BEAMFORMING ANTENNAS IN IMT-2020 SYSTEMS

Introduction

A key. feature of IMT-2020 systems are beamforming array antennas which use phase shifting to an array of individually fed antenna elements to dynamically steer a beam towards a specific user in order to maximise throughput.

The main beamforming antenna as specified in SEAMCAT is the Beamforming (Composite) antenna, which is in-line with the specifications outlined in section 5 of Rec. ITU-R M.2101. An implementation of 3GPP TR 37.840 is also available – the differences between these implementations are explained below.
Beamforming antenna arrays in SEAMCAT are specified at two levels – first the individual element antenna is specified as a regular antenna plugin, which is then used to form the larger array specified in a separate plugin. These are described in the following sections

Beamforming element antenna

The beamforming element antenna is specified as a standard equation based antenna plugin in SEAMCAT.

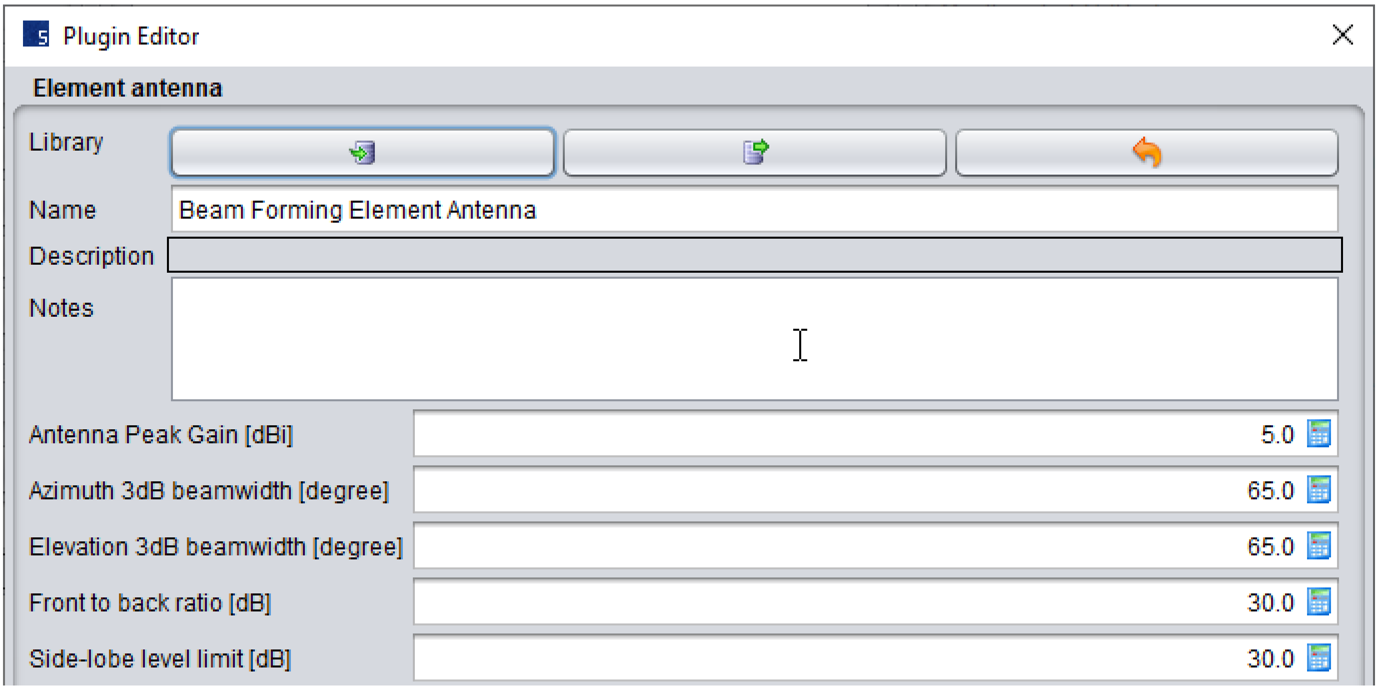

Figure: Beamforming element antenna parameters

The input parameters and the corresponding notation as used in the following equations are:

- Antenna Peak Gain (dBi): $G_{E,max}$
- Azimuth 3dB beamwidth (degrees): θ_{3dB}
- Elevation 3dB beamwidth (degrees): φ_{3dB}
- Front to back ratio (dB): A_m
- Side-lobe level limit (dB): SLA_v

The total gain $A_E(\theta,\varphi)$ is calculated as follows:

$$A_E\left(\theta,\varphi\right) = G_{E,max} - \min\left\{-\left|A_{E,H}\left(\theta\right) + A_{E,V}\left(\varphi\right)\right|, A_m\right\}$$

$$A_{E,H}\left(\theta\right) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$$

$$A_{E,V}\left(\varphi\right) = -\min\left[12\left(\frac{\varphi-90}{\varphi_{3dB}}\right)^2, SLA_v\right]$$

Note that the notation for azimuth and elevation planes in these sections is the opposite of that used in M.2101 – this is for consistency with the wider SEAMCAT conventions, where φ=elevation and θ=azimuth.

This implementation is equivalent to the 3GPP TR 36.814 antenna pattern (Table A.2.1.1-2) which is also available in SEAMCAT as a separate antenna.

Note that it is possible to use the element antenna in isolation (i.e. not as part of a beamforming array), however in this case any tilt settings will not be handled correctly. For this case it is recommended to instead use the 3GPP TR 36.814 antenna plugin directly.

Beamforming composite antenna

Once the element antenna has been specified, it can be applied to the composite array plugin which specifies the dimensions of the array:

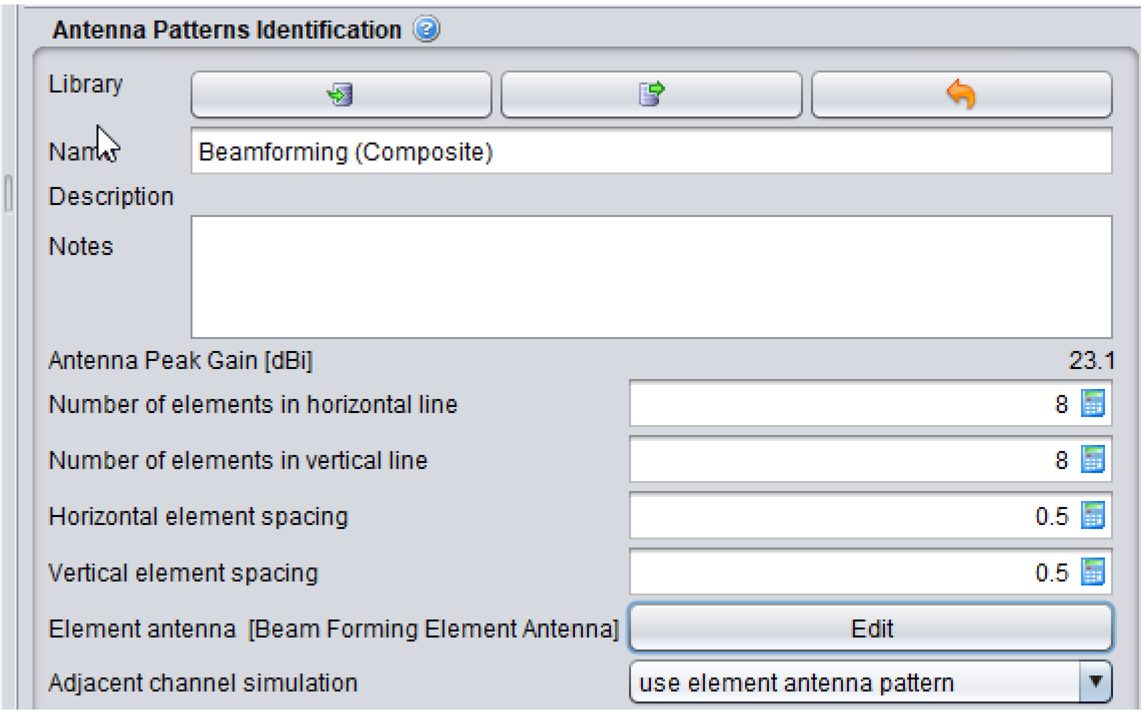

Figure : Beamforming composite array parameters

The element antenna can be modified by selecting Edit next to Element antenna. The other input parameters and the corresponding notation as used in the following equations are as follows

