Activity Report 2017

Team CASA

Opportunistic Networking and Computing

D2 - NETWORKS, TELECOMMUNICATION AND SERVICES

1 Team composition

Faculty

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2 Overall objectives

2.1 Overview

The research activity of team CASA aims at supporting communication and service provision in mobile networks that operate by exploiting transient radio contacts between mobile devices. Such networks are usually referred to as opportunistic networks in the literature[PPC06], although the terms delay-tolerant and disruption-tolerant networks (DTNs) are sometimes used instead. Indeed, according to Mota et al., delay/disruption-tolerant networks should actually be considered as a subset of opportunistic networks[MCM+14].

In an opportunistic network, the topology of the network can be modeled as a dynamic graph. This graph is usually not connected, as a consequence of the sparse distribution of mobile nodes, and because radio transmissions between these nodes can only be performed at short range.

In such conditions, mobility can be considered as an advantage as it makes it possible for messages to propagate network-wide, using mobile nodes as carriers that can move between remote fragments of the network. Each mobile node can thus store each message for a while, carry messages while moving around, and use any radio contact as an opportunity to forward messages to another node. This *store, carry and forward* principle is the foundation of opportunistic networking.

Part of our activity in team CASA consists in designing routing protocols for opportunistic networks, and implementing these protocols in communication middleware so they can be tested in real conditions. We also investigate how distributed applications can be designed so as to perform satisfactorily in such networks. Indeed, designing distributed applications that require network-wide communication and coordination in an opportunistic network is quite a challenge, when communication and coordination depend on unpredicted pairwise contacts between neighbor nodes. The term *Opportunistic Computing* has been introduced in the literature in order to refer to a new computing paradigm that relies exclusively on such pairwise contacts[CGMP10]. Team CASA strives to contribute to the development of this computing paradigm by designing methods, models, and middleware tools that make it easier for programmers to tackle the challenges presented by opportunistic networks.

2.2 Scientific foundations

2.2.1 Opportunistic networking

In the early 2000s the IETF initiated the DTN Research Group (DTNRG), whose charter was to define an architecture for both Delay- and Disruption-Tolerant Networks. This group was

[PPC06] L. PELUSI, A. PASSARELLA, M. CONTI, “Opportunistic Networking: Data Forwarding in Disconnected Mobile Ad Hoc Networks”, *IEEE Communications Magazine 44*, 11, November 2006, p. 134–141.

[MCM+14] V. F. S. MOTA, F. D. CUNHA, D. F. MACEDO, J. M. S. NOGUEIRA, A. A. F. LOUREIRO, “Protocols, Mobility Models and Tools in Opportunistic Networks: A Survey”, *Computer Communications 48*, July 2014, p. 5–19.

[CGMP10] M. CONTI, S. GIORDANO, M. MAY, A. PASSARELLA, “From Opportunistic Networks to Opportunistic Computing”, *IEEE Communications Magazine 48*, 9, September 2010, p. 126–139.

concluded in April 2016. In the meantime it has defined the architecture requested by the IETF (in two versions), together with a bundling protocol (BP) specification[SB07], and several "profile" documents that contain descriptions of convergence layers intended to fit the needs of specialized networking environments (e.g., space, water, sensor networks).

The DTN2 architecture and the associated bundle protocol (BP) are often believed to constitute an all-purpose solution for any kind of challenged network lacking end-to-end connectivity. Moreover, the fact that the DTN Research Group has concluded its work in 2016 may be interpreted as an indication that no further research activity is required along that line. Yet several authors have observed that although the Bundle Protocol is perfectly suited for inter-planetary networking, other kinds of networks (e.g., vehicular networks, pocket-switched networks, and mobile wireless sensor networks) may as well rely on alternative, lighter solutions[WEH09,WHFE09,Voy12]. Mota et al. suggest that the term delay-tolerant network should be used only for networks that strictly adhere to the DTN2 architecture, and they propose that the term opportunistic network be used for any kind of challenged network that exploits transient radio contacts between mobile nodes[MCM+14].

Thus, although the activity around the DTN2 architecture is now discontinued, message routing in opportunistic networks is still a hot topic for many research teams, including team CASA. The team continuously designs and evaluates opportunistic routing protocols, exploring different kinds of forwarding algorithms (content-based epidemic forwarding, location-based routing, service-oriented routing, etc.). The latest results obtained along that line are presented in §3.

2.2.2 Opportunistic Computing

Opportunistic computing is an emerging paradigm that builds on the results of several research areas (including autonomic computing and social networking), moving forward from simple communication to develop a framework to enable collaborative computing tasks in networking environments where long disconnections and network partitions are the rule[CGMP10].

Service-oriented computing appears to be a well-suited model for ambient computing environments, including those involving opportunistic communication. Building applications by combining software services is now well mastered and supported by many techniques and tools, among which the most popular Web Services. Since this approach fosters decoupling between applicative entities, it should be ideally suited to accommodate the connectivity constraints observed in opportunistic networks. Yet, although several middleware solutions have

[SB07] K. SCOTT, S. BURLEIGH, "Bundle Protocol Specification", IETF RFC 5050, November 2007.

