Scalable and Efficient Parallel and Distributed Simulation of Complex, Dynamic and Mobile Systems

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joint work with

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Presentation outline

- Simulation of large scale and complex models
- The ARTìS software architecture
- Simulation of massive, complex and dynamic systems
  - High Performance Computing (HPC)
- The CR-PADS logical structure and implementation
- Further optimizations for PADS:
  - Hyper-Threading / Multi-Core support
  - Data Marshalling
- Conclusions and future work

Simulation of large scale and complex models

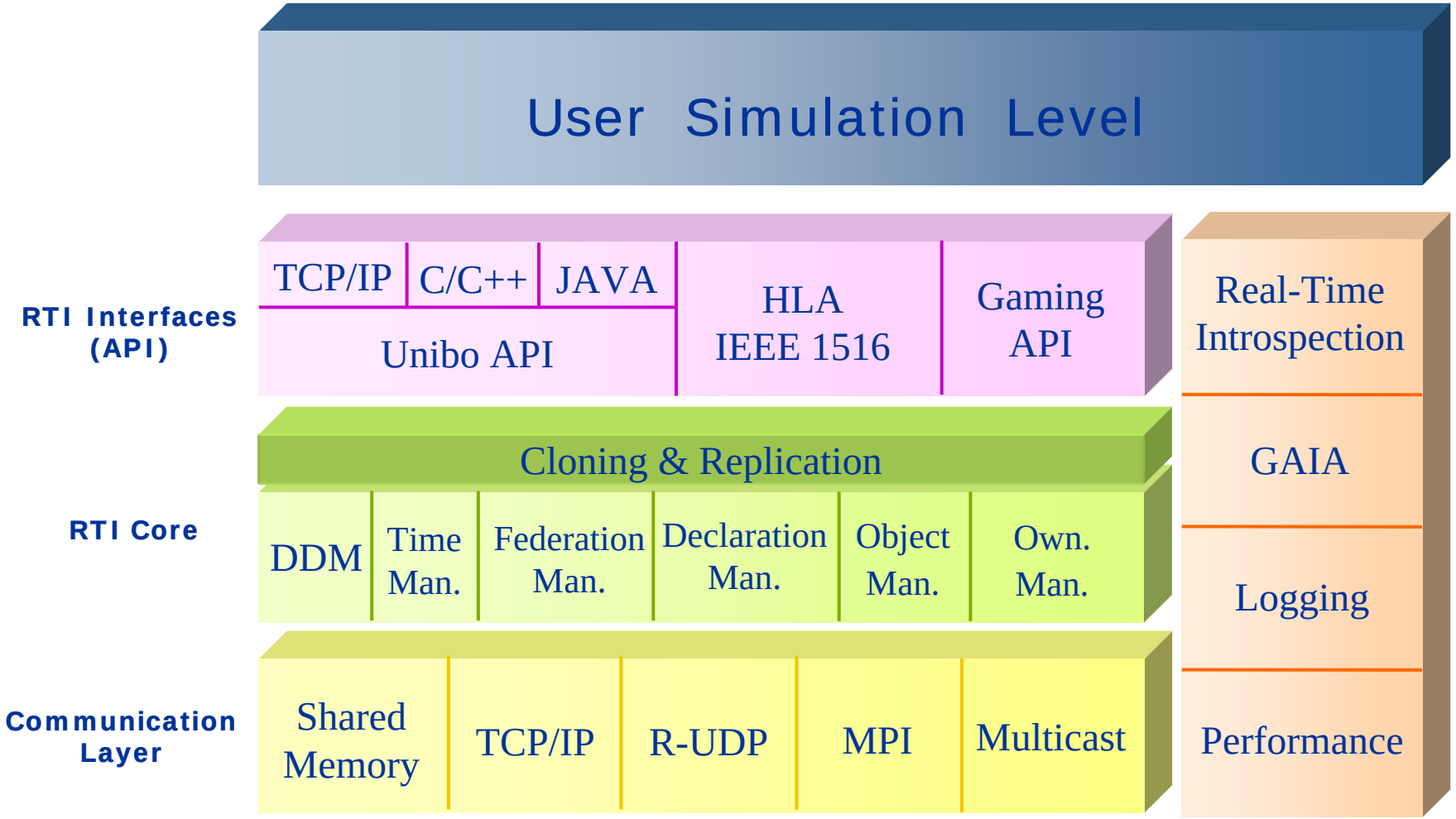
- Simulation models currently of interest may include a potentially huge number of simulated objects
- Large scale and complex simulation models may be unpractical to simulate on a single-processor execution unit: **huge memory requirements**, large amount of **time** required to complete the simulation runs
- The **memory** bottleneck reduction, **scalability** and **speed-up** can be achieved by using *parallel/distributed models and execution architectures*
- Goal: to **increase the simulation speed**, reduce the **Wall Clock Time (WCT)** required to complete the simulation runs

The ARTìS software architecture

Advanced RTI System (ARTìS), parallel and distributed simulation middleware:

- Model components' heterogeneity, distribution and reuse
- Adaptive evaluation of the communication bottlenecks and dynamic adaptation of the inter-process communication layer
- Generic Adaptive Interaction Architecture (GAIA): model components' migration mechanism to support load balancing and data distribution management (DDM) overhead reduction
- Support for High Performance Computing clusters (HPC): scalability evaluation of the middleware
- Concurrent Replication of Parallel and Distributed Simulation (CR-PADS) and cloning

ARTìS: logical architecture



Performance evaluation: Ad-Hoc wireless network model

Simulated model:

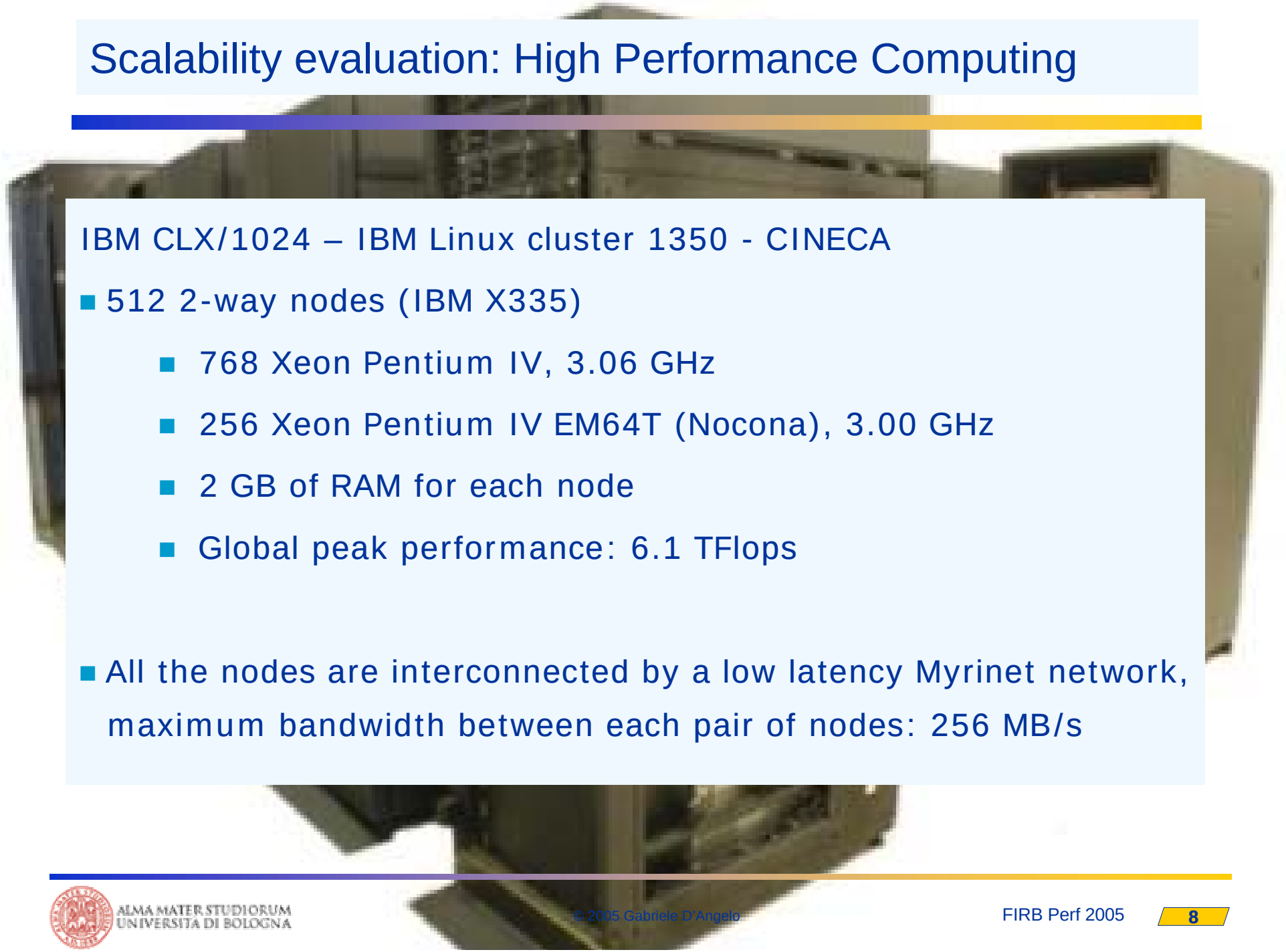
- A set of **Simulated Mobile Hosts** (SMHs)
- Mobility model:
  - Random Mobility Motion model (RMM)
  - uncorrelated SMHs' mobility
- Traffic model:
  - ping messages (CBR) by every SMH to all neighbors within the wireless communication range (250 m)
- Propagation model
  - open space (neighbor-SMHs within detection range)

Ad-Hoc network model characterization

Computation and communication issues:

- The **computation** required for each SMH per time-step is in the order of **O(#SMH^2)**: to determine the neighbor set
- The **communication** required among SMHs is in the order of **O(K*#SMH)** per time-step, with K defined as a constant value based on SMHs density (assumed as constant)

