# Roadside Networks for Vehicular Communications:

## Architectures, Applications, and Test Fields

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# Chapter 12
# Information Dissemination in Urban VANETs:
## Single-Hop or Multi-Hop?

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## ABSTRACT

*In recent years, Vehicular Ad-hoc NETworks (VANETs) have experienced an intense development phase, driven by academia, industry, and public authorities. On the basis of the obtained results, it is reasonable to expect that VANETs will finally hit the market in the near future. In order to reach commercial success, VANETs must effectively operate during the first years of deployment, when the market penetration rate will be unavoidably low, and, consequently, only a small number of suitably equipped vehicles (VANET-enabled) will be present on the roads. Among the possible strategies to face the initial sparse VANET scenarios, the deployment of an auxiliary network constituted by fixed Road Side Units (RSUs), either Dissemination Points (DPs) or relays, is certainly one of the most promising. In order to maximize the benefits offered by this support infrastructure, the placement of RSUs needs to be carefully studied. In this chapter, the authors analyze, by means of numerical simulations, the performance of an application that leverages on a finite number of DPs for disseminating information to the transiting vehicles. The positions of the DPs are determined through a recently proposed family of optimal placement algorithms, on the basis of proper vehicular mobility traces. The analysis is carried out considering two realistic urban scenarios. In both cases, the performance improvement brought by the use of multi-hop broadcast protocols, with respect to classical single-hop communications with DPs, is investigated.*

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## INTRODUCTION

Nowadays, most of the vehicles moving on our streets are powerful mobile computing devices, with sensorial, computational, and cognitive capabilities. Moreover, in the near future they will likely possess wireless communication capabilities as well, in order to exchange data with existing wide area networks (e.g., cellular networks) and to implement Dedicated Short-Range Communications (DSRCs) with the surrounding vehicles. The possibility of creating decentralized and self-organized vehicular networks, commonly denoted as Vehicular Ad-hoc NETworks (VANETs), is one of the most appealing applications which will be enabled by the exploitation of "smart vehicles."

It is widely recognized that the implementation of effective VANET-based services is a complex task, for several reasons:

1. The highly dynamic network topology, due to high vehicle mobility;
2. The severe fading that often characterizes the wireless communication channel;
3. The plethora of services with different requirements that may be supported in VANETs, ranging from safety-critical applications, with strict latency and reliability requirements, to bandwidth-consuming infotainment applications;
4. The large spectrum of traffic conditions that occurs in real roads, ranging from fluid traffic flow situations (as it happens in rural areas or during the night-hours) to jammed urban roads or congested freeways.

Historically, most of the research efforts have been focused on dense networks, with the aim of designing efficient and congestion-avoidance forwarding protocols. However, lack of connectivity in sparse networks will be the first critical issue to be addressed by VANET-based commercial communication systems. In fact, during the first years of deployment the market penetration rate of the inter-vehicular communications technologies will be unavoidably low, thus yielding to scenarios where VANETs will be typically sparse.

Among the possible approaches to avoid the lack of connectivity, the deployment of a complementary network infrastructure, constituted by fixed network nodes, is one of the first feasible solutions. These fixed nodes, denoted as Road Side Units (RSUs), are commonly equipped with the same communication technology of the vehicular mobile nodes. The RSUs can play different roles, acting as Disseminating Points (DPs) or relays. In the first case, we assume that a DP generates "new" information to be disseminated in a spatial region around itself—the size of this region depends on the communication strategy (either single-hop or multi-hop), as will be shown later. DPs are inter-connected by means of a backbone network constituted by either wireless or wired communication links. Since the backbone capacity is typically much higher than that of a VANET, it is reasonable to assume that a given information (generated by a control center) will be simultaneously available at every DP. In the second case, a relay actively participates to the forwarding process, by relaying the received packets a single time or by storing them for a certain finite time, periodically broadcasting them (store-and-forward). In this case, relays act as independent entities, without requiring to be connected to a backbone infrastructure.

On the basis of the considerations above, it emerges that RSUs will be highly instrumental to a successful commercial deployment of VANETs. In order to be cost-effective and to guarantee a significant improvement, in terms of Quality of Service (QoS), the number and the placement of the RSUs need to be properly optimized. However, despite the importance of this issue, to date a small number of works has addressed it.

In this chapter, we focus on the problem of optimizing the dissemination of information from a group of DPs to the vehicles in an urban scenario. We take into account a push transmission paradigm, where the DPs send data to all vehicles transiting in their neighborhoods, without the need of an explicit query. This approach is suitable for disseminating information of public interest, and, as shown in Kone, Zheng, Rowstron, and Zhao (2010), it is more efficient than a pull approach, in which the transiting vehicles have to explicitly query the desired data.

The goal of this chapter is two-fold:

1. To present the state-of-art approaches for the optimal placement of DPs;
2. To analyze, by means of numerical simulations, the performance of a dissemination application in realistic urban scenarios, by analyzing, from a comparative perspective, the performance with single-hop and multi-hop dissemination protocols.

## BACKGROUND

The concept of drive-thru Internet—the idea of providing Internet connectivity to the vehicles by exploiting the existing roadside access points—was first introduced in Ott and Kutscher (2004). Subsequent experimental studies have confirmed the feasibility of WiFi-based vehicular Internet access, at least for non-interactive applications (Bychkovsky, Hull, Miu, Balakrishnan, & Madden, 2006; Eriksson, Balakrishnan, & Madden, 2008).

However, by only relying on the existing network infrastructure, it is difficult to guarantee a sufficiently high QoS. For this reason, in all scenarios with strict QoS requirements, the deployment of a network of dedicated RSUs is an unavoidable requirement. In order to reduce the economic and logistic burden caused by the deployment of a dedicated network of RSUs, it can be helpful to use a planning tool to optimize the number and placement of the RSUs.

A number of works in the literature has tackled the problem of planning the deployment of RSUs for data dissemination in VANETs. Most of them merely propose heuristics for the deployment of the RSUs, thus relying on simulation analysis to validate the performance of the proposed approaches (Lochert, Scheuermann, Caliskan, & Mauve, 2007; Leontiadis, Costa, & Mascolo, 2009).

Theoretical frameworks have also been proposed to determine the quasi-optimal positions of the RSUs, on the basis of specific QoS criteria. For example, in Banerjee, Corner, Towsley, and Levine (2008), the authors propose an analytical model (also supported by experimental results) that offers significant insights on the tradeoffs, faced by a considered family of dissemination protocols, among the vehicle spatial density, the number of RSUs, and the roadside network architecture.

In Abdrabou and Zhuang (2011), the authors derive a relationship between the number of RSUs and the maximum end-to-end delay in a complementary (with respect to Banerjee, Corner, Towsley, & Levine, 2008) scenario, where the vehicles send data to the RSUs. In Zhao, Zhang, and Cao (2007), the authors present several dissemination protocols, whose parameters can be tuned in order to maximize the amount of data that can be disseminated in a given area.

In Zheng, Sinha, and Kumar (2009), the authors propose the concept of alpha-coverage, useful for characterizing a given DPs deployment, in terms of contacts between the DPs and the transiting vehicles. A more refined solution has been presented in Zheng, Lu, Sinha, and Kumar (2010), where the authors have introduced the concept of contact opportunity, which allows to characterize not only the number of contacts between the vehicles and the DPs, but also the fraction of time (or space) spent by a vehicle while connected with some DPs. They also present a DPs' deployment algorithm to maximize the worst-case contact opportunity, under some "budget" constraints—the budget is typically constituted by the total number of DPs. Similar metrics—with different names but approximately the same meaning—were considered in Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010):

1. The coverage ratio, defined as the percentage of vehicles that have a contact with the DPs;
2. The coverage time, defined as the average sojourn time of the vehicles within the transmission range of the DPs.

In Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010), the authors propose a method for the quasi-optimal placement of DPs, on the basis of a maximum coverage approach, in order to maximize either the coverage ratio or the coverage time.

While all the above-mentioned works are focused on single-hop communications, in Malandrino, Casetti, Chiasserini, and Fiore (2011) the authors consider the more general problem of the content downloading in vehicular networks. By following a graph-theoretic approach, the authors investigate various types of data dissemination: namely, direct transfer (e.g., single hop from the DPs), multi-hop forwarding (multihop unicast communications), and carry-and-forwards (vehicles store and carry the data).

A comparative investigation of single-hop and multi-hop communications, in the realm of wireless networking, is of interest. In fact, in a single-hop communication scenario, the concepts of coverage time and contact opportunity have a practical meaning, as the amount of data that can be transferred from the DPs to the passing vehicles can be estimating by simply considering the transmission rate of the DPs. On the contrary, when multi-hop (broadcast) dissemination protocols are used, this direct relationship no longer holds, since the amount of data that can be transferred depends on a broad range of parameters, including the vehicle spatial density, the vehicles' speed distribution, and the medium access protocol in use. Therefore, a direct comparison between single-hop and multi-hop communications in VANET-based system is expected to shed light on the design and implementation of future urban wireless vehicular dissemination systems.

## PHYSICAL CHANNEL CONSIDERATION

### The Wireless Channel in VANETs

The statistical characterization of the physical channel of V2V communications is a challenging. First of all, a common reference scenario it is difficult to define, because of the wide variety of environments of interest for IVCs. Roads can run in a desert countryside, inside a tunnel, or in a "urban" canyon surraunded by with skyscrapers. Furthermore, because of its metallic nature, the density and the type of surrounding vehicles have a huge impact on the number of multi-path reflections experienced by the receiver. Moreover the antenna radiation pattern is highly influenced by its placement with respect to the vehicle (namely, inside or on the roof). The second, but not less important, reason is the consequent difficulty in deriving statistically accurate empirical models.

