INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team D-NET

Dynamic Networks

Grenoble - Rhône-Alpes

Theme : Networks and Telecommunications

Activity Report

2009

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D-NET is a common project with CNRS, ENS Lyon, University of Lyon. The team has been created on July,1st 2009.

1. Team

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2. Overall Objectives

2.1. Overall Objectives

The main goal of the D-NET team is to lay solid foundations to the characterization of dynamic networks, and to the field of dynamic processes occurring on large scale interaction networks. In order to develop tools of practical relevance in real-world settings, we propose to ground our methodological studies on real data sets obtained through large scale in situ experiments.

Let us consider the example of health science and public health policy. The spread of infectious diseases remains an urgent public health issue. All spreading models validity crucially depend on our ability to understand and describe the interactions among individuals in the population. Building this knowledge requires the availability of individuals interaction records. Only recently it has become possible to study large scale interaction networks, such as collaboration networks, e-mail or phone call networks, sexual contacts networks, *etc.* This has prompted many research efforts in complex network science, mainly in two directions. First, attention has been paid to the network structure, considered as static graphs. Second, a large amount of work has focused on the study of spreading models in complex networks, which has highlighted the role of the network topology on the dynamics of the spreading. However, the dynamics of the networks, *i.e.*, topology changes, and in the networks, *e.g.*, spreading processes, are still generally studied separately. There is therefore an important need developing tools and methods for the joint analysis of both dynamics.

The D-NET project emphasizes the cross fertilization between these two research lines which should definitively lead to considerable advances. The D-NET project has the following fundamental goals:

1. To develop distributed measurement architectures based on sensor networks in order to capture physical phenomon in space and time;
2. To develop the study of dynamic interaction networks, through the design of specific tools targeted at characterizing and modeling their dynamic properties.
3. To study dynamic processes occurring in dynamic networks, such as spreading processes, taking into account both the dynamics of and in the network structure.
4. To apply these theoretical tools to large scale experimental data sets.
5. to set up and foster multidisciplinary collaborations in order to study these interaction networks in their original context.

Most activity on complex networks has up to now focused on static networks, the characterization of their structure, and the understanding of how their structure influences dynamic processes such as spreading phenomenon. The important step that the D-NET project wants to undertake is to consider that the networks themselves are dynamic entities. Their topologies evolve and adapt in time, possibly driven by or in interaction with the dynamic process unfolding on top of it. Measuring this dynamic is now affordable mainly thanks to the deployment of sensor networks that can be deployed close to the physical interacting objects. As an example, in the MOSAR context, sensors measure contacts between individuals. The resulting dataset is an opportunity to develop analysis methods and tools directly connected to real-world situations and adapted to the specific context from where the dataset is issued. Still in the MOSAR context, a better understanding of dynamic processes on dynamic interaction networks should help the development of appropriate response measures and protocols to the spreading of AMRB.

The D-NET project therefore addresses both very fundamental and very applied aspects that are tightly linked. On one hand, to develop knowledge in the networking field, in order to provide a better understanding of dynamic graphs. This fundamental work is grounded on real world large scale dynamic networks. On the other hand, to help develop a better understanding of the physical objects and networks that are studied. This point requires the joint study of both dynamics of the network and in the network, and requires a tied collaboration with the research disciplines where the objects come from.

The impact of the research developed in D-NET goes beyond the context of disease spreading studied within the MOSAR context, thanks to the inherent interdisciplinary of the complex networks research field. Dynamic processes on dynamic networks are indeed present in numerous fields, including rumor spreading in social networks, opinion formation, fashion phenomena, the innovation diffusion in a population, *etc.* The spread of computer viruses may take place through email networks or bluetooth connections, which are both dynamical. The development of efficient algorithms for information spreading in wireless/P2P/DTN networks should also be improved by the understanding of the dynamics of these networks and their temporal properties. The study of all these processes should benefit from the tools developed in this project. It represents an important opportunity to study real-world dynamic processes occurring on interaction networks whose dynamics can be measured.

2.2. Highlights

Tubexpo & MOSAR. 2009 has been the witness of the deployment of large scale in situ sensor network experimentations within the Life Science & Health context. The first in situ experiment took place within the AFSSET[1] Tubexpo project. The main goal of the Tubexpo project is to measure the exposure of health care workers to the tuberculosis. Within this context, two experiments of 3 months implying more than 100 persons were conducted at the Bichat-Claude Bernard Hospital and at the La Pitié-Salpétrière Hospital.

Another experiment was also conducted from May 2009 to November 2009 in the context of the IP LSH MOSAR project. The goal of MOSAR is to better understand the dynamic of AMRB[2] transmission. The experiment conducted at the Hospital Maritime de Berck gathered more than 500 people and was the subject of several press covers.

SensLAB Launch of the SensLAB platform. The first 256 sensor nodes open testbed platform was open on Nov 2009. For the occasion, the first SensLab tutorial was organized.

3. Scientific Foundations

3.1. Sensor network, distributed measure and distributed processing

Participants: Guillaume Chelius, Eric Fleury, Andreea Chis.

