GETRF delivrable 1:

General Architecture

Paul Mühlethaler, Pascale Minet, Emmanuel Baccelli, Cédric Adjih
Hipercom Project-Team
Inria Paris-Rocquencourt

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Contents

1 Introduction

Communication in wireless networks always faces the bandwidth issue. The radio spectrum is a scarce resource and radio propagation is also difficult to control due to obstacles, reflectors, interference etc. Thus the available bandwidth is always limited in a wireless network. This is particularly true in Mobile Ad hoc NETworks (MANETs) as the packets can be retransmitted many times to ensure network connectivity.

In Wireless Sensor Networks (WSNs) the available bandwidth is also limited. WSNs are usually MANETs where the nodes have limited resources and are not very mobile. Thus in WSNs not only is the available bandwidth limited but so are the energy, the computation power and the memory.

The goal of the GETRF project is to find strategies to overcome these limitations. In MANETs, we will study how the nodes can gain the greatest benefit from the available radio spectrum. We will also study how packets can reach their destination if the MANET mobility leads to temporarily disjointed networks. In WSNs we will study the energy issue. We will propose strategies to optimize network consumption. We will consider two cases. In the first case the number of transmissions in the network is significant. In the second case the network only carries a very limited payload.

This document is organized as follows. Section 2 presents a general overview. The context and applications of WSNs and MANETs are described. Then the constraints of these networks and the goals of the GETRF project are explained. Section 3 presents the state-of-the-art for the physical and MAC layers for WSNs and MANETs. The limitations, trade-offs and possible improvements are presented. Then the crosslayer possibilities are introduced. Section 4 introduces the state-of-the-art for WSNs and for MANETs. Then the limitations, trade-offs and possible improvements in this layer are discussed. Section 5 describes the transmission paradigms in the application layer. The example of Delay Tolerant Networks (DTNs) and networks in overlay are explained. Various transmission techniques such as unicast, multicast, convergecast, geocast are presented. Section 6 describes the architecture proposed in the GETRF project. Section 7 concludes the document.

2 General overview

2.1 Context : WSNs and Mobile Ad-hoc NETworks

We can distinguish between small communication systems which are usually called Wireless Sensor Networks (WSNs) and more advanced and complex systems called ad-hoc networks. In the military context, ad-hoc networks are usually called tactical networks. There are two main differences between WSNs and tactical networks. Most often WSN nodes are small and simple devices that are very constrained by energy consumption. WSNs are usually captors but they can also be actuactors. Tactical networks are more complex systems which are much less constrained by energy. In general[1], WSNs are static networks whereas tactical networks are dynamic : Mobile Ad hoc NETworks (MANETs).

2.2 Target applications of WSNs : electronic surveillance systems, virtual mine field, platoon networks

Periodic surveillance systems are systems designed to report periodic measures or states. Usually periodic surveillance systems comprise nodes disposed in a given area (under surveillance) and a special node called the sink which collects all the information of the other nodes. Generally the nodes which are distributed in the area use wireless communications to report their measures to the sink. If needed, the packet can be relayed to reach the sink.

Examples of the parameters that are monitored can be the temperature of an area, the pressure of a gas (more generally any measures in an industrial plant), the water level in a river, the humidity rate of a soil, ground movements, the number of birds of a species protected living in a given area, accident detection, traffic road monitoring, home temperature regulation. Other surveillance systems can be used in the security field to monitor an area.

In the military domain such periodic surveillance systems can be seen as virtual mine field. The goal is to detect intrusions in a given area. In complex military systems such as battleships, WSNs can also be very useful in actions such as predictive maintenance, fire detection, etc.

[1] In certain conditions, the WSN nodes can be part of other systems such as robots, drones, etc. In these cases the WSN will actually be a mobile network.

2.3 Target applications of ad-hoc networks

In contrast to WSNs where the nodes incorporate detection features in addition to wireless communication capabilities, ad hoc networks mostly incorporate wireless communication capabilities. Target applications of ad-hoc networks are voice (with facilities such as push-to-talk, setting up conference calls, etc.), image and video diffusion, data such as email, cooperative edition tools. QoS and security are very important concerns in tactical networks. In the GETRF project we will not address security issues.

In ad-hoc networks, we aim to improve diffusion and unicast when mobility is very high. These improvements will be obtained using network coding.

Forwarding algorithms used in DTN will allow connectivity of ad-hoc networks to be improved when there is a lot of mobility.

2.4 Constraints: power conservation, throughput, coverage connectivity, mobility

2.4.1 Power conservation

Wireless sensor networks consist of a large number of wireless sensor nodes that organize themselves into multi-hop radio networks. Sensor nodes are able to monitor a wide variety of physical parameters such as temperature, humidity, light, radiation, noise, *etc*. These sensor nodes have a low cost, small size and wireless data transfer capability. Hence, sensor networks are expected to find widespread use in applications such as environment protection, health monitoring, diagnosis help in maintenance applications, traffic monitoring on freeways or urban street intersections, seismic data-gathering. The sensor nodes are typically equipped with power-constrained batteries, which are often difficult, expensive or even impossible to replace once the nodes have been deployed. Therefore, energy aware protocols are becoming a key research challenge in sensor networks.

In fact, several researchers have addressed energy conservation aiming at maximizing the network lifetime. The energy consumed by a node depends on its state. We distinguish four states: *(1) transmit*, *(2) receive*, *(3) idle* when the node keeps listening even when no messages are being transmitted and finally *(4) sleep*, where the radio module is switched off: no communication is possible. Table 1 reports the power used in each state for both IEEE 802.11 and IEEE 802.15.4 nodes.

State	Power (Watts)	
	IEEE 802.11	IEEE 802.15.4
Transmit	1.3	0.1404
Receive	0.9	0.1404
Idle	0.74	0.0018
Sleep	0.047	0.000018

Table 1: Power value in each radio state.

