Agència de Gestió d'Ajuts Universitaris i de Recerca

UNIÓ EUROPEA
Fons Social Europeu

Memòria justificativa de recerca de les beques predoctorals per a la formació de personal investigador (FI)

La memòria justificativa consta de les dues parts que venen a continuació:
1.- Dades bàsiques i resums
2.- Memòria del treball (informe científic)

Tots els camps són obligatoris

1.- Dades bàsiques i resums

Títol del projecte ha de sintetitzar la temàtica científica del vostre document.
Information Mobility: Information Dissemination in Mobile Networks
(Mobilitat de la informació: Difusió d'Informació en Xarxes Mòbils

Dades de l'investigador (benficiari de l'ajut)

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Universitat Politècnica de Catalunya,
Departament d'Arquitectura de Computadors

Número d'expedient
2011FI_B2 0001

Paraules clau: cal que esmenteu cinc conceptes que defineixin el contingut de la vostra memòria.
xarxes wireless, xarxes oportunístiques, informació tolerant retard, estalvi d'energia, models de mobilitat

Data de presentació de la justificació
03/02/2012

Nom i cognoms, i signatura del beneficiari/ària

Vist i plau del/de la director/a del projecte

Generalitat de Catalunya
Departament d'Economia i Coneixement

Resum en la llengua del projecte (màxim 300 paraules)

En el nostre projecte, considerem un escenari urbà o interurbà on persones amb dispositius mòbils (smartphones) o vehicles equipats amb interfícies de comunicació, estan interessats en compartir fitxers entre ells o descarregar-los al creuar Punts d'Accés (APs) propers a la carretera. Estudiem la possibilitat d'utilizar la cooperació en les trobades casuals entre nodes per augmentar la velocitat de descàrrega global. Amb aquest objectiu, plantejem algoritmes per a la selecció de quins paquets, per a quins destins i quins transportistes s'escullen en cada moment.

Mitjançant extenses simulacions, mostrem com les cooperacions carry&forward dels nodes augmenten significativament la velocitat de descàrrega dels usuaris, i com aquest resultat es manté per a diversos patrons de mobilitat, col•locacions d'AP i càrregues de la xarxa.

Per altra banda, aparells com els smartphones, on la targeta de WiFi està encesa contínuament, consumeixen l'energia de la bateria en poques hores. En molts escenaris, una targeta WiFi sempre activa és poc útil, perque sovint no hi ha necessitat de transmissió o recepció. Aquest fet es veu agreujat en les Delay Tolerant Networks (DTN), on els nodes intercanvien dades quan es creuen i en tenen l'oportunitat.

Les tècniques de gestió de l'estalvi d'energia permeten extendre la duració de les bateries. El nostre projecte analitza els avantatges i inconvenients que apareixen quan els nodes apaguen períodicament la seva targeta wireless per a estalviar energia en escenaris DTN.

Els nostres resultats mostren les condicions en que un node pot desconnectar la bateria sense afectar la probabilitat de contacte amb altres nodes, i les condicions en que aquesta disminueix. Per exemple, es demostra que la vida del node pot ser duplicada mantenint la probabilitat de contacte a 1. I que aquesta disminueix ràpidament en intentar augmentar més la vida útil.

Resum en anglès(màxim 300 paraules)
We consider a complex road or urban scenario where pedestrians or vehicles equipped with communication interfaces are interested in sharing files from node to node or downloading large files from road-side Access Points (APs). We investigate the possibility of exploiting opportunistic encounters among mobile nodes so to augment the transfer rate experienced by downloaders. To that end, we devise solutions for the selection of carriers and data chunks at the APs.

Through extensive simulations, we show that carry&forward transfers can significantly increase the download rate of users in urban/suburban environments, and that such a result holds throughout diverse mobility scenarios, AP placements and network loads.

Moreover, wireless nodes such as smart-phones in which the WiFi wireless card is continuously on, consume battery energy in just a few hours. In many scenarios, an always-on wireless card is useless because there is often no need for transmission or reception. This fact is exacerbated in Delay Tolerant Network (DTN) environments, in which nodes exchange data when they meet.

Power Saving Management techniques enable the lifetime of the nodes to be extended. Our project analyses the trade-offs that appear when wireless nodes periodically turn off the wireless card in order to save battery in DTN environments.

Our results show the conditions in which a node can switch off the battery without impacting the peer-to-peer contact probability, and those in which this contact probability is decreased. For example, it is shown that node lifetime can be doubled while keeping the peer-to-peer contact probability equal to one. But, further increase of the node lifetime quickly decreases peer-to-peer contact probability.

2.- Memòria del treball (informe científic sense limitació de paraules). Pot incloure altres fitxers de qualsevol mena, no més grans de 10 MB cadascun d'ells.

