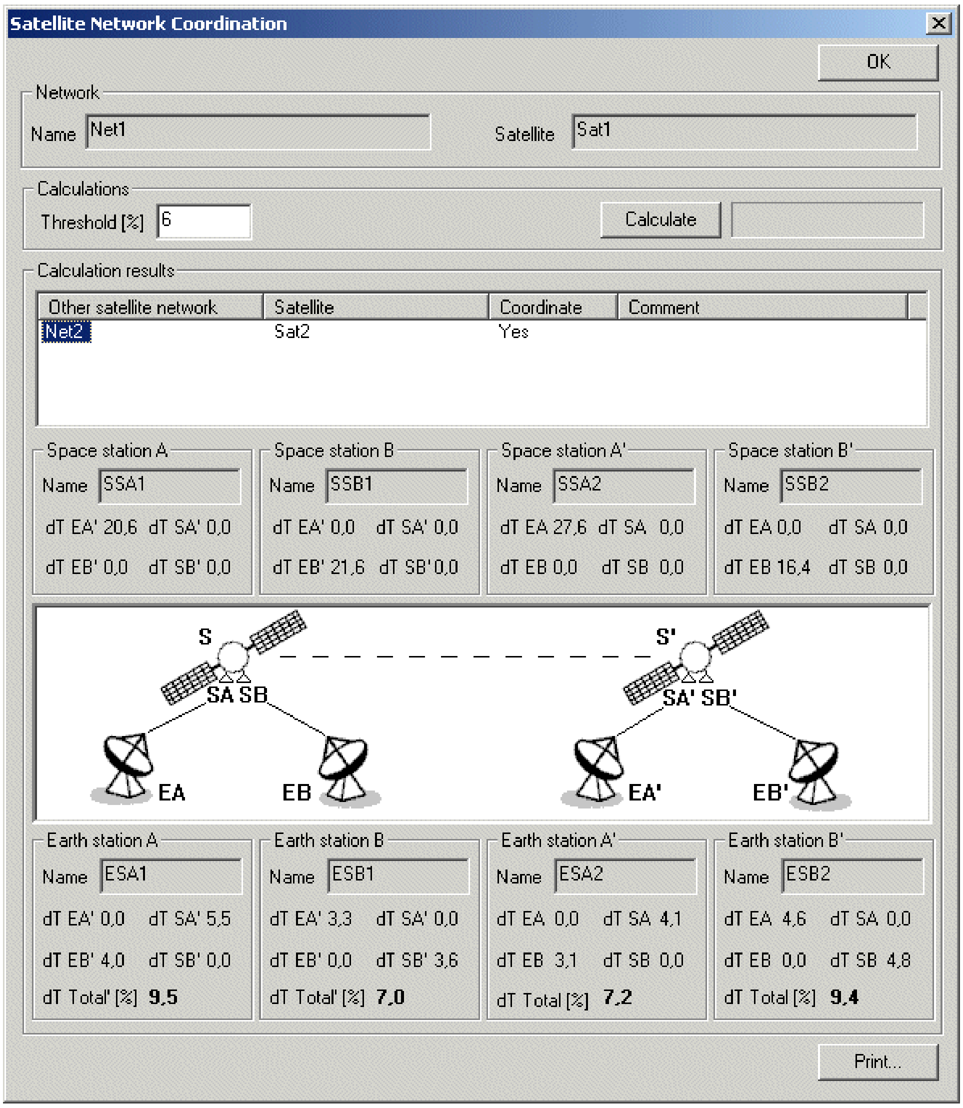

Figure 17.2: *Example of result display for Satellite Network Coordination.*

17.4 EXAMPLE: COORDINATION OF A SATELLITE NETWORK

The purpose of this example is to demonstrate how to use WRAP to identify whether there is a need for coordination for a new satellite network. Before performing calculations it is necessary to enter the networks, each comprising one or two earth stations and one satellite. The beginning of this exercise describes how to enter the data. A sample project containing all necessary data exists and can be used directly. Go directly to **17.4.2** to start with the calculations, without entering the data in the new project.

17.4.1 Example: Forming the satellite network

The following procedure should be followed to form the satellite networks that subsequently can be used for coordination calculations:

1. Create the satellite stations

2. Create the satellite(s) as a *Group.* This forms the satellite, which can contain a number of satellite stations.

3. Create the earth stations

4. Create the satellite networks. This connects the earth stations with the satellite stations to form the satellite links.