Furthermore, we can refine the receive state as follows:

- *overhearing*: when a sender transmits a packet, all its neighbors will receive this packet even if it is intended for only one of them. Thus, in the overhearing state, any one-hop neighbor of the sender that is not the destination uses energy needlessly;
- *interference*: each node located between transmitter range and interference range receives the packet but can not decode it;

More generally, energy efficient techniques tend to minimize the energy wasted in useless states from the application point of view such as idle listening, overhearing, interference, collision. Consequently, these techniques increase the network lifetime and improve energy efficiency. We can classify these techniques into four categories:

- *energy-aware routing protocols* select routes that minimize the energy consumed by an end-to-end transmission or visit nodes with high residual energy;
- *node activity scheduling algorithms*, whose objective is to turn off the sensor radio when it neither transmits nor receives data;
- *mechanisms to reduce the amount of data transferred* like data aggregation, because the energy consumed depends on the data size;
- *topology control methods* which tune node transmission power.

2.4.2 Throughput

Throughput is a very important concern in ad hoc networks. Thanks to the seminal work of Gupta and Kumar, it is known that the total throughput in an ad hoc network[2] can only scale in $\frac{\sqrt{n}}{\log(n)}$ where n denotes the number of

[2] nodes are located according to a homogeneous Poisson point process.

active stations. This result shows that the throughput is a very constrained performance parameter. Can the network coding improve this throughput? Under a scaling law, it has been shown that network coding can only improve capacity by a constant factor [2].

2.4.3 Coverage connectivity

In WSNs, the initial configuration could result from a random deployment throughout the terrain targeted. In some scenarios (rescue or military mission in an unknown area), all mobile sensor nodes are initially grouped at the same location before spreading. Usually, this initial deployment does not meet the application requirements. These requirements can be defined in terms of coverage and connectivity. Coverage means the ability to sense any event occurring in the area considered. Connectivity means that any node can communicate with at least one sink via single or multiple hop(s). Coverage can be full if the whole area remains permanently covered or partial, in which case each portion of the area is inspected once by at least one mobile sensor. Connectivity with a sink(s) can be permanent or intermittent. Terrain surveillance, intrusion detection and industrial processes are application examples that need full coverage and permanent connectivity. Table 2 gives some scenarios with various coverage and connectivity requirements.

Table 2: Examples of coverage and connectivity requirements

	Coverage	
	Full	*Partial*
Connectivity: Full	• terrain surveillance • intrusion detection • industrial process control	• rescue operation with a static sink
Connectivity: Intermittent	• mobile sink to gather data from static not connected sensors • predictive maintenance with a mobile handheld device	• rescue operation • terrain exploration

Full coverage and permanent connectivity are closely related. In fact, if the sensing range r and the radio range R satisfy $R \geq 2r$, then it is sufficient to ensure full coverage, connectivity is a consequence, as shown in [3]. In that case, we can relax the connectivity constraint. Hence, an optimal placement of sensors in a 2-dimensional terrain offering full coverage can be obtained by a triangular lattice (or, equivalently, by regular hexagons as illustrated in

Figure 1), and proved in [4].

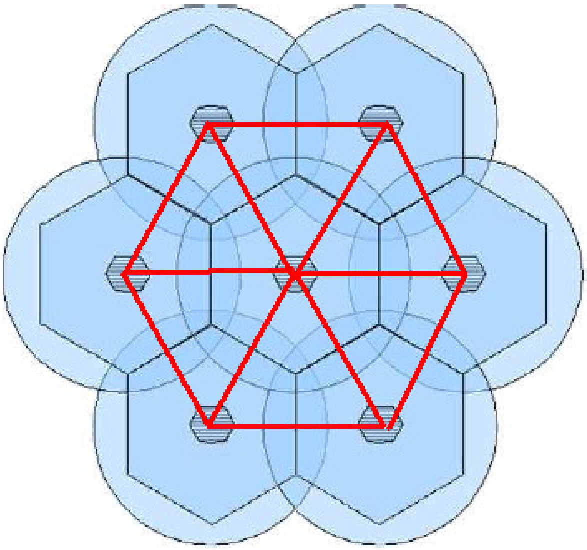

Figure 1: Triangular lattice deployment.

2.4.4 Mobility

In spontaneous wireless networks (such as ad hoc networks, sensor networks, vehicular networks) standard IP protocols and many applications are disrupted because they can no longer rely on link-local services. Indeed, wireless communication versatility due to mobility is not in accordance with the concept of IP links [16], an atomic element on which the protocol stack is based. Spontaneous wireless networks are thus disruptive because they require network protocols to track many more topology changes than usual, with much less control traffic than usual. For these reasons, new IP standards are being developed to accommodate such characteristics, including novel IP address autoconfiguration schemes, novel routing protocols for hybrid wired/wireless ad hoc networks, etc. Moreover, new protocols are currently being developed that can accommodate intermittent connectivity or permanent absence of end-to-end connectivity due to mobility (phenomena which are observed in various environments ranging from power-saving sensor networks, to vehicular networks, MANETs, and beyond that, in deep-space internetworking). They are for now mostly based on epidemic routing [17], or gossiping techniques, which have recently been analyzed to theoretically reach a number of nodes in the network that grows quadratically with respect to the elapsed time since the gossip was seeded [9].

2.5 Presentation of the general goals of the project

The goal of the GETRF project is to provide mechanisms which improve the performance of the network (in extreme conditions of functioning) or which can provide gains close to the optimal.

We will study

- the coloring technique to distribute TDMA slots. We will study the delay/efficiency compromise and take into account the asymmetry of the traffic to optimize the transmission delay
- In WSNs we will study the combination of opportunistic routing with MAC techniques operating in low duty cycles. This scheme allows the control traffic to be minimized and is very suitable when the network payload is low.
- Opportunistic routing and DTN techniques will also be used to ensure the connectivity of MANETs in which the node are highly mobile.
- Another technique to cope with such MANETs will be studied: network coding. We will use this technique more on the network and application layer than on the physical layer.