Veure document adjunt:
MemoriaJustificativaDeRecerca-Trullols-InformationMobility.pdf

Memòria Justificativa de Recerca*
Information Mobility: Information Dissemination in Mobile Networks

Oscar Trullols Cruces,
Tutor de Tèsi: José M^a Barceló Ordinas

February 1, 2012

*Aquest treball ha estat realitzat amb el suport econòmic de la Generalitat de Catalunya, mitjançant un contracte predoctoral per a la formació de personal investigador novell FI-DGR amb número d'expedient 2011FI-B2 00019

Contents

1 Introduction

1.1 Motivation

In the beginning, Internet was planned as a network to share resources between research labs, the network had low requirements, the traffic volume was quite small and there were no quality requirements or security concerns. In 1988 the first commercial interests on Internet began, but Internet waited a decade before gaining a public face, with the World Wide Web project and the first web browsers(1991). ISPs population increased rapidly, starting the second phase of development. New killer applications appeared, like the peer-to-peer file sharing, gaining widespread popularity and leading to an explosion in both the number of connected hosts and the traffic they generate. Industry's effort during the nineties was devoted to dealing with this phenomenon.

In 1991 the precursor to Wi-Fi was invented and we can find the first 802.11 Wi-Fi patents from 1996. This was the first step to make Internet available without wires, you just have to be close to an Access Point to connect to the Internet at very high bandwidths.

Nowadays people is used to Internet, and there is an interest in accessing it from anywhere at anytime. For example, in some use cases, people use it just to check the email from an airport, to find directions or use online maps in a city, read the last minute news during a bus trip, finding restaurants and facilities around their current position, instant messaging, gaming, online radios, and a lot of services still under development. The penetration rate and stakeholders are increasing, we are not talking about future applications and services anymore, the interest exists and we can find people using them on the streets.

Currently, users connect to Internet at streets using the Cellular network (3G), but it has some drawbacks: (i) It is expensive, (ii) at cities it has some zones where you can not find a good coverage or where it disappears suddenly, (iii) at smaller cities or towns, it could be hard even finding coverage, (iv) the bandwidth offered by the current technology is low for some applications, (v) and Cells are big, there are a lot of people inside each cell and 3G could not offer enough bandwidth to each user if there is a high penetration of mobile users connecting at the same time (e.g football stadiums, beach towns in summer).

Future 4G also known as LTE (Long Term Evolution) is expected to improve the bandwidth in the cells. But Cellular networks have another problem, the backhaul (the intermediate links between the core, or backbone, of the network and the small subnetworks at the edge) were not deployed planning to support the aggregation of several high bandwidth edge subnetworks. And it will be very expensive to improve them, so this upgrade will have to wait until companies can afford the inversion (while for example, Spain is still deploying 3G and 3.5G).

On the other side, ad hoc wireless networks, are cheaper and much easier to deploy. Users travel, move with information in their devices (music, videos, cached news just downloaded from a wired network, content generated on the run by the users themselves, ...) and these devices already have wireless interfaces. So, "*Information Mobility*" already exists, and we just want to let the users share their resources in order to obtain some of the services they would expect from Internet and also to offer some new services that appear in these scenarios.

The concept of *Information Mobility* referes to Information Dissemination in Mobile Networks. It is introduced to point out that the contents are being stored in mobile nodes and that the contents move and replicate before being accessed, following a store, carry and forward model instead of a receive and forward or discard if next hop is unavailable. So, to clarify, throughout this document, when we make use the term "Information Mobility", we refere to "Information Dissemination in Mobile Networks".

New Internet services and applications are also characterized by the increasing role played by end users who have already became content and applications producers and providers. In the proposed evolution, additionally, end users may also be the carriers of the information.

We have been used to Internet first and wireless communications later, soon we will use them everywhere, Cellular networks can be a good choice, but they also have some drawbacks and the Wireless networks based on Wifi and the Information Mobility Paradigm have their chance to complement Cellular weaknesses.

1.2 Scope and outline of the document

Our project focuses mainly, but not exclusively, on the development and analysis of algorithms and solutions to deal with Information Mobility in real scenarios: (i) Using the cooperation among nodes to improve the performance of this kind of networks; (ii) planning the Access Point and/or Roadside Unit deployment to disseminate information to nodes more effectively; (iii) proposing and studying the effects on Network metrics of Power Saving Management techniques to extend battery lifetime of wireless nodes; (iv) and the analysis of Random Linear Network Coding techinques, that offer great advantages in this kind of scenarios, to define precisely the decoding probability. Before our research, just an upper bound was known for this decoding probability.

The idea for this Thesis, had its origins in a Network of Excelence (NoE) European project where we participated, called "Information Mobility", leaded by my PhD advisor Jose M. Barcelo-Ordinas, Claudio Casetti, Gunnar Karlsson and Susana Sargento. During the project, we settled the framework and first ideas that we have developed during my thesis. Information Mobility inherits some ideas proposed for Wireless Sensor Networks, Pedestrian Networks, Vehicular AdHoc Networks, Delay Tolerant Networks and Content Distribution Networks. In fact, our Information Mobility Paradigm, will consist in pedestrian or vehicular nodes that contact other nodes. They use infrastructure and wireless sensors placed along streets or roads to obtain some delay tolerant services from some content distribution networks. This content can be distributed among several nodes, in order to improve their access to the data when nodes can not find infrastructure to access to the wired network.

