Project-Team OCIF

Objets Communicants - Internet du Futur
Communicating Objects - Future Internet

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Activity Report

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2 Overall Objectives

2.1 Overview

The OCIF project's goal is to design a new Internet architecture and protocols to provide innovative network elements for the Internet of Things (IoT).

During the past 30 years, the Internet network has proved its evolution capabilities; from an academic network developed initially to test datagram concepts to a universal protocol that interconnects applications and services. The architecture, often represented as an hourglass[Dee11], leads to a simple protocol focused on packet forwarding and network interconnection, and a common interface between applications and transmission media. Nevertheless, this model faces criticisms related to the gained momentum, which makes the evolution of the network an extremely burdensome process, a perfect example of which is the slow adoption of IPv6.

Research works on the Internet architecture can be divided into two main categories: the disruptive approaches also known as the *Clean Slate* redefining every concept from scratch, and the incremental ones which aim at evolving the existing infrastructure and protocols. The OCIF project is clearly centered around the latter strategy. We consider an evolutive scenario compatible with the existing network, but allowing for disruptive changes to the architecture

[2] in bold, thesis defended in 2014 or in January 2015

[Dee11] S. Deering, "IETF-51 plenary talk: Watching the Waist of the Protocol Hourglass @ONLINE", August 2011, http://www.iab.org/wp-content/IAB-uploads/2011/03/hourglass-london-ietf.pdf.

when needed. The most important assumption is that we will not alter the core network, but allow for the transformation to come from the edges where networks may have heterogeneous characteristics, significantly different from the Internet core.

The Internet of Things (IoT) and the Intelligent Transport Systems (ITS) provide a perfect example of how such an evolution coming from the edges reveals the limits of the existing models. The new paradigms emphasize the lack of efficient mechanisms capable of handling mobility and multihoming, taking delay tolerant applications into consideration, and the need for less energy consumption. Due to the intrusiveness of the collected information or the life-critical applications that can be deployed, they put a stronger accent on the trustworthiness of the environment, and its capabilities of service confinement.

The *OCIF* project can be divided into 5 research domains organized around Internet protocol and architectural evolution, and the related innovative services. These fields of study are aimed at solving the needs and constraints of the future Internet and providing realistic experimentation grounds for the new architectures to be tested. The domains are:

- **Internet architecture and protocols**. The aims is to adapt existing protocols and architectures for new environments. We mainly focus on layer 3 with low constraints IPv6 stack for IoT and layer 4 with congestion control mechanisms.
- **Economics**. we model and analyze the economic interactions among all actors in the Internet ecosystem (users, content and service providers, regulators...).
- **Auto-configuration and spontaneous networks**. We study the architecture of IoT and Home network environment, especially in term of auto-configuration and provisioning.
- **Confinement**. Some services from the IoT will be life-critical (for instance e-health) or will be used for security (home monitoring). The goal is to define scalable architectures allowing service confinement based on trusted communication services and application layer protections.
- **Applications and services**. We focus on Intelligent Transport System (ITS) and Smart Grid. These two domains are not exclusive since, for instance, electric cars will have to interact with the power grid and with local energy management systems (smart building).

2.2 Key Issues

Key issues for the OCIF project are the following:

- Internet Architecture: *Current Internet is ossified and evolutions are slow. How can we develop new architectural concepts which allow compatibility with the existing protocols and take into account new network ecosystems?*
- Congestion Control: *End-to-end rate control, as performed by the TCP protocol, has been key to ensure the stability of the Internet, by avoiding congestion collapse and by*

allowing applications and users to share network resources in a "reasonably fair" manner. However, in spite of its remarkable robustness, flexibility and evolvability, TCP is showing more and more its limits. Congestion control mechanisms, whether they are implemented end-to-end (as in TCP) or in network nodes (as in active queue management algorithms), have to keep on evolving to be able to cope with new networking technologies, scenarios and applications. Even if studies are currently applied to core network and web applications, the challenging context of Internet of Things will soon be confronted to congestion issues and our research can be applied to this domain.

- Network economics: *In an extremely fast-evolving context with exploding economic stakes, the power relationships among stakeholders can dramatically change over a short period of time. How can we anticipate the result of such complex interactions, and drive it toward socially desirable outcomes is one of the main questions we are aiming to answer in our studies.*

- Wireless Mesh Networks: *Wireless communications will take an important part in the future Internet. The architectures are subject to evolve. Current networks (e.g., the cellular network), are made of multiple wireless base stations, linked together through a wired network. The only wireless link in this architecture is the one between a mobile station and a base station. Future architecture will include relaying, peer-to-peer communications, multi hops network, software radio and efficient energy management.*

- Trusted communication services: *By taking an important part in the development of Internet, electronic mail currently represents one of its fundamental building blocks. But even if its success nowadays is so impressive that it should be impossible to do without it, it hides however serious deficiencies. Using electronic mail in a professional context requires the support of several services contributing to the global security of the system. The capabilities of a professional and secured messaging system, even if they are essential, could be however enriched and completed in order to achieve a messaging system in which users can trust. One main cornerstone of this area consists in the study and the definition of a precise concept of trust in the case of a messaging system by identifying and defining the capabilities which can guarantee trust. This can be applied to other environment such as Internet of Things.*

- Application layer protection: *Nowadays, more than 40% of successful attacks concern the application/service layer software. It is crucial to propose innovative security mechanisms to improve the security of services widely vailable on the Internet. We look for detection or protection techniques able to detect or block unknown attacks. We compare traffic to requirements given by the security policy, the protocol description or any ad hoc specification to detect what is not expected and considering it as an attack. In recent projects, we have applied these principles to detect intrusions on web transactions.*

- Intelligent Transport Systems: *Intelligent Transport Systems consists of communication objects such as sensors, vehicles, roadside units, and central server that aim at providing road safty (e.g., reducing the number of injuries and accidents), road efficiency*

(e.g., preventing traffic jam), and multimodal traveling (e.g., reducing commuter travelling time). As Intelligent Transport Systems relies on ability of objects' communications each other, the development of efficient communication mechanisms and adaptation to various transportation scenarios are core research to Intelligent Transport Systems. In that vein, we are investigating an integration of emerging communication paradigms such as DTN Routing and Probabilistic Routing to Intelligent Transport Systems.

- Smart Grid: *Smart Grid is the evolution of the electricity distribution system, and is commonly referred to as the "marriage of the Power Grid and the Internet". A big part of the technical challenges are in essence an application of Machine-to-machine communication paradigm - be it the protocols involved or the algorithms governing the real-time functioning of the system. In this aspect, it is the perfect use case for long-time research directions of the team, including Network economics, Internet architecture and Mesh networks.*

- Context awareness: *Context awareness appears as an interesting tool to enhance the already existing services with a level of personalization and ability to adapt their behaviour in function of changing situation as well as to adapt the way network ressources are used. One important issue concerns the systematic introduction of contextual information in the development of communication services.*

3 Scientific Foundations

3.1 Network Architecture

Keywords: Internet, Wireless Sensor network, Architecture.

Glossary :

6LoWPAN Set of algorithms to allow IPv6 to run on constrained networks. 6LoWPAN defines a IPv6 header compression mechanism.

CoAP A simplified version of HTTP which can be run on constraint devices. This protocol helps to extent REST paradigm to sensors and actuators.

IPv6 The new version of the IP protocol to face the address exhaustion.

The Internet is victim of its success; the network evolution is rendered difficult due to the large number of users, the huge amount of available contents. Furthermore, at layer 3, the interconnection model promoted by IP imposes that each node implement the same protocol. The introduction of IPv6 is a perfect example of the difficulties to make the network evolve: the exhaustion of the IPv4 took effect in 2012 but neither providers nor content producers moved to IPv6 until the IPv4 addresses shortage was a reality.

At layer 4, SCTP or DCCP should have replaced TCP or UDP or at least be a substantive part of the traffic. Introducing new protocols at layer four is theoretically easier than at layer 3 since it involves only the end nodes and not all the nodes on the path. Nevertheless, even a simple rollback mechanism to TCP introduces delays [FI09] and make applications more

[FI09] B. Ford, J. Iyengar, "Efficient Cross-Layer Negotiation", *Presented at HotNets-VIII*, 2009.

complex to program. The result is that applications will use only the most commonly accepted protocol.

Polymorphic Internet The introduction of new form of networking, such as Wireless Sensor Networks where energy used to transmit or receive data is one of the most important factor or Intelligent Transport Systems where mobility, ad-hoc networking and possible disruption in connectivity, shows the limit of a single layer 3 protocol to allow global connectivity.

For the Internet of Things, the most common approach to allow communication between the core network and the Wireless Sensor Network is to use Application Level Gateways (ALG) interconnecting the classic Internet and the sensor networks. Layer 3 and 4 protocols are different. To be compatible with the large majority of applications, HTTP/TCP/IPv4 protocol stack is used in one side and in the other side, protocols CoAP/UDP/6LoWPAN is adapted to the constrained environment. Based on the REST architecture, generic resources are manipulated and identified by an URI. These resources can be information from the real world, meta-information such as ciphering keys or access right and signalling messages.

Another approach is to leave interconnection at layer 3 - packet format may change from one family of network to another and IPv6 remains the common language allowing interoperability between different technologies. However, even if packet format is allowed to change, each node should continue to have a global IP address and may be joined or send packets to any other IP-addressable node. In opposition with the REST model, there is no assumption on the nature of the flow.

Routing In a Wireless Sensor Networking routing remains a complex task since the environment is changing and energy management remains a strong constraint limiting the control traffic inside the network. Neighborhood Area Network (NAN) used in Smart Grid Architecture to collect information for electrical smart meters is a perfect example of such environment. Even if energy constraints are weaker, Outdoor Power Line Communications raise a lot of performance problems since the media is subject to significant perturbations or attenuations. The length of the electrical wire imposes relaying among smart meters. Different approaches, mainly proactive with RPL and reactive with LOAD protocols are subject to a debate.

The G3-PLC standard proposal promotes the usage of a *mesh-under* packet forwarding mode, in which the local network is viewed as a single link at the IPv6 layer. Route discovery is performed with the help of a reactive routing protocol called 6LoWPAN Ad Hoc On-Demand Distance Vector Routing (LOAD).The protocol, an adaptation of the well-known AODV, defines three types of messages (*request, response and error*) and relies on the existence of two tables - one for established routes and one for tentative route requests.

The IETF has specified a Distance Vector-based, proactive protocol adapted to the requirements of Low-Power and Lossy Networks (RPL). RPL is designed for applications typically seen in sensor networks - a central node (called a border router) communicating with a set of senors via fluctuating, low-bandwidth links. As required by RPL, each node acts as a router, e.g. the packet forwarding is *route-over*. There are two distinct types of traffic - from the *border router* to the nodes, and vice-versa. Different mechanisms maintain the topology information for these types of traffic. The protocol maintains a view of the network in the form of

a Destination Oriented Directed Acyclic Graph (DODAG), the destination being the border router.

3.2 E2E network protocols

Keywords: Congestion control, active queue management, latency, transport-layer evolution.

Glossary :

Congestion control End-to-end congestion control may refer to any mechanism aimed at dynamically adapting data rates according to network conditions and network resource usage, with the goal of avoiding overutilization (of transmission capacity, of buffer space. . .) and data loss due to congestion. Diverse signals can be used by endpoints (i.e., data senders and/or receivers) to infer the presence of congestion along the end-to-end path. Packet loss is a direct and explicit—but not always accurate—indicator of congestion; losses are the main, and often only, congestion signal used by TCP. Other protocols may also use e.g. end-to-end latency as a "proxy" indicator of overutilization. Complementary mechanisms such as explicit congestion notification (ECN) can be leveraged to improve the response of congestion controllers.

Active queue management (AQM) AQM refers to algorithms and methods to control the amount of data stored in network node buffers. The basic principle of AQM is that of "preventively" discarding packets depending on some metric of local congestion or queue utilization. They can also serve as the basis of explicit congestion notification, by e.g. marking packets instead of dropping them.

