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pour obtenir

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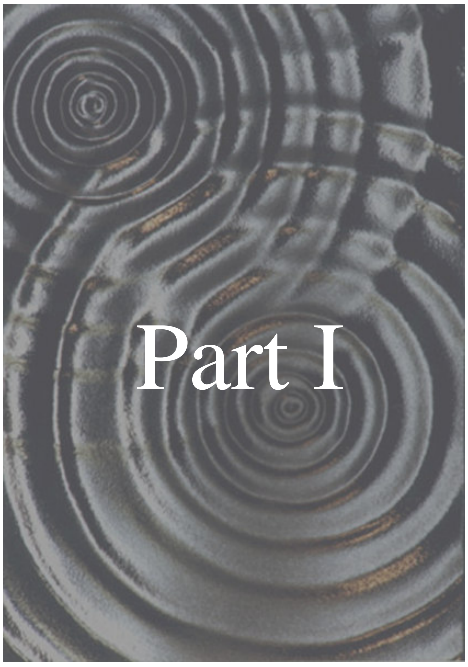
Abstract

Nowadays the rapid developments in most wireless technologies promote the use of wireless communications anywhere and anytime. In the future, more and more mobile devices will become networked, following the trend toward ubiquitous networking. One of the main goals in current research is to design new wireless networks that are flexible, low-cost, and require little administration. In this context, the principle of light infrastructure networking received much interest during the past five years. A Light Infrastructure Network (LIN) represents a network of many nodes that communicate with one another in an ad hoc fashion, most often wirelessly, with little supervision of central entities. Mobile ad hoc networks (MANETs), wireless mesh networks (WMNs), wireless sensor networks (WSN) and vehicular networks (VANETs) are examples of such light infrastructure networks. These networks are expected to play an important role in future communications, where they will find wide application scenarios in daily life events. However, many efforts must be done in order to make these networks more mature. In fact, LINs still present significant technical challenges and our concern was to propose novel mechanisms and solutions that address part of these challenges.

Keywords: Vehicular networks, ad hoc networks, sensor networks, mesh networks, protocols, performance evaluation, simulation, analytical models, and experimentation.

Contents



Part I

Research Activity

Chapter 1

Introduction

1. Light Infrastructure Networks

The last decade has seen a tremendous boom in the mobile communications market. People have become accustomed to the convenience of making calls with mobile phones and browsing the Internet with notebooks and smart phones via wireless connections. Two prime examples of this development are the great success of the Global System for Mobile Communication (GSM) and the huge number of Wireless Local Area Networks (WLANs) deployments. In the future, more and more mobile devices will become networked, following the trend toward ubiquitous networking. One of the main goals in current research is to design new wireless networks that are flexible, low-cost, and require little administration.

In this context, the principle of light infrastructure networking received much interest during the past five years. A Light Infrastructure Network (LIN) represents a network of many nodes that communicate with one another in an ad hoc fashion, most often wirelessly, with little supervision of central entities. Mobile ad hoc networks (MANETs), wireless mesh networks (WMNs), wireless sensor networks (WSNs) and vehicular networks (VANETs) are examples of such light infrastructure networks. These networks are expected to play an important role in future communications, where they will find wide application scenarios in daily life events (networking in smart homes, safety and comfort for drivers/passengers, healthcare, body area networking, community networks, large scale and long-range networks in developing regions, and others, where no central administrator exists, or where administration would prove to be too costly). However, many efforts must be done in order to make these networks more mature. In fact, LINs still present significant technical challenges. They inherit some of them from wireless networks and more precisely the wireless channel related problems (hidden terminal problem, packet losses due to interference or collisions, ease of snooping on wireless transmissions, etc.). In addition, they suffer from other problems related to their specific characteristics, such as network partitions (especially for vehicular networks), route failures that would result from nodes mobility, node battery depletion (especially for WSNs), scalability, and multi-hop communications.

Our concern was to propose novel mechanisms and solutions that address part of the challenges faced by such kind of networks.

1.1 Wireless Multi Hop Ad hoc Networks

A wireless ad hoc network is a multi hop radio packet network composed of a set of nodes which form in a spontaneous way a network able to convey, gradually, data packets through radio interfaces. The facility of deployment, the dynamic reconfiguration aspects, the possibility of capacity addition without preliminary planning and its low implied cost are major assets in favor of ad hoc networks. However, certain technological issues are to be solved to hope for real deployment in a public context of generalized mobility. Among them, we can quote the following: quality of service and scalability.

In this context, proposing innovative solutions to cope with these challenges constitutes an important part of our work. Our contributions are positioned at different OSI layers (transport, network, and link) that are summarized in the following.

TCP within Wireless Multi-hop Networks: TCP is considered as the most popular reliable transport protocol today. We carried out a complete study (simulation and experimentation) in order to evaluate the existing TCP variants within wireless ad hoc environments. We found that TCP as it exists nowadays may not well fit in wireless ad hoc networks since it was designed for wired networks where network congestion is the primary cause of data packet losses. The problem of TCP and all its existing variations within MANETs resides in its inability to distinguish between different data packet loss causes. In order to handle the different packet loss causes, we propose TCP-WELCOME. This latter follows a two-step process: (i) first, distinguish between most common packet loss causes, and (ii) then, triggers the most appropriate packet loss recovery according to the identified loss cause. The performance evaluation shows that TCP-WELCOME enhances the quality of service by optimizing both energy consumption and throughput. Also, TCP-WELCOME does not change the standard and can operate with the already existing TCP variants.

Self-Organization in Large Scale Wireless Ad hoc Networks: To communicate efficiently in a large scale wireless ad hoc network, some form of organization has to take place. In fact, for a given set of wireless devices, the potential number of interactions (connection links) grows with the square of the number of devices. A wireless network needs organization at various levels. We focused in our work on layer 3 organization in order to: (i) minimize the need for manual configuration, (ii) use distributed solutions rather than centralized ones, and (iii) use only local control traffic overhead. We proposed PARTY, a new network layer for large scale wireless multi-hop networks. PARTY is decentralized, scalable, and independent of IP-like addressing limitations. Each node has its own universal identifier and is assigned a temporary address according to its relative location in the network. Nodes change addresses as they move, so that their addresses have a topological meaning. A tree-like logical topology is created, which describes the relative location of the nodes according to their neighborhood in the physical network. This new addressing structure eases the routing in such networks. The routing strategy provided by PARTY is a distributed one, where the forwarding process is done hop by hop in a way that resembles to the forwarding process in Pastry Peer-to Peer protocol [23]. PARTY is scalable and enhances the quality of service by reducing considerably the traffic overhead and providing seamless communications.

Cooperation in Multi-hop Ad hoc Networks: The concept of cooperative relaying promises gains in robustness and energy-efficiency in wireless networks. In cooperative relaying, multiple nodes cooperate to forward a packet within a network. A node denoted as relay overhears the direct transmission between source and destination and on demand forwards this data to the destination. The destination receives the same message via two independent paths, which introduces diversity and thus mitigates small scale fading. It depends on the coherence time of the channel whether a relay retransmission is preferable to a retransmission by the source. For instance, for a long coherence time, the retransmission from the source would suffer the same error probability as in the original transmission. In such cases relaying is preferable. The same data received via different paths can be combined at the destination using combination techniques like Maximum Ratio Combining (MRC). We addressed the drawbacks of cooperative relaying regarding its spectral inefficiency and its channel over reservation compared to direct transmissions in a multi-hop ad hoc network. We proposed a cross-layer solution that exploits routing information in cooperative relaying to reduce these disadvantages. Relays are selected by taking route information into account. We addressed a complete system design of *Multi-Hop-Aware Cooperative Relaying (*MHA-Coop-Relaying). Performance tests indicate that it significantly enhances the quality of service in terms of throughput and energy.

We also proposed CoRe-MAC a MAC protocol for relay selection and cooperative communication as an extension to CSMA/CA which addresses resource reservation, relay selection, and cooperative transmission while keeping the overhead in terms of time and energy low. Performance evaluation show that CoRe-MAC enhances the quality of service in terms of throughput, delay, and reliability especially for transmission over unreliable communication links in mobile ad hoc networks.

1.2 Vehicular Networks

Vehicular networks are an instantiation of mobile ad hoc networks. However, vehicular networks behave in different ways than conventional MANETs. Driver behavior, mobility constraints, and high speeds create unique characteristics of VANETs. These characteristics have important implications for designing decisions in these networks. They accentuate the research challenges (like quality of service and scalability) comparing to traditional wireless ad hoc networks. In this context, we proposed innovative solutions at different OSI layers (network and link layers) to cope with some of these challenges. We summarize them in the following

Traffic Density Estimation in Vehicular Networks: Temporary disconnection in vehicular network is unavoidable. It is thereby of imminent practical interest to consider the vehicular traffic density. Therefore, at first, we proposed IFTIS a completely distributed and infrastructure–free mechanism for city road density estimation. In fact, the existing centralized approaches for traffic estimation are characterized by important response times. They are also subject to high processing requirements and possess high deployment costs. IFTIS is based on the distributed exchange and maintenance of traffic information between vehicles traversing the routes. The performance analysis of the proposed mechanism shows the accuracy of the algorithm for different traffic densities. The proposed mechanism is suitable for being a critical metric for determining vehicular data routing paths or may also be adopted for use in a real-time traffic congestion warning system.

Routing in Vehicular Networks: Based on such traffic information system, we proposed a novel intersection-based geographical routing protocol GyTAR (improved Greedy Traffic Aware Routing protocol), capable to find robust and optimal routes within urban environments. GyTAR handles efficiently rapid topology changes and frequent network fragmentation. In fact, current MANET routing protocols fail to fully address these specific needs especially in city environments (nodes distribution, constrained but highly mobility patterns, signal transmissions blocked by obstacles, etc.). GyTAR consists of two modules: (i) dynamic selection of the junctions through which a packet must pass to reach its destination, and (ii) an improved greedy strategy used to forward packets between two junctions. GyTAR enhances the quality of service and performs other routing protocols in terms of packet delivery ratio, end-to-end delay, and routing overhead.

Characterizing Multi-hop Communication in Vehicular Networks: In parallel to that we showed, using extensive real experimentations, the feasibility of multi-hop communication based on the IEEE 802.11 technology for different scenarios (crossing, following, etc.). We confirm the feasibility of using multi hop routing to extend the transmission range of the infrastructure and the connection time for cars in motion. We also found that distance and line of sight communication are the two main factors affecting the network communication.

Data Dissemination in Vehicular Networks: In order to help the efficient support of dissemination-based applications, a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI) was proposed, which can be deployed in intersections with an acceptable level of vehicular density. The GVI is emulated by a bounded-size subset of vehicles currently populating the intersection region where the virtual infrastructure is to be deployed. This is realized in an attempt to both approaching the performance of a real infrastructure while avoiding the cost of installing it. GVI consists on electing vehicles that will perpetuate information broadcasting within an intersection area. This mechanism can be used to keep information alive around an intersection area (nearby accident warnings, traffic congestion, road works, advertisements and announcements, available parking lot at a parking place, etc.). GVI mechanism periodically disseminate the data within an intersection area, enhances the quality of service by efficiently utilizing the limited bandwidth and ensuring high delivery ratio.

Vehicular Networks Connectivity: Connectivity is of major importance especially for routing protocols. In vehicular networks the cars are constrained in a topology limited by the geometry of the road compared to the two dimensional topology of mobile ad hoc networks. This constraint limits the connectivity of vehicular networks since a multi-hop route may exist between two cars only if there are cars in the space between them whereas in MANET other routes may exist. A network is said to be fully connected if there exists a route between any two cars in the network regardless of the number of intermediate hops. We investigated the issue of connectivity in vehicular networks within: (i) multi-lane highways and (ii) roads in inner city with turns, junctions and roundabouts. We show that road topology affects clearly the probability of full connectivity and that there is a need of infrastructure in order to provide services with acceptable quality in vehicular networks.

Medium Access Control in Vehicular Networks: Similar to ad hoc networks, multi-hop vehicular communication represent a major challenge on the reliability of communication. Consequently, efficient MAC (Medium Access Control) protocols need to be in place, while adapting to the highly dynamic environment of vehicular networks, and considering messages priority of some applications (ex, accidents warnings). We proposed a new MAC protocol for VANET known as SOFT MAC. The protocol divides the roads into cells and allocates each cell a group of subcarriers. Within the cell, the nodes share the available subcarriers using a combined TDMA/CSMA protocol. Compared to 802.11p basic access, SOFT MAC enhances the quality of service and shows improvement in throughput.

2. Document organization

The remainder of this document is organized as follows. Chapter 2 focuses on our contributions related to the conventional multi hop ad hoc networks. Chapter 3 is dedicated to our contributions related to the challenging vehicular networks. Chapter 4 summarizes our conclusions and details our main perspectives.

Chapter 2

Wireless Ad hoc Networks

1. Research Context

An ad hoc network is a multi hop radio packet network composed of a set of nodes which form in a spontaneous way a network able to convey, gradually, data packets through radio interfaces. Such networks do not require any kind of fixed infrastructure or centralized administration. However, the use of an infrastructure can be considered and is sometimes necessary to ensure a minimal connectivity in the network and/or to offer an interconnection with external networks like the Internet.

Originally, ad hoc networks appeared to meet military needs during the seventies for the instantaneous deployment of communication networks between mobile terminals. Thanks to its original and entirely distributed architecture, this technology is currently arousing the interest of the various universities and industrial laboratories throughout the world (HP, Hitachi, Nokia, etc.) and standardization working groups (IETF MANET). This technology is also candidate in more static environments, such as wireless mesh networks (WMNs) and wireless sensor networks (WSNs). Typically, a WMN comprises static wireless mesh routers, also called access points (APs). Each AP serves multiple mobile users and connects them through multi-hop wireless routing to the wired network. The mesh nodes connected directly to the wired network are called gateways. As opposed to ad hoc networks, WMNs have a stable topology, which changes occasionally due to AP failures or when new APs are added to the system. A wireless sensor network can be viewed as a particular case of wireless ad hoc networks, where designers have to cope with the limited power and processing capacities of the sensor nodes. Despite these limitations, the growing capabilities of these tiny motes, which consist of sensing, data processing, and communicating, enable the deployment of reliable WSNs based on the cooperative effort of a large number of sensor nodes. In contrast to the traditional networks that aim to achieve high QoS levels, sensor network protocols focus primarily on power conservation, because of the limited capacity of the sensor nodes' batteries.

The facility of deployment, the possibility of capacity addition without preliminary planning and its low cost, the consideration of the mobility in an intrinsic manner to the ad hoc routing are major assets in favor of ad hoc networks. We can quote the following advantages of such a solution: (i) Extensibility and easiness of deployment: All the tasks of management done in a traditional network by a centralized entity are in an ad hoc network shared between nodes in an entirely distributed way. These properties allow the introduction of new terminals and in consequence the addition of capacity without preliminary planning. Moreover, no configuration is necessary for the terminal to have access to the network, only a suitable routing protocol is needed; and (ii) Reduced deployment cost: In an ad hoc network the presence of a centralized infrastructure is not essential. Another advantage of the solution is the network resource sharing. Indeed, terminal resources are shared in order to convey data from other users and for the tasks of network management.