- Number of elements in horizontal line: NH
- Number of elements in vertical line: NV
- Horizontal element spacing (relative to the wavelength of the wanted signal): dHλ
- Vertical element spacing (relative to the wavelength of the wanted signal): dVλ

The parameter "Adjacent channel simulation" determines how beamforming is handled in adjacent channels, with the following options:

1. "use element antenna pattern": in this case **no beamforming is applied** outside of the system link's own channel. This is in line with the M.2101 specifications
2. "use composite antenna pattern": in this case **beamforming is applied** outside of the system link's own channel. This option provides additional flexibility to the user, recognising that in practice some degree of beamforming will occur in nearby channels (see section 10.6.4 below for additional options).

For example:

- If VLR uses Beamforming antenna and is selected "use element antenna pattern" then for Unwanted interference SEAMCAT will use composite antenna gain for VLR and for Blocking interference it will use element antenna gain for VLR (outside channel).
- If ILT uses Beamforming antenna and is selected "use element antenna pattern" then for Unwanted interference SEAMCAT will use element antenna gain for ILT (outside channel) and for Blocking interference it will use composite antenna gain for ILT.

The antenna peak gain is pre-calculated and shown for the input parameters (e.g. 23.1 dBi in Figure above). This is provided for validation purposes.

Tilting of antennas is handled as for other antennas (see section x.y.z).

The beamforming gain Gθ,φ is calculated as follows:

$$G(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\frac{\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\cos Z_{n,m}\right|^2 + \left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\sin Z_{n,m}\right|^2}{N_H N_V}\right)$$

$$Z_{n,m} = 2\pi\left((n-1)\left(\frac{d_V}{\lambda}\right)(\cos\varphi + \sin\varphi_{i,etilt}) + (m-1)\left(\frac{d_H}{\lambda}\right)(\sin\theta\sin\varphi - \cos\varphi_{i,etilt}\sin\theta_{i,escan})\right)$$

Where:

- AEθ,φis the element gain as calculated in equation above
- φi,etilt is the elevation beamsteering direction
- θi,escanis the azimuth beamsteeting direction

(Note that the equations differ from those in M.2101 to remove the dependency on complex numbers, but are mathematically equivalent).

The beamsteering angles represent the pointing of the beam from BS to UE for downlink (or UE to BS for uplink) on the **system link**, and the same values are used for the interference link, e.g. for IMT-2020 as the interfering system:

φi,etilt=-φILT→ILR NB this angle is specified with respect to the mechanical boresight (normal to the array) with positive values indicating downtilt.

θi,escan=θILT→ILR

The system link gain is calculated for θILT→ILR and φILT→ILR as:

$$G_{ILT\to ILR} = G\left(\varphi_{Z_I LT\to ILR}, \theta_{ILT\to ILR}\right) = A_E\left(\varphi_{Z_I LT\to ILR}, \theta_{ILT\to ILR}\right) + 10\log_{10}\left(\frac{\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\cos Z_{n,m}\right|^2 + \left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\sin Z_{n,m}\right|^2}{N_H N_V}\right)$$

where:

$$Z_{n,m} = 2\pi\left((n-1)\left(\frac{d_V}{\lambda}\right)\left(\cos\theta_{Z_I LT\to ILR} + \sin\varphi_{i,etilt}\right) + (m-1)\left(\frac{d_H}{\lambda}\right)\left(\sin\varphi_{Z_I LT\to ILR}\sin\theta_{ILT\to ILR} - \cos\varphi_{i,etilt}\sin\theta_{i,escan}\right)\right)$$

Note that the subscript Z in φZ_ILT→ILR indicates the transformed angle with respect to the Z axis (axis of rotation of the downtilt of the array – see section x.y.z).

The same equations are applicable for IMT as the interfering link receiver, with ILT→ILR replaced by ILR →ILT.