One important observation is that earth station antennas are automatically directed towards their associated satellite. Satellite antennas however are directed towards their defined *aim point*, which is defined as the geographical coordinates on the surface of the earth at which the satellite beam is aiming. Earth station antennas are automatically redirected if the associated satellite is moved. Satellite antennas point at the defined aim point even if the associated earth station is moved or the satellite is moved.

Perform the following to create the project that subsequently can be used in the APS8 coordination calculations. The object is to create two complete geostationary satellite networks, each with two earth stations and one satellite with two satellite stations. In total four earth stations, four satellite stations and two satellites.

- Start a new project by selecting **File – New.** Make the following settings:
  - In the top menu bar – select **Settings – Geographical – GTOPO30**
  - Right-click in the Map Viewer, select **Properties… - Vector Data – Vector, line.** Check **IDWM** for visible status. Accept and close with **OK.**

- One way of forming the networks is to start with the satellite, as follows:
  - Select **Group – New – Group** in the top menu bar.
  - In the **Edit Group - Main** tab, perform the following:
    -- Write name: **Sat1**
    -- Select **Type – Satellite**
    ..-- Check **Geostationary.** Note that this automatically gives the standard height of the geostationary orbit. The value can be edited if desired.
    -- Enter **Position** to 25°E, 0°N

- Continue with next tab, **Stations.** This is empty. Create a new satellite station as follows:
  - Click on **New.** Select the **Space service** folder.
  - Select the template **WRAP Satellite 72 M.**
  - Set a name **SSA1** (this station will be used in Sat1 as station A)
  - Go the **Frequencies** tab. Enter 4000 MHz for the

transmitter and 6000 MHz for the receiver.
- Go to the **Transmitter** and **Receiver** tabs just to see what equipment the satellite template has assigned.
- Go to the **Space station specific** tab. Enter the following
  -- **Noise temperature:** 150 K.
  -- **Transponder gain:** 100 dB.
  -- Check **Fq changing transponder**
  -- select **IFL class**: EA (the choice is not important)
..-- Set the **Aim point** to 10°E, 57°N
- Accept and close with **OK.**

- Mark the just created satellite station and press **Duplicate.** Then mark the duplicate, press **Edit** and perform the following changes:
  - **Name:** SSB1
  - **Frequencies:** TX 4500 MHz; RX 6500 MHz
  - **Aim point**: 25°E, 57°N
  - Close with **OK.**

- Then select the **Satellite Network** tab. Make the following entries:
  - **Name**: Net1, then press **Add**
  - Mark the Net1 name in the list
  - Select **Earth station A** – **New**
  - Select the **Wrap Earth station 6G/72 M** template
  - Make the following settings in **Edit Station**
    -- **Name:** ESA1
    -- **Position**: 10°E, 57°N
    -- **Frequencies**: TX 6000 MHz; RX 4000 MHz
    -- **TX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
    -- **EIRP:** Press **Calculate**, set to 70 dBW
  ..-- **RX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
    -- Accept and close with **OK.**
  - Press **Select** for **Space station A** and select SSA1
  - Press **Select** for **Space station B** and select SSB1

  Continue now to create Earth station B as follows:

  - Select **Earth station B** – **New**
  - Select the **Wrap Earth station 6G/72 M** template
  - Make the following settings in **Edit Station**
    -- **Name:** ESB1
    -- **Position**: 25°E, 57°N
    -- **Frequencies**: TX 6500 MHz; RX 4500 MHz

-- **TX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
-- **EIRP:** Press **Calculate**, set to 70 dBW
..-- **RX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
-- Accept and close with **OK**.

- Finally, the transmission gain must be calculated. Perform this as follows:
  - Mark the name of the network, Net 1
  - Press **Transmission gain [dB], Calculate** for both links.

