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Efficient Large Electromagnetic Problem Solving by Hybrid TLM and Modal Approach on Grid Computing

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Abstract— This paper deals with the electromagnetic modeling of large and complex electrical structures by means of extensive parallel modeling based on grid computing (GC). The numerical modeling is based on a hybrid approach which combines Transmission Line Matrix (TLM) and the mode matching methods. The former is applied to homogeneous volumes while the latter is used to describe planar structures presented within the entire simulation domain. The results prove the benefits of the combined GC and hybrid approach to solve electrically large structures.

Index Terms— Transmission line matrix methods, mode matching methods, grid computing, high performance computing, large-scale systems.

I. INTRODUCTION

In the context of Information Communications Technology (ICT), the RF-designers, taking care of the link budget, are very often asked to model the presence of obstacles in the propagation channel.

Thereby, we are interested to bring out a numerical tool for the rigorous calculation of the electromagnetic scattering phenomena inside very large structures, such as tunnels, airplane cockpit and fuselage, containing large electrical size and complex patterns. Since a conventional full-wave electromagnetic simulation would require enormous amount of computational resources, a time-domain hybrid based on computing domain decomposition, according to diakoptics procedure, is proposed. A general view over the presented approach is shown in Fig. 1. As example, a large homogeneous waveguide is discretized upon TLM-Symmetrical Condensed Nodes (SCNs). The termination is modelled by modal approach as a multi-port surface impedance. Since the electromagnetic modeling of the complex structures considered in the present communication is not accessible by means of traditional computational resources, the resolution is based on a GC - Grid5000 French platform.

A numerical approach, based on an asymptotic code and the PoWer Balance (PWB) method, to evaluate the high frequency coupling in a complex oversized structure is described in [1]. A Grid-enabled time domain TLM system for full-wave analysis of complex electromagnetic structures is presented in [2]. In [3], the discontinuity

is discretized upon TLM and the homogeneous space is modelled by modal approach, given the low computing resources. In [4], the compromise is met by reducing the

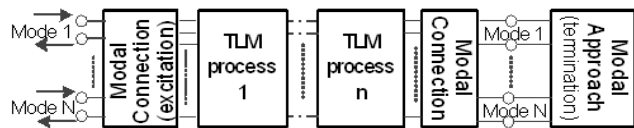


Fig. 1. Schematic view of the modeling approach.

TLM discretized space and setting the modal absorbing boundaries a few cells away from the discontinuities and considering only the first 4 modes.

In this paper, a hybrid numerical approach based on the coupling between TLM (for homogeneous volumes modeling) and mode-matching (for the planar structures modeling) is used and the results prove the benefits of the GC environment to solve electrically large structures.

II. NUMERICAL METHODS AND PARALLELIZATION

This approach (Fig. 1), is validated by the electromagnetic simulation of the TE_{10} mode propagation inside an homogeneous rectangular waveguide. The boundaries of the discretized domain are two reference planes called *Modal Connection*, representing a coupling matrix that converts the EM field from a TLM form, such as voltage pulses on transmission lines having the free space impedance, to a modal form, also in time domain with the same impedance, or vice versa. A Gaussian pulse excites the network of transmission lines on the excitation plan.

For a homogeneous load (match load), the amplitude of the reflected mode is calculated as the convolution product between the amplitude of the termination incident mode and the modal impulse response of the discontinuity, which is the reflection coefficient. A non-homogeneous load, as an inductive strip, excites an infinite number of $TE_{(2n+1)0}$ modes ($n=0,1,2,\dots$), propagating and evanescent, that couple each other. The multi-modal surface admittance matrix

TABLE I
Summary of Computed Structures

No.	Millions of TLM cells	X	Y	Z	t
1	145	345	173	2432	10000
2	36	172	86	2432	10000
3	290	345	173	4864	19610
4	580	345	173	9728	39061
5	194	400	200	2432	10000
6	1400	400	200	17500	70549

of the non-homogeneous load is given by :

$$[Y] = \frac{1}{\sum_{n=N+1}^{\infty} Z_n \langle \mathbf{g}_e | \mathbf{f}_n \rangle^2} [A][A]^T \quad (1)$$

$$[A]^T = [\langle \mathbf{g}_e | \mathbf{f}_1 \rangle \langle \mathbf{g}_e | \mathbf{f}_2 \rangle \cdots \langle \mathbf{g}_e | \mathbf{f}_N \rangle]$$

where, N is the number of propagating modes, the sum refers to all evanescent modes, Z_n is the impedance of the n^{th} evanescent mode, \mathbf{g}_e is an entire-domain trial function used in Galerkin's method for modeling the current density on the metallic strip, \mathbf{f}_n is the n^{th} basis function of the normal modal basis in the waveguide. The amplitude of the reflected modes is calculated similarly as in the case of homogeneous load.

