ASCE: Auto-organización en sistemas de comunicación emergentes – Self-Organization in Emergent Communication Systems
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Abstract

This grant studies the behavior of emergent communication systems (communication networks without centralized control, like Internet or ad-hoc networks). We consider systems formed by a number of nodes that communicate and interact locally through links. The nodes route and schedule the transmission of data packets across the links, to reach a consistent global behavior. Our objective is to ensure that these systems are able to adjust their behavior without a centralized control (hence the term emergent).

In this project we make pessimistic assumptions about the system users’ behavior, in order to evaluate the quality of service that the systems can guarantee. To do the analysis under the worst case conditions, we assume the existence of a (bounded) adversary that controls the system. Under this assumption, we evaluate routing and scheduling algorithms, first studying the system stability (impossibility of the adversary to make the number of packets in the system to grow unboundly), and then their performance with respect to other parameters (latency, memory requirements, etc.). For these studies we use models of static networks that we have recently proposed (Continuous Adversarial Queueing Theory, a generalization of the Adversarial Queueing Theory model) and we generalize them for dynamic networks. Moreover, to complement the theoretical studies, we want to compare our analytical results with empirical studies. To do so, we evaluate and compare different algorithms by simulation. Finally, we study the possibility of integrating the algorithms in real networks protocols.

Additionally, we want to study strategies that force the system users to respect certain limits in their behavior (for instance, limiting the amount of traffic they generate). To do so, we want to model their interactions with the system as a game and to use Game Theory to analyze it. Our objective is to understand how different rules may influence the users’ strategies, and hence to be able to select the appropriate rules to enforce certain network properties.

Keywords: communication networks, emergent behavior, packet scheduling, routing.

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1 Grant Objectives

The main global objective of the coordinated grant is the design of packet scheduling policies and routing algorithms for communication systems, to guarantee that their resources are efficiently used without centralized control. Researchers from both institutions have proposed a model of communication network that could be used to explore the emergent behavior of communication systems under worst-case (adversarial) scenarios [7]. This model, termed Continuous Adversarial Queuing Theory (CAQT), is a generalization of the classical Adversarial Queuing Theory (AQT) model [9, 4]. In the new model the synchronous evolution of the system, assumed in AQT, is replaced by an asynchronous or “continuous” evolution, similar to the one assumed in Network Calculus [10]. In this model, like in its predecessors, a key target is to achieve stability in the system under adversarial traffic arrival. We have used the new CAQT model as starting point for the work of this grant.

Then, the grant wants to explore in depth the properties of this new CAQT model, and its generalizations for dynamic systems (systems in which properties like the topology or the link bandwidths change with time). Additionally, it will evaluate empirically whether the properties observed at the analytical level also apply to real environments. Finally, since the CAQT model assumes that the traffic arrival is “well-behaved,” in the sense that no part of the network is overloaded, the grant will attempt to propose rules and games to guarantee that this behavior is in fact achieved in a system with uncoordinated (possibly selfish) users.

1.1 Structure of the Grant

The tasks in the coordinated grant have been grouped into 6 modules to reflect the set of objectives described above. Each module roughly faces each one of the above objectives. The following is a brief description of these modules and their objectives. Only technical modules are presented. There is a seventh module not shown here that is in charge of the management and coordination of the grant.

Module I: Study of Static Systems In this module the grant explores static communication systems under the CAQT model and some of its generalizations. Several routing algorithms and scheduling policies will be devised and evaluated analytically for these models. The objectives of the module are to propose new interesting generalizations of CAQT, and to identify efficient algorithms and policies under adversarial traffic for these models. This module is assigned to the research group of the Universidad Rey Juan Carlos (URJC).

Module II: Study of Dynamic Systems In this module the grant will propose suitable extensions of the CAQT model to dynamic systems, and explore the properties of these new models. Again, routing algorithms and scheduling policies will be devised and evaluated analytically for these models. The objectives of this module are to propose models that accurately reflect the characteristics of real dynamic systems (like MANETS), and derive efficient algorithms and policies for these models (which hopefully will be useful in the real systems). This module is assigned to the research group of the Universitat Politècnica de Catalunya (UPC).