The two main areas for the GETRF project will be energy saving and the support of high mobility. In Figure 2, we present these two areas and the technologies that will be developed by the GETRF project. Other aspects such as throughput and delay will also be studied. Energy saving is a key point for sensor networks and wireless nodes consume nearly as much energy when they are in active wait mode as when they are receiving or transmitting. A key to energy saving is thus to be able to turn off the wireless nodes when appropriate. To do so we will study two techniques. In the first scheme we use coloring techniques to distribute TDMA slots; when two nodes are given the same color it means that the two nodes can transmit in the same time slot. In the second scheme, we will use a MAC technique to synchronize the transmissions and receptions of nodes. The relaying will rely on opportunistic and geographic techniques.

Another key point is the adaptation to high mobility. In contrast to classical multihop ad hoc networks, tactical networks are very mobile. The network may split due to the mobility of the nodes or due to enemy action.

For the network coding, the first goal is to conceive a complete protocol which is able to decode in real time and is suitable for diffusion (multicast, broadcast) and robust unicast. The objective is to maintain network connectivity with high mobility when a classical routing protocol could not compute the routes without significantly increasing resource utilization.

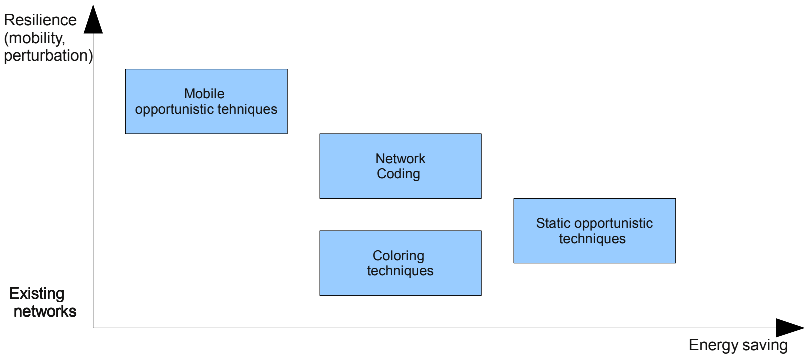

Figure 2: The areas of the GETRF project.

	Energy saving	Bandwidth optimization	Delay optimization	Mobility support
Coloring techniques	X	X	X	
Static opportunistic techniques	X			
Mobile opportunistic techniques				X
Network Coding				X

Figure 3: The techniques studied in the GETRF project.

3 Physical and MAC layers

3.1 WSN

3.1.1 Overview of standardized technologies 802.15.4, ZigBee, OCARI

The tremendous development of technology and the progress in miniaturization have given birth to a plethora of sensors. These sensors are able to provide information about temperature, pressure, location, humidity, velocity, acceleration, radiation, fissure metering, glucose, blood pressure, concentration of a pollutant. However, sensors would have limited utility if the information collected locally could not be transmitted to where it will be used. That is why we are now witnessing a transition from fixed sensors to wireless networked sensors. This trend is reinforced by the Internet of Things where a myriad of connected devices other than classical terminals/routers is coming. Sensors, smart dust, home appliances, smartphones, vehicles and robots will exchange information without human intervention. Since an exponential growth in the number of such connected devices is foreseen in the next five years, many standards development organizations and industrial groups want to play an important role. They all propose solutions that may be proprietary, incompatible or at least competing. Which solution should be adopted in such a jungle of technologies and standards? This problem is more crucial for industries with complex processes of high criticality and long lifespan. Examples can include the supervision of radioprotection in a nuclear plant, the predictive maintenance on a ship, the temporary instrumentation of a worksite to prevent pollution and detect fire. Such applications have various needs in terms of autonomy target (from one week to twenty months), mobility (from fixed sensors to sensors moving at pedestrian speed) and transmission period (from less than a second to several hours). Such requirements with regard to the wireless sensor network (WSN) can be summarized as follows:

- Micro-mobility of sensors (e.g. mobile sink carried by a walking human or mobile robot) should be supported,
- Medium access times and delivery times should be predictable and reproducible,
- Gathered data should be consistently dated,
- Energy autonomy should be maximized and radio spectrum efficiency should be optimized,
- Scalability, auto-configuration and self-healing should be provided.

The OCARI project [33] (Optimization of Ad hoc Communications in Industrial networks), funded by ANR, started in February 2007 and ended in 2010, with EDF, Inria, LIMOS, TELIT, LATTIS, DCNS and LRI. It proved the technical feasibility of industrial wireless sensor networks that support such requirements. The development of OCARI targets the following industrial applications:

- Real time centralized supervision of personal dose in electrical power plants,
- Condition Based Maintenance of mechanical and electrical components in power plants as well as in warships,
- Environmental monitoring in and around worksites,
- Temporary instrumentation,
- Structure monitoring of hydroelectric dams.

To meet the requirements of supported applications (remote command of actuators, tele-diagnostic, etc.), new solutions will be brought to manage several communication modes, ranging from deterministic data transfers to delay tolerant transfers. A key issue is how to adapt routing algorithms to the industrial environment, taking into account more particularly limited network resources (e.g.; bandwidth), node mobility and hostile environment reducing radio range.

The OCARI project aims at developing a wireless sensor communication module, based on the IEEE 802.15.4 PHY layer and supporting the EDDL and HART application layers. OCARI is based on a mesh topology, where routers (or star coordinators), in charge of the communications with the end devices in their transmission range, are able to communicate together thanks to a multi-hop routing scheme. The PAN coordinator, in charge of network initialization, is connected to the industrial backbone. The main innovations of OCARI are 1) MaCARI: a medium access method that provides determinism, energy efficiency and differentiation of services and 2) OPERA that provides an adaptive multi-hop routing protocol supporting micro-mobility and enables spatiotemporal reuse of channel capacity (see Section 4).

MACARI operates over the IEEE 802.15.4 standard at 2.4GHz with a throughput of 250kbit/s. It provides a deterministic access by synchronizing the activities of each star belonging to the OCARI network. This synchronization is provided by the PAN coordinator thanks to a beacon and forwarded multi-hop protocol in the network. Hence, all entities in the network know when they are allowed to transmit or receive and when they can sleep to save energy. Each star is sequentially awakened to collect its internal traffic and forward it to its parent in the data gathering tree. As a consequence, with MaCARI, all nodes may sleep to save energy, even routers unlike ZigBee. Furthermore, two types of traffic are supported: time-constrained (e.g. alarm) and unconstrained (e.g. regular traffic).