In order to avoid a heavy TLM calculation, the discretized area is divided into subdomains that are calculated, in parallel, on different grid computing nodes that communicate between them to do the entire job. The interaction between processes is achieved by an exchange of messages using Message-Passing Interface (MPI). The speedup is a parameter used to evaluate the gain in terms of simulation time with N parallel computing processors compared to the same calculation performed on a single processor. The total simulation time equals the summation of the communication time and computing time of the longest task. The computational efficiency is the ratio between the speedup and the number of processes.

To estimate the computing time T_{cal} , we define a prediction model according to the algorithm of the application:

$$T_{cal} = c_1 + XYc_2 + tXYc_3 + tXYZc_4, \quad (2)$$

where X, Y, Z represent the number of TLM cells on the three spatial directions, t is the number of time steps and $c_i, i=1..4$, are the time coefficients corresponding to different blocks in the code of the hybrid approach implementation. The coefficients are determined using a linear programming formulation based on a history of experiments and an iterative approach. The maximum number of processes n required for computing a problem with the efficiency of at least e , is given by:

$$n \leq \frac{c_1 + XYc_2 + tXYc_3 + (1-e)tXYZc_4}{e(c_1 + XYc_2 + tXYc_3 + 4tT_{com})}, \quad (3)$$

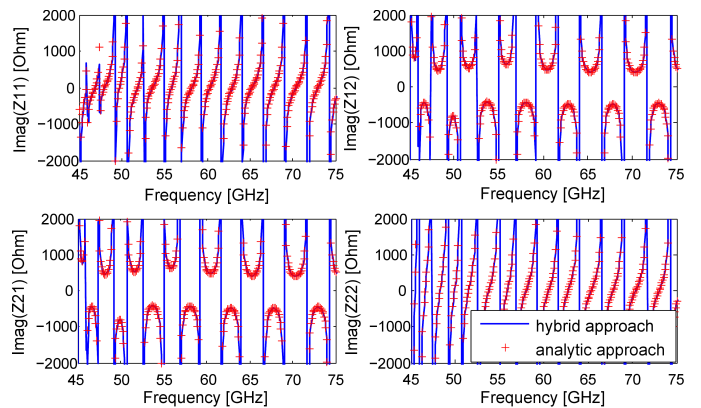


Fig. 2. Input impedance matrix elements (imaginary part)

where T_{com} is the communication time required for sending a message at each time step, 4 represents the case when a task sends and receives from the two neighbors.

III. RESULTS

The TLM/Modal Approach Hybrid was validated from the computation of the input Z-parameters - Fig. 2, of a length of lossless waveguide (10 mm width, 5 mm height and 25 mm length) terminated by a metallic strip (1mm width) printed on a perfectly magnetic wall and modelled by (1). The TLM mesh step is of 0.2mm. We consider the excitation of the two first lower-order TE propagating modes and 300 evanescent modes. The computed 2x2 input impedance matrix is in excellent agreement with one derived from analytical approach based on Integral Equation Formulation [5]. Here, the index 1 denotes the TE_{10} mode while the index 2 designates the TE_{30} mode.

In order to evaluate the performance of our application on a large scale parallel system in terms of computing time, simulations have been performed on cluster and on grid environment using different rectangular waveguide structures outlined in Table I. The simulation time curves are presented on a logarithmic scale and show the scalability of our application as increasing the number of processes.

Fig. 3 displays the simulation times on cluster versus the number of processes, for various numbers of TLM cells, when the waveguide is matched at its termination. As we increase the number of processes, the simulation time becomes smaller. The simulation time of the first structure in one process is about 46 hours, but using 184 processes, it takes only 16 minutes. The speedup is 164 and the efficiency is 89%. The computing and communication times of the second structure are shorter, due to the dimensions of such structure. The speedup value is 181 while the efficiency, 98%. Time limitations and memory resources constraints do not allow us exploring the simulation times for the structures 3 and 4 with a small number of processes. The communication time for

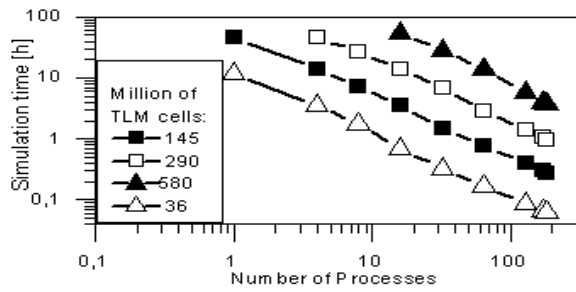


Fig. 3. Simulation times on cluster for different TLM cell numbers.