2. Main Challenges

Regardless of the attractive applications, the features of wireless ad hoc networks introduce several challenges that must be studied carefully before a wide commercial deployment can be expected. Among them, we can quote the following:

– *Routing*: in a dynamic environment, routing is a difficult task. We must indeed manage the mobility of nodes acting as routers in a transparent way to the users. Two strategies could be adopted to achieve this aim: proactive where paths are continuously computed in the whole network. Or reactive where paths are calculated only at the request of the applications. Some protocols are standardized by the MANET working group in IETF like OLSR (Optimized Link State Routing) and AODV (Ad hoc On demand Distance Vector). Nevertheless, an extension of these protocols remains essential to achieve advanced functionalities like QoS, security, etc. Multicast routing is another challenge because the multicast tree is no longer static due to the random movement of nodes within the network,

– *Quality of service*: ad hoc networks by their dynamic character let appear new problems for the introduction of QoS solutions, which can be summarized in what follows:
  - Unpredictable links: predicting the capacity of the wireless medium is indeed a difficult task in particular in an ad hoc network. Signal propagation must deal with the fast attenuation and interferences. More especially, packet collision is an inevitable phenomenon in such networks. All these properties make that resources measurements such as bandwidth and delay on a given link are difficult or even impossible,
  - Resource limitation: mobile equipments generally work on limited resources, in particular energy and bandwidth. A reliable QoS architecture must thus include mechanisms for energy and bandwidth management,
  - Routing: in such an environment, a QoS-aware routing protocol requires a resource reservation at intermediate nodes. However, with a dynamic topology, these nodes can move, and new routes will appear. Thus, the maintenance of the reservation as well as the update of the routes become real problems,

– *Security and Reliability*. In addition to the common vulnerabilities of wireless connection, an ad hoc network has its particular security issues due to e.g. nasty neighbor relaying packets. In addition to the injection of the malicious traffic, the modification of the control traffic by hackers can put in danger the entire network. The feature of distributed operation requires different schemes of authentication and key management. Further, wireless link characteristics introduce also reliability problems, because of the limited wireless transmission range, the broadcast nature of the wireless medium (e.g. hidden terminal problem), mobility-induced packet losses, and data transmission errors,

- *The fair resource sharing*: the philosophy of pure ad hoc networking imposes a sharing of resources of each terminal on the profit of the other users. If this concept seems well-established within pure ad hoc networks used by communities sharing common interests (military, first-aid workers...), it must be encouraged between anonymous users. Certain research tasks thus aim at the same time founding confidence and at rewarding this solidarity by modulating the use of the total resources according to the contribution in the tasks of network management (rate of resource sharing) for a given node,

- *Internetworking*: In addition to the communication within an ad hoc network, internetworking between MANET and fixed networks (mainly IP based) is often expected in many cases. The coexistence of routing protocols in such a mobile device is a challenge for the harmonious mobility management,

- *Power Consumption*: For most of the light-weight mobile terminals, the communication-related functions should be optimized for lean power consumption. Conservation of power and power-aware routing must be taken into consideration,

- *Scalability*: routing protocols using a flat vision of the network have more or less acceptable performances in networks with small and middle size. However, this type of solutions is not scalable. Indeed, when the size of the ad hoc network reaches a certain threshold, the generated overhead decreases the dynamic capacity of reconfiguration of the network as well as the bandwidth offered to the applications. To deal with this limitation, hierarchical routing constitutes a good compromise to set up effective solutions which are robust and scalable.

Technologically, many different aspects of wireless ad hoc networks still need ideas and results from research. In this context, proposing innovative solutions to cope with some of these challenges constitutes an important part of our work. Our contributions are positioned at different OSI layers (transport, network and link layers). Some of our selected research aspects will be presented in the following section.

3. TCP within Wireless Multi-hop Networks

3.1 Research Context

Most of the applications are designed to be compatible with TCP. This makes TCP the most famous protocol in the TCP/IP protocol stack with more than 90% of the Internet traffic today. TCP was developed and optimized for wired infrastructure networks. Its congestion control algorithm and the data flow mechanism it employs makes it performing well in such networks. Through controlling the number of data packets transmitted over the connection and taking into consideration the advertised data to be received at the receiver side, TCP has the ability to manage the utilization of the available bandwidth. The success of TCP within the wired networks, in addition to the wide variety of applications that are compatible with it, made TCP the first transport protocol to be used within almost all the deployed data networks.

Taking into consideration the differences between wired and wireless (infrastructure and light-infrastructure) data networks, we expect that TCP performance would differ when applied within each of them. Many researches [1][2][3] were done recently to help understand the performance of TCP within wireless cellular and wireless ad hoc networks. These researches reveal the problems that can be found within wireless networks and do not exist within wired ones, such as wireless channel errors and link failure problems. These problems represent new challenges to TCP since it was not originally developed to deal with underlying issues. In fact, TCP was developed to solve the problem of data packet loss due to congestion within network, and originally is a congestion-control-oriented protocol. This was logical since the main cause of data packet losses within wired network is congestion. On the other hand, within wireless (infrastructure and light-infrastructure) networks, there are many other causes of data packet losses. Indeed, wireless ad hoc networks represent a highly challenging environment for TCP as it suffers from new causes of data packet losses that TCP was not designed to deal with. Actually, TCP underperforms drastically within wireless ad hoc networks. The researches done recently [4] show that the performance of TCP is highly impacted when used within wireless ad hoc networks, since, again, it was not designed to cope with wireless networks data packet loss causes. Therefore, it was our conclusion that TCP should be able to:

1- Distinguish and cope with different data packet loss models over the connection,

2- Recover from data packet losses in such a way to enhance its performance over such networks.

These TCP enhancements are among our major contributions. Our final objective was to present a new variant of TCP that is most adapted to the nature of wireless ad hoc networks and their most common data packet loss causes.

3.2 Contributions

As a first step, we carried out a complete study in order to evaluate both throughput and energy consumption (communication energy consumption and computational energy consumption) of the existing TCP variants and their congestion control mechanisms (Slow-Start, Fast Retransmit/Fast Recovery, and Congestion Avoidance). This study was conducted in order to evaluate the performance of TCP in detail when confronted with different data packet loss situations within wireless ad hoc environments. The new TCP variant was developed according to the conclusions gained from this performance study. In fact, the problem of TCP within wireless ad hoc networks comes from its inability to distinguish between the different data packet loss models within the network. This often leads to an aggressive reaction from TCP when faced with a data packet loss that is not due to congestion. Indeed, dealing with any data packet loss as if it were due to congestion results in resource waste both at the network and nodes' levels. This waste is represented by low bandwidth utilization and high energy consumption. Therefore, in order to enhance the performance of TCP within wireless ad hoc networks, it is obvious that TCP should be able to identify each data packet loss cause and react accordingly, triggering the most suitable loss recovery action that optimizes both the network and node's resources.

Hence, and as a second step we proposed TCP-WELCOME, which stands for "*TCP variant for Wireless Environment, Link-losses and COngestion packet loss ModEls*", a new TCP variant for wireless ad hoc networks. TCP-WELCOME is able to distinguish among and recover from the following data packet loss situations that we identified: (i) link failure, (ii) wireless channel related errors, and (iii) congestion. It includes a Loss Differentiation Algorithm (LDA) that is able to distinguish among the above mentioned data packet loss situations, and a Loss Recovery Algorithm (LRA) that is capable to recover from each of these different data packet loss situations. TCP-WELCOME is developed with the aim to optimize TCP performance: maximizing the utilization of the available bandwidth (throughput), while minimizing the nodes overall (communication and computational) energy consumption.

The main idea of TCP-WELCOME is based on coupling loss and delay over the connection in order to classify the cause of data packet losses and then reacting properly to recover from that loss as shown in the next figure.

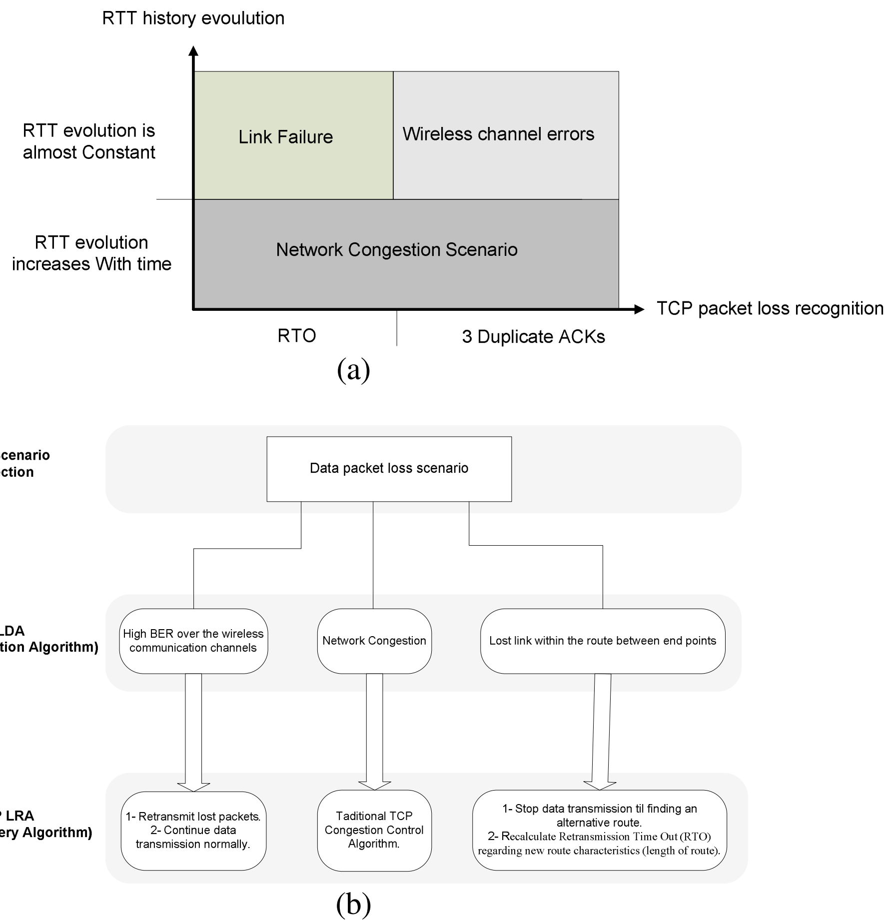


Figure 2.1. TCP Proposed (a) LDA and (b) LRA Algorithms.

3.3 Summary of Results

To conclude, we can summarize our first contribution in the context of ad hoc networks as follows. We proposed TCP-WELCOME, a new TCP variant that is suitable for wireless mobile ad hoc network environments. Unlike other TCP variants, it uses a Loss Differentiation Algorithm (LDA) that is able to identify accurately the three common data packet loss causes within such network: network congestion, wireless channel errors, and link losses. Moreover, TCP-WELCOME adopts a new Loss Recovery Algorithm (LRA) that reacts efficiently to each identified data packet loss cause with the most appropriate action.

In order to show the performance improvement of TCP-WELCOME we implemented it into both Linux Kernel and the Network Simulator NS-2. We compared its performance to different TCP variants under different data packet loss scenarios (congestion, interference, link failure, and signal loss). This comparative study showed that both TCP average throughput and total energy consumption have been significantly improved. We also showed that TCP-WELCOME outperformed other TCP variants in most cases thanks to its ability to identify correctly the type of data packet loss through its loss differentiation algorithm and to take the most appropriate reaction to recover from data losses (loss recovery algorithm).

This work was the focus of a PhD dissertation carried out by Alaa Seddik-Ghaleb, University of Evry, and defended in 30 March 2009 (see papers [P31][P35][P48][P50][P51]).

4. Self-Organization in Large Scale Wireless Ad hoc Networks

4.1 Research Context

As defined before, light infrastructure networks are systems where many devices communicate with one another in an ad hoc fashion over multiple hops, most often wirelessly. For a large set of devices of various origins to build a network and communicate efficiently, some form of organization has to take place. The term "*Self-organization*" is described as the emergence of system-wide adaptive structure and functionality from simple local interactions between individual entities.

For LIN, we believe that a model by which central server collects information about all nodes and links, computes "The Organization" and feeds back all nodes with their new state, is a bad one for several reasons. First, the network scalability and reliability would be compromised by the bottleneck effect and single point of failure mode of the central server. Second, we expect that reacting to a mere local variation of operating conditions by transferring the information from the nodes to the central server and back from the server to the nodes, would be a bad utilization of resources. To best overcome the limitations listed for the centralized model above, self-organization should be truly distributed among all the nodes, and should only make use of local information. The functions that self-organization must accomplish in such networks [17] are: (i) resource sharing and management, (ii) structure formation and maintenance, and (iii) helping the deployment of communication protocols.

A wireless network needs organization at various levels. Medium access control through channelization of the medium and channel allocation to nodes, for example, is an organization process of layer 2. At layer 3, the routing protocol must be able to uncover multi-hop routes by using other intermediate nodes to relay the messages. This vast area is wide open to research. We focused in our work on layer 3 organization only.

The aims of layer 3 organization for large scale wireless multi-hop networks should be: a) minimize the need for manual configuration, b) avoid centralized solutions and node specialization in favor of distributed and peer-to-peer solutions, and c) localize control traffic overhead. One of the most important components of the network layer is the routing protocol. The current ad hoc routing protocols and architectures work well only up to a few hundred nodes. Most of the current research in ad hoc routing protocols focuses more on performance and power consumption related issues in relatively small networks, and less on scalability. The main reason behind the lack of scalability is that these protocols rely on flat and static addressing. With scalability as a partial goal, some efforts have been made in the direction of hierarchical routing and clustering [18]-[20]. These approaches are promising, but they do not seem to be actively pursued. Moreover it appears to us as if these protocols would work well in scenarios with group mobility [21], which is also a common assumption among cluster based routing protocols.

4.2 Contributions

In this work, we presented PARTY, a new network layer for large scale wireless multi-hop networks. PARTY is decentralized, scalable, and independent of IP-like addressing limitations. Each node has its own universal identifier (we can use as an identifier, the node's IP address or its MAC address) and is assigned a temporary address according to its relative location in the network. Nodes change addresses as they move, so that their addresses have a topological meaning. A tree-like logical topology is created, which describes the relative location of the nodes according to their neighborhood in the physical network.

This new addressing structure eases the routing in such networks. The routing strategy provided by PARTY is a distributed one, where the forwarding process is done hop by hop in a way that resembles to the forwarding process in Pastry Peer-to Peer protocol [23].

This protocol is composed of four major algorithms, *address allocation algorithm*, *routing algorithm*, *registration algorithm* and *lookup algorithm*. The basic operation of PARTY is as follows: In PARTY each node has a globally know and unique identifier and dynamically assigned a unique address which changes with node movement to reflect node's location in the network, this address is used to simplify routing in the network. Since the address of the node changes with node movement, we need a lookup service which will provide the address of a given node identifier. Before sending its first packet to some destination, the sender looks up the current address of the destination node using the lookup service. The routing is done in a way similar to the one done in Pastry [23] one hop at a time, where each node forwards the message to its immediate neighbor who gets the message as close as possible to the destination. If the destination cannot be reached, the lookup table is consulted along the way to find the new address of the destination.