3.1.2 Limitation, tradeoff and possible improvements

The IEEE 802.15.4 does not guarantee determinism in multihop networks. Determinism is specifically require by applications that should be certified. Moreover the throughput of IEEE 802.15.4 i.e. 250 kbps is very limitative. Some extensions consider multichannel transmissions to increase parallelism and throughput on the one hand and to improve robustness by avoiding channel with pertubations on the other hand.

Another requirement is the consistent time-stamping of events detected in the networks. This time-stamping is usually based on clock synchronisation algorithms.

For some applications the localisation of the nodes is required. For this the UWB technology can be used.

In WSNs there is a tradeoff between the network lifetime and the quality of event detection (latency, probability of detection).

There is also a tradeoff between mobility and determinism.

More generally there is a tradeoff between a WSN specifically designed for a given application and a standardized WSN that should be open but may provide less performance for this application. A promising approach is cross-layering.

3.1.3 Cross-layer possibilities

At the MAC layer, there is a strong interaction with SERENA the node coloring algorithm (see section 4) implemented at the network layer of the OCARI stack. Indeed, SERENA assigns colors to nodes. The number of colors is used by MaCARI to dimension the cycle length (e.g. one time slot per color). Furthermore the knowledge of the color of the node and the colors of its one-hop neighbors are used by the node to make it sleep or wake up when needed. More precisely, any node must be awake in the time slots corresponding either to its color (to send its messages if any) or to the color of its neighbors (to receive their messages if any). It sleeps in the other slots. This strong collaboration between MaCARI and SERENA contributes to maximizing the network lifetime and increase spatial reuse of the bandwidth (two nodes with the same color transmit simultaneously without interfering).

3.2 Mobile ad hoc networks

3.2.1 Overview of standardized technologies

As with most technologies, one defining constraint of mobile ad-hoc networks, is the available radio spectrum that the equipment is allowed to used. A second constraint is the commercial availability of radio equipment.

It comes as no surprise therefore that, in the civilian world, most of the deployments of mobile ad hoc networks (such as Freifunk [8], SkyMesh [10], etc.), use off-the-shelf hardware, based on standards such as Wifi (802.11, b, g, a, n, etc.), operating in the non-licensed ISM bands.

3.2.2 Limitation, tradeoff and possible improvements

The focus of unlicensed civilian wireless technology for computer networking is on the short-range wireless communication (802.11 Wifi, 802.11ad Wigig, etc.). Although, one may find numerous deployments of wireless technology on a larger scale (at the city scale for instance, [7], or even with links over 300 kilometers, for instance [13]), the wireless technology was not designed for such usage. Thus, for instance the delay spread [7] might be higher than assumed in the technology design, leading to intersymbol interference, and packet loss.

3.2.3 Cross-layer possibilities

Traditionally, the cross-layer possibilities have been limited in civilian wireless digital technologies, since typically off-the-shelf equipement is based on ASIC chipsets.

With the advent of software-defined radio, which has been largely financed by the military, cross-layer at the physical level has been largely studied with a lot of possibilities.

4 Network layer

4.1 WSN

4.1.1 Overview of standardized technologies

ROLL, 6LOWPAN

The Internet of Things (IoT) is expected to soon connect billions of communicating machines, including devices ranging from actuators to home appliances, from smart meters to smart dust. The outcome of on-going debates and deployments will shape the proportion of such devices that will actually be connected to the Internet and be assigned an individual IP address. Efforts such as Auto-ID Labs [20] and EPC Global [21] propose approaches, while the IETF [18] currently pushes towards solutions where most devices would be identified and reachable via an IPv6 address.

Sensor networks are a typical example of this new galaxy of communicating devices expected to make the Internet of Things. Sensors are devices used for distributed and automated monitoring of various parameters such as temperature, movement, noise or radioactivity levels etc., depending on the type of sensor. While some of these sensors will connect to the network via wire or power line communication, most sensors will use radio communications. Typically, a number of such devices, identical to one another, are scattered in the zone to be monitored. Each sensor then monitors the parameters to be measured in its vicinity and communicates through its single radio interface with its peers, spontaneously creating a wireless network – GETRF targets such networks, among others. Using this network, sensors self-organize distributed computations, or convergecast, *i.e.* information gathering at a central control point – which is generally called the *sink*, in this context.

From a networking point of view, scattered sensors may be more or less remote from one another – a given sensor may, for instance, require some peers to forward information towards the sink, because the sink is beyond of its radio range. Appropriate network protocols are thus required to enable each sensor to, on the one hand, directly communicate with peers that are within its radio range, and on the other hand, indirectly communicate with other devices that are only reachable through some peer with which the sensor can directly communicate.

Various standard technologies can be used to enable direct wireless sensor communication at the link layer (layer 2), such as ultra-low power IEEE 802.11b/g/n (Wifi), IEEE 802.15.1 (Bluetooth), or IEEE 802.15.4 (Zigbee). The most common link layer technology used today by wireless sensors is 802.15.4-2006, often preferred for its low power requirements. The way sensors are scattered is generally unplanned (apart from of the central role of the sink), and may evolve over time as sensors are added or removed from the network, or as they move about. Complementary mechanisms are thus used to enable indirect wireless sensor communication at the network layer (layer 3), i.e. protocols for multi-hop wireless sensor networks, which is the focus of the IETF and of the ROLL working group in particular.

New, or revised IP protocols are needed because, sensors do not allow simple, atomic link-local services on which many IP protocols and applications rely, and require network protocols to discover and track topology with extremely little control traffic in order to meet stringent power constraints: transmitting and receiving drains batteries that are generally expected to last months or years before being replaced. With standard IP protocols, sensor batteries typically fail to last that long. Moreover, today's wireless sensors are typically cheap devices that have a few kilobytes of RAM and a few tens of kilobytes of ROM [22], slightly less than what was available on the first computers (Honeywell DDP-516) on the ARPANET in the early 1970s! This is a rather small amount of memory to run on for a single protocol nowadays. The challenge is that *the whole protocol stack and applications* must share that little memory.

