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A New Computational Parallel Model Applied in 3D Ray-Tracing Techniques for Radio-Propagation Prediction

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***Abstract* — A computational parallel model based on 3D ray-tracing for wireless channel modeling is presented. This approach considers that the main tasks in a 3D ray-tracing technique can be evaluated in an independent and/or parallel way. The workload distribution among the participant nodes of the parallel architecture (cluster of PC's) is performed through a random assignment of the initial rays and the field points for them. Simulations are realized in order to validate and evaluate the performance of the proposed model.**

***Index Terms* — Parallel computing, cluster of PC's, 3D ray-tracing, radio propagation.**

I. INTRODUCTION

The great growth in mobile communications needs fast and accurate prediction of radio wave propagation for system deployment. Such predictions can represent an important role in determining network parameters including coverage, transmitted-data rates, optimal base station locations, and antenna patterns. In this context, ray-tracing based radio propagation prediction models have shown promise, mainly in modern radio wave propagation environments [1]-[5]. Although ray-tracing approaches are very useful in the design, analysis, and deployment of wireless networks, it has been recognized that these models are computationally very expensive and require a considerable amount of processing time to attain reasonable accurate prediction results [2],[4].

Several approaches have been proposed to shorten the computation time for ray-tracing prediction models [2],[5]-[6]. However, all these approaches have a common trade-off: they trade prediction accuracy for processing time. A natural way to overcome the above trade-off is to use the parallel and/or distributed computing techniques to speed up computations, while keeping the accuracy intact [4].

Recently, some parallel computational strategies have been proposed in order to reduce the required computational time without affecting the prediction accuracy requirements [4], [7]. In [4], the strategy of parallelization proposed is very complex and hard to implement. This approach was applied in a 2D ray-tracing model, being also tested in a kind of 3D ray-tracing that have some restrictions in the diffraction mechanism (Vertical Plane model) [2]. Both model versions are very dependent on the ray-tracing algorithm (SBR) implementation. In [7], the parallel computational strategy was applied only to the ray-processing stage. The parallel model proposed in this paper is schematized to the overall process, being very simple to implement computationally and can be applied easily in full 3D ray-tracing channel model without any diffraction restrictions (if desired). This new approach allows to reduce or even eliminate many restrictions early imposed in ray-tracing models by practice reasons (high computational cost), favoring to improve the accuracy and a possibility of incorporating new propagation mechanisms, such as diffuse scattering [4],[8] and propagation in forest environment [9]. Additionally, it allows analyzing more complex structures (scenes).

In this work the parallel model was developed over a ray-tracing algorithm based on SBR approach, because this technique is already intrinsically parallel, due to the rays that are launched by the transmitting antenna are independent from each other, allowing the SBR code to be directly applicable in the parallel programming paradigm.

This paper is organized as follows. Section II outlines the parallel computational model proposed. Section III presents some simulations in order to validate the parallel ray-tracing model. Conclusions are made in Section IV.

II. PARALLEL MODEL

The proposed parallel model for SBR algorithms was schematized in three stages, according to shown in Fig. 1: Pre-Processing, Processing of Rays and Post-Processing ones. The basic idea of this model is that after a data pre-processing phase, the total workload can be divided among the nodes that compose parallel architecture (cluster of PC's), through a random distribution among them, of the initial rays to be launched and field points (reception points) to be evaluated. The efficiency of this approach is guaranteed by the independence of the involved entities (rays and field points) and by the form of the employed distribution (random). The random approach tends to be more efficient in the load-balancing issue as larger the total number of emitted rays and the field points are, exactly the case that most justifies the use of parallel computing [7].

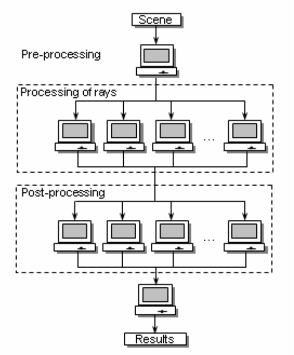

Fig. 1. Model of parallelization for the 3D SBR algorithm.