[1] Agence Française de Sécurité Sanitaire de l'Environnement et du Travail
[2] Antibiotic Multi Resistant Bacteria

Sensor network for distributed embedded measure. In order to gather information on the dynamic of a specific physical phenomena, a distributed embedded measure must be performed. The quality of the measure is crucial and largely impacts the analysis. Moreover, by conducing and controlling the measure and its bias during the experiment, one may adapt and optimize the analysis.

Sensors networks offer an efficient way to measure physical phenomena at various space and time scales. The important challenge is to take advantage of a communicating sensor node that can be associated to a physical object in order to design a large scale distributed measurement system that can monitor and sense the physical world. Given a target application, the goal is to design adequate sensor nodes and to set up the way they communicate, cooperate and collect their data in order to fulfill the application constraints. Fulfilling this goal requires the development of theoretical and practical techniques to help the dimensioning and deployment of such distributed sensing tools, to manage the distributed measures and to perform efficient and reliable distributed computing on top of the network. With these main tasks in mind, we define the following objectives:

Design of a global sensing tool. Based on the deployment context, we should propose a methodology to design the most appropriate and accurate measurement architecture that matches the application constraints. Heterogeneity is a fundamental, beneficial quality of distributed sensing tool, not just a problem to overcome. Heterogeneous sensing systems are more immune to the weaknesses of sensing modalities and more robust against defective, missing, or malicious data sources than even carefully designed homogeneous systems. However, data heterogeneity also presents main challenges when trying to integrate data from many different sensors.

Measure characterization and dimensioning. Measure characterization and dimensioning must take into account the different correlations in space and time that exist between all sensors. It must also handle the various time scales that may exist in the measures. The challenge is due to the heterogeneous data resolution. Moreover, data is generally multi modal and multi scale with possible irregularities and offer much correlation in time and/or space. Data sets collected by various sensors may be characterized by the lack of most common simple statistical properties such as stationary, linearity, or Gaussianity. Relevant time scales may be difficult to identify, or may even not exist. Observed properties have non-trivial relations and even the choice of the time scale granularity that should be used in the measure and the analysis is a complex problem as it may bias the analysis in an uncontrolled way.

In-network distributed processing. As some computation can be delocalized closer to the sensed phenomena, in the sensor nodes, space/time correlations can be exploited in order to optimize the amount of data sent through the network.

3.2. Statistical Characterization of Complex Interaction Networks

Participants: Guillaume Chelius, Eric Fleury, Adrien Friggeri.

Evolving networks can be regarded as "*out of equilibrium*" systems. Indeed, their dynamics is typically characterized by non standard and intricate statistical properties, such as non-stationarity, long range memory effects, intricate space and time correlations.

The dynamics of complex networks often exhibit no preferred time scale or equivalently involve a whole range of scales and are characterized by a scaling or scale invariance property. Another important aspect of network dynamics resides in the fact that the sensors measure information of different nature. For instance, in the MOSAR project, inter-individual contacts are registered, together with the health status of each individual, and the time evolution of the resistance to antibiotics of the various strains analyzed. Moreover, such information is collected with different and unsynchronized resolutions in both time and space. This property, referred to as multi-modality, is generic and central in most dynamical networks. With these main challenges in mind, we define the following objectives.

From "primitive" to "analyzable" data: Observables. The various and numerous modalities of information collected on the network generate a huge "*primitive*" data set. It has first to be processed to extract "*analyzable data*", which can be envisioned with different time and space resolutions: it can concern either local quantities, such as the number of contacts of each individual, pair-wise contact times and durations, or global measures, *e.g.*, the fluctuations of the average connectivity. The first research direction consists therefore in identifying, from the "primitive data", a set of "analyzable data " whose relevance and meaningfulness for the analysis of network dynamic and network diffusion phenomena will need to be assessed. Such " analyzable data " needs also to be extracted from large " primitive data " set with " reasonable " complexity, memory and computational loads.

Granularity and resolution. The corresponding data will take the form of time-series, "condensing" network dynamics description at various granularity levels, both in time and space. For instance, the existence of a contact between two individuals can be seen as a link in a network of contacts. Contact networks corresponding to contact sequences aggregated at different analysis scales (potentially ranging from hours to days or weeks) can be built. However, it is so far unclear to which extent the choice of the analysis scale impacts the relevance of network dynamics description and analysis. An interesting and open issue lies in the understanding of the evolution of the network from a set of isolated contacts (when analyzed with low resolution) to a globally interconnected ensemble of individuals (at large analysis scale). In general, this raises the question of selecting the adequate level of granularity at which the dynamics should be analyzed. This difficult problem is further complicated by the multi-modality of the data, with potentially different time resolutions.

(non-)Stationarity. Stationarity of the data is another crucial issue. Usually, stationarity is understood as a time invariance of statistical properties. This very strong definition is difficult to assess in practice. Recent efforts have put forward a more operational concept of relative stationarity in which an observation scale is explicitly included. The present research project will take advantage of such methodologies and extend them to the network dynamics context.

The rationale is to compare local and global statistical properties at a given observation scale in time, a strategy that can be adapted to the various time series that can be extracted from the data graphs so as to capture their dynamics. This approach can be given a statistical significance via a test based on a data-driven characterization of the null hypothesis of stationarity.