Module III: Simulation of Scheduling Policies and Routing Algorithms In this module, proposed scheduling policies and routing algorithms will be evaluated empirically via simulation. The simulations will cover different models, topologies, and traffic arrival patterns. The objective of the module is to determine whether the derived analytical performance of
these policies and algorithms is also observed in more “realistic” environments. This module is assigned to the research group of the URJC.

Module IV: Integration of Scheduling Policies in the IP Protocol In this module the grant will explore the possibility of integrating the proposed scheduling policies in real networks. For that, it will explore how the IP protocol (and specifically its packet format) has to be extended to allow the use of policies that have been found to be more efficient than FIFO. Additionally, it will modify an existing implementation of the TCP/IP stack to support these extensions and evaluate the resulting implementation. The objective of this module is to prove that the proposed policies can be integrated in current networks with little effort and that they in fact increase their performance. This module is assigned to the group of the URJC.

Module V: Computation of Equilibria Strategies in Congestion Games In this module new congestion games will be defined to model the desired fundamental characteristics of traffic control. For this, Game Theory will be used as the basic framework. Initially, simple games will be analyzed to move to more complex and repetitive games. The objective of this module is to understand basic concept of congestion games to use them in the following module. This module is assigned to the research group of the UPC.

Module VI: Conception of Rules to Control the User Behavior The evaluation of scheduling policies and routing algorithms assume some form of “well-behaved” traffic. This module will attempt to design traffic admission rules and mechanisms to enforce this good behavior at a global level without coordination. For this module the experience obtained in the previous module is expected to be very useful. The objective of the module is to propose local rules that guarantee “good” global properties of the traffic load in the system. This module is assigned to both research groups.

1.2 Means Required and Timetable

Due to the strong theoretical nature of the intended research, most of the budget requested in the grant proposal was allocated to acquire personal computers and travel expenses. Regarding the time distribution of the modules, they are designed to advance in parallel, and practically all of them are designed to last the full extent of the grant duration. Partial results obtained in one module are expected to be used in other modules, but this is not expected to finish the former, since possibly room for further study still exist.

2 Success Level Achieved

The following subsections describe the current level of progress for each of the technical modules described above. So far, we have not found any problem significantly delaying the advance of any of the modules.

2.1 Module I: Study of Static Systems

As part of this module, members of both research groups have completed the CAQT paper with new results [5]. Among others, these results show the existence of universally stable policies in AQT that are not so in CAQT (hence, showing that the adversary has more power in the later
than in the former), and include a complete characterization of networks that are universally stable under CAQT with any link bandwidth configuration.

A second important achievement in this module has been the proposal of a generalization of CAQT for systems in which the clocks of the network nodes need not be synchronized [11]. This characteristic influences the good performance of scheduling policies that use time and assume global synchronization. We analyze the performance of these policies in the new model and propose a new policy that maintains their good properties but is not affected by the lack of synchrony.

There is a third fundamental result that is in the process of being written and which will be submitted in the next few months. This result shows that multi-class queuing networks with the feedforward property [12] are stable even at full load. The networks obtained with the CAQT model are a special case of multi-class queuing networks, and hence this result also applies to them. This result also opens a line of work in the grant on devising routing algorithms that guarantee this kind of route behavior.

Another open line of work in this module is the characterization of stability given the network topology, the bandwidth assignment, and the scheduling policy used.

2.2 Module II: Study of Dynamic Systems

In this module the first achievement has been a thorough study of dynamic networks whose change is due to node and link failures. This work has been completed [1], with a comprehensive set of results on network and policy stability under several failure models.

Currently, new models of dynamic systems are being considered. In fact, two proposals have already been defined and are being evaluated.

2.3 Module III: Simulation of Scheduling Policies and Routing Algorithms

In this module we have already chosen the simulator to be used (J-Sim, from The Ohio State University) and have modified and extended it to be able to run some of our simulations. In fact we have already coded several scheduling policies and one routing algorithm, among other changes and extensions. We have already used the simulator to evaluate the performance of several scheduling policies in small simple topologies. In particular, we have simulated scenarios without synchronized clocks, which have been included in [11]. We have also evaluated a hierarchical network and a ring to compare the results obtained with those observed in real executions [14]. We are currently running a larger collection of simulations in these small networks.