[WEH09] L. WOOD, W. M. EDDY, P. HOLLIDAY, "A bundle of problems", *in : Aerospace conference, 2009 IEEE*, IEEE, p. 1–17, 2009.

[WHFE09] L. WOOD, P. HOLLIDAY, D. FLOREANI, W. M. EDDY, "Sharing the Dream: the Consensual Hallucination Offered by the Bundle Protocol", *in : Internation Congress on Ultra Modern Telecommunication (ICUMT'09)*, IEEE, p. 1–2, 2009.

[Voy12] A. G. VOYIATZIS, "A Survey of Delay- and Disruption-Tolerant Networking Applications", *Journal of Internet Engineering 5*, 1, June 2012, p. 331–344.

[MCM+14] V. F. S. MOTA, F. D. CUNHA, D. F. MACEDO, J. M. S. NOGUEIRA, A. A. F. LOUREIRO, "Protocols, Mobility Models and Tools in Opportunistic Networks: A Survey", *Computer Communications 48*, July 2014, p. 5–19.

[CGMP10] M. CONTI, S. GIORDANO, M. MAY, A. PASSARELLA, "From Opportunistic Networks to Opportunistic Computing", *IEEE Communications Magazine 48*, 9, September 2010, p. 126–139.

been proposed during the last decades to support service provision and invocation in mobile ad hoc networks (MANETs), they can only be used in connected networks. In opportunistic networks, the absence of network-wide end-to-end connectivity, and the transmissions delays induced by the store, carry, and forward model require that specific solutions be devised in order to support both service discovery and service invocation.

Beside service-oriented computing, other computing paradigms have also long proved useful for designing distributed applications. Group communication, publish-subscribe systems, message queues, tuple spaces, are thus abstractions or systems for which efficient implementations are available in software development kits. Yet most of these implementations have been realized for traditional, connected environments. They cannot operate satisfactorily in partially or intermittently connected environments, and must be completely revised in order to tolerate network partitions, transmission disruptions, or long transmission delays.

2.3 Application domains

The research work carried out in team CASA is focused on the design and the implementation of middleware support for applications targeting challenged networking environments. We are particularly interested in providing support for mobility and continuity of service, even in the absence of any stable communication infrastructure. This applies to multiple environments where adaptive and cooperative applications are required, but where cost or technical constraints preclude the deployment of stable computing and communication resources. Possible application domains are:

- Collaborative computing in crisis operation fields (e.g., military operations, disaster relief situations);
- Sensor and actuator networking, as part of the Internet of Things (e.g., environment monitoring, crowd sensing, robot/drone control);
- Automotive computing (e.g., vehicle-to-vehicle and vehicle-to-roadside communication);
- Home automation (e.g., smart home applications);
- Nomadic computing (e.g., coordination and data sharing in rural or developing areas);
- Crowd-sensing (e.g., distributed content production and sharing);
- Personal communication systems (e.g., group communication, social interactions);
- Mobile health (e.g., ambulatory patient monitoring).

To date the activities conducted in team CASA already cover several of these application domains. For example, the problem of controlling mobile robots remotely through intermittent transmission links is considered in project ASAWoO (see §5.1.1). Data sharing among people during social events such as cultural or sports events is addressed in project C3PO (see §5.1.2). Monitoring the health status of people wearing biometric sensors during their daily activities is addressed in project SHERPAM (see §5.1.3); and using Web browsers to support opportunistic distributed applications is addressed in project O'Browser (see §5.1.4).

Most of the middleware systems developed in team CASA over the recent years can also be considered as enablers for the above-mentioned application domains. Please refer to the team's Web site[2] for further information about these systems.

3 Scientific achievements

3.1 Middleware systems for content-based opportunistic communication

Participants: F. Guidec, Y. Mahéo, P. Launay.

Although opportunistic networking has been studied for over a decade, few operational implementations of opportunistic systems are available. Team CASA maintains an activity in designing an implementing middleware systems for opportunistic communication so that these systems can be tested in real conditions. DoDWAN is such a system : it is a flexible Java-based platform for content-based opportunistic communication (see also § 4.4) that has been developed a few years ago, and has been improved continuously since then. Moreover, a suite of applications called DoDWAN-Apps, mainly targeting Android smartphones, is maintained as a demonstrator of the concept of opportunistic networking.

Current work aims at overcoming the fact that the standard operating systems running on smartphones (e.g., iOS, Android) do not allow the user to set the Wi-Fi interface in ad hoc mode, which therefore hampers the use of opportunistic communication on such devices. The architecture of DoDWAN has been revised so that applications can be clearly separated from the DoDWAN middleware. This new architecture makes it possible to run a user application on any (non-rooted) smartphone, while DoDWAN's core runs on an external, more controllable, device. A protocol has been devised to support the interaction between these two elements, using websockets and Bluetooth.

DoDWAN-Apps can serve as a tool for field experiments, with the objective to gain a better understanding of how data disseminate in real conditions. A series of such experiments took place in the end of 2017. The last one involved a dozen volunteers, who were asked to roam our university campus while exchanging messages with DoDWAN-Apps running on an Android smartphone. Statistical data and visualizations are available online[3].

3.2 Disruption-Tolerant Mobile Health Monitoring

Participants: M. Bagot (PhD), P. Launay, F. Guidec.