From the point of view of the network layer, a physical wireless channel behaves as an ON-OFF system, since the packet can be either successfully received or discarded. Typically, a checksum is used to determine the reception status of the channel (e.g., the FCS in the IEEE 802.11 model). In network simulator, a common approach consist in defining a hard threshold, the receiver sensitivity, denoted as $RX_{TH}$ (dimension: [dB], such that a packet is successfully received, only and only if the received power $P_r$ (dimension: [W] is higher then the sensitivity. On the other hand, the packet is discarded with probability 1 when $P_r < RX_{TH}$. Owning to this assumption, in order to know if a packet is correctly received or not, it is only necessary to derive $P_r$ and compare it to $RX_{TH}$. Once the transmit power, denoted as $P_t$ (dimension: [W]), has been fixed, the value of $P_r$

depends only on the inner characteristics of the wireless channel, and the distance between the transmitter and the receiver. There are two main families of physical channel models: deterministic and stochastic. With a deterministic path-loss model, such as Friis and Two Ray Ground (TRG) models, once the transmit power and the receiver sensitivity has been set, it is possible to compute the transmission range, defined in this work with the symbol z (dimension: [m]). When the distance is longer then the transmission range, the packet is never received, conversely it is always correctly detected for distance shorter than the transmission range. On the opposite, in stochastic models the instantaneous power is a random variable, and only the average received power can be computed. In this case, a finite transmission range cannot be defined, since it is not possible to a-priory predict, even knowing the distance from the source, if a packet will be successfully decoded. However, we will define the transmission range with respect to the average received power. Depending on the characteristic of the channel, there are several types of stochastic model, such as the shadowing, Rayleigh, or Nakagami.

The Friis model is valid in quite unrealistic scenarios, without any obstacles, while the TRG can be used where the transmitter and receivers antennas are near to the ground. In particular, according to the Friis model, the received power can be expressed as follows:

$$\mathrm{P_r}(d) = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2,$$

where $G_t$ and $G_r$ denote the antenna gain of, respectively, the transmitter and the receiver, while λ (dimension: [m]) is the wavelength corresponding to the used the carrier frequency, denoted with $f_c$ (dimension: [Hz]) (e.g., $\lambda=c/f_c$, where *c* represents the speed of light).

The TRG model is defined by the following equations:

$$P_r(d) = \begin{cases} P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 & d \le d^* \\ P_t G_t G_r \left(\frac{h_t h_r}{4\pi d}\right)^2 & d > d^*, \end{cases}$$

where $h_t$ and $h_r$ are the heights of the transmitter and the receiver antenna, while d* is a threshold defined as:

$$d^* = \frac{4\pi h_t h_r}{\lambda}.$$

It is trivial to observe that in the interval [0, $d^*$] the Friis and the TRG models are identical.

According to a m-Nakagami distribution the signal amplitude is distributed as follows:

$$f_x(x) = \frac{2^m m^x 2^{m-1}}{\Gamma(m)\Omega(m)} \frac{y^{m-1}}{\Gamma(m)} \exp\left(-\frac{mx^2}{\Omega}\right),$$
$$x \ge 0, \Omega > 0, m > 0.5,$$

where *m* and Ω are suitable parameters—in particular Ω is the average received power.

The corresponding Probability Density Function (PDF) of the received power *Pr* it is therefore given by a gamma distribution of the following form:

$$f_Y(y) = \left(\frac{m}{\Omega}\right)^m \frac{y^{m-1}}{\Gamma(m)} \exp\left(-\frac{my}{\Omega}\right),$$
$$y \ge 0.$$

In order to use the Nakagami model it is necessary to specify the average received power (Γ). In Chen, Schmidt-Eisenlohr, Jiang, Torrent-Moreno, Delgrossi, and Hartenstein (2007), the authors define Ω (expressed in dB) as a piecewise constant function of *d*:

$$\Omega(d)[dB] = \begin{cases} 10\gamma_0 \log(d / d_{ref}) & 0 < d \le d_0^\gamma \\ 10\gamma_0 \log(d_0^\gamma / d_{ref}) + 10\gamma_1 \log(d / d_0^\gamma) & d_0^\gamma < d \le d_1^\gamma \\ 10\gamma_0 \log(d_0^\gamma / d_{ref}) + 10\gamma_1 \log(d_1^\gamma / d_0^\gamma) + 10\gamma_2 \log(d / d_1^\gamma) & d_1^\gamma < d, \end{cases}$$

where $d_{ref}$ represents a reference distance that can be freely chosen (we set $d_{ref}$ = 1 m), while $\gamma_0, \gamma_1, \gamma_2$, $d_0$, and $d_1$ have been set according to the empirical values obtained by measurements. Obviously, by setting $\gamma_i = 2$ for $i = 0, 1, 2$ in equation (2.4), we have the same attenuation of the Friis model.

The parameter *m* has a strong impact, since it determines the shape of the PDF. For instance: when $m = 1$ the Nakagami PDF coincides with a Rayleigh PDF; when $m < 1$ the Nakagami distribution determines a severe fading (worse than Rayleigh); while with $m > 1$ one obtains a Ricean model, less sever than Rayleigh (e.g., if $m \to \infty$ the Nakagami distribution reduces to deterministic model). In [113] the authors define *m* as a piecewise constant function of *d*:

$$m(d) = \begin{cases} m_0 \\ d < d_0^m \\ m_1 \\ d_0^m \le d < d_1^m \\ m_2 \\ d_1^m \le d, \end{cases}$$

where $m_0, m_1, m_2, d_0^m, d_1^m$ have been set according to the empirical values presented in Chen, Schmidt-Eisenlohr, Jiang, Torrent-Moreno, Delgrossi, and Hartenstein (2007) (see Table 1).

## Basic IEEE 802.11 Mechanisms

As VANETs are characterized by the high speed of the nodes, a new communication standard, fit for this type of network, was required.

For this reason in 2003 the definition of a new communciation standard for the Wireless Access in Vehicular Enviromental (WAVE), the so called IEEE 802.11p, started.

The physical layer can rely on seven channel each one with a bandwith of 10 MHz and can use frequencies higher than 5 GHz.

The MAC layer in WAVE standard is equivalent to the IEEE 802.11e Enanched Distributed Channel Access (EDCA), introduced in the IEEE 802.11e amendment. The EDCA maintains the distributed approach of the CSMA/CA protocol as in legacy DCF, but introduces four Access Categories (ACs), each one defining a priority level for channel access and having a corresponding transmission queue at the MAC layer. Each AC in the queue behaves like a virtual station, and it follows its own DCF algorithm, independently contending with the others to obtain the channel access. Each *i-th* AC has a set of distinct channel access parameters, including Arbitration Inter-Frame Space (AIFS) duration and contention window size (CWmin[i] and CWmax[i]).

In Table 2, the more relevant parameters of the PHY and MAC layers of IEEE 802.11p are summerized, with the exception of the EDCA parameters which are listed in Table 3. From Table 2 we observe that IEEE 802.11p uses the same CWmin and CWmax values of the original IEEE 802.11e specification, but slightly modified

*Table 1. Main parameters of Friis, TRG, and Nakagami propagation models*

| Parameters | Values |
|---|---|
| $f_c$ | 5.9 GHz |
| Gt, Gr | 1 |
| Ht, Hr | 2 m |
| γ0, γ1, γ2 | 1.9, 3.8, 3.8 |
| $d_0^\gamma d_1^\gamma$ | 200, 500 m |
| $m_0$, $m_1$, $m_2$ | 1.5, 0.75, 0.75 |
| $d_0^m d_1^m$ | 80, 200 m |

*Table 2. Main parameters of the IEEE 802.11p standard*

| Parameter | IEEE 802.11p |
|---|---|
| Carrier Frequency [GHz] | 5.9 |
| Bandwidth [MHz] | 10 |
| OFDM Guard Time [μs] | 1.6 |
| CWmin | See Table 3 |
| CWmax | 1023 |
| *TSLOT* [μs] | 13 |
| *TSIFS* [μs] | 32 |
| Data rates [Mbit/s] | 3, 4.5, 6, 9, 12, 18, 24, 27 |

*Table 3. EDCA parameters of the IEEE 802.11p standard*

| AC | CWmin | CWmax | AIFSN |
|---|---|---|---|
| AC_BK | 15 | 1023 | 9 |
| AC_BE | 15 | 1023 | 6 |
| AC_VI | 7 | 15 | 3 |
| AC_VO | 3 | 7 | 2 |

AIFSN values. While in standard WLAN the AC_VI and AC_VO means, respectively, Video and Voice, in the case of IEEE 802.11p, AC_VI and AC_VO have to interpreted as ACs reserved for prioritized messages (e.g., critical safety warnings) (see Figure 1).

## REFERENCE SCENARIOS

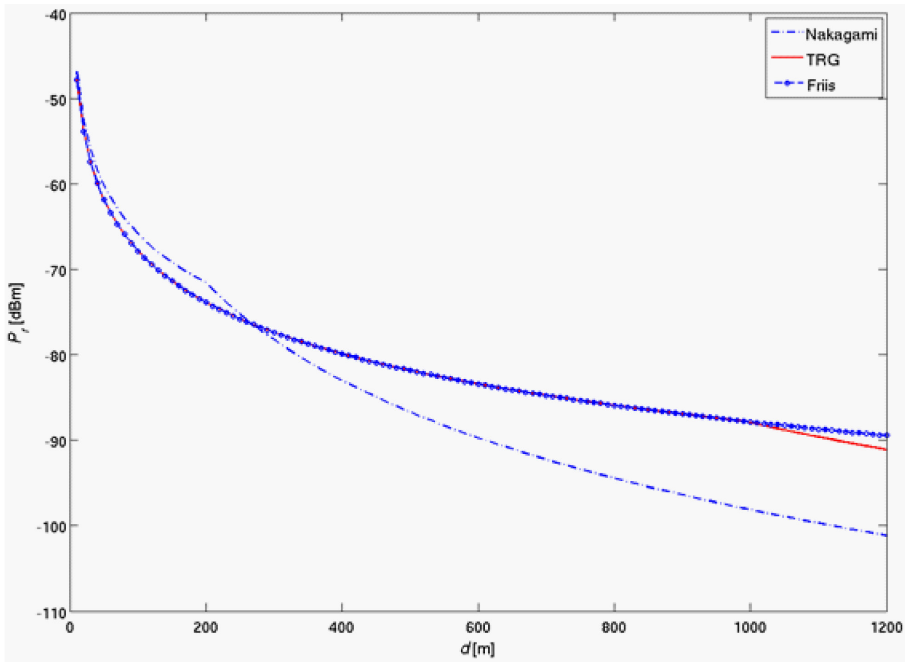
### Network Topology

In this work, we consider two urban scenarios: in the first, the roads form a symmetric Manhattan grid, while the second corresponds to a portion of a European-like city (namely, Parma, Italy), where the road structure is irregular. In both cases, the movements of the vehicles are generated using an open-source mobility simulator, called SUMO (Karnadi, Mo, & Lan, 2007) and freely available (SUMO Project). SUMO is a microscopic road traffic simulator that allows to create a scenario by converting an existing map or, alternatively, by using one of the external tool provided by the SUMO project itself (for example, NETGEN or NETCONVERT). Among the several vehicle mobility models supported by SUMO, we have employed a car-following dynamic model largely based on a physical model denoted as KWG from the name of the authors that first proposed it in Krauss, Wagner, and Gawron (1997).