Even if it is a fairly mature field, the area of transport protocols and congestion control in IP networks keeps on posing both new, interesting research challenges and significant practical problems. In some instances, it would appear as if old problems are revisited a decade or so after they were first studied and "solved"—either because (a) the solutions that were then proposed were far from optimal and/or were never widely adopted, or because (b) new networking scenarios have appeared that require rethinking many assumptions underlying the existing protocols. An example of the former are active queue management techniques: the RED algorithm has been shunned in settings where it may be useful, probably due in part to the difficulty of configuring it properly. Datacenter environments are an example of the latter: the peculiarities of traffic patterns and the very stringent bounds on latency may make protocols like "classic" TCP to perform poorly[VPS+09].

End-to-end latency optimization and throughput-latency tradeoffs Paradoxically, today *broadband* does not always mean *fast*. The most prominent example of this is the issue of *bufferbloat*[Get11]. Cheap memory has led to a "bigger-is-better" mentality among networked systems designers, and ubiquitous excess buffering has resulted both in huge latencies—

[VPS+09] V. Vasudevan, A. Phanishayee, H. Shah, E. Krevat, D. Andersen, G. Ganger, G. Gibson, B. Mueller, "Safe and Effective Fine-grained TCP Retransmissions for Datacenter Communication", *in : Proceedings of ACM SIGCOMM*, p. 303–314, Barcelona, August 2009.

[Get11] J. Gettys, "Bufferbloat: Dark Buffers in the Internet", *IEEE Internet Computing 15*, 3, 2011, p. 95–96.

sometimes, on the order of *seconds*—and in breaking TCP's feedback loop. On top of it, aggressive loss-recovery (ARQ) mechanisms in e.g. wireless systems worsen the latency problem.

Arguably, it will be easier—at least in the short term—to circumvent bufferbloat by changing the transport layer at end-points, rather than changing all the problematic intermediate systems or access link technologies. This opens new avenues for proposing solutions to a very serious performance problem, for multi-homed and/or single-homed hosts. For instance, in recent years we worked at developing new congestion controllers for multipath transports, but with the goal of optimizing throughput while ensuring TCP fairness. It would be interesting to extend such multipath approaches to optimize for end-to-end delay.

Active queue management will also be needed to tackle the latency issue. Indeed, buffers *are* needed to cope with traffic burstiness, so bufferbloat cannot be solved *only* by naively reducing buffer sizes to very low values. However, classic AQM algorithms were not always designed for enforcing very low latency. Recent proposals like Nichols and Jacobson's CoDel, and Cisco's PIE[NJ12], have on the contrary been conceived with latency as the main performance parameters, but it is still unclear e.g. whether they are robust enough in the face of several TCP congestion control flavors.

Adapting transport layer protocol behavior to network conditions The congestion control mechanism implemented in TCP and in SCTP is essential to the Internet. However it is inefficient when used over mobile networks[BPSK97,LL06]. This is due to the fact that the congestion control mechanisms misinterpret packet losses as a consequence of a congestion in the network. Although this is not always the case, especially over wireless accesses where handover and dramatic variation of the available bandwidth and delay may occur. Moreover mobile networks technology is moving towards a new emerging paradigm called Cognitive Radio (CR). Cognitive Radio brings its own share of problems for TCP however more importantly it brings the capability to gather more knowledge about its radio environment. TCP will face same problems, if not more, when used over mobile networks enabled with CR technology[YP09]. However, these new CR capabilities open the door for better cross layer TCP optimisation techniques.

A modification in the TCP/IP architecture allowing cross layer exchanges of information between TCP and the layers that knows something about what happens on the wireless link (at link and network level). For example Freeze TCP [GMPG00] allow the mobile receiver to anticipate the losses pausing the transmission at the serveur side. The same kind of mechanism

[NJ12] K. Nichols, V. Jacobson, "Controlling Queue Delay", *Commun. ACM 55*, 7, July 2012, p. 42–50, `http://doi.acm.org/10.1145/2209249.2209264`.

[BPSK97] H. Balakrishnan, V. N. Padmanabhan, S. Seshan, R. H. Katz, "A comparison of mechanisms for improving TCP performance over wireless links", *IEEE/ACM Transaction on Networking 5*, 1997, p. 756 – 769.

[LL06] H.-C. Leung, V. O. K. Li, "Transmission control p rotocol (TCP) in wireless networks: issues, approaches, and challenges", *IEEE Communications Surveys and Tutorials 8*, 2006, p. 64 – 79.

[YP09] Y.R.KondaReddy, P.Agrawal, "Effect of Dynamic Spectrum Access on Transport Control Protocol Performance", *in : IEEE Globecom*, 2009.

[GMPG00] T. Goff, J. Moronski, D. S. Phatak, V. Gupta, "Freeze-TCP: A true end-to-end TCP enhancement mechanism for mobile environments", *in : IEEE INFOCOM*, 2000.

has been proposed for the mobile routeur to be transparent to the end-user devices[SSB12]. More efficient cross layer technics could even be distributed between the mobile side and the access router to avoid losses and forecast interruptions. The results show that these mechanism can improve the link utilisation efficiency as compared to standard TCP.

Facilitating the evolution of the Internet's transport layer Currently, the Internet's transport layer is ossified. TCP has proved to be very robust in the face of changes in networking technology; indeed, TCP was designed in the 1980's, yet several of its most fundamental features have changed little since. However, design limitations of the protocol (like e.g. the size of the options field) are becoming more and more of a hurdle when trying to make the protocol evolve. The heterogeneity and unpredictability of the behavior of networking equipment, along the end-to-end path, makes such hurdle very difficult to overcome (see e.g. [HNR+11]). Attempts at deploying more recent and flexible standard protocols, like SCTP and DCCP, have been either fairly modest successes (SCTP[3]) or total failures (DCCP). The practical issues faced by the MPTCP design team illustrate how tough it can be to extend the TCP protocol [RPB+12].

It is therefore interesting to explore new techniques that enable the transport layer to evolve; these will have to consider the fact that there is a huge installed base of legacy filtering middleboxes. Works like [WNG11,NTI+12] have suggested new, interesting ideas worth exploring.

3.3 Network economics

Keywords: Game theory, pricing, regulation.

Glossary :

Game theory A field of economics focusing on the interactions among self-interested agents. The key notion is that of Nash equilibrium, describing a stable outcome.

Pricing The way by which prices for a service or a good are computed. In the telecommunication ecosystem, the most frequently used pricing mechanisms include flat-rate (for Internet access, charged by ISPs), usage-based (say, for transit traffic among ISPs), auctions (to allocate spectrum usage licenses among operators).

[3]Adoption of SCTP as a data-channel protocol for RTCWeb will likely give a boost to SCTP usage but, interestingly, it will be "hidden" to middleboxes through additional UDP encapsulation.

[SSB12] K. D. Singh, D. R. Sanchez, J.-M. Bonnin, "Optimising TCP over cognitive radio networks for trains", *in : ITST 2012: 12th International Conference on ITS Telecommunications*, 2012.

[HNR+11] M. Honda, Y. Nishida, C. Raiciu, A. Greenhalgh, M. Handley, H. Tokuda, "Is it still possible to extend TCP?", *in : Proceedings of the 11th ACM Internet measurement Conference (IMC'11)*, Berlin, November 2011.

[RPB+12] C. Raiciu, C. Paasch, S. Barré, A. Ford, M. Honda, F. Duchène, O. Bonaventure, M. Handley, "How Hard Can It Be? Designing and Implementing a Deployable Multipath TCP", *in : USENIX Symposium of Networked Systems Design and Implementation (NSDI'12)*, San Jose (CA), USA, April 2012.

[WNG11] M. Welzl, F. Niederbacher, S. Gjessing, "Beneficial Transparent Deployment of SCTP: The Missing Pieces", *in : Proceedings of IEEE GLOBECOM*, Houston, December 2011.

[NTI+12] M. Nowlan, N. Tiwari, J. Iyengar, S. Amin, B. Ford, "Fitting Square Pegs Through Round Pipes: Unordered Delivery Wire-Compatible with TCP and TLS", *in : USENIX Symposium of Networked Systems Design and Implementation (NSDI'12)*, San Jose (CA), USA, April 2012.

Regulation The set of rules defining the allowed moves by actors, hence defining the framework in which those actors interact (the game they play).

Telecommunication networks involve a lot of different stakeholders, that have their own preferences: while users mainly focus on the Quality of Service, their experience, and the price they are charged (and sometimes other considerations such as their provider reputation), service providers are interested in the revenue they get from subscribers, in the management costs incurred by user traffic, etc. Those discrepancies are the core reason for applying economic reasoning to telecommunication networks: since not all stakeholders are interested in the same outcomes, one has to consider the conflicts that appear –and the trade-offs that should be imposed– among the preferences of the actors in the whole ecosystem. This aspect is particularly salient within the *Internet of Things* paradigm, that involves an exploding number of actors with local objectives.

The added value of game theory in telecommunications. Before game theory concepts were applied to telecommunication systems, the main tools used for the design and study were coming from the optimization field. The objective could then be to optimize routing, resource provisioning for QoS, transmission power management, ... Those tools are of course still applied extensively, but the multiplicity of the decision makers involved in networks has made it unrealistic to assume that one can control all actors. It has therefore become necessary to understand (and possibly anticipate) the behavior of those actors. But that involves taking into account the interactions of decision makers, each of which focuses selfishly on his own objective.

That framework can be seen as a kind of *distributed* optimization, with individual actors making their own –locally optimal– decision. The *stable* points of the interactions will then be the situations where all local optimization problems are jointly solved. Those situations, called Nash equilibria, play a key role in game theory. Local problems being simpler to solve in general than global ones, it is of particular interest to see whether the conjunction of local optimizations leads to an outcome that is globally satisfying. If it is not the case, then tools can be used to anticipate the impact of a change in the settings, like a modification of the regulation policy or the introduction of pricing.

The telecommunication ecosystem is full of situations with interacting agents, that can be analyzed through game theory. Of particular importance are the *externalities* in the system, that describe the costs or benefits resulting from the actions of the others. A few examples of interactions and (negative) externalities are given below.

- *Peer-to-peer file sharing systems, Grid computing systems.* In such systems, each participant tries to benefit from others' offered services, while limiting its own contribution[CW06].

- *Routing (user level).* When routes taken by packets are decided by the sending node, each node will try to find the best route for its traffic (minimizing delay, energy, or

[CW06] C. Courcoubetis, R. Weber, "Incentives for large peer-to-peer systems", *IEEE JSAC 24*, 5, May 2006, p. 1034–1050.

maximizing throughput)[RT02]. But the intermediate links are shared with other flows: because of the negative externality coming from congestion, the choices of all nodes are interdependent.

- *Ad-hoc networks.* The principle of ad-hoc networks is that intermediate nodes act as radio relays for any two other nodes willing to communicate. A prominent problem concerns the incentives to forward the traffic of neighbors. And like in the case of peer-to-peer and grid computing systems, the service disappears if there are no contributors.

- *Congestion control*: the Internet success is largely due to the TCP/IP stack, where the TCP congestion control scheme automatically adapts the transmission rates of flows to the network capacities [Jac88]. The mechanism relies on flow emitters to reduce their sending rate when a loss (interpreted as a congestion signal) is detected. However, each sender would improve its individual throughput by ignoring losses and maintaining a high rate, and the network performance collapse if too many users adopt this selfish behavior.

  The exact same principle applies to congestion control at the link layer: in WiFi for example, nodes have to obtain the right to send data through a RTS (ready to send) message that they send on a shared channel. Nodes are supposed to wait a (randomly chosen) time before sending their RTS message, in order to limit collisions (and in the case of collisions those RTS are backlogged). It is clearly better for each individual node to disobey that rule and always immediately send one's RTS messages, however as soon as two nodes simultaneously implement that strategy the system collapses (with infinitely repeated collisions).

