Activity Report 2021

Team CASA

Opportunistic Networking and Computing

D2 – NETWORKS, TELECOMMUNICATION AND SERVICES

1 Team composition

Researchers and faculty

Yves Mahéo, Assistant professor (HDR), Univ. Bretagne Sud, head of the team
Frédéric Guidec, Professor, Univ. Bretagne Sud
Pascale Launay, Assistant professor, Univ. Bretagne Sud
Nicolas Le Sommer, Assistant professor, Univ. Bretagne Sud
Lionel Touseau, Assistant professor, Académie Militaire de Saint-Cyr Coëtquidan
François Lesueur, Assistant professor, Univ. Bretagne Sud, from September 2021

Administrative assistants

Anne Idier, Martine Milcent.

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. According to Mota et al. [MCM+14], delay/disruption-tolerant networks should actually be considered as a subset of opportunistic networks..

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 studying routing protocols for opportunistic networks, namely by 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

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[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. 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 [WHFE09,Voy12]. In [MCM+14] 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

A plethora of routing protocol have been proposed for more than a decade [DKAGD21] but very few of them are implemented and used in effective opportunistic networks. It is now admitted that the research effort should target the deployment of large-scale opportunistic networks [TKD+17], and scalability issues. The work of team CASA is conducted in this perspective, by focussing on the emulation of large opportunistic networks and the development of practical solutions for deploying opportunistic networks.

2.2.2 Opportunistic Computing

Opportunistic computing is a 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].

The service-oriented paradigm has been the first to be well-suited for opportunistic networks as it fosters decoupling between applicative entities, and is able to accommodate intermittent connectivity constraints, and building applications by combining software services is now well mastered and supported by many techniques and tools, among which the most popular Web Services. In opportunistic networks, the absence of network-wide end-to-end connectiv-

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

[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.

[DKAGD21] R. Dalal, M. Khari, J. P. Anzola, V. García-Díaz, "Proliferation of Opportunistic Routing: A Systematic Review", *IEEE Access*, 2021.

[TKD+17] S. Trifunovic, S. T. Kouyoumdjieva, B. Distl, L. Pajevic, G. Karlsson, B. Plattner, "A Decade of Research in Opportunistic Networks: Challenges, Relevance, and Future Directions", *IEEE Communications Magazine 55*, 1, January 2017, p. 168–173.

[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.

ity, 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, or conflict-free replicated datatypes 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).

Most of the middleware systems developed in team CASA over the recent years can be considered as enablers for the above-mentioned application domains. Please refer to the team's Web site [1] for further information about these systems.

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

3 Scientific achievements

3.1 Opportunistic computing with Web browsers

Web browsers could now be considered as the most widely deployed execution environments, and, empowered with browser-to-browser communication capabilities, they make possible a wide range of peer-to-peer applications. In the framework of ANR project O'Browser (see Section 5.1.1), team CASA has studied 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. We have also designed a programming paradigm adapted to this context.

3.1.1 Smartphone-Targeted Opportunistic platform

Participants: Frédéric Guidec, Yves Mahéo, Pascale Launay, Lionel Touseau.

Although smartphones may appear as perfect candidates to implement opportunistic networking protocols and algorithms, it turns out that their ability to support D2D transmissions is quite constrained, which hinders the deployment of opportunistic applications at a large scale. Acknowledging this fact we designed Ligo, a device that is meant to behave as a peripheral device of a smartphone, providing this smartphone with the opportunistic networking services it cannot implement natively. A prototype, based on a Raspberry Pi has been developed. It hosts several software components that enable the communication in the opportunistic network and the interaction with the smartphone via Bluetooth [2].

3.1.2 Foglet-based Opportunistic computing environment

Participants: Yves Mahéo, Lionel Touseau.

In the context of project O'Browser, a *foglet* is an ephemeral cooperative distributed piece of software executed by a web browser. The foglet programming model relies on shared data structures and on a *foglet network*, which enables communication between foglet instances to ensure data consistency across instances. In order to cope with mobile web browsers in an infrastructure-less context, we proposed an opportunistic foglet network that enables foglets to be distributed on smartphones' web browsers, without any network infrastructure. The resulting opportunistic computing environment allows foglet developers to write opportunistic distributed Javascript applications able to run on mobile browsers. The solution has been validated on off-the-shelf smartphones, as well as on a simulated environment [4].

3.2 Evaluation and comparison of opportunistic computing algorithms

Participants: Frédéric Guidec, Pascale Launay, Yves Mahéo.

The full understanding of the behavior of opportunistic protocols and applications, and the evalution of their performance are difficult tasks. For this purpose, developers usually rely on simulators, more rarely on emulators or "real world" experiments. However, exploiting the results produced by such experiments is tedious, and comparing these results with those produced by other researchers is even harder, because of the lack of relevant and well-established metrics and standardized data formats [r5].

Team CASA aims to develop a unified evaluation platform to facilitate the evaluation and comparison of experiment results pertaining to opportunistic networking and computing.

