Virtual Distributed Simulation Platform for the Study and Optimization of Future Beyond 3G Heterogeneous Systems

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Abstract. This paper proposes and assesses a new distributed simulation platform for heterogeneous wireless communications. The objective of the ICARUS platform is to investigate cross-layer and cross-system algorithms for heterogeneous beyond 3G systems through a virtual distributed testbed that will allow the research community to share their individual simulation platforms and improve their research capacity through a cooperative simulation effort. This paper discusses the advantages of the ICARUS platform, and demonstrates its capacity to assess heterogeneous beyond 3G systems and reduce the simulation time.

Keywords: Distributed Simulation Platform, Beyond 3G Systems, Simulation Cluster.

1 Introduction

Technology evolution points to an always best connected wireless paradigm [1] with different technologies coexisting in the same area. The so-called seamless connectivity, and the resulting benefit for the user Quality of Experience (QoE), can be only accomplished through the coordination of the coexistent wireless technologies. This trend towards cooperation among heterogeneous Radio Access Technologies (RAT) is also known as beyond 3G communications. Its main goal is to serve each user with the RAT best-suited to the running application. The relevance of the concept of RATs cooperation in beyond 3G networks to improve the end user experience has been deeply studied in other European IST Projects, like Ambient Networks [2], Aroma [3] and Daidalos [4] with the common objective of improving the end user experience.

This complex heterogeneous framework requires an underlying architecture that allows users to be seamlessly served by different technologies. To this aim, the Common Radio Resource Management (CRRM) entity should decide on which is the optimal network for each user and service demand, provided that users should be able to switch transparently from one RAT to another.

The challenging design of advanced CRRM algorithms raises the need of a heterogeneous simulation platform capable of adequately modeling the key aspects of heterogeneous beyond 3G wireless networks. The development of such heterogeneous platforms requires a significant development effort that can hardly be undertaken by individual research teams. In addition, the development of heterogeneous platforms by different teams duplicates development efforts and makes difficult a fair comparison of research proposals. It is also important to note that the emulation of various RATs in a single computer can significantly increase the simulation times and compromise the capacity to conduct high-impact research. To overcome this situation, several initiatives have been launched to develop virtual and distributed simulation platforms that allow the research community to efficiently share and run individual simulation clusters.

The WHYNET (Wireless Hybrid NETwork) project in the United States [5] and the Panlab (PAN european LABoratory infrastructure implementation) project in Europe [6] are key examples of research efforts to develop distributed simulation platforms. WHYNET is focused on the development of a scalable and distributed testbed for next generation mobile technologies, and its main aim is to study the cross-layer interactions. On the other hand, the main objective of PanLab is to create a federation of testbeds using the most innovative clusters in Europe.

In this context, this article presents an innovative distributed simulation platform for heterogeneous wireless technologies designed within the ICARUS project. The ICARUS platform is being designed to investigate advanced CRRM and RRM [7,8] policies for heterogeneous beyond 3G systems through the implementation of a virtual geographically distributed pan-european testbed. This testbed will allow the research community to share their individual RAT simulation platforms, and investigate advanced cross-layer and cross-system policies through an efficient, scalable and distribute platform. As a result, ICARUS is aligned with the objectives and procedures of Panlab.

The ICARUS network organization is shown in Fig. 1. The simulate RATs are emulated in different computers, which could be located in different locations. This architecture provides an important differential value to local platforms because of its flexibility and computational advantages. The ICARUS platform is expected to

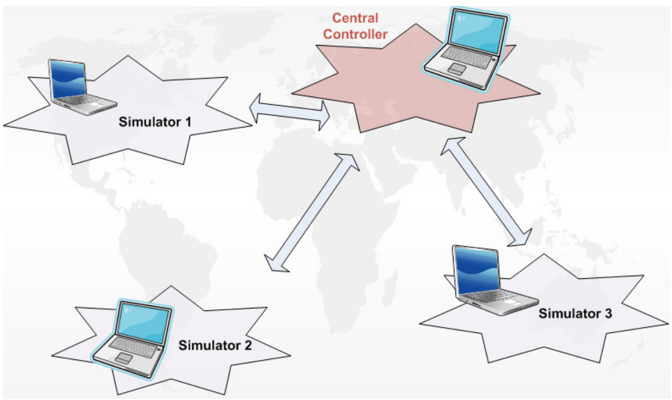


Fig. 1. Concept of the ICARUS virtual distributed simulation platform.

achieve faster simulation times through the use of distributed computational resources, and reduce the implementation load by sharing the use of different simulators that can be easily shared thanks to the modular and scalable design of the platform. In this context, the ICARUS platform will provide a valuable environment for testing advanced cross-layer and cross-system optimization algorithms that will be key for an efficient deployment and operation of heterogeneous beyond 3G systems.