The following window should now be shown:

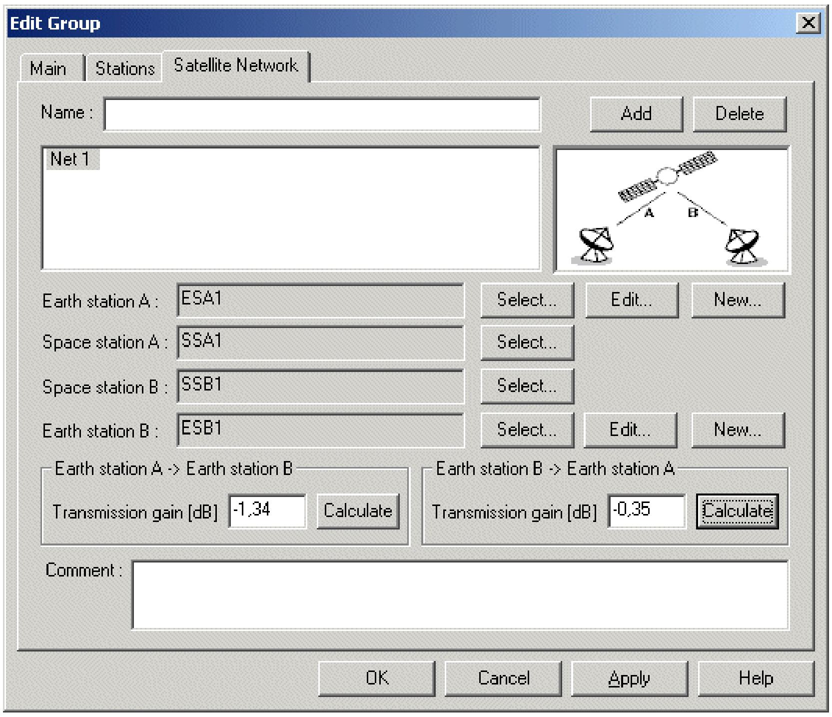

***Figure 17.3:** Satellite network Net 1 being created.*

- Accept and close the **Edit Group** window by selecting **OK**.

This procedure is then repeated in order to create Satellite Network 2, which for the purposes of this exercise is located near Net 1 but with slightly different but overlapping frequency bands. Perform the following:

- Select **Group – New – Group** in the top menu bar.
  - In the **Edit Group - Main** tab, perform the following:
    -- Write name: **Sat2**
    -- Select **Type – Satellite**
    ..-- Check **Geostationary**. Note that this automatically

gives the standard height of the geostationary orbit. The value can be edited if desired.
-- Enter **Position** to 10°E, 0°N

- Continue with next tab, **Stations**. This is empty. Create a new satellite station as follows:
  - Click on **New**. Select the **Space service** folder.
  - Select the template **WRAP Satellite 72 M.**
  - Set a name **SSA2** (this station will be used in Sat2 as station A)
  - Go the **Frequencies** tab. Enter 4005 MHz for the transmitter and 6005 MHz for the receiver.
  - Go to the **Space station specific** tab. Enter the following
    -- **Noise temperature:** 150 K.
    -- **Transponder gain:** 100 dB.
    -- Check **Fq changing transponder**
    -- select **IFL class**: EA (the choice is not important)
  ..-- Set the **Aim point** to 10°E, 50°N
  - Accept and close with **OK.**

- Mark the just created satellite station and press **Duplicate.** Then mark the duplicate, press **Edit** and perform the following changes:
  - **Name:** SSB2
  - **Frequencies:** TX 4505 MHz; RX 6505 MHz
  - **Aim point**: 25°E, 50°N
  - Close with **OK**.

- Then select the **Satellite Network** tab. Make the following entries:
  - **Name**: Net2, then press **Add**
  - Mark the Net2 name in the list
  - Select **Earth station A – New**
  - Select the **Wrap Earth station 6G/72 M** template
  - Make the following settings in **Edit Station**
    -- **Name:** ESA2
    -- **Position**: 10°E, 50°N
    -- **Frequencies**: TX 6005 MHz; RX 4005 MHz
    -- **TX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
    -- **EIRP:** Press **Calculate**, set to 70 dBW
  ..-- **RX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
    -- Accept and close with **OK**.
  - Press **Select** for **Space station A** and select SSA2
  - Press **Select** for **Space station B** and select SSB2

Continue now to create Earth station B as follows:

- Select **Earth station B - New**
- Select the **Wrap Earth station 6G/72 M** template
- Make the following settings in **Edit Station**
  - -- **Name:** ESB2
  - -- **Position**: 25°E, 50°N
  - -- **Frequencies**: TX 6505 MHz; RX 4505 MHz
  - -- **TX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
  - -- **EIRP:** Press **Calculate**, set to 70 dBW
  - ..-- **RX Equipment, Antenna:** Change to "Earth APS7/8/30B, 50 dBi"
  - -- Accept and close with **OK**.

