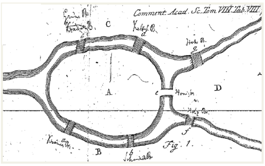

# THE EULER NEWSLETTER

## In this issue



## 2nd TERANET 2011 workshop

The 2nd edition of the TERANET (Toward Evolutive Routing Algorithms for scale-free/Internet-like NETworks) international workshop took place on September 19, 2011, in Rome, Italy (details at http://www-sop.inria.fr/mascotte/EULER/wiki/pmwiki.php/Events/TERANET2011). It was organized by the EULER research project and co-located with the 25th International Symposium on Distributed Computing (DISC 2011). This yearly workshop focuses on current research and related challenges on new paradigms for distributed and dynamic routing schemes applicable to the Internet and its evolution. Six internationally renowned experts coming from institutes crossing EU borders presented talks on the latest developments in these fields. Around 40 participants attended this event.

**Ginestra Bianconi** (Northeastern University, Boston, MA, USA) presented the talk entitled "**Evolution and entropy of complex networks**". This talk introduces the recent advances on quantifying the complexity of complex networks using principles and models borrowed from thermodynamic and information theory. Models of network growth consider that i) at each time step a new node is added to the system, and ii) that this new node connects to a node *i* already present with a probability $\Pi(i)$. In the Bianconi and Barabási model, $\Pi(i)$ depends on the node degree $k_i$ and on the node fitness $\eta_i$ ("generalized preferential attachment"), being the fitness a concept that models the "attractiveness" of a node. On the one hand, such model based on fitness can be mapped to a Bose gas and, consequently, the thermodynamic theory can be used to study its complexity. Based on this mapping, networks can show Bose-Einstein condensation, which explains the emergence of super hubs (nodes with a very high degree). On the other hand, complexity is characterized by its non trivial structural properties which can be quantified by an entropy measure of randomized network ensembles. Starting from the works defining the Shannon entropy of a network ensemble and evaluating how it relates to the Gibbs and von Neumann entropies of network ensembles, this talk discussed the relationship between entropy and scale-free networks. The hypothesis is that real networks are single instances of an ensemble of possible networks which would equally well perform the function of the existing network. It turns out that the complexity of a real network is a decreasing function of the entropy of this ensemble and scale-free network ensembles with low power law exponent have a low entropy. The key research challenge is to advance in finding an answer to the question "How complex is a complex network?". Is it the constraint induced by the distribution associated to the degree, or the degree-degree correlation that defines the level of complexity of complex networks?

**Sergey Dorogovtsev** (University of Aveiro, Aveiro, Portugal, and Ioffe Institute, St. Petersburg, Russia) presented the talk entitled "**Solution of the explosive percolation quest**". This talk proposes an analytical model to demonstrate that the so-called "explosive percolation" in complex networks is not explosive but continuous. The modern understanding of disordered systems in statistical and condensed matter physics is essentially based on the notion of percolation. When one increases progressively the number of connections between nodes in a network, above some critical number (percolation threshold) a giant connected (percolation) cluster emerges in addition to finite clusters. This percolation cluster contains a finite fraction of nodes and links in a network. Until recently, the percolation phase transitions were believed to be continuous. However, in the work by D. Achlioptas et al. (2009), a remarkably different, discontinuous phase transition was reported in a new so-called "explosive percolation" problem. Each link in this problem is established by a specific optimization process. Employing strict analytical arguments and numerical calculations, it can be shown that the explosive percolation transition is continuous though with a uniquely small critical exponent of the percolation cluster size. The key research challenge here is, thanks to the observed properties of this phase transition, to further explore this class of irreversible systems.

**Marián Boguñá** (University of Barcelona, Barcelona, Spain) presented the talk entitled "**The hidden hyperbolic structure of the Internet**". This talk provides strong empirical evidences that it is possible to construct a graph that reproduces with a high accuracy the hidden space properties of the observable Internet topology. Such network model combines the small-world effect, scale-free degree distributions, and high clustering coefficient with metric properties. These evidences are corroborated by the the scale-free and highly clustered properties of the Internet topology. It has been further observed that the properties of this hidden structures define a metric space that is hyperbolic (negatively curved). In this space, greedy routing strategies achieves the optimal performance without requiring detailed non-local knowledge of the network topology. In other words, greedy embedding of the real Internet graph offers a readily available solution for inter-domain routing. One key research challenge is to find a way so that a network node can compute its hyperbolic coordinate without global knowledge of the topology.