2 ICARUS platform

The ICARUS project is aimed at providing a virtual distributed platform for the emulation of a heterogeneous mobile and wireless communication system. In this context, the different RATs considered within the ICARUS platform could be implemented in different simulators independently developed and running on physically distributed computers. To ensure that all these independent simulators are integrated to synchronously emulate the same scenario through a virtual and distributed simulation platform, different functionalities must be implemented at a common level to carry out the global management of some scenario simulation aspects. Fig. 2 illustrates the different management levels considered within the ICARUS Virtual Distributed Testbed (VDT). These management levels are:

- Common Management Level. To be able to emulate a unique common scenario, functions that need to work globally are located at this management level. These common functions are implemented externally to all the simulators. The main entity in the Common Management Level is the Central Controller. This entity manages the information exchange between software simulators and common management functional modules. All the entities located at the Common Management Level will make up the so-called VDT-Controller (VDT-C). It is not mandatory to implement all the common functionalities included in the VDT-C in the same computer. They can be distributed in different computers and remotely connected to the platform to ensure the maximum flexibility and extendibility.
- Individual Management Level. The functions located at this level are implemented within each simulator, and will individually manage specific functions for each of the simulators implemented and run remotely.

To identify which functions must be implemented at the common functional level, two objectives have to be considered. The first one is to minimize the information

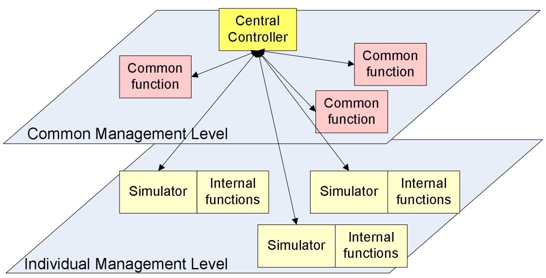


Fig. 2. ICARUS platform functional levels.

exchange between remote simulators or functional modules integrating the ICARUS platform since a constant exchange of messages through the Internet will increase the execution times. In addition, to facilitate the integration of individual simulation clusters within ICARUS, the number of modifications in these platforms should be minimized. In this context, the main identified functions that need to be implemented at the common management level are: CRRM, Session and Traffic Generation, and Mobility Management.

The interaction between the remote modules (simulators and common functional modules) composing the ICARUS platform will be made through the exchange of signalling messages. However, the different modules composing the platform will be only able to communicate with and through the Central Controller (see Fig.2). In this context, the Central Controller is in charge of managing all the messages exchanged in the ICARUS platform: all the messages are sent to the Central Controller which interprets the received messages, and creates and sends the necessary messages to the targeted modules. For example, if a user assigned to a given RAT needs to know the channel quality of other RATs at a given time, the current RAT will demand this information to the Central Controller which will ask this information to the other RATs implemented in different simulators.

To illustrate the potential and benefits of the ICARUS platform, a simple scenario has been initially considered. This first scenario considers a heterogeneous system composed by the EDGE (Enhanced Data-rates for GSM/Global Evolution) and HSDPA (High Speed Downlink Packet Access) RATs. These RATs are emulated by two different applications of the SPHERE (Simulation Platform for HEterogeneous wiREless systems) simulator [9] located in two different computers. A third computer implements the VDT-C to manage and run advanced cross-layer and cross-system studies through the ICARUS distributed testbed. The SPHERE platform, the VDT-C and the mechanisms to carry out the remote interaction between modules are described in following subsections.