Scalability evaluation: High Performance Computing



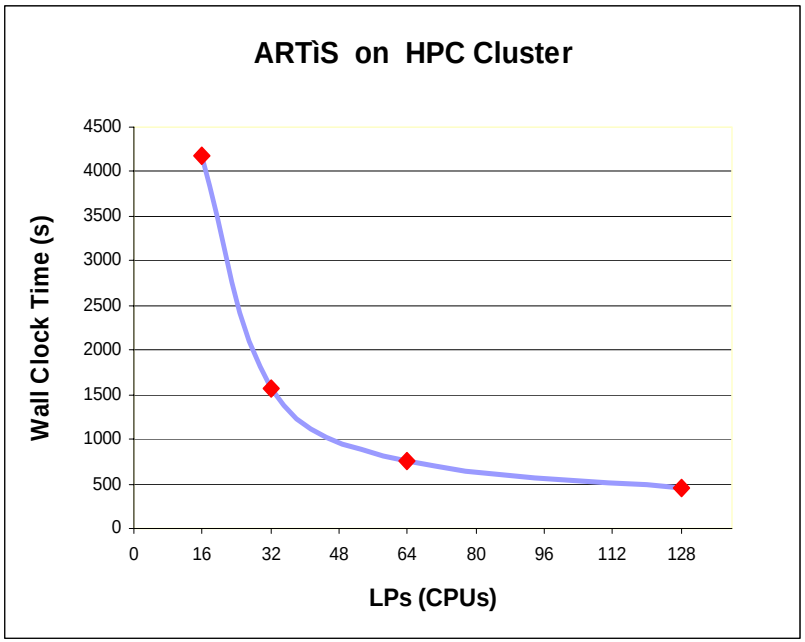
IBM CLX/1024 – IBM Linux cluster 1350 - CINECA

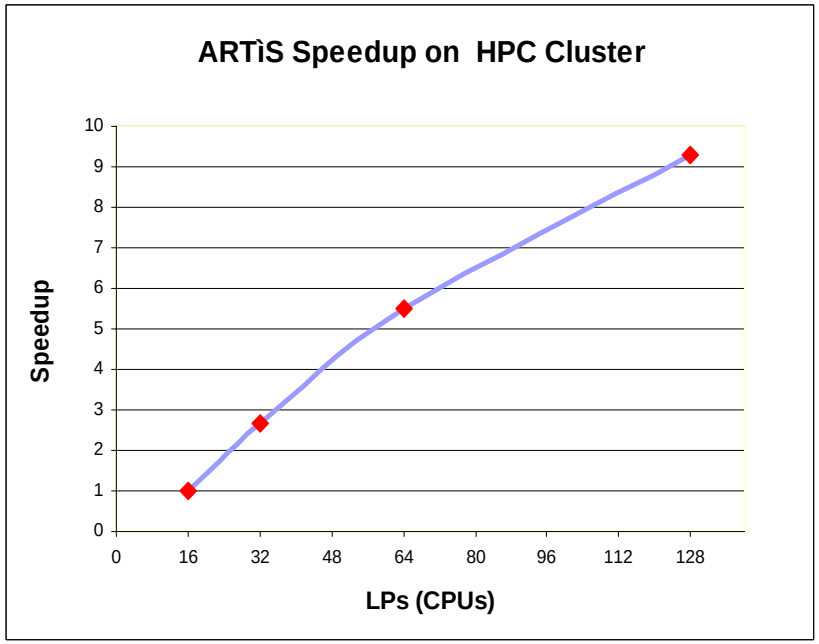
- 512 2-way nodes (IBM X335)
  - 768 Xeon Pentium IV, 3.06 GHz
  - 256 Xeon Pentium IV EM64T (Nocona), 3.00 GHz
  - 2 GB of RAM for each node
  - Global peak performance: 6.1 TFlops

- All the nodes are interconnected by a low latency Myrinet network, maximum bandwidth between each pair of nodes: 256 MB/s

ARTìS on High Performance Computing (HPC)

1 million of Simulated Mobile Hosts (*1 Timestep of simulated time*)