This document is organized as follows, next sections enumerate the related work and background on Vehicular Ad Hoc Networks and Pedestrian Networks related to the paradigm of Information Mobility: Section 2 eviews Content Distribution networks from a general point of view and how they can be seen from the DTN perspective; Section 3 describes Mobile Ad hoc networks, and Section 4 shows the main characteristics of DTN. While Section 5 discusses the Information Mobility Paradigm. A summary of the original work published in the context of our research is provided in Section 6. Finally, Conclusions are given in section 7.

2 Content Distribution Networks

Content distribution networks (CDN) are a mature technology. But until the moment, content delivery research in *wireless ad hoc networks* has been faced and treated as wired networks with a wireless last hop dealt with overlay applications, with information querying and with data broadcasting techniques (e.g. as we did for a vehicular scenario in [2] or others like [14]).

The idea that networks should provide access to contents, rather than to hosts, is currently permeating researchers (see for instance content-centric networking at [15]). This idea is manifested in content distribution networks based on peer-to-peer networks of hosts where contents are stored on an infrastructure of large caching nodes located close to edge networks. In our project, we explore the concept with respect to wireless ad hoc networks: nodes want to access to a data but they don't care where this data comes from, or which nodes are sending or forwarding it.

Content distribution in wired networks is focused on acceleration techniques. Paper [16] categorizes them into: *(i) Network scaling* that distributes contents in the network; it has web caching and CDN as examples (content delivery networks such as Akamai). *(ii) Endpoint acceleration* (load balancing techniques on servers). *(iii) Protocol and content optimization* such as HTTP, TCP or coding techniques.

If we shift our attention to the Wireless scenario, proposed ideas mainly work as follows: *(i)* a wireless user requests content from Internet servers by wireless access through a base station; *(ii)* the server sends the reply for the request to the Base Station acting as a gateway support node (GSN), *(iii)* the GSN (or BS) forwards the content through the air interface.

If we go one step further: in this system we could take profit from our knowledge about node mobility, and we can use the mobile nodes as one-hop cooperators. Using cooperators to carry-&-forward packets to the destination node, see [2].

3 Mobile Ad Hoc Networks

Mobile Ad Hoc Networks (MANETs) are characterized as networks in which nodes, static or mobile, act as a host **and** as a router extending the one-hop coverage area of a single wireless network. These networks are self-organized, and typically, nodes follow random mobility patterns. Mobile Ad Hoc Network consider all kind of Mobile nodes, but for our case, we base our work mainly on pedestrians [17] and vehicles[18].

MANETs may be impacted by several factors:

- high velocity of the nodes,
- environment factors,
- determined mobility patterns that depend on source to destination path and on street/roads conditions,
- intermittent communications (isolated nodes or small clusters due to the fragmentation of the network) and possible need of efficient geo-casting and flooding mechanisms,
- high congestion channels (e.g. due to high density of nodes)

Packets traverse an ad hoc network by being relayed from one node to another until they reach their destination. Because nodes are moving, the topology of the network is in constant change, and to find the destination and the route could be a hard challenge. Routing in mobile ad hoc networks is a well-studied topic, several routing protocols have been proposed, such as OLSR [19], AODV [20], DSR [21], or a review of routing protocols for mobile ad hoc networks [22].

These solutions are very useful in some kind of networks, but they would not work under our proposed scenarios because they incorrectly assume the existence of:

- An end-to-end path between any pair of nodes.
- Small maximum round-trip time between them.
- Small hop-by-hop and end-to-end packet drop probability.

Due to this inherent limitations, in our scenario, Information Mobility applications should be designed as applications and Services tolerant to the delay. And a huge amount of research is already done in *Delay tolerant Networks (DTN)* (see next Section 4).

4 Delay Tolerant Networks

If we compare DTN [23] with common Internet characteristics, the main differences are:

Network partitions: End-to-end disconnection may be more common than connection, and a consequence of a fault or not. DTN protocols must to understand that the lack of reachability may be the result of a normal situation.

High latency, long queuing times: The challenging medium affects the transmission and propagation delays. On the common networks, queuing time rarely exceeds a second and if next-hop neighbors are not instantaneously reachable packets are discarded. On DTN, queuing time could be extremely large.

Uncertain Error probability: On common networks, links could offer a delimited error probability, while at DTN the error probability of a link may change unexpectedly.

Limited Devices: In some kinds of delay tolerant networks nodes with highly restricted power, memory or processing capability are used, due to price, technical or size limitations.

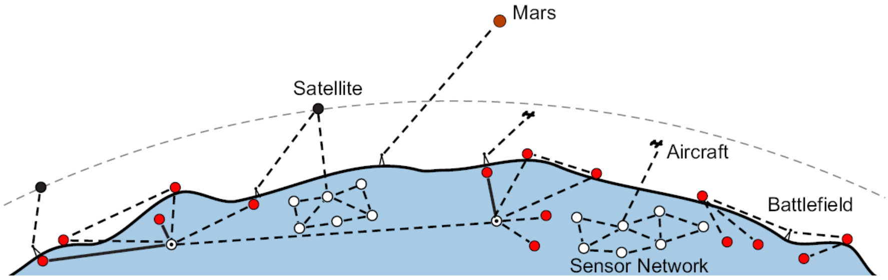

Figure 1: DTN networks, taken from paper [23])

Kevin Fall [24] faces the DTN challenges studing which features of the common and experienced Internet protocols will fit in the delay tolerant scenario and which features should be avoided.