Through this strategy, the processing load of a homogeneous cluster is balanced through the distribution of the equal number of initial rays and field points (randomly chosen) for each node. For a heterogeneous cluster, the rays and field points number of each node must be proportional to its processing capacity. Evidently, discovering the processing capacity of computers may be done previously, being it even possible to estimate it based on characteristics of hardware and software.

In the context of the parallel and distributed computing, the proposed model can be inserted in the SPMD (Single Program Multiple Data) paradigm [11], because for a specific scene, each node performs the same SBR program over distinct data (initial rays and field points). The initial communication strategy among the nodes in order to supply such input data through the network could be implemented, for instance, using MPI (Message Passing Interface) standard communication library [12]. However, a simplest strategy was implemented, where customized input files (rays file and table file) for each node are previously created and distributed through a network file system, as the NFS (Network File System), used in UNIX systems [13]. After the generation and loading of the input files (Pre-Processing stage), each node will perform the processing of the rays randomly defined for it (rays file). When the rays simulation is over, each isolated process (node) can send their results through the network using MPI, or make available in the form of local file shared through the NFS (in this paper, the NFS strategy was adopted). The processing of rays result is a report of all the rays that reached the field points defined in the scene. The reception and organization of results provided by each node consist in the post-processing stage. In such one, each node will be responsible for the prediction results evaluation (electric field, received power, arrival angle for each ray, etc) and generation of the output files with such information just for the field points randomly assigned in its table file.

III. RESULTS

In order to validate the proposed parallel model, it was considered as study of case an outdoor scene in Ottawa city (Canada). The scene considered is within the 1000 m x 600 m area according to shown in Fig. 2. The transmitter was located in the position labeled as “Tx” at a height of 8.5 m and the field points were placed along the Laurier street at a height of 3.65 m (Fig. 2). All antennas were vertically polarized. As ray-launching algorithm it was considered the full 3D SBR model together with the UTD (Uniform Theory of Diffraction), both presented in [10]. The fields were calculated at a frequency of 910 MHz considering raypaths up to 4 reflections and 2 diffractions. The effects of paths that diffract over the rooftops were neglected due to the transmitting and receiving antennas were located right below the building heights (according to information reported in [14], and in these situations, such paths are usually of negligible power compared to other paths that propagate among the buildings [9]. Although this supposition, the proposed full SBR 3D model was still performed. The building data for the calculations were obtained directly from the maps in [15] which contained the footprints of the buildings. In [14] no information about the terrain was reported, being assumed a flat terrain in all calculations. Following the suggestion in [15], it was set the relative permittivity of all the building walls to 6, and the conductivity to 0.5 S/m. A relative permittivity of 15 and a conductivity of 0.05 S/m were used for the ground.

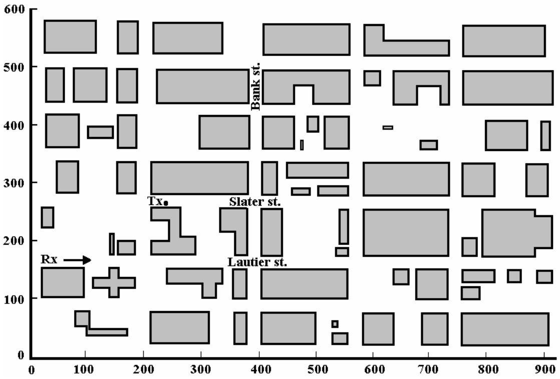

Fig. 2. Map of Ottawa.

The simulations were carried out under a cluster consisting of four (04) nodes with Pentium IV HT 3.2 GHz processors and main memory of 1.0 GB. All computational code was implemented using C++ object oriented software language. The used compiler was the g++ version 3.3.5 20050117 (pre-release) under a GNU/Linux operating system. The master/slave paradigm was used in order to implement the Unix network file system (NFS - Network File System). Customized input files (setup file and rays file) to each process (node) were previously constructed. All those files jointly with the scene file were distributed on the network through the Unix NFS. To evaluate the performance of the proposed parallel model, some interesting metrics were adopted, as speedup (S_n), workload expansion ratio (W_n), resource utilization (U_n) and (E_n) [4],[11].

