Simulation of EM-Wave Propagation from an Antenna Element

Maksims Abalenkovs  Luis Cebamanos  Dr Fumie Costen

School of Electrical and Electronic Engineering
University of Manchester

MANSKADS-3
Manchester, United Kingdom
SKADS Context

- SKADS Position: 2-PAD
- SKADS Activity:
  - numerical simulation of EM-wave propagation
  - various UWB antenna elements (geometric shape and material)
  - excitation source → antennas
- COTS → commercial software (MATLAB, CST Studio ++):
  - not enough precision, small-scale (up to 4 elements)
  - little parallelisation capabilities → in-house software
  - might be competitive in 5 years
Working procedure

- **Strong coupling:**
  - David Zhang $\rightarrow$ element geometry, shape
  - Ahmed El-Makadema $\rightarrow$ array geometry, placement

- **Input:** shape + placement

- pattern of EM-field distribution and coupling

- new shape + new placement

- ...
Antenna Element Design

Vivaldi Antenna – antenna best suited for transmission of broad spectrum signals.

Validation of a new antenna:

- Analysis of radiation pattern around the antenna

(a) Vivaldi Antenna Scheme

(b) Vivaldi Antenna Array
Perspective Antenna Designs

- (c) Comb-Line Vivaldi Antenna (CLVA)
- (d) Bunny Ear Comb-Line Antenna (BECA)
- (e) Octagon Rings Antenna (ORA)
Finite Difference Time Domain (FDTD)

Kane S. Yee, 1966, FDTD classical approach:

- Initial EM-field values
  - Maxwell’s Equations (ME)
  - system of hyperbolic PDE
  - unique solution

- Second order finite centred approximation to derivatives in ME

- Explicit algorithm
  - current values = function of previous values in time

- Simulation
  - CPU, memory, I/O-intensive

Figure: Yee Unit Cell
Frequency Dependent – FDTD (FD-FDTD)

- Reflects medium and material properties
- Permittivity $\epsilon$ and conductivity $\sigma$ are frequency dependent

Figure: Yee Unit Cell
Method Implementation

- Set antenna geometry and material for the FD-FDTD calculation
- FD-FDTD simulation software → Fortran, MPI
  - Workload division → z-axis
  - Data output → textual ASCII and binary formats

Real-world simulation:
- 5000 time steps × 16 CPUs × 250 MB data files ≈ 19.07 TB
- Single file production time: 3-58 min

Data post-processing → shell scripts, Fortran, MPI
  - Point plotting
  - Plane visualisation

CPU frequency and RAM size are vital

Conclusion → optimisation of data production and post-processing
Produced Data: Structure and Character

One file for each time step for each processor, e.g. 100 time steps × 2 processors = 200 files

File:
  - Name: `<timestep>_<rank>.<format>`
  - Structure:

<table>
<thead>
<tr>
<th>Spatial Coordinates</th>
<th>Field Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>y</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>189</td>
<td>467</td>
</tr>
</tbody>
</table>
Achievements

- Achievements up to date:
  - simulation of specific pre-defined antenna shape
    - normal Vivaldi antenna design, specified by David, 1 element
  - developing the functionality for automatic radio environment setting
    - antenna shape recognition
  - improving the simulation efficiency (load-balancing)
    - non-dedicated I/O-server → data collection and output
Current Research Activities

- improving the efficiency of data post-processing
- near- to far-field conversion
- development of subgridding technique for the EM-wave propagation problem
SKA Comparison

- international SKA R&D:
  - ASTRON, simulation package

- Approaches for data storage
  - text, binary, scientific format, database

- SKA-ready performance
  - 1 element vs \( 8 \times 8 \) element array

- Further challenges:
  - Computation and I/O speed-up
    - subgridding techniques, parallelisation, binary format
  - Data analysis speed-up
    - smarter and faster post-processing tools

- Publication
  - one conference paper submitted (HDF5)
  - journal and conference papers on subgridding expected
Discussion

- Questions
- Answers