The concept of Wireless Biomedical Sensor Network (WBSN) opens up new opportunities for biomedical monitoring, such as the long-term, continuous monitoring of patients in a clinical environment or at home. In a typical deployment scenario, one or several wireless sensors are attached to a patient, and wireless transmission is used to forward data to a remote site (such as a physician's desktop computer or a hospital's monitoring center), usually through a local gateway. In traditional mHealth (Mobile Health) scenarios, it is commonly assumed that the transmission link between sensor and monitoring site is continuously available and reliable:

[2] https://www-casa.irisa.fr/software

[3] https://casa-irisa.univ-ubs.fr/dodwan/field_expe_2018_01.html

the general assumption is thus that frequent, long-term disruptions should never occur while a patient's health status is being monitored. Such an assumption holds when a patient does not move much around the gateway, as is the case in a hospital environment or at home. Yet there are other circumstances when the connectivity between sensor and base station can be seriously disrupted by the patient's mobility. In team CASA we investigate the possibility of using opportunistic networking as a means to tolerate transmission disruptions between sensors worn by highly mobile people in outdoor conditions, and a remote monitoring center. A flexible architecture for disruption-tolerant mobile health monitoring has been designed along this line, and an Android application has been developed as part of this architecture (see §4.3 and §5.1.3) [2, 3].

3.3 Spontaneous and Ephemeral Social Networking

Participants: N. Le Sommer, L. Touseau, Y. Mahéo, P. Launay, F. Baklouti (PhD).

Spontaneous and Ephemeral Social Networks (SESNs) are social networks that are limited in time and space. They rely on a peer-to-peer distributed architecture formed spontaneously by mobile devices carried by people and, optionally, by fixed devices that can be deployed to support such networks. Members of SESNs can communicate with each others thanks to their mobiles devices, which are equipped with short radio range wireless interfaces, such as Bluetooth or IEEE 802.11 (Wi-Fi). Due to their spontaneous and ephemeral nature, SESNs target the production and the sharing of multimedia contents, and also participatory micro-journalism, during events such as conferences and cultural or sports events [12, 7]. In most of these events, people move and are not necessarily located in the same place at the same time. The topology of the network formed by their devices therefore changes continuously and can be fragmented into distinct communication islands.

In order to allow the members of such social networks to exchanges data and communicate using off-the-shelves mobile phones, we developed a communication middleware system, called C3PO, that implements opportunistic networking techniques relying on the concepts of *micronets* and *macronets* [14]. Thanks to this middleware system, the network is structured as a collection of micronets, grouped together in independent macronets. We define a micronet as a subset of devices connected using a common communication technology, that are able to communicate directly with each other. A micronet is an abstraction of a piconet for Bluetooth, a basic service set (BSS) for Wi-Fi legacy, or a group for Wi-Fi direct. We consider that devices in a micronet communicate *directly*, as there exists a network layer that allows any device to address and send messages to any other device in its micronet, even if that is not the case at the MAC layer (messages being forwarded through a Bluetooth master, Wi-Fi Direct GO or Wi-Fi AP). We call a *one-hop neighbor* of a device any other member of the same micronet, and a *micronet link* the (virtual) link between two one-hop neighbors. We define a macronet as a group of micronets interconnected through devices that are members of at least two micronets. A macronet can thus link together any number of devices provided they are close enough to each other and can form connected micronets. The resulting communication network is a collection of independent macronets.

3.4 Middleware Support for the Web of Things

Participants: M. Auzias (PhD), N. Le Sommer, Y. Mahéo, F. Raimbault, L. Touseau.

Cyber-physical objects have been implemented based on the concept of "Avatar" as defined in project ASAWoO (see Section 5.1.1). An avatar relies on Web standards to provide a virtual representation of a physical "thing", thus participating in a Web of Things (WoT). Details on how objects describe their functionalities semantically and publish them as RESTful services are available in [3][16, 18, 19].

"Things" are by nature prone to connectivity disruptions. Indeed, self-powered devices shut their radio interface down when they do not need to communicate, or are regularly put in sleep mode, for energy saving purposes, thus introducing connectivity disruptions. In addition, these disruptions increase when some devices forming a WoT are mobile and that they communicate using short radio range wireless interfaces. As a result, such networks should be considered as partially or intermittently connected. To address this issue, CASA has integrated a disruption-tolerant communication module in the ASAWoO WoT platform. This module allows avatars and/or users of a WoT application to interact with cyber-physical objects, even if no end-to-end path is available between these elements.

In 2017, the ASAWoO WoT platform and its opportunistic computing support were evaluated in the agricultural context, in conjunction with IRSTEA. The experiment spanned over 4 months during which two tractors carrying ASAWoO instances collected data from sensors opportunistically in an experimental farm. Another experiment involving a robot mobile platform was conducted in Bordeaux, in collaboration with ASAWoO partner GenerationRobots. This experiment aimed at evaluating the Web of Things aspect of ASAWoO. Descriptions and results of these experiments are presented in an article, which is currently under review.