2.1 SPHERE platform

SPHERE (Simulation Platform for HEterogeneous wiREless systems) is a novel, ambitious and scalable radio simulation platform for heterogeneous wireless systems initially developed by the University Miguel Hernandez of Elche, and subsequently jointly developed together with the Polytechnic University of Valencia [9]. The platform currently integrates four advanced system level simulators, emulating the GPRS (General Packet Radio Service), EDGE, HSDPA and WLAN Radio Access Technologies (RATs). SPHERE is a unique discrete-event system level simulation platform that emulates all four RATs in parallel at the packet level, which enables an accurate evaluation of the final user perceived QoS through the implementation of novel CRRM and RRM mechanisms. The radio interface specifications [10,11] of these four technologies have been faithfully implemented in the SPHERE simulation platform, which works with a high time resolution (in the order of some milliseconds). This modeling approach guarantees the capability of the SPHERE simulation platform to dynamically and precisely evaluate the performance of RRM/CRRM techniques.

Fig. 3 shows the scenario modeled by the SPHERE platform which includes the GPRS, EDGE, HSDPA and WLAN radio interfaces and concentrates on the downlink. As shown in Fig. 3, the SPHERE platform does not only model the radio interface of the four technologies, but also implements various RAT specific RRM features and a centralized CRRM entity. This entity directly collects specific RAT information (e.g. load, channel quality conditions, etc) and interacts with the RRM entities of each RAT. The logical structure of the SPHERE simulation platform is also shown in Fig. 4. This figure depicts the modular and scalable design of the platform [9], which guarantees an easy adaptation of the platform configuration to specific requirements, and allows the rapid integration of new functionalities.

2.2 SPHERE adaptation to the ICARUS platform

As shown in Fig. 4, the initial SPHERE simulator incorporates all the functionalities that have to be located in the Common Management Level in the ICARUS platform. For example, the SPHERE platform incorporates its own Session and Traffic Sources (see Fig. 4). As previously explained, the session and traffic generation needs to be implemented as global and common functions to all the simulators that compose the ICARUS platform. As a result, the Session and Traffic Sources have been disabled in the SPHERE simulator, and have been relocated in the VDT-C at the common management level. In this case, each time a new session is generated, all the information regarding the traffic session (session start time, session duration, service type, number of traffic objects to transmit, size of the traffic objects, etc.) is created in the VDT-C. This information is then sent to the distributed SPHERE simulators that store the traffic information in the User Context, a new module created to store the information related to the user traffic session sent by the VDT-C. To emulate the transmission of the traffic session, the SPHERE Traffic Manager will read the User

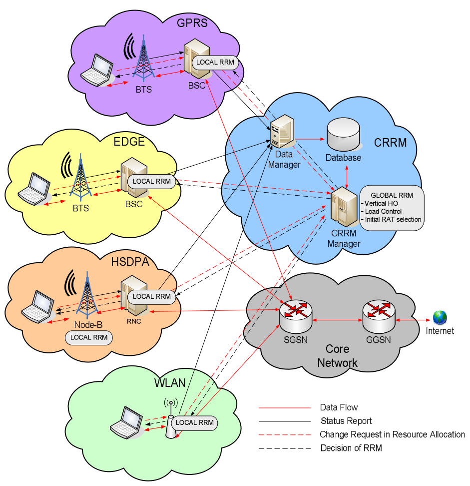


Fig. 3. SPHERE heterogeneous scenario.

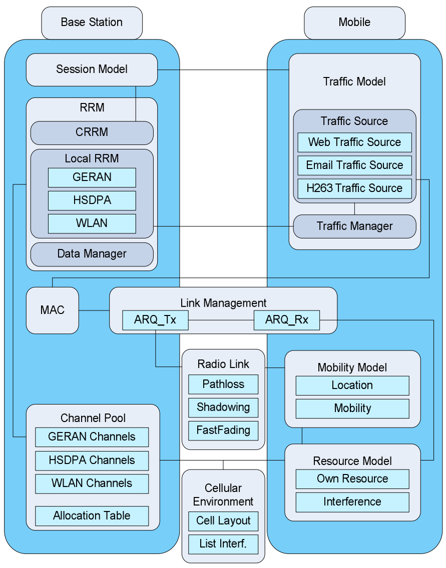


Fig. 4. SPHERE logical structure.