Table I shows the load-balancing (number of processed rays / processing time) by each the nodes in several cluster configurations for 655362 rays launched by the source, presenting a maximum processed rays difference related to average value (number of processed rays in serial mode/ number of nodes) around 1.12%. Although each node processing a different number of rays, the largest obtained processing time to each cluster configuration was always below to expected ideal average time (serial execution time / number of nodes).

Table II shows the performance evaluation metrics applied in the proposed parallel model. According to shown it, the workload expansion ratio obtained in all cases was always below ideal case (W_n = 1.0), decreasing its value as the number of nodes increases. It features that it is possible expecting a good scalability of the model. The resource utilization rates obtained are very close to the ideal utilization rate indicating that all nodes spend little time in idle status. The efficiency of the proposed model improved with the increase of the number of nodes, presenting values above ideal efficiency in all considered cluster configurations.

TABLE I
LOAD-BALANCING (PROCESSED RAYS / PROCESSING TIME)

Node	Serial	*2-nodes Cluster*	*3-nodes Cluster*	*4-nodes Cluster*
0	12431017/ 11226.838s	62325589 / 5304.846 s	41107549 / 3380.315 s	30881464 / 2439.285 s
1	-	61984584 / 5329.656 s	41899821 / 3390.986 s	31214554 / 2431.279 s
2	-	-	41302803 / 3379.247 s	31154001 / 2445.582 s
3	-	-	-	31060154 / 2432.800 s

TABLE II
PERFORMANCE EVALUATION METRICS

n-node *Cluster*	S_n	W_n	U_n	E_n [%]
1	1.000	1.000	1.000	100.0
2	2.106	0.947	0.998	105.3
3	3.310	0.904	0.998	110.3
4	4.591	0.868	0.996	114.7

As the unique difference among the processes of each node is the data volume of the input files, these performance evaluation results show that the processing time of the tasks performed by each node presents a reduction rate above linear related to reduction rate of the handled data volume, mainly in procedures related to the scanning of the used data structures and memory allocating. It implies that if the SBR algorithm is partitioned (i.e, distribution of initial rays and field points among several input files) and it is structured to be performed of serial way, nevertheless it will be more attractive than being performed in serial way with no partition. The scalability of the model is naturally guaranteed due to independence of the initial rays and field points. However, this super-efficiency presented by the model only will be maintained while the speedup gain obtained in the ray-processing stage of each node in a certain cluster configuration is large enough and overcoming the speedup losses generated in the other procedures. This requirement can be achieved increasing the complexity of the scene and/or increasing the resolution of the initial rays to be launched. Besides improving the efficiency model, the increase of these entities (scene complexity and ray resolution) makes the SBR algorithm more accurate.

In order to give some indication of the prediction quality provided by the 3D SBR model along Laurier street, the predicted propagation path loss was compared to measurements reported in [14]. The results are shown in Fig.3.

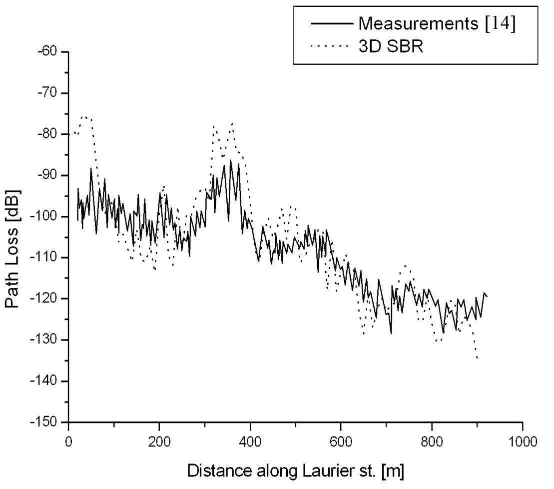

Fig. 3. Path Loss along Laurier St.

