OSKAR Station Simulator: Conceptual Diagram

1 Overview

The simulator is loosely arranged into five modules:

1. Sky simulation
2. Antenna signal simulation
3. Weight generation
4. Beamforming simulation
5. Metrics/Visualisation/Post-processing

Each of these modules is designed to be a largely self-contained 'black-box,' with a few sharing common input parameters. The module interfaces are described in more detail in the 'Data Flow and Interface Specification,' while this document gives a more general overview of the modules in terms of their user inputs, functional blocks, and data checkpoints.

2 User inputs

User inputs are specified in green on the concept diagram. Each module has the following inputs:

2.1 Sky simulation

Name	Description
Channelized sky model	A database of point sources. The database includes variations of source amplitude and phase offset with channel number, for both horizontal and vertical polarizations.
Antenna field-of-view	The field of view (zenith angle) is required to select visible sources from the sky database.
Observation parameters	Includes the station position, observation start time, channel selection, sample rate, length of observation.
Direction-dependent corruptions	A map of directional amplitude and phase offsets, to allow for ionospheric effects and local interfering sources. This will need to be updated periodically.
Simulator operating mode	Full simulation or diagnostic.
Diagnostic parameters	Grid resolution, output type, channel selection.

2.2 Antenna signal simulation

Name	Description
Antenna element pattern	A map of amplitude and phase offsets due to the antenna response, as a function of azimuth and elevation.
Antenna locations within station	A database of antenna locations relative to the station phase centre. Used to generate antenna signals with required phase offsets due to the array geometry.
Non-direction-dependent corruptions	A map of amplitude and phase offsets which are independent of direction, to allow for antenna-level effects such as cross-coupling.

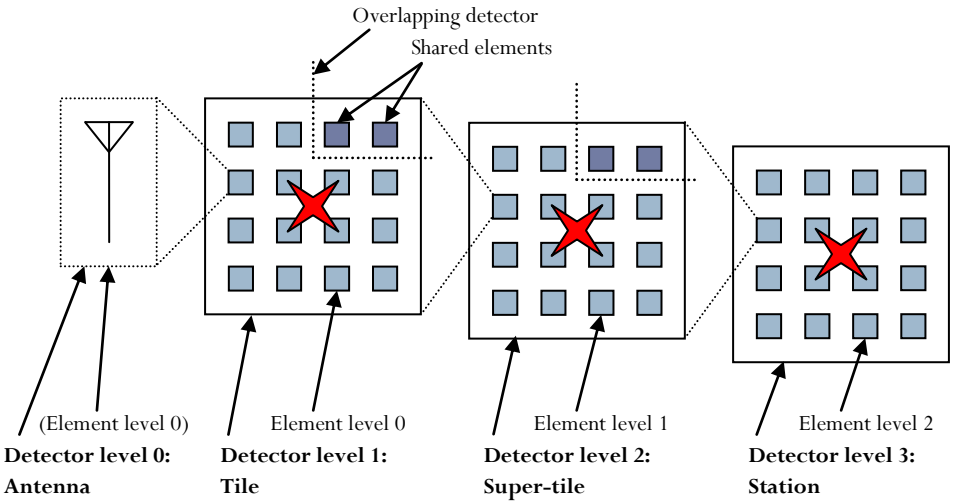

Figure 1: The station configuration in terms of element and detector hierarchy. Each detector phase-centre is marked in red.

2.3 Weight generation

Name	Description
Station configuration (detector hierarchy) and number of levels	A database specifying how elements are grouped into detectors for each level in the beamformer hierarchy, as shown in Figure 1. For example, individual antennas (elements and detectors at level 0) may be grouped into tiles (detectors at level 1). Tiles (elements at level 1) may be grouped into super-tiles (detectors at level 2), and super-tiles (elements at level 2) may be grouped into a station (the final detector, at level 3). In general, each element may belong to more than one detector, so, for example, different logical tiles may share a single antenna. The station configuration database must start at the antenna level (level 0), and end at the station level (level *n*, where *n* is specified by the user).
Element locations	A database of element locations relative to each detector phase centre. Element locations must be specified for each level of the beamformer hierarchy.
Detector levels at which to form complete beams	A list of levels at which to form complete beams. If a level is omitted from the list, it is used to block the beamforming matrix to form partial beams at that level.
Beam/null directions	A database to specify beam (and optionally, null) directions in celestial coordinates for each level in the beamformer hierarchy.
Algorithm choice	The beamformer algorithm must be specified for each level in the hierarchy.
Simulator operating mode	Full simulation or diagnostic.
Apodisation function	Specify amplitude scaling of elements relative to the detector phase centre.
Correction data	Phase and amplitude offsets to apply to each detector element. This could be obtained by inverting the corruptions introduced as part of the simulation.