Dependencies, correlations and causality. To analyze and understand network dynamics, it is essential that (statistical) dependencies, correlations and causalities can be assessed among the different components of the " analyzable data ". For instance, in the MOSAR framework, it is crucial to assess the form and nature of the dependencies and causalities between the time series reflecting e.g., the evolution along time of the strain resistance to antibiotics and the fluctuations at the inter-contact level. However, the multimodal nature of the collected information together with its complex statistical properties turns this issue into a challenging task. Therefore, Task1 will also address the design of statistical tools that specifically aim at measuring dependency strengths and causality directions amongst mutivariate signals presenting these difficulties. The objective is to provide elements of answers to natural yet key questions such as : Does a given property observed on different components of the data result from a same and single network mechanism controlling the ensemble or rather stem from different and independent causes? Do correlations observed on one instance of information (e.g., topological) command correlations for other modalities? Can directionality in correlations (causality) be inferred amongst the different components of multivariate data? These should also shed complementary lights on the difficulties and issues associated to the identification of " important " nodes or links...

3.3. Theory and Structural Dynamic Properties of dynamic Networks

Participants: Guillaume Chelius, Eric Fleury, Qinna Wang.

Characterization of the dynamics of complex networks. We need to focus on intrinsic properties of evolving/dynamic complex networks. New notions (as opposed to classical static graph properties) have to be introduced: rate of vertices or links appearances or disappearances, the duration of link presences or absences. Moreover, more specific properties related to the dynamics have to be defined and are somehow related to the way to model a dynamical graph.

To go further in the Classical graph notions like the definition of path, connected components and k-core have to be revisited in this context. Advanced properties need also to be defined in order to apprehend the intrinsic dynamic structural issues of such dynamic graphs. The notion of communities (dense group of nodes) is important in any social / interaction network context and may play an important role within an epidemic process. To transpose the static graph community concept into the dynamical graph framework is a challenging task and appears necessary in order to better understand how the structure of graphs evolves in time. In these contexte we define the following objectives:

Toward a dynamic graph model and theory. We want to design new notions, methods and models for the analysis of dynamic graphs. For the static case, graph theory has defined a vast and consistent set of notions and methods such as degrees, paths, centrality measures, cliques. These notions and methods are completely lacking for the study of dynamic graphs; not only do we not have basic notions allowing the description of a graph and its dynamics, but we also lack the basic definitions and algorithms for manipulating dynamic graphs. Our goal is therefore to fill this lack, by providing the basic notions for manipulating dynamic graphs as well as the notions and indicators to describe its dynamic meaningfully (as complex networks theory does for static complex networks).

Dynamic communities. The detection of dynamic communities is particularly appealing to describe dynamic networks. In order to extend the static case, one may apply existing community detection methods to successive snapshots of dynamic networks. This is however not totally satisfying for two main reasons: first, this would take a large amount of time (directly proportional to the data span); moreover, having a temporal succession of independent communities is not sufficient and we loose valuable information and dependencies. We also need to investigate the temporal links, study the time granularity and look for time periods that could be compressed within a single snapshot.

Tools for dynamic graph visualization. Designing generic and pure graph visualization tools is clearly out of the scope of the D-NET project. Efficient graph drawing tools or network analysis toolkit/software are now available (e.g., GUESS, TULIP, Sonivis, Network Workbench). However, the drawback of most softwares is that the dynamics is not taken into account. Since we will study the hierarchy of dynamics through the definition of communities we plan to extend graph drawing methods by using the communities' structures. We also plan to handle the time evolution in the network analysis toolkit. A tool like TULIP is well designed and could be improved by allowing operations (selection, grouping, sub graph computation...) to take place on the time dimension as well.

4. Application Domains

4.1. Life Science & Health

In parallel to the advances in modern medicine, health sciences and public health policy, epidemic models aided by computer simulations and information technologies offer an increasingly important tool for the understanding of transmission dynamics and of epidemic patterns. The increased computational power and use of Information and Communication Technologies makes feasible sophisticated modeling approaches augmented by detailed in vivo data sets, and allow to study a variety of possible scenarios and control strategies, helping and supporting the decision process at the scientific, medical and public health level. The research conducted in the D-NET project finds direct applications in the domain of LSH since modeling approaches crucially depend on our ability to describe the interactions of individuals in the population. In the MOSAR project we are collaborarting with the team of Pr. Didier GUILLEMOT (Inserm/Institut. Pasteur/Université de Versailles). Within the TUBEXPO project, we are collaborationg with Pr. Jean-Christopge Lucet (Professeur des universités Paris VII – Praticien hospitalier APHP).

4.2. Complex networks

In the last ten years, the study of complex networks has received an important boost with large interdisciplinary efforts aimed at their analysis and characterization. Two main points explain this large activity: on the one hand, many systems coming from very different disciplines (from biology to computer science) have a convenient representation in terms of graphs; on the other hand, the ever-increasing availability of large data sets and computer power have allowed their storage and manipulation. Many maps have emerged, describing many networks of practical interest in social science, critical infrastructures, networking, and biology. The D-NET project targets the study of dynamically evolving networks, from the point both of their structure and of the dynamics of processes taking place on them.