- Finally, the transmission gain must be calculated. Perform this as follows:
  - Mark the name of the network, Net 1
  - Press **Transmission gain [dB], Calculate** for both links.

The complete networks can be shown in the Map Viewer. First you may for instance select to show the ITU Digitized World Map, by right-clicking in the Map Viewer, go to **Properties…** and check the **IDWM – Visible** box.

Show all stations in the list view, mark them all and select **Show in Map Viewer.** This will give a display as shown in **Figure 17.4.**

> ***Note 1:*** *Save the project under a suitable name.*

> ***Note 2:*** *Right-clicking on the satellite group in the list view and selecting "Save in database" will save all stations, satellite and network information to the database. Retrieving the data from the database is done by searching in "Groups in Database" for the satellites, right-clicking on the satellite group and selecting "Add to Project".*

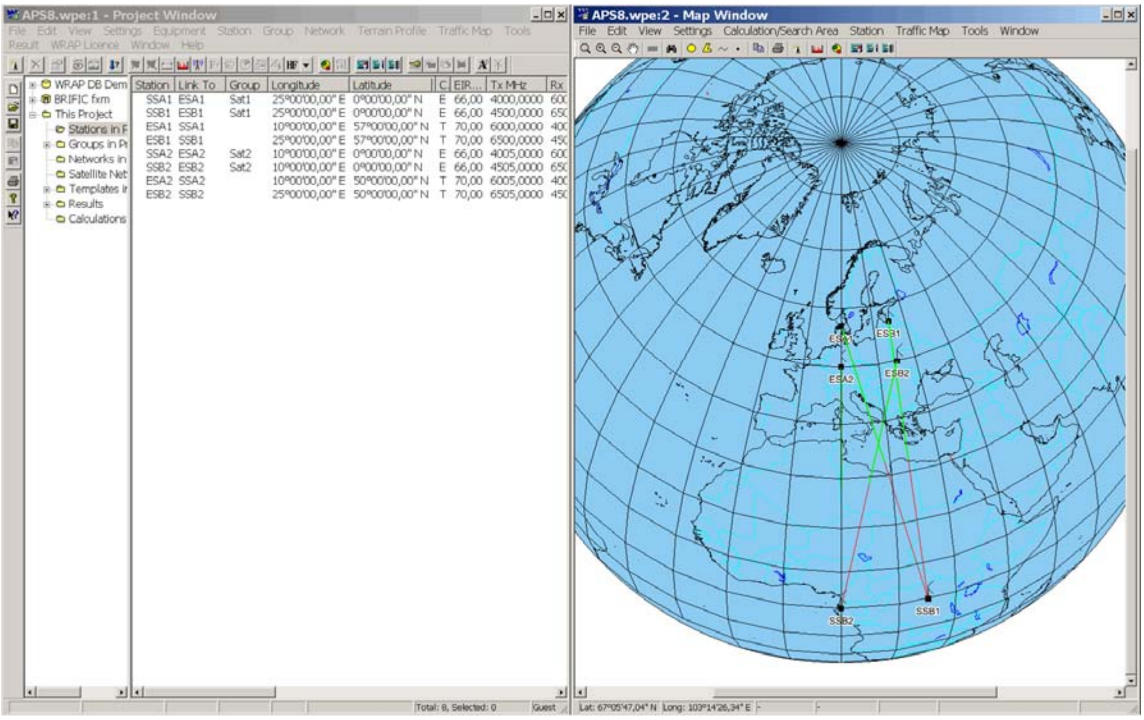

Figure 17.4: *Satellite networks for the ITU Radio Regulations Appendix S8 coordination exercise.*

17.4.2 Example: Coordination calculation for a satellite network

> ***Note:*** *A demonstration project APS8.wpe exists in the Samples folder. This can be opened and used for the continued exercise.*

Continue now with the calculation as follows.

- List the networks by opening the **Satellite Networks in Project** folder. This should list two networks: Net 1 and Net 2.
- Mark Net 1 and open the **Satellite Network Coordination** tool.
- Press **Calculate**.
- When the calculation is ready, mark the network name in the listbox. Then the results are displayed.