The interference link gain is calculated for θILT→VLR and φILT→VLR as:

$$G_{ILT\to VLR} = G\left(\varphi_{Z_I LT\to VLR}, \theta_{ILT\to VLR}\right) = A_E\left(\varphi_{Z_I LT\to VLR}, \theta_{ILT\to VLR}\right) + 10\log_{10}\left(\frac{\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\cos Z_{n,m}\right|^2 + \left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\sin Z_{n,m}\right|^2}{N_H N_V}\right)$$

$$Z_{n,m} = 2\pi\left((n-1)\left(\frac{d_V}{\lambda}\right)\left(\cos\varphi_{Z_I LT\to VLR} + \sin\varphi_{i,etilt}\right) + (m-1)\left(\frac{d_H}{\lambda}\right)\left(\sin\varphi_{Z_I LT\to VLR}\sin\theta_{ILT\to VLR} - \cos\varphi_{i,etilt}\sin\theta_{i,escan}\right)\right)$$

where φi,etilt and θi,escan are the same as calculated for the system link.

Similar cases apply for IMT-2020 as the victim system with:
φi,etilt=-φVLT→VLR
θi,escan=θVLT→VLR
and ILT→VLR replaced by VLR→ILT in the remaining terms.

Pointing settings

Beamforming arrays are applicable for both base stations and UEs.

For the case of base stations (downlink transmitter or uplink receiver) the array pointing reference is fixed according to the cellular layout, where the azimuth reference is towards East, and the elevation reference is towards the horizon. The user may specify an offset from this direction in the azimuth plane (Azimuth additional offset), and a mechanical downtilt (Elevation additional offset) where negative values indicate downtilt.

For the case of mobile stations (UEs), it is possible to set the pointing reference with respect to the base station (BS). The default settings in SEAMCAT are as follows:

Azimuth:

- Pointing reference: towards the BS
- Additional offset: Uniform distribution from -60° to +60°

Elevation:

- Pointing reference: towards the horizon
- Additional offset: Uniform distribution from -90° to +90°

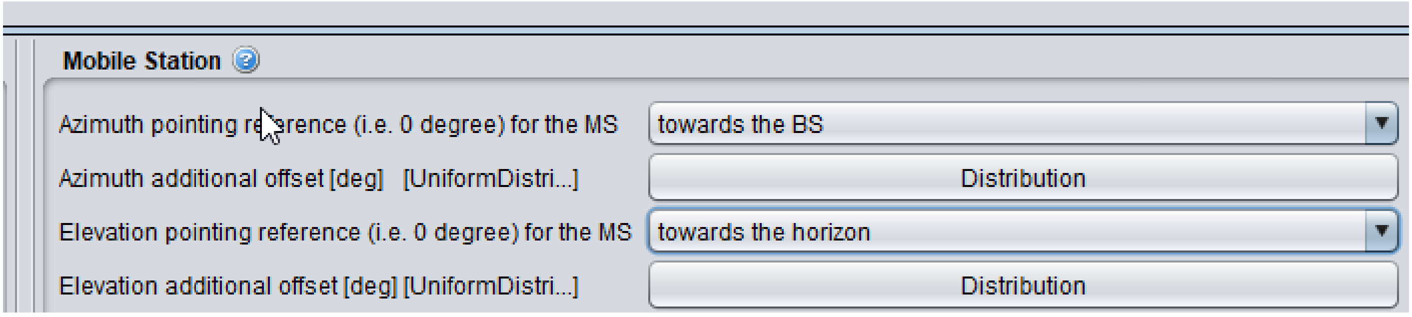

Figure: Mobile station pointing settings

This is intended to reflect random user behaviour with the implementation of a UE with 2 antenna arrays pointing in opposite directions, where only the array which points towards the serving base station is active.

3GPP TR 37.840 implementation

A separate implementation of the beamforming antenna in 3GPP TR 37.840 section 5.4.4 is available in the library. This antenna is equivalent to the M.2101 antenna as outlined above, with the exception that there is an additional correlation parameter ρ which allows the user to specify the degree of beamforming correlation (between 0 and 1) according to:

$$G(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(1+\rho\left(\frac{\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\cos Z_{n,m}\right|^2+\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V}\sin Z_{n,m}\right|^2}{N_H N_V}-1\right)\right)$$

Beamforming antenna plotting

The antenna pattern for beamforming antennas may be verified using the antenna gain plot as for other antennas (see section x.y.z), with the following additional options for "Link type":

1. Gain envelope: this shows the maximum gain at each angle if φi,etilt and θi,escan are equal to the plot angles (i.e. for horizontal plane θi,escan equals the azimuth angle for each plot, and φi,etilt equals the slice angle; for vertical plane φi,etilt equals the elevation angle for each plot, and θi,escan equals the slice angle). This represents the system link case and indicates the maximum possible gain at each angle, limited by the mechanical constraints of the array.
2. Full pattern: this shows the full beamforming gain across the full range of plot angles, with φi,etilt and θi,escan defined by the user. This represents the interference link case and can be used to verify the shape of the pattern as well as the gain to a victim at a specific offset angle.