Typical PDES + PADS problems

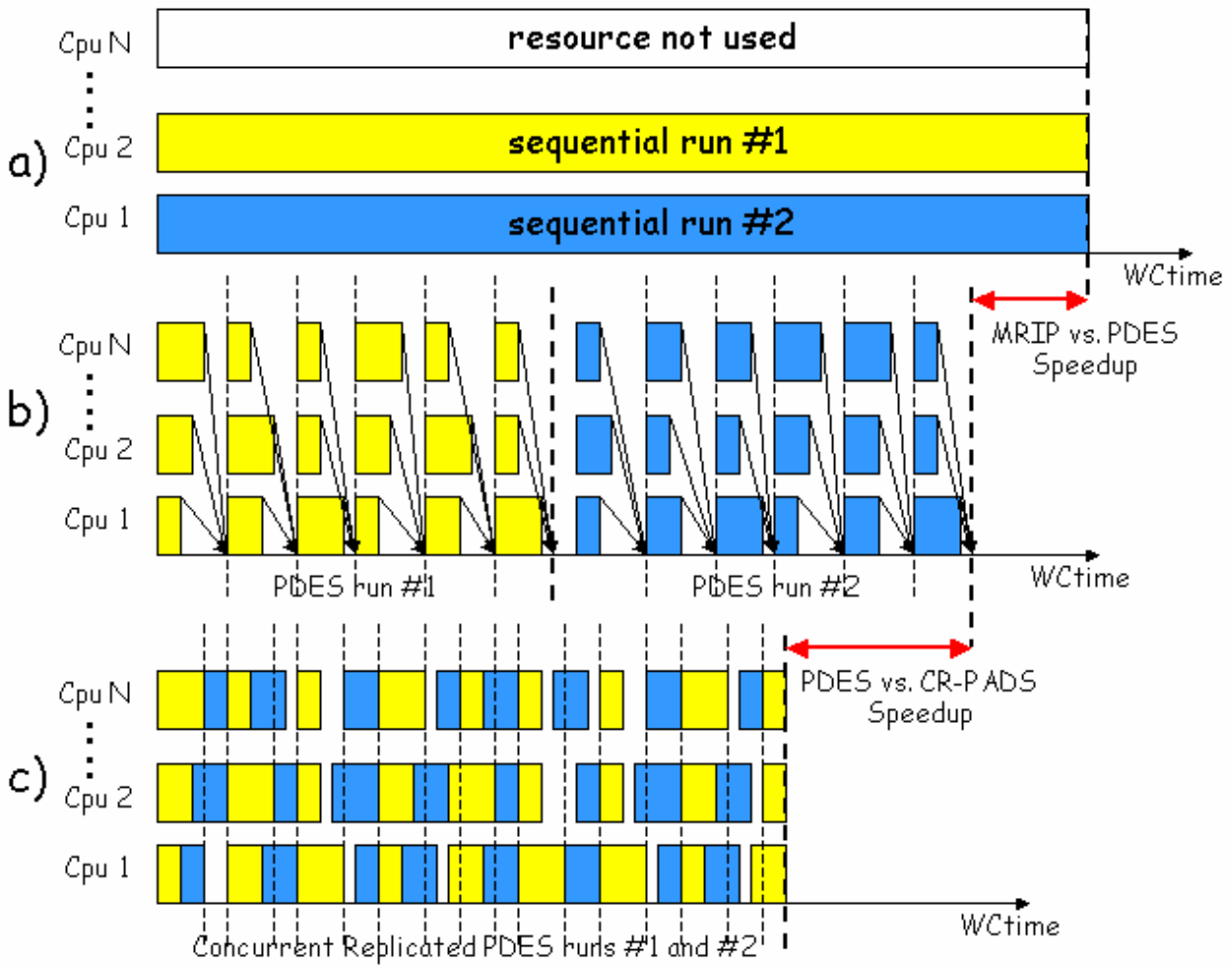
- A typical simulation-based investigation requires to collect many independent observations for a correct and significant statistical analysis of results
- In the PADS environment **frequent synchronizations** are required among the model components
- Each simulation component swings between **computation and communication phases**
- The whole set of processes advance with the **speed of the slowest**
- Some phases (usually before the synchronization barriers) could be communication intensive and may led to network congestions (further increasing the communication overhead)

Our idea is to obtain a more **fluent computation and communication** by concurrently merging the execution of more PADS replicas

Concurrent Replication of PADS (CR-PADS)

- The CR-PADS is a mechanism that **duplicates** the logical processes (LPs) of PADS runs starting from the **initialization phase** of every single run
- Every replica is based on the same model definition, realizes an **independent execution** based on local initial parameters, variable factors of the analysis and different random number generator seeds
- CR-PADS is absolutely **different** from **simulation cloning**
- The risk of this mechanism is to spend too much time in switching processes' execution, in the creation of communication bottlenecks and live-locks, resulting in trashing effects

The CR-PADS approach



Simulation test-beds

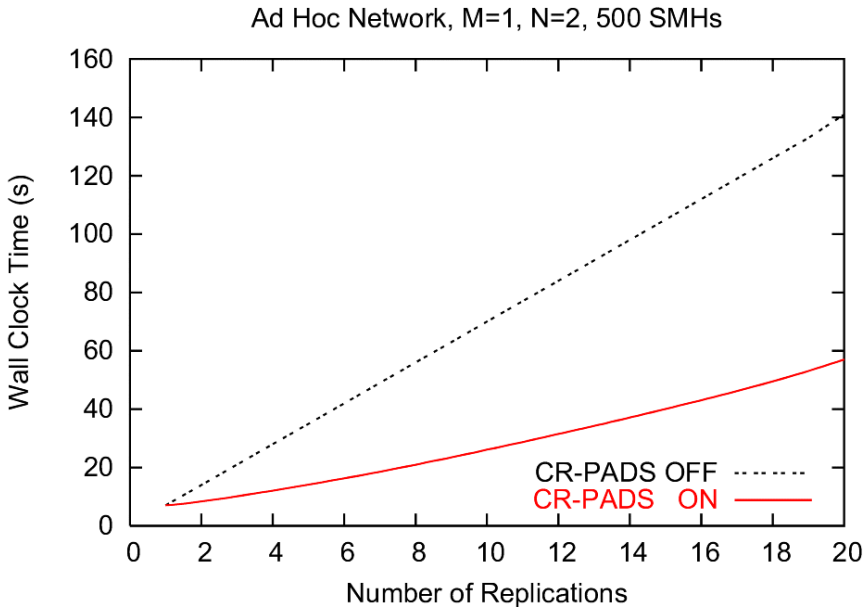
Two different environments:

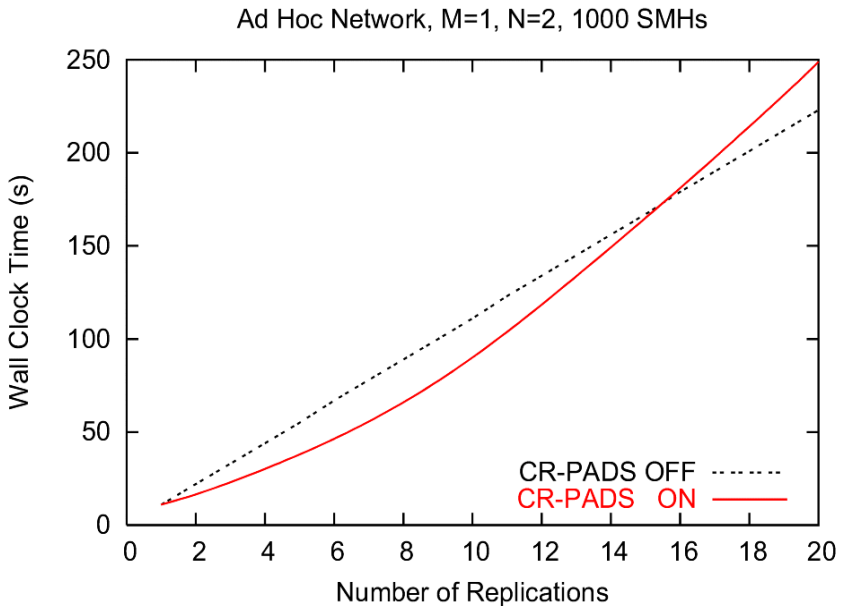
- **Parallel**: a single Physical Execution Unit (PEU)
- **Distributed**: a set of PEU, interconnected by a Fast Ethernet LAN (100 Mb/sec)
- Each PEU is an Intel Dual Xeon Pentium IV 2800 MHz, with 3 GB RAM, Debian GNU/Linux OS with kernel version 2.6.x
- Conservative time-stepped simulation: 300 time-steps