Most of the problems come from the Internet's idea of *fate sharing*. One of the Internet basis' idea was that the per-connection state should remain only in the ends, to avoid that a failure in any of the forwarding nodes of the path could heavily impact the connection. But in some scenarios of DTNs, it would be very useful to allow the end nodes to delegate their end-node connection state to other nodes.

Based on Internet experience, the DTN system should have an overlay routing capability, similar of that used in peer-to-peer systems, combined with a delay an disconnection tolerant properties similar of that used by electronic mail.

The RFC4838 (Delay-Tolerant Networking Architecture [25]) proposes a general architecture to overcome all the previous challenges based on store-and-forward message switching. It is based on asynchronous messaging and uses postal mail as a model of service classes and delivery semantics. It introduces a novel approach to end-to-end reliability across frequently partitioned and unreliable networks and proposes a model for securing the network infrastructure against unauthorized access.

Blocks of user data, called **bundles** (RFC5050, see [26]), are forwarded from the source to a storage on another node, that assumes the responsibility for reliable delivery of the bundle to its destination, these nodes are called **custodians**. The bundle would travel along a path of custodians that eventually reaches the destination (e.g [27]). Figure 2.

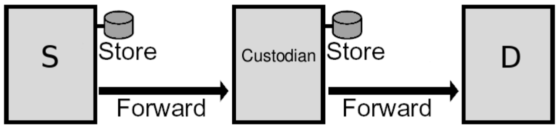

Figure 2: Custodians may store bundles for long times in persistent storage

5 The Information Mobility Paradigm

The aims of information mobility in an ad hoc network are twofold:

- to bridge gaps in content availability due to the lack of coverage of infrastructure networks, for information travelling from the infrastructure to the ad hoc domain,
- to make content of local relevance available in a designated area with arbitrarily high probability over any time period.

The first aim requires a protocol for information exchange, and it depends on the connectivity of the ad hoc network. This problem has been addressed by several proposals in recent years. While some suggest the use of explicit routing, other proposals focus on general dissemination based on replication of data [28, 29, 30]. The main issue is when and to whom to forward a content item. Note that this includes replication where a node forwards multiple copies of the item in order to face uncertainty in forwarding decisions.

The second aim of the information mobility requires two additional functions. First, the forwarding has to be geographically scoped in order to limit the availability of a content item to within its geographic scope of relevance. The second function is to provide custody of the contents in order to make them available also over time (see [31] for some work on custodianship in delay-tolerant networks).

The forwarding of a content item to a specific node whose past locations are known need to estimate the forwarding node's movement trajectory and the trajectory of the node it peers with [32]. Replication might be used to hedge against uncertainty in the information that is used for the forwarding decisions [14]. The representation and estimation of movement trajectories is not solved, and how to take decisions for replication is also open.

Cache management and garbage collection are both necessary in the network nodes. The cache management has to weigh content availability in the network against conservation of nodal storage [33]; garbage collection weighs opportunistic forwarding of requests and contents for increasing the probability of matching against the cost in terms of communication resources. Both processes are vital and difficult, especially in view of the long-term availability of content in the network that might exceed any node's sojourn time in the area.

In brief, information mobility means that information is provided in a wireless domain at the locations where it is requested, irrespective of where it originated and of how the nodes of the network are moving.

6 Summary of original work

The aim of our work was to develop the idea of Information Mobility, studing and improving several aspects of this paradigm. During this project we have divided our efforts in different lines of work. Each one has their own entity and is completely meaningful beyond our paradigm, in their own field of knowledge (e.g. Vehicular Networks, MANET, Network Coding, ...), but we think that the synergies among the different topics, help to get a better overall picture of our intended scenario.

Our project focuses, mainly, on the development and analysis of algorithms and solutions to deal with Information Mobility in real scenarios. And every line of work can be summarized as follows:

1. Using the **cooperation among nodes** to improve the performance of this kind of networks;
2. planning the Access Point and/or **Roadside Unit deployment** to disseminate information to nodes more effectively;
3. proposing and studying the effects on Network metrics of **Power Saving Management techniques** to extend battery lifetime of wireless nodes;
4. the **analysis of Random Linear Network Coding** techinques, that offer great advantages in this kind of scenarios, to define precisely the decoding probability. Before our research, just an upper bound was known for this decoding probability;
5. and other independent projects and collaborations with international research groups, about the impact of the Infrastructure in Information Mobility Scenarios, and Mobility Modeling Challenged by Feedback Loops.