The regular scenario, represented in Figure 2(a), is a square-shaped sub-region, with an area equal to $1\text{Km}^2$, of a Manhattan grid of infinite size. The considered region is constituted by 4 vertical (south-north) and 4 horizontal (east-west) roads, intersecting in uniformly-spaced junctions (the distance between two adjacent roads is equal to 200 m). Each road has a length equal to $L_{\text{road}}$ (dimension: [m]) and is composed by two adjacent lanes: one reserved for the vehicles entering the network (inbound) and the other one reserved for the vehicles exiting the network (outbound). Each intersection is regulated by a Traffic Light (TL), with a deterministic and constant duty cycle. During its duty cycle, a TL stays green for $T_{\text{green}} = 55s$, red for $T_{\text{red}} = 60s$, and amber for $T_{\text{amber}} = 5s$. Obviously, the TLs lying in vertical roads have an orthogonal duty cycle with respect to those in the horizontal roads, under the assumption that the amber and green colors are orthogonal with respect to the red color. Moreover, in the presence of multiple intersections we assume that all TLs in the horizontal road are synchronized. An extension of this analysis to encompass the presence of roundabouts can be carried out by considering the approach presented in Busanelli, Ferrari, and Giorgio (2011).

The second scenario, shown in Figure 2(b), is based on a real urban map of a square-shaped portion of the city of Parma (Italy), with area equal to $1\text{Km}^2$. The map has been retrieved from

*Figure 1. Received power obtained with the Friis, TRG, and Nakagami propagation models, using the parameters summarized in Table 2, and Pt = 100mW*

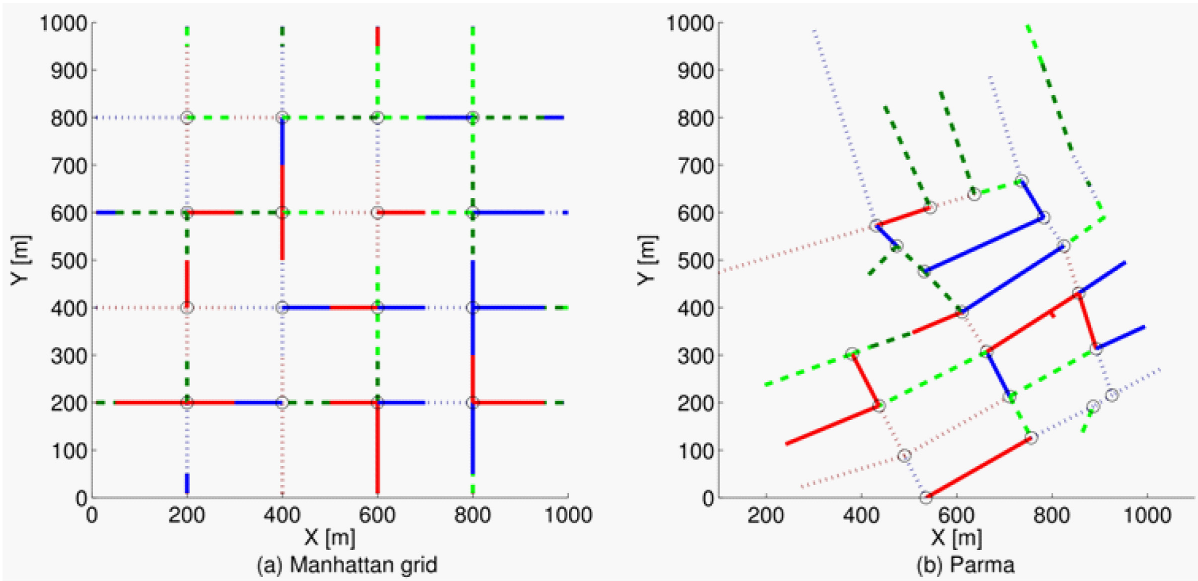



the website of the Open Street Map (OSM) project (Open Street Map). In this case, the roads are characterized by an irregular shape and there are junctions—note that the number of junctions is slightly higher than in the regular scenario.

In both scenarios, the vehicles' movements are generated as follows. The vehicular flow entering the considered spatial region is created according to a global (i.e., over all inbound lanes of the scenario at hand) time-domain Poisson process of parameter $\gamma$ (dimension: [veh/s]). Once generated, each vehicle appears in one of the available inbound lanes and it then follows a random itinerary along the available roads, randomly determining its direction in correspondence to each junction. In the Manhattan scenario, we have assumed unbalanced probabilities of choosing the inbound lane, in order to generate a slightly asymmetric traffic pattern (e.g., some roads have a higher probability to be selected). Otherwise, due to the intrinsic symmetry of the scenario, every junction would have observed (on average) the same traffic load, making useless the execution of the DPs placement algorithms (e.g., all the intersections would have been statistically identical). On the contrary, in the second (Parma) scenario, the probabilities of choosing the inbound lane are assumed to be uniform, since in this case this road topology is intrinsically asymmetric. The vehicle generation process stops as soon a pre-fixed number of vehicles, denoted as , have been generated. As shown in Figure 3, with the considered parameters' set ( $\gamma = 0.5$ veh/s), the initial transitory phase ends after approximately 2000 s, while the generation process ends, on average, after approximately 14000 s.

Therefore, during the temporal window (2000 s, 13000 s) (with length equal to $T_{\text{obs}} = 11000s$), the network is stationary, in the sense that the number of entering vehicles is (on average) equal to the number of the exiting vehicles. In other words, in these conditions the global number of vehicles in the network varies little around its average.

*Figure 2. (a) The regular scenario characterized by a Manhattan grid topology and (b) the irregular scenario representing a portion of the city of Parma (Italy)*



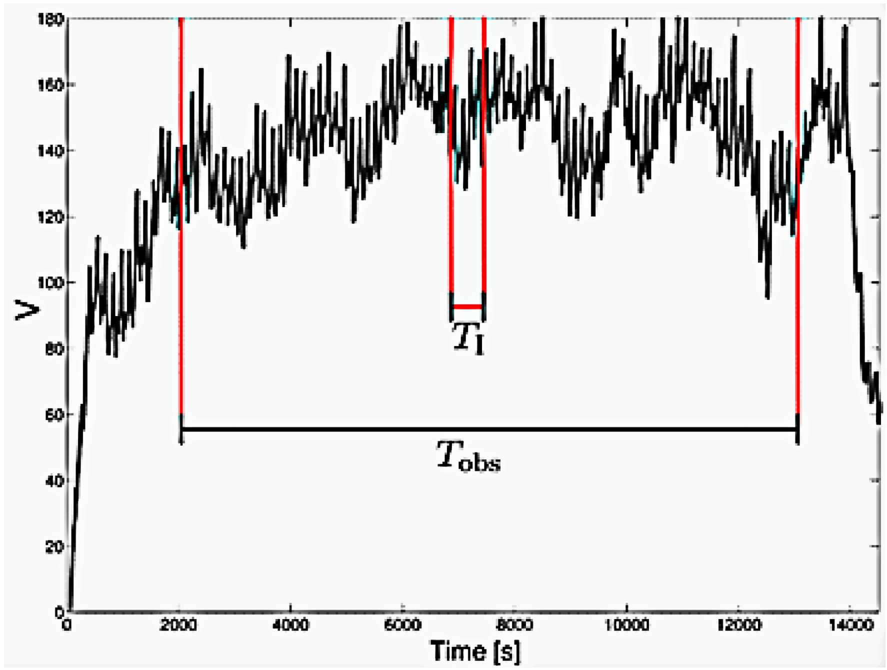

The average vehicular spatial density at a generic instant $t$ of a generic road $R$, denoted as $\rho_s^R(t)$, is obtained by dividing the number of vehicles located within the road $R$, for the length of the road itself. By averaging over the simulation duration, it is possible to obtain the average per-road vehicular density denoted as $\rho_s^R$ (dimension: [veh/m]).

## Data Dissemination Paradigm

In this work, we consider a content distribution application in which the DPs broadcast public interest information to all the vehicles in a given spatial region. The contents to be broadcasted (e.g., the list of free parking places available in the city or the list of the currently congested streets) might be provided by some public authorities and periodically updated. Furthermore, it is reasonable to assume that the inter-update interval has a fixed length, denoted as $T_\mathrm{I}$ (dimension: [s]).The DPs are synchronized together by means of a backbone infrastructure: therefore, they send the same information at the same time. Each information block has a fixed size equal to $N_\mathrm{p}P$ bytes, where $N_\mathrm{p}$ is the number of MAC-layer frames (note that in this section the words "frame" and "packet" are used interchangeably) that compose the block and $P$ (dimension: [bytes]) denotes the fixed packet size. The packets are generated with a constant generation rate equal to $\lambda$ (dimension: [pck/s]) and are transmitted according to a fixed datarate $R$ (dimension: [Mbits/s]). The DPs continuously retransmit the information block for its entire "lifetime" (namely, $T_\mathrm{I}$). The effective duration of an information block coincides with $\tau = \frac{N_\mathrm{P}}{\lambda}$, while the number of the retransmissions, denoted as $N_\mathrm{R}$, can be computed as $N_\mathrm{R} = \frac{T_\mathrm{I}}{\tau}$. Finally, we assume that the vehicles and the DPs have the same deterministic transmission range, denoted as (dimension: [m]).