The results should display similar to **Figure 17.5**.

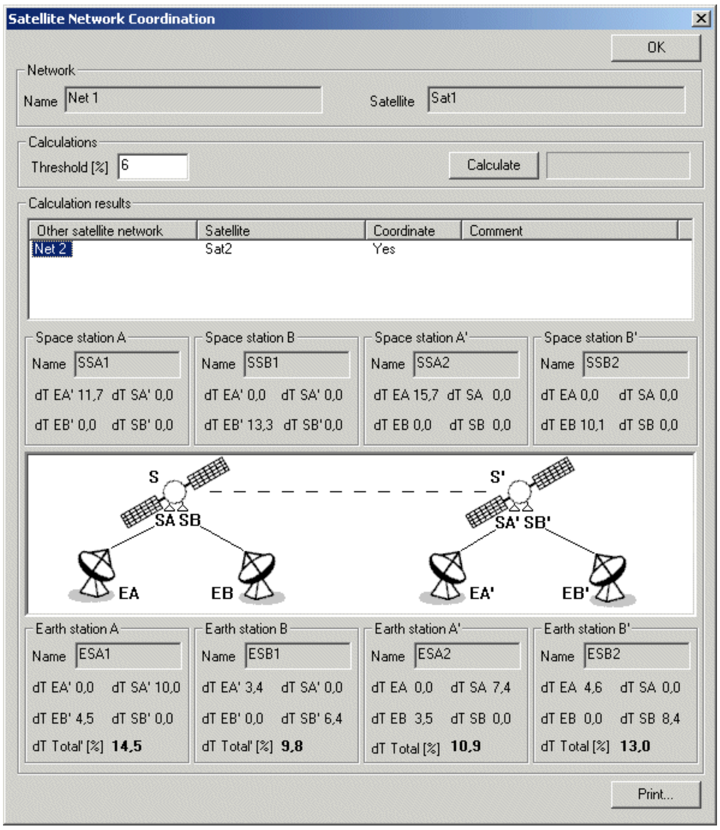

Figure 17.5: *Result display of the Satellite Network Coordination exercise.*

The results are shown as the percentage increase (ΔT/T) in the noise temperature caused by each individual interferer in each individual receiver. The total result is given in the bottom line for each earth station. Results in bold numbers are above the threshold that can be set in the upper part of the window. In this case the result indicates that coordination needs to be carried out.

The ITU Radio Regulations Appendix 8 method is designed very conservatively, to indicate need for coordination in a worst-case situation. The continued analysis of such a case goes into more detail in level calculations, using a more accurate propagation model and very importantly, considering the transmitter spectral shape and receiver selectivity. Such calculations are performed in the WRAP *Interference* tool.

17.4.3 Example: Interference calculation for satellite networks

Having identified a need for coordination based on the ITU RR Appendix 8 method a further analysis can be conducted in WRAP. This is done in the *Interference* tool, where suitable propagation models for the space-to-earth path is available, and a proper interference power calculation can be performed. This calculation accounts for the actual spectral shapes and receiver selectivities defined for the transmitters and receivers.

Perform the following:

- Open the **APS8.wpe** project and list the stations in the list view.

- From the previous APS8 coordination calculation it was identified that for instance satellite station SSB1 gave interference in earth station ESB2. Mark **ESB2** in the list and start the **Interference** tool.

- Make the following selections under **Settings…** (default values if not defined otherwise):
  - **Propagation model**
    -- **Terrestrial – Interferer: Longley-Rice**
    -- **Space – Wanted: P.619**
    -- Space – Interferer: P.619, with **Settings – Time percentage 0.01%**

- Accept and close **Interference Settings** with **OK.**

- Mark the frequency in the upper list box to list the individual contributions in the lower list. You will see that only one major interferer exists, and that is as expected SSB1.

- Then select **As interferer** to identify the amount of interference that ESB2 gives. You will find that ESB2 interferes only with SSB1, also as expected.

See **Figure 17.6** for the results for ESB2 as interfering and as interfered station.