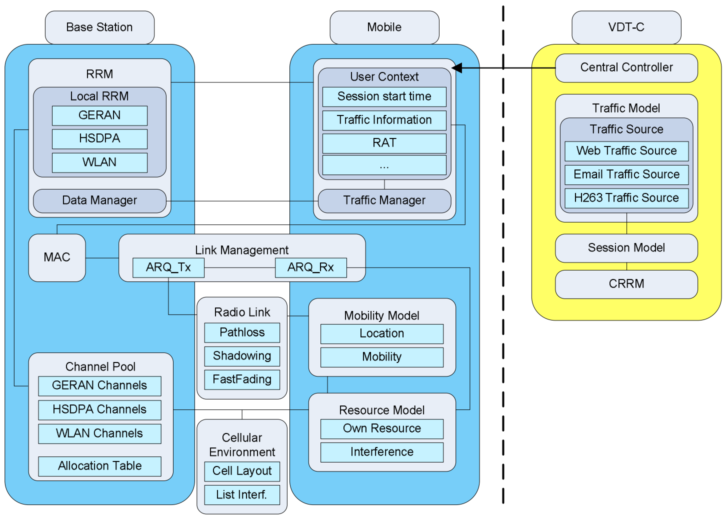


Fig. 5. SPHERE logical structure adapted to the ICARUS platform.

Context information associated to the corresponding user and will create all the related traffic events. The adapted logical structure of the SPHERE simulator to interact with the VDT-C in a distributed manner is depicted in Fig. 5. This figure shows that the CRRM entity has also been disabled in SPHERE and located in the Common Management level. In the ICARUS platform, the CRRM decisions are taken at the VDT-C; the VDT-C is the more suitable location given that it can communicate directly with all the simulators composing the platform. In this regard, each time a new user requests access to the system, the CRRM entity located at the Common Management Level will take the CRRM decision, as for example, to select the RAT over which to convey the user session among all available RATs emulated in the ICARUS platform. Then, the VDT-C will communicate the corresponding simulator that a new user is assigned to the selected RAT. The simulator will still be in charge of performing RRM functions within each RAT.

2.3 VDT-C

Fig. 5 shows the logical structure of the implemented VDT-C. The main entity of the VDT-C is the Central Controller which is in charge of the management of the information exchange between the different modules. The Central Controller is also responsible of the whole platform synchronization. Due to the fact that each simulator might run at different speeds, synchronization points to carry out the communication among the different modules have to be established. Otherwise, a simulator could send an event with an execution time previous to the current simulation time of the destination simulator, and then a conflict would take place. In the ICARUS platform, these synchronization points are referred as Time Steps and are periodically scheduled. When a simulator reaches a Time Step, it notifies the Central Controller of this fact. Then the simulator pauses its simulation process waiting for the other simulators, and no new events will be exchanged among different modules until all simulators notify that they have reached the same Time Step. When the Central Controller knows that all simulators are at the same Time Step, it asks the simulators for new messages. When all the messages have been sent and processed, the Central Controller orders the simulators to resume their simulation until the next Time Step.

The other common functionalities that are currently implemented in the ICARUS VDT-C are the Session and Traffic Sources and the CRRM entity. The session and traffic models implemented in the VDT-C are those considered in the initial SPHERE simulator, and a short description was given in Section 2.1. On the other hand, the CRRM entity is in charge of the common management of the total available radio resource in the system. In the introduction of this section, the Mobility Management was also identified as a necessary global functionality. The global Mobility Management becomes really necessary when handovers between RATs implemented in different simulators are considered. When a user is handed over to a different RAT, the new RAT must be able to carry on with the user movement without abrupt direction changes and jumps. In this case, a global management of the user movement is needed. Since the initial scenario that has been used to validate the ICARUS platform considers a simple initial RAT selection policy without vertical handovers, the mobility model is kept at the SPHERE simulators. The authors are currently working to migrate this model to the VDT-C for more advanced CRRM studies.