Furthermore, the most common link layer technology used today by wireless sensors is 802.15.4-2006, which communicates with packets that carry a maximum payload of 102 bytes (81 bytes if link layer security is on). This is an order of magnitude less than the standard IPv6 packet size of 1280 bytes. Standard IPv6 and UDP headers alone require 48 bytes, a meager 33 bytes of payload is thus left for applications and other protocol headers [19], which is generally not enough.

The IETF has thus recently engaged in multiple efforts aiming to address the limitations of standard IP protocols on wireless sensor networking. For instance, the 6LOWPAN [24] working group has focused on developing an intermediate layer between 802.15.4 and the IP layer, enabling IPv6 to operate on wireless sensor networks with IPv6 formats compression. Meanwhile, efforts such as Contiki [27] [28] and Tiny OS [29] proposed small foot-print IP stacks that aim at fitting the memory constraints of sensors, and very recently, a working group dedicated to light-weight implementations of IP protocols, has taken shape at the IETF: the LWIG working group [25]. Other standards in development aim at adapting HTTP to constrained devices such as sensors: the CORE working group [26] is currently developing a specific protocol called COAP, also based on REST. Yet another family of standards under construction aims at providing multi-hop wireless sensor communication with IPv6, which requires specific routing protocols: this is the focus of the ROLL working group [23], which has recently proposed a new routing protocol primarily targeting sensor networks and convergecast: RPL [30] .

OCARI

In the OCARI stack, we find OPERA at the network layer. OPERA is the second main innovation in OCARI. It consists of two modules EOLSR and SERENA. EOLSR is an energy-efficient routing protocol that builds and maintains, for each node, a path toward the sink in charge of gathering data. This path has the smallest energy cost and avoids nodes with low residual energy. SERENA uses node coloring to allow spatial reuse of the bandwidth: two nodes with the same color can transmit simultaneously without interfering. As a consequence, SERENA significantly reduces the number of slots needed to allow any node to transmit in a TDMA cycle. SERENA allows any node to sleep during the slots that are not attributed to its color or to its one-hop neighbors. SERENA contributes to a more efficient use of energy: less energy is spent in the idle and interference states. Hence, network lifetime is considerably increased. SERENA has been optimized for the specific context of OCARI (i.e.; very limited bandwidth 250kbps, small size messages 127 bytes, limited memory and limited processing power). Furthermore, SERENA ensures with a three-hop tree coloring that all data collected during a cycle can reach the sink in this cycle, ensuring time consistency of these data. Moreover, the coloring is still valid even if the parent of a node in the data gathering tree is replaced by one of its one-hop neighbors.

MaCARI and OPERA have been implemented in the OCARI stack. At the end of the OCARI project in 2010, EDF the coordinator decided to continue the project with a reduced number of partners: TELIT, LIMOS (Clermont Ferrand University) and INRIA. The goal was to prove the feasibility on commercially available cards of the OCARI stack designed during the ANR project and to give a public demonstration of this product. During the year 2011, the OCARI stack was improved and implemented on the ZE51 module of TELIT based on the Texas Instrument CC2530 Chipset. OCARI allows industrial applications to have a more accurate view of data. It simplifies the access to measures generated by cooperating sensors, the instrumentation of harsh areas as well as the deployment for temporary instrumentation.

4.1.2 Limitations, tradeoff and possible improvements

The goal of the OCARI Alliance is now to promote an open standard which is safer and validated for highly constrained industrial environments for industrial wireless sensor networks. In the Connexion cluster [34] that started in April 2012, new partners (CEA, CNRS/CRAN, ENS Cachan, INPG LIG, Telecom ParisTech, ALSTOM, AREVA, Atos WorldGrid, Rolls-Royce Civil Nuclear, Corys TESS, Esterel Technologies, All4Tec and Predict) have joined forces to face three new challenges:

- Cope with an ionizing environment by developing special hardware able to support such an environment,
- Support high mobility by allowing mobile nodes to redeploy themselves in a given area and provide area coverage and network connectivity to allow any event occurring in the area to be detected and reported to a sink. Another goal could be to redeploy the network in a given direction while maintaining connectivity.
- Qualify hardware and software performances, using simulation tools and testbeds.

OCARI contributes to the scalability in new measurement and actuation capability. It also provides a more accurate view of the monitored process because of the time consistency of gathered data, the ability to instrument devices in harsh area and the flexibility of deployment for temporary instrumentation.
More generally, benchmarks and performance evaluation will be done in the near future to compare the different standards in WSNs.
Tools will be developed to help in the WSNs deployment to ensure a better quality of service. Communication protocols able to adapt themselves to changing environment conditions and application requirements will be preferred.

4.1.3 Cross-layer possibilities

Various techniques are used to contribute to energy efficiency, see for instance the survey [32] we published at the WMNC 2011 conference. In the OCARI2 project, we have designed and implemented an energy efficient routing protocol and a node activity scheduling algorithm allowing router nodes to sleep. We have applied a cross-layering approach allowing the optimization of MAC and network protocols taking into account the application requirements and the environment in which the network operates. This activity has been done in collaboration with our partners EDF, LIMOS and TELIT. More particularly, EOLSR builds and maintains on each router a path toward the sink(s) and not a path toward any other node. This significantly reduces the routing overhead. To maximize network lifetime, it selects the end-to-end path minimizing energy consumption avoiding nodes with low residual energy and links with poor quality. Hence, EOLSR uses the knowledge of:

- node residual energy provided by a cross layering,
- link quality provided by the MAC layer,
- node type sink or not provided by the application layer.

SERENA uses the knowledge of:

- the type of application supported: data gathering application or general application: this enables SERENA to reduce the data gathering delays;
- the type of communications used in the WSN: the support of broadcast or not, the support of immediate acknowledgements (the receiver acknowledges the receipt of a frame in the slot of the sender) or not. This knowledge allows SERENA to optimize the color assignments
- the type of WSN: dense networks with a MAC layer having strong constraints on the frame size have led us to optimize SERENA in such an environment.

