Activity Report 2023

Team INZU

Opportunistic computing and networking for secure and dependable applications

D2 – NETWORKS, TELECOMMUNICATION AND SERVICES

Team INZU was created in June 2023. It follows on from team CASA (Irisa, Dept D2), without any major changes in the team composition. This report hence covers the activity of CASA for the first half of the year and the activity of INZU for the second half.

1 Team composition

Researchers and faculty

Yves Mahéo, Assistant professor (HDR), Univ. Bretagne Sud, head of the team
Frédéric Guidec, Professor, Univ. Bretagne Sud
Mawloud Omar, Professor, Univ. Bretagne Sud
Pascale Launay, Assistant professor, Univ. Bretagne Sud
Nicolas Le Sommer, Assistant professor, Univ. Bretagne Sud
François Lesueur, Assistant professor, Univ. Bretagne Sud, until July 2023
Lionel Touseau, Assistant professor, Académie Militaire de Saint-Cyr Coëtquidan

Postdoctoral Fellows

Edward Staddon, Project RECSANet (AID RAPID), since November 2023

PhD students

Huy Dat Nguyen, since September 2023

Administrative assistants

Anne Le Tohic, Martine Milcent.

2 Overall objectives

2.1 Overview

The research activity of team INZU 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.

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 INZU consists in 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 INZU 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.

One of the challenges pertaining to opportunistic networking as well as to opportunistic computing is the security. Indeed the security mechanisms developed for traditional networks, that most often assume a permanent access to a trust authority, are hardly applicable in the context of opportunistic networking. Team INZU has started to investigate this field of research, with the objective to propose practical solutions for selected application domains (cf. for example the RECSANet project, section 5.1.1).

[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.

[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.

2.2 Scientific foundations

2.2.1 Opportunistic Networking

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

[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.

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 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, 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 INZU 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 INZU 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-inzu.irisa.fr/software

3 Scientific achievements

3.1 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 INZU has initiated the development of several CRDT-based demonstrators in order to show that distributed applications based on CRDTs can perform very effectively in OppNets, despite the very low connectivity observed in such networks. The first of these demonstrators is called QuillOpp, and it is meant to support collaborative text editing. It relies on Quill[2] (a web-based text editor), Yjs[3] (a Javascript library implementing several types of CRDTs), and our opportunistic communication middleware DoDWAN[4].

A real-world experiment based on QuillOpp has been conducted at the end of 2022, and the results of this experiment have been presented in [2]. During this experiment, six members of team Inzu used QuillOpp (running on their laptops) to edit a shared document collectively over nine days, relying exclusively on opportunistic radio contacts between their laptops to synchronize their contributions to the document. The analysis of the log files produced during this experiment confirmed the opportunistic nature of the network formed by the laptops, and the ability of the CRDT-based editing system to maintain the consistency of the replicas stored on each laptop. Besides, a simulation run involving 200 instances of QuillOpp with as many virtual contributors confirmed the scalability of the system.

3.2 Opportunistic Networking in Low-Power Wide Area Network

Participants: Nicolas Le Sommer, Lionel Touseau, Huy Dat Nguyen, Edward Staddon, Yves Mahéo.

Team INZU investigates the possibility of using LoRa (one of the main technology for Low-Power Wide Area Networks (LPWANs) in the design of a distributed system dedicated to the observation of the environment, and relying on opportunisting networking techniques. 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 proposed an alternative solution, called LoRaOpp [r4], that supports opportunistic multi-hop communications in LoRa-based networks. LoRaOpp allows (mobile) nodes to communicate together at several hops, and also allows

[2] https://quilljs.com
[3] https://github.com/yjs
[4] https://casa-irisa.univ-ubs.fr/dodwan

nodes to send data to (mobile) gateways, also at several hops. LoRaOpp is designed so as to be configured dynamically in order to change for example the power transmission, the spreading factor, etc. With LoRaOpp, nodes and gateways can temporarily store messages in a local cache, and to retrieve them after a deep sleep phase in order to restransmit them when a opportunity appears. LoRaOpp is designed to run resource-constrained devices (e.g. ESP32 or STM32 mico-controllers).

Recently, we worked on the usage of LoRaOpp in the context of project RECSANet (see section 5.1.1), which mainly aims at studying and developing a self-configuring, self-adapting, resilient and energy efficient multi-technology communication middleware for resource-constrained devices.