6.1 Opportunistic Cooperation

6.1.1 Paper: Cooperative download in vehicular environments [1]

Authors: Oscar Trullols-Cruces, Marco Fiore, Jose M. Barcelo-Ordinas
Published in: IEEE Transactions on Mobile Computing (TMC), Issue 99
Date: 2011
Impact Factor and/or CORE rank: 2.647, A*

Summary:
We consider a complex (i.e., non-linear) road scenario where users aboard vehicles equipped with communication interfaces are interested in downloading large files from road-side Access Points (APs). We investigate the possibility of exploiting opportunistic encounters among mobile nodes so to augment the transfer rate

experienced by vehicular downloaders. To that end, we devise solutions for the selection of carriers and data chunks at the APs, and evaluate them in real-world road topologies, under different AP deployment strategies. Through extensive simulations, we show that carry&forward transfers can significantly increase the download rate of vehicular users in urban/suburban environments, and that such a result holds throughout diverse mobility scenarios, AP placements and network loads.

6.1.2 Paper: A Cooperative Vehicular Network Framework [2]

Authors: O. Trullols-Cruces, J. Morillo-Pozo, J. M. Barcelo-Ordinas, J. Garcia-Vidal
Published in: IEEE International Conference on Communications ICC '09, Dresden, Germany,
Date: 2009
Impact Factor or CORE rank: A

Summary:
Vehicular Ad Hoc Networks are networks characterized by intermittent connectivity and rapid changes in their topology. This paper addresses car-to-road communications in which vehicles use Access Points (AP) in a Delay Tolerant Network architecture. Results show how the combination of a Delay-Cooperative ARQ mechanism reduces packet losses and in conjunction with a Carry-and-Forward cooperative mechanism improves performance parameters in terms of total file transfer delay and number of AP needed to download files.

6.1.3 Paper: A Cooperative ARQ for Delay-Tolerant Vehicular Networks [3]

Authors: J. Morillo-Pozo, J. M. Barcelo-Ordinas, **O. Trullols-Cruces**, J. Garcia-Vidal
Published in: IEEE International Workshop on Delay-Tolerant Mobile Networks (DTMN'08),
Date: 2008
Impact Factor or CORE rank: B (was A until ERA2010 conference list)

Summary:
This paper proposes a Cooperative ARQ protocol to be used in delay-tolerant vehicular networks. The proposed scheme has been implemented and evaluated through an experimental testbed, showing that packet losses in transmissions from an access point to cars can be reduced to the half without any cost as long as cooperation takes place on areas where connectivity with access points is not present. In these areas, cars in a platoon recover from other cars packets that they have failed to receive from the access point.

6.1.4 Paper: Evaluation of a Cooperative ARQ Protocol for Delay-Tolerant Vehicular Networks [4]

Authors: J. Morillo-Pozo, J. M. Barcelo-Ordinas, **O. Trullols-Cruces**, J. Garcia-Vidal
Published in: Lecture Notes in Computer Science (LNCS), Volume 4396, pp 43-61,
Date: 2008
Impact Factor or CORE rank: 0.4

Summary:
This paper evaluates a Cooperative ARQ protocol to be used in delay-tolerant vehicular networks. The scenario consists in cars downloading information from Access Points along a road. The key difference between proposed Cooperative ARQ protocols is when the cooperation takes place. Simply C-ARQ cooperation occurs in a packet-by-packet basis. In this proposal, that we call DC-ARQ (Delayed Cooperative ARQ), the cooperation is delayed until cars are out of the coverage area of the Access Point. The scheme has been evaluated through simulations. A comparison of DC-ARQ with a baseline case in which no cooperation is used has been performed under different vehicle densities scenarios.

6.1.5 Paper: Applying Cooperation for Delay Tolerant Vehicular Networks [5]

Authors: J. Morillo-Pozo, J. M. Barcelo-Ordinas, **O. Trullols-Cruces**, J. Garcia-Vidal
Published in: Fourth EuroFGI Workshop on Wireless and Mobility 2008, Barcelona, Spain
Date: 2008
Impact Factor or CORE rank: -

Summary:
This paper proposes a Cooperative ARQ protocol to be used in delay-tolerant vehicular networks. The proposed scheme has been implemented and evaluated through an experimental testbed, showing that packet losses in transmissions from an access point to cars can be reduced to the half without any cost as long as cooperation takes place on areas where connectivity with access points is not present. In these areas, cars in a platoon recover from other cars packets that they have failed to receive from the access point

6.2 Roadside Unit deployment for information dissemination

6.2.1 Paper: RSU Deployment for Content Dissemination and Downloading in Intelligent Transportation Systems [6]

Authors: M. Reineri and C. Casetti and C.F. Chiasserini and M. Fiore and **O. Trullols-Cruces** and J.M. Barcelo
Submitted: Submitted as a Book Chapter to "Roadside Networks for Vehicular Communications: Architectures, Applications and Test Fields"
Date: 2012
Impact Factor or CORE rank: -

Summary:
The focus of this Chapter is twofold: information dissemination from infrastructure nodes deployed along the roads, the so-called road-side units (RSUs), to passing-by vehicles, and content downloading by vehicular users through nearby RSUs. In particular, in order to ensure good performance for both content dissemination and downloading, the presented study addresses the problem of RSU deployment and reviews previous work that has dealt with such an issue. The RSU deployment problem is then formulated as an optimization problem, where the number of vehicles that get in contact with any RSU is maximized, possibly considering a minimum contact time to be guaranteed. Since such optimization problems turn out to be NP-hard, heuristics are proposed to efficiently approximate the optimal solution. The RSU deployment obtained through such heuristics is then used to investigate the performance of content dissemination and downloading through ns2 simulations. Simulation tests are carried out under various real-world vehicular environments, including a realistic mobility model, and considering that the IEEE 802.11p standard is used at the physical and medium access control layers. The performance obtained in realistic conditions is discussed with respect to the results obtained under the same RSU deployment, but in ideal conditions and protocol message exchange. Based on the obtained results, some useful hints on the network system design are provided.