2.4 Remote communications

The communications and exchange of information among remote modules and simulators has to be made over the Internet. In this regard, sockets have been employed to carry out this remote communications and correctly control the exchange of data. To establish the communications, each simulator and functional module has to implement an API (Application Programming Interface) that implements all the functions related with the sockets management and exchange of information. This API can be written in different programming languages based on the simulator or functional module it is integrated with. In addition, a gateway needs to be implemented for each remote module to interpret the exchanged information, and adapt it to the format required by the local simulator or functional module. The communications between remote modules has been implemented as a Client-Server interaction as shown Fig. 6. In this context, the VDT-C is always listening for messages, while the distributed simulators send messages to the VDT-C and then wait for answers.

In the current implementation, all the common functionalities located in the VDT-C have been implemented in the same computer. As a result, only the messages needed for the communications of the remote simulators with the VDT-C have been defined:

- *Initial configuration* message (*ic*). This message is sent by the Central Controller before the simulation itself starts, and allows each simulator to load the needed configuration parameters.
- *Add user* message (*au*). This message is sent by the Central Controller to one of the distributed simulators when a user needs to start a service session using

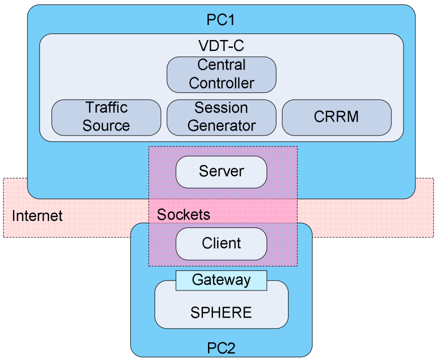


Fig. 6. ICARUS interaction among remote modules.

the RAT associated to that simulator. With this message, the controller provides the simulator with the needed information regarding the user and the type of service required.

- *End simulation period* message (*ep*). This message is sent by each simulator to the Central Controller when a Time Step is achieved, i.e, a simulation period is finished. The simulator includes in this message information regarding the users and RAT status.
- *Resume simulation* message (*sr*). After the exchange of information between remote nodes at a given Time Step, the VDT-C sends the resume simulation message to all the distributed simulators, so that they continue their simulation until the next Time Step.
- *End simulation* message (*es*). This message is sent by each simulator to the Central Controller at the end of the complete simulation.
- *ACK* message. To guarantee the robustness of the distributed ICARUS platform, all the exchanged messages have to be confirmed, which is the role of the ACK messages. All the messages sent through the network have related a timeout. If the ACK message is not received before the timeout expires, the message is re-sent.

3 Use case implementation and performance

To test and validate the first version of the ICARUS platform, as well as the adaptations carried out on SPHERE, a first evaluation scenario has been proposed. In this first scenario, a heterogeneous system only composed by the RATs EDGE and HSDPA is considered. Both RATs are emulated by two different applications of the SPHERE simulator in two different computers, and the VDT-C is also located in a third computer. In this scenario, only the initial RAT selection dilemma is considered and vertical handovers have not been implemented. This simple CRRM policy will assign the user to the RAT corresponding to the demanded service based on a pre-defined relationship RAT-service type [12]. In this scenario, email users will be assigned to EDGE, while web transmissions will be conveyed over HSDPA.

Fig. 7 shows the flowchart of the simulation process in both the simulators and the VDT-C. At the beginning of the simulation, the SPHERE simulators and the VDT-C read the configuration parameters from the configuration file (*ic* message). Then, the SPHERE simulators send to the Central Controller the *ep*[1] message indicating that it has reached the first Time Step (synchronization point), and wait for new events from the Central Controller. The Central Controller waits to receive the *ep* message from all the active SPHERE simulators. When this happens, the Central Controller asks the Session Source if new sessions have arrived, and if this is the case, the new sessions are assigned to users and the traffic related to each session is created. The CRRM algorithm is then executed and the RAT to which each user will be assigned is decided. At this moment, the Central Controller sends the *au* message to inform the corresponding simulators that new users are assigned to the RAT they are emulating. When the corresponding simulator receives the *au* message, it processes the event and stores in the User Context of each new user the traffic session information sent in the *au* message. Based on this traffic session information, events are created in the RAT simulator to emulate the session transmission. The simulator waits for more events until receiving the *sr* message indicating to resume the simulation until the next Time Step, i.e., for another simulation period. The *sr* message is sent by the Central Controller when it has processed all its events and the corresponding messages have been sent to the simulators. After sending the *sr* message, the Central Controller runs until the next Time Step and waits for the simulators to conclude the current simulation period. If a user ends the traffic session transmission, the RAT simulator