**Fragkiskos Papadopoulos** (Cyprus University of Technology, Lemesos, Cyprus) presented the talk entitled "**Greedy forwarding in the Internet using its metric structure**". This talk exploits the metric space lying underneath the observable (AS) Internet topology is negatively curved, i.e., hyperbolic, so as to facilitate greedy forwarding with efficiency characteristics close to theoretically best possible. Indeed, as already commented in the previous talk, a mechanism to efficiently forward packets inside a network without requiring that nodes have a global view of the network topology is to build a metric space and then assign coordinates to nodes so that they can forward packets greedily based on distances in that space. The performance however depends strongly on the relation, if any, between the observable network topology and the geometry of the underlying space. Some greedy forwarding properties in hyperbolic space are: 1) simple greedy forwarding strategies are quite robust to disturbances in the topology, and to topology growth; 2) new ASs can compute their coordinates using localized techniques; 3) large percentage of greedy paths are automatically policy-compliant; 4) no congestion side effects. Some of the key research challenges are: 1) find improved embedding techniques and/or more sophisticated greedy forwarding strategies that would always yield 100% success rate, low stretch, being robust to network dynamics and evolution, and 100% policy compliant; 2) add traffic engineering considerations; 3) find a mapping functionality to translate destination IP addresses to coordinates; 4) study incremental deployment and interoperability issues (could we use such an approach in conjunction with BGP?).

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**Nicolas Schabanel** (LIAFA University Paris Diderot, and CNRS, Paris, France) presented the talk entitled "**Decentralized routing in small worlds**". This talk compared several routing algorithms in Kleinberg's small worlds and its implications in real social networks. Kleinberg's small world model consists of a d-dimensional grid $\{-n,\ldots,n\}^d$ augmented with one "long-range" directed link per node pointing to a random node at distance *r* chosen with probability proportional to $1/r^\alpha$, where α is a parameter of the model. Kleinberg's most striking result is that only when α=d, decentralized algorithms may find short paths between random pairs. Kleinberg's model raises two main types of questions. First, from the algorithmic and peer-to-peer network design point of view, can we beat the greedy algorithm? Second, from the sociological point of view, what does this model tell us about real social networks? Three types of algorithms essentially exist: greedy, based on local exploration, and based on non-local exploration. The greedy path contains long-range links of all lengths while the two others tend to follow longer long-range links; the local exploration based algorithm tends to follow fewer long-range links than the non-local one and these are much longer. One key research challenge is to identify which algorithm is used by human/social networks and extend such results to other general smallwordization processes.

**Liam Roditty** (Bar-Ilan University, Ramat-Gan, Israel) presented the talk entitled "**A survey on distance oracles**". This talk surveyed the research on the data structures called distance oracles until the most recent advances in the field. Distance oracles are a replacement of the all-pairs shortest paths matrix of a graph by a data structure that answers distance queries in constant time. Given an n-vertex weighted undirected graph with m edges, Thorup and Zwick showed that it is possible to preprocess the graph in $O(mn^{1/k})$ time and generate a distance oracle of size $O(n^{1+1/k})$ which achieves a multiplicative stretch of 2k-1, for any integer k ≥ 1. Patrascu and Roditty's recent work presented a distance oracle with a multiplicative stretch of 2 and additive stretch of 1, whose space is $O(n^{5/3})$, which is in between the distance oracle of size $O(n^{1.5})$ for k=3 and the distance matrix of size $n^2$ for k=1. Is the stretch 2 the limit? Probably yes, if we insist on constant query time. Finally, some of the key research challenges were listed: 1) identify a linear time algorithm for constructing distance oracles; 2) understand the general trade-off (upper and lower bounds); 3) find (2,1)-stretch routing scheme with routing tables of size $n^{2/3}$; 4) study distance oracles for restricted families of directed graphs.

During the **concluding talk** several open issues and challenges were discussed: 1) explore complexity of complex networks is an open problem; 2) weighted graph models of the Internet topology would be interesting; 3) a mapping functionality from IP addresses to hyperbolic coordinates is needed; 4) coordinates are required at the level of border routers but usually models use coordinates at the AS level; 5) how multicast routing can be achieved with hyperbolic coordinates?; 6) can each node compute its coordinate without global knowledge of the Internet topology? How to perform this computation in a distributed way? In Boguña's and Papadopoulos's work, one node needs to know its neighbors and the coordinates of the neighbors, and then it can calculate its coordinates.