To achieve this goal, the team has worked on the identification of several ways to characterize mobility and contacts scenarios, as well as applicative scenarios, using various metrics adapted to dynamic graphs, and exploiting the DGS file format of GraphStream (http://graphstream-project.org/). We have developed tools that take various input taken from these characterizations, in order to produce pertinent statistics or graphical results, namely for comparison purposes. Recently, several of these tools have been integrated in the MUON software (see Section4.1).

3.3 Causal and delta-causal broadcast in opportunistic networks

Participants: Frédéric Guidec, Pascale Launay, Yves Mahéo.

Causal broadcast is a fundamental communication abstraction for many distributed applications. Several implementations of this abstraction have been proposed over the last decades for traditional networks, that is, networks that assume the existence of a continuous bi-directional end-to-end path between any pair of nodes. Opportunistic networks constitute a kind of networks in which this assumption cannot be made, though, so the implementation of causal broadcast in such networks must be addressed differently.

Team CASA has proposed two algorithms based on causal barriers that can ensure the causally-ordered delivery of broadcast messages in an opportunistic network, considering both cases where the messages propagate in the network without or with a bounded lifetime [1]. The latter case is especially interesting in networks that must run for a long time, or with a population of nodes that changes continuously.

3.4 Conflict-free Replicated Data Types for opportunistic networks

Participants: Frédéric Guidec, Yves Mahéo.

Conflict-Free Replicated Data Types (CRDTs) are distributed data types that support optimistic replication: replicas can be updated locally, and updates propagate asynchronously among replicas, so consistency is eventually obtained. This ability to tolerate asynchronous communication makes them ideal candidates to serve as software building blocks in opportunistic networks (OppNets).

Team CASA investigates the problem of implementing operation-based, state-based, and delta-state-based CRDTs [3] in an OppNet, and proposes specific synchronization algorithms for each variant.

3.5 Opportunistic Networking in Low-Power Wide Area Network

Participants: Nicolas Le Sommer.

Over the last years, Low-Power Wide Area Networks (LPWANs) have received much attention from the research community and the industry for Internet of Things (IoT) applications. Team CASA has started investigating the possibility of using LoRa (one of the main technology for LPWANs) in the context of opportunistic networking. Lora includes interesting features such as symmetric modulation for uplink and downlink, which allows nodes to establish device-to-device (D2D), and a potential radio range of several kilometers, but the standard MAC layer associated with the LoRa physical layer (i.e., LoRaWAN) operates a network in a simple star topology, in which nodes and gateways must be in the radio range of each other to communicate. We propose an alternative solution, called LoRaOpp, that provides an opportunistic multi-hop routing protocol for LoRa. It allows nodes that are not in the radio coverage area of gateways to communicate with these gateways through intermediate nodes, even if there is no end-to-end routes between them.

LoRaOpp is designed considering both the resource limitations of nodes and the specific features of LoRa, such as the half-duplex transmissions, the spread spectrum, and the resilience in the presence of concurrent transmissions. LoRaOpp combines several mechanisms to efficiently forward messages in the network while limiting the number of messages that are disseminated (source routing, limitation of the number of copies using a "spray and focus" approach, limitation of the number of hops of messages, message lifetime, etc.). The preliminary results, both in real conditions and simulation, show that this protocol is efficient and quite promising for a usage in real conditions.

4 Software development

4.1 MUON

Participants: Pascale Launay, Frédéric Guidec, Nicolas Le Sommer.

MUON (Miscellaneous Utilities for Opportunistic Networking) is a platform that is being developped by team CASA in order to provide online access to conversion, analysis and presentation tools relying on the data formats and metrics defined in our team, and thus provide a unified framework for the evaluation and comparison of opportunistic routing protocols. Analysis tools have been developped to calculate and present metrics to characterize mobility and contact scenarios, and to evaluate the performance of algorithms. Conversion tools have been developped to transform, filter and sanitize datasets. These tools are made accessible through a Web front-end that makes it possible for a user to upload mobility, contacts and experiment log files, run conversion and analysis tools, and display and download results.

Currently, several tools have been developped and are used by the team members to analyze the traces of field experiments and simulations carried out in their projects. The Web front-end is functional, and under test before it is put online for external users.

4.2 DoDWAN

Participants: Frédéric Guidec, Yves Mahéo.

DoDWAN[2] 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)[3].

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).

Recently, a plugin mechanism has been added to DoDWAN that allows a developer to add new functionalities or to modify existing functionalities. The first set of plugins that has been developped adds a network API to DoDWAN so that it can be used by an external piece of software, via TCP or WebSocket. This namely offers the possibility to control DoDWAN from a web browser (cf. Section 3.1). Another set of plugins provides additional device to device communication in order to support causal broadcast and the implementation of CRDTs (cf. Sections 3.3 and 3.4).

5 Contracts and collaborations

5.1 National Initiatives

5.1.1 Project O'Browser

Participants: Frédéric Guidec, Pascale Launay, Yves Mahéo, Lionel Touseau.