Parallel environment: 500 and 1000 SMHs

M = # PEU

N = # LP

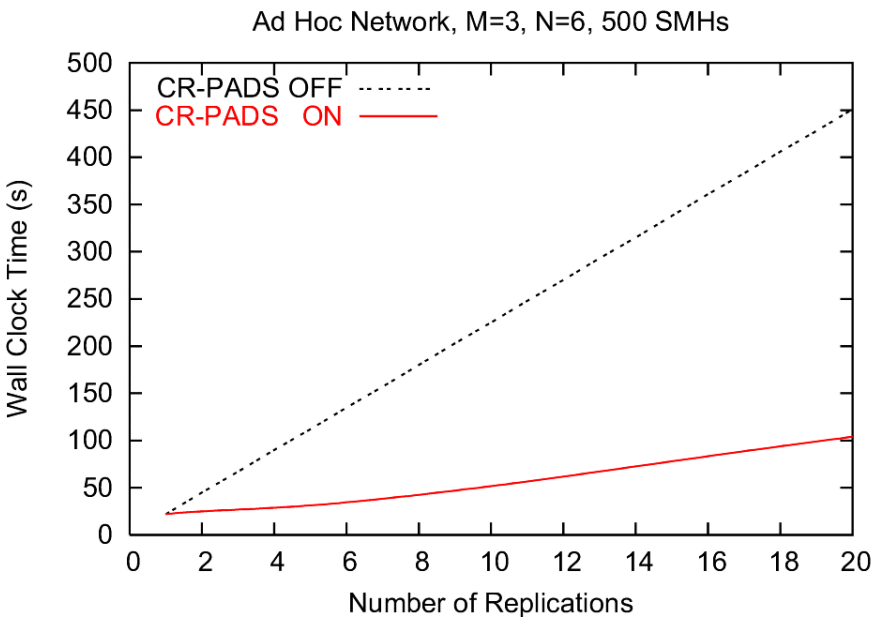


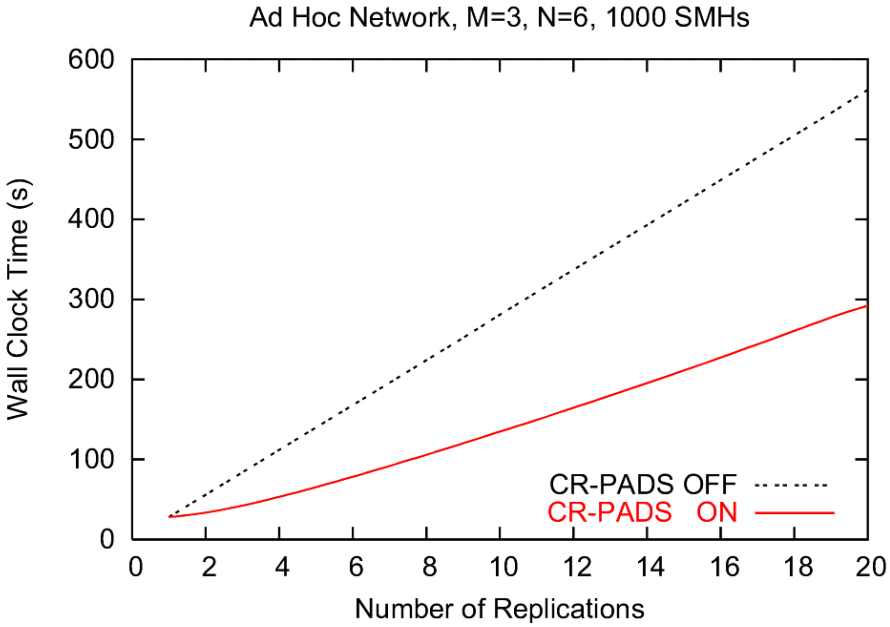


Distributed environment: 500 and 1000 SMHs

M = #PEU

N = #LP

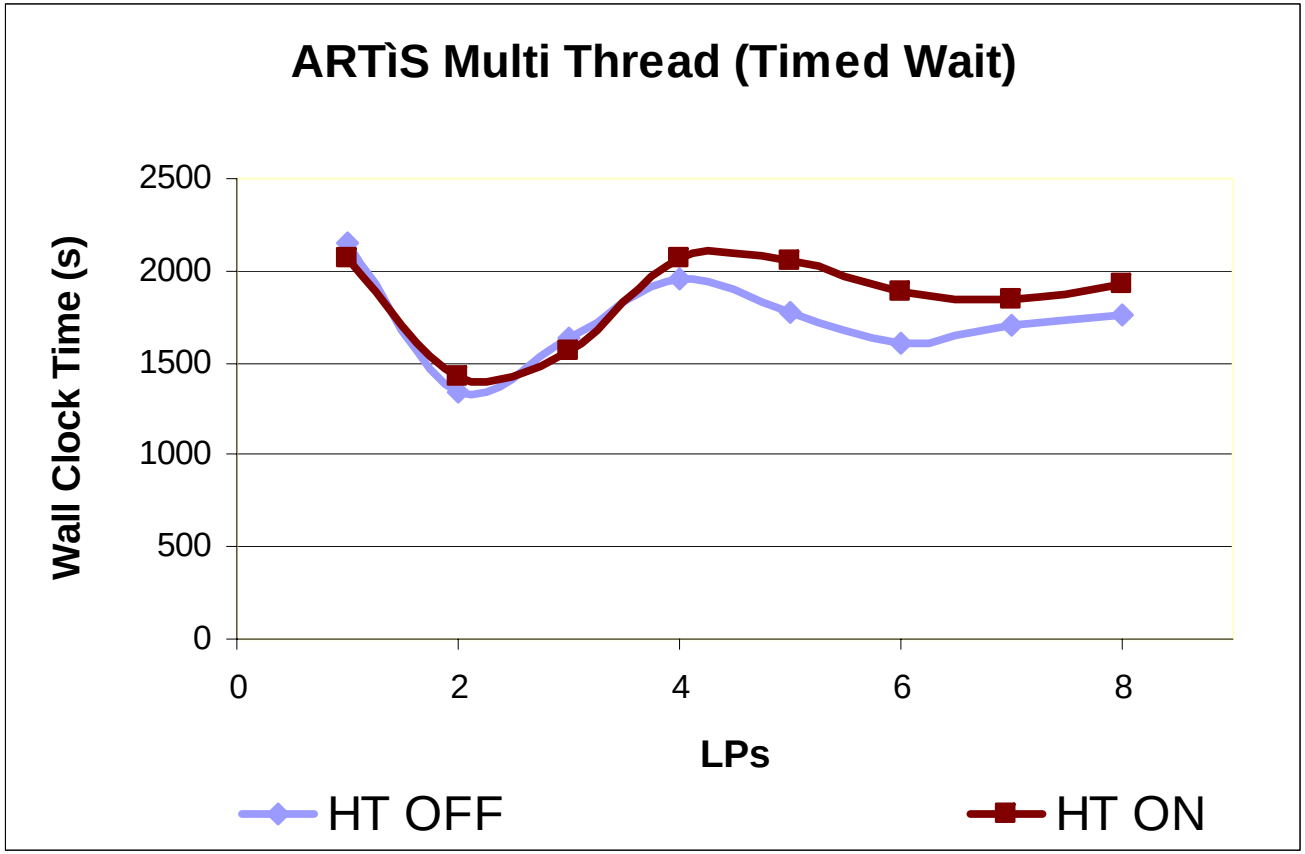




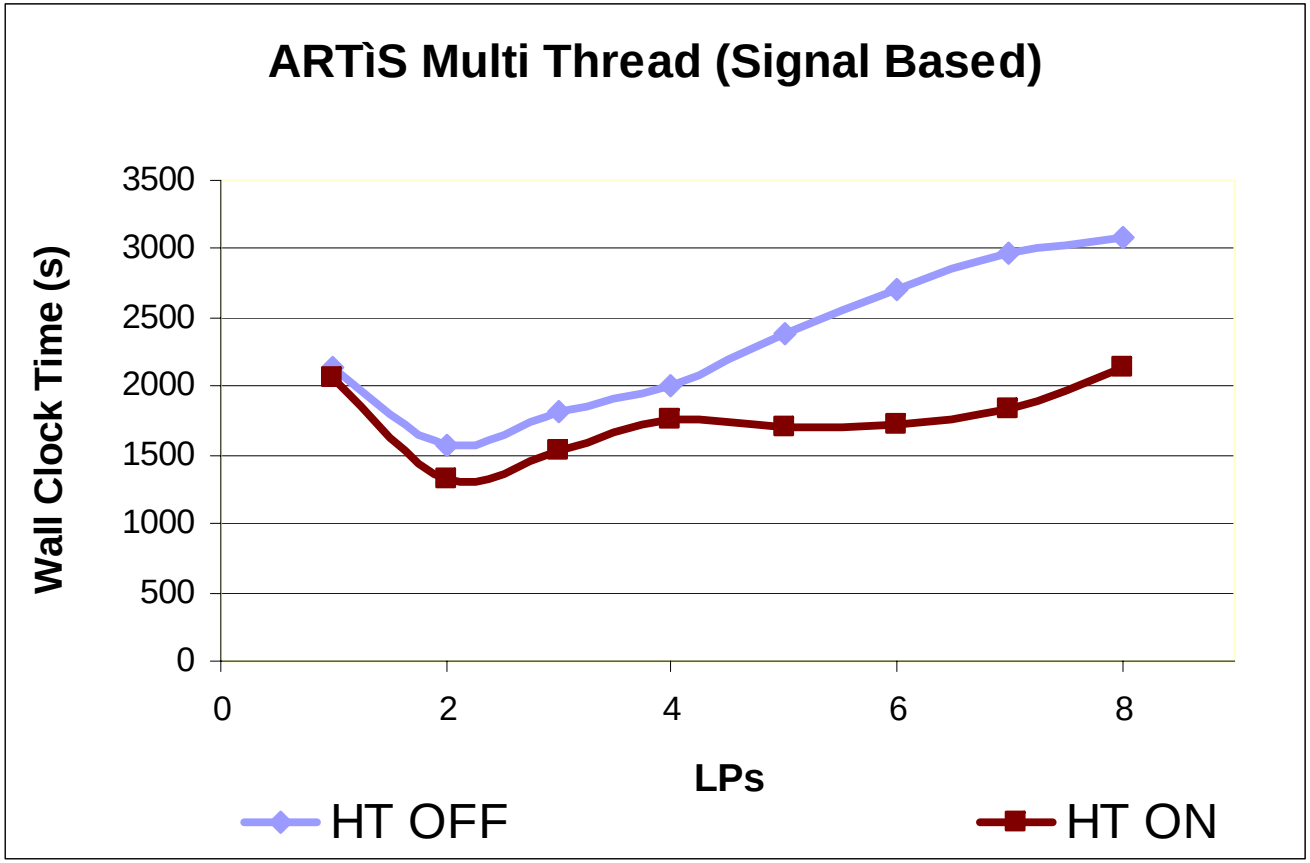
Optimizations: Hyper-Threading (HT) support

- The Hyper-Threading technology (HT) is a **new processor architecture** recently introduced by Intel
- The HT technology duplicates the high level portion of the architecture state on each logical processor, while logical processors share a subset of the physical processor execution resources
- HT technology makes a **single physical processor appearing as two logical processors** at the user level: one physical execution resource (CPU) is **shared** between two logical processors
- The influence of HT technology on PADS architectures and frameworks has not been investigated in detail