CoAP (Constrained Application Protocol) is a key protocol in the the Web of Things: it proposes a resource-oriented vision, using the HTTP features that contributed to the success of the Web, while taking into account the limited capacity and energy constraints of small objects. However, it still assumes a connected IP network, supporting only very little asynchronism between the communicating entities. Hence it is not adapted to opportunistic networks that involve frequent and potentially long communication disruptions. In order to solve this problem we have proposed a series of adaptations to CoAP in order to accommodate a transport mechanism suited to opportunistic and DTN networks, implemented by the Bundle Protocol [1]. This adapted CoAP protocol, called BoAP, has been integrated in the context of the ASAWoO platform [16]. Moreover, a platform has been designed that leverages BoAP in order to provide the main features of a service-oriented framework, including discovery and invocation of RESTful services [1].

3.5 Peer-to-peer and opportunistic communication techniques for Intermittently-Connected Hybrid Networks

Participants: A. Esnault (PhD), N. Le Sommer, F. Guidec.

The number of devices that are likely to get connected to the Internet (e.g., smartphones, sensors), and the amount of data produced by people using these devices grow continuously, especially in cellular networks. Latest developments performed on the physical layer to increase the network's bandwidth might be insufficient in the future, because of the emergence of the Internet of things. Therefore, it seems to be interesting to study new or complementary network architectures. Intermittently-Connected Hybrid Networks (ICHN), which are composed both of an infrastructure part and of parts formed by mobile device communicating using ad hoc mode, are examples of those architectures that deserve to be studied.

In [9] and [8], we have proposed an approach relying on peer-to-peer mechanisms and opportunistic networking techniques to support communications in wide ICHNs. This approach is based on a decentralized unstructured peer-to-peer overlay architecture. We have proposed two communication modes: a unicast mode to support communication between peer devices in the network and an anycast mode for data offloading in ICHNs. This approach has been implemented in a prototype, which has been evaluated in simulation. To build this peer-to-peer overlay architecture, this prototype performs a proactive discovery of fixed and mobile neighbor devices, and creates and maintains logical links between fixed devices so as to form a backbone. This discovery relies on both a beaconing mechanism and a Cyclon-based service. This backbone helps cover a wide area and support communications between remote mobile devices. The scalability of our system results from the existence of this backbone. In order to perform an efficient message forwarding in this overlay, each device computes a list of so-called "trail values" (TV) and shares these values with its neighbors. A trail value computed by a device for a given destination reflects its capacity to forward a message to this destination, either directly or through intermediate devices using opportunistic communication techniques. Disseminating such pieces of information can be costly because each device can maintain trail values for a large number of devices, even in the worst case for all the devices present in the network. In order to address this issue, we have implemented a modified version of the Exponential Decay Bloom Filter (EDBF), which is itself an extension of the traditional Bloom filter that encodes probabilistic forwarding tables in a highly compressed manner. This modified version of EDBF is called TBF (for Trail Bloom Filter). It makes it possible to store and disseminate efficiently the trail values of each device in the overlay system. We have also implemented a forwarding algorithm called BTSA for "Best Trail Selection Algorithm (BTSA)" in this prototype. This algorithm uses the transitive property of the TBFs and promotes, while forwarding a message, the devices that met the destination of the message the most recently. To do so, each device takes a local decision based on its own TBF and on those sent by its neighbors. When a device receives a message from a neighbor or from a local application, it forwards this message to the neighbor that has the greatest trail value for the destination, provided that this value is greater than its own value. When a device receives a TBF from one of its neighbors, it looks for all the messages it maintains in its local cache, and it sends to this neighbor copies of the messages for which it considers the neighbor as a better forwarder than itself.

3.6 Opportunistic computing with Web browsers

Participants: F. Guidec, Y. Mahéo, P. Launay.

Web browsers have turned into the most widely deployed execution environments in the world. Empowered with browser-to-browser communication capabilities, they can be seen as nodes of a wide range of peer-to-peer applications. In the framework of ANR project O'Browser (see §5.1.4), team CASA studies how browser-to-browser communication can be achieved when browsers run on mobile devices in an infrastructure-less context, hence relying on opportunistic networking to cope with the lack of connectivity. The use of a content-based opportunistic middleware system such as DoDWAN (see §4.4) has been identified as a good approach for this purpose (techniques such as WebRTC are not an option, due to the need of stable servers to initiate communication). As a proof-of-concept, a simple user application has been developed in Javascript. This application can run in a browser on any smartphone and interacts with an instance of DoDWAN hosted in a battery-powered Raspberry Pi. This kind of architecture will allow the distributed sofware tools that are to be developed in project O'Browser to be experimented in real conditions.

3.7 Composition of opportunistic services

Participants: F. Baklouti (PhD), N. Le Sommer, Y. Mahéo.