- *Power control in wireless networks*: increasing your transmission power will induce a better QoS, but at the expense of others' interferences (forming negative externalities).

In all those cases, a selfish behavior of actors can lead to low performance situations, hence a need to better understand such behaviors and if necessary design some incentives/rules driving toward preferable outcomes.

Pricing, multi-level games. It is reasonable to assume that when deciding what pricing mechanism to apply, providers endeavor to anticipate the effect of that mechanism. To do so, they consider the interactions that would take place among users (i.e., at a lower level) for any mechanism, and then take the result of those interactions as simple inputs to select the optimal mechanism (in the sense of their objective function, often the revenue). Such a method can be generalized to more decision levels, and is called *backward induction.*

In previous works within OCIF, that method has been applied, notably to analyze the impact of licensing the wireless spectrum versus leaving it unlicensed, or to investigate some aspects of the Network Neutrality debate.

[RT02] T. Roughgarden, E. Tardos, "How bad is selfish routing?", *Journal of the ACM 49*, 2, Mar 2002, p. 236–259.

[Jac88] V. Jacobson, "Congestion Avoidance and Control", *ACM Computer Communication Review; Proceedings of Sigcomm '88 18*, 4, 1988, p. 314–329.

Price of Anarchy, Price of Stability, regulation. Closely linked to the notion of efficiency or global performance of an outcome, is the concept of Price of Anarchy, a term coined by Koutsoupias and Papadimitriou [KP99]. That metric quantifies the loss of efficiency due to the selfishness of the actors in presence, by comparing the outcome of the noncooperative setting (the Nash equilibria) to the most efficient reachable outcome (that we call the social optimum).

The Price of Anarchy (PoA) is defined as a ratio between the performance measures of the worst equilibrium and the optimal outcome, so that we have PoA≥ 1 in general. The Price of Anarchy can be used to evaluate the need for an exterior intervention in the game (e.g., regulation). For example, if PoA is close to 1, then introducing some coordination among players can only yield a limited improvement, that may be overcome by the costs of implementing the coordination: letting players behave selfishly appears to be the best option. On the contrary, a large PoA suggests that the noncooperative situation can be very inefficient, and that appropriate measures could significantly improve the global performance of the system; it is then up to the exterior controller (regulator) to properly design those measures so as to reduce the PoA.

Note that the Price of Anarchy metric is pessimistic, in the sense that it considers the *worst* Nash equilibria and thus measures the worst loss of efficiency due to selfishness. The optimistic counterpart of the Price of Anarchy is the so-called *Price of Stability* (PoS), that instead compares the *best* Nash equilibria to the ideal coordinated outcome, and thus measures the minimum cost –in terms of the global performance measure– of having a stable situation (i.e., where no actor has an incentive to change actions).

Mechanism design. Consider the problem of a decision maker (e.g., a network owner or a regulator) willing to optimize some global objective, but who needs some information privately owned by other agents (typically, users) to do so. For example, to choose a resource allocation in a network to maximize social welfare, a regulator needs to know the user payoff functions; an information that users would reveal only if in their interest. A *mechanism* is a set of rules chosen by the decision maker to that end: it consists in

- a set of available actions for each agent,
- an *outcome rule*, that maps the action profiles of agents to an outcome (say, an allocation of resource, possibly along with payments).

The decision maker is interested in the outcome of the game, and therefore intends to design rules to reach his objective(s), given the fact that the game will be played by selfish agents, hence the name *mechanism design* for that field of game theory.

Within OCIF, mechanism design will be considered for the new ecosystem created by electrical vehicles, in order to improve the energy management. Indeed, the vehicles' batteries can be seen as ways to store energy (so as to use it at home for example during peak hours), and even to transport it (i.e., exploiting the vehicle's travels). Designing mechanisms so that

[KP99] E. Koutsoupias, C. Papadimitriou, "Worst-Case Equilibria", *in: Proc. of 16th Annual Symposium on Theoretical Aspects of Computer Science (STACS 1999)*, *1563 of* Lecture Notes in Computer Science, p. 404–413, 1999.

the selfish behavior of vehicle owners approaches a globally optimal situation remains a major challenge.

3.4 Random processes for network performance evaluation

Keywords: modeling, random process, Markov chain, steady-state performance.

Glossary :

Modeling (Simplified) representation of a real problem through a mathematical formulation.

Random process A system evolving over time, according to phenomena modeled as probabilistic variables.

Markov chain A particular type of random processes, characterized by a "limited memory" property: *what will happen next depends only on the current state, not on the previous ones.*

Steady-state performance The expected performance of a system modeled as a random process, over a large time span.

The thematics of the OCIF team often imply systems evolving over time, and the performance evaluation of such systems can be carried out thanks to mathematical modeling. Of particular interest are the methods based on (discrete state space) Markov chain modeling, where the current situation of a system is among a discrete set of *states*. Those models are very powerful (in terms of representative capabilities), and in general lead to tractable computations of the stationary (or steady-state) situation in which the system lies. This is represented mathematically by the *stationary distribution* of the process, from which the steady-state performance of the evolving system can be derived.

Such tools can be used for very different purposes, such as the dimensioning of a system, or the optimization of the system parameters with various objectives (QoS, energy consumption, financial revenues).

3.5 Wireless Network

Keywords: Handovers, 802.11 scanning, multiple interfaces management, opportunistic relaying.

Glossary :

Handovers The process for a mobile device of changing its point of attachment to the network. A mobile device is getting access to the network by connecting to an Access Point (or Base Station). When for example a user is moving out of the coverage area of this access point, it must transit to a new access point. Depending on the location of the new access point, a handover can only involve layer 2 mechanisms (when both points attachment are on the same network, or layer 3 mechanism when the two points of attachment are on different subnets). We call horizontal handover the roaming between two access points of the same technology, while a vertical handover refers to an inter-technology handover.

802.11 scanning 802.11 scanning refers to identifying which access points are available in a given area. For example, a mobile device that needs to change access point, starts by determining which are the available candidates access point in its radio range. This process

can be done pro-actively, by sending Probe Request messages, or passively, by listening to beacons sent by access points.

Nowadays, mobile users run different kind of applications over the Internet, e.g., messaging, web-browsing or multimedia streaming. These applications generate an important number of flows and gather a high variety and amount of information. Additionally, the variety of available access network technologies, and the increased capacity of computing devices supporting several NICs, motivates users to be always best connected [GJ03]. Different types of portable devices have been introduced in the market in the last years, and very frequently, they embed different wireless access technologies, like IEEE 802.11 (WLAN), 2G/3G/4G cellular, WiMAX or Bluetooth interfaces. In general, these access technologies have been designed to support different use-cases, e.g., cellular networks for large coverage and fast mobile data communications, WLAN for local area communications or Bluetooth for proximity services. Due to the increasing number of deployments of these networks and because no wireless technology could cover all market needs, every single Mobile Station (MS) is able to access one or several networks in any given place. In our recent work [CBML12], we have shown that a user currently has access to different technologies at any time. For example, in a urban area, we have observed that the WLAN availability is equivalent to the 3G cellular availability.

802.11 handovers If we focus on 802.11 network first, even if areas covered by this technology are large, especially in downtown, a mobile user still needs to roam between access points because of the limited coverage (around one hundred meters). Mobility support appears as the key to use 802.11 in highly mobile scenario. However, the fact that 802.11 networks are so widely deployed produces that a mobile user may deal with a high variety of scenarios. These scenarios consist on heterogeneous access point (AP) deployments, managed by several operators and characterized by overlapping frequencies, traffic load and high interference. Moreover, these conditions cannot be anticipated by the mobile user while moving between APs and thus appropriate scanning algorithms are needed to select and roam to the best point of attachment.

The process of moving to other point of attachment is referred as a ***Handover***. The handover process deals with time related constraints, due to scanning, authentication and association tasks. So the duration of each stage should be minimized to avoid losing performance on the client side due to high packet loss and delay. The 802.11 standard specification has established two different mechanisms to obtain information about the next AP to associate, referred as *Passive* and *Active Scanning*. Both approaches have a number of limitations that affect the effectiveness of the handover process, producing that in some cases no AP is found and a permanent link layer disconnection occurs.

Multiple interfaces management Going beyond 802.11 accesses and considering today's multi-technologies environment, a user could also associate to more than one network, leading to multihoming. Connecting to multiple networks allows exploiting the diversity of the

[GJ03] E. Gustafsson, A. Jonsson, "Always best connected", *Wireless Communications, IEEE 10*, 1, feb. 2003, p. 49 – 55.

[CBML12] G. Castignani, A. Blanc, N. Montavont, A. M. Lampropulos, "Urban 802.11 Community Networks for Mobile Users: Current Deployments and Prospectives", *Mobile networks and applications*, august 2012, p. 1 – 12.

networks by gaining in reliability and performance. However, in a mobile and multihomed environment, the definition of the policies establishing how to map flows to interfaces, the so-called "network selection process", is still an open research topic [Par11] (the Parallel-to-Serial (and back) problem in [Par11]). In the literature, solutions for network selection follow two different directions. First, there are solutions aiming to manage vertical handovers, i.e., the decision-making process to establish when to switch all the on-going flows to a different interface. A typical example for vertical handover is an MS connected to a 3G network aiming to switch all the flows when entering in a WLAN zone. A second approach for network selection, in which we are interested, aims at assigning the different flows to the available interfaces, enabling load spreading and a simultaneous usage of the wireless interfaces. The objective is to take advantage of the heterogeneous network interfaces by distributing each different application flow over the most suitable interface (in terms of bandwidth, delay, energy, cost, etc.).

The flow-interface assignation strategy in the network selection process can highly impact the user experience. The lack of an efficient decision-making process can lead, for example, to situations where some wireless interfaces become overloaded while others having an acceptable available capacity are not even used. Also, this may lead to drastically drain the MS battery when multiple interfaces are not properly used.

As illustrated in Fig. 1, network selection in wireless multihomed devices implies different processes. The goal is to find and apply the assignation of the on-going application flows to the different available interfaces that optimizes a given set of criteria. First, in order to identify when a new assignation has to be computed, the MS has to *monitor* the current status of the flows and the interfaces, while also doing network discovery to find the available points of attachment. Under certain conditions, the MS may decide that the current assignation is no longer optimal and so a *decision-making* process has to be triggered in order to find a new optimal assignation. The conditions to trigger the decision-making process may be related to interfaces or networks becoming active/inactive, to the initialization or termination of a new application flow or some QoS degradation. The decision-making process itself considers a set of *criteria* to evaluate the optimality of the assignation and then *search* for optimal solutions. Finally, an *enforcement* process is carried out to set up the new assignations on the device. During this enforcement process, the MS seamlessly switches the application flows to the new optimal interfaces based on existing multihoming support protocols like shim6, MCoA or HIP, or new transport protocols supporting multihoming like SCTP.

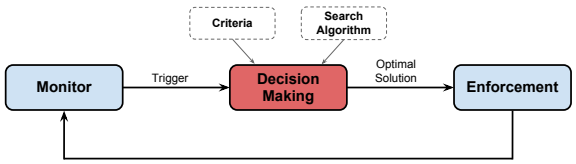

Figure 1: The Network Selection Process

[Par11] C. Partridge, “Forty data communications research questions”, *SIGCOMM Comput. Commun. Rev. 41*, 5, October 2011, p. 24–35, http://doi.acm.org/10.1145/2043165.2043170.

4 Application Domains

4.1 Smart Grid

Participants: Alexander Pelov, Nicolas Montavont, Laurent Toutain, Patrick MailléBaptiste Gaultier, Tanguy Ropitault, Alejandro Lampropulos, Jean-Marie Bonnin, Bruno Stévant, Benjamin Cama, Guillaume Le Gall, Wenjin Shuai, Feng Yan.
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Keywords: Smart Grid, Smart Metering, Smart Campus, Energy Efficiency, Electrical Vehicles.

Glossary :

Smart Grid A Smart Grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety[4].