We have to mention here that PARTY is not an overlay network protocol, where nodes communicate in an application level fashion, like Pastry [23]. Instead, PARTY operates at the network level and is completely independent of a global connectivity ensured by a network-level routing protocol. PARTY creates a topology which is a virtual network representation, where nodes are identified by their neighborhood in the physical network.

4.3 Summary of Results

To conclude, we can summarize our second contribution in the context of ad hoc networks as follows. We proposed a novel network layer called "PARTY", which could be used as a standalone layer or as a layer under the existing IP layer in large scale multi hop networks. PARTY proposes an addressing structure and allocation that ease routing in such networks.

A small amount of information suffices to implement PARTY routing; low signaling overhead is generated due to only local neighborhood communication, the routing table size is $O(q)$, where q is the number of immediate neighbors of the node. Moreover, a node movement does not affect Party's address tree organization, i.e., it does not require the assignment of new addresses to other nodes already present in the network. PARTY is an innovative and promising approach for spontaneous networks with low dynamic topology changes.

The analytical and simulation studies achieved in this work confirmed the benefits of the protocol. Namely they showed that PARTY performs better than the current legacy ad hoc protocols, where it reduces considerably the traffic overhead and provides seamless communications.

This work was the focus of a PhD dissertation carried out by Ghazi Al-Sukkar, Telecom SudParis, defended in November, 26th, 2008 (see papers [P44][P45][P49]).

5. Cooperative Relaying in Multi-hop Ad hoc Networks

5.1 Research Context

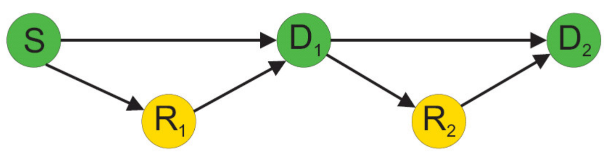
Mobile radio communications suffer from large-scale and small-scale fading effects that attenuate the communication signal. While large-scale fading is caused by a distance-dependent path loss and shadowing effects, small-scale fading is caused by multipath propagation. For mobile receivers or transmitters, small-scale fading can cause rapid fluctuations of the received signal-to-noise ratio (SNR); if a mobile device moves only a small distance, it may experience deep fading, even if it had perfect signal reception just an instant before. Cooperative relaying [5] is a concept, where a relay node assists the communication between two nodes when the direct link is affected by small scale fading. The information is relayed via a spatially different path which is likely not affected by the same fading effects as the direct link at the same time. Thus, using such a relay communication channel can improve the network capacity by implementing spatial diversity for the communication paths [6]. Cooperative diversity is expected to be more beneficial, if the cooperative relaying protocol is designed according to the following: First, it should have a low overhead. A large number of communication attempts are expected to succeed without the need for alternative communication paths. Thus, in the case of a successful transmission, a cooperative relaying protocol should have minimal overhead in comparison to non-cooperative transmission schemes. Second, the protocol should exploit cooperative diversity to an extent that makes the effort for the more complex interaction between wireless nodes worth it. Finally, the protocol should be implementable with state-of-the-art hardware.

During the past years, the research focus has been predominantly on physical layer aspects and information theoretical bounds. Recently, protocol and system aspects of cooperative relaying have started to be investigated [7]-[14]. The interplay of cooperative relaying and layers above the Medium Access Control (MAC) layer and also potential synergies of combining cooperative relaying tasks with tasks of upper layers have not yet been intensively addressed. We investigated the benefits of exploiting routing information in cooperative relaying. We call such a scheme Multi-Hop-Aware Cooperative Relaying (MHA-Coop-Relaying).

5.2 Contributions

We addressed the drawbacks of cooperative relaying regarding its spectral inefficiency and its channel over reservation compared to direct transmissions. We proposed a cross-layer solution that exploits routing information in cooperative relaying to reduce these disadvantages. We presented a complete system design of Multi-Hop-Aware Cooperative Relaying and investigated different relay selection policies for it.

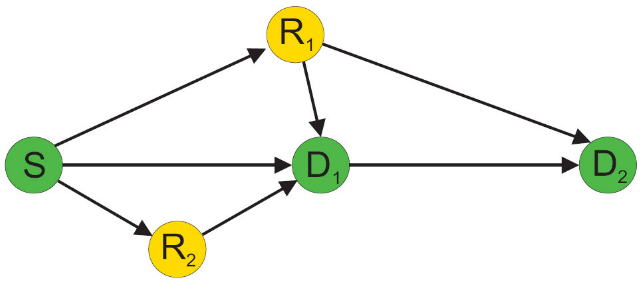
Let us explain the basic idea of our contribution. In the example depicted in next figure, R_1 and R_2 support the transmission from S to D_1 and from D_1 to D_2, respectively. Cooperation is performed in a hop-by-hop manner to enhance the reliability of each individual link – cooperation between



multiple hops is not exploited. We denote such schemes in the sequel as *hop-by-hop cooperative relaying*.

Selection of cooperative relays and overhearing direct transmissions consume time and energy. Furthermore, the wireless channel needs to be reserved for both the direct and the cooperative transmission phase. Nevertheless, the necessity of cooperation is a random process that depends on the instantaneous CSI (Channel State Information). Thus, whenever the direct transmission succeeds, energy and time invested for cooperation is spent without any benefit. The channel utilization is also decreased, since the medium was reserved for the duration of the complete cooperative process and cannot be used by other terminals – we call this situation *over-reservation*. Given that the overall task is to deliver messages to a final destination and not to an intermediate node, hop-by-hop cooperative relaying suffers from its limited perspective.

We proposed a different approach of cooperative relaying which exploits routing information. The next figure depicts a sub-path of a route. Node S has to forward the message to the next hop identified by D_1. D_2 is in a two hop distance of S. R_1 is in transmission range of S, D_1 and D_2. We call R_1 a *multi-hop relay*. R_2 is just in transmission range of D_1 and D_2 and is thus denoted as *single-hop relay*. A multi-hop aware relay delivers also information to D_2 during the cooperative transmission phase. This information can be used as some kind of incremental redundancy [15][16] in a following cooperation process initiated by D_1. Multi-hop relays should forward the received messages regardless of the direct transmission success. D_2 may already receive the message correctly from the relay making a later transmission from D_1 unnecessary. Whenever the message being routed reaches D_2 during a cooperation process initiated by S a *two-hop-progress* is achieved. The fact that multi-hop relays always transmit the overheard data avoids over-reservations and improves channel utilization. MHA-Coop-Relaying utilizes time, energy, and bandwidth spent for the cooperation process more efficiently than hop-by-hop cooperative relaying.



5.3 Summary of Results

To conclude, we can summarize our third contribution in the context of ad hoc networks as follows. We proposed MHA-Coop-Relaying which exploits synergy effects between cooperative relaying and message routing in wireless ad hoc networks. Relays are selected by taking route information into account, so that they are in transmission range of three consecutive hops of a routed message. We discuss via simulations three different relay selection policies and showed that all of them outperform hop-by-hop cooperative relaying in terms of throughput and outage probability (an outage occurs whenever a retransmission of a packet from the source is necessary).

This work was the focus of a PhD dissertation carried out by Helmut Adam, University of Klagenfurt, and will be defended in 2010 (see paper [P34]).

6. MAC-Protocol for Cooperative Relaying in Ad hoc Wireless Networks

6.1 Research Context

As stated in the last section, the concept of cooperative relaying promises gains in robustness and energy-efficiency in wireless networks. Cooperative relaying can be divided into three main phases: direct transmission, relay selection, and cooperative transmission. In the *direct transmission* phase the source transmits its data, whereas destination and relay (or potential relays) try to receive it. In the *relay selection* phase a neighboring node of source and destination is selected. The *cooperative transmission* phase, where the relay forwards the data to the destination, occurs only if the destination has failed to retrieve the data from the source during the direct transmission. Relay selection is a distributed task which requires time and energy and thus introduces additional overhead. Thus, it is beneficial to explore the current realization of the channel between source and destination and to do relay selection only on demand [14]. Relay selection can be done before direct transmission (proactive relay selection) or after direct transmission (reactive relay selection). Proactive relay selection is considered to have energy advantages over reactive relay selection since only the selected relay needs to spend energy for listening to the transmission of the source [11]. However, it introduces a constant overhead to all transmissions. Reactive relay selection is only done if a direct transmission fails and relaying candidates have already received the original data from the source properly. A disadvantage is that all potential relaying nodes need to listen to the transmission of the source.

MAC changes considerably in the presence of cooperative relaying. In non-cooperative schemes, the wireless medium is reserved just in the neighborhood of source and destination for the time of the direct transmission and the acknowledgment. In cooperative relaying, however, the channel reservation needs to be extended in space and time for the relaying. This leads to reduction of the spatial re-usability of the network since the channel reservations for the relay might interfere or block other communications which otherwise could be done concurrently if the relay is not used. Furthermore, in proactive relay selection, relays are selected and the channel floor for them is reserved before direct transmissions. Whenever the direct transmission succeeds, those reservations block other communications and degrade the overall throughput.

The motivation for our protocol is that relaying is not always needed. Thus, we tried to minimize the introduced overhead due to cooperative relaying. The new MAC protocol should behave as standard non-cooperative protocols in the absence of link errors on the direct link in terms of throughput (reactive relay selection).

6.2 Contributions

We proposed a novel Cooperative Relaying Medium Access protocol (CoRe-MAC) for wireless networks which extends the standard Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA) protocol. The objective is to increase reliability and throughput of the communication if the Signal-to-Noise-Ratio (SNR) over the direct link between source and destination is below an acceptable level, while avoiding overhead to the communication if the direct transmission is successful. To this end, in the proposed protocol a reactive (on demand) relay selection is invoked only in case of transmission failures.

Our protocol also addresses the highly energy consumption of reactive schemes by determining whether cooperation can be used or not before direct transmission and by limiting the number of nodes listening to the data transmission between source and destination (Only nodes which can provide an overall PER –Packet Error Rate- from source to the destination which is smaller than the PER of the direct channel should be considered and should consume energy overhearing the direct transmission).

6.3 Summary of Results

To conclude, we can summarize our last but not least contribution in the context of ad hoc networks as follows. We proposed CoRe-MAC, a MAC protocol for cooperative relaying built on IEEE 802.11 mechanisms. Special importance was attached to make the protocol feasible on state-of-the-art systems and to evaluate its performance under realistic assumptions. We discussed via simulations the efficiency of such a protocol for packet error rate, throughput, and message delay in a multi-hop ad hoc network.

The protocol extends the IEEE 802.11 mechanisms for handling transmission failures by space/time diverse channels. In the case the direct transmission is successful, our protocol comes with no additional overhead for the relay selection. Thus, for good SNR between source and destination CoRe-MAC has similar performance as the standard CSMA/CA approach. In the case of a transmission failure, e.g., due to small scale fading, our approach supports transmission via a different communication path implementing spatial diversity via a selected relay. Thus, especially for transmission over unreliable communication links, the throughput, the delay, and reliability of wireless communication can be improved. We plan to implement and evaluate the protocol on a hardware testbed, consisting of a cluster of wireless nodes.

This work was the focus of a PhD dissertation carried out by Helmut Adam, University of Klagenfurt, and will be defended in 2010 (see paper [P29]).

Chapter 3

Vehicular Networks

1. Research Context

Vehicular networks are considered as a novel class of wireless networks that have been emerged thanks to the advances in wireless technologies and automotive industry. Vehicular networks are spontaneously formed between moving vehicles equipped with wireless interfaces that could be of homogeneous or heterogeneous technologies. These networks, also known as VANETs (Vehicular Ad hoc Networks), are considered as one of the wireless ad hoc networks real-life applications enabling communications among nearby vehicles as well as between vehicles and nearby fixed equipments, usually described as roadside equipments. Vehicles can be either private, belonging to individuals or private companies, or public transportation means (e.g., buses, and public services vehicles such as police cars). Fixed equipments can belong to the government, or private network operators or service providers.

These networks are attracting considerable attention from the research community as well as the automotive industry. A high interest for these networks is also shown from governmental authorities and standardization organisms. In 1999, the U.S. Federal Communication Commission (FCC) allocated 75MHz of Dedicated Short Range Communication (DSRC) spectrum at 5.9GHz (5.850GHz-5.925GHz) to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle communications in North America. The DSRC spectrum is divided into seven 10MHz wide channels. Channel 5885MHz-5895MHz is the control channel, which is generally restricted to safety communications only. The two channels at the edges of the spectrum are reserved for future advanced accident avoidance applications and high powered public safety usages. The rest are service channels and are available for both safety and non-safety usage. On the other hand, in Japan, the allocated frequency bands, namely for DSRC, range from 5.770GHz to 5.850GHz. In Europe, one obstacle to introduce VANETs for road safety was the lack of a dedicated frequency spectrum. Compared to North America and Japan, the process for frequency allocation is considerably complex and time consuming since all European countries and their national authorities are involved. A decision by the European Commission to designate the spectrum has been carried out and the spectrum has been allocated on middle of 2008 and is in its way for implementation by the EU countries. Eventually, the frequency bands 5875–5905MHz for road safety, additional 20MHz above this band as future extension, and 5855–5875MHz for non-safety will be available. The allocated frequency of

50MHz and the additional 20MHz are similar to the 75MHz ITS band in North America. On the other hand, the Car-to-Car Communication Consortium (C2CC, http://www.car-to-car.org) has been initiated in Europe by car manufacturers and automotive OEMs (Original Equipments Manufacturers), with the main objective of increasing road traffic safety and efficiency by means of inter-vehicle communication. IEEE is also advancing within the IEEE 1609 family of standards for Wireless Access in Vehicular Environments (WAVE). The DSRC radio technology is essentially IEEE 802.11a adjusted for low overhead operations in the DSRC spectrum and it is being standardized as IEEE 802.11p. The overall DSRC communication stack between the link layer and applications is being standardized by the IEEE1609 working group. There are also other international committees defining architectures and standards for vehicular communication, namely ISO TC 204 (CALM, http://www.tc204wg16.de) and the newly formed ETSI TC ITS (http://www.etsi.org/).

Vehicular networks can be deployed by network operators, service providers or through integration between operators, providers and a governmental authority. The recent advances in wireless technologies and the current and advancing trends in ad hoc networks scenarios allow a number of deployment architectures for vehicular networks, in highways, rural, and city environments. Such architectures should allow the communication among nearby vehicles and between vehicles and nearby fixed roadside equipments. Three alternatives include: i) a pure wireless Vehicle-to-Vehicle ad hoc network (V2V) allowing standalone vehicular communication with no infrastructure support, ii) an Infrastructure-to-Vehicle or Vehicle-to-Infrastructure (I2V, V2I) architecture with wired backbone and wireless last hops, iii) and a hybrid architecture that does not rely on a fixed infrastructure in a constant manner, but can exploit it for improved performance and service access when it is available. In this latter case, vehicles can communicate with the infrastructure either in a single hop or multi-hop fashion according to the vehicles' positions with respect to the point of attachment with the infrastructure.