The agreement is good considering the quality of the building data and the lack of information on building materials. It is worthwhile to comment on one of the more notable difference with the measurements. The error at the beginning of Laurier St. is surprising because there is nearly a line-of-sight path from the transmitter. An explanation is that probably there are some trees or other obstructions that scatter the signal in such area.

IV. CONCLUSIONS

In this paper, it was presented a computational parallel model applied in 3D ray-tracing techniques for radio-propagation prediction. Such approach is based on independence of the tasks in the SBR ray-tracing algorithm in order to efficiently distribute the total workload (by a random distribution of the initial rays and the field points) among the nodes of the parallel architecture (cluster of PC's). Several issues related to practical implementation of the parallel model were described. Some simulation results have been presented in order to demonstrate the efficiency of the proposed parallel model.

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REFERENCES

[1] J. Richter, M.O. Al-Nuaimi, and L.P. Ivrissimtzis, “Optimization of radio coverage in urban microcells using a UTD based ray-tracing model,” Antennas and Propagation, IEE Proceedings, vol. 151, Issue: 3, 21 June 2004, pp. 187 - 192.

[2] Z. Chen, A. Delis, and H. L. Bertoni, “Building footprint simplification techniques and their effects on radio propagation predictions,” Comput. J., 47 (1) (January 2004) 103-133.

[3] R. A. Kipp, and M.C. Miller, “Shooting-and-bouncing ray method for 3D indoor wireless propagation in WLAN applications,” Antennas and Propagation Society Symposium, 2004, vol. 2, 20-25 June 2004, pp 1639 - 1642.

[4] Z. Chen, A. Delis, and H. L. Bertoni, “Radio-wave propagation predictions using ray-tracing techniques on a network of workstations (NOW),” J. Parallel Distrib. Comput., 64 (2004) 1127-1156.

[5] T. Kurner, and A. Méier, “Prediction of outdoor and outdoor-to-indoor coverage in urban areas at 1.8 GHz,” IEEE J. Selected Areas Comm., 20 (3) (April 2002) 496-506.

[6] Z. Chen, H. L. Bertoni, and A. Delis, “Progressive and aproximate techniques in ray-tracing based radio wave propagation prediction models,” IEEE Trans. Antennas Propagation, 52 (1) (2004) 240-251.

[7] A. M. Cavalcante, M. J. Sousa, C. S. Sales Jr, J. C. W. A. Costa, C. R. L. Francês, and G. P. S. Cavalcante, “Computational parallelization strategy applied in full 3D ray-tracing wireless channel modeling,” International Microwave and Optoelectronic Conference - IMOC’2005, Brasília - DF, Brazil, July 2005.

[8] V. Degli-Esposti, D. Guiducci, A. de’Marsi, P. Azzi, and F. Fuschini, “An advanced field prediction model including diffuse scattering,” IEEE Transactions on Antennas and Propagation, vol. 52, Issue: 7, July 2004, pp. 1717 - 1728.

[9] H. L. Bertoni, Radio propagation for modern wireless systems, Prentice-Hall - Wireless Communications Series, 2000.

[10] M. F. Cátedra, and J. P. Arriaga, Cell Planning for Wireless Communications, Artech House - Mobile Communications Series, 1999.

[11] Y. Foster, K. Kennedy, J. Dongarra, and G. Fox, Sourcebook of Parallel Computing, Morgan Kaufmman Pub, 2002.

[12] W. Gropp, E. Lusk, A. Skjellum, and R. Thakur, Using MPI: Portable Parallel Programming with the Message Passing Interface (Scientific and Engineering Computation), 2nd Edition, MIT Press, 1999.

[13] A. S. Tanenbaum, Computer Networks, 4th Ed.,Prentice Hall, 2002.

[14] J. H. Whitteker, “Measurements of path loss at 910 MHz for proposed microcell urban mobile systems,” IEEE Trans. Veh. Technol., vol. 37, no. 3, pp. 125-129, Aug. 1988.

[15] S. Y. Tan and H. S. Tan, “Propagation model for microcellular communications applied to path loss measurements in Ottawa city streets,” IEEE Trans. Veh. Technol., vol. 44, no. 2, pp. 313-317, Aug. 1995