Towards a distributed computing model that characterizes dynamics of mobile networks

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Abstract. *Our main goal in this proposal is to present the research possibilities opened by two previous cooperations among groups from France and Brazil in dynamic systems.*
Basically, we intend to add up the expertise of the French group on distributed systems with the skills of the Brazilian group on the practical use of theoretical tools in order to create a new distributed model for mobile networks (MANET). Despite the fact that both groups have conducted their researches independently, we believe that to join efforts to define such a model would be very promising and would open an interesting field of research.

1. Teams Presentation

Regal is a joint research group of **LIP6, Paris6** and **INRIA-Rocquencourt** (`http://regal.lip6.fr/`) that investigates systems or distributed algorithms for large-scale, hierarchical or self-organized environments such as peer-to-peer, Grid platforms, and mobile or sensor networks. It aims at providing solutions for tolerating failures and/or reducing the time for getting an information or data. One of the fields of our research is to propose new distributed, adaptive and/or fault tolerant algorithms that cope with the dynamics, scalability or communication latency heterogeneity of such environments. Regal research has both a theoretical and an experimental approaches since we prove the correctness of the algorithms and we usually develop prototypes on top of simulators, cluster-based emulated platforms or testbed platforms like Grid5000 [gri] in order to perform evaluation experiments.

The **Distributed Systems Research** group of **IME-USP** (`http://gsd.ime.usp.br/`) gathers several professors and students interested in aspects of parallel, distributed, and mobile computing. Currently, the main research areas of the group are related to Grid Computing and the middleware InteGrade (`http://www.integrade.org.br`), mobile computing, and networks with somehow predictable behavior. The ongoing research on the group aims at producing software and experimental results based on a strong theoretical basis.

2. Brazilian-French Cooperations

Regal (INRIA/LIP6): A CAPES/COFECUB (projet 497/05) cooperation project with the Federal University of Bahia (UFBA), the Federal University of Campina Grande

(UFCG), and several French laboratories (ADEPT Team, GRAND LARGE Team, REGAL Team and ENST Bretagne) took place during the period of 2005-2008. The focus of the project was distributed/Grid computing systems and algorithms. In this projet, we have particularly worked with Prof. Fabiola Greve of UFBA (Distributed Computing Group GAUDI) by proposing an algorithm that implements an unreliable failure detector for mobile wireless network (MANET) [Sens et al. 2008a][Sens et al. 2008b]. Informally, an unreliable failure detector can be seen as a per process oracle, which periodically provides a list of processes suspected of having crashed. We have considered a distributed system where nodes connected by a wireless network could move, did not have a full knowledge of the network, and could only communicate to their respective neighbors. However, some specific properties were added to our model in order to satisfy the properties of the unreliable failure detector themselves. Furthermore, links between nodes were bi-directional, and we assume that, in spite of changes in the topology, there is always a path between two correct nodes. That is, there are no network partitions in the system in spite of node failures and mobility.

Distributed Systems Research (IME-USP): There were several well succeeded previous cooperations between the distributed systems research group of IME-USP and French institutions. The first projects were conducted together with INP Grenoble, and were mainly based on scheduling for parallel and distributed computing. Cooperations were supported either by CNPq-CNRS or USP-COFECUB. The main publications from the first cooperation were related to scheduling on clusters while the second cooperation focused on several aspects related to Grid Computing. More recently a very successful cooperation between the same Brazilian group and the research team Mascotte from INRIA-Sophia Antipolis was supported by FAPESP-INRIA. In this project, Evolving Graphs were used on several experiments on realistic settings and we were able to improve the state of art with several publications [Monteiro et al. 2006, Ferreira et al. 2009, Monteiro 2008, Ferreira et al. 2007a, Ferreira et al. 2007b]. A Brazilian student which did his master science degree during this project received a prestigious INRIA scholarship to do his PhD in another team of INRIA-Sophia Antipolis.

3. Proposal of a new Brazilian-French Cooperation

Some of the results and open questions raised on both CAPES/COFECUB cooperation (Regal group with UFBA) and FAPESP-INRIA cooperation (IME-USP distributed systems research group with INRIA Mascotte) have motivated the current proposal. The former has shown us the need of defining a more suitable and comprehensive distributed computing model that characterizes the dynamics of mobile networks and on top of which well-known distributed algorithms (e.g. consensus, unreliable failure detectors, partition detectors, etc.) would be built. At the same time, we believe that such a model is strongly related to the theory of Evolving Graphs [Ferreira 2004], since the latter is based on the definition of paths (journeys) that change over time and which we would like to exploit in our proposed model.