The next step is to use the simulator for large networks with topologies similar to the Internet. For that, we have already been able to import into the simulator topologies generated with the popular GT-ITM (http://www.cc.gatech.edu/projects/gtitm) program, which generates Internet-like topologies. However, we have found limitations on the simulator for large networks and are trying to find ways to overcome them.
2.4 Module IV: Integration of Scheduling Policies in the IP Protocol

This module is largely complete, since the most difficult tasks have been already solved. We have identified appropriate changes in the IP packet format to carry additional information (in particular, timestamps) to be used for scheduling. Then, we have modified a Linux kernel so that several of our policies of choice are available, some of which make use of the additional information. Finally, we have implemented programs that generate and receive packets with the extended format. All these developments have proven the viability of the approach.

We have set a small real network and used our own kernel to route packets. The topologies evaluated are the same that have been evaluated by simulation [14], which has allowed to compare the differences between real systems and simulations. The paper [14] also describes the changes in the IP packets and the kernel that have been done. The code is available at the web of the group http://ladyr.es. The work that remains in this module mostly consists on implementing other policies, and making more extensive tests.

2.5 Module V: Computation of Equilibria Strategies in Congestion Games

In this module we have studied the computational complexity of several families of strategic and extensive games [3, 13]. Our results yield a satisfactory classification of the computational complexity of several basic problems on strategies, Nash equilibria, and game equivalence.

2.6 Module VI: Conception of Rules to Control the User Behavior

Regarding this module, we have concluded that the game model that seems to be most suited to analyze the adversarial behaviour is maximal congestion games. We are developing characterizations of Nash equilibria for this class of games, trying to find efficient algorithms that allow the computation of such equilibria.

Preliminary results suggest that the search for disjoint paths will play an important role in these games. For that reason we have developed algorithms that find disjoint paths in graphs [5, 6], which we believe will be useful for defining and analyzing these games.

The preliminary results presented in [2] show that a round robin assignment of a maximal set of disjoint paths characterizes the Nash equilibrium of single source single destination maximal congestion games. Furthermore this characterization shows the existence of a polynomial time algorithm to compute a Nash. We are working towards extending those results to other classes of maximal congestion games.

3 Results Indicators

This section provides information that should allow quantitatively and qualitatively evaluate the degree of success of the grant.

3.1 Degree of Completion of the Objectives

As described in Section 2, we have made progress and obtained results in all the technical modules in which the grant has been divided. As presented there, Module IV has almost all
its objectives completed. Considering all the modules globally, one may say that we have been able to achieve at least 50% of the objectives, since we have completed the first work on CAQT, proposed and analyzed extensions of CAQT both for static and dynamic systems, and are in the way of exploring routing and mechanism design for traffic admission.

3.2 Scientific and Technological Production

In Section 2 we have already mentioned the papers that have been produced directly from this grant. These are [2], [8], [11], and [14] by the URJC group, and [1], [3], [5], [6], [8], and [13] by the UPC group. Additionally, both groups have been working on other lines of research that in one form or another have benefited from this grant. A list of the publications generated in the period of the grant in these lines is given in Appendix A.

Additionally, as part of the production of the grant we have the code of the adapted Linux kernel and the new modules introduced in the J-Sim simulator, which are freely available.

3.3 Relevance and Originality of the Obtained Results

The grant results obtained so far have interested to a high scientific level audience. We consider this a clear guarantee of their relevance and originality. These results have been presented to the audience in the form of papers and talks. First, the quality of the results has been ensured by the reviewers of the conferences and journals in which these results have been accepted. Secondly, the results have been presented at several conferences in which the audience has also shown constructive criticism.

Finally, part of the results have been presented in specialized fora as well. For instance, in November of 2006 six researchers of the grant, three from each group, attended the Bertinoro Workshop on Adversarial Modeling and Analysis of Communication Networks (see details at http://www.lri.fr/~adiro/bertinoro/waman.html). This was an invitation-only workshop on adversarial models like AQT. Both groups presented subsets of the results described in Section 2 to a specialized audience of researchers from top institutions (e.g., MIT, Technion, Bell Labs, Columbia U.). Maria Blesa presented the talk “Stability of Communication Networks in the Presence of Adversarial Traffic and Failures: Models and Management,” and Antonio Fernández presented the talk “A Continuous Model of Adversarial Queuing Theory.”