4.2 Mobile ad hoc networks

4.2.1 Overview of standardized technologies

In performance-constrained networks, the topology of radio networks is usually dense and often varies. MANET protocols propose two ways to create routes in ad-hoc networks: proactive protocols and reactive protocols:

- In proactive protocols every node emits HELLO messages in order to learn the topology (a mechanism is then used to broadcast this information or a sufficient part of it to be able to compute routes);
- On the other hand, a very simple way of finding a route consists in flooding. The source floods the network with a packet and the path followed by the packet to reach the destination is used. This is done in reactive protocols.

With respect to the control overhead, these two approaches are very different. Reactive protocols are very attractive for two reasons: information is stored only for the routes which are currently active while the rest of the topology may be ignored. It allows one route to be quickly created. Most of the early protocols used this mechanism. The most popular is arguably

AODV [11] and its successor DYMO (AODVv2), and an alternative is DSR [5].

On the other hand, proactive protocols capitalize on the extensive experience gained in designing, analyzing and implementing routing protocols. For example, one knows that OSPF reacts better to link and node failure than RIP. The typical proactive protocol (and the proactive protocol which is in the standardization process of the IETF) is OLSR [12], inspired by the routing part of HiPERLAN type1 (and an alternative is TBRPF [6]).

It is a link state protocol (comparable to OSPF regarding several principles), with specific optimizations for radio networks. It takes advantage of knowledge of the local topology, in order to provide an efficient broadcast mechanism.

4.2.2 Limitations, tradeoff and possible improvements

Proactive protocols are suitable when there is mobility, when there are many active routes or there are strong constraints on the latency of packet delivery.
Reactive protocols are suitable when the network is not too mobile and there is a small number of active routes. There should not be strong constraints on the latency of packet delivery because of the delay induced by the route discovery.
To maintain a low overhead these protocols should adapt to the state of the network. In a stable state the timers of the protocols should be large and these timers should become smaller when the network is perturbated.
For both proactive and reactive protocols there are connectivity problems when the the mobility of nodes is too high. To cope with this difficuly, the GETRF project plans to use two techniques. The first technique uses network coding whereas the second one use a store-carry-forward scheme.

5 Transmission paradigms in the application layer

In GETRF, we are focusing on providing a set of network communication primitives for applications. They include unicast, multicast, convergecast and

5.1 Unicast, Multicast

Unicast is the traditional primitive of communication offered to applications. A destination is identified by an address (which might be further provided by an external name resolution service): the application simply send messages by providing a destination address. Depending on the network layer, further parameters may be used to discriminate between the target applications at destination node (for instance, in IP networks: TCP or UDP ports).

One other specific form of communication is *multicast* where all users (a *multicast group*) must receive the messages transmitted by all the others. It is a natural form of communication for some applications, such as videoconferencing and streaming. To enable such communications, multicast routing is required. At the same time, it is challenging in wireless multi-hop networks because it must meet many requirements, including dynamicity of the network. One of the major constraints is the limited bandwidth of ad hoc networks on the one hand, and high requirements of multicast applications like videos on the other, which makes efficient use of multicast a key issue.

Other specific forms of communications include *convergecast*, which can be seen as a multicast in the reverse direction (instead of having one source transmitting to several destinations, convergecast is when many destinations send to a single source), or *geocast* which is a specific form of unicast using geographic addressing.

In the traditional vision of networking, the responsibility of *routing* is devoted to the lower layers (network layer in below), hence the traditionnal design is to integrate routing protocols (for unicast, multicast, convergecast, geocast, ...) below and independently from applications.

However, in some cases, the applications themselves, or application level protocols, participate in routing, for instance because they have more knowledge of the network topology. Two primes examples are delay-tolerant networks (where the network is not necessarily connected, hence at a given point of time, it is not possible to compute a route on the current graph of the network), or multicast, where unicast routing might exist, but without support for multicast itself ; and where it is still possible to send to several destinations.

5.2 Example in the DTNs

The idea behind DTNs is simply that if data communication can wait for better paths to become available due to changes in network topology, substantial gains in throughput will be obtained – if by "better paths" we mean "paths that offer more throughput". Recent work has focused on a radical version of this paradigm: even if the network graph is such that no path to the destination ever exist at any given time, data could still be stored and carried by a sequence of nodes that will eventually end up in the vicinity of the destination and deliver the data, thus improving the throughput from 0 to something strictly positive. Such networks are sometimes referred to as Intermittently Connected Networks (ICNs), but more commonly also called DTNs which is the term used in this report. The DTN paradigm stems from a variety of industrial contexts, ranging from sparse spontaneous wireless networks intermittently connecting mobile nodes (such as vehicular ad hoc networks), to networks made up of fixed nodes that may suddenly switch to sleep mode at any time in order to save energy (such as sensor networks), or even to deep space internetworking, where nodes can only infrequently communicate with one another, and round-trip times are extremely long.

5.3 Examples of network in overlay

Overlays are a common networking technique, where a “virtual topology” is built over an actual topology. The advantages includes the fact that new technologies might be implemented over pre-existing networks, and also the fact that it may also be further application of the layering (as in the Internet, or OSI model).

The recent success of the field of *network virtualization* [14] can be seen as a generalization of network overlays, expending virtualization to other dimensions than just virtual topology.

Example of use of overlay in networks include *multicast overlays*: a multicast structure computed by the protocols, creates shared multicast spanning tree, which is constructed as an overlay tree linking all group members. This approach has several important advantages. It implies that only nodes interested in taking part in the multicast communication would need to participate in the protocol operation. In addition, the overlay tree approach can offer high robustness and reliability for the multicast service. An exemple of multicast overlay is the *Multicast Overlay Spanning Tree* protocol (MOST [15]).

Other examples of overlay networks, include the peer-to-peer networks.