In the context of IoT and LPWANs, we also studied the dynamic firmware updating of devices following an incremental and modular approach, considering both LoRAWAN networks and opportunistic communications over the LoRa physical layer using LoRaOpp (PhD of H.D. Nguyen). Such a modular approach aims at being able to perform partial updates instead of replacing the whole firmware, thus allowing to reduce the network load and the power consumption. Moreover, in our approach, parts of the firmware can be replaced and loaded dynamically, thus avoiding to reboot devices when it is not needed.

3.3 Opportunistic X2V Energy Trading Framework

Participants: Mawloud Omar.

Modern vehicles are increasingly pivotal in the realm of information and service provision, becoming integral to future transportation systems and wireless networks. This integration is especially relevant in power transfer, propelled by advancements in energy harvesting and transfer technologies. The burgeoning number of electric vehicles necessitates a shift towards distributed, scalable charging solutions to accommodate massive demands and enable fast-charging services.

In this context, we proposed an X2V energy trading framework, adapting to the environment's dynamic nature [r5]. It utilizes a distributed coalition of UAVs (Unmanned Aerial Vehicles) for energy transfer. The framework consists of two modules: energy-transportation management and commitment management. The former focuses on selecting the best seller combination and synchronizing the UAV fleet for efficient energy transportation. The latter deals with commitment execution and participant reliability assessment before establishing smart contracts.

Our main contributions include a collaborative UAV-based energy recovery and transportation system, a dynamic seller selection mechanism, an optimized energy transportation process, a distributed trust model for reliability assessment, and a hierarchical trust model for commitment management. These innovations aim to improve service availability, fault tolerance, and reduce energy transportation latency and overhead, marking a significant advancement in energy trading and electric vehicle charging infrastructure.

4 Software development

4.1 Ligo

Participants: Frédéric Guidec, Yves Mahéo.

Ligo, a device (based on a Raspberry Pi) 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 Ligo unit hosts several software components that enable the communication in the opportunistic network and the interaction with the smartphone via Bluetooth.

A new software component has been developed recently in order to confer agility in the formation of the opportunistic network, that can be based on both the ad hoc mode and the managed mode of Wi-Fi, and be coupled with the LEPTON emulator[5] developped in the team.

4.2 DoDWAN

Participants: Frédéric Guidec, Yves Mahéo.

DoDWAN[6] is a flexible Java-based middleware platform that has been developed in team INZU in order to support content-based, disruption-tolerant communication in opportunistic networks. It is distributed under the GNU General Public License (GPL)[7].

DoDWAN includes a plugin mechanism so that its behavior can be modified or extended. Recent work has focused on the enhancement of the YJS DoDWAN provider plugin, one the plugins developed by the team in order to support the synchronization of Yjs CRDTs[8]. The YJS DoDWAN provider can support the synchronization of multiple CRDTs and provide neighboring information.

5 Contracts and collaborations

5.1 National Initiatives

5.1.1 Project RECSANet

Participants: Lionel Touseau, Nicolas Le Sommer, Edward Staddon.

- Project type: AID RAPID
- Dates: 2023–2026
- Partners: CGWireless, IRISA/GRANIT

RECSANet project addresses both military and civilian concerns : from battlefield digitalization to forest firefighting. It proposes to study and define a resilient hardware and software

[5]https://www-inzu.irisa.fr/lepton
[6]DoDWAN stands for “Document Dissemination in Wireless Ad hoc Networks”
[7]https://www-inzu.irisa.fr/dodwan
[8]https://github.com/yjs/yjs

support for the creation of infrastructure-less and sovereign networks. Such networks should be able to tolerate the loss of communicating devices. RECSANet networks will have to support distributed applications for data gathering and sharing. The data considered in RECSANet can be provided by fixed or mobile sensors which communicate through a self-adaptable opportunistic protocol, able to operate despite connectivity disruptions. The protocol will rely on a multi-technology and multi-band hardware layer built with low-cost off-the-shelf components.

In this context, the contribution from INZU team will consist in designing and implementing a multi-technology opportunistic protocol as well as a middleware to support RECSANet distributed applications.