ARTìS and Hyper-Threading



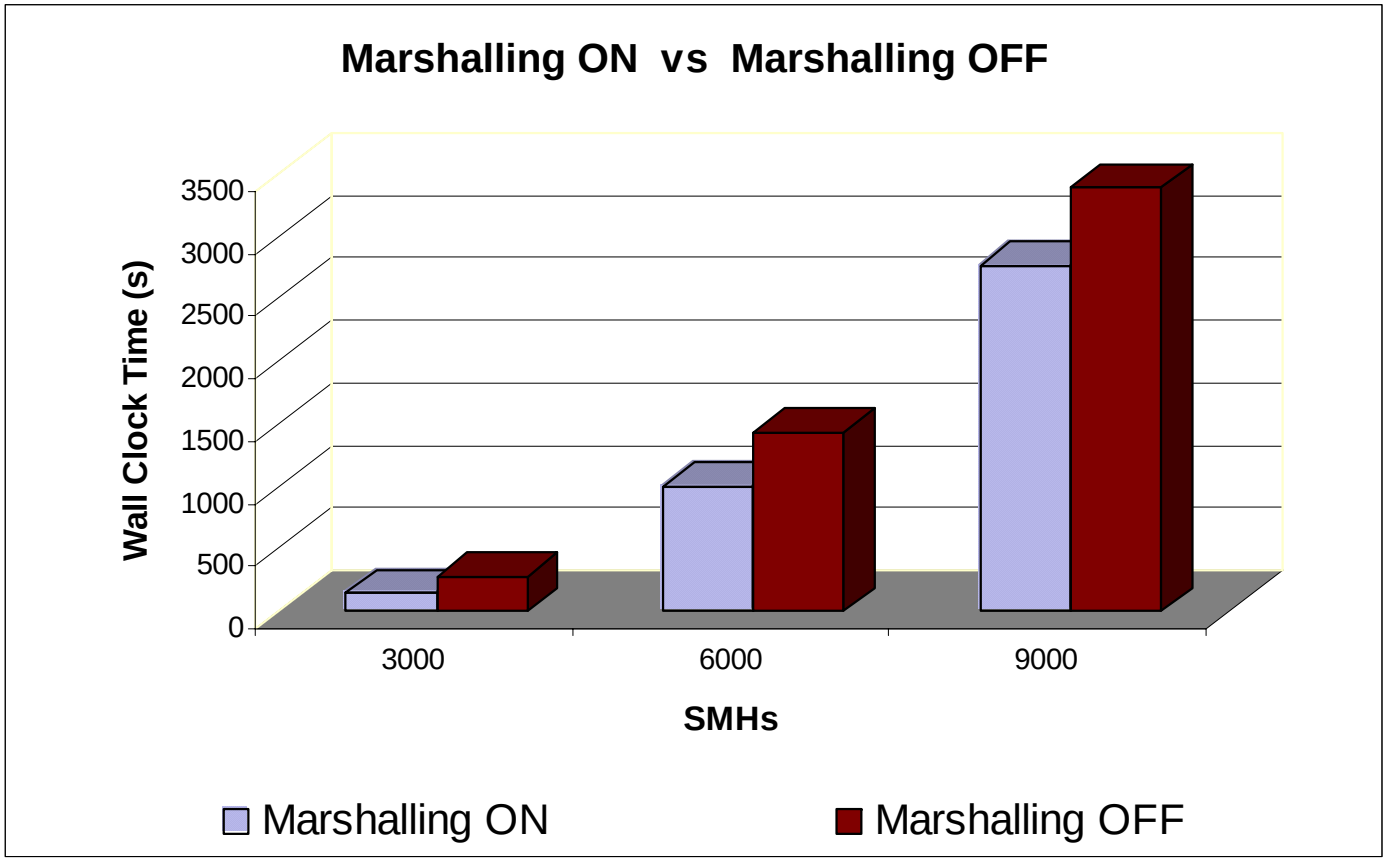
ARTìS and Hyper-Threading



Optimizations: communication marshalling

- The **communication efficiency** is one of the main factors determining the efficiency of a parallel or distributed simulation
- The data marshalling approach consists in the **concatenation** of more than one logical message in the same communication messages
- The data marshalling process is controlled by a timer: once every a maximum time limit the messages buffered on the LP are sent in a data marshalling packet (or frame)
- Inverse trade-off: degradation in the average communication **latency**
- The proposed optimization has been applied both to shared memory and TCP/IP communications

Communication Marshalling: distributed environment



Conclusion and Future work

- ARTÌS is a scalable, optimized parallel and distributed simulation middleware, used to simulate dynamic complex systems
- Careful and enhanced evaluation of the proposed optimizations
- Further improve the ARTÌS middleware
  - Data structures optimization (event-management)
  - SCTP support (IP based communication protocol)
  - IEEE 1516 full compatibility
  - New models (es. Detailed MAC protocols)
  - Migration based middleware for Internet games

References

1. L.Bononi, M.Bracuto, G.D'Angelo, L.Donatiello. **Analysis of High Performance Communication and Computation Solutions for Parallel and Distributed Simulation**. Proc. Of HPCC 2005
2. L.Bononi, M.Bracuto, G.D'Angelo, L.Donatiello. **Concurrent Replication of Parallel and Distributed Simulations**. Proc. of *ACM/IEEE/SCS PADS 2005*
3. L.Gardenghi, S.Pifferi, G.D'Angelo, L.Bononi. **Design and Simulation of a Migration-based Architecture for Massively Populated Internet Games**. Proc. of *IEEE NIME 2004*
4. L.Bononi, M.Bracuto, G.D'Angelo, L.Donatiello. **ARTIS: a Parallel and Distributed Simulation Middleware for Performance Evaluation**. Proc. of *ISCIS 2004*
5. L.Bononi, M.Bracuto, G.D'Angelo, L.Donatiello. **A New Middleware for Parallel and Distributed Simulation of Dynamically Interacting Systems**. Proc. of *IEEE DS-RT 2004*
6. L.Bononi, M.Bracuto, G.D'Angelo, L.Donatiello. **Performance Analysis of a Parallel and Distributed Framework for Large Scale Systems' Simulation**. Proc. of *ACM/IEEE MSWiM 2004*
7. L.Bononi, G.D'Angelo. **A Novel Approach for Distributed Simulation of Wireless Mobile Systems**. Proc. of *IFIP-TC6 PWC 2003*
8. L.Bononi, G.D'Angelo, L.Donatiello. **HLA-based Adaptive Distributed Simulation of Wireless Mobile Systems**. Proc. of *ACM/IEEE/SCS PADS 2003*

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