By suitably choosing the parameters listed above, the proposed data dissemination paradigm

*Figure 3. Overall number of vehicles in the Parma network, as a function of the time. The interval $T_{\mathrm{I}}$ and $T_{\mathrm{obs}}$ are also shown.*




can encompass a wide array of applications, ranging from notifications, where the DPs disseminate a small amount of information (a few Kbytes), to media distribution applications, where the DPs disseminate a large amount of information (a few Mbytes). Regardless of the dimension of the information block, we consider a "best effort" transmission paradigm, based on a broadcast transmission protocol, without any feedback from the vehicles. Therefore, the vehicles send neither ACK nor NACK packets, but have no guarantee of receiving the distributed content.

We consider both single-hop and multi-hop broadcast protocols. The single-hop protocol, in the following denoted as SH, operates in a trivial manner: the DPs send a packet that is received by all the vehicles whose distance from the nearest DP is smaller than $z$. Besides the SH protocol, we also consider a multi-hop probabilistic protocol, denoted as Irresponsible Forwarding (IF) and previously introduced in Busanelli, Ferrari, and Panichpapiboon (2009). In Figure 4 the propagation flows obtained by using, respectively, the SH and the IF broadcasting protocols, are shown.

The protocol is probabilistic in the sense that a vehicle decides if retransmit or not a packet in a probabilistic manner, according to a certain Probability Assignment Function (PAF), defined as follows:

$$p(d) = \exp\left(-\frac{\rho_{\mathrm{s}}^{\mathrm{v}}(t)(z-d)}{c}\right), \tag{1}$$

where $d$ is the distance between the last transmitter and the receiver of the packet; $c \geq 1$ is a tunable parameter which can be selected to "shape" the probability of rebroadcasting—the higher the value of c, the higher the probabilityof rebroadcasting at any position $d$—and $\rho_{\mathrm{s}}^{\mathrm{v}}(t)$ is the local vehicle spatial density, evaluated by each vehicle, independently from the other vehicles, at time $t$.

The local spatial density $\rho_s^v(t)$ can differ from the per-road vehicle spatial density $\rho_s^R(t)$, but they usually have the same order of magnitude. According to definition of PAF in Equation (1), it emerges that the retransmission probability is an increasing function of the distance from the last (re-)transmitter of the packet. In other words, the further is a node from the DP, the higher is its retransmission probability: it becomes 1 when z=d The inter-node distance can be estimated accurately under the assumption that the vehicles are equipped with a GPS receiver.

Without loss of generality, the operations of the IF protocol, with respect to a single DP, can be described as follows.

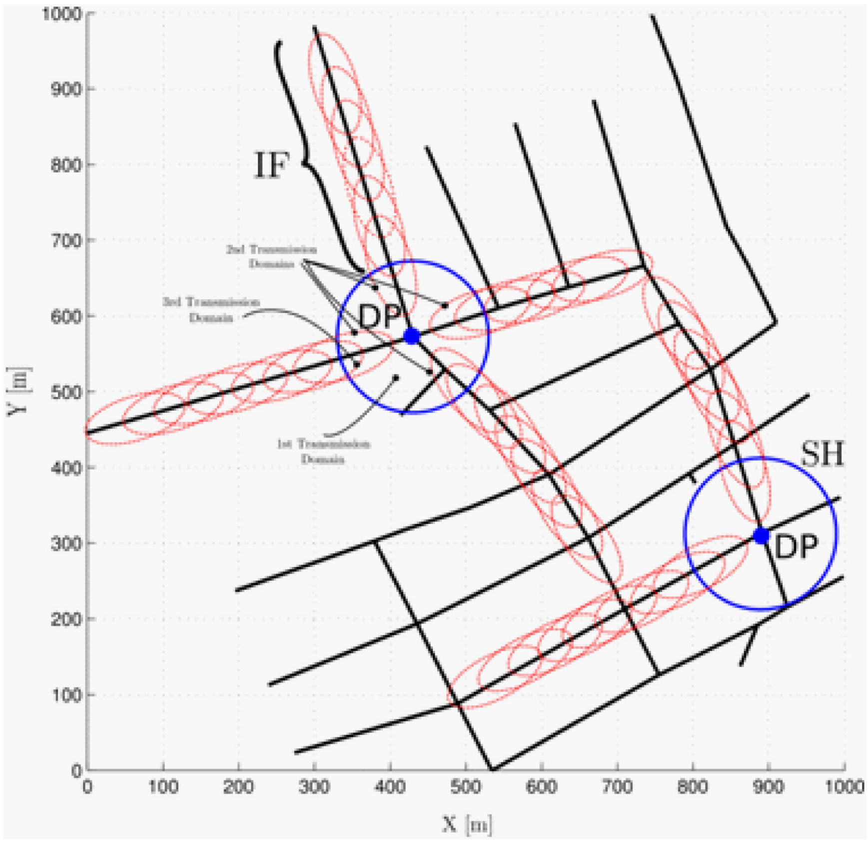
1. The DP sends a new frame.
2. The nodes within a distance $z$ from the DP receive the packet and form the so-called 1-st transmission domain (as shown in Figure 4). If a node has already received a copy of the packet, it silently discards it without joining the 1-st transmission domain.This allows to prevent the formation of loops.
3. Every node in the 1-st transmission domain probabilistically computes the distance from the DP (i.e., $d$) and decides, according to the PAF in equation (1), to retransmit (or not) the packet.
4. The potential forwarders (i.e., the nodes of the 1-st transmission domain which have decided toretransmit) compete for channel access, by using the channel access mechanism of the underlying MAC protocol. As a consequence, a subset of the nodes within the first transmission domain may retransmit the packet.
5. Since the DP is placed in a road intersection, the re-broadcasters will likely belong to different roads. This implies that, at the second hop, there will a number of 2-nd transmission domains equal to the number of intersecting roads. In other words, the information originated at the DP tends to propagate in all roads entering into the intersection.
6. The whole process (from step 1) is restarted at the 2-nd transmission domains (as shown in Figure 4). The only difference is constituted by the fact that the distance, required to evaluate the PAF, is measured with respect to the node from which a packet has been received, and not from the DP.
7. The propagation process is therefore constituted by multiple packet retransmissions, which continue at most till the end of the considered region—as will be clear in the following, with a probabilistic broadcasting protocol might stop the retransmission process might terminate before reaching the end of the network.

For more details about the IF protocol and its applications to urban junctions (with either traffic lights or roundabouts), the reader is referred to Busanelli, Ferrari, and Giorgio (2011).

## OPTIMIZED PLACEMENT OF THE DISSEMINATION POINTS

In Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010), the authors introduce a few algorithms that, on the basis of mobility traces, determine the optimal positions of a fixed number of DPs in a scenario constituted by a finite number of roads intersecting in a finite number of junctions.The algorithms only consider the road intersections as valid positions for the DPs, under the assumption that the number of DPs, denoted as $k$, is smaller than the number of the junctions. This assumption is clearly motivated in Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010) and can be intuitively understood by observing that the vehicles spend (on average) a longer time in the proximity of intersections, rather than in the midst of a generic road segment.

*Figure 4. The SH and IF propagation flows in the Parma scenario*




A mobility trace contains the discrete sequence of the movements of all the vehicles' transiting in the area of interest in a finite temporal interval. In order to have statistically meaningful information, a trace has to span a sufficiently long time interval. The mobility trace can be obtained either by means of experimental data or through numerical simulations, executed according to a statistically meaningful mobility model. In Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010), the authors have used traces obtained from experimental traffic data. At the opposite, in our current work the mobility traces have been "artificially" generated using the SUMO simulator, in the manner described in the previous section.

In Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010), the optimization of the DPs positions is performed in terms of two metrics, the coverage ratio and the coverage time. The former is defined as the ratio between the numbers of vehicles that experience at least one contact with a DP during the considered period, with respect to the number of vehicles in the scenario.From a communication viewpoint, as the coverage ratio increases, a larger number of vehicles is able to receive at least a packet from the DPs. The coverage time (dimension: [s]) is defined as the sojourn time of a vehicle within the transmission ranges of the DPs. The coverage time offers a rough estimation of the amount of information that can be transferred from the DPs to a certain vehicle. The actual amount of transferred data depends on a large series of factors (the fluctuations of the wireless channel, the data rate, the MAC protocol, the forwarding protocol), that has not been modeled in the framework. In order to assess the amount of transferred data, we introduce a suitable defined metric, improperly denoted as throughput, which is meaningful from a network-layer viewpoint. In fact, the throughput is defined as the ratio between the number of unique packets received by a given node, and the number of packets in the information block sent by the DPs (e.g., $N_{\mathrm{p}}$).

The information offered by the considered mobility trace can be mapped in a couple of matrices. More specifically, denoting as $V$ the number of vehicles contained in the input mobility trace, we introduce the following $N \times V$ matrix, denoted as $\mathbf{P}$, whose $(i, j)$ element is defined as follows:

$$\mathbf{P}_{i,j} = \begin{cases} 1 \\ vehicle\_j\_crosses\_junction\_i \qquad i = 1, \ldots, V \quad j = 1, \ldots, N \\ 0 \qquad otherwise \end{cases}$$

Similarly, it is possible to introduce a $N \times V$ matrix, denoted as $\mathbf{T}$, whose $(i, j)$ element represents the total time spent by the $j - \mathrm{th}$ vehicle under the coverage area of a DP hypothetically located at the intersection $i$.