- Project type: ANR, generic programme
- Dates: 2017–2021
- 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.

[2]DoDWAN stands for "Document Dissemination in Wireless Ad hoc Networks"
[3]https://www-casa.irisa.fr/dodwan

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Journal

Reviewer - Reviewing Activities

- Y. Mahéo: reviewer for Sensors (MDPI),
- N. Le Sommer: reviewer for Ad Hoc Networks (Elsevier), Computing Surveys (ACM), Sensors (MDPI), Future Internet (MDPI), Applied Sciences (MDPI), Actuators (MDPI), Technologies (MDPI), Computers (MDPI), Agronomy (MDPI), Journal of Sensor and Actuator Networks (MPDI).

6.1.2 Scientific Expertise

- F. Guidec has served as an expert to evaluate PhD funding applications for ComUE Normandie Université.

6.1.3 Research Administration

- F. Guidec serves as the local representative of IRISA at Université Bretagne Sud.

6.2 Teaching, supervision

6.2.1 Teaching

- F. Guidec
  M1: Network administration, 52h
  M2: Wireless networking technologies, 52h
  M2: Innovative systems and networks, 15h
  M2: Internet of Things, 26h
- Y. Mahéo
  M1: Introduction to Distributed Systems, 26h
  M1: Network administration, 52h
  M2: Distributed middleware, 29h
  M2: Innovative systems and networks, 26h
  M2: Distributed programming, 12h
  M2: Personal Project, 48h
- P. Launay
  M1: Distributed Systems: Java Networking, 12h
  M1: Advanced Object Programming, 57h, ENSIBS
  M1: Middleware for distributed computing, 54h, ENSIBS
  M2: Innovative systems and networks: WebRTC, 8h
  M2: Graduation projects supervision, ENSIBS

- N. Le Sommer
  M1: Project management tool, 4h
  M2: Development of mobile applications, 20h
- L. Touseau
  ESM2 (M1): Project supervision, 30h, AMSCC
  ESM2 (M1): Databases, 40h, AMSCC
  EMIA2 : Mobile development, 50h, AMSCC

6.2.2 Supervision

- Camille Moriot: "Analysis of Distributed Denial-of-Service (DDoS) attacks and their impact on the Internet architecture", PhD in progress at University Lyon, co-supervised by F. Valois (CITI, Agora), F. Lesueur (IRISA, CASA), and N. Stouls (CITI, Phenix).

7 Bibliography

Major publications by the team in recent years

[r1] M. BAGOT, *Plateforme adaptative pour le suivi de l'état de santé de patients mobiles*, PhD Thesis, Université Bretagne Sud / Université Bretagne Loire, July 2020.

[r2] F. BAKLOUTI, N. LE SOMMER, Y. MAHÉO, "Performing Service Composition in Opportunistic Networks", *in: IFIP Wireless Days Conference*, IEEE, p. 1–3, Manchester, Great Britain, March 2019.

[r3] F. BAKLOUTI, *Service Composition in Opportunistic Networks*, PhD Thesis, Université Bretagne Sud / Université Bretagne Loire, March 2019.

[r4] N. LE SOMMER, Y. MAHÉO, F. BAKLOUTI, "Multi-Strategy Dynamic Service Composition in Opportunistic Networks", *Information 11*, 4, March 2020, p. 180.

[r5] A. SÁNCHEZ-CARMONA, F. GUIDEC, P. LAUNAY, Y. MAHÉO, S. ROBLES, "Filling in the missing link between simulation and application in opportunistic networking", *Journal of Systems and Software 142*, August 2018, p. 57–72.

[r6] L. TOUSEAU, N. LE SOMMER, "Contribution of the Web of Things and of the Opportunistic Computing to the Smart Agriculture: A Practical Experiment", *Future Internet 11*, 2, February 2019, p. 1–19.

Articles in referred journals and book chapters

[1] F. GUIDEC, P. LAUNAY, Y. MAHÉO, "Causal and Δ-Causal Broadcast in Opportunistic Networks", *Future Generation Computer Systems 118*, May 2021, p. 142–156.

Publications in Conferences and Workshops

[2] F. GUIDEC, Y. MAHÉO, P. LAUNAY, L. TOUSEAU, C. NOÛS, "Bringing Opportunistic Networking to Smartphones: a Pragmatic Approach", *in: 45th Computers, Software, and Applications Conference (COMPSAC)*, IEEE, p. 574–579, Madrid, Spain, July 2021.

[3] F. GUIDEC, Y. MAHÉO, C. NOÛS, "Delta-State-Based Synchronization of CRDTs in Opportunistic Networks", *in: 46th Conference on Local Computer Networks (LCN)*, IEEE, p. 335–338, Edmonton, Canada, October 2021.

[4] L. TOUSEAU, Y. MAHÉO, C. NOÛS, "A Smartphone-Targeted Opportunistic Computing Environment for Decentralized Web Applications", *in: 46th Conference on Local Computer Networks (LCN)*, IEEE, p. 363–366, Edmonton, Canada, October 2021.