4.3. Biologging

The research conducted in the D-NET project finds direct applications in the domain of bio-logging. Bio-logging consists in equipping animals with tracking and sensing devices such that its mobility, environmental conditions and social interactions can be monitored. In the Dispop project and in collaboration with the DEPE of the IPHC, the D-NET project is active in the biologging field, more particularly on three principal topics : the design of efficient sensing devices, also called biologgers, the conception of a generic trajectometry software and the design of analytical tools for the study of social interactions in an animal population.

4.4. Biomechanics, physiology and sport

The research conducted in the D-NET project finds direct applications in the domains of bio-mechanics, physiology and sport. In the context of the SensTools project, the D-NET has contributed to the design of a distributed multi-sensor architecture that can be worn by an individual and that records bio-mechanical, physiological and environmental data. Deployment of this architecture will take place during the 25th Marathon des Sables.

5. Software

5.1. WSNet

Participant: Guillaume Chelius [correspondant].

WSnet is a wireless sensor network simulator that was designed to offer the following features:

- a modular, flexible and accurate simulation of the radio physical medium;
- support for the simulation of environmental phenomena;
- support for interaction between nodes and their environment (sensor-actuator architecture);
- interconnection with the sensor platform emulator WSim to support the distributed emulation of wireless sensor networks.

WSNet is currently in its second release. The number of WSNet users is still growing and several research works reference the software. Many pointers can be found on the project website. Maintenance and support of the software is handled by the D-NET project but also by several contributors from the CITI laboratory (INSA de Lyon), Orange R&D. The WSNet community is quietly spreading in France as well as abroad.

5.2. WSNet-3

Participant: Guillaume Chelius [correspondant].

Driven by the feedback gathered among WSNet users, we have started the development of the third WSNet release. While still private, the project web page is available. The objectives behind this new development is:

- to ease the simulation of new radio architectures / standards : *e.g.* MIMO schemes, UWB, multi-interfaces system;
- to ease the writing of new modules through the use of *High Level Languages* such as Python or Ruby for the development of protocols, *etc* ;
- to ease the debugging and compilation of results during a simulation.

These developments are handled by a core of developers from different affiliations (INSA de Lyon, Orange R&D, INRIA) lead by the D-NET team.

5.3. Dispop

Participant: Guillaume Chelius [correspondant].

The objective of this development is the design of a generic trajectometry software that can study the trajectory of individuals based on location tracking technologies such as ARGOS or GPS, as well as the spatial dynamics of the population and the environmental factors that rule these dynamics. More specifically, at that time, we propose software resources that can:

- import data from classical location tracking technologies such as ARGOS or GPS
- filter errors on location records
- interpolate trajectories
- perform statistical analysis on trajectories

Numerous further developments are planned, from minor ones, such as the addition of new interpolation methods, to major ones, such as the parallel study of several individuals to derive population dynamics and to investigate the environmental factors driving the dynamic. This project is leaded through a collaboration with CNRS researchers in biology and ecology at the IPHC (Strasbourg, France). The project web page is available on the INRIA Gforge.

5.4. SensTOOLS

Participants: Eric Fleury [correspondant], Loïc Lemaître [ADT SensTOOLS].

The main and most important goal of the SensTOOLS ADT project (See also http://www.senstools.info/) is to foster the design, development, tuning, and experimentation of real large scale sensor network applications. Sensor networks have recently emerged as a premier research topic. However, due to their massively distributed nature, the design, implementation, and evaluation of sensor network applications, middleware, and communication protocols are difficult time-consuming tasks. The purpose of the SensTOOLS is to provide both software and hardware toolboxes in order to offer the developer appropriate tools and methods for designing, testing and managing his/her large scale wireless sensor network applications. D-NET contributes to teh SensTOOLS project by developping and maintening the developpment tool suite (WSIM and WSNET). D-NET also contributes to the developpemnt of devices and librairies (portage of SimpliciTY, portage of Contiki OS, FreeRTOS, TinyOS).

6. New Results

6.1. Simulation of wireless sensor networks

In wireless multi-hop networks (i.e., ad hoc, sensor and mesh networks), there is a growing need for the performance evaluation of protocols and distributed applications. Three main methodologies are generally adopted to investigate the performance and the behavior of networking protocols: theoretical analysis, experimentation and simulation. Due to the high complexity of wireless communications, analytical studies are often based on unrealistic assumptions and inaccurate physical layer, e.g., the so-called Unit Disk Graph model. The experimentation approach may provide valuable insight into the performance and the behavior of wireless systems, however, setting-up testbeds is a tedious and expensive task. At the end, simulations are generally considered as the most convenient methodology to explore the behavior of protocols and distributed applications. Nonetheless, the complexity of the physical phenomena constituting the radio medium (PHY) introduces a tradeoff between accuracy and computational cost in wireless network simulation. In [6], we have focused on the physical layer modeling issue and we have investigated its impact on the accuracy and the complexity of wireless network simulations. The question we have raise is *what is the real cost of PHY simulation accuracy ?* We have deliberately kept aside optimizations and scalability of the node and protocol aspects of simulations which have been the subject of other studies. We have used a flexible and modular simulation framework, WSNet, to evaluate the PHY tradeoff and better understand the impact of the PHY layer on the obtained simulation results.