Vehicular networks applications ranges from road safety applications oriented to the vehicle or to the driver, to entertainment and commercial applications for passengers, making use of a plethora of cooperating technologies. The primary vision of vehicular networks includes real-time and safety applications for drivers and passengers, allowing for these latter safety and giving essential tools to decide the best path along the way. These applications thus aim to minimize accidents and improve traffic conditions through providing drivers and passengers with useful information including collision warnings, road sign alarms and in-place traffic view. Nowadays, vehicular networks are promising in a number of useful drivers and passengers oriented services, which include Internet connections facility exploiting an available infrastructure in an "on-demand" fashion, electronic tolling system, and a variety of multimedia services.

Vehicular networks have special behavior and characteristics, distinguishing them from other types of mobile networks. In comparison to other communication networks, vehicular networks come with unique attractive features, as follows:

- *Unlimited transmission power*: Mobile devices power issues are usually not a significant constraint in vehicular networks as in the case of classical ad hoc or sensor networks, since the node (vehicle) itself can provide continuous power to computing and communication devices,
- *High computational capability*: Indeed, operating vehicles can afford significant computing, communication and sensing capabilities,

- *Predictable mobility*: Unlike classical mobile ad hoc networks, where it is hard to predict the nodes' mobility, vehicles can have very predictable movement that is (usually) limited to roadways. Roadway information is often available from positioning systems and map-based technologies such as GPS. Given the average speed, current speed, and road trajectory, the future position of a vehicle can be predicted.

However, to bring its potency to fruition, vehicular networks have to cope with some challenging characteristics [24] that include:

- *Potentially large scale*: As stated in the last section, most ad hoc networks studied in the literature usually assume a limited network size. However, vehicular networks can in principle extend over the entire road network and include so many participants,

- *High mobility*: The environment in which vehicular networks operate is extremely dynamic, and includes extreme configurations: in highways, relative speed of up to 300 km/h may occur, while density of nodes may be 1-2 vehicles per kilometer in low busy roads. On the other hand, in city, relative speed can reach up to 60 km/h and nodes' density can be so high, especially in rush hours,

- *Partitioned network*: Vehicular networks will be frequently partitioned. The dynamic nature of traffic and a low penetration of the technology may result in large inter-vehicle gaps in sparsely populated scenarios, and hence in several isolated clusters of nodes,

- *Network topology and connectivity*: Vehicular networks scenarios are very different from classical ad hoc networks ones. Since vehicles are moving and changing their position constantly, scenarios are very dynamic. Therefore the network topology changes frequently as the links between nodes connect and disconnect very often. Indeed, the degree to which the network is connected is highly dependent on two factors: the range of wireless links and the fraction of participant vehicles, where only a fraction of vehicles on the road could be equipped with wireless interfaces.

2. Main Challenges

Vehicular networks' special behavior and characteristics create some challenges for vehicular communication, which can greatly impact the future deployment of these networks. A number of technical challenges need to be resolved in order to deploy vehicular networks and to provide useful services for drivers and passengers in these networks. Generally speaking, scalability and interoperability are two important issues that should be satisfied, and the employed protocols and mechanisms should be scalable to a numerous number of vehicles, and interoperable with different wireless technologies. The following subsections discuss a number of these challenges where some ones are in common with conventional ad hoc networks but are more accentuated for vehicular networks:

- *Quality of service*: Applications envisioned for vehicular networks require fast association and low communication latency between communicating vehicles in order to guarantee: (i) service's reliability for safety-related applications while taking into consideration the time-sensitivity during messages' transfer, and (ii) the quality and continuity of service for passenger's oriented applications,

- *Security*: Security is a crucial aspect in vehicular networks in order to become a reliable and accepted system bringing safety on public roads. Vehicular communication and its services will only be a success and accepted by the customers if a high level of reliability and security can be provided. This includes authenticity, message integrity and source authentication, privacy, and robustness,

- *Applications distribution*: From a general view, we can notice that building distributed applications involving passengers in different vehicles requires new distributed algorithms. As a consequence, a distributed algorithmic layer is required for managing the group of participants, and ensuring data sharing among distributed programs. Such algorithms could assimilate the neighborhood instability to a kind of fault. However, the lack of communication reliability necessitates employing fault tolerant techniques,

- *IP configuration and mobility management*: The potential vehicle-to-infrastructure architecture is promising in allowing vehicular Internet access as well as provision of Internet-related services to drivers and passengers. However, two technical challenges exist under this issue: IP address configuration and mobility management. These challenges can threaten the services' quality and precisely the services' continuity. Regarding the vehicular networks characteristics, IP address configuration should be carried out in an automatic and distributed manner. So far, there is no standard for IP auto-configuration in ad hoc networks, and hence the problem becomes complex for vehicular networks. We notice a considerable work in progress by a number of standardization bodies aiming to resolve this problem. Besides the IETF efforts through the Autoconf WG for developing IPv6 solutions for ad hoc networks including vehicular networks scenarios. As for mobility management, this is a crucial problem for non-safety applications, where messages dissemination is not broadcast based. Indeed, the absence of mobility management mechanisms threatens services commercialization in vehicular networks, and loses the benefit of the vehicle-to-infrastructure architecture since all Internet related services would guarantee neither services' quality nor their continuity,

- *Business models*: Business models represent an important challenge for services' commercialization in vehicular networks. As a matter of opening a new business opportunity, business models should be rentable for telecom operators and service providers aiming to promoting services and attracting clients. It is also important that business models be affordable and attractive to clients, taking into account the cooperation between mobile clients in vehicular networks, where nodes can be compensated (rewarded) according to their participation.

Technologically, many different aspects of vehicular networks still need ideas and results from research. In this context, proposing innovative solutions to cope with some of these challenges constitutes an important part of our work. Our contributions concern network and link layers and they include: routing protocols, efficient data dissemination protocols, fair and scalable medium access (MAC) schemes, high performance and efficient physical layer transmission schemes, to name the most critical ones. Some of our selected research aspects will be presented in the following sections.

3. Traffic Density Estimation

3.1 Research Context

One of the most important components of the Intelligent Transportation System (ITS) is the road traffic information handling (monitoring, transmission, processing and communication). The existing traditional ITS traffic information systems are based on a centralized structure in which sensors and cameras along the roadside *monitor* traffic density and *transmit* the result to a central unit for further *processing*. The results will then be *communicated* to road users via broadcast service or alternatively on demand via cellular phones. The centralized approaches are dependent on fixed infrastructures which demand public investments from government agencies or other relevant operators to build, maintain, and manage such infrastructure: a large number of sensors are needed to be deployed in order to monitor the traffic situation. The traffic information service is then limited to streets where sensors are integrated. Besides, centralized designs have the disadvantage of being rigid, difficult to maintain and upgrade, require substantial computing/communications capabilities, and are susceptible to catastrophic events (sabotage or system failures). Moreover, such systems are characterized by long reaction times and thus are not useable by all the applications requiring reliable decision making based on accurate and prompt road traffic awareness.

Our objective was to provide a completely decentralized mechanism for the estimation of traffic density in city-roads. The estimated road traffic density information is useful for several ITS-related applications. Particularly, it is suitable for integration to real-time traffic congestion warning systems, leveraging on the proposed distributed mechanism that provides updated traffic information to drivers. It may also be used as a critical metric for determining optimal vehicular data routing paths in vehicular networks as will be shown later.

3.2 Contributions

We proposed a completely decentralized mechanism for the estimation of vehicular traffic density in city-roads IFTS (Infrastructure-Free Traffic Information System). The decentralized approach is based on the traffic information exchanged, updated and maintained among vehicles in the roads and revolves around the core idea of information relaying between groups of vehicles rather than individual vehicles. More precisely, the vehicles are arranged into location-based groups. For that, each road (section of street between two intersections) is dissected into small fixed area cells, each defining a group. Note that the cell size depends on the transmission range of vehicles and the coordinates of the cell center gives the cell a unique identifier. Cells, and hence groups, overlap in such a way that any vehicle moving from one cell to the next belongs at least to one group. Among vehicles within the zone leader[1], the closest vehicle to the cell center is considered as the group leader for a given duration. Note that the overlapping zone is so small that it is not possible that a vehicle is considered to be group leader of both adjacent cells.

[1] A small area around a cell center where a vehicle is elected as a group leader.

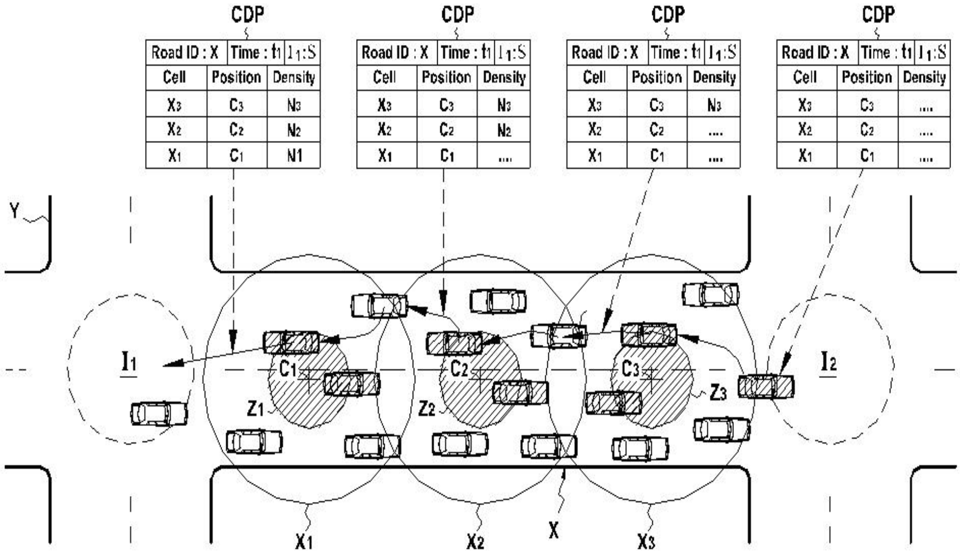


Figure 3.2. Relaying local density information between groups.

Local density information is then computed by each group leader and relayed between groups using Cell Density Packet (CDP). The CDP gathers the density[2] of a given road (i.e., all its cells). When initiating the CDP, a vehicle records the road ID, the transmission time[3] and a list of anchors through which the packet has to pass while travelling to the other intersection, and then, sends the packet in the backward direction. The CDP header includes a limited list of anchors corresponding to the position of the cells' centers. Then, the CDP is forwarded towards the first anchor on the basis of greedy forwarding. Once the message is received by a group leader (the closest vehicle to the cell center), this later updates it by including the density of the corresponding cell (the number of its neighbors) and then forwards it towards the next anchor. This is repeated until the CDP is completed while arriving to the destination intersection. After the last anchor (the destination intersection) is reached, the CDP is propagated to vehicles which are around the intersection so that all vehicles traversing through the intersection will receive it. These vehicles analyze the packet content and calculate the density for the respective road from which the CDP was received. This analysis is done by computing (i) the average number of vehicles per cell N_{avg} and (ii) the standard deviation of cells densities σ. Note that the standard deviation indicates how much variation there is away from the N_{avg}: a large standard deviation indicates that the cells densities are far from the mean and a small standard deviation indicates that they are clustered closely around the mean.

3.3 Summary of Results

To conclude, we can summarize our first contribution in the context of vehicular networks as follows. We proposed a completely distributed and infrastructure free mechanism to determine the vehicular traffic density in city environments. The distributed mechanism is a scalable mechanism that makes efficient use of the vehicles traversing the intersections to optimally manage and drive the traffic density estimation process. The performance analysis of the proposed mechanism depicted the accuracy of IFTIS and the promptness of information delivery based on delay analysis at the road traffic intersections. The analysis, conducted for

[2] By density, we mean the number of vehicles within the cell.

[3] Note that all the vehicles are synchronized by GPS.

different density values indicates that IFTIS can scale well enough to adapt to changing traffic conditions. Thanks to its distributed nature, IFTIS has various potential applications. Particularly, the proposed mechanism is suitable for being a critical metric for determining vehicular data routing paths or may also be adopted for use in a real-time traffic congestion warning system.

This work was the focus of a PhD dissertation carried out by Moez Jerbi, University of Evry, and defended in November, 06^{th}, 2008 (see papers [P8][P43]).

4. Routing in Vehicular Networks

4.1 Research Context

Vehicular networks behave in different ways than conventional mobile ad hoc networks. High-speed node movement, frequent topology change, and short connection lifetime especially with multi-hop paths create unique characteristics of vehicular networks. These characteristics degrade significantly the performance of conventional MANET routing protocols. This is due to packet control overhead (route discovery, route maintenance, etc.) caused by frequent update of routing information of the whole network, route failures, and transient nature of links.

Topology-based and position-based routing are two strategies of data forwarding commonly adopted for vehicular networks. The increasing availability of GPS equipped vehicles makes position-based routing a convenient routing strategy for these networks. However, the position-based protocols developed for MANET may not be directly applied to vehicular environments owing to the unique vehicular network characteristics [24]. Several variants of position-based concept have been proposed for data forwarding in vehicular networks [25]-[31]. Three classes of forwarding strategies can be identified for position-based routing protocols: 1) restricted directional flooding, 2) hierarchical forwarding, and 3) greedy forwarding [P8].

Most of these protocols do not take into account the vehicular traffic, which means that such algorithms may fail in case they try to forward a packet along streets where no vehicles are moving. Such streets should be considered as 'broken links' in the topology. Moreover, a packet can be received by a node that has no neighbors nearer to the receiver than the node itself. In this case, the problem of a packet having reached a local maximum arises. These problems can be overcome to some extent knowing the real topology, by opting to use only streets where vehicular traffic exists. In addition, in [30], forwarding a packet between two successive intersections is done on the basis of a simple greedy forwarding mechanism. This classic greedy approach works well since it is independent of topological changes but it suffers from inaccurate neighbor tables since it does not consider the vehicle direction and velocity. Thus, it may be possible to lose some good candidate nodes to forward the packets.

Our objective was to conceive a routing protocol that provides a solution to the above-mentioned problems capable to find robust routes within city environments. This routing protocol is well-suited for delay sensitive ad hoc applications like on-vehicle chat or gaming and equally applicable for infrastructure-related delay-tolerant applications like the access to info-mobility or infotainment services. In other words, this routing protocol ensures the user connectivity in specific environments, allows service continuity and possible extension to the wired network.