Both of these options are illustrated below:

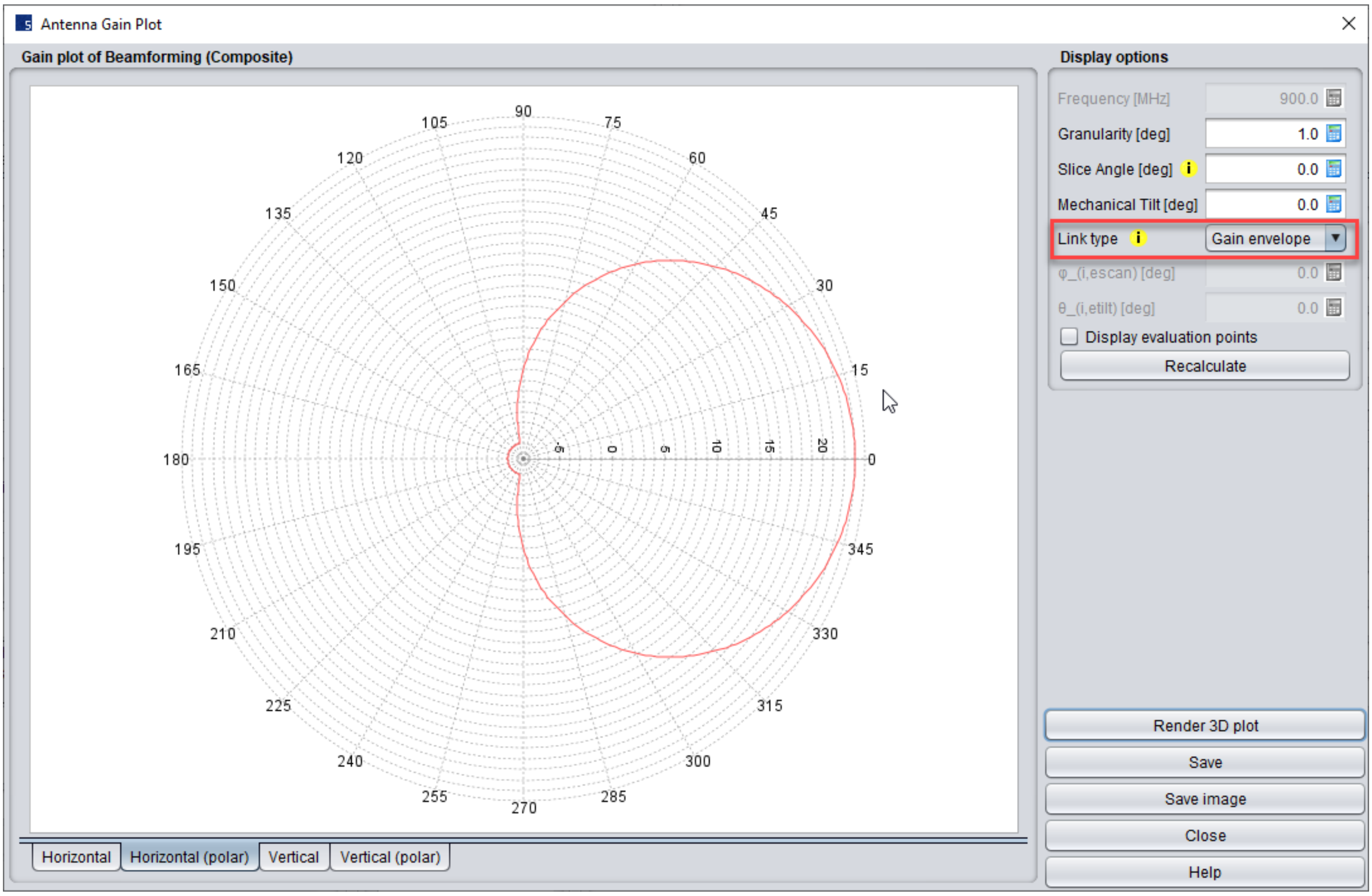

Figure: Beamforming antenna plot using "Gain envelope" mode