In this work, we consider three of the algorithms originally introduced in Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010), used to solve the following problems:

1. The Max Coverage Problem (MCP); and
2. The Knapsack Problem (KP) consist of the maximization of the number of contacts between the vehicles and at least a DP;
3. The Maximum Coverage with Time Threshold Problem (MCTTP) consists of the maximization of the number of vehicles that stay at least $\tau$ seconds in contact with a DP.

The algorithms used to solve the MCP and MCTTP assume to know the identity of the vehicles, while the algorithm used to solve the KP is sub-optimal, since it needs to know only the number of vehicles that get in contact with the DPs, ignoring their identities. Given $\mathbf{T}$, $\mathbf{P}$, $N$, $V$, and $\tau$, it is possible to solve the MCP, MCTTP, and KP by using the greedy approaches described in Trullols, Fiore, Casetti, Chiasserini, and Barcelo Ordinas (2010). With respect to the dissemination paradigm considered in our work, the minimum contact time $\tau$ considered in the MCTTP algorithm will be assumed to coincide with the duration of an information block.

In Figure 5, we show the optimized placement of the DPs obtained by executing, respectively, the MCP and the MCTTP algorithms in the Manhattan scenario, by considering $z = 100\mathrm{m}$, several values of $k$ (namely, 1, 4, 6, and 8), and two values of $\tau$ (namely, 3s and 30s). Obviously, the value of $\tau$ only affects the behavior of the MCTTP algorithm. It is interesting to observe that the MCTTP with $\tau = 3\mathrm{s}$ leads to the same DPs' configuration returned by the MCP algorithm. Figure 6 has been derived by considering the Parma scenario and the same set of parameters. In both scenarios, the width of a generic line is directly proportional to the average spatial vehicular density of the corresponding road (because of the internal structure of SUMO, the road between two junctions is typically composed by two distinct segments).

From Figure 5, it can be observed that the rightmost vertical roads and the upmost horizontal roads have a value of $\rho_{\mathrm{s}}^{R}$ significant higher than those of the other roads. For this reason, for small values of $k$, the MCP and MCTTP algorithms tend to concentrate in those roads the majority of the DPs. However, for increasing values of $k$ the distribution of the DPs becomes "fairer." It can be also noted that the MCP and MCTTP algorithms lead to very different DPs architectures. From Figure 6, it can be observed that traffic tends to concentrate in a few, whereas most of the remaining roads tend to experience a limited vehicular traffic load. For this reason, in this scenario the differences between the MCP and MCTTP algorithms are less evident.

In order to evaluate the performance of the different DPs placement solutions, we first generate an independent mobility trace, with the same parameters of the SUMO simulator. In this case, we consider a shorter observation period with duration equal to $T_{\mathrm{I}} = 60\mathrm{s}$: this interval is selected in the center of the stationary region of the mobility trace, as shown in Figure 3. Then, we compute the approximated Cumulative Distribution Function (CDF) of the network coverage time, obtained by positioning the DPs according to the placements provided by the MCP, MCTTP, and KP algorithms, considering $z = 100\mathrm{m}$, two values of $\tau$ (namely, 3s and 30s), and several values of $k$ (namely, 1, 4, 6, and 8). The CDF of the coverage time can be derived in two easy step: (1) to collect in a histogram the coverage times experience by each vehicle transiting in the scenario during the interval $T_{\mathrm{I}}$; (2) to normalize the histogram in order to obtain the PMF, and finally the CDF of the coverage time. The CDF of the throughput can be attained with a similar procedure.

The results obtained in the Manhattan scenario are shown in Figure 7, while those obtained in the Parma scenario are shown in Figure 8. As expected, in both scenarios the MCP and the MCTTP algorithms with $\tau = 3\mathrm{s}$ lead to the same coverage time. In Figure 8, relative to the Parma scenario, there is a clear outcome: the MCP algorithm offers the best performance, the KP algorithm the worst (as expected), while the MCTTP algorithms with $\tau = 30\mathrm{s}$ offers an intermediate performance level. In the Manhattan scenario, there is not a clear winner, especially in the case with a large value of $k$.

## NUMERICAL ANALYSIS

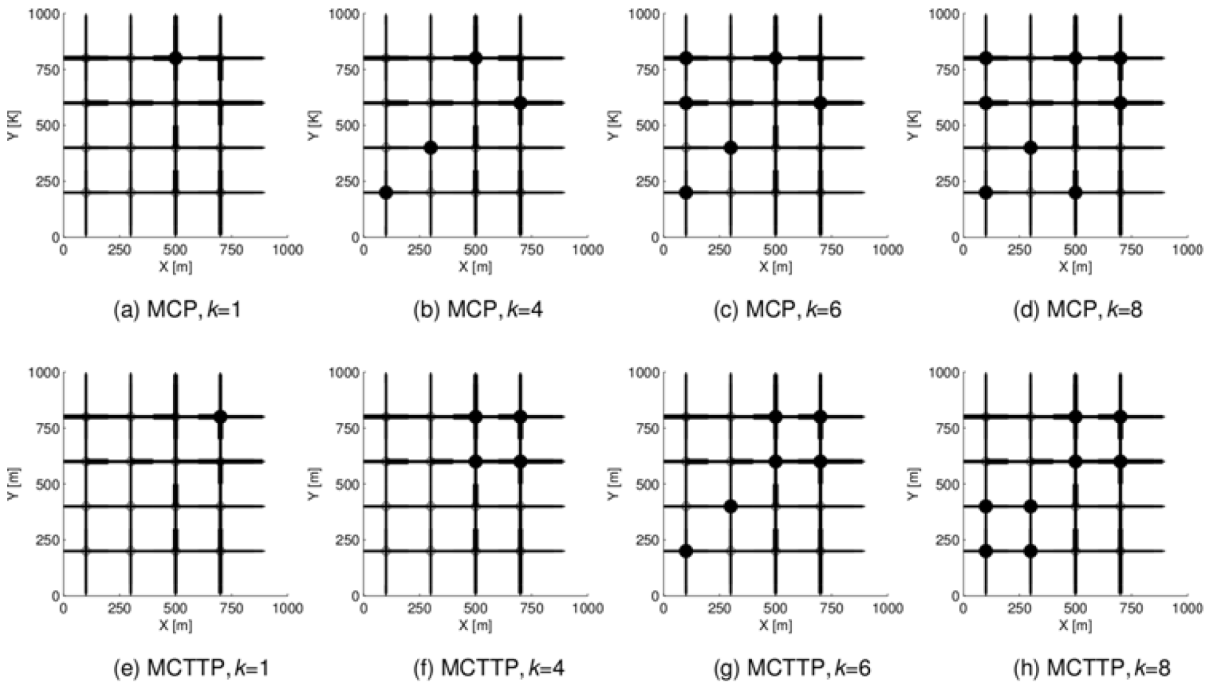
### IEEE 802.11 Implementation in ns-2

The last release of ns-2 (ns-2.34) contains two implementations of the IEEE standard, the default IEEE 802.11b module and a new IEEE 802.11p module, which differ in several aspects.

The default IEEE 802.11b module of ns-2 is not well coded and full of bugs. In particular, in, the authors have found several issues, not entirely fixed in the subsequent releases. In the current version there are still two main problems, both described in Schmidt-Eisenlohr, Letamendia-Murua, Torrent-Moreno, and Hartenstein (2006). The first is an incorrect management of the EIFS inter-frame after a collision, that leads to slightly better performance in congested networks. The second problem is related to the standard interpretation. As explained in Section 1.2.2, according to the IEEE 802.11 specifications a node should not enter in pre-backoff state if the channel is idle and it is sending the first frame of a burst or an isolated frame. The default IEEE 802.11b module of ns-2 acts differently. In particular, the senders always perform the pre-backoff wait even in sending an isolated packet and the channel is idle. This waste of time leads to slightly worse performance in non-congested scenarios, but it does not affect the saturated scenarios. On the other hand, it is beneficial in broadcast communications, since it avoids collisions in the first frames of the communication. We also remark that this approximation has been widely adopted in many theoretical studies (Oliveira, Bernardo, & Pinto, 2009).

The IEEE 802.11p module has been designed from scratch and simplements a completely revised architecture for the PHY and MAC modules (Chen, Schmidt-Eisenlohr, Jiang, Torrent-Moreno, Delgrossi, & Hartenstein, 2007). More precisely, the MAC layers models the basic DCF IEEE 802.11p mechanism, but without supporting the EDCA mechanism foresees by the IEEE 802.11p

*Figure 5. The placement of the DPs in the Manhattan scenario, obtained by using the MCP and theMCTTP algorithms, by considering several values of k, namely, 1, 4, 6, and 8.The width of every line is proportional to the traffic density in the underlying road.*