6.2. Interference modeling in multi-hop wireless networks

As interference plays a crucial role in ad hoc networks, these networks are often referred to as interference limited networks. Indeed, the network capacity is related to the radio channel reuse which is limited by the interference. As interference results from the summation of signals issued by concurrent transmitters, it strongly depends on the transmitters location. The point process used to model the nodes location is thus fundamental in any study of such networks. In previous works, the spatial distribution of the radio nodes has generally been modeled thanks to a Poisson point process. However, the Poisson point process is accurate for very sparse networks only and suffers from a lack of realism in dense ones. It relies on the assumption that transmitters are independently distributed whereas in practice, the Medium Access Control (MAC) protocol defines medium access rules to avoid collisions and by this way introduces a spatial correlation between the transmitters. Therefore, the spatial independence does not hold. Recent works already tackle this problem by modifying the initial Poisson process according to the mechanisms of a CSMA/CA protocol and use the well known Matérn point process. However, this approach still suffers from two strong limitations. First, it tends to underestimate the number of concurrent transmitters and as a consequence, the interference level is strongly under-estimated in dense networks. Second, it assumes that a transmitter defers its transmission if it detects a busy medium due to the nearest previously selected transmitter. Albeit, medium access policies may rely either on carrier detection or on energy level. In the case of carrier detection, the inhibition model can be effectively related to the strongest signal, according to the Matérn selection process. However, in the case of energy detection, the candidate transmitter does not defer its transmission according to the strongest interference but rather to the interference level induced by all effective transmitters. In this case, the inhibition process should be related to all concurrent transmitters and inhibition balls are not adequate. In [12], we investigate original processes that comply with the CSMA/CA policies. We propose the use of the *Simple Sequential Inhibition* point process to model CSMA/CA networks where carrier detection depends on the strongest emitter only. This point process is then extended to a family of new point processes modeling effective transmitters in a busy medium detection mode based on the strength of all concurrent signals. The impact of these different models on the interference distribution is evaluated and we highlight large variations with respect to the different point processes. In particular, we show that the use of a Poisson process is generally inaccurate to model CSMA/CA networks. We finally study the theoretical Bit Error Rate resulting from the different point processes.

6.3. Tuberculosis exposition

In parallel to the advances in modern medicine, health sciences and public health policy, epidemic models aided by computer simulations and information technologies offer an important alternative for the understanding of transmission dynamics and epidemic patterns. In this work, we have focused on the first steps that may lead towards the design of accurate epidemic models, i.e. the measure and analysis of interactions within a closed socio-professional context. More precisely, this project was motivated by the study of the Health Care Workers (HCWs) exposure to tuberculosis in their work environment.

Despite the progresses in treatment and prevention, tuberculosis remains a disease in expansion and represents the third cause of death by infectious pathologies in the world. In the health care context, if the transmission is globally controlled, the HCWs exposure remains obscure. Individual factors associated to the contamination of HCWs in their work environment are not precisely known. Our study has focused on the evaluation of the intensity and the frequency of contacts between tuberculosis infected patients and HCWs. To gather this information, classical methods consist in performing audits, consulting medical and administrative files or using self-reports of conversations and trusting HCW souvenirs. All these methods are time-consuming, subject to memory failures and interpretations. As an alternate method, we have chosen to dedicate a Wireless Sensor Network (WSN) to gather these interactions inside a Service of Infectious and Tropical Diseases (Bichat-Claude Bernard Hospital, Paris) and a Service of Pneumology (La Pitié Salpétrière Hospital, Paris). Within the two services, each room has been equipped with a sensor node and each HCW carries an autonomous sensor during his presence in the service. An important characteristic of this measurement campaign is that it was performed in a closed environment, over a closed population and during a large continuous period of time. That is, the presence of all HCWs of the units was monitored in all patient rooms, 24/7 during a three months period: january to april for Bichat and Mai to August for La Pitié Salpétrière. In addition to the experimental deployment, we have started analyzing and characterizing in [19], [13] this huge and unique data set describing a complex dynamic interaction network. More results are expected in 2010.

6.4. Dynamic network analysis

During the last decade, the study of large scale complex networks has attracted a substantial amount of attention and works from several domains: sociology, biology, computer science, epidemiology. This emerging domain has proposed a large set of tools that can be used on any complex network in order to get a deep insight on its properties and to compare it to other networks. Such *fundamental* properties are used as characterization parameters in the study of various problems such as virus spreading in the epidemiology context, or information / innovation diffusion for instance. Whereas most of such complex networks are inherently dynamic, this aspect has less been studied. Most approaches consider *growing models*, such as the preferential attachment model or analyze the aggregation of all interactions. Both approaches may miss the real dynamic behavior while there is a strong need for dynamic network models in order to sustain protocol performance evaluations and fundamental analyzes.

In [10], we address the description and the simulation of sensor mobility networks (interaction networks like the one we'll need to analyze within the MOSAR context). The proposed methods come from various research domains (signal processing, graph theory and data mining). This emphasizes the necessity of interdisciplinary research since dynamic networks are becoming a central point of interest, not only for engineers and computer scientists but also for people in many other fields.

We introduce some simple methods to describe the network dynamics and propose models of dynamic networks :

1. We study graph properties as function of time to provide an empirical statistical characterization of the dynamics.
2. We also compute global indicators from the dynamics of the network (connected components, triangles, and communities).
3. We propose models to perform random dynamic networks simulations.