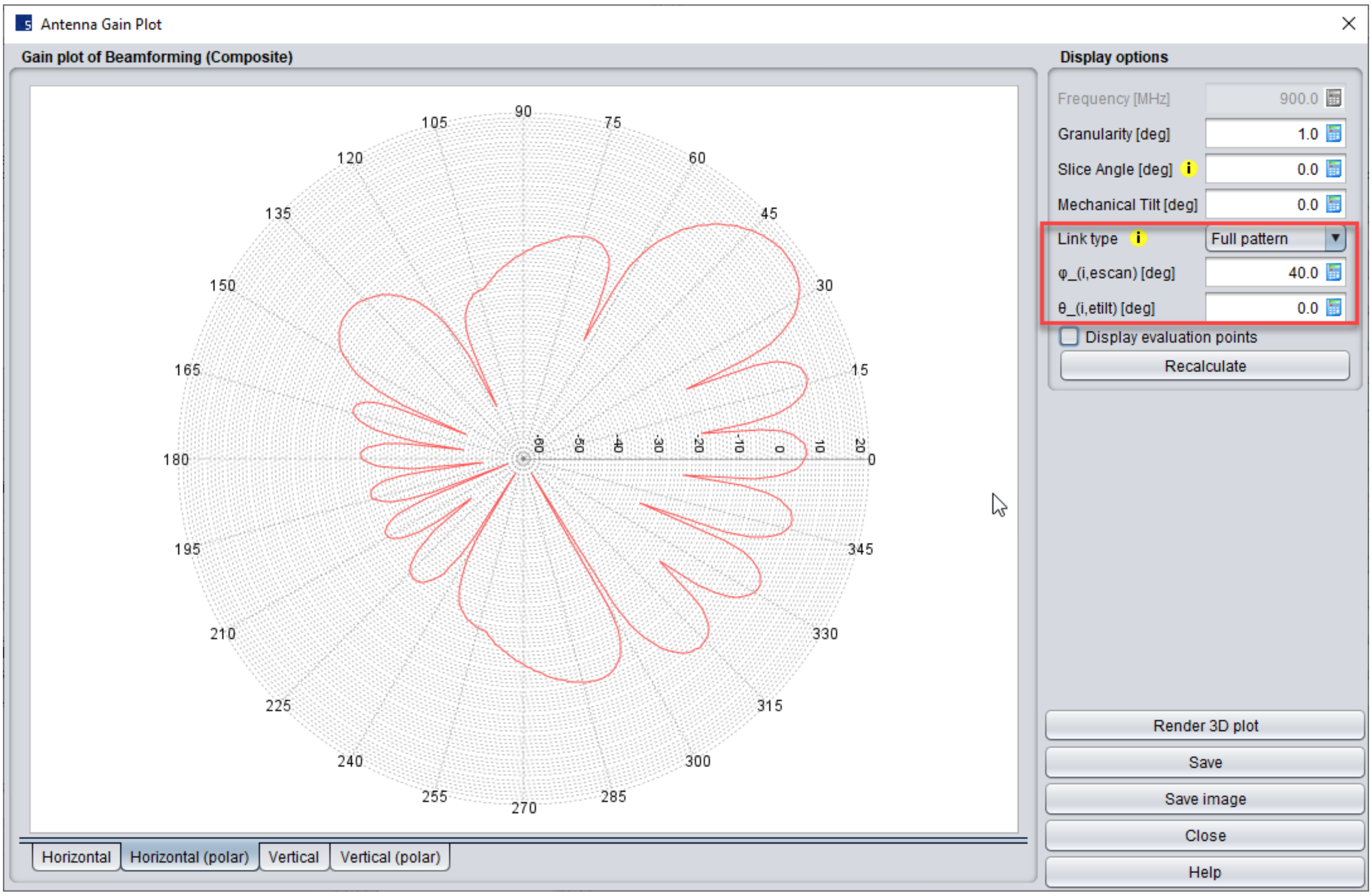

Figure: Beamforming antenna plot using "Full pattern" mode, with azimuth beamsteering angle set to 40 degrees