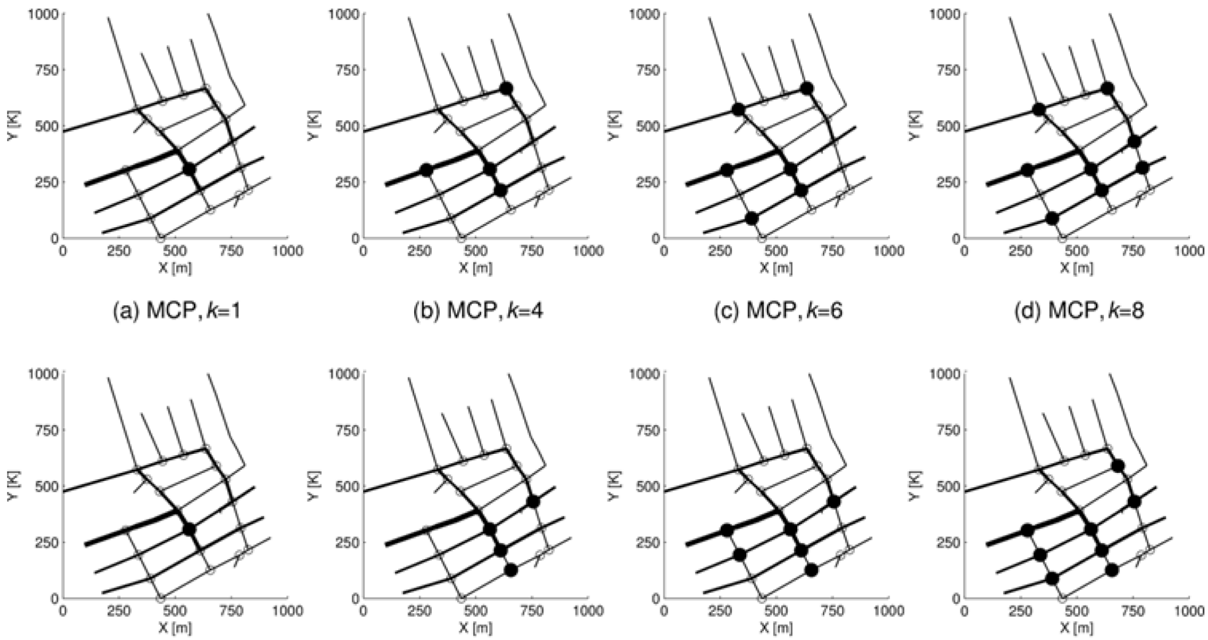

(a) MCP, $k$=1 (b) MCP, $k$=4 (c) MCP, $k$=6 (d) MCP, $k$=8

(e) MCTTP, $k$=1 (f) MCTTP, $k$=4 (g) MCTTP, $k$=6 (h) MCTTP, $k$=8

amendment. Therefore. using the IEEE 802.11p module the multi-channels features of the IEEE 802.11p/WAVE stack protocol cannot be simulated. We observe that in this implementation, the authors have correctly interpreted the standard, and hence, a node does non enter in the pre-backoff when sending the first frame of a burst. However, from the point of view of broadcast communications, the new implementation of the MAC behaves as the default IEEE 802.11 module. In fact, the reception of a frame is followed by a DIFS period, during which the receiver sees a busy channel. Therefore, in the case of a broadcast multihop protocol, all the retransmissions by the forwarder see a busy channel, and, hence, they always experience a pre-backoff. This happens as long the delay introduced by the higher layers is shorter than DIFS.

The PHY component of IEEE 802.11p module introduces a more advanced management of the interference, and of the phenomenon of "packet capturing." In particular, the PHY modules continuously tracks the cumulative received power comprehensive of both noise and signal(s), thus computing the Signal-to-Interference plus Noise Ratio (SINR) for every packet. A packet can be successfully decode if its SINR remains over a suitable threshold, associated to the used modulation format (i.e., 5 dB for Binary Phase Shift Keying, BPSK), for the entire packet duration. Unlike the standard module, the PHY module ignores the concept of receiving threshold, without assessing if the cumulative received power is over the carrier sense threshold, which is used to determine the status of the channel. done in the IEEE 802.11b module. We by-pass this problem by imposing that the carrier sense threshold value is identical to the sum of the modulation threshold (i.e., 5 dB for BPSK) and the noise power.

*Figure 6. The placement of the DPs in the Parma scenario, obtained by using the MCP and the MCTTP algorithms, by considering several values of k, namely, 1, 4, 6, and 8. The width of every line is proportional to the traffic density in the underlying road.*




(a) MCP, $k$=1 (b) MCP, $k$=4 (c) MCP, $k$=6 (d) MCP, $k$=8

(e) MCTTP, $k$=1 (f) MCTTP, $k$=4 (g) MCTTP, $k$=6 (h) MCTTP, $k$=8

## Simulation Setup

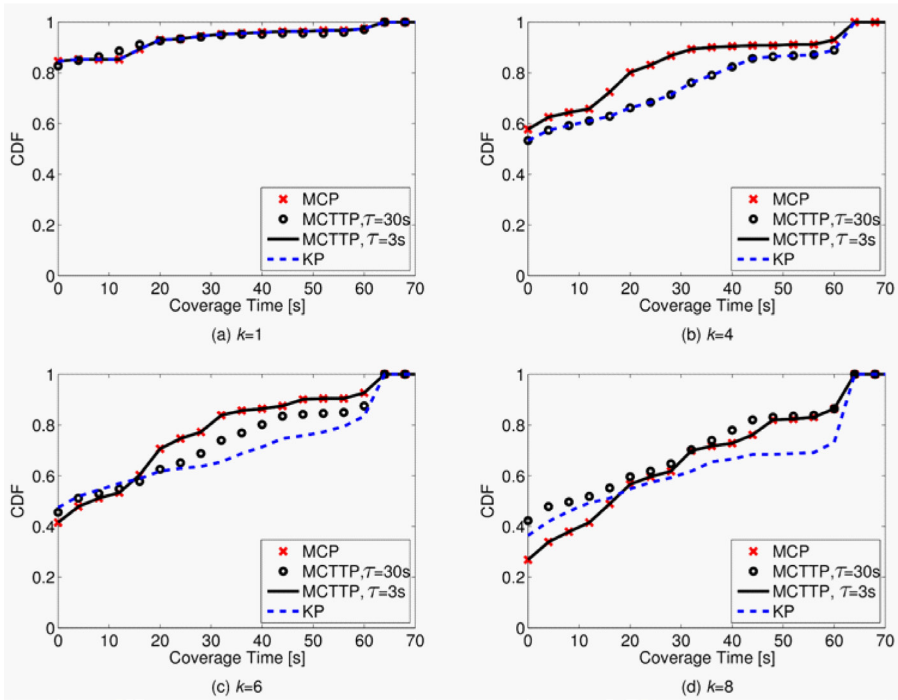
In this section, we analyze the performance of the considered urban scenarios, in terms of throughput and coverage ratio, by means of numerical simulations carried out with the ns-2 simulator (Network Simulator 2 [ns-2]). For the basic setup of simulations we assume that both the vehicles and the DPs are equipped with radio interfaces compliant with the IEEE 802.11b standard (IEEE, 2007), with a transmission range $z = 100\text{m}$, data rate $R = 1\text{Mbit/s}$, and different values of packet size $P = 10,\ 100,\ 1000$bytes. We set $T_{\mathrm{I}} = 60\text{s}$ and we assume that each information block is constituted by 2.4Mbits. As a consequence of that, the number of packets for each information block is $N_p = 300$ packets.

In order to make the network simulation-based analysis more comprehensive, we made a comparison between IEEE 802.11b and IEEE 802.11p with Mac802_11Ext and WirelessPhy_Ext that are MAC and PHY layer extensions from IEEE 802.11a to IEEE 802.11p.

These extensions allows to correctly model the noise, the capture effect, the use of multiple modulation schemes.

It can be shown that when using a multihop broadcast protocol as IF, because of the contention of the channel and of the collisions due to the hidden terminal problem, the maximum sustainable data rate (e.g., with no packet losses) is approximately 80 Kbit/s. On the opposite, a SH protocol can support a much higher data rate (roughly equal to 800 Kbits/s) without packet losses.

*Figure 7. CDF of the coverage time in the Manhattan scenario, obtained by considering the DPs placed according to the MCP, the MCTTP, and the KP algorithms, by considering different numbers of DPs, respectively, k=1, 4, 6, and 8, $z = 100\mathrm{m}$, and two values of $\tau$, respectively,3s and 30s*




On the basis of the previous considerations, the simulations are carried out by considering 3 different parametric sets:

1. IF protocol with $\lambda = 10$ pck / s $(\tau = 30\mathrm{s})$,
2. SH protocol with $\lambda = 10$ pck / s $(\tau = 30\mathrm{s})$, and
3. SH protocol with $\lambda = 100$ pck / s $(\tau = 3\mathrm{s})$.

As previously explained, the identification of the DPs' optimized positions is based on a very long mobility trace, whereas the communication performance analysis is carried out by considering a portion of a (stable) mobility trace whose duration coincides with $T_{\mathrm{I}}$. For this reason, in our ns-2 simulations we have considered the same mobility trace used in the previous section for deriving the CDF of the coverage time, with duration equal to $T_{\mathrm{I}} = 60\mathrm{s}$ and positioned in the center of the steady region of a longer mobility trace, as shown in Figure 3.

## Simulation Results

In Figure 9(a) and Figure 9(b), we show the coverage ratio obtained, respectively, in the Manhattan and Parma scenarios. It can be observed that in all cases the IF protocol offers a significantly higher throughput than the SH protocol. This is expected, as using probabilistic multi-hop forwarding around the "hot" (from a vehicular traffic perspective) junctions allows to reach a very large number of vehicles ("packed" around the junction). However, in both scenarios the coverage ratio with the IF protocol reaches a saturation value approximately at $k = 4$. This limit is almost equal to 1 in the Manhattan scenario, but it is much lower in the Parma scenario (roughly 0.75). This phenomenon can be interpreted as follows.