4.2 Contributions

We proposed GyTAR (improved Greedy Traffic Aware Routing protocol); an intersection-based geographical routing protocol, capable to find robust and optimal routes within urban environments. GyTAR scheme is organized into three mechanisms: (i) a completely decentralized scheme for the estimation of the vehicular traffic density in city-roads, (ii) a mechanism for the dynamic selection of the intersections through which packets are forwarded to reach their destination, and (iii) an improved greedy forwarding mechanism between two intersections. Using GyTAR, packets will move successively closer towards the destination along the streets where there are enough vehicles providing connectivity. We do not impose any restriction to the communication model, and GyTAR is applicable to both completely ad hoc and infrastructure-based routing.

For the first mechanism "Traffic density estimation", we used IFTIS presented in the previous section.

For the second mechanism "Intersection selection", GyTAR adopts an anchor-based routing approach with street awareness. Thus, data packets are routed between vehicles, following the street map topology. However, unlike GSR [29] and A-STAR [30], where the sending node statically computes a sequence of intersections the packet has to traverse in order to reach the destination, intermediate intersections in GyTAR are chosen dynamically and in sequence, considering both the variation in the vehicular traffic and distance to destination. The vehicle traffic estimation is performed using IFTIS. Partial successive computation of the path has a threefold advantage: (i) the size of packet header is fixed; (ii) the computation of subsequent anchors is done exploiting more updated information about vehicular traffic distribution; (iii) subsequent anchors can be computed exploiting updated information about the current position of the destination. When selecting the next destination intersection, a node (the sending vehicle or an intermediate vehicle in an intersection) looks for the position of the neighboring intersections using the map. A score is attributed to each intersection considering the traffic density and the curvemetric distance[4] to the destination. The best destination intersection (i.e., the intersection with the highest score) is the geographically closest intersection to the destination vehicle having the highest vehicular traffic.

After determining the destination intersection, the last mechanism "improved greedy strategy" is used to forward packets towards the intersection. For that, all data packets are marked by the location of the next intersection. Each vehicle maintains a neighbor table in which the velocity vector information of each neighbor vehicle is recorded. Thus, when a data packet is received, the forwarding vehicle predicts the position of each neighbor using the corresponding recorded information (velocity, direction, and the latest known position), and then selects the next hop neighbor (the closest to the destination intersection). Note that most of the existing greedy-based routing protocols do not use the prediction and consequently, they might lose some good candidates to forward data packets. Despite the improved greedy routing strategy, the risk remains that a packet gets stuck in a local optimum (the forwarding vehicle might be the closest to the next intersection). Hence, a recovery strategy is required. The recovery strategy adopted by GyTAR is based on the idea of '*carry- and-forward*' [32]: the forwarding vehicle of the packet in a recovery mode will carry the packet until the next intersection or until another vehicle, closer to the destination intersection, enters/reaches its transmission range.

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[4] This term describes the distance measured when following the geometric shape of a road.

4.3 Summary of Results

To conclude, we can summarize our second contribution in the context of vehicular networks as follows. We proposed an improved greedy routing protocol designed to operate optimally in urban environments. GyTAR efficiently utilizes the unique characteristics of vehicular environments like the highly dynamic vehicular traffic, road traffic density as well as the road topology in making routing and forwarding decisions. The selection of intermediate intersections among road segments is performed dynamically and in-sequence based on the scores attributed to each intersection. The scores are determined based on the dynamic traffic density information and the curvemetric distance to the destination. The optimum values for the weighting factors of the traffic density and distance information components in the intersection scores were evaluated and their sensitivity were analyzed showing a good balance between these two parameters. Simulation results showed that GyTAR performs better in terms of throughput, delay and routing overhead compared to other protocols (LAR and GSR) proposed for vehicular networks. The robust intersection selection and the improved greedy carry-and-forward scheme with recovery, suggests that GyTAR should be able to provide stable communication while maintaining high throughput and low delays for vehicular routing in urban environments.

This work was the focus of a PhD dissertation carried out by Moez Jerbi, University of Evry, and defended in November, 06^{th}, 2008 (see papers [P8][P47]).

5. Data Dissemination in Vehicular Networks

5.1 Research Context

As stated before, the opportunities and applications areas of vehicular networks are growing rapidly. However, many of these applications rely on disseminating data, e. g., on the current traffic situation, weather information, road works, hazard warning, etc. Typically, such applications are based on some form of proactive information dissemination in an ad hoc manner. Proactive information dissemination is, however, a difficult task due to the highly dynamic nature of VANETs. Indeed, VANETs are characterized by their frequent fragmentation into disconnected clusters that merge and disintegrate dynamically. In addition, the results presented in [33] clearly show that during the rollout of VANET technology, some kind of support is needed. Otherwise, many envisioned applications are unlikely to work until a large fraction of vehicles participates.

One of the largely accepted solutions towards efficient data dissemination in vehicular networks is by exploiting a combination of fixed roadside infrastructures (e.g. Road Side Units, RSU) and mobile in-vehicle technologies (e.g. On Board Units, OBU). There are some recent examples of broadcasting protocols specifically designed for vehicular networks with infrastructure support [34][35]. While such infrastructure-based approaches may work well, they may prove costly as they require the installation of new infrastructures on road network, especially if the area to be covered is large.

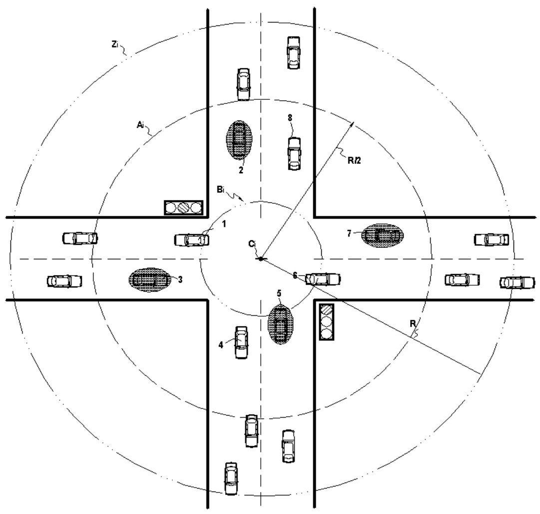
In this context, the main contribution of this section was to propose a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI) by a bounded-size subset of vehicles populating the concerned geographic region. This is realized in an attempt to both approaching the performance of a real infrastructure while avoiding the cost of installing it.

Among the various choices that influence the design and the analytical modeling of the GVI is the question related to where to position the GVI in order to allow for a best-possible support of VANETs. As we are dealing with the city environment, an intersection sounds suitable as geographic region because of its better line-of-sight and also because it is a high traffic density area. Hence, the proposed GVI mechanism can periodically disseminate the data within a signalized (traffic lights) intersection area, controlled in fixed-time and operated in a range of conditions extending from under-saturated to highly saturated. Thus, it can be used to keep information alive around specific geographical areas [36] (nearby accident warnings, traffic congestion, road works, advertisements and announcements, etc.). It can also be used as a solution for the infrastructure dependence problem of some existing dissemination protocols.

5.2 Contributions

We proposed a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI). This latter is emulated by a bounded-size subset of vehicles currently populating the geographic region where the virtual infrastructure is to be deployed.

The geo-localized virtual infrastructure mechanism consists on electing vehicles that will perpetuate information broadcasting within an intersection area. To do so, the GVI is composed of two phases: (i) selecting the vehicles that are able to reach the broadcast area (i.e. a small area around the intersection center, where an elected vehicle could perform a local broadcast); then, (ii) among the selected vehicles, electing the local broadcaster which will perform a local single-hop broadcast once it reaches the broadcast area (i.e. at the intersection center).



In the first phase, among the vehicles which are around the intersection, only those within the notification region A_i (a cell centered on C_i and delimited by a ray of $R/2$ where R is radio range) could participate to the local broadcast. They are selected as candidates if they are able to reach the intersection center C_i.

In the second phase, a waiting time is assigned to each candidate vehicle. This waiting time considers the geographical location, direction and speed of the vehicle and also the desirable broadcast cycle time T of GVI. The candidate vehicle with the shortest waiting time will broadcast a short informative message telling other candidate vehicles that it has been elected as the local broadcaster.

5.3 Summary of Results

To conclude, we can summarize our third contribution in the context of vehicular networks as follows. We proposed an elegant solution for building a Geo-localized Virtual Infrastructure using inter-vehicle ad-hoc networks. GVI emulates an infrastructure disseminating data periodically so that all vehicles in circulation within the dissemination region will receive the data. This mechanism is particularly well suited for an urban environment where there is a high density of vehicles within the intersections.

The proposed mechanism has various potential applications ranging from safety to convenience applications (useful information for drivers, traffic conditions, density of segment of route generated by IFTIS, etc.), solving by the way the infrastructure dependence problem of some existing dissemination protocols.

Analytical and simulation results show that the proposed GVI mechanism can periodically disseminate data within an intersection area, efficiently utilize the limited bandwidth and ensure high delivery ratio. More precisely, with varying the broadcast cycle time *T*, we can have a kind of compromise between two metrics, namely the number of copies of the same message (which corresponds to a measure of the cost to provide the service) and the probability to inform a vehicle (which corresponds to a measure of quality of service). Indeed, if we want that all vehicles receive the message, we should decrease the broadcast cycle time value which will generate an overhead. However, we can minimize the number of copies of the same broadcast message received by a vehicle as long as we tolerate the fact that certain vehicles fail to receive the message. Analytical models showed that that GVI fails only when the traffic density is extremely low.

This work was the focus of a PhD dissertation carried out by Moez Jerbi, University of Evry, and defended in November, 6th, 2008 (see papers [P37][P38]).

6. Vehicular Networks Connectivity

6.1 Research Context

Connectivity is a measure of how many nodes in the network are able to communicate with each other. A network is declared to be fully connected, i.e. has a connectivity of 100%, if there exists a route between every pair of nodes in the network. Connectivity is particularly important for routing information packets across the network. A network with low connectivity suffers from route discontinuities leading to complications in the network layer to guarantee packet delivery. Low connectivity means the network is divided into isolated clusters or groups.

Although connectivity has been analyzed for MANET and closed form expressions were obtained, VANET is a unique case. In VANET the cars are constraint in a topology limited by the geometry of the road compared to the two dimensional topology of MANET. This constraint limits the connectivity of VANET since a multi-hop route may exist between two cars only if there are cars in the space between them whereas in MANET other routes may exist.

6.2 Contributions

We proposed a model to calculate the connectivity in VANET. In fact, the probability of full connectivity of VANET and MANET has been considered in several papers [1-4]. They assumed the cars are uniformly distributed in a single dimension. However the distance between the cars is usually approximated by the exponential distribution. These papers assume also straight roads whereas roads can have curves, junctions and turns thus affecting the connectivity. Hence, in this work we first investigated the connectivity of VANET in straight single and multi-lane roads with an interspacing distance following the exponential distribution. Then, we analyzed the connectivity of VANET in roads in inner cities where roads form turns, junctions and roundabouts. Thus, we introduced new models for: (i) roads with curves and turns, (ii) road junctions, (iii) roundabouts, and (iv) straight single and multi-lane roads.

Beside the probability of full connectivity, we used another measure, average connectivity, which is the average number of cars each host can communicate with divided by the total number of cars. In a large and dynamic network such as VANET, it is very difficult to achieve full connectivity all the time. Several VANET applications, e.g. safety, require only the exchange of information between neighboring cars. In these cases, the average connectivity gives better insight than the probability of full connectivity.

6.3 Summary of Results

To conclude, we can summarize our fourth contribution in the context of vehicular networks as follows. We investigated the issue of connectivity in vehicular networks within: (i) straight single and multi-lane roads with an exponential inter-vehicle spacing and (ii) roads in inner city with turns, junctions and roundabouts.

For straight roads and for communication range *R*, car densities of 7cars/*R* or more were found sufficient to provide full connectivity within the city compared to 12cars/*R* for highways. Roads with several lanes show high average connectivity but low probability of full connectivity since cars tend to cluster into groups. This leads to isolated groups or even isolated cars thus resulting in very low probability of full connectivity. The isolated cars, however, have little effect on the average network connectivity. We also investigated the effect of penetration rate on connectivity. We found that for penetration rates of 50-70% achieving 80% probability of full connectivity requires 10cars/*R*/lane while for penetration rates of 5-20% the probability for the same car density is less than 10%. Hence, during the rollout of VANET technology, some kind of support is needed using a fixed infrastructure.

For a city and for curved roads, the probability of full connectivity drops as the road angle increases and improves as the road width increases. Junctions have higher connectivity compared to curves since multiple routes may exist. However if the line of sight is blocked by obstacles, as in roundabouts, the connectivity drops considerably and becomes worse than road with curves.

This work was the focus of a PhD dissertation carried out by Ghassan Abdalla, University of Plymouth, UK, and will be defended in December 2009 (see paper [P107][P108]).

7. Medium Access Control in Vehicular Networks

7.1 Research Context

The IEEE is working on a Medium Access Control (MAC) standard known as IEEE 802.11p. The standard is based on the previous 802.11e which uses an Enhanced Distributed Coordination Function (EDCF), an extension of the Distributed Coordination Function (DCF), to organize channel access. DCF is a random access mechanism based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), it has an unreliable broadcasting service, achieves low throughput as the number of devices increases and has little support for Quality of Service (QoS) [37]. A request-to-send/clear-to-send (RTS/CTS) handshake, supported in DCF, can be used to improve the performance of point-to-point transfers but is not applicable to broadcast messages. Since a large number of applications in VANET is broadcasting by nature (e.g. safety messages, location messages, traffic condition messages, etc.), the RTS/CTS handshake cannot be used with these applications. Moreover the number of vehicles (nodes) varies with time and location, and peaks in congested areas leading to severe degradation in DCF performance [37]. EDCF provides some QoS by using different queues and counters for each QoS requirement, but still packets contend for the channel and may collide with packets having the same QoS requirements (e.g. safety messages from different vehicles).

DCF and EDCF use CSMA for channel access. Under heavy load, the performance of TDMA is superior to CSMA, however under light traffic CSMA shows better performance. The Point Coordination Function (PCF) of 802.11 uses a combination of TDMA and CSMA. The base station announces a contention free period (CFP) in which it polls node for data (TDMA). After the polling finishes or the maximum CFP period has elapsed, the base station announces the end of the CFP and a contention period (CP) starts in which nodes use DCF [39].

7.2 Contributions

We proposed a MAC protocol which is a combination of Space, Orthogonal Frequency and Time Division Multiple Access called SOFT MAC protocol. In SOFT MAC the space (road) is divided into cells and a portion of the available subcarriers is assigned to each cell. These subcarriers are then shared between nodes within the cell in time via a TDMA protocol. Time is divided into frames and each frame is divided into slots. However unlike existing protocols R-ALOHA [38] and ADHOC MAC, SOFT MAC has two types of slots or periods, namely reserved transmission slots (TS slots) and reservation slots/period (RS slots). TS slots cannot be accessed without prior reservation while the RS period is accessed via a random access scheme (e.g. DCF or slotted ALOHA). The number of TS slots varies with the number of reservations and the RS period occupies the rest of the frame. Under low traffic, most of the frame will be RS period. At high traffic, most of the nodes will have a large amount of data and reserve TS slots. Therefore most of the frame will be TS slots and hence the performance will approximate that of TDMA systems. Thus the protocol should provide the performance of random access methods under low traffic and TDMA performance under heavy traffic.