Due to arbitrary failures, energy restriction, disconnections, arrivals, departure, or mobility of nodes, a MANET is in fact an extremely dynamic system where connections between nodes change over time. The temporal variations in the network topology thus implies that MANET can not be viewed as a static connected graph over which paths between nodes are established before the sending of a message but it should be seen as a set of dynamic graphs, as proposed by the Evolving Graph theory. Furthermore, lack of connectivity between nodes (temporal or not) makes of MANET a *partitionable system*, i.e., a system in which nodes that do not crash neither leave the system might be unable to communicate between themselves. It is worth mentioning that even if some works in the literature propose computing models for dynamic systems [Mostefaoui et al. 2005], [Tucci P. and Baldoni 2007], [Baldoni et al. 2007], none of them have considered that paths are dynamically established over the time nor that the system is a partionable one.

The specification of a distributed computing model for MANETs should try to characterize as much as possible the dynamic and self-organizing behavior of MANETs. In principle, the model should cover the following points:

- A node in MANET has not a global knowledge of the system. It neither knows the number of participants of the system nor the identity of them. In addition, such a number can be bounded or not;
- Nodes can move, crash/recover and dynamically enter or leave the system;
- The network is not fully connected and a node can only send messages to nodes that are within its transmission range. Hence, it may be that a message sent by a node should be routed through a set of intermediate nodes until reaching the destination node;
- Connections between nodes should be considered unidirectional. For instance, it might happen that a node can receive a message from another node but has insufficient remaining energy to send it back a message;
- A path between two nodes is built over the time, i.e., a connection between two intermediate nodes of a path is not necessarily established beforehand but dynamically whenever a node sends a message to the following one in the path;
- Different types of links can exist in the network: links can be reliable or not (loss of messages), they can present bounds for message transmission or not (synchrony assumptions), etc;
- Lack of links between nodes partitions the network into components.

Based on such dynamic characteristics, the reader can realize that the specification of a distributed computing model for MANETs is an interesting field of research. However, it is far from trivial. On the other hand, the previous mentioned cooperation FAPESP-INRIA validated the use of an interesting theory (Evolving Graphs) that characterizes dynamic systems. More than just the possible use of the theory itself there are several theoretically proved algorithms that could also be useful. We thus think that the theory of Evolving Graphs [Ferreira 2004] could help us and should be strongly exploited in the definition of our model since they characterize connectivity over time and temporal dependance of paths in dynamic systems like DTNs (disruption tolerant networks) [Arantes et al. 2009] or even MANETs. Concisely, an evolving graph is a time-step indexed sequence of subgraphs, where the subgraph at a given time-step corresponds to the network connectivity at the time interval indicated by the time-step value. Instead of dealing with end-to-end paths between nodes, there is the concept of journeys (paths that change over time). The FAPESP-INRIA cooperation project has proposed several optimal algorithms in order to calculate shortest journeys (with less nodes), foremost journeys (with smallest arrival time), and fastest journeys (with smallest time in "transit"). However, all these algorithms consider that nodes have a global knowledge, i.e., a centralized approach.

Another important aspect of MANETs that our model should consider is how to characterize stable periods in dynamic MANETs. In other words, since a MANET network is a partitionable system, its partitions (some or all) should present some *eventual stability condition* (or a *stability* whose duration is long enough) in order to ensure that applications that run on top of it can progress and terminate. In this sense, the theory of evolving graph could also be useful since in this theory a partition can be viewed as a so defined time-connected strongly connected component. Notice that it might be interesting to consider that stable partitions are not necessarily isolated one from another and also that the network presents some "stable partitions" or "connectivity islands" while the rest of the network has a dynamic behavior. Some applications could then run on stable partitions.

The main goals of our proposal is therefore:

- the implementation of a distributed version of the Evolving Graphs algorithms, i.e., nodes do not have a global view of the network;
- the definition of a distributed computing model for MANETs which (1) exploits the concept of Evolving Graph journey concept, (2) nodes do not have a global view of the network, (3) different types of links can be characterized and (4) network partitions can be detected;
- the characterization of time-dependent connected components, whose connections may be represented by journeys with bounded transmission delay which will thus allow the definition of stable partition concept.
- The proposal, implementation, and proof of correctness of well-known distributed algorithms (e.g. consensus, unreliable failure detectors, group communication, etc.) on top of the new model.
- a framework where the above algorithms could be easily implemented and tested.

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