The Internet of Things is characterized by the variety of devices susceptible to provide services. Besides, these services are likely to be basic functionalities for collecting, generating or processing data, due to the limitation of the devices themselves or that of the network they are connected to. Yet, the end-user is preferably provided with a rich application, that actually combines a set of basic functionalities. We study the dynamic composition of services in the context of an opportunistic IoT, that is to say when the devices form an opportunistic network. The absence of end-to-end connectivity is a challenge for the composition process and state-of-the-art techniques are mostly inapplicable. These techniques are generally designed for an Internet-like context and are likely to cause prohibitive delays because they implement entire conversations between devices that induce several transmissions across the whole network. We have proposed a middleware system that supports the discovery, the selection, the invocation and the composition of services in opportunistic networks. A composition request issued by a node that has discovered a service is implemented according to one of two strategies, based respectively on choreography and orchestration. These strategies can be parameterized with a utility function that makes it possible to estimate the delay and the success of a transmission between a service client and a service provider, and to select the provider according to these values. A prototype middleware has been developed on top of the C3PO communication library (see §4.2) and a comparative study of the two strategies has been conducted on several deployment scenarios [4, 5].

4 Software development

4.1 Platform ASAWoO

In the context of project ASAWoO[4], which was concluded in 2017, team CASA has participated in the design and development of a middleware platform for the Web of Things. Our main contributions consisted in designing and implementing:

- the avatar runtime container architecture;

[4] `https://projet.liris.cnrs.fr/asawoo`

- the functionality and WoT modules in charge of instantiating and publishing functionalities of avatars (i.e. virtual representations of devices);
- the WoT application manager which enables applications deployment based on available functionalities and contextual information;
- the opportunistic communication adaptation layer.

The ASAWoO platform also integrates a reasoning module and a context adaptation module that make it possible for avatars to reason on the semantic descriptions of their capabilities and their functionalities, and thus help them to infer new high-level and complex functionalities that better match the users' needs than the low-level capabilities, and that are suited to their running context.

The source code of the ASAWoO platform is distributed under the CeCILL license (compatible with GNU GPLv2). It is available in a GIT repository[5], and documentation for users and developers can be accessed on project ASAWoO's website.

4.2 C3PO development

C3PO (*Collaborative Creation of Contents and Publishing using Opportunistic networks*) is a middleware platform that has been developed in project C3PO[6], which was concluded in 2017 [10]. This platform implements opportunistic communication techniques relying on the concepts of micronets and macronets. It makes it possible to create mobile ad hoc networks using off-the-shelves mobile devices, as well as hybrid networks composed of both infrastructure and mobile parts. To do so, it supports various communication modes and wireless technologies (e.g. Bluetooth, Wi-Fi legacy mode, Wi-Fi ad hoc mode, Wi-Fi Direct, 3G/4G, XBee). This platform provides two distinct application-level communication paradigms: a topic-based publish/subscribe model, and a channel-based send/receive model.

The topic-based publish/subscribe communication model makes it possible to develop applications that can publish multimedia contents on specific topics, and subscribe in order to receive the contents related to given topics. The model implemented in the C3PO framework relies on a purely peer-to-peer decentralized approach. Topic names are assumed to be already known by the application, as a given topic is generally pre-defined or handled by a single application module that performs both production and consumption. The subscription and the publication are local to each device. Thanks to the store-carry-and-forward principle, contents published in a topic by publishers are disseminated opportunistically in the communication network by mobile devices, being either devices hosting subscribers for this topic or ordinary intermediate devices, and are thus delivered to the topic subscribers.

The point-to-point communication paradigm using the concept of channel is intended for applications that allow users to communicate with each others by sending messages addressed to specific recipients. In the framework, a channel between two devices is identified by the addresses of the devices and a channel ID. Messages sent through a channel are opportunistically forwarded by intermediate devices towards their destination according to one of the message forwarding strategies implemented in the framework. Primitives similar to the ones used for

[5] `https://gitlab.com/asawoo`

[6] `http://laboratoirehubertcurien.fr/c3po-anr`

Java sockets are available to the programmer (open, accept, receive...). Asynchronous receiving is also possible by registering a message listener associated with a channel.

C3PO-based mobile Android applications dedicated to sport events have been developed in project C3PO [13]. Wi-Fi access points embedding this platform have also been built in this project. These access points have been used during experiments in order to help network formation and to collect data and traces generated by users for analytical purposes. These mobile applications and these access points have been tested in real conditions during several running events, and especially during the semi-marathon of Beaune, where more than 1200 people used the C3PO-based mobile application dedicated to that event to share multimedia contents, to follow the run and to obtain the results of the semi-marathon.

The first version of this middleware platform has been registered with the French Agence pour la Protection des Programmes (IDDN.FR.001.100015.000.S.C.2018.000.10000).

4.3 SHERPAM health monitoring system

A software system is under development in the framework of project SHERPAM (see §5.1.3). This system shall make it possible to monitor continuously the health status of fragile people during their daily activities, supporting all stages of data acquisition, transmission, and processing.

Sensors worn by a subject are used to acquire data pertaining to the subject's status (acceleration, gyroscope, heart rate or full-featured ECG, temperature, location, etc.). Data streams produced by these sensors are gathered by a portable "gateway", which is also worn by the subject. This gateway pre-processes data, so they can be transferred to a remote site for storage and analysis. The sensors and the gateway together constitute a Body Area Network (BAN), and transmissions in this BAN rely on Bluetooth links (including Bluetooth Low Energy). Support for other transmission technologies (e.g., ANT+) may be included later in the system.

Before transferring data to a remote site, the gateway can pre-process these data in order to reduce the amount of data to be transferred, or in order to detect interesting patterns in these data. In the latter case, the subject can be warned directly by audible or visual notifications.

In the framework of project SHERPAM, the gateway is typically an Android smartphone running a dedicated application The first version of this Android application has been registered with the French Agence pour la Protection des Programmes (IDDN.FR.001.540019.000.S.P.2015.000.31230). Further details are available on the project's Web site[7].

4.4 DoDWAN

DoDWAN is a flexible Java-based middleware platform that has been developed in team CASA in order to support content-based, disruption-tolerant communication in opportunistic networks. It is distributed under the GNU General Public License (GPL)[8].

In content-based networking, information flows towards interested receivers rather than towards specifically set destinations. This approach notably fits the needs of applications and

[7] `https://sherpam.cominlabs.u-bretagneloire.fr/results/prototype`
[8] `http://www.irisa.fr/casa/dodwan`

services dedicated to information sharing or event distribution.

A suite of applications suitable for disconnected MANETs has been developed on top of the DoDWAN middleware system. This suite is called DoDWAN-Apps, and it is available for laptops and netbooks running Linux or Windows, as well as for Android smartphones. DoDWAN-Apps is meant to be a fully-functional demonstrator of the concept of opportunistic ad hoc networking. With a mobile device running DoDWAN-Apps a user can for example locate other users in the neighborhood and exchange text messages, voice messages, or files with any other user or group of users.

DoDWAN and DoDWAN-Apps have been tested and demonstrated on several occasions during the past years (communications on the battlefield, while trekking in remote areas, etc.). Recently, an experiment involving volunteers roaming our university campus has been performed, and its results are presented on the team's Web site[9].

DoDWAN is registered with the French Agence pour la Protection des Programmes (IDDN.FR.001.170036.000.S.P.2013.000.10200). Recent developments concerning this platform are discussed in §3.6.

5 Contracts and collaborations

5.1 National Initiatives

5.1.1 Project ASAWoO

- Participants: M. Auzias (PhD), F. Baklouti (PhD), N. Le Sommer, Y. Mahéo, F. Raimbault, L. Touseau
- Project type : ANR, programme INFRA 2013
- Dates : 2014-2017
- Partners : team LIP/AVALON (Lyon 1), teams LIRIS/DRIM and LIRIS/SOC (Lyon 1), team LCIS/COSY (Univ. Pierre Mendès-France), and company Génération Robots (Lyon)

Project ASAWoO *(Adaptive Supervision of Avatar/Object Links for the Web of Objects)* addresses the domain of the Web of objects. The objective is to improve the integration of connected objects in the Web. A software platform shall be developed, that will facilitate the communication and control of connected objects, as well as the cooperation of several such objects. This platform will benefit from advances in complementary disciplines, such as semantic Web for knowledge processing, service-oriented architectures for interoperability and scalability, context-aware computing for situation-driven multi-level decision making, multi-agent systems for autonomous cooperation between objects, delay/disruption-tolerant networking for communication, and cloud technology for reduced power consumption.

5.1.2 Project C3PO

- Participants: N. Le Sommer, Y. Mahéo, P. Launay, L. Touseau, F. Baklouti (PhD)

[9] https://casa-irisa.univ-ubs.fr/dodwan/field_expe_2018_01.html

- Project type : ANR, programme CONTINT 2013 (ANR-13-INFR-012)
- Dates : 2014-2017
- Partners : team INRIA/DICE (Lyon), team SATIN at LT2C (Saint-Étienne), team LEMNA/SSG (Nantes), and company ChronoCourse (Vannes)

The objective of project C3PO *(Collaborative Creation of Contents and Publishing using Opportunistic networks)* is to support so-called "Spontaneous and Ephemeral Social Networks" (SESNs), based on a peer-to-peer distributed architecture and on mobile ad hoc networks. A SESN is meant to allow nomadic people to interact according to their affinities and centers of interest, so they can cooperate to perform specific tasks within a SESN. Several application domains are considered for SESNs, such as the collection of data and the production of digital content during cultural or sports events. The contents thus produced shall be accessible from the users' mobile terminals, and be replicated on dedicated servers or in traditional social networks so they can also be accessed by remote users, and remain accessible beyond the lifetime of a SESN.

5.1.3 Project SHERPAM

- Participants: M. Bagot (PhD), P. Launay, F. Guidec
- Project type : LabEx CominLabs
- Dates : 2014-2019
- Partners : LTSI (Rennes 1), M2S (Rennes 2, ENS Rennes), LAUREPS (Rennes 2), CIC-IT 804-CHU Rennes

The objective of project SHERPAM *(Sensors for HEalth Recording and Physical Activity Monitoring)* is to design, implement, and validate experimentally a system based on biopĥysical sensors to monitor people during their daily life. Two application domains are considered specifically in this project: the evaluation of the functional limitations of arteriopathic patients, and the recognition and quantization of physical activity for a given population.

5.1.4 Project O'Browser

- Participants : F. Guidec, Y. Mahéo, P. Launay
- Project type : ANR, generic programme
- Dates : 2017-2020
- Partners : teams LINA/GDD (Nantes), IRISA/ASAP (Rennes), and Orange Labs Research (Lannion)

The objective of project O'Browser *(Opportunistic Fog Computing with Browsers)* is to propose a novel programming framework, whereas distributed applications can be deployed on Web browsers, and operate based on browser-to-browser communication, without relying on a cloud or a central authority. When the browsers involved run on mobile devices, opportunistic networking will be used as a means to cope with connectivity disruptions.

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Journal

Reviewer - Reviewing Activities

- F. Guidec
  - Reviewer for the Ad Hoc Networks journal (Elsevier)

6.2 Teaching, supervision

6.2.1 Teaching

- F. Guidec
  - Master 1: “Technological watch”, 20 h
  - Master 1: “Network administration”, 38 h
  - Master 2: “Wireless networking technologies”, 52 h
  - Master 2: “Network support for multimedia applications”, 26 h
- Y. Mahéo
  - Master 1: “Introduction to distributed systems”, 20 h
  - Master 1: “Technological watch”, 16 h
  - Master 1: “Tutored projects”, 8 h
  - Master 1: “System administration”, 30 h
- P. Launay
  - Master 1: ”Distributed systems: Java Networking”, 12 h
  - ENSIbs[10] 2: “Advanced Object Programming“, 36 h
  - ENSIbs 2: “Computer Networks“, 30 h
  - ENSIbs 2: “Middleware for distributed computing“, 38 h
  - ENSIbs 3: “Graduation projects supervision“
- F. Raimbault
  - Master 1: "Introduction to Distributed Systems", 12 h
  - Master 1: "Tutored Projects", 12 h
  - Master 2: "Distributed Programming", 40 h
  - Master 2: "High Performance Computing for the Big Data", 32 h
- N. Le Sommer
  - Master 2: “Development of mobile applications”, 20 h
  - Master 1: “Project management tools”, 4 h

[10]ENSIbs: Engineering school.

6.2.2 Supervision

- A. Esnault, "Peer-to-peer systems for opportunistic computing", supervised by F. Guidec and N. Le Sommer, PhD defense in Jan. 2017 [2]
- M. Auzias, "Programming Support for a Delay-Tolerant Web of Things", supervised by Y. Mahéo and F. Raimbault, PhD defense in Dec. 2017 [1]
- F. Baklouti, "Definition of an adaptive service-oriented shared space for spontaneous ephemeral social networks", supervised by Y. Mahéo and N. Le Sommer, PhD in progress
- M. Bagot, "Adaptive disruption-tolerant data transmission for the biomedical monitoring of mobile subjects", supervised by F. Guidec and P. Launay, PhD in progress

7 Bibliography

Major publications by the team in recent years

[1] M. AUZIAS, Y. MAHÉO, F. RAIMBAULT, "CoAP over BP for a Delay-Tolerant Internet of Things", *in: 3rd International Conference on Future Internet of Things and Cloud (FiCloud 2015)*, IEEE CS, Rome, Italy, August 2015.

[2] M. BAGOT, P. LAUNAY, F. GUIDEC, "A Flexible Architecture for Mobile Health Monitoring", *in: 18th International Conference on e-Health Networking, Applications and Services (Healthcom'16)*, IEEE, p. 1–6, Munich, Germany, September 2016.

[3] M. BAGOT, P. LAUNAY, F. GUIDEC, "Toward an Open-Source Flexible System for Mobile Health Monitoring", *in: 6th EAI International Conference on Wireless Mobile Communication and Healthcare (MobiHealth'16)*, p. 1–4, Milan, Italy, September 2016.

[4] A. BENCHI, P. LAUNAY, F. GUIDEC, "A P2P Tuple Space Implementation for Disconnected MANETs", *Peer-to-Peer Networking and Applications 8*, 1, January 2015, p. 87–102, ISSN:1936-6442, 1936-6450.

[5] A. BENCHI, P. LAUNAY, F. GUIDEC, "JMS for Opportunistic Networks", *Ad Hoc Networks 25*, B, February 2015, p. 359–369.

[6] A. BENCHI, *Middleware Systems for Opportunistic Computing in Challenged Wireless Networks*, PhD Thesis, Université de Bretagne-Sud / Université Européenne de Bretagne, June 2015.

[7] A. BOUTET, S. FRÉNOT, F. LAFOREST, P. LAUNAY, N. LE SOMMER, Y. MAHÉO, D. REIMERT, "C3PO: A Network and Application Framework for Spontaneous and Ephemeral Social Networks", *in: Proceedings of the 16th International Conference on Web Information Systems Engineering (WISE 2015)*, J. Wang, W. Cellary, D. Wang, H. Wang, S.-C. Chen, T. Li, Y. Zhang (editors), *Lecture Notes in Computer Science*, *9419*, Springer International Publishing, p. 348–358, Miami, FL, USA, November 2015.

[8] A. ESNAULT, N. LE SOMMER, F. GUIDEC, "A Peer-to-Peer Overlay System for Message Delivery in Wide Intermittently-Connected Hybrid Networks", *in: 12th International Conference on Wired & Wireless Internet Communications (WWIC 2014)*, *Lecture Notes in Computer Science*, *8458*, Spinger, p. 200–213, Paris, France, May 2014.