It is also possible to see the beamforming pattern on the individual event results – this can be useful to verify the gain values in a specific direction, as illustrated below:

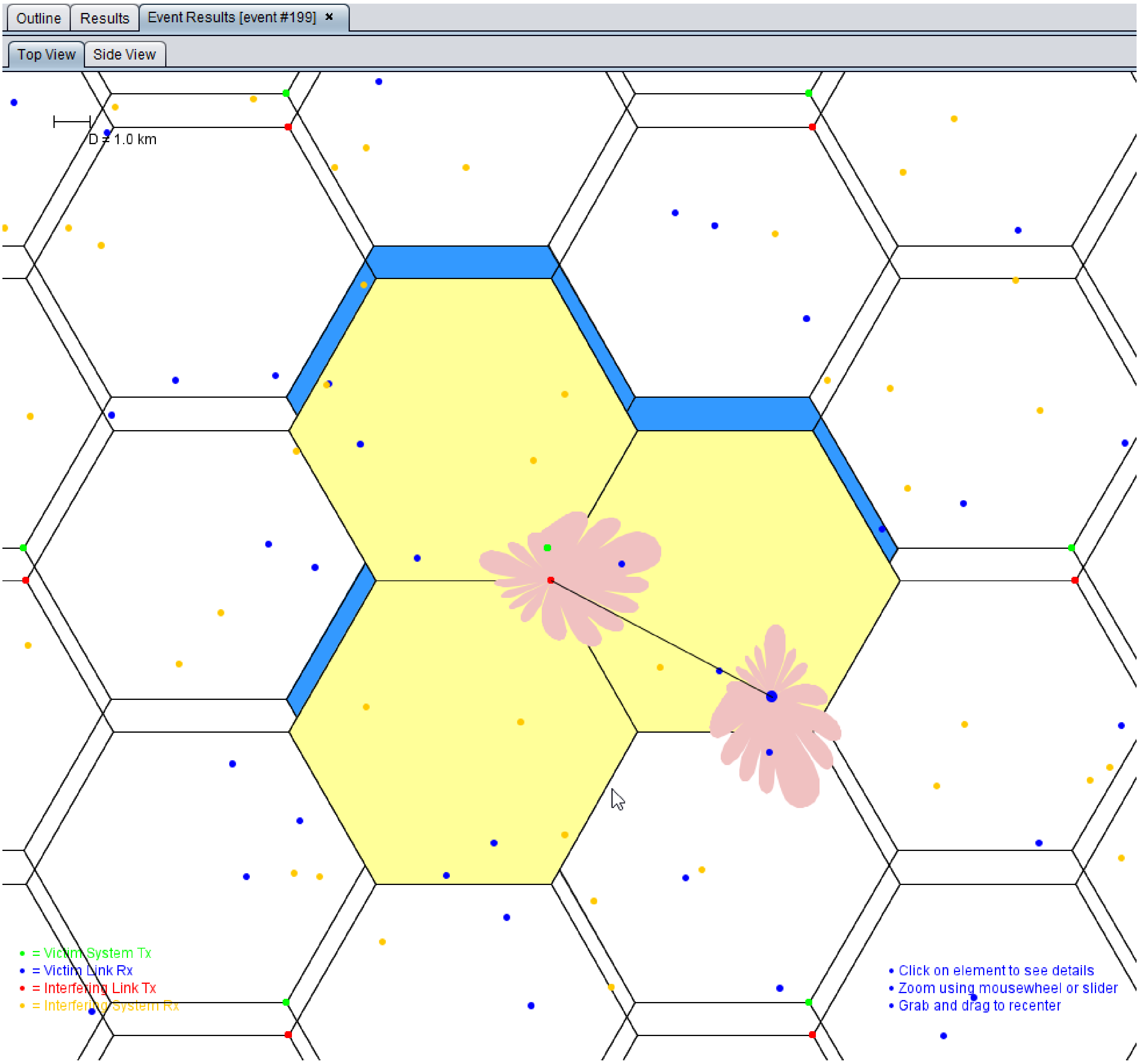

Figure: Example of beamforming plots for interference between 2 IMT-2020 networks - ILT BS (red) to VLR UE (blue) - on the Event Results layout

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