5.4 Convergecast

In data gathering applications, which represent most of the applications in WSNs, every node senses parameters of its environment like temperature, pressure, velocity and these sampled data must be transmitted to a sink in charge of collecting and processing them. In most WSNs, the sink is not in range of all the sensor nodes, so multi-hop transmissions are required. These transmissions are done according to a routing tree which includes all network nodes and is rooted at the sink. The associated transmission paradigm used is called convergecast, where any node receives messages from its children and transmits them to its parents in the convergecast tree. We distinguish two types of convergecast: with or without aggregation. Aggregation allows any intermediate node to aggregate messages received from its children before forwarding them to its parents. If all messages received can be aggregated in a single message, any node transmits only a single message to its parents. This is no longer the case, when aggregation is not used. In such a case, nodes close to the sink have a high number of messages to forward. Convergecast without data aggregation is usually called raw data convergecast. Intermediate nodes in a data gathering tree simply apply the store-and-forward strategy, without processing the received packets.

Most of these applications share the requirement of deterministic delay bounds and a guarantee of packet delivery. Medium access protocols that are contention-based protocols are clearly inadequate as they suffer from collision and non deterministic delays, especially under heavy traffic conditions. To meet these requirements and increase the efficiency of transmissions, slotted communications are used. Slots are assigned to transmitters in such a way that only non-interfering transmitters can transmit in the same slot. The problem consists in finding the minimum number of slots needed to allow each node to transmit its data and the data sent by its children. This problem of optimal slot assignment for convergecasts has been shown to be NP-complete both with and without aggregation. The optimal number of slots has been computed for various topologies, in a single or multi-channel environment, with a single or several radio sink interfaces. Optimized heuristic algorithms exist for both and they reach the optimal number of slots in various configurations but not all.

5.5 Geocast

Geocast refers to the delivery of information to a group of destinations in a network identified by their geographical locations. It is a specialized form of multicast addressing used by some routing protocols for mobile ad hoc networks.

There exist many protocols for geocast, see [31]. The main idea of these algorithms is to limit a pure broadcast and to steer the packets towards the geographical locations of the geocast group.

6 Architectures proposed

6.1 Coloring

The coloring architecture requires a framing module. This module will be in charge of creating time-slots in which the packets will be sent. It will be either a GPS system or a synchronisation algorithm to acquire a precise time synchronisation.
The coloring algorithm is in charge of assigning a color to each node in the network such that two nodes with the same color can transmit simultaneously without interfering. The total number of colors should be minimized. To achieve the best performances the coloring algorithm must be aware of the type of communications used by the applications (with/without support of broadcast, with/without support of immediate acknowledgement, data gathering tree, etc.) For this purpose, the coloring algorithm will use information coming from the Neighborhood discovery and Route computation modules. Colors are mapped into time-slots. A node is awaked in the time-slots corresponding to its color to transmit its packets anb in the time-slots corresponding to the colors of its one-hop neighbors to receive their packets.
The coloring algorithm provides this schedule to the MAC layer that monitors the sending of packets in the suitable time slots. The MAC module will send packets to the framing module and thus the packets will be sent in their dedicated time-slots.
The schedule provided by the coloring algorithm is also used by the physical layer to switch off the transceiver in order to save energy when the node is asleep on the one hand and on the other hand to wake-up the transceiver when appropriate.

6.2 Low duty cycle architecture

This architecture encompasses a module to obtain the node's localization. This module can use the GPS or any other positioning system. In the low duty cycle architecture we also find a beaconing module. The node uses this module to indicate that it is awake and ready to receive data from other nodes. The last module of the the low duty cycle architecture is a transmission/retransmission and reception module. Except when the node is itself the source of the information the node is re-transmitting information. This retransmission occurs after the reception of a packet. This retransmission is driven by the reception of beacons of neighbor nodes.

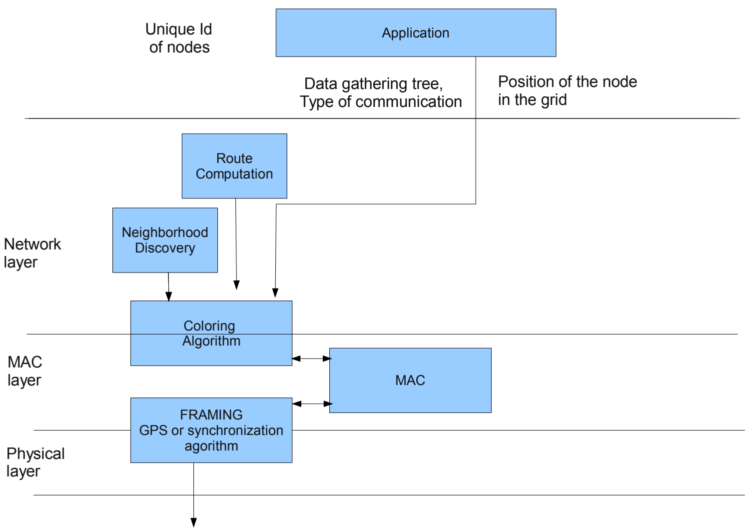

Figure 4: The coloring architecture.

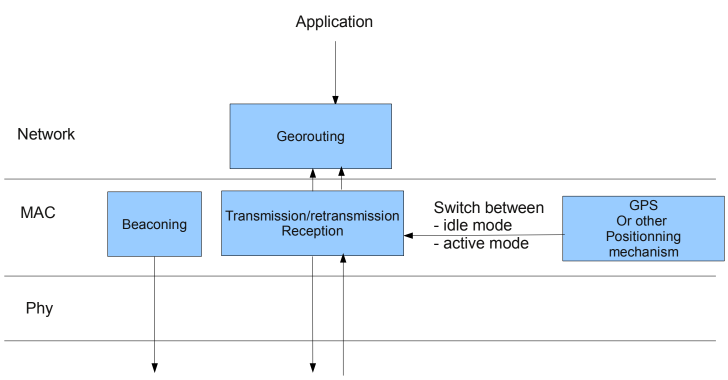

Figure 5: The low duty cycle architecture.

6.3 Network coding

This architecture includes a network coding module which is the heart of the network coding architecture. The network coding module acts as an intermediary between the applications and the network layers:

- From the application side to network layers:
  The module will receive packets from the application. According to the type of connexion : unicast or broadcast and taking into account topological information, the node will decide the suitable coding that should be used with the incoming packets.