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Journal

Reviewer - Reviewing Activities

- Y. Mahéo: reviewer for Applied System Innovation (MDPI)
- N. Le Sommer: reviewer for Applied System Innovation (MDPI), Sensors (MDPI), Drones (MDPI), Future Internet (MDPI)

6.1.2 Scientific Expertise

- Y. Mahéo evaluated the project proposal 7102-K in the framework of the Collaborative Scientific Research Programme of the Indo French Centre for the Promotion of Advanced Research (CEFIPRA/IFCPAR).
- 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 Universié Bretagne Sud.
- F. Guidec is a member of the steering committee of the doctoral school (ED) MathSTIC - Bretagne Océane.
- M. Omar is a member of the evaluation committee of the doctoral school (ED) MathSTIC - Bretagne Océane.

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: Personal Project, 48h

- P. Launay
  M1: Introduction to Distributed Systems, 21h
  M1: Advanced Object Programming, 39h
  M2: Innovative systems and networks, 8h

- N. Le Sommer
  M1: Project management tool, 4h
  M2: Development of secure mobile applications, 40h

- L. Touseau
  ESM2 (M1): Project supervision, 30h, AMSCC
  ESM2 (M1): Databases, 30h, AMSCC
  ESM2 (M1): Object-oriented programming, 20h, AMSCC

- M. Omar
  ENSIBS (M1): Identity and Access Management, 25h
  ENSIBS (M1): IA and Cybersecurity, 20h
  ENSIBS (M1): Project supervision, 20h
  ENSIBS (M2): Project supervision, 20h

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 Université de Lyon, supervised by F. Valois (CITI, Agora), F. Lesueur (IRISA, INZU), and N. Stouls (CITI, Phenix).

- Huy Dat Nguyen: "Opportunistic protocol for distributed update of an IoT-based environmental observation system relying on participatory science", PhD in progress at Université Bretagne Sud, supervised by Yves Mahéo (IRISA, INZU), Nicolas Le Sommer (IRISA, INZU) and Lionel Touseau (IRISA, INZU).

- Roumaissa Bekkouche: “Securing 5G Networks”, PhD in progress at University of Gustave Eiffel, supervised by R. Langar (UGE) and M. Omar (IRISA, INZU).

6.2.3 Juries

- M. Omar: member of the PhD jury (reviewer) of Nathanaël Denis (Telecom SudParis), “For a private and secure Internet of things with usage control and distributed ledger technology”, 2023/10/03.

7 Bibliography

Major publications by the team in recent years

[r1] F. GUIDEC, P. LAUNAY, Y. MAHÉO, “Causal and Δ-Causal Broadcast in Opportunistic Networks”, *Future Generation Computer Systems 118*, May 2021, p. 142–156.

[r2] F. GUIDEC, Y. MAHÉO, C. NOÛS, “Supporting conflict-free replicated data types in opportunistic networks”, *Peer-to-Peer Networking and Applications*, December 2022.

[r3] N. LE SOMMER, Y. MAHÉO, F. BAKLOUTI, “Multi-Strategy Dynamic Service Composition in Opportunistic Networks”, *Information 11*, 4, March 2020, p. 180.

[r4] N. LE SOMMER, L. TOUSEAU, “LoRaOpp: A Protocol for Opportunistic Networking and Computing in LoRa Networks”, *in : 18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2022), 2022 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, IEEE, p. 308–313, Thessalonique, Greece, October 2022.

[r5] M. OMAR, A. BAZ, H. ALHAKAMI, W. ALHAKAMI, “Reliable and Secure X2V Energy Trading Framework for Highly Dynamic Connected Electric Vehicles”, *IEEE Transactions on Vehicular Technology 72*, 7, 2023, p. 8526–8540.

[r6] 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.

[r7] 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] D. ZAMOUCHE, S. AISSANI, M. OMAR, M. MOHAMMEDI, “Highly efficient approach for discordant BSMs detection in connected vehicles environment”, *Wireless Networks 29*, 1, January 2023, p. 189–207.

Publications in Conferences and Workshops

[2] Y. MAHÉO, F. GUIDEC, C. NOÛS, “CRDT-based Collaborative Editing in OppNets: a Practical Experiment”, *in : 17th Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (Ubicomm 2023)*, IARIA, p. 13–21, Porto, Portugal, September 2023.