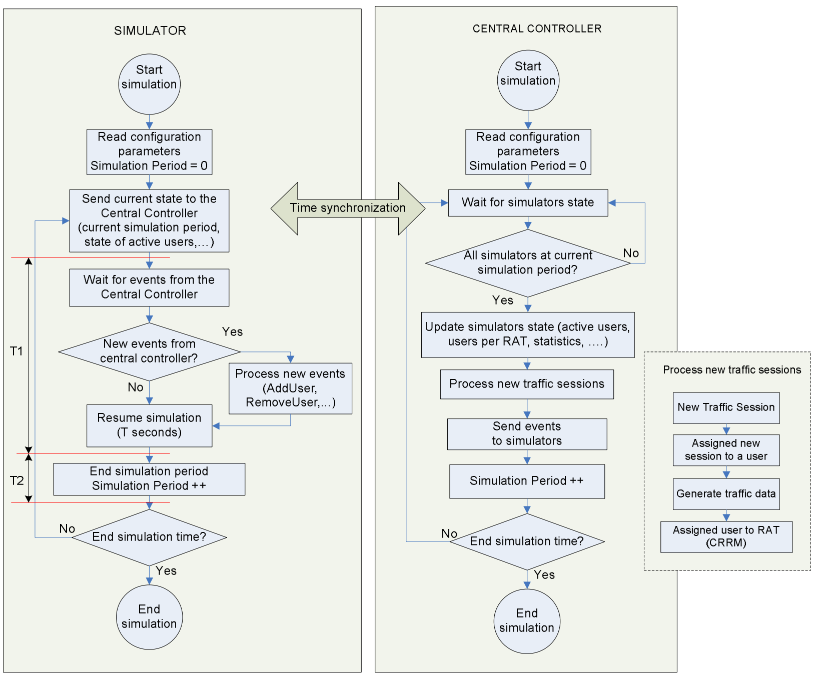


Fig. 7. ICARUS simulation process.

will inform the VDT-C in the next *ep* message and send the corresponding transmission statistics.

Table 1 summarises the ICARUS platform's configuration. The ICARUS platform emulates a 27 omnidirectional cellular layout, with 500m radius cells offering EDGE and HSDPA coverage. Base stations for both RATs are co-located in the centre of a cell. Each simulated RAT has been assigned a single frequency carrier per cell, which results in eight channels, or timeslots, for EDGE, and fifteen channels, or codes, for HSDPA. A multimedia traffic environment with email and web users is emulated with a session arrival rate of 0.08 and 0.09 sessions per second respectively.

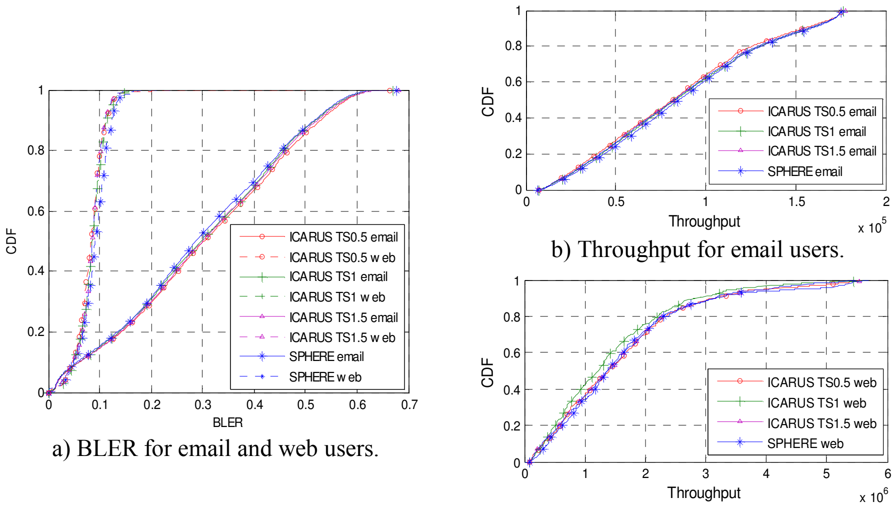
To validate the capability of the distributed ICARUS platform to accurately investigate CRRM techniques, the performance achieved with the ICARUS testbed has been compared to that achieved with a single SPHERE platform emulating simultaneously and in a single computer the EDGE and HSDPA RATs. This comparison will allow identifying the expected benefits and trade-offs in terms of simulation time and results accuracy. Fig. 8 depicts the performance results in terms of BLER (Block Error Rate) and throughput obtained when simulating the described scenario in the distributed ICARUS platform, or in a single computer simultaneously emulating the EDGE and HSDPA RATs. Different simulation periods (time between two consecutive Time Steps) have been configured in the ICARUS platform to evaluate the negative effects that this parameter can introduce in the simulator's performance accuracy. Fig. 8 shows that the results obtained with both simulation approaches are very similar irrespectively of the considered Time steps[2].