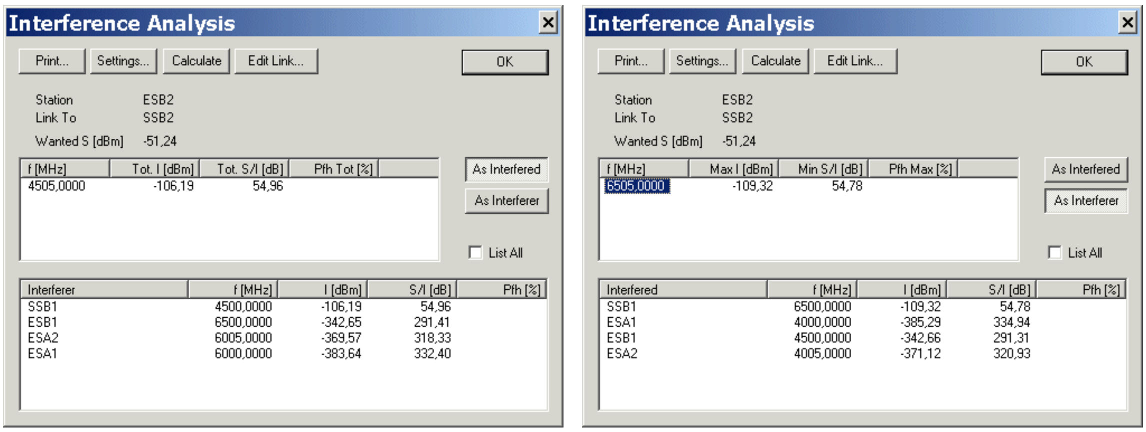

Figure 17.6: *Interference results for Earth station ESB2. Left: As interfered. Right: As interferer.*

The calculation can be repeated for the other stations in the project. You may notice that each of the satellite stations gets interference from and interferes with the other station in the same satellite. This is due to the fact that their antennas are located very closely together (actually in exactly the same position), and the equipment data is such that insufficient interference protection exists within the satellite. The antenna positions within the satellite may be edited by opening the **Edit Station** window for the satellite station and changing the x/y/z coordinates in the local coordinate system within the group.

The resulting signal-to-interference ratio may be compared with the specifications for the earth station and satellite receivers, as stored in the database. In this case there should not be any problem due to the increased noise temperature, since the S/I requirement is 20 dB to compare with the result of about 55 dB S/I.

17.4.4 Example: Calculation of power flux density on the surface of the earth

Another area of concern for satellite networks is the maximum power flux density produced by the satellites on the surface of the earth. Maximum permissible values for different frequency bands and reference bandwidths of the transmission can be found in the ITU Radio Regulations, Article S21, Table S21-4.

Perform the following to calculate the PFD from the satellites in the APS8.wpe project.

- Open the **APS8.wpe** project. List the stations in the project in the list view.
- Show all stations in the **Map Viewer**. Change the map settings as follows:
  - Right-click on one of the earth stations in the project and select **Centre Map**
  - Right-click in the map and select **Projection – National Grid**
  - Right-click in the map and select **Scale – 1:50 000 000**
- Draw a calculation circle that encloses all four earth stations as follows:
  - Right-click in the map and select **Calculation/Search Area – Circle**
  - Place the cursor at a point between the four earth stations, left-press and move the cursor until a circle with a radius of 3500 km has been drawn.

> ***Note:*** *The display will actually not show a circle. The shape is changed in accordance with the map projection. The true shape of the area is a circle, though.*

- Mark all the satellites **SSA1, SSB1, SSA2, SSB2** by holding down the **Ctrl** key while left-clicking on each satellite name.

- Start the **Coverage** tool and make the following settings:
  - **Calculation: Power Flux Density**
  - **Mobile:** Any mobile will do, but select an **Earth Station** template.
  - **Propagation Model: P.619**
  - **Atmospheric Attenuation** in the **Propagation model** window: **Space paths**
  - **Resolution: High**
  - Default settings otherwise.
  - Write a name for the calculation in the **Description** field.
  - Accept the settings and start the calculation with **OK.**

- Open the **This Project – Results – Coverage Results – Coverage Results Area** folder and double-click on the result that was just calculated. Notice that the minimum value is extremely low, indicating that the calculation area included parts of the earth that were not visible from the satellite.