2.4 Beamforming simulation

Name	Description
Detector levels at which to form complete beams	A list of levels at which to form complete beams. If a level is omitted from the list, it is used to block the beamforming matrix to form a partial beam at that level.

2.5 Metrics/Visualisation/Post-processing

Name	Description
Data source and desired output	To be defined

3 Functional blocks

Functional blocks are indicated in blue on the concept diagram. Each module will have the following functions:

3.1 Sky simulation

Name	Description
Find visible sources	(If in full simulation mode). Queries the sky database, using the station position, local sidereal time, and antenna field-of-view to find visible sources.
Convert source positions to horizon coordinates	(If in full simulation mode.) Converts celestial coordinates of visible sources into local horizon coordinates.
Simulate source noise	(If in full simulation mode.) Adds optional random noise to source amplitude and phase.
Generate diagnostic source(s)	(If in diagnostic mode). Generates diagnostic source(s) at given grid positions.
Apply direction-dependent corruptions	Applies direction-dependent amplitude and phase offsets to sky model.
Fill sky buffer	Construct a buffer of source data (in local coordinates) indexed by time-stamp, source ID and channel ID. This is passed to the antenna signal simulator.

3.2 Antenna signal simulation

Name	Description
Generate antenna signals	Generates antenna signals given a database of antenna positions, and a buffer of local sky data.
Simulate sky background noise	(If in full simulation mode.) Simulates background noise from the whole sky.
Simulate antenna noise	(If in full simulation mode.) Simulates noise from each antenna.
Apply non-direction-dependent corruptions	Apply amplitude and phase offsets that are independent of direction, to allow for antenna-level effects such as cross-coupling.
Fill antenna buffer	Construct a buffer of antenna signals indexed by time-stamp, antenna ID and channel ID. This is passed to the simulator beamforming module.

3.3 Weight generation

Name	Description
Convert beam celestial coordinates to horizon coordinates	Converts celestial coordinates of beams into local horizon coordinates.
Generate weights	For a given buffer of detector signals, generate weights to form beams in the required directions using the chosen algorithm at each level. Also requires a database describing the element layout with respect to the detector phase centre, and an optional apodisation function.

3.4 Beamforming simulation

Name	Description
Route antenna signals to beamformer	Routes correct antenna signals for beamformer to work with.
Route weights to beamformer	Routes correct weights buffer for beamformer to work with.
Apply weights to generate (partial) beams for each level in hierarchy	Beamformer module: Multiply-accumulate operation.
Post-beam processing	Combine beams if beam-space processing is requested.
Fill beam buffer	Construct a buffer of beam data indexed by time-stamp, beam ID and channel ID. This is passed on to further post-processing routines.

3.5 Metrics/Visualisation/Post-processing

Name	Description
Generate sky image from single-pixel beams	(Full simulation mode) Generate an image of the sky using each beam as a single pixel.
Generate sky image by pixellating input model	(Self explanatory)
Generate beam pattern	(Diagnostic mode) Sweep a beam over the sky to visualise the beam pattern.
Generate array factor	(Diagnostic mode) Sweep a test source over the sky to visualise the array response to a given set of weights.
Visualise weights	(Diagnostic mode) Plot complex weights applied to each antenna.
Visualise antenna signals	(Diagnostic mode) Plot phase and amplitude of signals from a given set of antennas.
Option: Correlate beams from tiles to form an image	(On the wish-list)

4 Data checkpoints

Data checkpoints are indicated in yellow on the concept diagram: these are locations which can be used to load data into the simulator, or save data from the simulator at a convenient stage for later re-use. Each module will have the following checkpoints:

4.1 Sky simulation

Name	Description
Uncorrupted, channelized sky model	A snapshot of the uncorrupted, channelized sky, in local horizon coordinates, for a given time sample.
Corrupted, channelized sky model	A snapshot of the corrupted, channelized sky, in local horizon coordinates, for a given time sample.
Buffer of corrupted, channelized sky model	A buffer of the corrupted, channelized sky, in local horizon coordinates.

4.2 Antenna signal simulation

Name	Description
Uncorrupted, channelized antenna signals	A snapshot of the uncorrupted, channelized antenna signals, for a given time sample.
Corrupted, channelized antenna signals	A snapshot of the corrupted, channelized antenna signals, for a given time sample.
Buffer of corrupted, channelized antenna signals	A buffer of the corrupted, channelized antenna signals.

4.3 Weight generation

Name	Description
Beam positions	A database of beam positions for each level at each required time, in local horizon coordinates.
Weight buffer	A buffer of weights for a given (partial) level in the detector hierarchy.

4.4 Beamforming simulation

Name	Description
Beams	Snapshot of beams for a given time sample and detector.
Buffer of beams	Buffer of beams for a given time sample and detector.

4.5 Metrics/Visualisation/Post-processing

Name	Description
Final outputs	As required by the user.