3.4 Applicability of the Results and Contact with the Social-Economic Environment

Regarding a direct transference of the results obtained in this grant, and related issues, we have maintained several meetings with the company Teldat, which expressed its interest on the grant proposal. We expect to be able to find applications of some of the results derived in the grant to their products in the future. Meanwhile we will maintain the flow of information and will attempt to have frequent contacts.
Additionally, there have been already two byproducts of the grant, namely the modified Linux kernel in which our scheduling policies can be used (and the accompanying programs) and the simulator modules that we have developed. Both pieces of code are publicly available and are part of the contribution of the grant to the community.

3.5 Human Resources Education

Although none of the groups had resources assigned to training and education by the grant, both groups have been active in the latest years, and in particular during the development of this grant, in activities of post-graduate education.

The URJC group has been actively involved in a PhD program that has quality mention of the Spanish Ministry of Education. Regarding thesis direction, the thesis “Innovative Topology Self-Adaptation Mechanisms for Efficient Resource Location in Peer-to-Peer Networks” by Luis Rodero Merino was recently completed, and the theses by José Luis López and Christopher Thraves are expected to be finished during 2007. The thesis of Christopher is directly related to the topic of this grant. Another thesis is also in progress by Juan Martínez, which deals with the empirical evaluation aspects of the grant. Finally, there have been several Diploma Theses (Proyectos Fin de Carrera) directed by members of the group.

The group of the UPC has covered partially the participation of members of the research team in training activities. In particular Maria Blesa and Alina García have attended the Dynamo Training School (DYNAMO) at Lisbon, Portugal, June-July 2006.

A part of the efforts of the team has been devoted also to training. Members of the team participate actively in the Postgraduate program in Computing including a Master and a PhD program at the UPC. Maria Serna is the coordinator of this postgraduate program. The program is the continuation of the former Software PhD Program, that has got the quality mention of the Spanish Ministry of Education since 2003 (MCD-2003 00130). The participation is mainly in offering and organizing courses, and advising or co-advising PhD Theses, PhD Theses proposals, and Master Theses. The group also participates in the supervision of Diploma Theses mainly of students of the Informatics Engineering studies of the UPC.

Among the education and training activities developed since the beginning of the project, we may mention the defense of the PhD Thesis “Stability in Communication Networks under adversarial models” by Maria J. Blesa in February 2006, the approval of the PhD Theses proposals “Game isomorphism and orchestration analysis” by Alina García and “Network Reinforcement problems under restrictions” by Marc Comas, and the direction of 10 Diploma Theses.

3.6 Collaborations with International Groups

Both research groups maintain contact and fruitful collaboration with a wide collection of international research groups. In the specific topic of AQT, both groups have frequent contact with other groups working in the same area, most of which where also invited to the workshop at Bertinoro mentioned above. Examples are Zvi Lokter, from the Ben-Gurion University, Marcos Kiwi, from the Universidad de Chile (in fact the thesis of Christopher Thraves mentioned above is codirected by Marcos Kiwi and the grant coordinator), or Adi Rosén, from the Technion. Then each group has stronger links with some specific groups. For instance, the URJC has contact with Matthew Andrews and Lisa Zhang at Bell Labs, and Ashish Goel at Stanford,
while the UPC has contacts with the group of Paul Spirakis at the Computer Technology Institute.

At a wider level, both groups have been actively doing research with other groups in many different lines of research. For instance, the group of the URJC is working on the area of distributed computing with groups from the IRISA and the University of Cyprus. Additionally, members of the group are participating in the EU-funded grants I-Camp and Ecospace, and are currently coordinating a FET-Open short proposal with 5 other European institutions whose main topic is Game Theory and Mechanism Design applied to distributed systems.

Similarly, the UPC group is an active participant of the action COST 295 DYNAMO, with Maria Serna in its management committee. In fact, profiting of this action, part of the group attended the Dynamo Training School held in Lisbon in Jul. 2006. The topic of this school was dynamic networks, and covered issues related with those of the grant. This group also participates in the EU-funded project “AEOLUS: Algorithmic principles for building efficient Overlay computers,” which is the FET pro-actives Integrated Project 15964. This project started in Sep. 2005, and has Maria Serna as the group leader at Barcelona, leading also the work package “Stability and Fault-tolerance.”