6.2.2 Paper: Planning Roadside Infrastructure for Information Dissemination in Intelligent Transportation Systems [7]

Authors: O. Trullols-Cruces, M. Fiore, C. Casetti, C.F. Chiasserini, J.M. Barcelo-Ordinas,
Published in: Published in Computer Communications, Elsevier,
Date: January 2010
Impact Factor or CORE rank: 0.933

Summary:

We consider an intelligent transportation system where a given number of infrastructured nodes (called Dissemination Points, DPs) have to be deployed for disseminating information to vehicles in an urban area. We formulate our problem as a Maximum Coverage Problem (MCP) and we seek to maximize the number of vehicles that get in contact with the DPs over the considered area. The MCP is known to be NP-hard in its standard formulation, therefore we tackle it through heuristic algorithms, which present different levels of complexity and require different knowledge on the system. Next, we address the problem of guaranteeing that a large number of vehicles travel under the coverage of one or more DPs for a sufficient amount of time. We therefore give a different formulation of the problem, which however is still NP-hard and requires a heuristic approach to be solved. By evaluating the proposed solutions in a realistic urban environment, we observe that simple heuristics provide near-optimal results even in large-scale scenarios. However, we remark that a near-optimal coverage of mobile users can be achieved only when the characteristics of vehicular mobility are known.

6.2.3 Paper: A Max Coverage Formulation for Information Dissemination in Vehicular Networks [8]

Authors: O. Trullols-Cruces and M. Fiore and C. Casetti and C.F. Chiasserini and J.M. Barcelo
Published in: IEEE Int. Conf. on Wireless and Mobile Computing, Networking and Communications,Marrakech, Morocco,
Date: 2009
Impact Factor or CORE rank: C

Summary:
We consider that a given number of Dissemination Points (DPs) have to be deployed for disseminating information to vehicles travelling in an urban area. We formulate our problem as a Maximum Coverage Problem (MCP) so as to maximize the number of vehicles that get in contact with the DPs and as a second step with a sufficient amount of time. Since the MCP is NP-hard, we solve it though heuristic algorithms. Evaluation of the proposed solutions in a realistic urban environment shows how knowledge of vehicular mobility plays a major role in achieving an optimal coverage of mobile users, and that simple heuristics provide near-optimal results even in large-scale scenarios.

6.2.4 Paper: Information Dissemination in VANETs: Deployment Strategies for Maximizing Coverage [9]

Authors: O. Trullols and M. Fiore and C. Casetti and C.F. Chiasserini and J.M. Barcelo
Published in: Euro-NF Workshop on Wireless and Mobility, Stresa, Lake Maggiore, Italy,

Date: 2009
Impact Factor or CORE rank: -

Summary:
We consider that a given number of Dissemination Points (DPs) have to be deployed for disseminating information to vehicles travelling in an urban area. We formulate our problem as a Maximum Coverage Problem (MCP) so as to maximize the number of vehicles that get in contact with the DPs. Since the MCP is NP-hard, we solve it though heuristic algorithms. Evaluation of the proposed solutions in a realistic urban environment shows how knowledge of vehicular mobility plays a major role in achieving an optimal coverage of mobile users, and that simple heuristics provide near-optimal results even in large-scale scenarios.

6.3 Power Saving Management techniques

6.3.1 Paper: Power Saving Trade-offs in Delay/Disruptive Tolerant Networks [10]

Authors: **O. Trullols** and J. Morillo and J. M. Barcelo and J. Garcia-Vidal,
Published in: IEEE WoWMoM 2011, Lucca,
Date: 2011
Impact Factor or CORE rank: A

Summary:
Wireless nodes such as smart-phones in which the WiFi wireless card is continuously on, consume battery energy in just a few hours. Moreover, in many scenarios, an always-on wireless card is useless because there is often no need for transmission and/or reception. This fact is exacerbated in Delay/Disruptive Tolerant Network (DTN) environments, in which nodes exchange Delay Tolerant Objects (DTO) when they meet. Power Saving Management (PSM) techniques enable the lifetime of the nodes to be extended. This paper analyses the trade-offs that appear when wireless nodes periodically turn off the wireless card in order to save battery in DTN environments. The paper shows the conditions in which a node can switch off the battery without impacting the peer-to-peer contact probability, and those in which this contact probability is decreased. For example, it is shown that node lifetime can be doubled while keeping the peer-to-peer contact probability equal to one. But, further increase of the node lifetime quickly decreases peer-to-peer contact probability. Finally, the impact of power savings in DTO dissemination time is also analyzed.