*Figure 8. CDF of the coverage time in the Parma scenario, obtained by considering the DPs placed according to the MCP, the MCTTP, and the KP algorithms, by considering different numbers of DPs, respectively, k=1, 4, 6, and 8, $z = 100\mathrm{m}$, and two values of $\tau$, respectively,3s and 30s*

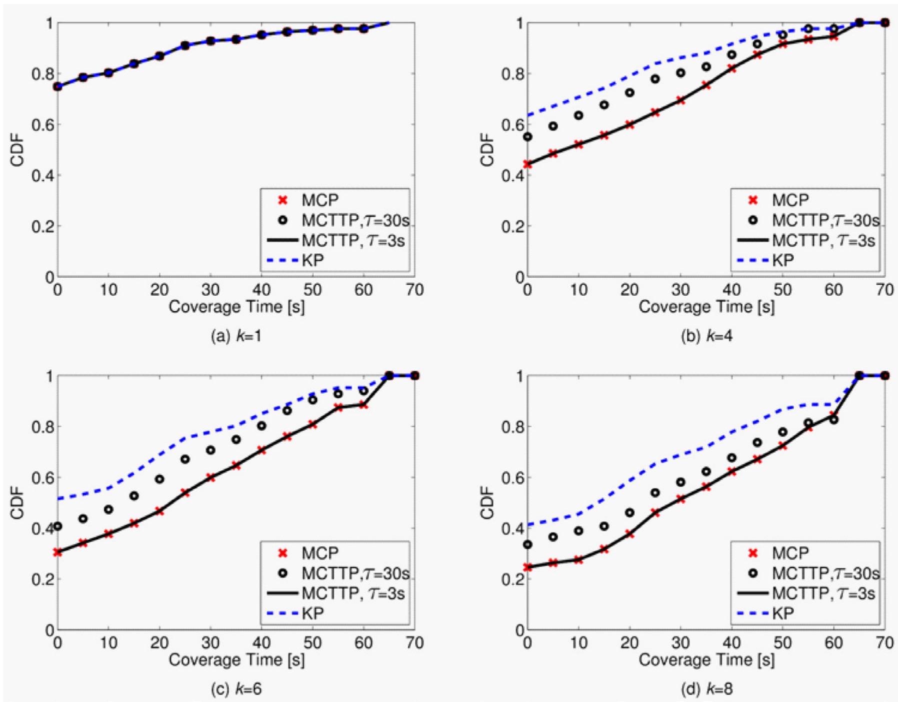



*Figure 9. Coverage ratio as a function of $k$ in the Parma scenario, obtained by considering the DPs placed according to the MCP, the MCTTP, and the KP algorithms, by considering different numbers of DPs, respectively, k=1, 4, 6, and 8, $z = 100\mathrm{m}$, and two values of $\tau$, respectively,3s and 30s*

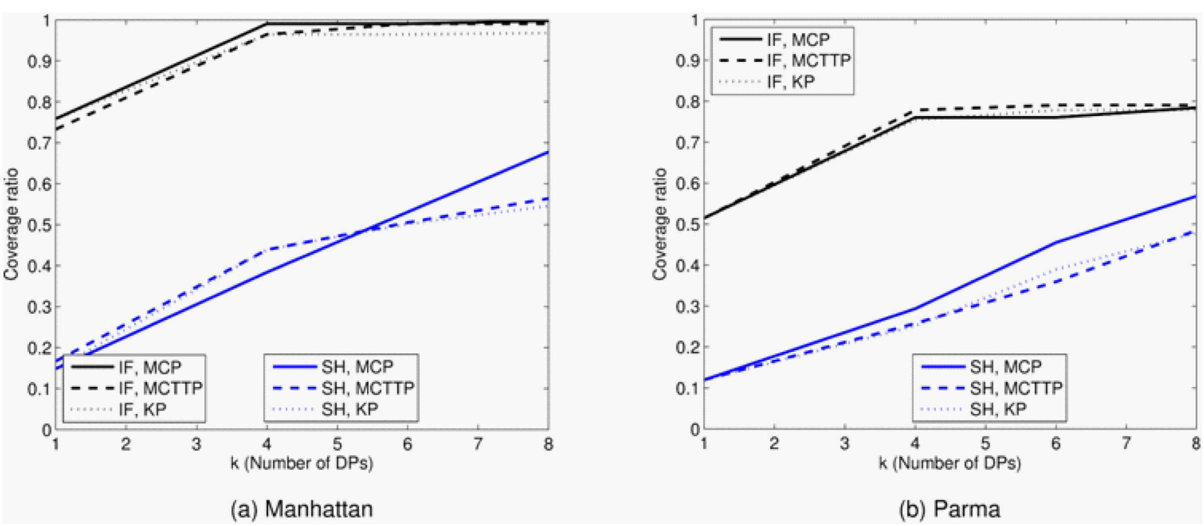
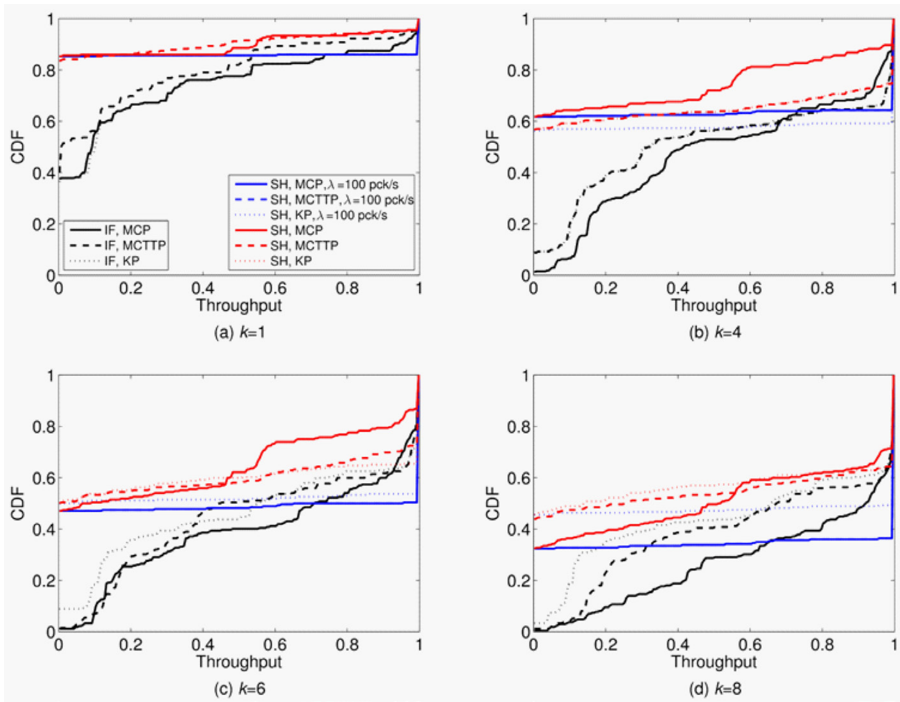


*Figure 10. CDF of the throughput in the Manhattan scenario, obtained by considering the DPs placed according to the MCP and MCTTP algorithms, and by considering different numbers of DPs, respectively, k=1, 4, 6, and 8*




The Parma topology is irregular and, therefore, there is a significant number of roads with a small vehicular spatial density, which makes ineffective increasing the number of DPs, even under the use of multihop communication protocols. In other words, in the considered Parma scenario there are approximately 4 “hot” traffic junctions, whereas the remaining junctions do not experience a large vehicular flow: therefore, they contribute very little to information dissemination. In this case, the introduction of a fixed relays around the hot traffic junctions might represent a more effective solution to extend the coverage area guaranteed by the use of IF. It can be also observed that in the case of the SH protocol, the MCP algorithm tends to provide a higher coverage ratio in both scenarios, while when using the IF protocol the advantage is less significant. Finally, it is important to remark that the coverage ratio of the SH protocol is the same for both values of $\lambda$.

The coverage ratio gives an idea of the number of vehicles that get in contact with a DP at least once: as expected, the use of a multihop broadcast protocol is expedient to increase it. However, the coverage ratio does not provide any information concerning the quality of the connection between the DPs and the vehicles: in other words, it does not offer information about the effective amount of data that can be transferred. For this reason, we now move our attention to the throughput. In particular, in Figure 10 and Figure 11 we show the throughput obtained in the Manhattan and Parma scenarios, respectively, by considering the same parametric sets used in Figure 9.

From the results in Figure 10, the following considerations can be drawn.

- For a given value of $\lambda$, the IF protocol shows a significant advantage with respect to the SH protocol. However, if we con-

*Figure 11. CDF of the throughput in the Parma scenario, obtained by considering the DPs placed according to the MCP, the MCTTP, and the KP algorithms, by considering different numbers of DPs, respectively, k=1, 4, 6, and 8,* $z = 100\mathrm{m}$, *and two values of* $\tau$, *respectively, 3s and 30s*

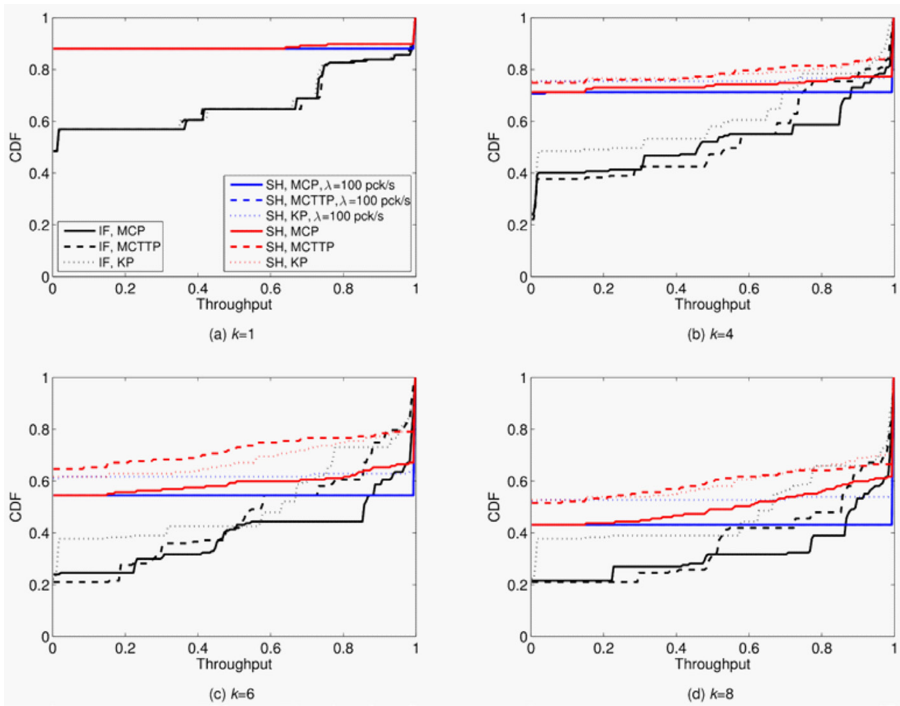
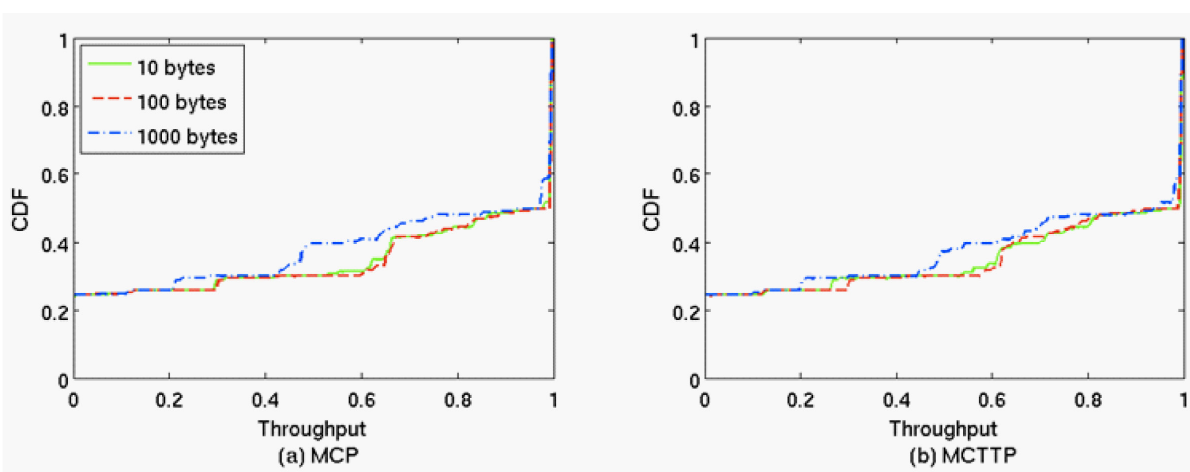