**TERANET 2012** workshop is expected to further advance in these topics and try to answer to some of these questions.

## Publications and talks

M. Camelo, P. Vilà, L. Fàbrega, P. Pedroso, D. Careglio, and D. Papadimitriou, "Functional Model of a Routing System Architecture", *1st Int. Workshop W-FIERRO 2011*, Cartagena, Spain, July 7-8, 2011.

I. Abraham, and C. Gavoille, "On approximate distance labels and routing schemes with affine stretch", in Proc. 25th Int. Symp. DISC 2011, Roma, Italy, September 20-22, 2011.

D. Papadimitriou, and B. Sales, "A path towards strong architectural foundation for the internet design", *2nd ETSI Workshop on Future Network Technologies*, Sophia Antipolis, France, September 26-27, 2011.

## How the EULER project is progressing?

The EULER project, started on October 1st, 2010, completed the fourth quarter of the 3-year project duration.

A plenary project meeting took place on 7-9 November 2011 at Universitat Politécnica de Catalunya, Barcelona, Spain. It consisted of two-days and half meeting. The first full day has been dedicated to routing system modelling with dedicated groups working on functional model and information model. Two parallel sessions on Topology modelling and Routing algorithms based on Greedy and Compact schemes have been the topics of the discussions during the second day. Finally, the last day focussed on the experimental and simulation evaluation and comparison of routing protocols.

The hierarchical decomposition of the functional model for the routing system architecture has been finalized as well as its application to selected compact and greedy schemes. The information model valid for all distributed routing schemes has been also completed. In addition, researches on new and more efficient compact and greedy routing schemes are ongoing.

A significant research effort has been putted on Internet topology modelling. An intra- and inter-tier analysis of the topology properties of the Internet network (at the AS level), using the CAIDA maps, have been performed. The purpose is to use the measured properties in order to develop a tier-based topology model for the Internet. On the other hand, progress on the study of graph properties (e.g. asymptotic modularity, hyperbolicity) has been obtained. Studies on Internet measurements continue with emphasis on the evaluation of dynamics, path stability, scalefree-ness, and diffusion phenomena among P2P networks.

Several partners continued the development of experimental tools and described their characteristics in D4.2 "Experimental methodology, scenarios, and tools". In particular, the development of the DRMSim simulator continues now including a routing model, a system model and a metric model and allows customized simulation scenarios. In addition, ad-hoc experimental activities are in progress such as comparisons between different greedy embeddings and topology dynamics modelling.

In the context of dissemination activities, D5.2 "Dissemination Plans" has been finalized and delivered in month 12. The document is organized in two parts and reports the dissemination plans (Part 1) as well as the dissemination activities performed during the first year of the project (Part 2). It is worth mentioning that IT tools continue to be enhanced: javascript-based math equation rendering tool has been included to improve the readability of the text; public and private calendar linked with FIRE events have been included and the files repository has been secured with regular backups. Finally, Dimitri Papadimitriou (ALB), David Coudert (INRIA) and Davide Careglio (UPC) participated to the FI week held in Poznan, Poland on October 24-28, 2011.

For more information: **http://www.euler-fire-project.eu.**

## Call for Papers

**4th Int. W. on Management of the Future Internet** **10/12/2011**
http://www.manfi.org/
April 16, 2012, Maui, Hawaii, USA

**2nd Spring School in Graph Theory** **15/01/2012**
http://ssgt2012.cs.mcgill.ca/
June 11-July 6, 2012, Montreal, Canada

**13th IEEE Int. Conf. HPSR 2012** **20/01/2011**
http://hpsr2012.etf.bg.ac.rs/
June 24-27, 2012, Belgrade, Serbia

**11th Int. Symp. on Experimental Algorithms (SEA)** **25/01/2012**
http://sea2012.labri.fr/
June 7-9, 2012, Bordeaux, France

**2012 Int. Symp. SPECTS** **31/01/2012**
http://atc.udg.edu/SPECTS2012/
July 8-11, 2012, Genoa, Italy

**24th ACM Symp. SPAA** **01/02/2012**
http://www.cs.jhu.edu/~spaa/
June 25-27, 2012, Pittsburgh, PA, USA