Smart Meter A smart meter is usually an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes.[5]

Smart Grid is an disruptive evolution of Power grid. One of its main characteristics is the availability of bidirectional data communications between all elements of the grid. The main drivers behind this evolution may vary significantly from country to country, and are determined by the politico-economic context and the historical development of the region. They include (but are not limited to) energy efficiency, self-healing, integration of Distributed Energy Resources, demand response, integration of electrical vehicles, theft prevention, ...

The Smart Grid is a novel terrain in which classical networking problems arise with additional constraints.

The OCIF team has identified several domains of contribution, which fall under the broad field of Smart Grid research. These include energy monitoring systems, demand response, smart metering infrastructure, electrical vehicle integration.

Smart Grid has quickly became a hot topic, a focal point of multiple research fields. Our strategy since we've initiated the work in this direction has been to build solid foundations in terms of appropriate funding and collaborative programs. The following paragraphs will outline projects that have been funded.

SmarTB SmarTB is a project of instrumenting the campus of Telecom Bretagne with sensors and actuators to deploy a framework to monitor, control and show the energy consumption and production of the campus. It builds upon the multi-year experience working on sensors networks and energy efficiency of the school and provides the following features, such as : deploying and experimenting of research proposals in a real-world environment, proposing a framework to the students of the university to develop code on sensor network programming,

[4]http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group1.pdf
[5]http://www.ferc.gov/legal/staff-reports/12-08-demand-response.pdf

defining a control system to regulate the energy consumption of the campus, displaying and analyzing the energy consumption information.

This technological demonstrator is based on different sensing devices (smart meter, smart plugs, humidity, CO2, temperature, etc.) interconnected with diverse networking technologies (e.g. 6LoWPAN/RPL/CoAP). The development activities performed in the scope of this project can be divided into three main aspects :

1. Networking - Standardized IPv6 protocols for the communication between sensors to organize themselves in a network, and send the collected data to a sink or a database. Our focus has been on integrating IETF 6LoWPAN to various wireless and wired technologies (PLC, DECT, 802.15.4), with IETF RPL as the routing protocol. We have included this project in the works related to proposing new mechanisms to auto-configure networks typical for Smart Meter and Smart Home environments (e.g. address allocation, neighbor discovery, gateway discovery).

2. Energy Management Algorithms - Control mechanisms to smooth the energy consumption depending on the locally produced energy and the plugged devices at home or on the campus. This requires the ability to perform Non-Intrusive Load Monitoring (NILM) in order to identify the type of electrical equipments without human intervention. In long term, we will be working on energy management algorithms that combine real-time electricity pricing and apply it to the cases of a single household, a neighborhood and a university campus.

3. Visualization Software and Algorithms - Development of a standardized interface (open-source web app) to represent the collected data in real time. The interface has been developed as a control system for generic device - an off the shelf device such as a tablet PC or an energy box. The system is extensible via a fully documented REST API and provides an easy way to process, log and visualise energy, temperature and other environmental data Based on the latest web technologies (PHP, MySQL, HTML5/CSS3, Ajax, SVG), it incorporates a powerful notification system based on user defined events, such as reaching a certain threshold or a sensor becoming inactive.

This project has been driven entirely in a community-friendly, open-source and open-hardware manner. The developed hardware includes Smart Plugs (sensors/actuators placed between an electrical equipment and the power outlet) and Energy Meter Readers (sensors allowing the real-time reading of a classical Power Meter via a wireless or wired network). We designed several prototypes of these devices, based on the Arduino platform.

The SmarTB project is a laureate of the C̈all for Innovationsg̈rant of the Institut Mines-Telecom for the year 2013.

Algorithms for Electrical Vehicle Charging We started working on algorithms for charging electrical vehicles with two internships that took place in the summer of 2012. The continuation of this work will be performed in the context of two French projects: the EGUISE project funded by the ADEME agency, and the Greenfeed FUI project. Both aiming at designing solutions to enable smart electric vehicule charging management.

A PhD student started her work in March 2013.The thesis aims at analyzing the evolution of the Power Grid, from a technical, and mostly economic point of view, with a focus on electric vehicles, that open some new perspectives in terms of storage and transportation of energy. With the development of distributed energy resources, the formation of Micro Grids (energetically self-organized regions), the upcoming electricity markets will dramatically change, involving a soaring number of self-interesting agents (energy producers, carriers, brokers, consumers, and agents simultaneously playing several of those roles). In addition to those agents, we will investigate the impact of the introduction of electric vehicles: their (selfish) behavior should indeed have a strong impact on the management of the Smart Grid, since the vehicles' batteries can be used to smooth demand, with the possibility of having some vehicles store or deliver some energy in response to (rapid) demand variations.

The objective of this thesis is to investigate the outcomes resulting from the non-cooperative interactions among vehicles, and between vehicles and the Smart Grid. Among the expected contributions, we intend to provide insights regarding the global performance (measured in terms of, e.g., societal or environmental impact) in such systems, and the potential improvement that proper regulation or pricing policies could yield. In terms of methodology, we shall build on the tools and methods developed in the context of the recently deregulated telecommunication networks: stochastic demand modelling, optimization, and game theory. The models that we will develop will however need to encompass the strong specificities of electric energy (costly storage and transportation, hardly predictable and largely distributed production, large demand variations), and the new flexibility opportunities offered by targeted consumption control.

As electric vehicles are popularizing, the introduction of fast charging for electric vehicle aims to ease their usage and improve acceptability. But the simultaneous charging of a large number of electric vehicles requires a precise management of the available energy inside the electricity distribution infrastructure. Large-scale scenarios will imply that the power consumption can be lowered or even differed. Such management should also take into account different parameters like battery characteristics, user preferences, etc. Telecom Bretagne is involved in several projects (VELCRI, EGUISE, GreenFeed, SEAS) in which communication requirements and architecture to make various use-cases feasible are studied.

Optimizing the charging process of an Electric Vehicle (EV) is becoming a key factor for the acceptability of e-mobility. During the charging process, the charging point should deliver sufficient energy for the EV according to the user demand, but respecting the energy constraints of the charging infrastructure (i.e. not exceed the maximum power to be delivered instantaneously for simultaneous charging). After charging, the billing process should be as transparent as possible for the user (Charging as a Service). Several projects have been initiated to work on the optimization of these phases in different use-cases.

The VELCRI focused on the realization and the deployment of electrical vehicles for the average users. Typical scenarios are described for the use and charge of these vehicles such as charging in a parking lot or at home, and battery swapping. Our studies in this project focus on the ISO/IEC 15118 standard that describes the communication between the EV and the charging point. This standard is the keystone for the communication architecture required for the charging management.

The EGUISE project focuses on the "smart campus" scenario where e-mobility is part of

global objective for energy efficiency. This scenario involves electric vehicles with inductive charging, which raise new challenges for the charging management and the communication infrastructure, the need for wireless communication for example. The complementary GreenFeed project aims to define a complete value chain for the charging service addressing the reservation of charging point, the management of energy inside a public parking infrastructure and economic considerations. In these two projects the focus has been made on ISO/IEC 15118 protocol to exchange informations about the charging process. We aim at exploring more interactive relations between electric vehicles and the local energy manager since we think it could allow smarter energy management, for exemple to be able to cope with intermittent sources.

We also consider how to integrate the intelligence of the process as an application in the ISO ITS communication architecture simplifying by the way the development of compatible vehicle and even allow a quite simple retrofit using a simple smart-phone to run an ISO/IEC 15118 application. Of coarse it lead to interesting architectural concerns regarding reliability and security of the system. In terms of service, we are interested in evaluating the potential benefit of having continuous transparent IPv6 connectivity offered by our architecture.

In the SEAS project we aim at using data produced by electric vehicle while charging its battery and also the SoC (State of Charge) while it is on the road or parked somewhere. Knowing this information in real time, the smart-grid could be able to plan the need for energy and control the way vehicles charge their batteries. A smarter grid could also consider energy stored in vehicles and use it while required (Vehicle to Grid).

Based on the first realizations inside these projects, Telecom Bretagne plans to build a local demonstrator with electrical vehicles integrated with a smart management of the energy consumption of the campus.

Routing Protocols for PLC-based Smart Metering Infrastructure As active participants of the G3-PLC Competence Center formed with Texas Instruments and ITRON, we have performed an in-depth study of the performance of routing protocols for G3-PLC based Smart Metering Infrastructure.

Through this project we have developed models for simulating the G3-PLC network and a validation platform based on 10 hardware nodes. The routing protocols under study include representatives of the reactive and the proactive routing families. The results of this cooperation have resulted in founding a grant for a PhD student.

4.2 Intelligent Transport Systems

Participants: Jean-Marie Bonnin, Bruno Stévant, Emmanuel Thierry, Benjamin Cama, Guillaume Le GallSara BahamouChristophe CouturierKamal Deep Singh.

The OCIF team has been involved in several collaborative projects dealing with the Internet mobility and its application to ITS (Intelligent Transportation Systems): European projects (ANEMONE, CVIS and ITSSv6), French national projects (ANR REMORA, ...), and French regional projects (LoCoSS, LoCoMotive, ...). The team also developed strong partnership with mobile network operators for terminal centric mobility management and network centric mobility management in extra-flat network architecture. By the way we have designed several

mobile terminal cross layer architectures able to take into account information coming from various stakeholders while making intelligent decisions regarding handover management, flow routing (in multihoming case), and interface management. The later architecture is able to provide information to the applications allowing them to adapt their behavior to varying network conditions. It relies on the information coming from network interfaces so that it could have an accurate view of the current network conditions. In addition, we will tend to be compatible with communication architectures defined in ITS contexts: the ICOM[6] for the railway domain, the ISO CALM and the ETSI ITS set of ITS standards. The work we perform in the ITS field is consistent with European projects or initiatives, like CVIS, ITSSv6, and COMeSafety, in which the OCIF team is involved.

A common way to take QoS into account in the mobility management, is to rely only on a mobile node side and use the sensing features of the mobile node. In fact, it can be beneficial to take QoS-related decisions at higher layers of the IP stack. This ability to sense and estimate the quality of the channel can be used by an intelligent middleware to take proactive decisions. When this information is combined with the QoS requirements of each flow, the intelligent middleware can guarantee the QoS required, i.e., it is able to adaptively lower priorities of some flows and to provide higher priorities to the important flows. Cognitive Radio is a potential lower layer technology that enables to transfer informative parameters of physical and link layers to the upper layers, especially to the intelligent middleware. The cognitive radio module could take place into an architecture where the mobility gradually impacts all the layers depending on the importance of the mobility event and its duration [14]. Other characteristics of the new communication technologies such as beam forming could also be used to improve the way we share the spectrum and then the overal efficiency [10]. In addition to the utilization of the lower layers information, the intelligent middleware can obtain precise information related network conditions as it combines informative parameters of higher layers with those of the lower layers and make better decisions.

Most of available research for mobility management has considered host-based mobility management, i.e., mobile node is done at the mobile router or terminal level, with the later being responsible for managing available resources independently on each interface. These years we studied, in collaboration with ReOP team, network-based mobility management solutions and how they fit requirements of large-scale deployments. In the next coming years we will study how network-based mobility management (such as PMIPv6) could be adapted to multi-interfaces capable terminals. Such an approach could allow efficient handovers while relaxing design constraints that weigh the wireless infrastructure down while making mobility and QoS provisioning transparent to mobile nodes. A simulation-based evaluation has to be done in order to assess: functionality, deployability (in a railway context for the CORRIDOR project), and performance (signalling, message overhead, handover latency, etc. ...).

Adaptating the behavior of the nework layer to current networking conditions could be done in various way. At the packet level, priorities or time sensitivity [6] associated to different flows could be taken into account. Queue management techniques may protect a subset of the traffic when resources become scarce, but they will not prevent applications to send traffic and

[6]ICOM is an intelligent communication framework developed in the context of the InteGRail FP7 project to achieve, using middleware solutions, integration of wireless communication technologies in the railway domain.

to fill queues up. A more efficient adaptation could be performed by applications through a specific interface with a management plan to get accurate information on the access network capabilities. But this would require the former to be mobility-aware and to understand information coming from various medias. Moreover the implementation of a decision mechanism has to be embedded in the application. Since it already implements a regulation mechanism, the transport layer itself looks as a more-fit candidate for dealing with transport-layer issues. Besides, some proposals for coping with transport-layer issues in wireless networks designed for dealing with handovers could perhaps be useful in mobile networks, to e.g. avoid TCP timeouts during spectrum sensing, handover and temporary signal drop along the path.

We also aim at studying the impact of events detected at the media level (e.g. at the cognitive radio interface) on transport protocols behavior, and to identify the best adaptation strategies. Our goal is to propose an adapted interface between the management plan and the transport layers (flavor of SCTP or TCP) to allow a smart, dynamical tuning of the transport protocol parameters, depending on actual radio conditions and short-term predictions.

4.3 Communication Services

Participants: Jean-Marie Bonnin, Ahmed Bouabdallah, Sylvain Gombault, Bruno Stévant, Houssein Wehbe, Erwan Abgrall, Laurent Cailleux, Michal Szczerbak, Djibrilla Amadou Kountché, Ewa Janczukowicz,.

Context Awareness The first focus is dedicated to interpersonal conversational services. A comprehensive state of the art [TBZD11] allows the identification of various issues together with the development of an original methodology initiating the systematic introduction of context data during the complete service life cycle.

Conversational services suffer however from the underlying communication model inherited from the traditional telco area and originally organized around one main communication mean, namely the telephone call. This outdated model still constitutes the fundamental communication paradigm structuring the terminal user interface. We propose a new communication model leading to a natural articulation between conversational services and social media [WB12]. This approach has also been tackled on another angle leading to the definition and the development of KRAMER (Kind of Reasoning that Abstracts

Metasituations for Empowering Recommendations), a new original social media [15].

We explored also the association between contextual data and a live uplink streaming service developed in the Zewall project investigating new capabilities of the broabdand mobile networks LTE [13, 36, 38]. We focus on an innovative usage associated with this new capability and defined by the simultaneous transmission toward websites or distant spectators of live video caught through end user devices like smartphones, together with contextual data generated

[TBZD11] F. Toutain, A. Bouabdallah, R. Zemek, C. Daloz, "Interpersonal context-aware communication services", *IEEE communications magazine 49*, 1, january 2011, p. 68 – 74.

[WB12] H. Wehbe, A. Bouabdallah, "A User-Centric Communication Model for Mobile Web / The 9th International Conference on Mobile Web Information Systems", *Procedia computer science 10*, 2012, p. 680 – 687.

by the device. The contextual information may indeed be precious to the spectator for several reasons. On one side, this information cannot be deduced from the video images currently displayed. On the other side, being closely related to the live event currently displayed, context can be fruitfully exploited by the spectator to complete her understanding of what she is presently watching and to possibly interact with the filming person to influence the rest of the capture. The main property of this new feature can be expressed as a synchronization constraint between the video and the contextual data. Ensuring this property is challenging due to the presence of variable delays in the end-to-end path.

Confident Communication Services The ease of use and efficiency of the email service contributed to its widespread adoption. It became an essential service and authorizing multiples and various uses (private, professional, administrative, governmental, military ...). However, all existing systems are technically reduced to the implementation of global policies, compiling in a static way a limited set of features. These approaches prevent differentiated adaptations of the system to the uses. The rigid and monolithic nature of these policies can moreover lead to unnecessary execution of expensive treatments or to the inability to simultaneously satisfy conflicting requirements [20]. We address this problem of the evolution of e-mail in the general context of interpersonal communication of a sender to a receiver. We identify the sender's intention of communication, as a key parameter of any interpersonal communication, insofar as it allows to finely discriminate the successful communications, between all the ones that are understood. A second parameter which is orthogonal to the first, defined as the context of the sender, is important because it allows to determine the successful aspect of an interpersonal communication. The declination of these two parameters in the electronic mail led us to define the concept of electronic correspondence. This one is a generalization of the email the implementation of which provides a sufficient condition of qualification successful exchanges via this medium. A correspondence allows taking into account for each message, the intention of communication and context of its sender. Its implementation requires in certain points of the network, the enforcement of specific policies depending of an administrative domain and which take as argument the intention of communication and the current context of the sender. A second benefit provided by this concept concerns the level of customization of messaging reaching a maximum granularity, because it can be applied in a differentiated way, to each message instance. These works led to the description of a representative architecture and the definition of three extensions to existing standards (SUBMISSION, IMF and S/MIME). Our approach has been illustrated through two main use cases, compliant with recommended specifications for administration (RGS - Référentiel Général de Sécurité) and military (MMHS - Military Message Handling System) domains [21].

APIs for Specialized Network Services Real-time communications are much more than only traditional voice services. They have become interactive, transversal and are expected to be integrated as a feature of other applications. More and more communications services are offered by web companies that have been taking advantage of Internet flat rate charges and mostly use best-effort capabilities. Simultaneously, many efforts are currently devoted to improve the quality of experience of clients using communication services. We analyse current implementations of managed VoIP and emerging WebRTC technology in order to assess the

possibility of offering through deidated APIs specialized media flow treatments to real-time web communications [28, 29].

Software Defined Networking (SDN) is deemed to empower next generation network and cloud services in several aspects. We argue that its high flexibility can be exploited not only in retrieving services efficiently but also in yielding new ones by introducing programming capabilities on its top. This however requires to structure its northbound interface (NBI) with an abstract application programming interface (API), the definition of which is actually one of the SDN challenges. We propose a global analysis of the capabilities of the NBI of the SDN articulated to a generic but simple double sided model of service lifecycle. Its analysis determines interesting properties of the NBI leading to precisely identify the associated API. We derive from this service lifecycle a general framework structuring the internal architecture of the SDN in two orchestrators dedicated respectively to the management of services and resources. Our approach provides a firm foundation for the implementation of the NBI [18].

5 Software

5.1 pico IPv6

Participants: Laurent Toutain [contact point], Nicolas Montavont, Alexander Pelov, Alejandro Lampropulos, Baptiste Gautier.

IPv6, even with 6LoWPAN optimization, may not fit requirements for constraint environments. We have adapted the Contiki microIPv6 stack to elements, such as Arduino UNO devices running with 32 KB of flash memory for code and 2 KB of RAM memory for buffers and variable. Stack optimization follows two axes:

- Neighbor Discovery Suppression: This protocol allowing nodes' auto-configuration is mandatory in IPv6 stack. Nevertheless, the adaption to Wireless Sensor Environment is not trivial since NDP require multicast and periodic messages. The pico-IPv6 stack do not require Neighbor Discovery. Instead the prefix is set by border routers, and routers are discovered through a simplify implementation of RPL. Another benefit of this approach is to manage in a better way multi-homing between different protviders.

- 6LoWPAN as Layer 3 protocol: In current implementation of 6LoWPAN, the packet is compressed and decompressed when processed by intermediary nodes acting as routers. This imply two buffers: one for the compressed and the uncompressed header. In our implementation we process directly 6LoWPAN header. This also allows to add other informations to the 6LoWPAN header allowing a better management of the LoWPAN network (as explained in 3.1).

These principle have been included in the Wave2M standard through the ANR ARES2 project and a implementation for Arduino is available [Gau12].

[Gau12] B. Gauthier, "pico IPv6 implementation for Arduino", August 2012, `https://github.com/telecombretagne/Arduino-IPv6Stack/wiki`.

5.2 G3PLC simulator

Participants: Tanguy Ropitault, Alexander Pelov, Laurent Toutain [contact point].

After a careful analysis, we chose to base the simulations on a popular discrete-event network protocol simulator, with an additional adaptation layer that would allow the integration of realistic physical layer characteristics based on dedicated, power network simulators. The OPNET Networking Simulator was preferred as a basis for our simulation architecture, because of its popularity in the industrial domain (as compared to OMNET++, ns-2 and ns-3).

Realistic PLC models are complex and require significant computational ressources. In order to be able to simulate large topologies (e.g. 1000 nodes) we have chosen to split the simulation into two components - a physical PLC simulator which generates the topology and the physical line characteristics (in the form of a matrix), which are then fed into the OPNET simulator.

The Smart Meter Infrastructure topology generated by the external tool provides the SNR levels c_{ijk} for every pair of nodes i and j on every group of channels k. The SNR matrix $C = \{c_{ijk}\}$ is (possibly) asymmetric, thus allowing the simulation of non-isotropic signal propagation. During the simulations, the OPNET model uses the C matrix to determine the transmission range, the Bit-error-rate (BER) for all available modulations and for all frequency groups. This is in turn used to dynamically calculate the Tone Map (e.g. which channels should be used) and the neighbors of a given smart meter (e.g. the meters capable of correctly receiving a frame sent with the most robust modulation, which is used for broadcast communications).

In order to further reduce the simulation time complexity, we've introduced an interface providing the MAC layer with a macroscopic view of the PHY layer.

The MAC layer follows the G3-PLC specifications derived from IEEE 802.15.4 standard. The link can be modeled through a vector L where L_i indicates the Link Status for node i:

- F (Free) - no signal is transmitted nor received
- B (Busy) - a node is sending a frame and the signal has been received by the others so CSMA/CA would detect it and will not start sending a frame
- U (Unknown) - medium is either busy or free. Collisions are possible due to signal propagation delays.
- C (Collision) - a collision has occurred. The sender continues to emit since it cannot detect the collision.

Model behavior has been calibrated on a real testbed. LOAD and RPL protocols have been implemented to follow implementations by industrial of these protocols and respect the options they have selected. The tools are currently used to study the conditions in which these protocols react the best.

5.3 Wi2me

Participants: Nicolas Montavont [contact point], Tanguy Kerdoncuff, German Castignani – University of Luxembourg.

With the increasing popularity of WiFi technologies, mobile users may now take advantage of heterogeneous wireless networks. In contrast to cellular networks, community networks, based on sharing WiFi residential accesses, show a high access points density in urban areas but uncontrolled performance. In this scenario, the goal for a users is to have multiple interfaces, and exploit them the best he/she can, by always selecting the best matching between flows and interfaces. In order to have real traces and to evaluate the performance, the availability and the potentiality of these networks, we introduce a new mobile sensing tool, called Wi2Me Traces Explorer, an Android-based application that performs network discovery, automatic authentication and TCP traffic generation through WiFi and 3G. In 2012, we particularly focused on Community Networks deployments in urban areas to study their potential for providing ubiquitous Internet access.

The Wi2Me Traces Explorer application, running on Android 2.1 (Eclair) and 2.2 (Froyo), executes two main threads, the WiFi thread and the Cellular thread. The WiFi thread scans for APs, discards those having a signal level lower than a threshold (by default 85dBm), and finally selects the CN AP having the highest signal level in order to attempt a connection (i.e., level-2 association and DHCP request for an IP address). If the connection succeeds, the application tries to perform HTTP-level authentication with the CN to obtain access to the Internet. Then, in order to perform a first test, a set of ping requests are sent to the default gateway and to a known remote server deployed in our laboratory. Afterwards, the application may upload and download different files (via HTTP). The possible file sizes are 50 KB, 100 KB, 250 KB, 500 KB, 1 MB and 2 MB. These files are uploaded to and downloaded from our remote server. The application allows the user to choose the minimum and maximum file size. The smartphone performs first a download then an upload of each file, starting from the smallest file and finishing either with the largest file or with a layer-2 disconnection. The cellular thread receives the base station information from the beacon channel and attempts Internet connections to evaluate the performance of each base station. Once the connection is set up (i.e., a dedicated channel is assigned to the device), the application also uploads and downloads files the same way the WiFi thread does. Since we aim at evaluating TCP performance, we have also monitored the network traffic on the server side. For each connection initiated by Wi2Me Traces Explorer on the smartphone, the web-server triggers the collection of socket statistics (using the ss command), including the TCP congestion window, the round trip time and the throughput. Additionally, we capture all the packets on the server side using tcpdump. In order to avoid biasing the performance measurements in both WiFi and 3G, the application makes use of a firewall tool (Droidwall1) to prevent other applications (e.g., mail synchronization, weather or contact list updates) from making use of the Internet connection.