You should now select appropriate PFD contours for the presentation. Table S21-4 in Article S21 of the Radio Regulations states that the maximum power flux density is in the range of –142 dBW/m^2 to –152 dBW/m^2, with the higher value valid for elevation angles as seen from the earth of 25°-90°, and the lower value for elevation angles less than 5°. The limit between 5° and 25° is a function of the elevation angle. These values refer to a reference bandwidth of 4 kHz. In this particular example the transmission bandwidth is 72 MHz. To represent the permissible PFD in a 4 kHz bandwidth, the following bandwidth adjustment factor A_{bw} shall be applied:

$$A_{bw} = 10\log(72000/4) = 42.55\ dB$$

The maximum permissible value of PFD for a 72 MHz wide transmission (with constant spectral density across the transmission bandwidth) is thus

$$-142 + 42.55 = -99.45 \text{ dBW/m}^2$$

- Select the **Edit Result – Presentation** tab. Add one more result contour by pressing the **+ sign**. Set the values -99.45 and -109.45 dBW/m^2 to the contours to be shown. Close with **OK.**

- Right-click on the result name and select **Visible.** Right-click again and select **Show Cursor Value.**

A result similar to that in **Figure 17.7** should appear in the Map Viewer.

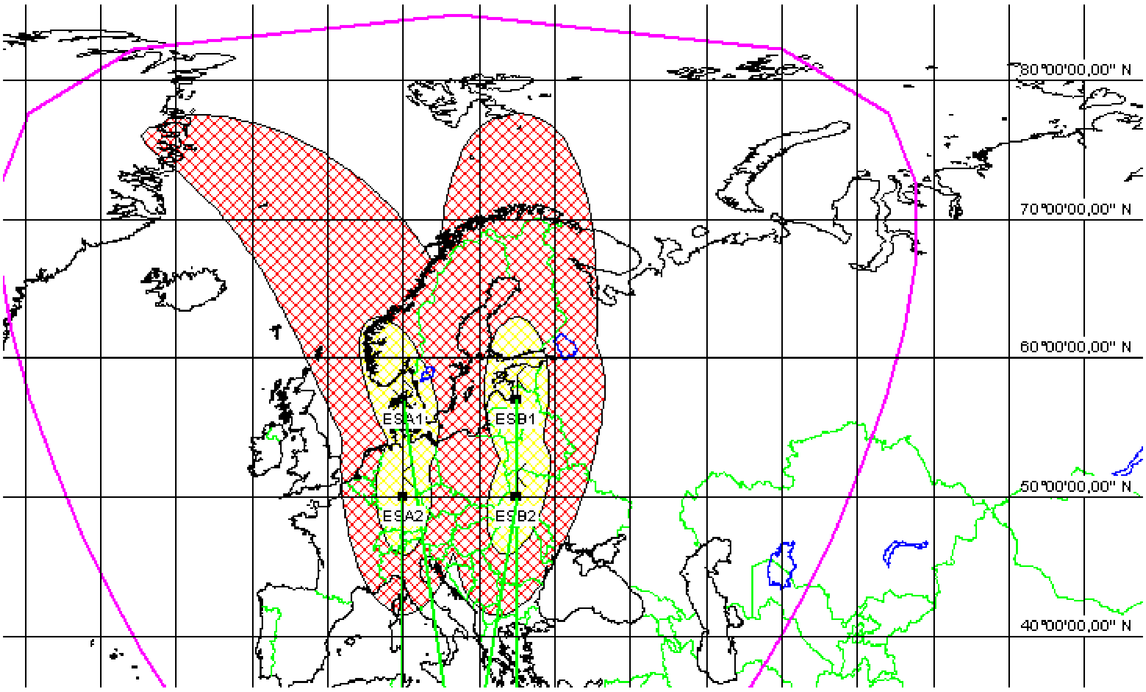

Figure 17.7: *Power flux density on the surface of the earth from the satellites in the APS8.wpe project. Yellow colour (areas around earth stations) indicates too high values compared to Article S21 Table 4 limits.*

Note that strange shape of the satellite footprints are due to the distortion by the selected map projection. You may experiment with the other suitable projections, such as **Orthographic** (the world globe) and the **Great Circle**. They give nice displays.

Moving the cursor within the calculation area will quickly reveal the limits where the satellite is not visible from the earth. The PFD values abruptly get very low at this limit.

The maximum value can be read directly in the **Edit Result** window or in this case by placing the cursor at the earth station locations and reading the value. This shows that the satellites have about 3 dB too high radiated power. Reducing the power density by 3 dB will therefore fulfil the ITU limits for maximum power flux density.