Additional indicators of the international projection of both groups have to do with their participation in international events. Then, Antonio Fernández, from the URJC, gave an invited course at the II Escuela de Verano en Matemáticas Discretas, organized by the Universidad de Chile in Jan. 2007, was an invited attendant at the “Gossip-based Computer Networking Workshop” held at the Lorentz Center, Netherlands, in Dec. 2006, and was member of the Technical Program Committee of the 7th European Dependable Computing Conference, EDCC-7, the 2007 International Conference on Networking, Architecture, and Storage, NAS 2007, the 12th IEEE International Symposium on Pacific Rim Dependable Computing, PRDC 2006, and the 7th Latin American Theoretical INformatics conference, LATIN 2006.

Similarly, from the UPC, we have that María Blesa has co-chaired the 3rd and the 4th Workshops on Hybrid Metaheuristics (HM 2006, HM 2007), and Maria Serna has chaired the 5th International Workshop on Experimental Algorithms (WEA 2006). María Blesa has been in the Program Committee of the 6th and 7th IEEE International Conference on Intelligent Systems Design and Applications (ISDA 2006, ISDA 2007), and the ACM Genetic and Evolutionary Computation Conference (GECCO 2006, track on Ant Colony Optimization and Swarm Intelligence); María Serna has been in the PC of the “COST 293 GRAAL and COST 295 DYNAMO Discussion Workshop and MC meetings,” the Workshop on Internet and Network Economics (WINE 06), the 2nd International Conference on Distributed Computing in Sensor Systems (DCOSS 06), and the IEEE International Workshop on Foundations and Algorithms for wireless networking (FAWN 2006); and Fatos Xhafa has been in the PC of EvoCOP 2006, of the International Symposium on Grid computing, high-performAnc and Distributed Applications (GADA 2006), the Third International Workshop on Hybrid Metaheuristics (HM 2006), the 20th ACM Symposium on Applied Computing (SAC 2006, Evolutionary Computation Track), and The 17th IASTED Int. Conference on Modelling and Simulation (MS 2006). Finally, members of the UPC team have been in the Organizing Committee of seven international conferences and workshops.
3.7 Grant Development and Management

At the local level, each group maintains periodic local plenary meetings every 2 to 4 weeks, in which any new result obtained is presented, problems found are discussed attempting to collectively find a solution, and new tasks to be done are identified and assigned. Then, approximately every 6 months we are holding a coordination meeting with large representations of both groups. A web page has been created to maintain the information generated by the grant (http://gsyc032.dat.escet.urjc.es/ladyr/asce) where copies of the reports, documents, and minutes of some of the meetings are held.

3.8 Coordination and its Benefits

As mentioned previously, the work plan had a module specifically devoted for coordination of the grant. Its objective is to guarantee that both research groups are aware of the other’s findings, they help each other, and the grant has a clear direction. This is done mainly by organizing periodic meetings, exchanging reports, and maintaining a web page. As part of the tasks of this module, three coordination meetings have already taken place. In April 2006 a meeting was held in Barcelona, in which formal presentations of advances were done and a final session of future lines of work was held. This meeting was very useful to put together findings and problems, and hence to steer the direction of the grant.

A second coordination meeting was held during the Bertinoro Workshop on Adversarial Modeling and Analysis of Communication Networks, in the Fall of 2006, in which 3 researchers from each group were present. This meeting was less formal and was used to review advances and define new tasks to face.

Finally, a third meeting has been held in Móstoles, with a format similar to the first. In this meeting, the recent advances of each group were put together. Then, a session of future work was used to review all the timetable of the work plan, and to identify tasks of the technical modules that were at risk of falling behind schedule. This session was used to define the immediate future issues to tackle.

The cross interaction of both groups has been very useful in these coordination meetings, since both groups have different backgrounds and skills. While the URJC group has a strong profile on communications and networks from a practical point of view, the UPC group is extremely strong in theoretical approaches and analysis. This is a clear complement that has proven very useful in defining realistic models and solving problems.

References


A Additional Publications

Universidad Rey Juan Carlos:


Universitat Politècnica de Catalunya:


