
Project-Team CASA

# *Disruption-Tolerant Networking and Computing*

*Vannes*

*Activity Report*

*2012*

# 1 Team

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# 2 Overall Objectives

## 2.1 Overview

**Keywords**: ambient, pervasive, ubiquitous, computing, delay-tolerant, disruption-tolerant, opportunistic, networking.

The research activity of team CASA aims at supporting communication and service provision in challenged environments, and most notably in partially or intermittently connected networks. A network can become disconnected when, for example, the nodes that compose this network are not always up and running, or when transmission links between these nodes are not always available. The whole network can then appear as a non-connected dynamic graph, whose topology changes continuously as nodes and links get up and down. Communication between nodes that belong to a connected fragment (a.k.a. an "island") of the network is possible, but no temporaneous end-to-end communication is possible between nodes that reside on distinct islands.

Delay/Disruption-Tolerant Networking (DTN) is an approach that can help in such conditions [Fal04]. With this approach a message can be stored temporarily on a node, in order to be forwarded later by this node when circumstances permit. This *store-and-forward* mechanism is actually the foundation of DTN.

[1] UBS: Université de Bretagne-Sud

[Fal04] K. FALL, "Messaging in Difficult Environments", *research report*, Intel Research Berkeley, 2004.

In team CASA we mostly focus on mobile ad hoc networks (MANETs), and investigate how the DTN approach can help support communication and services when such networks are disconnected. Indeed, in a disconnected mobile network, 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. In the literature the term *Opportunistic Networking* is often used to denote solutions that apply this *store-carry-and-forward* principle in disconnected MANETs (or D-MANETs), for radio contacts between mobiles nodes are often non-predictable and must thus be exploited opportunistically [PPC06b].

Part of our activity in team CASA consists in designing opportunistic routing protocols for D-MANETs, and implementing these protocols in communication middleware so they can be tested in real conditions. We also investigate how distributed applications can be designed and implemented for networks whose characteristics keep changing spontaneously and unpredictably. Indeed, designing distributed applications that require network-wide communication and coordination in a D-MANET is quite a challenge, when communication and coordination depend on unpredicted pairwise contacts between neighbor nodes. The term *Opportunistic Computing* has been introduced recently in the literature in order to refer to a new computing paradigm that relies exclusively on such pairwise contacts [CGMP10,CK10]. 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 D-MANETs.

# 3 Scientific Foundations

## 3.1 Challenges According to FET-Proactive Initiatives

The work conducted in team CASA addresses some of the challenges identified by several FET[2]-Proactive initiatives, including:

- *FP7-5 Self-Awareness in Autonomic Systems (AWARENESS):* the challenge is to create computing and communication systems that are able to optimise overall performance and resource usage in response to changing conditions, adapting to both context (such as user behaviour) and internal changes (such as topology).

- *FP7-1 Pervasive Adaptation (PERADA):* the challenge is to design massive-scale pervasive information and communication systems, capable of autonomously adapting to highly dynamic and open technological and user contexts.

[2]FET *(Future and Emerging Technologies)* is the European Union's incubator for long-term research in the area of information and communication technologies. (http://cordis.europa.eu/fp7/ict/fet-proactive)

[PPC06b] L. PELUSI, A. PASSARELLA, M. CONTI, "Opportunistic Networking: Data Forwarding in Disconnected Mobile Ad Hoc Networks", *IEEE Communications Magazine*, nov 2006.

[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.

[CK10] M. CONTI, M. KUMAR, "Opportunities in Opportunistic Computing", *Computer 43*, 2010, p. 42–50.

- *FP6 Situated and Autonomic Communications (SAC):* the challenge is to design communication/networking systems that can be characterised as situated (i.e. reacting locally on environment and context changes), autonomously controlled, self-organising, radically distributed, technology independent and scale-free.

## 3.2 Opportunistic Communication in Disconnected Mobile Ad hoc Networks

A Mobile Ad hoc NETwork (or MANET for short) is a network that is composed of a number of mobile digital devices featuring interfaces for short-range wireless transmissions (such as Wi-Fi, Bluetooth, or ZigBee interfaces). Each device can communicate directly with other devices, provided these devices are within its transmission range.

During the last two decades the mainstream research activity on mobile ad hoc networking has mostly aimed at achieving dynamic routing between mobile devices [BKP02,RT99]. Most of the proposals designed along this line rely on the assumption that communication between two devices in a network is possible only if a temporaneous end-to-end transmission route can be established (using multi-hop forwarding if necessary) between them whenever needed. Yet it is now widely admitted that this hypothesis about continuous end-to-end connectivity in a MANET is somewhat contrived. Many real MANETs are actually either partially or intermittently connected, and routing protocols that assume continuous connectivity cannot perform satisfactorily in such conditions [NG09,PPC06a]. Specific protocols must thus be designed for disconnected MANETs (a.k.a. D-MANETs), and these protocols must opportunistically exploit transient unpredicted contacts between mobile nodes.

Team CASA has thus designed and tested several opportunistic protocols over the last years, exploring different kinds of forwarding algorithms in these protocols (content-based epidemic forwarding, location-based routing, service-oriented routing, etc.). The last results obtained by the team are presented in Section 6.1.

## 3.3 Opportunistic Computing in Disconnected Mobile Ad hoc Networks

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 applications seem well suited for ambient computing environments in general, and for MANETs –and especially disconnected MANETs– in particular. Building applications based on software services is now well mastered and supported by many techniques and tools, among which the most popular Web Services. Moreover this approach fosters decoupling between interacting applicative entities. It should therefore accommodate well with the connectivity constraints of discon-

[BKP02] C. BASILE, M.-O. KILLIJIAN, D. POWELL, "A Survey of Dependability Issues in Mobile Wireless Networks", *Technical report number 02637*, LAAS CNRS Toulouse, France, oct 2002.

[RT99] E. M. ROYER, C.-K. TOH, "A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks", *IEEE Personal Communications*, April 1999, p. 46–55.

[NG09] H. A. NGUYEN, S. GIORDANO, "Routing in Opportunistic Networks", *International Journal of Ambient Computing and Intelligence (IJACI) 1*, 3, 2009, p. 19–38.

[PPC06a] L. PELUSI, A. PASSARELLA, M. CONTI, "Beyond MANETs: Dissertation on Opportunistic Networking", *research report*, IIT-CNR, aug 2006.

nected MANETs. Indeed, a significant amount of research work has been produced in recent years on middleware solutions for service provision in MANETs. Nevertheless, most of them consider only connected MANETs and focus on the performance of service discovery. Providing support for service-oriented applications poses specific problems in disconnected MANETs. The main challenge is to cope with the absence of end-to-end connectivity guaranty brought upon by the continuous fragmentation of the network into several communication islands, which impacts not only on service discovery but also on service invocation.

Beside service-oriented computing, other computing paradigms have 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.

# 4 Application Domains

## 4.1 Overview

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 particulary 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;
- Sensor and actuator networks;
- Automotive computing (especially inter-vehicle applications);
- Home automation (pervasive multimedia and general purpose applications);
- Nomadic computing;
- Personal communication systems;
- Mobile health (mHealth).

# 5 Software

## 5.1 DoDWAN

**Keywords**: opportunistic, content-based, epidemic, networking, middleware.

DoDWAN[3] is a flexible Java-based middleware platform that has been developed in team CASA in order to support content-based, delay-tolerant communication in disconnected MANETs. It is distributed under the GNU General Public License (GPL)[4].

In content-based networking, information flows towards interested receivers rather than towards specifically set destinations. This approach notably fits the needs of applications and services dedicated to information sharing or event distribution. It can also be used for destination-driven message forwarding, though, considering that destination-driven forwarding is simply a particular case of content-driven forwarding where the only significant parameter for message processing is the identifier of the destination host (or user).

DoDWAN implements a selective version of the epidemic routing model proposed in [VB00]. It provides application services with a publish/subscribe API. When a message is published on a host, it is simply put in the local cache maintained on this host. Afterwards each radio contact with another host is an opportunity for the DoDWAN system to transfer a copy of the message to that host. In order to receive messages an application service must subscribe with DoDWAN and provide a *selection pattern* that characterizes the kind of messages it would like to receive. The selection patterns specified by all local application services running on the same host define this host's *interest profile*. DoDWAN uses this profile to determine which messages should be exchanged whenever a radio contact is established between two hosts. As a general rule, a mobile host that defines a specific interest profile is expected to serve as a mobile carrier for all messages that match this profile. Yet a host can also be configured so as to serve as an altruistic carrier for messages that present no interest to the application services it runs locally. This behavior is optional, though, and it must be enabled explicitly by setting DoDWAN's configuration parameters accordingly. Details about this interaction scheme and about how it performs in real conditions can be found in [HG10].

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 several times during the past years. They have notably been used in a military tactical network, using VHF battlefield radios with built-in modems, and proved very robust and reliable in such harsh conditions [HGCT09]. More recently, a field experiment has been conducted during the 4th Extreme Conference on Communication (ExtremeCom 2012 - The Alpine Expedition[5]) [8, 9]. During this experiment volunteers were

[3] DoDWAN stands for "Document Dissemination in Wireless Ad hoc Networks".

[4] http://www-irisa.univ-ubs.fr/CASA/DODWAN

[5] http://www.extremecom.org

[VB00] A. VAHDAT, D. BECKER, "Epidemic Routing for Partially Connected Ad Hoc Networks", *research report*, Duke University, April 2000.

[HG10] J. HAILLOT, F. GUIDEC, "A Protocol for Content-Based Communication in Disconnected Mobile Ad Hoc Networks", *Journal of Mobile Information Systems 6*, 2, 2010, p. 123–154.

[HGCT09] J. HAILLOT, F. GUIDEC, S. CORLAY, J. TURBERT, "Disruption-Tolerant Content-Driven Information Dissemination in Partially Connected Military Tactical Radio Networks", *in : 28th IEEE Military Communication Conference (MILCOM'2009)*, IEEE CS, p. 2326–2332, Boston, USA, October 2009.

equipped with Android smartphones running DoDWAN-Apps, which allowed them to communicate together during outdoor activities (such as igloo building, snowshoe hikes, etc.). Again DoDWAN and DoDWAN-Apps proved quite effective in these conditions, while GSM/UMTS services were unavailable most of the time.

## 5.2 JOMS

**Keywords**: opportunistic, computing, message, service, middleware.

JOMS (Java Opportunistic Message Service) is an opportunisitc message-oriented middleware system that has been designed in order to operate in partially or intermittently connected ad hoc networks [2, 3]. JOMS is actually a provider for the standard Java Message Service (JMS), so distributed applications using JMS message queues and topics can be deployed and executed in challenged networking environments. An opportunistic, content-driven communication model (based on DoDWAN) is used to enable message forwarding in such networks, using mobile hosts as carriers that allow messages to propagate network-wide.

JOMS is distributed under the terms of the GNU General Public License[6].

## 5.3 JION

**Keywords**: opportunistic, computing, tuple-space, JavaSpace, middleware.

The concept of tuple space is interesting for both communication and coordination in distributed applications, and the JavaSpaces technology provides a functional implementation of this concept for Java applications. Yet most current JavaSpaces implementations are server-based systems. Since no host in a D-MANET can be considered as stable and accessible enough to play the role of a server for all other hosts, a server-less implementation of the JavaSpaces specification is required for applications targeting D-MANETs.

JION (JavaSpaces Implementation for Opportunistic Networks) has been designed and implemented along that line. It provides a fully-distributed, peer-to-peer JavaSpaces implementation, while tolerating transmission disruptions and delays [4]. It is distributed under the terms of the GNU General Public License[7].

## 5.4 FelixDroid

**Keywords**: service-oriented, computing, OSGi, Android.

FelixDroid is an Android-embedded version of Felix OSGi Felix Apache framework, an open-source implementation of the OSGi specification. FelixDroid is also a framework dedicated to the development and the execution of OSGi graphical applications in Android. It provides graphical tools in order to manage the OSGi Felix framework (management of the bundle repositories, deployment and management of bundles, etc.). FelixDroid is distributed under the terms of the CeCiLL licence[8].

[6] http://www-irisa.univ-ubs.fr/CASA/JOMS
[7] http://www-irisa.univ-ubs.fr/CASA/JION
[8] http://www-irisa.univ-ubs.fr/CASA/dev/felixdroid

It is currently used by several and companies (Bull, Orange Business Services, SOGETI High Tech, Proxym-it, DEV1.0...) and academic teams (Université de Valenciennes, École des Mines d'Ales, Carnegie Mellon University, ETH Zürich, TU-Berlin...).

# 6 New Results

## 6.1 Routing Protocols for Opportunistic Networking

**Keywords**: opportunistic, delay-tolerant, disruption-tolerant, protocols.

**Participants**: A. Makke (PhD student), Y. Mahéo, N. Le Sommer, P. Launay, F. Guidec.

Team CASA develops opportunistic protocols for different kinds of partially and intermittently connected networks.

As mentioned in Section 5.1 the team has notably developed an opportunistic protocol for content-based information dissemination in D-MANETs. This protocol is implemented in the DoDWAN middleware platform, and it has been steadily improved and fine-tuned over the last years [HG10]. Version 2 of the protocol has thus been issued in 2012, and field experiments have been conducted during the ExtremeCom conference in order to observe how this new version performs in real conditions [8, 9].

Besides D-MANETs that are only composed of mobile nodes, an interesting class of networks is one that combines fixed infostations and mobile nodes. In such an IHCM (Intermittently Connected Hybrid Network), infostations may be directly connected with one another, although that is not an obligation. An ICHN can actually be viewed as an extension of an already existing infrastructure network, including mobile nodes that are not always in range of an infostation but that can however benefit from services deployed on this infostation thanks to opportunistic networking techniques. Team CASA has designed a middleware platform for service provision in ICHNs. We considered the situation in which the infostations are hosting service providers and the mobile devices act as clients willing to invoke a service provided on any of the infostations, even though these client devices are not in direct contact with the infostations. We notably developed a protocol called TAO (Time-Aware Opportunistic routing protocol), dedicated to the routing of service invocation requests and responses between a mobile node and a fixed infosation in an ICHN [10]. The main contribution in this protocol is a heuristic for the choice of the best neighbor to route a message, heuristic based on the recording of the last date of contact with an infostation.

The team also considers networking environments where mobile nodes are able to determine their location. OLFServ is a protocol that has been designed in order to efficiently support service provision in such conditions. This protocol notably has the capability of circumscribing service discovery and invocation to limited geographic areas. It implements several self-pruning heuristics whose goal is to efficiently control the dissemination of service advertisements and service discovery requests. Additionally service invocation requests and responses are performed at minimal cost thanks to geographic source-based routing [1].

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[HG10] J. HAILLOT, F. GUIDEC, "A Protocol for Content-Based Communication in Disconnected Mobile Ad Hoc Networks", *Journal of Mobile Information Systems 6*, 2, 2010, p. 123–154.

## 6.2 Middleware Support for Opportunistic Computing

**Keywords**: middleware, opportunistic, computing.

**Participants**: A. Benchi (PhD student), P. Launay, F. Guidec.

As explained in Section 3.3, designing and implementing distributed applications capable of running satisfactorily in disconnected MANETs (or D-MANETs) is quite a challenge. The peer-to-peer model should generally be preferred over the client-server model, because in many real D-MANETs no host can be considered as stable and accessible enough to play the role of a server for all other hosts. Additionally, any distributed application running in a D-MANET must obviously be able to tolerate long transmission delays, and occasional transmission failures as well.

The concept of middleware has long proved efficient in easing the development of distributed applications for traditional wired networks. It can be expected that carefully designed middleware systems might bring similar benefits for D-MANETs.

Developers need to be able to rely on well-known distributed computing abstractions when designing applications for challenged networks. Yet standard implementations for message queues, tuple spaces, etc. can hardly run satisfactorily in D-MANETs, as they have originally been designed to operate in resilient connected networks. Members of team CASA are thus revisiting these "standards" in order to provide new implementations that can tolerate network partitions, long transmission delays, and transmission failures. An opportunistic middleware system called JOMS (Java Opportunistic Message Service) has been designed in order to support message queues and topics in D-MANETs [2, 3]. Likewise, JION (JavaSpaces Implementation for Opportunistic Networks) is a middleware system that implements the concept of tuple space in D-MANETs [4]. Both middleware systems are distributed under the GNU General Public License (see Section 5.1), and have been tested experimentally in real mobile networks.

## 6.3 Disruption-Tolerant Biometric Sensors for Health Monitoring

**Keywords**: mHealth, mobile, health, disruption-tolerant, biometric, wireless sensors.

**Participants**: D. Benferhat (PhD student), 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: 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 project CoMoBioS (Communicating Mobile Biometric Sensors) we investigate the possibility of using the DTN (Delay/Disruption Tolerant Networking) approach as a means to tolerate transmis-

sion disruptions between sensors worn by highly mobile people in outdoor conditions, and a remote monitoring center. We selected a scenario we consider as a most challenging one: monitoring the cardiac activity of runners during a marathon race, using a limited number of base stations deployed along the marathon route. These stations provide a sparse coverage of the route, so cardiac sensors worn by runners must record data continuously during the race, and use episodic contacts with roadside base stations to upload data to the monitoring center. A first prototype has been developed, using IEEE 802.15.4 (ZigBee) technology to support the transmissions between sensors and base stations. Field experiments conducted with this prototype revealed that 802.15.4 transmissions can hardly meet the stringent requirements of the marathon scenario [6]. A second prototype has then been developed, using Android smartphones as relays between sensors and roadside base stations, and IEEE 802.11 (Wi-Fi) transmissions on the smartphone-to-base-station wireless segment. Field experiments confirmed that this architecture is viable, and allows to transmit biometric data during the marathon race with no data loss [5].

The marathon scenario has deliberately been selected as a most-challenging test case, the underlying idea being that solutions designed to meet its requirements may also be reused in less constrained situations. In order to illustrate this idea we conducted field experiments in order to demonstrate that the health of non-hospitalized subjects can be monitored during their daily activity, using Wi-Fi community hotspots for opportunistic data uploading. Experiments involving a subject walking in a residential area confirm that the density of community hotspots in such an environment is sufficient to ensure regular updates of the data collected by the monitoring center. Other trials conducted in different conditions (subject at work, shopping, practising sports, etc) have led to similar conclusions [7].

# 7 Dissemination

## 7.1 Involvement in the Scientific Community

- Frédéric Guidec is a member of the editorial board and/or program committee of the International Journal on Advances in Internet Technology, the International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UbiComm), the International Conference on Wireless and Mobile Communications (ICWMC), and the International Symposium on Wireless Personal Multimedia Communications (WPMC). As such he has reviewed several papers for these journal and conferences in 2012. He presided the doctoral committee of Gaël Cédric Abou-Nze (“Étude de la structure des graphes de connexion dans les réseaux mobiles ad hoc”, Université du Havre) in October 2012. Since 2012 he is a member of the Scientific Committee of the “Images & Réseaux” Cluster.

- Nicolas Le Sommer is a member of the editorial board and/or program committee of the International Journal on Advances in Internet Technology, International Journal of Handheld Computing Research (IJHCR) and the International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UbiComm). As such he has reviewed several papers for these journal and conferences in 2012, as well as for the International Journal of Systems and Software (Elsevier). He has been a member of the doctoral committee of Dana Popovici in December 2012 (“Gestion du contexte pour des applications mobiles dédiées aux transports”, Université de Valenciennes et du Hainaut Cambrésis). He acted as session chair in the 5th Inter-

national Conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications (Mobilware 2012).

- Yves Mahéo serves as deputy head of the UBS site of IRISA. As such he represents IRISA in various local commitees, notably in the Scientific Council of UBS.

### 7.2 Teaching

- Frédéric Guidec teaches computer networking at different levels, from Licence 3 to Master 2. He is notably in charge of course unit CSR ("Communication and Services in Auto-Organized Wireless Networks") in the research master's degree in computer science (MRI), and serves as an academic director for the second year of Master WMR (Web, Multimédia, Réseaux) at Université de Bretagne-Sud.

- Pascale Launay teaches object programming, computer networking and middleware at ENSIBS (École Nationale Supérieure d'Ingénieurs de Bretagne Sud). She is the academic director for the Computer Science Departement of ENSIBS.

- Frédéric Raimbault teaches programming language theory and compiler construction, computer architecture, distributed systems and semantic Web at different levels, from Licence 2 to Master 2. He serves as an academic director for the first year of Master WMR (Web, Multimédia, Réseaux) at Université de Bretagne-Sud.

- Nicolas Le Sommer teaches database theory, Web application programming and the programming, the supervision and the management of distributed applications at the Computer Science department of the IUT de Vannes. He manages and supervises the student projects in the Computer Science department.

- Yves Mahéo teaches computer systems, distributed systems and middleware, at different levels at UBS, from Licence 1 to Master 2. He notably participates in the course unit CSR ("Communication and Services in Auto-Organized Wireless Networks") in the research master's degree in computer science (MRI). He also gives a course on system administration in the UBS Master WMR (Web, Multimédia, Réseaux) relocated in Morocco.

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[3] A. BENCHI, F. GUIDEC, P. LAUNAY, "JOMS: a Java Message Service Provider for Disconnected MANETs", *in : 8th International Workshop on Heterogeneous Wireless Networks (HWISE'12)*, IEEE CS, p. 484–489, Fukuoka, Japan, March 2012.

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