6.4 Analysis of Random Linear Network Coding

6.4.1 Paper: Exact Decoding Probability Under Random Linear Network Coding [11]

Authors: O. Trullols-Cruces, J.M. Barcelo-Ordinas, M. Fiore,
Published in: IEEE Communication Letters, January 2011, ISSN:1089-7798, (online)
Date: November 2010
Impact Factor or CORE rank: 1.140

Summary:
In this letter, we compute the exact probability that a receiver obtains N linearly independent packets among K ¿ N received packets, when the sender/s use/s random linear network coding over a Galois Field of size q. Such condition maps to the receivers capability to decode the original information, and its mathematical characterization helps to design the coding so to guarantee the correctness of the transmission. Our formulation represents an improvement over the current upper bound for the decoding probability, and provides theoretical grounding to simulative results in the literature.

6.5 Other publications

6.5.1 Paper: VANET Mobility Modeling Challenged by Feedback Loops(Invited Paper) [12]

Authors: H. Meyer and **O. Trullols** and A. Hess and K.A. Hummel and J.M. Barcelo and C.E. Casetti and G. Karlsson,
Published in: 10th IEEE/IFIP Annual Mediterranean Ad Hoc Networking Workshop (IEEE/IFIP Med-Hoc-Net 2011),
Date: 2011
Impact Factor or CORE rank: -

Summary:
VANET applications are often providing street traffic information to vehicles and drivers, regarding, for instance, traffic conditions and parking space availability. This information influences in turn the driving behavior in real-world settings. Mobility models used in current VANET simulations are mostly ignoring this feedback entirely. In cases the feedback is included, it is mainly based on ad-hoc approaches with lack of generality. With this paper, we contribute to the investigation of such feedback loops within VANETs by describing the levels at which feedback loops can be introduced, i.e., on strategic, tactical, and operational levels of mobility. We further describe how feedback loops can be introduced in arbitrary mobility models and in particular in elementary mobility models. We exemplify our ap-

proach by introducing two types of feedback loops for the Manhattan Mobility model, the Random Trip model, and the Constrained Random Trip model. One feedback loop represents points of interest attracting vehicles, such as free parking spaces attracting vehicles searching for parking. The other feedback loop focuses on repelling vehicles, such as a traffic jam. We discuss the impacts of the feedback in terms of the mobility metrics: vehicle density per area, number of direction changes, and intensity of direction changes. Furthermore, we discuss the effects in terms of information availability and delays of transmission in an opportunistic vehicular network.

6.5.2 Paper: Impact of the Infrastructure in Mobile Opportunistic Networks(Invited Paper) [13]

Authors: O. Trullols and J. Morillo and J. M. Barcelo,

Published in: 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2011)
Date: 2011
Impact Factor or CORE rank: -

Summary:
Epidemic modeling has been used to analyze many disciplines such as biology, ecology and medicine. In the last years, it also has been applied to networking paradigms such as social networks, virus spreading in Internet and lastly to opportunistic networking in mobile networks. In this paper we revise some of the facts of epidemic modeling in mobile networks and use these models to analyze the impact of adding infrastructure to sparse opportunistic mobile networks. We show how the position in which infrastructure is placed takes an important impact in the dissemination delay.

7 Conclusions and results

The work presented here is part of my ongoing Doctoral Thesis. We are still working on some additional projects and extensions of the previous work that we hope that will obtain some interesting results. We intend to publish them at important Conferences and Journals in our area, we target IEEE INFOCOM and IEEE Transactions on Mobile Computing for two of our last submissions before the Theses defense.

But so far, we have already obtained excellent results, we have published in:

7.1 Journals

1. IEEE Transactions on Mobile Computing, Impact Factor 2.647,
2. IEEE Communication Letters, impact factor 1.140,
3. IEEE Computer Communications, impact factor 0.933,

7.2 Conferences

1. IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks, WoWMoM, CORE list: A
2. IEEE International Conference on Communications, ICC, CORE list: B
3. IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, WiMob, Not ranked yet
4. International Symposium on Applied Sciences in Biomedical and Communication Technologies (Invited Paper)

7.3 Workshops

1. IEEE Workshop on Delay-Tolerant Mobile Networks DTMN, in conjuction with 28th International Conference on Distributed Computing Systems ICDCS
2. IEEE/IFIP Annual Mediterranean Ad Hoc Networking Workshop (Invited Paper)
3. SPRINGER-VERLAG Lecture Notes in Computer Science
4. EuroFGI Workshop on Wireless and Mobility
5. Euro-NF Workshop on Wireless and Mobility

7.4 Book Chapters

1. (submitted and in its final revision) "Book: Roadside Networks for Vehicular Communications: Architectures, Applications and Test Fields", ed. by R. Daher, A. Vinel, IGI Global

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[12] H. Meyer, **O. Trullols**, A. Hess, K. Hummel, J. Barcelo, C. Casetti, and G. Karlsson, "VANET Mobility Modeling Challenged by Feedback Loops (Invited Paper)," in *10th IEEE/IFIP Annual Mediterranean Ad Hoc Networking Workshop (IEEE/IFIP Med-Hoc-Net 2011)*, 2011.