5.4 RoCaWeb

Participants: Sylvain Gombault [contact point], Djibrilla Amadou Kountché.

A version of RoCaWeb software has been developed in collaboration with KEREVAL. We have developed the learning module (described in paragraph 6.7) and the GUI, while KEREVAL developed the reverse proxy. This software is tuned by DGA MI experts and is develeped under the responsability of KEREVAL, as they want, with the goal of using it to

provide services.

5.5 XSS Test Driver

Participants: Sylvain Gombault [contact point], Erwan Abgrall.

XSS Test Driver is a framework that has been designed for evaluating the exposure of a web browser to XSS attacks. We have collected a large set of publicly available vectors, and build unit test cases by combining them with innocuous load. This tool is regularly updated with new vectors, and we keep it online to demonstrate how web browsers to test browsers' vulnerabilities to XSS vectors. This tool is publicly available on GitHub[7] with a demo version online[8]. This tool is the corner stone of the work presented paragraph 6.7).

6 New Results

6.1 Internet Architecture and Protocols

Participants: Patrick Maillé, Nicolas Montavont, Ndeye Amy Dieng, Alexander Pelov, Florent Fourcot, Laurent Toutain.

We extend behaviour of existing protocol. For IPv6, we developed the concept of IPv6 Address Spreading. Our idea consists in spreading the identification part of IPv6 addresses, the way that CDMA protocol spreads the spectrum by sending data on a pseudo-random sequence of frequencies. This spreading changes one fundament of the current Internet. All protocols, Operating Systems and Applications are think with the idea of addresses stabilities. And if it was not easy enough, we have to deal with this heritage to stay compatible with the current network, and to integrate our solution [22, 4].

For the Internet of Things, we propose the notion of IPv6 local extensions, with a scope limited to a LOWPAN network. The goal of the draft [41] is to redefine the 6LoWPAN Mesh header to offer a more generic extension which can manage more optimally tunnels, routing and hop by hop extensions,. . . .

For Home networks, we propose some new metrics taking into account electromagnetic emissions. It has been a challenging goal to make path selection based on ecological criteria that are closely linked to the external environment (e.g. EM radiation); instead of the conventional routing metrics inherently dependent on network state (e.g. delay). We develop a new concept of radiation-aware routing algorithm for heterogeneous home networks in order to reduce radiated emissions level within a given area. We propose of two models of electromagnetic radiated emissions stemming from Wi-Fi and PLC links based on a set of assumptions and mathematical approximation methods. We have then formulated a link-adaptive radiation-aware routing metric.

[7] `https://github.com/g4l4drim/xss_test_driver`
[8] `http://xss.labosecu.rennes.telecom-bretagne.eu`

At layer 4, we have started our investigation of root causes of excess Internet latency, by assessing the LEDBAT congestion control mechanism [SHIK12], in terms of the delay impact it may have on latency-sensitive flows (like e.g. interactive web traffic). LEDBAT, a delay-based rate controller, has been recently standardized by the IETF and, more importantly, has been massively deployed in the Internet — it is implemented in several BitTorrent peer-to-peer clients. LEDBAT is supposed to behave in a "scavenger" or "less than best effort" manner, however, our first results show that this may not always be the case, and that under some conditions it may degrade significantly the user experience, by sustaining a non-negligible queuing delay along the end-to-end path. This study has been published in a top international journal, and it was done in cooperation with our partners at the University of Oslo [12]. Following this work, we have explored the set of optimal parameters allowing LEDBAT protocol to effectively perform as an LBE traffic. This work has been published in [40].

In the context of an ongoing EU STREP project, called RITE, we study a novel scheduling algorithm for multipath transport called Delay Aware Packet Scheduling (DAPS) which aims to reduce the receiver's buffer blocking time considered as a main parameter to enhance the QoS in wireless environments. We develop an analytical model of maximum receiver's buffer blocking time and extend the DAPS algorithm considering implementation issues. Performance evaluations based on *ns*-2 simulations highlight the enhanced QoS that DAPS can provide. With reference to the classical multipath transport protocol CMT-SCTP, we observe a significant reductions of the receiver's buffer occupancy, down by 77%, and the application delay, down by 63% [31].

Other publications: [32, 30].

6.2 Economics

Participants: Patrick Maillé, Vladimir Fux, Wenjing Shuai, Alexander Pelov.

We have developed further the analysis of models to study the *net neutrality* debate, and have extended it to investigate the economic aspects of Content Delivery Networks through some preliminary models, in order to see the impact of revenue-oriented behavior of CDN actors on users and content providers. This is particularly relevant in the context of the net neutrality debate, where CDNs are often forgotten but may have a strong influence.

Additionally, we have continued our research effort on the *search neutrality* debate, that focuses on the behavior of search engines (e.g., Google, but also the search engines in classified ad websites or e-commerce websites). Our results include a characterization of the ranking strategies that maximize the search engine revenues, and a numerical illustration of the impact of that bias on the underlying ecosystem (e.g., how does the ranking bias affect the survivability of newcomer content providers).

We have also studied the price competition among access network providers, in the specific context of vehicular networks, where interesting interactions occur due to the movements of vehicles.

[SHIK12] S. Shalunov, G. Hazel, J. Iyengar, M. Kuehlewind, "Low Extra Delay Background Transport (LEDBAT)", RFC 6817, IETF, December 2012, `http://tools.ietf.org/html/rfc6817`.

Finally, we have started developing an activity on the economics of electric vehicle charging, comparing all the existing economic approaches to build a literature survey.

Publications: [1, 42, 7, 8, 5, 34, 35, 23]

6.3 Confinement

Browser's Evolutions and XSS Detection. [9]

This work has been initited during DALI project[10] whose objective was to innovate in the context of *Design and Assessment of application Level IDS* (DALI). As web success is associated with the expansion of threats on browsers and servers, we choose to focus on this application level service. Fifteen years after the CERT released an advisory on *cross site scripting* (XSS) vulnerability[11], XSS attacks are still the major threat for web browsers, and one of the resons is the constant evolution of web browsers. Althoughs, we have wondered if this feature-driven engineering has a side-effect on software components relying on the browser and their underlying security ?

To demonstrate and measure browsers' evolutions impact on security and facing the lack of available tool, a main contribution of our work is the design of *XSS Test Driver*, see 5.5, a new cross-browser XSS vector testing tool. During the preliminary tests, we have discovered that any web browser was vulnerable to at least one vector. Regarding a set of browsers belonging to the same family, we advocate the use of a shared security testing benchmark, and propose a new methodology associated with our online tool *XSS Test Driver*[12], based on a set of publicly available XSS vectors to ensure that all the regression test regarding these vectors have been driven, when a new release is delivered [17].

We have enforced our work to measure precisely browser's characteristics, and discover a new way to fingerprint browsers. Our technique is based on HTML parser quirks, the same quirks used in XSS vectors by attackers to evade anti-XSS filters. Quirks mode is defined as the technique offered by some browsers for keeping downward-compatibility with pages designed for previous browsers, instead of strictly satisfying W3C standards in standards mode. To get a better idea of the security impact of such browser-fingerprinting techniques, we studied how it was used in *drive-by download* attacks, by providing an overview of existing browser fingerprinting techniques along with a presentation of our own technique.

We eventually propose a detection strategy to uncover *client-side* attacks using honeyclients and headless browsers in a sandboxed environment in the last part of this thesis [2]. Our proposal relies on browser fingerprinting to improve stealthiness of *honeyclients* by uncovering flaws in browser emulation. We have used Thug *honeyclient* as a framework and our testing work has helped improving this framework through practical evaluation of its scripting execution capabilities.

Publications: [17], [2]

[9] This PhD is a collaboration between Télécom-Breatgne, The University of Luxembourg and KEREVAL.
[10] http://dali.kereval.com
[11] http://www.cert.org/historical/advisories/CA-2000-02.cfm.
[12] `http://xss.labosecu.rennes.telecom-bretagne.eu`

6.4 Auto-configuration and spontaneous networks

Participants: Nicolas Montavont, Alberto Blanc (ReOP), Dareen shehadeh, Tanguy Kerdoncuff, Guillaume Habault.

Wifi access point density Using the Wi2me application, we analyzed the scanning process in IEEE 802.11 networks in an urban setting characterized by a high Access Point (AP) density. Most of these APs belong to a community network, known as a collection of APs announcing the same network name (Service Set Identifier or SSID). The owner of an AP can optionally configure the community network of his/her AP, resulting in an irregular topology for each community network as there is no central planning authority. We investigate the relationship between the time spent in each channel while scanning for available APs and the number of AP actually detected. In particular we show that, in order to discover all available APs at a given location, we need to combine the results of multiple scans. Based on this result we argue that the efficiency of the scanning process could be greatly improved by using a database shared by all the users of a community network, containing the available APs at different locations.

Publications: [33, 19]

Wi-Fi community network for the Internet of things End-systems connected to the Internet are subject to a tremedeous change with the development of the Internet of things. Sensors of different kind and monitoring devices now use IP to exchange collected data and commands. With the heterogeneous access technologies currently available in urban area, we proposed a service-based acccess selection that allows choosing the *best* access for a given device / application. We developed a service announcement mechanisms by re-using existing advertisement messages, such as the Wifi Beacon or the IPv6 Router Advertisement. We proposed an ontology to address the scalability issues and to organize the different possible services. We also studied the impact of our service announcement mechanism proposal in a Wi-Fi M2M scenario, and how Wi-Fi sensors can be supported in community networks. We used network simulation and Markov chains to model this Wi-Fi M2M scenario. We instanciated this model by real traces that we obtained with the Wi2me application in urban areas. We showed that the service annoucement allows deivces to discover a service in few seconds, and the the M2M traffic does not significantly impact more classical network traffic. However, we identified that the connection phase is really slow and takes more than 60% of the total coverage time for a moving device. More efficient mechanisms should be developed to address this issue.

Publications: [25]

6.5 Applications and services.

Participants: Alexander Pelov, Laurent Toutain, Tanguy Ropitault, Renzo Navas, Alejandro Lampropulos, Samantha Gamboa, Jean-Marie Bonnin, Kamal Deep Sing, Sylvain Gombault, Erwan Abgrall, Djibrilla Amadou Kountché.

Routing in Smart Grid. Narrowband powerline communications are one of the core technologies for the evolution of the power grid enabling the dialogue between the power meters and the utilities. The new environment, traffic patterns and application requirements make the choice of network protocols in these networks non- trivial. we analysed the behavior of the Contiki RPL stack, the most popular and open implementation of the IETF RPL standard. We provide evidence why the state-of-art implementations do not behave in an optimal way for Smart Grid applications and propose mechanisms and parameter selection politics that lead to improved performance during the route formation phase of the network. Since smart grids are still in a research and test phase, it is very difficult to get access to real-world topology data. We provided a comprehensive analysis of the power- line communication topology of a real-world smart grid, the one currently deployed and tested in Luxembourg. Building on the results of this analysis we implement a generator to automatically create random but realistic smart grid communication topologies. These can be used by researchers and industrial professionals to analyze, simulate, design, compare, and improve smart grid infrastructures.

Publications: [37, 26, 16]

Energy Efficient Networks Renewable energy (RE) has been introduced as a promising solution to reduce the "non-green" energy consumption of cellular networks. we studied the electric bill reduction of a cellular network powered by both RE sources and the power grid in a variable electricity price environment. We decomposed the problem of electric bill reduction into three sub-problems: RE allocation, energy consumption minimization and radio resource allocation (RRA). In this context, we proposed a new algorithm that adjusts the network configuration to increase the utilization of RE. Results show the efficiency of our proposed algorithm, where it achieves 30% reduction of energy consumption and outperforms a benchmark algorithm with a gain of up to 20 percentage points in terms of electric bill reduction.