- From network layers to applications:
  The module will also receive packets from the MAC. These packets can be decoded and sent to the application if the node is the destination of these packets.

Internally, the network coding will operate transparently from the application layers: packets may also be relayed as they are or re-combined.

The network coding protocol is defined by two key decisions:

- which packets should be coded (or not coded together)?

- when should packets be emitted?

In addition, information related to the network coding propagation process may also by exchanged, piggybacked on application coded packets, or out-of-band with a specific protocol.

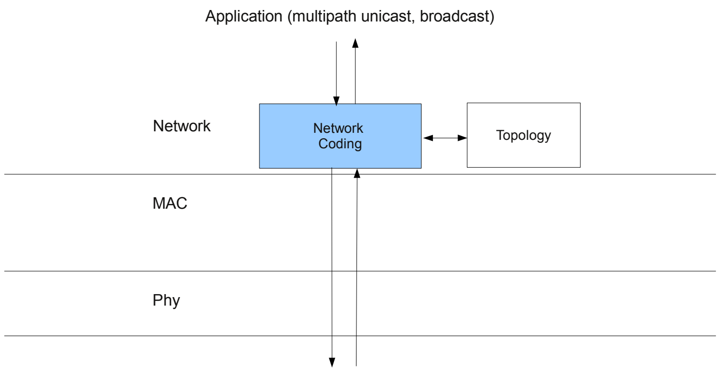

Figure 6: Network coding architecture.

6.4 Disruption tolerant store-carry-forward architecture

This architecture encompasses a module to obtain the node's location and its speed: module and direction. This module can use the GPS or any other positioning system. In the store-carry-forward architecture we also have a transmission/retransmission and reception module. This module will handle packets which have been sent directly by the node or packets relayed by this node. Depending on the speed of the node and the position of the destination, the node will keep the packet or will re-transmit it. When a node receives a packet and depending on its speed and the position of the destination, the node may decide to handle this packet. In such a case an acknowledgement will be sent. This acknowledgement will warn the other potential relays that the packet has been dealt with. The packet may also have reached its final destination.

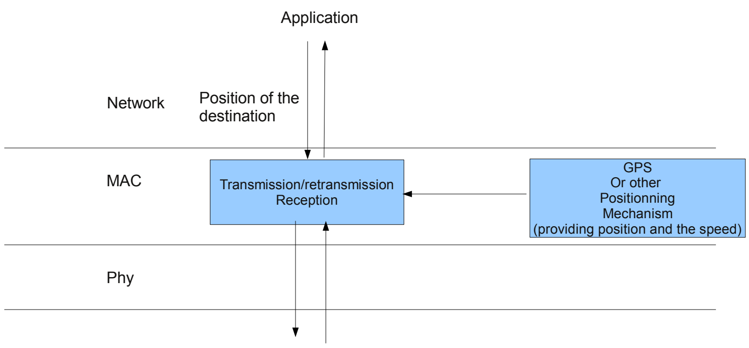

Figure 7: Disruption tolerant store-carry-forward architecture.

6.5 Combination of techniques

The coloring scheme can operate with the network coding scheme. In this case the coloring scheme will schedule the transmission of packets while the network coding scheme will code and decode the packets. Here we have the "superposition" of both techniques.

The coloring scheme can operate with the low duty cycle scheme. We divide the time into periodic superframes. Each of these superframes can be divided into two frames: one time frame where the coloring scheme will operate and the other time frame where the low duty cycle scheme will operate. The network will successively operate in the coloring mode and then in the low duty cycle mode.

The coloring scheme can operate with the store-carry-forward scheme. With this combination the store-carry-forward scheme will use the time-slots given by the coloring scheme to relay packets. This constraint may however significantly lower the performance of the whole scheme. Moreover it is generally difficult to use coloring techniques with moving nodes.

The network coding can work in principle with the low duty cycle mechanism, however it is difficult since the low duty cycle mechanism is optimize to use a minimum number of packets.

The network coding can work with the store-carry-forward algorithm. The moving nodes will code and decode packets while the store-carry-forward will handle the relaying of packets.

The low duty cycle can work with the store-carry-forward algorithm. The low duty cycle will indicate when the nodes are ready to handle a packet and the store-carry-forward algorithm handle the relaying of packets accordingly. There is an obvious convergence between the low duty cycle architecture and the store-carry-forward architecture. In both of these architectures a location module is the corner stone of the architecture. We also have a Transmission/retransmission Reception module in both architectures.

The summary of these combinations is shown in Figure 8.

7 Conclusion

In this document we review the context of WSNs and Mobile ad-hoc networks and their applications. We recall their constraints: power conservation, throughput, coverage, connectivity, mobility. We explain how the GETRF project expects to improve the previous parameters and finds the ways to obtain these improvements.

We then study the physical and MAC layers. We describe these layers in the standardized technologies such as IEEE 802.11, 802.15.4, ZigBee, OCARI. We detail the limitations, tradeoffs and possible improvements. We show that these improvements will result from a cross layer approach.

The network layer for WSNs and ad hoc networks is described with the presentation of the international work: ROLL and 6LOWPAN and the French

	Coloring (Co)	Network coding (Nc)	Low duty cycle (Ld)	Store-Carry-Forward (SCF)
Coloring (Co)				
Network coding (Nc)	complementary simultaneous Co and Nc			
Low duty cycle (Ld)	Complementary Co in frame LD in another frame	Can be combined but difficult		
Store-Carry-Forward (SCF)	Can be combined but difficult	complementary	Complementary DTN + Georouting	

Figure 8: Combination of techniques.

work: OCARI. We then propose an overview of the network layer for ad hoc networks mostly around the IETF work in the MANET work group. For both the WSNs and ad hoc networks we discuss the limitations, tradeoffs and possible improvements.

A section of this document is devoted to the transmission paradigms in the application layer. We discuss DTNs, the different types of transmissions such as unicast, multicast, convergecast, geocast.

The final section of this study describes the architectures that will be studied during the GETRF project. We have four architectures: the coloring architecture, the low duty-cycle architecture, the network coding architecture, the disruption tolerant store-carry-forward architecture. We briefly envision how the four architectures can be combined.

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