The descriptive analysis show that link (or edge) creation and deletion processes is mostly independent of other graph properties and that such networks exhibit a large number of possible configurations, from sparse to dense. From those observations, we propose simple yet accurate models that allow to generate random mobility graphs with similar temporal behavior as the one observed in experimental data.

In [11] we study another dynamic complex network comming from community shared bicycle systems, namely the Vélo'v program launched in Lyon in May 2005. Such a network is a public transportation programs that can be studied as a complex system composed of interconnected stations that exchange bicycles. They generate digital footprints that reveal the activity in the city over time and space, making possible a quantitative analysis of people's movements. A careful study relying on nonstationary statistical modeling and data mining is done to first model the time evolution of the dynamics of movements with V´elo'v, that is mostly cyclostationary over the week with nonstationary evolutions over larger time-scales, and second to disentangle the spatial patterns to understand and visualize the flows of V´elo'v bicycles in the city. This study gives insights about social behaviors of the users of this intermodal transportation system, the objective being to help in designing and planning policy in urban transportation.

6.5. Routing, deploying in network processing

In [15] xe consider a system composed of a set of mobile sensors, disseminated in a region of interest, which mobility is controlled (as opposed to mobility imposed by the entity on which they are embedded). A routing protocol in this context enables any point of the region to be reached. The strength of our proposition Grasp (GReedy stAteless Routing Protocol), beyond its simplicity, is that routing enables a free and close to optimal self-deployment of sensors over a given region. Grasp transparently copes with dynamic changes of the region of interest. In addition, Grasp is independent from the underlying communication model. Grasp ensures (i) that routing is always possible in a mobile WSN irrespective of the number of sensors and (ii) above a given number of sensors in a considered zone, the protocol eventually ensures that routing does no longer require sensors to move, thus providing self-deployment. In one dimension, Grasp converges to a full connected-coverage of the region with the minimum required number of sensors in a finite number of steps, ensuring an optimal deployment. In two dimensions, sensors reach autonomously a stable full coverage following geometrical patterns. This requires only 1.5 the optimal number of sensors to cover a region. A theoretical analysis of convergence proves these properties in one and two dimensions. Some simulation results matching the analysis are also presented.

In [9], [18], we provide a first analysis of the space and time correlations of the collected *live E!* measurements. We propose an original synchronous average-based model to decompose each time series in order to separate dependencies stemming from expected cyclic trends, such as seasonal (year) and daily effects from dependencies actually observed on residual fluctuations. Then, we investigate the auto- and cross- correlations of both the measurements observed at a given weather station and between measurements collected at adjacent stations.

6.6. Cross layer optimization

The desired behavior of embedded systems is usually subject to real-time constraints and it involves interactions with a set of physical devices or components, each with its own individual constraints. The general formalism of timed automata allows expressing the expected software behavior of a device in the form of a finite state automaton extended with real-valued variables called clocks. The particular constraints of physical devices themselves can also be expressed in this form. In this context, our goal is to provide an optimized mapping of a software protocol on a hardware device by taking advantage of all various low-power consumption states when possible, thus taking a cross-layer approach on the problem of energy consumption minimization. Generally the software to hardware mapping does not take benefit from all low-level functionality since it implies to ensure complex time constraints. In [14] we address the problem of mapping the free states of a software protocol expressed as a timed automaton to a physical device whose behavior is also expressed as an automaton with states of fixed or unbounded (but with lower limit constraint) duration. We propose a methodology that allows a mapping of those free states to unique states or paths between states in the device automaton with distinct edges, that guarantee that all the time constraints are met and all feasible transitions in the protocol automaton remain realizable, all while minimizing the energy consumed.

7. Contracts and Grants with Industry

7.1. Alcatel-Lucent / INRIA Lab

Participant: Eric Fleury.

D-NET is participating in the research action SeflNet of the Alcatel-Lucent / INRIA common lab. The Selnet research action is leaded by Bruno GAUJAL from the INRIA MESCAL project and Olivier Marce from Alcatel Lucent.

8. Other Grants and Activities

8.1. Regional Initiatives

8.1.1. ESPAD (FEDER)

Participants: Guillaume Chelius, Rodolphe Heliot.

The ESPAD (Embedded Sport Performance Analysis Data) is bio-mechanics / physiology logging project funded by FEDER. The goal is to contributed to the design of a distributed multi-sensor architecture that can be worn by an individual and that records bio-mechanical, physiological and environmental data.

8.1.2. Dispop (IXXI)

Participant: Guillaume Chelius [Prime Investigator].

Dispop is a biologging project funded by the Rhône-Alpes Institute of Complex Sciences. Bio-logging consists in equipping animals with tracking and sensing devices such that its mobility, environmental conditions and social interactions can be monitored. This project's goal is more particularly to explore and develop the measure and analysis tools which could help in modeling the dynamic of populations as a response to environmental factors. This project hosts members of the D-NET team and the DEPE – Département Ecologie, Physiologie et Ethologie department of the IPHC – Institut Pluridisciplinaire Hubert Curien (Strasbourg, France).

8.2. National Initiatives

8.2.1. SensLAB (ANR)

Participants: Eric Fleury [Prime Investigator], Guillaume Chelius, Jean-Pierre Poutcheu.