The execution time need to simulate a 30000s emulation is shown in Table 2. The results show that the execution time is reduced using the ICARUS distributed platform compared to when simulating in parallel and in the same computer different RATs using the SPHERE platform. Moreover, the execution time is reduced as the simulation period between two consecutive Time Step increases. However, although increasing the simulation period has not had negative effects on the performance of the scenario emulated in this work, this parameter will be actually critical when vertical handovers are considered. If the CRRM decision is not taken in a short time when a user requests a handover, for example due to low signal level, the user call could be dropped. In this context, a tradeoff between performance reliability and computation feasibility and cost will have to be achieved. Table 3[3] shows the measured T1 and T2 times depicted in Fig. 7 for each one of the simulators currently

Table 1. ICARUS configuration parameters.

Parameter	Value	Parameter	Value
Simulated cells	27 omnidirectional cells	Mobility	3 km/h user speed
Environment	Macrocellular urban scenario	Pathloss	Okumura-Hata COST 231 Hata
Cellular radio	500 meters	Shadowing	Log-normal with 6dB standard deviation
Channels per cell	8 EDGE channels, 16 HSDPA channels	Session arrival rates	Email: 0.08 sessions/s Web: 0.09 sessions/s
Users per cell	30 users		

[2] Despite these results, a performance difference is expected for higher Time Steps.
[3] Both simulators run in identical computers (Intel Dual-Core Xeon 3 GHz FSB 667MHz).



a) BLER for email and web users.

b) Throughput for email users.

c) Throughput for web users.

Fig. 8. Performance results.

Table 2. Execution time for a 30000s emulation.

	Execution time	Improvement (%)
SPHERE	62987s	-
ICARUS Time Step 0.5s	55696s	11.58
ICARUS Time Step 1s	47879s	23.99
ICARUS Time Step 1.5s	46183s	26.68

Table 3. Execution times of the ICARUS simulators for a 1 second Time Step.

	T1	T2
EDGE simulator	0.949s	0.647s
HSDPA simulator	0.204s	1.392s

composing the distributed ICARUS platform. T1 corresponds to the time spent exchanging messages with the VDT-C, while T2 is the time that the simulator actually spends emulating a new simulation period equal to the Time Step. The obtained results show that the exchange of information with the VDT-C only corresponds to the 12.78% of the total execution time, which is not that significant compared to the high computational requirements of the HSDPA simulator.

4 Conclusion

This work has presented a first successful implementation of a distributed platform for future beyond 3G heterogeneous wireless systems developed in the framework of the ICARUS project. The distributed approach allows interconnecting and collaboratively sharing simulation platforms developed by different groups for a more resource and performance efficient research on complex issues of Beyond 3G systems. To this aim, some common functionalities and interfaces between the different platforms have been identified and implemented in a control entity named VDT-C. To validate the distributed and cooperative simulation approach proposed in ICARUS, this paper has implemented a simple CRRM policy. The results obtained have initially validated the capacity of the ICARUS platform for cross-layer and cross-system studies in Beyond 3G scenarios. In addition, a gain in execution times with the distributed platform has also been highlighted.

Acknowledgement

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