[9] A. ESNAULT, N. LE SOMMER, F. GUIDEC, "An Anycast Communication Model for Data Offloading in Intermittently-Connected Hybrid Networks", *in: the 12th International Conference on Mobile Systems and Pervasive Computing, MobiSPC 2015, The 10th International Conference on Future Networks and Communications (FNC 2015) / The 12th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2015)*, *Procedia Computer Science*, 56, Elsevier, p. 59–66, Belfort, France, August 2015.

[10] S. FRÉNOT, A. GHORBALI, F. LAFOREST, P. LAUNAY, N. LE SOMMER, D. REIMERT, "Spontaneous and Ephemeral Social Networks: An Event-based Framework", *in: Proceedings of the 9th ACM International Conference on Distributed Event-Based Systems (Demo DEBS'15)*, ACM, p. 364–367, Oslo, Norway, 2015.

[11] F. GUIDEC, D. BENFERHAT, P. QUINTON, "Disruption-Tolerant Wireless Sensor Networking for Biomedical Monitoring in Outdoor Conditions", *Mobile Networks and Applications 19*, 6, January 2014, p. 684–697.

[12] F. LAFOREST, N. LE SOMMER, S. FRÉNOT, F. DE CORBIÈRE, Y. MAHÉO, P. LAUNAY, C. GRAVIER, J. SUBERCAZE, D. REIMERT, E. BRODU, I. DAIKH, N. PHELIPPEAU, X. ADAM, F. GUIDEC, S. GRUMBACH, "C3PO: a Spontaneous and Ephemeral Social Networking Framework for a Collaborative Creation and Publishing of Multimedia Contents", *in: International Conference on Selected Topics in Mobile and Wireless Networking (MoWNeT'2014)*, *Procedia Computer Science*, *40*, Elsevier, p. 129–134, Rome, Italy, September 2014.

[13] N. LE SOMMER, P. LAUNAY, Y. MAHÉO, S. FRÉNOT, F. LAFOREST, D. REIMERT, "Demo: C3PO - Spontaneous and Ephemeral Social Networks", *in: 10th Workshop on Challenged Networks, Demo session (CHANTS'2015)*, ACM, Paris, France, September 2015.

[14] N. LE SOMMER, P. LAUNAY, Y. MAHÉO, "A Framework for Opportunistic Networking in Spontaneous and Ephemeral Social Networks", *in: 10th Workshop on Challenged Networks (CHANTS'2015)*, ACM, Paris, France, September 2015.

[15] N. LE SOMMER, Y. MAHÉO, "Location-Aware Routing for Service-Oriented Opportunistic Computing", *International Journal on Advances in Networks and Services 5*, 3&4, December 2012, p. 225–235.

[16] N. LE SOMMER, L. TOUSEAU, Y. MAHÉO, M. AUZIAS, F. RAIMBAULT, "A Disruption-Tolerant RESTful Support for the Web of Things", *in: 4th International Conference on Future Internet of Things and Cloud (FiCloud 2016)*, IEEE, p. 17–24, Vienna, Austria, August 2016.

[17] A. MAKKE, *Pervasive Service Provisioning in Intermittently Connected Hybrid Networks*, PhD Thesis, Université de Bretagne-Sud / Université Européenne de Bretagne, March 2015.

[18] M. MRISSA, L. MÉDINI, J.-P. JAMONT, N. LE SOMMER, J. LAPLACE, "An Avatar Architecture for the Web of Things", *IEEE Internet Computing 19*, 2, March 2015, p. 30–38.

[19] M. TERDJIMI, L. MÉDINI, M. MRISSA, N. LE SOMMER, "An Avatar-Based Adaptation Workflow for the Web of Things", *in: 25th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE 2016)*, IEEE, p. 62–67, Paris, France, June 2016.

Doctoral dissertations and "Habilitation" theses

[1] M. AUZIAS, *Programming Support for a Delay-Tolerant Web of Things*, PhD Thesis, Université Bretagne Sud / Université Bretagne Loire, October 2017.

[2] A. ESNAULT, *Systèmes pair-à-pair pour l'informatique opportuniste*, PhD Thesis, Université Bretagne Sud / Université Bretagne Loire, January 2017.

Articles in referred journals and book chapters

[3] L. MÉDINI, M. MRISSA, E.-M. KHALFI, M. TERDJIMI, N. LE SOMMER, P. CAPDEPUY, J.-P. JAMONT, O. MICHEL, L. TOUSEAU, "Chap. 5 - Building a Web of Things with Avatars: A comprehensive approach for concern management in WoT applications", *in : Managing the Web of Things, Linking the Real World to the Web*, Q. Z. Sheng, Y. Qin, L. Yao, and B. Benatallah (editors), Morgan Kaufmann, 2017, p. 151–180.

Publications in Conferences and Workshops

[4] F. BAKLOUTI, N. LE SOMMER, Y. MAHÉO, "Choreography-based vs Orchestration-based Service Composition in Opportunistic Networks", *in : 13th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2017)*, Rome, Italy, October 2017.

[5] F. BAKLOUTI, N. LE SOMMER, Y. MAHÉO, "Opportunistic Service Composition in Pervasive Networks", *in : IFIP Wireless Days Conference*, IEEE, Porto, Portugal, March 2017.