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Fons Social Europeu

Memòria justificativa de recerca de les beques predoctorals per a la formació de personal investigador (FI)

La memòria justificativa consta de les dues parts que venen a continuació:
1.- Dades bàsiques i resums
2.- Memòria del treball (informe científic)

Tots els camps són obligatoris

1.- Dades bàsiques i resums

Títol del projecte ha de sintetitzar la temàtica científica del vostre document.
Information Mobility: Information Dissemination in Mobile Networks
(Mobilitat de la informació: Difusió d'Informació en Xarxes Mòbils

Dades de l'investigador (benficiari de l'ajut)

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Dades de la universitat / centre al que s'està vinculat

Universitat Politècnica de Catalunya,
Departament d'Arquitectura de Computadors

Número d'expedient
2011FI_B2 0001

Paraules clau: cal que esmenteu cinc conceptes que defineixin el contingut de la vostra memòria.
xarxes wireless, xarxes oportunístiques, informació tolerant retard, estalvi d'energia, models de mobilitat

Data de presentació de la justificació
03/02/2012

Nom i cognoms, i signatura del beneficiari/ària

Vist i plau del/de la director/a del projecte

Generalitat de Catalunya
Departament d'Economia i Coneixement

Resum en la llengua del projecte (màxim 300 paraules)
En el nostre projecte, considerem un escenari urbà o interurbà on persones amb dispositius mòbils (smartphones) o vehicles equipats amb interfícies de comunicació, estan interessats en compartir fitxers entre ells o descarregar-los al creuar Punts d'Accés (APs) propers a la carretera. Estudiem la possibilitat d'utilizar la cooperació en les trobades casuals entre nodes per augmentar la velocitat de descàrrega global. Amb aquest objectiu, plantejem algoritmes per a la selecció de quins paquets, per a quins destins i quins transportistes s'escullen en cada moment.

Mitjançant extenses simulacions, mostrem com les cooperacions carry&forward dels nodes augmenten significativament la velocitat de descàrrega dels usuaris, i com aquest resultat es manté per a diversos patrons de mobilitat, col•locacions d'AP i càrregues de la xarxa.

Per altra banda, aparells com els smartphones, on la targeta de WiFi està encesa contínuament, consumeixen l'energia de la bateria en poques hores. En molts escenaris, una targeta WiFi sempre activa és poc útil, perque sovint no hi ha necessitat de transmissió o recepció. Aquest fet es veu agreujat en les Delay Tolerant Networks (DTN), on els nodes intercanvien dades quan es creuen i en tenen l'oportunitat.

Les tècniques de gestió de l'estalvi d'energia permeten extendre la duració de les bateries. El nostre projecte analitza els avantatges i inconvenients que apareixen quan els nodes apaguen períodicament la seva targeta wireless per a estalviar energia en escenaris DTN.

Els nostres resultats mostren les condicions en que un node pot desconnectar la bateria sense afectar la probabilitat de contacte amb altres nodes, i les condicions en que aquesta disminueix. Per exemple, es demostra que la vida del node pot ser duplicada mantenint la probabilitat de contacte a 1. I que aquesta disminueix ràpidament en intentar augmentar més la vida útil.

Resum en anglès(màxim 300 paraules)

We consider a complex road or urban scenario where pedestrians or vehicles equipped with communication interfaces are interested in sharing files from node to node or downloading large files from road-side Access Points (APs). We investigate the possibility of exploiting opportunistic encounters among mobile nodes so to augment the transfer rate experienced by downloaders. To that end, we devise solutions for the selection of carriers and data chunks at the APs.

Through extensive simulations, we show that carry&forward transfers can significantly increase the download rate of users in urban/suburban environments, and that such a result holds throughout diverse mobility scenarios, AP placements and network loads.

Moreover, wireless nodes such as smart-phones in which the WiFi wireless card is continuously on, consume battery energy in just a few hours. In many scenarios, an always-on wireless card is useless because there is often no need for transmission or reception. This fact is exacerbated in Delay Tolerant Network (DTN) environments, in which nodes exchange data when they meet.

Power Saving Management techniques enable the lifetime of the nodes to be extended. Our project analyses the trade-offs that appear when wireless nodes periodically turn off the wireless card in order to save battery in DTN environments.

Our results show the conditions in which a node can switch off the battery without impacting the peer-to-peer contact probability, and those in which this contact probability is decreased. For example, it is shown that node lifetime can be doubled while keeping the peer-to-peer contact probability equal to one. But, further increase of the node lifetime quickly decreases peer-to-peer contact probability.

2.- Memòria del treball (informe científic sense limitació de paraules). Pot incloure altres fitxers de qualsevol mena, no més grans de 10 MB cadascun d'ells.

Veure document adjunt:
MemoriaJustificativaDeRecerca-Trullols-InformationMobility.pdf