The purpose of the SensLAB project is to deploy a very large scale open wireless sensor network platform. SensLAB's main and most important goal is to offer an accurate and efficient scientific tool to help in the design, development, tuning, and experimentation of real large-scale sensor network applications. The sensLAB platform is distributed among 4 sites and is composed of 1,024 nodes. Each location hosts 256 sensor nodes with specific characteristics in order to offer a wide spectrum of possibilities and heterogeneity. The four test beds are however part of a common global testbed as several nodes will have global connectivity such that it will be possible to experiment a given application on all 1K sensors at the same time.

8.2.2. SensTOOLS (INRIA ADT)

Participants: Eric Fleury [Prime Investigator], Guillaume Chelius.

The main and most important goal of the SensTOOLS ADT project is to foster the design, development, tuning, and experimentation of real large scale sensor network applications. Sensor networks have recently emerged as a premier research topic. However, due to their massively distributed nature, the design, implementation, and evaluation of sensor network applications, middleware, and communication protocols are difficult time-consuming tasks. The purpose of the SensTOOLS is to provide both software and hardware toolboxes in order to offer the developer appropriate tools and methods for designing, testing and managing his/her large scale wireless sensor network applications.

8.3. Actions Funded by the EC

8.3.1. MOSAR (FP6 - LSH)

Participants: Eric Fleury [Scientific leader], Guillaume Chelius, Adrien Friggeri.

MOSAR is an Integrated Project supported for 5 years by the European Commission under the Life Science Health Priority of the Sixth Framework Program. Infections caused by antimicrobial-resistant bacteria (AMRB) account for an increasing proportion of healthcare-associated infections, particularly in high-risk units such as intensive care units and surgery; patients discharged to rehabilitation units often remain carriers of AMRB, contributing to their dissemination into longer-term care areas and within the community. The overall objective of MOSAR is to gain breakthrough knowledge in the dynamics of transmission of AMRB, and address highly controversial issues by testing strategies to combat the emergence and spread of antimicrobial resistance, focusing on the major and emerging multi-drug antimicrobial resistant microorganisms in hospitals, now spreading into the community. Microbial genomics and human response to carriage of AMRB will be integrated with health sciences research, including interventional controlled studies in diverse hospital settings, mathematical modelling of resistance dynamics, and health economics. Results from MOSAR will inform healthcare workers and decision-makers on strategies for anticipating and mastering antimicrobial resistance. To achieve these objectives, MOSAR brings together internationally recognized experts in basic laboratory sciences, hospital epidemiology, clinical medicine, behavioural sciences, quantitative analysis and modelling, and health economics. MOSAR brings together 11 institutions recognized for their leadership in these areas, from 10 EU Member or Associated States, as well as 7 SMEs to develop and validate high-throughput automated molecular tools for detection of AMRB.

8.3.2. WASP (FP6-IST)

Participants: Eric Fleury, Andreea Chis.

WASP is an Integrated Project supported for 4 years by the European Commission under the Information Society Technologies of the Sixth Framework Program. An important class of collaborating objects is represented by the myriad of wireless sensors, which will constitute the infrastructure for the ambient intelligence vision. The academic world actively investigates the technology for Wireless Sensor Networks (WSN). Industry is reluctant to use these results coming from academic research. A major cause is the magnitude of the mismatch between research at the application level and the node and network level. The WASP project aims at narrowing this mismatch by covering the whole range from basic hardware, sensors, processor, communication, over the packaging of the nodes, the organisation of the nodes, towards the information distribution and a selection of applications. The emphasis in the project lays in the self-organisation and the services, which link the application to the sensor network. Research into the nodes themselves is needed because a strong link lies between the required flexibility and the hardware design. Research into the applications is necessary because the properties of the required service will influence the configuration of both sensor network and application for optimum efficiency and functionality. All inherent design decisions cannot be handled in isolation as they depend on the hardware costs involved in making a sensor and the market size for sensors of a given type.

8.3.3. DYNAMO (COST 295)

Participant: Eric Fleury.

COST 295 is an action of the European COST program (European Cooperation in the Field of Scientific and Technical Research) inside of the Telecommunications, Information Science and Technology domain (TIST).

The acronym of the COST295 Action, DYNAMO, stands for Dynamic Communication Networks. The Action is motivated by the need to supply a convincing theoretical framework for the analysis and control of all modern large networks. This will be induced by the interactions between decentralised and evolving computing entities, characterised by their inherently dynamic nature.

8.4. International Initiatives

8.4.1. STIC AMSUD – Dynamics of Layered Complex Networks

Participants: Eric Fleury, Guillaume Chelius.

D-NET is a member of a STIC AMSUD project between the National Laboratory for Scientific Computing (LNCC) in Brazil, the Faculdad de Ingeniera Universidad de Buenos Aires in Argentina, Laboratoire d'Informatique de Paris 6 (LIP6) and ENS Lyon in France. The goal of the project is mainly to investigate the fundamental characteristics of dynamic graphs and their applicability to the analysis of layered complex networks.

8.5. Exterior research visitors

- Artur Ziviani from LNCC, Brazils comes to visit D-NET from septenber 2009 fo February 2009.