7.3 Summary of Results

To conclude, we can summarize our fifth contribution in the context of vehicular networks as follows. We proposed a new MAC protocol for VANET known as SOFT MAC. The protocol divides the roads into cells and allocates each cell a group of subcarriers. Within the cell, the nodes share the available subcarriers using a combined TDMA-CSMA protocol. Time is split into frames and each frame has two periods. The first period consists of transmission slots (TS period) and is accessed after reservation. The second period is the reservation (RS) period and is accessed using a random access technique (DCF). The RS period is used to send reservation requests as well as data. A mathematical analysis of the saturation throughput was derived and used to analyze the protocol. Compared to 802.11 basic access, SOFT MAC shows improvement in throughput as long as the payload size exceeds 500 bytes. As the TS period increases, the performance improves but the number of nodes that can access the channel is reduced.

This work was the focus of a PhD dissertation carried out by Ghassan Abdalla, University of Plymouth, UK, and will be defended in December 2009 (see papers [P29]).

8. Characterizing Multi-hop Communication in Vehicular Networks

8.1 Research Context

As evoked before, the three deployment alternatives of vehicular networks include: i) a pure wireless Vehicle-to-Vehicle ad hoc network (V2V) allowing standalone vehicular communication with no infrastructure support, ii) an Infrastructure-to-Vehicle (I2V) architecture with wired backbone and wireless last hops, iii) and a hybrid architecture that exploits the fixed infrastructure using V2V communication.

The central question for the first architecture is: What is the expected performance of multi-hop communication for mobile users, particularly for users in automobiles trying to communicate in a multi-hop fashion (car following, games applications, etc.)? For the two other architectures, the question is: What is the expected performance of Wi-Fi networks for drivers/passengers as they move in urban and suburban areas where access points are currently widely deployed? We answered these questions by running a set of extensive experiments.

8.2 Contributions

We elaborated an extensive measurement campaign evaluating the performance of IEEE 802.11 in different vehicular communication scenarios: vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V). We concentrate our evaluation on multi-hop communication in these two scenarios. Our experimental study is unique in several ways. First, our test bed is larger using more than two vehicles. Second, we attempt to provide detail trends such as throughput, delay, and signal strength. Third, we focus on using V2V multi-hop communication to extend the operative range of access points.

8.3 Summary of Results

To conclude, we can summarize our last but not least contribution in the context of vehicular networks as follows. We proposed to evaluate the performance of V2V and I2V multi-hop communication based on the IEEE 802.11 technology. We found that distance and line of sight communication are the two main factors affecting the network communication. The experimental results confirm also the feasibility of using ad hoc networks to extend the transmission range of the infrastructure and the connection time for cars in motion.

This work was the focus of a PhD dissertation carried out by Moez Jerbi, University of Evry, and defended in November, 6^{th}, 2008 (see papers [P42][P46]).

Chapter 4

Conclusion

1. Concluding Remarks

The current Internet architecture was not designed to cope with the wide variety, and the ever growing number of networked applications, business models, edge devices, networks and environments that it has now to support. Its structural limitations in terms of scalability, mobility, flexibility, security, trust and robustness of networks and services are increasingly being recognised world-wide. The challenge is to comprehensively and consistently address the multiple facets of a future Internet, with energy efficiency also appearing as an important societal concern.

From a networking perspective, this entails a need to rethink architectures and protocols such that performance bottlenecks are overcome, a wider variety of service types can be supported and novel types of edge/access networks such as light infrastructure networks (*mobile ad hoc networks*, *mesh networks*, *wireless sensor networks*, and *vehicular networks*) may be integrated. Mobility and ever high end to end data rates also emerge as important design drivers. Light infrastructure networks are expected to play an important role in the future Internet. However, such networks are associated with a number of challenging problems. Among them, we can quote the following: quality of service and scalability.

To meet the scalability issue and ever-increasing QoS-demanding services, we proposed solutions for wireless ad hoc networks. The hot issue in this context can be summarized in this question: how can we ensure an efficient use of the scarce resources and improve the delivered quality of service in a wireless ad hoc network?

Wireless ad hoc networks by their dynamic and large scale character let appear new problems for the introduction of QoS solutions like unpredictable link qualities, bandwidth and energy resource limitation, and routing. The result of using multi-hop communication in a shared medium creates difficulties for delivering satisfactory QoS. It is therefore imperative that wireless ad hoc networks effectively utilize all the available resources. The response to this question was the key driver of our work. To achieve this, we proposed three main solutions: either by managing more efficiently the mobility of users and/or by routing more efficiently the traffic inside a large scale network and/or by performing a smarter use of wireless resources by enabling cooperative relaying.

A special case of wireless ad hoc networks, with more constraints, is vehicular networks. Vehicular networks have some own challenging characteristics that have injurious implications for designing solutions. We can mention: (i) high mobility, (ii) frequently partitioned network, (iii) geographically constrained topology, and (iv) scalability. In this regard, in contrast to traditional networks where the aim is to achieve adequate QoS levels, vehicular network protocols focus also on reducing the control traffic overhead in such large scale networks. However, this should be accomplished while respecting certain QoS constraints and information reliability especially for critical road safety applications (nearby accident warnings, road works, etc.). Achieving these two opposite requirements, i.e., the trade-off between control traffic overhead, QoS and information reliability was the key driver of our work on vehicular networks. To achieve this, we proposed several solutions by acting at the network and link layers.

2. Perspectives

Light infrastructure networks and especially vehicular networks are considered as a technology under development that merits a lot of research and field trials. Besides the ongoing standardization activities, a number of technical challenges need to be resolved aiming for wide scale deployment of these networks in the near future. In this thesis, we tried to resolve some of them. As an open perspective of our works, we can enumerate the following topics.

A lot of vehicular networks applications are based on some form of proactive information dissemination in an ad hoc manner - i.e. by forming a vehicular ad hoc network. We proposed GVI a solution for building a geo-localized virtual infrastructure in a geographic region like an intersection area solving by the way the infrastructure dependence problem of some existing dissemination protocols. Hence, one promising solution is the design of a new dissemination protocol based on the GVI mechanism. This new protocol will use GVI to periodically disseminate the data within the intersection areas and will efficiently disseminate information over the whole city. It should have the ability to minimize the use of bandwidth by using limited number of vehicles to relay packets.

With regard to the security and privacy, novel mechanisms need also to be proposed since they have a great impact on the future deployment and application of vehicular networks. Indeed, security and privacy is one of the major concerns in the development and acceptance of services and should not be compromised by ease-of-use of service discovery protocols. As the demand for service discovery is growing, passengers may use services in foreign networks and create immense security problems for themselves and for other network users. Consequently, it is important to propose innovative solutions for secure communication between participants as well as authorized and secure services' access. To enhance the vehicular network access ubiquity, these solutions should take advantage of: i) the ad hoc multi-hop authentication and communication concepts which on one hand allows secure communication and on the other hand extends the infrastructure coverage with the minimum deployment cost for the network operator, and ii) the distributed based authentication. Appropriate security architectures should be in place providing communication between vehicles and allowing different services' access. As well, a set of security mechanisms suitable for any vehicular network environment should be developed, providing trust, authentication, access control, authorized and secure services' access. In this context, authentication optimization is important to be studied for both infrastructure-based and infrastructure-less communications. Moreover, nodes behaviour is an important issue that can threaten the security of communication and services' delivery in vehicular networks, and hence worth consideration. Due to the open and dynamic environment of vehicular networks, nodes cooperation is an important aspect that should be satisfied for allowing successful communication between vehicles. We notice that nodes may behave selfishly by not forwarding messages for others in order to save power, bandwidth or just because of security and privacy concerns. Consequently, appropriate mechanisms should be developed to detect selfishness and enforce nodes cooperation in vehicular networks environment.

The penetration of vehicular networks technology is still weak, and hence there is a need for infrastructure support to help the penetration of these networks. At the same time, deploying new infrastructure for these networks necessitate a lot of investment and high cost. Hence, it is more economical to rely on the existing infrastructure (owned by network operators for instance) for accelerating the penetration of such technology with the least cost. Actually, the use of existing cellular networks in the context of vehicular communications is quite common nowadays. However, their use is mainly oriented towards the provision of data communication services for vehicles since their capabilities especially 3G and next-generation. These networks have evolved very rapidly within the last few years, and nowadays operators have many efficient communication mechanisms that may become very valuable in the vehicular environment, much beyond providing connectivity. 3G cellular networks can be used not only as a backup for data communication among vehicles, but also and especially as an efficient mechanism for the dissemination of control information. In the other side, vehicular sensor networks (VSN)[5] can be considered as a source of information for an operator/service provider. In fact, vehicular networks and existing cellular networks are complementary as shown in the next Figure. In addition, they are able to provide simple, scalable, comprehensive communications interoperability between different wireless ITS networks (private networks, C2C, etc.). Our aim is to demonstrate such complementarities by proposing a new architecture where the objectives are twofold: (i) improve the efficiency of the vehicular network protocols using a 3G network and (ii) provide the operator/service provider with useful information coming from the huge number of sensors that will be available in our cars and roads.

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[5] Vehicular Sensor Networks are an emerging paradigm in vehicular networks using different kind of sensing devices available in new vehicles and over the roads, to gather information about the driver's environment (speed, acceleration, temperature, seats occupations, road condition, etc.).

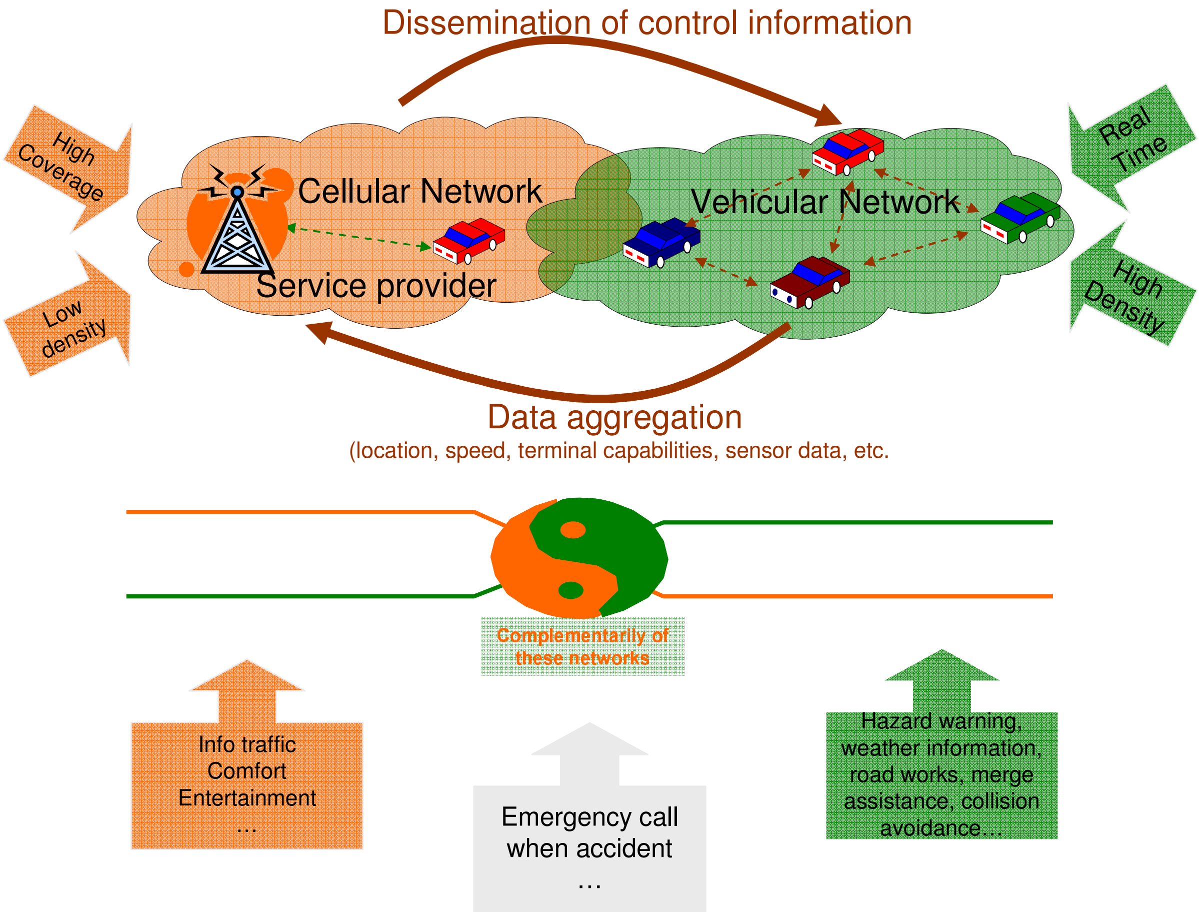

Figure 4.1. Complementarities between vehicular and cellular networks (source: Orange internal white paper).

One promising solution to increase the capacity of wireless ad hoc networks (including vehicular networks) is the use of multipath schemes and access heterogeneity. Heterogeneity implies in this context that the network nodes may use one or several wired and/or wireless communication interfaces (cellular, wifi, etc.). One radio technology is often not sufficient to provide global coverage for a given trip. The bandwidth of a single technology access radio capacity will also be limited to all services. Multipath schemes address three main issues: (i) Fault tolerance, (ii) Resource aggregation, and (iii) Load balancing. So, it will important to think about a multi-path solution that enables network nodes to comprehensively select, use and possibly aggregate available wired and radio resources in order to efficiently communicate with the other nodes in a multi-hop fashion.

The majority of protocols including cooperative communications and applied for Wireless Sensor Networks was derived from 802.11 MAC layer. As a consequence, all of them use RTS/CTS sequence in addition to other messages introduced for relay selection or for cooperative transmission synchronization. The high number of control packet makes these protocols talkative and energy consuming. WSNs do not have the same constraints as 802.11 networks. They are much more energy constrained (often use non-rechargeable batteries) and they dispose of a limited data rate. Moreover, the maximal packet size in WSN is 127 bytes. Therefore, RTS/CTS mechanism is not suitable for wireless sensor networks. One promising solution is a CSMA/CA based protocol that includes cooperative communication with a distributed relay selection algorithm (based on CSI and remaining battery). This protocol should consider WSN characteristics by not using RTS/CTS mechanism and should need only few control packets overhead for relay selection.

To avoid the routing layer from ruining the efforts of lower layers, cross-layer optimization of data link layer with physical, routing and transport layers is crucial. This leads also to further energy conservation. There exists some solutions about cross-layer optimization using routing, MAC and physical layer information, however more extensive research is required, essentially in the context of real-time applications where multiple metrics need to be optimized.

Routing for multicast or peer-to-peer applications is another important research topic. Many applications of wireless mesh networks need multicasting capability. For example, in a community or a city-wide network, video distribution is a common application. Conceiving new schemes to handle popular peer-to-peer or multicast applications is indeed a big challenge in WMNs.