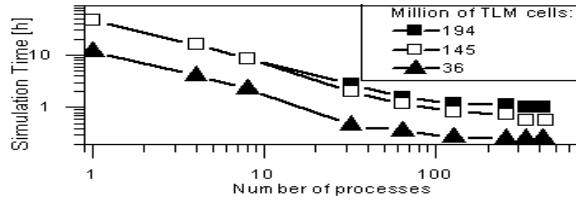


Fig. 4. Simulation times on grid for different TLM cell numbers.

these structures is still constant compared to the first one, but the computing time is much larger, according to the dimensions. The computing time increases, almost linearly, when the numbers of TLM cells and time steps increase. The ratio between the number of TLM cells of the first and second structures equals the ratio of their computing times: this ratio is found to be 4 because the height and width of the first structure are 2 times larger than ones of the second structure. The same is available for the structures 3 and 4, because of the length and the number of time steps parameters.

The Fig. 4 displays the simulation times on grid versus the number of processes, for various numbers of TLM cells, when the waveguide is matched at its termination. The simulation times are higher than those obtained on cluster, for the same structures, because the communication times are larger due to the informatics network latency. The speedup and efficiency values are also smaller. The first structure is simulated on 128 processes on cluster in 0.39 hours and on grid in 0.83 hours, with a speedup value of 55 and an efficiency of 43%. The predicted value given by (2) is 0.91 hours and the error, 10%. However, as we increase the number of processes, the efficiency becomes smaller. For an important number of processes, the simulation time tends to be invariant. Consequently, in order to launch efficient simulations we have to match the size of the structure with the number of resources used.

Fig. 5 shows the simulation times on grid versus the number of processes, for various numbers of TLM cells, when the waveguide is loaded by the metallic strip. Simulation times are also given by considering various numbers of modes generated during the electromagnetic scattering

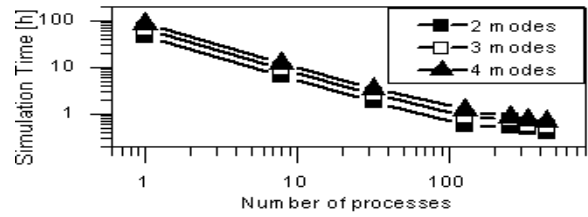


Fig. 5. Simulation times on grid for different number of modes.

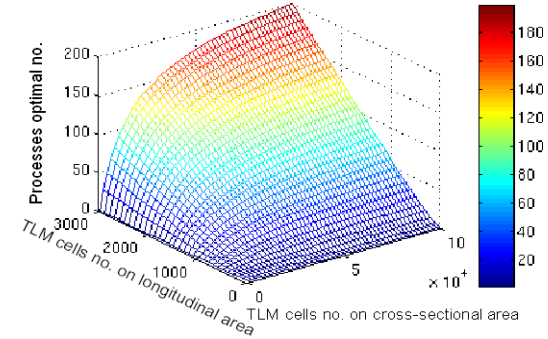


Fig. 6. Speedup for different TLM cell numbers simulated on a cluster.

of the incident field by the strip. As the number of modes increases, the simulation time increases too, since there is more information to be processed and exchanged.

In order to prove the real benefits of the grid environment, we have simulated the sixth structure, a supersized rectangular matched waveguide that would require 135 GB of RAM memory and more than 130 days of simulation time on a single process. On grid, we have computed this structure in 14 hours using 318 processes. The memory resources required on each process is about 0.5 GB.

Fig. 6 shows how many processes are necessary for calculation of a problem with the efficiency of 40%, according to the prediction model given by (3). For the first structure, 143 processes are estimated, with an error of 10%, compared to the measured value.

IV. CONCLUSION

This paper presents an original approach which combines hybrid CEM technique with grid computing in order to speed up the modeling of large electromagnetic problems. The study has highlighted the role of parallelization scheme, cluster versus grid, with respect to the size of the problem and its repartition. The analysis of the simulation performances has allowed to extract practical rules for the estimation of the required resources for a given problem.

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