9. Dissemination

9.1. Dissemination

9.1.1. Leadership within scientific community

- Guillaume Chelius is member of the scientific comitee board of CNRS ECOTRON. The European Ecotron is a research platform dedicated to the study of ecosystems and organisms in the context of environmental changes .
- Eric Fleury is Co-chair of the Networking group ResCom of the CNRS GDR ASR. He also a member of the scientific comitee of the GDR ASR.
- Eric Fleury is representative for the French part of the european project COST 295.
- Eric Fleury is head of the CNRS National platform on sensor network RECAP.
- Eric Fleury is in the scientific board and in the steering comitee of the IXXI – Complex Systems Institute.
- Eric Fleury has been an expert for Swiss National Science Foundation (SNSF) and for the Natural Sciences and Engineering Research Council of Canada (NSERC).

9.1.2. Editorial boards, conference and workshop committees

- Guillaume Chelius is Guest Editor of the Eurasip JWCN Special Issue on Simulators and Experimental Testbeds Design and Development for Wireless Networks
- Guillaume Chelius is Member of the Program Committee of :
  - ACM PEWASUN 2009.
  - IEEE IWCLD 2009.
  - AlgoTel 2009.
- Eric Fleury was chair of the track "Mobility and Dynamic Networks" at SSS 2009. The 11th International Symposium on Stabilization, Safety, and Security of Distributed Systems (SSS 2009).
- Eric Fleury was co-chair of the workshop Dynamics on and of Complex Networks at ECCS 2009 (European Conference on Complex Systems).
- Eric Fleury was a PC member of :
  - VTC 2009. 69th IEEE Vehicular Technology Conference VTC2009-Spring.
  - PERCOM 2009. Seventh Annual IEEE International Conference on Pervasive Computing and Communications.
  - ICC 2009. IEEE International Conference on Communications.
  - Symposium SinFra'09. Singaporean/French IPAL Symposium.
  - NETWORKING 2009. The 8th IFIP Networking 2008 conference(NETWORKING).

  - COMSNETS. First International Conference on COMmunication Systems and NETworkS (previously known as COMSWARE).

9.1.3. Invited conferences and other talks

- Guillaume Chelius was an invited speaker at the Dynamical Complex Systems workshop at the Faculdad de Ingeniera, Universidad de Buenos Aires (Buenos Aires, Argentina)
- Guillaume Chelius is co-author of the chapters *Géométrie stochastique et modélisation* [21]
- Guillaume Chelius and Eric Fleury were invited speaker at the IP and Sensor Networks Days.
- Eric Fleury organized with the great support of all SensLAB's team the first SensLAB tutorial.
- Eric Fleury was an invited speaker at RGE, RECAP, GDR MACS.
- Eric Fleury was an invited speaker at the Dynamical Complex Systems workshop at the Faculdad de Ingeniera, Universidad de Buenos Aires (Buenos Aires, Argentina) and at LNCC (Brazil).
- Eric Fleury was an invited speaker at the National workshop on complex systems: Vers une science et ingénierie des systèmes complexes (Paris, France).
- Eric Fleury was an invited speaker at the CRIMES Workshop (Saint-Denis de La Réunion, France).
- Eric Fleury has co-edited a book on Sensor Networks [21] and was co-author on the chapter *Scheduling Activities in Wireless Sensor Networks* [22].

9.2. Teaching

- Guillaume Chelius has given the *Sensor Networks* class in the Master 2 Research *Computer Sciences* at INSA de Lyon (Lyon, France)
- Guillaume Chelius has given the *Wireless Networks* class in the Master 2 System and Networks, IFI (Hanoi, Vietnam)
- Guillaume Chelius has given the *Wireless Networks* class in the Master 2 at the Yaounde 1 University (Yaounde, Cameroun)
- Guillaume Chelius has partially given the Algorithms for Networks and Communications in the Fundamental Computer Sciences Master at Department of computer science of ENS Lyon (Lyon, France)
- Eric Fleury is a professor at ENS Lyon in the Computer Science Department since 2007. The ENS Lyon is one of the four Ecoles normales supérieures in France. Eric Fleury is in charge of the undegraduate course on Architecture, System and Networking. He was also in charge of a Master 2 course on Dynamic Complex Network.
- Until september 2009, Eric Fleury was the chair of the MASTER in fundamental computer science at ENS Lyon and in charge for the CS department of the new option in modeling complex systems.
- Since september 2009, Eric Fleury is the Head of the Computer Science Department at ENS Lyon.

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[2] E. BEN HAMIDA, H. OCHIAI, H. ESAKI, P. BORGNAT, P. ABRY, E. FLEURY. *Measurement Analysis of the Live E! Sensor Network: Spatial-Temporal Correlations and Efficient Data Aggregation*, in "IEEE 3rd International Workshop on Practical Applications of Sensor Networking, États-Unis d'Amérique Seattle", 2009, http://hal.inria.fr/inria-00398802/en/JP.

[3] P. BORGNAT, E. FLEURY, J.-L. GUILLAUME, C. ROBARDET. *Characteristics of the Dynamic of Mobile Networks*, in "4th International Conference on Bio-Inspired Models of Network, Information, and Computing Systems, France Avignon", 2009, http://hal.inria.fr/inria-00433562/en/.

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