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[P3] M. Jerbi, **SM. Senouci**, Y. Gourhant, Y. Ghamri-Doudane,"Procédé de diffusion de paquets de données dans un réseau de nœuds mobiles et terminal associé.", 16/11/2007, INPI FR # 07 59115.

[P4] M. Jerbi, **SM. Senouci**, Y. Gourhant, Y. Ghamri-Doudane,"Procédé de diffusion de paquets de données dans un réseau de nœuds mobiles et terminal associé.", 26/10/2007, INPI FR 07 06771.

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[P84] M. Jerbi, **SM. Senouci**, Y. Ghamri-Doudane, AL. Beylot, "Geo-localized Virtual Infrastructure for VANETs", *Journée spécifique REVE du Pôle ResCom - GDR ASR – CNRS*, Evry, 20 October 2008.

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[P86] **SM. Senouci**, presentation invitee au séminaire Car-to-X communications, "Vehicular Networks: an operator viewpoint", Stuttgart, Germany, 14-15 November 2007.

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[P88] R. Meraihi and **SM. Senouci**, "Communications inter-véhicules (IVC): applications et perspectives", poster au salon de la recherche France Télécom R&D, Issy-les-moulineaux, France, Décembre 2005.

[P89] **SM. Senouci**, "Réseaux spontanés", poster au salon de la recherche France Télécom R&D, Issy-les-moulineaux, France, June 2005.

[P90] **SM. Senouci**, "Nouveaux algorithmes de routage pour l'Internet ambiant", Journée thématique atelier de présentation des résultats du projet ITEA Ambience au groupe Thalès-Communications, Décembre 2003.

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[P95] **SM. Senouci**, "Modélisation comportementale du réseau SDH avec UML", *Mémoire de DEA*, Laboratoire LIPN, Université de Paris 13, Septembre 1999.

[P96] **SM. Senouci**, "Un système expert d'aide à la reconstitution d'un réseau électrique après une panne généralisée", *Mémoire de fin d'études d'ingénieur*, USTO, Septembre 1995.

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[P99] Kaouthar Sethom, Hossam Afifi, **SM. Senouci**, "Dynamic router selection", January 2006, draft-sethom-dynamic-router-selection-01.txt.

Software and Platforms (6)

[P100] SEDLANE tool for the emulation of ad hoc networks.
[P101] TCP-WELCOME implementation improving TCP performances in ad hoc networks.
[P102] Mobility model generator for vehicular networks (can be used for simulations with NS2, Glomosim, and Qualnet simulators).
[P103] ROD implementation for data dissemination in vehicular networks.
[P104] Platform for the test/monitoring vehicular networks.
[P105] Platform for the test/monitoring video games in ad hoc networks.

Articles Submitted to International Journals (4)

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[P107] G. Abdalla, M. A. Abu-Rgheff, **SM. Senouci**, "On VANET Connectivity", Submitted to *IEEE Communications Letter*.
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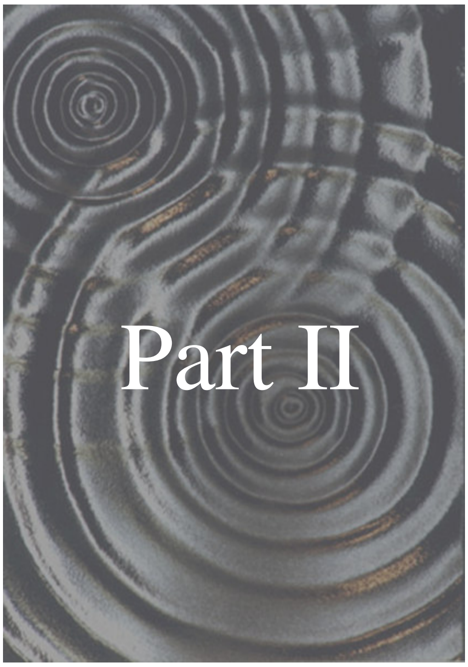

Curriculum Vitae

PART II: Curriculum Vitae (in French)

1. Etat civil

Sidi Mohammed SENOUCI
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2. Titres universitaires

1999 – 2003 : Doctorat de l'Université de Pierre et Marie Curie - Paris VI

Spécialité : Informatique, Télécommunications et électronique.
Laboratoire d'accueil : Laboratoire d'Informatique de Paris 6 (LIP6), équipe réseaux et performances (RP).
Mention : Très Honorable.
Titre de la thèse : Application de techniques d'apprentissage dans les réseaux mobiles.
Directeur de thèse : Pr. Guy PUJOLLE
Membres du jury : Pr. André Luc BEYLOT (ENSEEIHT, Toulouse) – Rapporteur
Pr. Younes BENNANI (Université de Paris XIII) – Rapporteur
Pr. Otto SPANIOL (Université d'Aachen, Allemagne)
M. Sami TABBANE (ESPTT, Tunisie)
M. Laurent REYNAUD (Chercheur France Télécom R&D)
Pr. Samir TOHME (ENST, Paris)
Pr. Dominique GAITI (UTT, Troyes)

1998 - 1999 : DEA de l'université de Paris XIII (Spécialité en Intelligence artificielle, Mention Bien, second de la promotion).

1990 – 1995 : Ingénieur en Informatique de l'USTO - Université des Sciences et de la Technologie d'Oran (Mention Très bien et major de la promotion 94/95).

1990 : Baccalauréat scientifique au lycée de Nédroma en Algérie (Série C, Mention Bien).

3. Parcours professionnel

Depuis Décembre 2004 : Ingénieur de recherche (Ingénieur-Expert en réseaux light infrastructure) à France Télécom R&D

- **Responsabilité de projets de recherche sur les réseaux light infrastructure**
  - Projet ML9 (depuis 01/09) : réseaux de véhicules. Projet interne FTRD, durée 1an, 9 contributeurs répartis sur 5 sites (Lannion, Paris, Pékin, Pologne, Tokyo).
  - Projet ML7 (depuis 01/09) : jeux vidéo sur réseaux ad hoc. Projet interne FTRD, durée 1an, 3 contributeurs sur Lannion.
  - Projet Pronto (de 01/2007-12/2008) : systèmes embarqués, réseaux maillés wifi et wimax, réseaux de capteurs, réseaux de véhicules. Projet interne FTRD, durée 2ans, 36 contributeurs répartis sur 5 sites (Lannion, Paris, Grenoble, Pékin, Pologne).
  - Projet Spontex (12/2004-12/2006) : réseaux pairs à pairs, réseaux ad hoc et capteurs, réseaux sociaux, systèmes auto-*. Projet interne FTRD, durée 3ans, 43 contributeurs répartis sur 6 sites (Lannion, Paris, Caen, Sophia, Rennes, SF).

- Montage et/ou participation à des projets collaboratifs
  - **Montage et participation au projet collaboratif RIAM MAD GAMES** avec des contributions sur l'amélioration de la qualité de service pour le support de jeux vidéo multi-joueurs sur une infrastructure de réseaux sans fil, en mode ad hoc (plus de détails dans la section projets de recherche).
  - **Participation au projet collaboratif RNRT SAFARI** avec des contributions sur la localisation et le routage dans les réseaux sans fil ad hoc (plus de détails dans la section projets de recherche).

- Encadrement de 3 thésards FTRD sur les réseaux light infrastructure (voir section encadrement).

- Montage et/ou suivi de 9 contrats de recherche externes CRE (projet bilatéral entre FTRD et un laboratoire académique expert sur un domaine particulier) sur le thème des réseaux light infrastructure et co-suivi des thésards externes travaillant dessus (voir section projets bilatéraux).

Durant ces cinq années, j'ai été en charge de l'organisation des activités de recherche de France Télécom R&D dans les thématiques suivantes :

- **réseaux de véhicules** (routage inter-véhicules, estimation de trafic routier, diffusion optimisée, couches MAC/PHY et mise en place d'une plateforme de test, auto-organisation de réseaux de véhicules opéré, auto-configuration IP).

- **réseaux multi sauts** (TCP, routage, diversité spatiale, diffusion optimisée, jeux vidéos sur réseaux ad hoc et mise en place d'une plateforme de test).

Je me suis également investi dans les activités sur des activités portant sur les M2M et les réseaux de capteurs (stratégies de coopérations et de partage de ressources, network coding, routage minimisant l'énergie).

Enfin, j'ai participé à consolider le rayonnement international et la renommée de France Telecom dans le domaine des réseaux light infrastructure (voir les sections responsabilités collectives).

J'ai enfin été sollicité pour dispenser des enseignements en réseaux, télécommunications et informatique (voir section activités d'enseignement).

2002 à 2004 : Attaché Temporaire en Enseignement et Recherche (ATER) à l'Université de Cergy Pontoise

- **Enseignement et recherche,** publications, séminaires, encadrement de stagiaires.

1999 à 2003 : Chercheur-doctorant à l'Université de Pierre et Marie Curie – Paris VI

Ma thèse de doctorat a porté sur l'apport des techniques d'intelligence artificielle dans le domaine des réseaux de télécommunications en particulier mobiles et sans fil. Mes contributions ont plus spécifiquement concerné :

- **La conception et le développement de protocoles pour les réseaux cellulaires**, ces nouvelles solutions concernent le contrôle d'admission des appels (CAC) et l'allocation dynamique de ressources radio.

- **La conception et le développement de protocoles de routage ad hoc avec qualité de service,** dans le cadre du projet ITEA Ambience. Ces protocoles utilisent des métriques de routage telles que l'énergie, le délai et la bande passante.

- **La conception et le développement d'un modèle multi-agent de contrôle pour constellation de satellites,** dans le cadre du projet RNRT constellation de satellites.

Ces activités ont été menées dans le cadre de deux projets de recherche sur lesquels mes travaux ont été financés :

- **Projet ITEA AMBIENCE** (2001-2003) se focalisant sur la création d'un environnement numérique adaptatif au contexte (plus de détails dans la section projets de recherche).
- **Projet RNRT SAFARI** (2003-2006) : Services Ad hoc/Filaires - développement d'une Architecture de Réseau Intégrée (plus de détails dans la section projets de recherche).
- **Projet RNRT Constellation de Satellites** (1999-2001) traitant les différents problèmes posés par les constellations de satellites de type LEO et MEO pour le transport d'applications multimédias (plus de détails dans la section projets de recherche).

Au cours de ma thèse, j'ai également dispensé des **enseignements en réseaux, télécommunications et informatique**, comme assistant chargé de CM/TD/TP (voir section activités d'enseignement).

1998 à 1999 : Stage de DEA à l'Université de Paris XIII

- **Conception et modélisation comportementale du réseau SDH,** dans le cadre du projet RNRT MAGDA (plus de détails dans la section projets de recherche).

1996 à 1998 : Ingénieur Informaticien à l'URBAT Tlemcen

- **Développement de SIG** (Systèmes d'Informations Géographiques) pour les mairies, GDO (Gestion Des Ouvrages) pour le compte de la Sonelgaz (équivalent EDF/GDF), traitement d'images, restauration de plans de villes pour les mairies, CAO (Conception Assistée par Ordinateur), PAO (Publicité Assistée par Ordinateur), **formation**.

4. Activités d'encadrement et jury de thèses

- Jury de thèses (5)
    - Examinateur de la thèse de Yacine Khaled, "contribution aux communications dans les réseaux de véhicules-Application à la pré-visibilité de route", UTC, soutenue le 26 Novembre 2007.
    - Examinateur invité de la thèse de Zeina Jrad, "Apport des techniques de l'intelligence artificielle dans la négociation dynamique de niveaux de services : interface utilisateur pour l'Internet de nouvelle génération", Université de Paris13, soutenue le 15 Mai 2006.
    - J'ai également fait partie des jurys de thèses des doctorants que j'ai encadrés : M. Jerbi (UEVE), G. Al-Sukkar (INT), A. Seddik-Ghaleb (UEVE).
- Encadrement
    - Postdocs (1)
        - R. Meraihi, postdoc FTRD, Les systèmes de communication Inter-véhicules, 2005-2006. [1 brevet, 4 publications] (encadrement 100%)
    - Thèses soutenues (3)
        - Thésards avec encadrement principal (1)
            - M. Jerbi, thèse FTRD – Protocoles pour les communications localisées dans les réseaux véhiculaires ad hoc, co-encadrement avec Y. Ghamri-Doudane (ENSIIE, Evry), soutenue le 06 Novembre 2008. [4 brevets, 20 publications]. M. Jerbi est actuellement consultant chez Steria Paris.
        - Thésards avec encadrement secondaire (2)
            - G. AL-Sukkar, thèse Telecom Sud-Paris (ex. INT Evry) – Discovering the Synergy between Wireless Ad hoc routing protocols and Peer-to-Peer Abstractions, co-encadrement avec H. afffi (Telecom Sud-Paris), soutenue le 26 Novembre 2008. [4 publications, encadrement à 30%]. G. AL-Sukkar est actuellement Maître de conférences en Jordanie
            - A. Seddik-Ghaleb, thèse U. Evry – TCP Performance Study and Enhancements Within Wireless Ad Hoc Network Environments, co-encadrement avec Y. Ghamri-Doudane (ENSIIE, Evry),

soutenue le 30 Mars 2009. [1 brevet, 7 publications, encadrement à 30%]. A. Seddik-Ghlaeb est actuellement en postdoc à l'ENSIIE.

- Thèses en cours avec encadrement principal (2)
  - A. Ben Nacef, thèse FTRD - Relais coopératifs dans un réseau de terminaux : performances limites et stratégies, co-encadrement avec Y. Ghamri-Doudane (ENSIIE, Evry) et A.L. Beylot (ENEEIHT, Toulouse), 2008-2011. [1 brevet en cours, 1 publication en cours]
  - M. Cherif, thèse FTRD – Optimisation des communications M2M pour des applications automobiles, co-encadrement avec B. Ducourthial (UTC, Compiègne), 2007-2010. [1 brevet en cours de dépôt, 8 publications]
- Thésards avec lesquels je collabore dans le cadre de contrats de recherche externes (3)
  - H. Adam - Diversité spatiale dans les réseaux ad hoc multi sauts, Université de Klagenfurt, directeur de thèse : C. Bettstetter, 2006-2010. [3 publications].
  - G. Abdalla - Couches physiques et liaisons pour réseaux fortement dynamiques, Université de Plymouth, directeur de thèse, M.A. Abu Rgheef, 2006-2010. [1 brevet, 7 publications].
  - F. El Ali, Protocoles de collecte de données dans les réseaux de véhicules, UTC Compiègne, directeur de thèse : B. Ducourthial, 2009-2012.