The network reconfiguration (NR) techniques are also key strategies to reduce the energy consumption in cellular networks. In our work, we studied how adding delay to user access can further improve energy efficiency, by extending BS sleep periods. We developed the analytical model of the mechanism dynamics and we evaluated it numerically for two NR strategies. We also implemented these strategies in the network simulator NS-3. The results show up to 13 percentage points of performance improvement regarding the traditional NR strategies for a maximal delay of 50s.

Publications: [24, 27]

6.6 Emerging IP Mobility Management Issue

Participants: Jean-Marie Bonnin, Kamal Deep SinghJong-Hyouk Lee.

Emerging IP Mobility Management Issue. With increasing usage of mobile devices, we are witnessing an explosion of mobile Internet traffic. In order to cope with recent traffic growth, current mobile network architectures are being flattened, and IP mobility support protocols need to be adopted in the evolution of mobile network architectures. Existing IP mobility support protocols rely on centralized mobility anchors that suffer from inefficient

routing and scalability issues due to rapidly increasing traffic volumes. In that vein, this article introduces a new IP mobility support protocol that does not rely on a single-handed mobility anchor, but utilizes distributed mobility anchors to overcome the limitations of the existing protocols while providing selective data offloading [9].

Emerging routing scheme for vehicular networks. Routing in Vehicular Networks has been strudied for a while but none of the proposed solutions can be standardized but georouting. In vehicular network, traffic could be sparse and direct end-to-end paths between communicating parties do not always exist. Thus, we need to cope with disconnexion and the fact that it is almonst impossible to identify uniquely a peer of a communication at the network level. Nevertheless Delay Tolerant networking could be used to meet specific communication requirements (e.g. data collection). Other vehicule can be used to carry and/or to relay the data toward the final destination [6].

Taking benefits of recent development in wireless communication technologies. Communication technologies continualy improve their performances, but they also evolve adding new capabilities that could be used to provide upper layer with new functionalities or should be controller in a smart way to take all the potentiality. In [11] we identified this new trends for wireless sensor networks. Among them Cognitive Radio is one of the most promising, and we studied how it can be used to improve wireless spectrum efficiency and routing in vehicular ad-hoc neworks [14]. We also show in collaboration with the IRISA / Dionysos team, how Beam Forming which allows to target a subset of the nodes attached to an access point, could be used to improve scalable video streaming in wireless networks [10].

6.7 Application Service Protection

Participants: Jean-Marie Bonnin, Sylvain Gombault, Ahmed Bouabdallah.

Web protection using positive security. RoCaWeb (Reverse-proxy using Contracts for Web protection) is a project based on the results of DALI project (Arpege ANR). In DALI, we presented a black-box approach and shown how the design-by-contract principles can be extended to enhance the protection of a web server by using a positive security model against bypass attacks. In a first step, our tool automatically analyses HTML pages in order to extract all the constraints on user inputs. Then, we leverage these constraints in a white list processed in a reverse-proxy tool named *Shield* that protects the server.

The limitation of the *Shield* is due to the automated learning phase as HTML has a limited set of controls, but we have seen all the advantages of applying a positive security model and a different set of rules for each web application. That's why RoCaWeb plans to use a white list of rules embedded in a reverse-proxy to enhance the protection of a web application, although the learning phase has changed. The constraints are set in a first step and learned from the network traffic going from client to server and collected during the normal test of the web application.

In the new version of RoCaWeb, our reverse proxy, the normal behaviour is modelled as a set of regular expressions generated using our algorithms: AMAA (*Another multiple alignment Algorithm*) and BRELA (*Basic Regular Expression Learning Algorithm*). Also, we plan to extend this model to include statistics and ontologies to name few.

Publications: [39]

Browser's Evolutions and XSS Detection. [13]

This work has been initited during DALI project[14] whose objective was to innovate in the context of *Design and Assessment of application Level IDS* (DALI). As web success is associated with the expansion of threats on browsers and servers, we choose to focus on this application level service. Fifteen years after the CERT released an advisory on *cross site scripting* (XSS) vulnerability[15], XSS attacks are still the major threat for web browsers, and one of the resons is the constant evolution of web browsers. Althoughs, we have wondered if this feature-driven engineering has a side-effect on software components relying on the browser and their underlying security ?

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We have enforced our work to measure precisely browser's characteristics, and discover a new way to fingerprint browsers. Our technique is based on HTML parser quirks, the same quirks used in XSS vectors by attackers to evade anti-XSS filters. Quirks mode is defined as the technique offered by some browsers for keeping downward-compatibility with pages designed for previous browsers, instead of strictly satisfying W3C standards in standards mode. To get a better idea of the security impact of such browser-fingerprinting techniques, we studied how it was used in *drive-by download* attacks, by providing an overview of existing browser fingerprinting techniques along with a presentation of our own technique.

We eventually propose a detection strategy to uncover *client-side* attacks using honeyclients and headless browsers in a sandboxed environment in the last part of this thesis [2]. Our proposal relies on browser fingerprinting to improve stealthiness of *honeyclients* by uncovering flaws in browser emulation. We have used Thug *honeyclient* as a framework and our testing work has helped improving this framework through practical evaluation of its scripting execution capabilities.

Publications: [17], [2]

[13] This PhD is a collaboration between Télécom-Breatgne, The University of Luxembourg and KEREVAL.
[14] http://dali.kereval.com
[15] http://www.cert.org/historical/advisories/CA-2000-02.cfm.
[16] `http://xss.labosecu.rennes.telecom-bretagne.eu`

7 Contracts and Grants with Industry

7.1 STREP RITE

We are involved in an EU three-year STREP project, called RITE (Reducing Internet Transport Latency), devoted to the problem of end-to-end latency in the Internet, and related topics like the so-called "bufferbloat" issue. RITE will develop solutions for improving latency, both at the transport and the network layers of the protocol stack. The project started in November 2012, and the consortium includes a large ISP / telecomm operator (British Telecom), a manufacturer of networking equipment (Alcatel-Lucent) and several leading European academic institutions.

7.2 OSEO SmartSensing

Participants: Laurent Toutain, Renzo Navas, Alexander Pelov, Jean-Pierre Lenarzul.

Smart Sensing goal is to integrate micro-sensors to fabric to create connected clothes to allow sportpersons to be monitored. OCIF team is working on CoAP integration to allow interconnectivity with other environments.

7.3 RAPID RoCaWeb

Participants: Sylvain Gombault, Djibrilla Amadou Kountché.

The RAPID (Régime d'APpui à l'Innovation Duale) RoCaWeb project is planed for 3 years (2013-2016), and our partners are KEREVAL and DGA MI. It is based on the results of the DALI project (ANR ARPEGE 2008) where KEREVAL was also our industrial partner. As DGA MI is interrested by these results in web reverse proxy innovation, we develop a close collaboration with their experts. Under the responsability of KEREVAL, RoCaWeb is developped as a product being directly used by these experts, and that KEREVAL can use to provide services to other companies.

7.4 FP7 STREP ITSSv6

Participants: Jean-Marie Bonnin, Bruno Stévant, Emmanuel Thierry, Benjamin Cama.

The goal of ITSSv6 is to implement and validate an enhanced set of IPv6 networking protocols as a standalone software module which can be incorporated into the communication architecture used in European Field Operational Tests (FOTs) of Cooperative Systems and other projects. For testing purposes, it shall be able to function independently from the ITS Station specific modules as defined by ETSI TC ITS and ISO TC204 WG16. In addition, ITSSv6 will also push new functions to relevant standard specifications defined by IETF, ISO, CEN and ETSI. We are involved in this project in order to enhance the existing specifications at IPv6 networking layer ISO-21210 by proposing new work items in SDOs and contribute to the standardization of the solution and to develop missing parts of the IPv6 networking layer into a ITS Station stack inheriting from CVIS core software and our previous work. In our

previous works we have shown the benefits behind cross-layer interactions and described the advantages of making upper levels, and even application level, aware of what is happening in lower levels. In this project, we aim at improving the mobile user experience by introducing additional modules in order to achieve multi-interface, flow routing, and interface management taking into account high level parameters and operator access network usage policies. Such a management plan has been defined in the ISO CALM architecture but the way to implement it is still to be explored even if the ICT CVIS project has produced a first implementation that does not implement all features. The French REMORA project has designed a specific architecture not compliant with the CALM specifications but which implement a bunch of interesting features. Beyond the main goals of the project, our main interest is to design a play ground where we will be able to experiment the main concepts and algorithms we developed in our cross-layer architecture.

7.5 ANR TTD CORRIDOR

Participants: Jean-Marie Bonnin, Kamal Singh, Jong-Hyouk Lee.

With new Cognitive Radio capabilities, the interaction between lower and upper layers of the communication stack has to be redefined to take advantage of the new possibilities. It is necessary to identify what can be monitored and provided to upper layers in order to improve he system's ability to adapt its behavior to the environment, i.e. its agility. Since a Cognitive Radio-based system may adapt itself to its environment, it is necessary to distribute the decision between upper and lower layers, and to design the interface that will allow to control the lower communication layers, while combining information coming from various layers will allow to improve decision accuracy.

7.6 AMI ADEME – EGUISE

Participants: Jean-Marie Bonnin, Alexander Pelov, Patrick Maillé, Wenjing Shuai, Feng Yan, Guillaume Le Gall, Benjamin Cama, Emmanuel Thierry.

The EGUISE project is founded by ADEME (AMI) and is led by DBT (charging point manufacturer). It aims at designing a smart fleet management system for the fleet of vehicles shared by the employees of a company. The EGUISE project focuses on the s̈mart campuss̈cenario where e-mobility is part of global objective for energy efficiency. This scenario involves electric vehicles with inductive charging which could also provide the campus power infrastructure with energy stored in the car battery pack. This raises new challenges for the communication infrastructure and the charging management, since it has to become more dynamic and takes various parameters (in-vehicle battery status, availability of sustainable source of energy, campus building energy consumption, price of grid energy, ...).

7.7 FUI – Greenfeed

Participants: Jean-Marie Bonnin, Bruno Stévant, Alexander Pelov, Patrick Maillé, Wenjing Shuai, Feng Yan, Guillaume Le Gall, Benjamin Cama,.

A French plan to develop electric and hybrid vehicles was set up in 2009 with the goal of putting 2 millions of these in circulation by 2020. To reach this goal, it is indispensable to develop all kinds of services "without borders" to be provided by operators along with the vehicles and their charging systems, along with easy identification and payment methods. The increase of the number of electric vehicles associated with the fast deployment of fast charging point (7 millions planed by 2035[17]) makes power grid management more challenging.

The GreenFeed project aims to define a complete value chain for the charging service addressing the reservation of charging point, the management of energy inside a parking infrastructure and economic considerations. The GreenFeed project is founded by BPI France (FUI). Its consortium is composed of innovative SMEs working on new mobility paradigms with support of ErDF and GIREVE (national e-mobility facilitator).

7.8 ITEA – SEAS

Participants: Jean-Marie Bonnin.

The increase energy consumption and the development of decentralized production raised societal challenges. Solutions for better energy management based on tight interactions between energy networks and information systems are growing everywhere and constitute a priority in the United States and Western Europe. Energy savings associated with the deployment of "smart grids" to 1400 TWh in 2035[18].

The SEAS project will address the problem of inefficient and unsustainable energy consumption, which is due to a lack of sufficient means to control, monitor, estimate and adapt the energy use of systems versus the dynamic use situations and circumstances influencing the energy use. The objective of the SEAS project is to enable energy, ICT and automation systems to collaborate at consumption sites, and to introduce dynamic and refined ICT-based solutions to control, monitor and estimate energy consumption. Proposed solution should enable energy market participants to incorporate micro-grid environments and active customers.

7.9 FUI – GREENCOMM

Participants: Nicolas Montavont,.

7.10 CominL@b – TEPN

Participants: Nicolas Montavont,.