*Figure 12. CDF of the throughput in the Parma scenario, obtained with the IF protocol and four DPs, with different values of packet size. Respectevely for the MCP and MCTTP algorithms, and a single value of* $\tau$ *3s.*

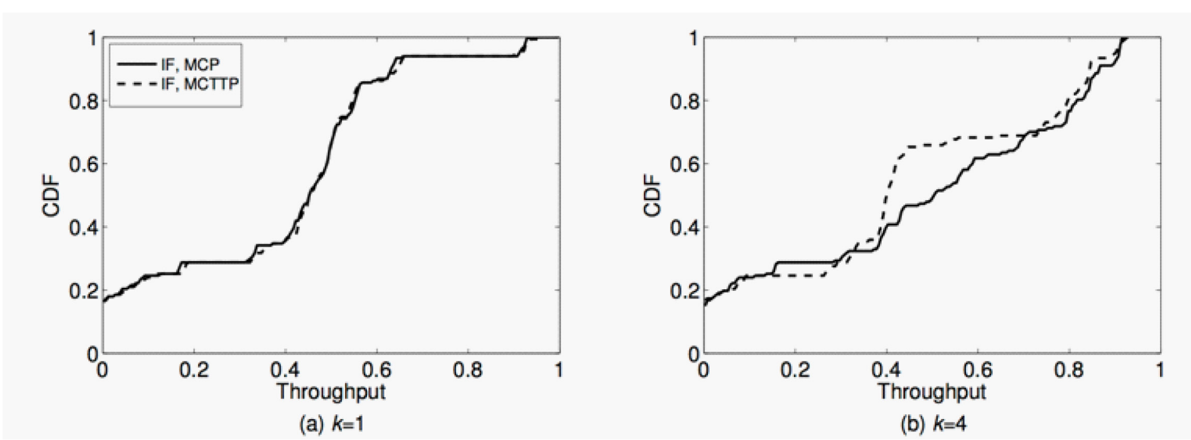


sider the SH protocol with a high value of $\lambda$ (100 pck/s), the results change significantly. In fact, it turns out that the IF protocol allows to send at least a bit of information to almost all vehicles, but only a small fraction of them can receive the entire information content. On the contrary, the (SH, $\lambda = 100$ pck / s) configuration has a bi-stable behavior, in the sense that a vehicle is likely to receiver either no information at all or the entire information block. Therefore, depending on the application requirement, the SH solution could be preferable or vice-versa. For example, the (SH, $\lambda = 100$ pck / s) option is a better choice if the information block is a file, since all fragments are required. On the opposite, if the information block is associated to a media streaming, a small fraction of them can be sufficient, and IF is more appealing.

- As expected, in the SH configuration, the MCTTP is the algorithm providing (more or less) the best performance, while the KP offers the lowest throughput. On the contrary, when using the IF protocol, the MCP offers the best performance. This can be easily justified by observing that the maximization of the coverage time by considering only SH communications, does not necessarily lead to the maximization of the coverage time by using multihop communications.
- Finally, by comparing the throughput CDFs obtained in the Parma and the Manhattan scenarios, it emerges that the former has a more irregular behavior, and this is due to the fact that the vehicles tend to be more clusterized than in the latter, where, instead, the vehicles distribution is slightly more homogeneous.

In Figure 12, we show the CDF of the throughput, for the Parma scenario in the case with 4 DPs, placed in according with the MCP and MCTTP algorithms—the KP case is similar to MCP case. We use different values of the packet size, namely 10, 100, and 1000 bytes. It can be observed that the performance, in both MCP and MCTTP cases, tends to remain similar regardless of the value of the packet size. Therefore, it can be concluded that the packet size has no influence on the network performance. This behavior is due to careful planning of the source position. The value of the

*Figure 13. CDF of the throughput in the Parma scenario, obtained with the IF protocol and respectively for k=1 and 4 DPs, with a packet size P=1000bytes. For the MCP and MCTTP algorithms, and a single value of $\tau$ 3s.*



packet size would have an impact if non-optimal sources placement was considered.

In the Figure 13, the CDF of the throughput is evaluated in the precence the Nakagami channel model, previously described. For this kind of simulation we used the same transmit power of the previous simulations, $P_{tx}$=1 mW. By comparing the performance of the Nakagami model with the Friis channel model, shown in Figure 11, it can be observed that the CDF in the Nakagami case increasis more rapidly than in the Friis case, even through the performances in both the scenarios are comparable.

The conclusion of the simulation analysis has shown that with optimized planning of the DPs the performance of the broadcast protocol, IF expecially with single hop communications, is not influenced by the choosen parameter and the channel model.

## FUTURE RESEARCH DIRECTIONS

The problem of placing a fixed network of RSUs has been extensively analyzed in the domain of MANETs and cellular networks, but it still remains an open problem in VANETs, for the reasons illustrated in the following.

All the state-of-art DPs placement algorithms, including those considered in this work, tend to select the DPs positions in the proximity of intersections with a high traffic load, in order to maximize the number of the vehicles covered by SH transmissions of the DPs. While this technique is certainly optimal when using SH protocols, complete network coverage can be reached only placing a large number of DPs (e.g., one per junction). In this work, it has been shown that better results can be obtained by making use of multihop communications protocols, which allow to reach a significantly larger number of vehicles. However, also the use of multihop protocols can be ineffective in scenarios with a large number of roads and a limited number of vehicles (i.e., sparse VANET scenarios). A possible countermeasure for coping with this problem consist in making use of some fixed relay nodes, not connected to the backbone network of the DPs and acting as bridges between different city areas connected by not sufficiently dense roads. According to these considerations, in the next future the algorithms currently available in the literature should be extended in order to encompass both the use of multihop broadcast protocols and the presence of fixed relay nodes. In fact, the optimized positions of relays tend to be typically different from the optimized DPs' positions.

## CONCLUSION

In this book chapter, we have presented an overview of the approaches, recently proposed in the literature, for the identification of the optimal placement of strategy of fixed DPs in VANET-based urban communication scenarios. In particular, it has been shown that the approaches based on single-hop and multi-hop communications lead to very different performance. In particular, the SH approach guarantees a high QoS to a small number of vehicles, while the multihop approach offers a better average performance level. However in the latter case a very small number of vehicles experience a satisfactory dissemination service. The inclusion of fixed relay nodes, with intermediate characteristics between DPs and vehicles, is an appealing research direction for the design of efficient urban information dissemination systems.

## ACKNOWLEDGMENT

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## KEY TERMS AND DEFINITIONS

**Broadcast Protocol:** A forwarding network protocol that allows transmitting information from a source to all the nodes of a given network, thus yielding to one-to-many communications. In this context, the definition of "network" is a broad concept that depends on the requirements of the applications of interest.

**Coverage Ratio:** The ratio between the number of vehicles that experience at least one contact with a DP (during the considered observation period) and the number of vehicles in the network.

**Coverage Time:** For a given observation period it is given by the time spent by a node under the coverage areas of all DPs during the considered observation period.

**Dissemination Point (DP):** A RSU in charge of disseminating information to the transiting vehicles in its proximity.

**Mobility Simulator:** Software that predicts the movements of a group of vehicles in a given environment, on the basis of approximate physical and behavioral models. The list of the generated movements can be saved in a database to be further analyzed or used by another (network) simulator.

**Multi-Hop Broadcast Protocol:** A broadcast protocol that foresees an active role for the network nodes that are supposed to forward to their neighbor, all received packet. In these protocols, the path covered by a packet is composed by multi-hop transmissions.

**Network Simulator:** A software that predicts the performance of a network (without an actual network being present), by considering an approximate behavioral model of the network nodes.

**Probabilistic Broadcast Protocol:** A multihop broadcast protocol, such that the network nodes probabilistically decide to participate to the forwarding process.

**Relay:** A RSU that does not generate information on its own, but that can only forward the received information.

**Road Side Unit (RSU):** A fixed network node, usually located beside a road infrastructure, which could coordinate or belong to a VANET.

**Throughput:** The ratio between the number of packets received by a given node and the number of packets in the information block sent by the DPs.

**Vehicular Ad-Hoc NETwork (VANET):** It is a particular type of mobile ad-hoc network, and its main feature is to provide communications among vehicles and between vehicles and fixed wireless nodes.