- Stages M2 et projets de fin d'études (14)
  - M. Max, Ingénieur UTC Compiègne – Mise en place d'une plateforme de diffusion d'annonces utilisant des réseaux de véhicules, 2009 (co-suivi avec M. Cherif). [4 publications, encadrement à 80%].
  - A. Bouhlel, Ingénieur ENSEEIHT Toulouse, Mise en place d'une plate forme de jeux vidéo multi-joueurs sur réseaux ad hoc et tests d'algorithmes de qualité de service, 2009. [encadrement à 100%].
  - G. Maiano, Ingénieur ENSIIE Evry – Amélioration de la qualité de jeux vidéo multi-joueurs sur réseaux sans infrastructure, 2008. [encadrement à 100%].
  - I. Salhi, Master 2 recherche de l'UPMC – Collecte d'information dans un réseau de véhicules, 2008. [2 publications, encadrement à 80%].
  - P. Marlier, Master 2 recherche de l'UTC – Communications optimisées dans un réseau véhiculaire multi-saut, 2007 (co-suivi avec M. Jerbi). [2 publications, encadrement à 80%].
  - A. Sardouk, Master 2 recherche de l'UTT – Multicast et diffusion optimisée avec contraintes temporelles dans les réseaux multi-sauts, 2007. [1 publication, encadrement à 50%].
  - P. Checca, Master 2 recherche de la faculté de Nantes – Jeux vidéo multi-joueurs sur réseaux Ad-hoc, 2006. [encadrement à 50%].
  - M. Al Haj, Stage d'école d'ingénieurs ESEO – Caractérisation expérimentale des communications multi-sauts dans un réseau véhiculaire ad hoc, 2006 (co-suivi avec M. Jerbi). [1 publication, encadrement à 80%].

- A. Seddik, DEA Réseaux de Paris VI – Etudes de performances de TCP en terme de consommation de l'énergie dans les réseaux mobiles ad hoc, 2004 (co-suivi avec Y. Ghamri-Doudane). [1 publication, encadrement à 50%].
- R. Kortebi, DEA Réseaux de Paris VI – Nouveaux protocoles de transport et/ou de signalisation pour les réseaux de capteurs, 2004. [encadrement à 100%].
- L. Ouakil, DEA Réseaux de Paris VI – Routage dans les réseaux ad hoc minimisant la consommation des batteries, 2002. [1 publication, encadrement à 100%].
- J. Rotrou, DEA Réseaux de Paris VI – Accès intelligent aux réseaux ambiants, 2002. [encadrement à 100%].
- S. Lohier, DEA Réseaux de Paris VI – Routage QoS dans les réseaux Ad hoc, 2002 (co-suivi avec Y. Ghamri-Doudane). [2 publications, encadrement à 50%].
- K. Rizkallah, DEA réseaux du Liban – Contrôle des réseaux ad hoc, 2001 (co-suivi avec Y. Ghamri-Doudane). [encadrement à 50%].
- Projets de 2ème année Ingénieurs à l'école d'ingénieurs EFREI.

- Apprenti
  - M. Duval, Formation d'ingénieur par apprentissage, Enssat Bretagne, 2009-2012. [encadrement à 100%].

5. Activités d'enseignement

2005 à 2010 : Vacataire

- **Qualité de service dans les réseaux** – Ingénieur 3ème année ENSIIE, Evry.
  - **Charge totale :** 24 heures CM (2009)
- **Réseaux spontanés** : réseaux ad hoc, réseaux P2P, réseaux mesh, réseaux Wimax, réseaux de véhicules – Master 2 de l'université de Paris 13.
  - **Charge totale :** 30 heures CM (2005, 2006, 2007, 2008 et 2009)
- **Réseaux light infrastructure** : Master 2 de l'Université de Technologie de Compiègne (UTC).
  - **Charge totale :** 3 heures CM (2008)

1996 à 2004 : ATER ou Chargé de CM/TD/TP

- **Réseaux spontanés**
- **Architecture de réseaux, couches de protocoles.**
- **Réseaux ambiants et Intelligence ambiante**, gestion de la mobilité (Mobile IP, Cellular IP, SIP, etc.), découverte de service (SLP, Jini, etc.), réseaux ad hoc, réseaux de capteurs.
- **La mobilité dans les réseaux**, GSM/GPRS/UMTS, réseaux locaux sans fil (IEEE 802.11, Hiperlan, Bluetooth), gestion de la mobilité, services mobiles et réseaux NGN.
- **Modélisation et performances des réseaux**, modélisation par chaînes de Markov : modèles simples, modélisation par réseaux de files d'attente.
- **Autres**, logique mathématique, initiation à l'algorithmique et la programmation.
- **Charge totale :** 567.5 heures

	1996	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2005-2009	Total (heures)
1er cycle (DEUG)		56			41	36		133
2ème cycle (Licence/ Maîtrise/Ing.)		26	12		55	62.5		155.5
Ecoles d'ingénieurs	40		80	104		16	24	264
3ème cycle (Master, DESS)				21		18	33	72
Total (heures)	40	82	92	125	96	132.5	57	**624.5**

6. Activités liées à la recherche

- Prix et distinctions
  - Senior Expert SEE depuis 2008.
  - Expert France Telecom sur les réseaux light infrastructure depuis 2006.
  - Best student paper award pour le papier "A Multi-Hop-Aware Cooperative Relaying", *IEEE VTC'2009 Spring*.
  - Best paper Award pour le papier "A dynamic Q-learning-based call admission control for multimedia cellular networks", *IEEE MWCN'2001*.
- Participation à des comités, Editorial boards, organisation de colloques, séminaires,…
  - Participation au comité scientifique de l'école d'été du pôle ResCom, GDR ASR, qui se tiendra en Juin 2010 sur « Communications dans les systèmes de transports intelligents ».
  - Co-chair du symposium Selected Area in Communications (SAC) dans IEEE Globecom 2010.
  - Co-chair du symposium Vehicular Communication Technology dans IEEE IWCMC 2010.
  - Membre actif de IEEE ComSoc Technical Committee on Information Infrastructure (TCII), et l'IEEE ComSoc Technical Committee on Ad Hoc and Sensor Networks (AHSN) depuis 2007.
  - TPC Co-chair du workshop VehiCom2009 associé à la conférence IEEE IWCMC.
  - Editeur d'un Special Issue du Journal UBICC sur "Ubiquitous Roads" paru en Mars 2008.
  - Fondateur et Chair du premier workshop international UBIROADS'2007 associé à la conférence IEEE GIIS'2007 le 06 Juillet 2007 à Marrakech, Maroc.
  - Co-organisateur et co-chair d'une session spéciale sur "Intelligent Transportation and Traffic Telematics - Challenges, Applications, Standardization" dans la conférence IEEE PIMRC 2008, en collaboration avec Jérôme Härri (Université de Karlsruhe) et Fethi Filali (Eurecom), 17 Septembre 2008.
  - Co-organisation dans le cadre du pôle Rescom du GDR CNRS ASR d'une journée sur les "Réseaux Véhiculaires – REVE", en collaboration avec Y. Ghamri Doudane et AL. Beylot, Evry, 20 Octobre 2008. Membre du comité de pilotage de cette série de journées thématiques.

- Co-organisation d'un workshop d'une journée intitulé "Réseaux pairs-à-pairs: axes de recherche" avec 9 intervenants dont 6 internes FTRD (W. Saddi, S. Pétrovic, M. Fayçal, F. Mathieu, F. Pianese, E. Le Merrer) et 3 externes (G. Simon, P. Felber, A.-M. Kermarrec) : choix des intervenants et animation de la journée, FTRD Rennes, 21 Novembre 2006.
- Organisation d'un workshop d'une journée intitulé "Ad Hoc Networks – Problems, Applications and Perspectives" avec 8 intervenants : F. A. Tobagi, C. Bettstetter, D. Simplot-Ryl, I. Guerin-Lassous, A. Bouabdallah, H. Afifi, K. Al Agha, M. Torrent-Moreno : choix des intervenants et animation de la journée, FTRD Issy-les-moulineaux, 14 Octobre 2005.
- Organisation de séminaires internes FTRD sur le thème des réseaux light infrastructure, 2005-2009.
- Membre des comités de programme de :
  - Conférences internationaux : IFIP Net-Con'2005, IWWAN'2006, IEEE ICC (2007, 2008, 2009, 2010), IEEE GLOBECOM (2007, 2008, 2009, 2010), CHINACOM'2007, NGMAST'07, WiVeC (2007, 2008), IIT'2007, PIMRC'2008, IFIP Wireless Days Conference (2008), IEEE MWCN (2008, 2009), IEEE VTC (2009, 2010), IEEE GIIS'2009.
  - Workshops internationaux : Ubiroads (2007, 2009), WITS2008, WEEDEV 2009, Vehicom'2009, Vehi Mobi'2010
- Membre du comité d'organisation des congrès scientifiques internationaux : IEEE/IFIP Networking'2000 sur Paris,
- Membre actif du comité d'organisation des congrès scientifiques nationaux DNAC (1999, 2000, 2001, 2002, 2003) sur Paris
- Evaluateur d'articles pour les journaux : Wireless Networks (WINET), IEEE Wireless Communications and Networking (WCNC), Journal of Internet Technology (JIT), Annales des télécom, ACM SIGMOBILE MC2R, Telecommunication Systems Journal, Wireless Communications and Mobile Computing journal, IEEE Wireless Communication Magazine, IEEE Transactions on Vehicular Technology, IEEE Network.
- Evaluateur d'articles pour les conférences : CFIP (2002, 2003), IFIP/IEEE MMNS (2003), ICSIS (2003), IEEE Infocom (2002), IFIP Med-Hoc-Net (2002, 2005), IFIP/IEEE IM (2005, 2006), IEEE VTC'2007, DRCN'2007, IIT 2007, IEEE AINA'2008, IEEE VTC2008-Spring, IFIP/IEEE Networking (2008), Networks2008, IFIP PWC 2008, ASFNS2008, IEEE VTC2009-Spring.
- Président de sessions "Vehicular Communications and Networks" dans ICC2009 et "Emerging Technologies" dans ICC2007, UBIROADS2007, PIMRC2008.

- Administration liée à la recherche
  - Coordinateur de plusieurs projets internes FTRD (voir section parcours professionnel)
  - Responsable de l'équipe réseaux de véhicules au sein de FTRD, 2009.
  - Co-editor et fondateur de l'IEEE ComSoc AHSN (Ad Hoc and Sensor Networks) News Letter en collaboration avec Y. Ghamri-Doudane (University of Evry), Mieso Denko (University of Guelph, Canada), 2008 et 2009.
  - Membre du groupe de travail inter GT NUMATEC Automotive et Transport & Télécoms dans le PdC System@tic, 2008-2009.
  - Contribution à la définition de la roadmap du groupe de réflexion Intercation ICT du PdC System@tic, 2009.

- Contribution à la définition de l'appel Européen FP7 dans le domaine "smart urban transportation systems and mobility", 2009.
- Contribution à la définition des objectifs du club télécom de la SEE, 2009.
- Review d'un projet ANR, 2007.
- Participation au comité de pilotage d'un contrat de recherche collaborative entre FTRD et INRIA Rocquencourt, MARDI (Modèles et Algorithmes pour Réseaux Décentralisés sur Internet), 2006.
- Animation de groupes de travail du DEA réseaux de Paris VI, 2002.
- Membre de Jury des soutenances des étudiants de DESS Ingénierie de l'Internet et des Services Réseaux (I2SR) en 2002 et 2004,
- Membre actif du club télécom de la SEE, 2009.
- Membre de l'IEEE et Communication Society depuis 2000.

7. Projets de recherche

- Projets bilatéraux
  - Académiques (projet entre FTRD et un laboratoire académique expert sur un domaine particulier avec un flux financier)
    - Étude de systèmes de routage overlay, GET INT Evry (2005-2008, 36 mois)**
    - Comportement de TCP dans les réseaux ad hoc mobiles, Université d'Évry (2005-2008, 36 mois)**
    - Diversité spatiale dans les réseaux ad hoc multi sauts, Université de Klagenfurt (2006-2008, 24 mois)**
    - Couches physiques et liaisons pour réseaux fortement dynamiques, Université de Plymouth (2006-2009, 36 mois)**
    - Services réseaux pour la communication entre objets mobiles fortement dynamiques, UTC (co-suivi avec D. Barthel FTRD) (2005-2008, 36 mois)*
    - Protocoles de collecte de données dans les réseaux de véhicules, UTC (2009-2010, 18 mois)**
    - Self-Hybrid access point and ad hoc bases hybrid wireless networks, Technion Israël (2005-2006, 18 mois)*
    - Modèles et Algorithmes pour les Réseaux Décentralisés sur Internet, INRIA Rocquencourt (2006, quelques mois)*
  - Industriels (projet bilatéral entre FTRD et un industriel expert sur un domaine particulier sans aucun flux financier)
    - Hitachi Europe, « Vehicular Networks and Services », depuis Mai 2009**
    - ILAB PEK "Self-organization wireless sensor networks and testbeds", (co-suivi avec D. Barthel FTRD) 2008*
    - ILAB Pologne, « Self-organization vehicular networks and DTN », 2007-2009 (co-suivi avec Y. Gourhant FTRD)**
    - ILAB TOK, « Vehicular Communications in Japan, A Vehicular Context Based Service » 2009**

    (** Suivi et montage, * Suivi seulement)

- Projets collaboratifs

- Projet RIAM MAD GAMES (2007-2010) : Projet ANR dont l'objectif est le développement de middleware réseau permettant le support de jeux vidéo multi-joueurs sur une infrastructure de réseaux sans fil, en mode ad hoc. Partenaires : U. Paris 13, U. Paris 6, Load Inc, FTR&D. Rôle : participation à la rédaction de la proposition de projet et responsable du projet pour FTRD. responsable d'un sous-projet, contributions techniques et encadrement de 4 stagiaires de Master et d'un thésard.
- Projet RNRT Safari (2003-2006) : Projet ANR dont l'objectif est de concevoir, intégrer et mettre en œuvre une architecture de réseau et de service nécessaire à l'accès transparent, la configuration automatique, l'intégration et l'adaptation des services sur un réseau IPv6 en mode ad hoc, comportant des interconnections filaires. Quelques partenaires : France Telecom R&D, Alcatel R&I, INRIA, LIP6, LRI, LSIIT, LSR-IMAG, SNCF, ENST. Rôle : participation à la rédaction de la proposition et quelques contributions techniques au projet.
- Projet ITEA Ambience (2001-2003): Projet ITEA se focalisant sur la création d'un environnement numérique adaptatif au contexte (CAE - Context Aware Environment). Quelques partenaires : Philips, ENST, FTRD, LIP6, Thomson multimedia, VTT, Barco., etc. Rôle : co-responsabilité du projet pour le LIP6 et participation au projet, co-encadrement de 2 stagiaires.
- Projet RNRT Constellation de satellites (1999-2001) : Projet ANR traitant les différents problèmes posés par les constellations de satellites de type LEO et MEO pour le transport d'applications multimédias. Quelques partenaires : PRiSM, INT, FTRD, Alcatel, CNES, Astrium, etc. Rôle : contributions techniques au projet.
- Projet RNRT MAGDA - Modélisation et Apprentissage pour une Gestion Distribuée des Alarmes (2001-2003) : Projet ANR traitant de la supervision des réseaux de télécommunications. Quelques partenaires : LIPN, FTRD, IRISA, Alcatel. Rôle : contributions techniques au projet.