As in almost all areas of engineering in the past several decades, the design of computer and network systems has been aimed at delivering maximal performance without regarding to the energy efficiency or the percentage of resource utilization. The only places where this tendency was questioned were battery-operated devices (such as laptops and smartphones) for which the users accept limited (but reasonable) performance in exchange for longer use periods. Even

[17] in French Law: "Loi sur la transition énergétique"

[18] Gartner, The Future of Home Automation Emerging trends and technologies for smart home energy, entertainment, security, and health, it is estimated publication date: 21 April 2011

though the end users make such decisions on a daily basis by checking their own devices, they have no way of minimizing their energy footprint (or conversely, optimize the network resource usage) in the supporting infrastructure. Thus, the current way of dimensioning and operating the infrastructure supporting the user services, such as cellular networks and data centers, is to dimension for peak usage. The problem with this approach is that usage is rarely at its peak. The overprovisioned systems are also aimed at delivering maximal performance, with energy efficiency being considered as something desired, but non-essential. This project aims at making the network energy consumption proportional to the actual charge of this network (in terms of number of served users, or requested bandwidth). An energy proportional network can be designed by taking intelligent decisions (based on various constraints and metrics) into the network such as switching on and off network components in order to adapt the energy consumption to the user needs. This concept can be summarized under the general term of Green Cognitive Network Approach.

7.11 E-WI2ME

Participants: Nicolas Montavont,.

IEEE 802.11 appears as the most popular technology for wireless access because of its low cost and high data rates capacity. In the recent years a new communication paradigm emerged, called the Community Networking, which takes advantage of existing residential 802.11 access points and is based on sharing some part of the bandwidth to members of the community. In this project, we are developing an Android based application that allow monitoring the IEEE 802.11 access point surrounding a mobile users and gathering statistics. By crowd sourcing and installing the application in many user phones, we expect to gather a large amount of data to study the Wi-Fi deployments.

7.12 Brittany region BEL – Open Energy Data

Participants: Laurent Toutain, Alexander Pelov, Nicolas Montavont, Patrick Maillé, Baptiste Gaultier,.

The goal is to develop an infrastructure to monitor Rennes Metropole citizen energy consumption and to provide some anonymous open data.

7.13 Peak Shaving

Participants: Laurent Toutain, Alexander Pelov, Nicolas Montavont, Patrick Maillé, Baptiste Gaultier..

The project's goal is to study the impact of a diffuse peak shaving on periodic devices such as air conditionner, fridge,...

7.14 Competence Center Smart Grid

Participants: Laurent Toutain, Alexander Pelov, Alejandro Lampropulos, Tanguy

Ropitault, Renzo Navas..

We have created a join Competence Center with Texas instruments and ITRON, a well knows meters manufacturer. The goal is to study Smart Grid architectures. In 2014 we focused our work on enhancing the RPL protocol to improve AMI traffic.

7.15 CIFRE Orange Labs - Opening the Network: Everything as a Service

Participants: Ahmed Bouabdallah, Jean-Marie Bonnin, Amin Aflatoonian.

7.16 CIFRE Orange Labs - Contextual connectivity in future multi-RAT architecture

Participants: Jean-Marie Bonnin, Siwar Ben Hadj Said.

Naming is a fundamental element to evolve the current Internet into the next stage. The new host-level and user-level scenarios of the future networks introduce great pressure towards the initial two-level naming system of the Internet, which is requested to evolve in order to answer these new requirements. More specifically, special attention should be paid to person-to-person communications and multi-device support in future naming schemes' design. This thesis concentrates on the study of the naming research trends considering to improve future Internet's support to both host-level and user-level requirements. The Identifier/Locator split concept has been widely approved as a crucial solution for current Internet's naming problems. This is why, we first concentrate our work on studying several Identifier/Locator split solutions. We provide a qualitative overview and a quantitative cost analysis of the proposed approaches. Based on the results that we have obtained, we emphasize the host-centric character of these solutions and we show that they have shortages regarding additional user-level requirements. We study in this thesis a new naming proposal named Service-Aware Naming Architecture (SANA). In this proposal we promote users and services identification and provide a transparent multi-device support to the network. User's session switching between different terminals can then be agnostic to applications and networks.

This work in done in collaboration with the IRISA/ReOp team.

7.17 CIFRE Orange Labs - Naming, addressing and mobility in future Internet

Participants: Jean-Marie Bonnin, Nahla Abid.

Managing the network connectivity in multi-access architectures becomes a critical issue as these architectures should be able to interwork between heterogeneous technologies and to face the new ecosystem challenges. Facing these shortcomings, the 3GPP standards body proposed the multi-access 3GPP system that aims at providing ubiquitous network connectivity. This proposal has many benefits but it brings also a lot of challenges for network operators. In fact, within this system, network mechanisms such as mobility management, Quality of Service (QoS) control and security mechanisms are designed to be activated in a systematic manner

leading to rising network operating costs. For instance, the location update mechanism is always performed even for static devices (e.g. sensors). However, network operators face the challenge to host several categories of subscribers such as static subscribers, subscribers with high mobility, subscribers requiring high security level, subscribers satisfied with just low security level, subscribers requiring high/low bandwidth, etc.

In this thesis [3] we analyze the current approaches in multi-access 3GPP system and we specified a number of requirements for multi-access architectures to face the new ecosystem challenges. Then we propose a Context-Aware Connectivity Management (CACM) module allowing efficient interworking between heterogeneous accesses technologies. It selects and activates network mechanisms in accordance with the contextual information. Finaly concrete applications of the proposed model are described.

This work is done in collaboration with the IRISA/ReOp team.

7.18 CIFRE Orange Labs – Service-based Networking for M2M Communications

Participants: Laurent Toutain, Nicolas Montavont, Guillaume Habault.

7.19 CIFRE Orange Labs -Telco APIs for Over-The-Top (OTT) communication services

Participants: Ahmed Bouabdallah, Jean-Marie Bonnin, Ewa Janczukovicz.

7.20 CIFRE – Smart Grid routing optimization.

Participants: Laurent Toutain, Alexander Pelov, Tanguy Ropitault..

7.21 Samantha Gamboa Thesis

Participants: Nicolas Montavont, Alexander Pelov..

7.22 Vladimir Fux thesis

Participants: Jean-Marie Bonnin, Patrick Maillé.

The work focused on the pricing and competition issues in wireless networks. We have shown how, in a single cell where several access points (or channels, possibly using different technologies) are available, the pricing can help optimize the repartition of flows among those access points. The competition among road-side unit operators offering connectivity services to vehicles has also been studied.

7.23 CIFRE OrangeLabs - Routing with Electromagnetic and Energy contraints

Participants: Alexander Pelov, Laurent Toutain, Hanane Elabdellaouy.

8 Other Grants and Activities

8.1 Internation Chair: NICE

The International Research Chair NICE (Network-based Information and Communication Ecosystems) has been established at Télécom Bretagne (Department RSM) in the framework of the RBUCE WEST program supported by the Marie Curie action, and has been running in the two-year period starting April 1, 2012, and ending March 31, 2014. Its main goal was to work on an advanced interdisciplinary framework for future telecommunication ecosystems, joining the perspectives of cutting-edge technology, sustainable economic and business models and user-centered research. Moreover, this strongly interdisciplinary project has focused on selected research questions in the areas of Quality of Experience as well as game theoretic modeling of cooperation and competition between users and/or providers. During the project NICE, advances have been achieved in several area including network neutrality, future communication services and, last not least, user-perceived service quality (Quality of Experience) and how to charge for it.

8.2 International Collaborations

- For the academic year 2014-2015, Patrick Maillé is visiting the Electrical Engineering and Computer Science department at UC Berkeley, within Jean Walrand's team. The research work focuses on the economics of telecommunication networks, and more precisely on the software-defined networking paradigm and the net neutrality debate.
- University of Luxembourg, Yves Le Traon, professor and member of the SNT (Security and Trust laboratory) heading the research team SERVAL (Security Design and Validation).
- University of Meknes (Morocco), Nabil Benamar is associate professor in the computer science department. We established a fruitful collaboration on the adaptation of DTN (Delay Tolerant Nerwork) concept in the vehicular network environment.
- Computer Science Engineering school (ENSI in Tunisia), Farouk Kamoun is emeritus professor within the Cristal team. We establish a long-lasting collaboration on ad-hoc and vehicular networking. We also study together how to improve the transfert of research labs outcomes to Tunisian industries. A new fablab should be launched next year on the La Manouba campus of Tunis.
- Peter Reichl spent almost two years in the OCIF team. He worked mainly on Network-based Information and Communication Ecosystems. He is now professor at the university of Vienna.

8.3 National Collaborations

- The OCIF team has a collaboration with INRIA/IMARA and Mines Paritech/LARA teams in order to develop an open source IPv6 communication stack for ITS applications. We also participate together in standardisation at IETF, ETSI ITS and ISO TC204 to develop a comprehensive set of standards. A start-up named YoGoKo has been launched in June 2014 to exploit the outcomes of this collaboration.

- The OCIF team has a long term collaboration with the IFSTTAR/Leost team (Lille) that lead us to adapt network and transport level mechanisms to be used in railway environment.

- The OCIF team has a long term collaboration with DGA MI[19] (Bruz, 35), more recently focussed on trusted e-mail and web protection.

- The OCIF team has a long term collaboration with KEREVAL[20], an SME providing solutions for tests and security, located in Thorigné Fouillard (35).

9 Dissemination

9.1 Involvement in the Scientific Community

- In 2014, the members of OCIF have been involved in the Technical Program Committees of several international events, such as ValueTools, NGI, ICCCN.

- Jean-Marie Bonnin is member of the scientific council of the GIS ITS

- Jean-Marie Bonnin is member of the scientific council the Id4Car cluster

- Jean-Marie Bonnin is an elected member of the Scientific Council of IMT

- Laurent Toutain is at the head of the AFNIC scientific council

- Erwan Abgrall took part to the organization of the first botnet fighting conference (BOTCONF'13) which was reconducted in 2014.

9.2 Invited talks

- Alexander Pelov, *Narrowband PLC technologies routing protocols*, ABB workshop, February 2014.

- Laurent Toutain, Alexander Pelov, *Lightweight Architecture and Protocols for the Internet of Things*, ITU - ITU Workshop on the Internet of Things - Trend and Challenges in Standardization ", February 2014

[19] `http://www.defense.gouv.fr/dga/la-dga2/expertise-et-essais/dga-maitrise-de-l-information`
[20] `http://www.kereval.com`

- Laurent Toutain, *IoT and IPv6: New IPv6 Architecture for Constraint Device*, IPv6 world, March 2014.
- Laurent Toutain, Alexander Pelov, *New Architecture for IoT*, Texas instruments workshop, September 2014
- Jean-Marie Bonnin, *Preliminary thoughts on Data Collection for Low Energy Devices*, Sesame School, Tunis, April 2014
- Jean-Marie Bonnin, *Retour d'expérience suite au MOOC : Principes des réseaux de données*, MOOC Camp, Tunis, June 2014
- Jean-Marie Bonnin, *Opportunistically fully-networked car*, GIT ITS days, Rennes, June 2014
- Peter Reichl, *Network-based Information and Communication Ecosystems: Advances and Perspectives*, RBUCE WEST Closing Workshop, Brest, France, February 2014.
- Peter Reichl, *Stability Issues for the Fixed-Point Problem of QoE-based Charging in the Internet*, 11th International Conference on Operations Research, La Habana, Cuba, March 2014.

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[2] E. Abgrall, *An Empirical Study of Browsers' Evolution Impact on Security & Privacy*, PhD Thesis, RSM - Dépt. Réseaux, Sécurité et Multimédia (Institut Mines-Télécom-Télécom Bretagne-UEB), IRISA - Institut de recherche en informatique et systèmes aléatoires (UMR CNRS 6074 - Université de Rennes 1 - INRIA - INSA de Rennes - ENS de Cachan - Télécom Bretagne - Université de Bretagne Sud), septembre 2014.

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