Bulk data transfer through VANET infrastructure

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Abstract—**Content distribution over ad-hoc networks has been widely studied and numerous solutions can be adapted to VANETs (vehicular networks). VANETs, however, can also benefit from an infrastructure in order to improve the efficiency of any content dissemination technique, while allowing more transmissions resources to be available for safety applications. Unfortunately, so far, no such solution has been proposed. In this paper, we introduce the use of an 802.11p infrastructure based on Road Side Units (RSU) for downloading data (*eg* a map) to vehicles on a highway. At the application level, the main challenge is then how to deliver data to a large number of moving receivers with limited connectivity.**

While broadcasting data through each RSU should efficiently provide the cars with most of the data, one could believe that some specific transmissions based on vehicles needs could help to reach full downloads. Using simulations, we observed however that the best performances are achieved by a pure broadcasting system.

I. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs for short) are expected to make driving safer with the help of specific applications implemented over a dedicated control channel [1][2][3][4]. On the other hand, "infotainment" applications could allow a faster and cheaper deployment of on-board communication devices. Nonetheless the "killer application" is still missing and may never appear because of the emergence of mobile devices connected to data networks. We will focus on a third class of applications, that could be described as "travel assistance". The aim of such an application is to provide the vehicle passengers with information related to their journey.

Safety applications should benefit from short range technologies such as IEEE 802.11p [5] while infotainment uses operated technologies such as cellular networks.

We believe that travelling assistance applications could benefit from multiple technologies. Some general information could be obtained from a wide-area operated network, be it bidirectional or not (*eg* satellite link, unicast or broadcast). Some information could also been retrieved through short-range technology, either in a managed architecture or through an ad-hoc network, with the help of peer to peer communications between vehicles.

Lots of work have been done on content distribution through ad-hoc networks and many studies are more specifically dedicated to VANETs. Most of these studies assume an ad-hoc system and aim to improve some P2P approach with the help of network coding [6], [7], [8] or data popularity [9], [10]. On the other hand, some studies have try to extend data access through vehicles acting as relay [11]. However, to the best of our knowledge, the use of an infrastructure (*eg* access points along the road) to help the efficiency of (possibly cooperative) content download has not been considered yet.

We will focus on this paper on a "map update" application, the main objective of which is to help vehicles maintaining an on-board map. This map is assumed rather static, updates being based on civil engineering. Of course, our work could be extended to many applications with similar constraints : unidirectionally download a relatively large amount of data to a large number of subscribers with no stringent time constraints.

In this context, we will try to determine how to use an infrastructure-based 802.11p network to reach the most efficient download. The metric we will then try to optimise is the reception ratio, from the vehicle point of view. The main question we tackle here is how the application should use the channel. Broadcast efficiency is challenged by the limited connectivity of mobiles. Some "dedicated" transmissions are expected to help reaching a full download.

The remainder of this paper is organised as follows. Section II introduces the scenario we focus on, then section III describes the model used in our simulations. Section IV presents a analytical analysis of one of the studied scenarios and section V discusses some results. Section VI then concludes this paper.

II. PROBLEM STATEMENT

The scenario studied in this paper is depicted in figure 1. A highway portion is assumed to be equipped with some RSUs (*Road Side Units*), acting as access points and implementing an infrastructure. Some vehicles enter the highway from one side and travel to the other side. Those vehicles use OBUs (*On Board Units*) to communicate with the infrastructure. The highway portion may not be fully covered.

An application server provides the vehicles with the map (or any other useful data). The map is split into numerous chunks of constant size, each chunks being sent in a single packet. We want to evaluate the number of chunks received by each vehicle and the end of the highway traversal in different conditions.

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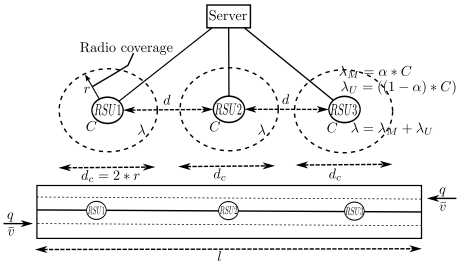

Fig. 1. Scenario

This performance criterion can be measured through different metrics, we will focus on the two following :

- The proportion of full downloads π_1 will help us to estimate the proportion of fully satisfied clients.
- The average reception rate τ can be an estimation of the average client satisfaction as far as a partial download can be useful (downloading map updates, that would mean that a partially up-to-date map could still be useful).

We will suppose that the map suffers no update during the simulated time, and thus the same map version will be sent periodically. We will assume independent transmissions on each RSU as far as the ground network resources are not an issue here. The application server has thus several options on packet sequencing on each RSU.

The most simple technique (hereafter entitled *sequential*) consists in the transmission of the chunks in the order in which they appear in the file. A predictable consequence is a high correlation of multiple transmissions among chunks. Another technique (hereafter entitled *randomised*) consists in using a different random order for each RSU. We will study both of these techniques.

III. MODEL DESCRIPTION

We will use the NS3 simulation tool to evaluate and compare the performance criteria for both techniques. This section summarises the simulated model.

A. Architecture and application model

1) The architecture: it is mainly described by figure 1. The highway of length $12000m$ has two lanes in both directions. 6 RSUs are evenly spaced along the highway.

2) At the application level: the server will indefinitely send the file as a sequence of N chunks, $C_1, \dots C_N$. The order in which the chunks are sent through a given RSU r is given by a permutation $\sigma_r : \{1 \dots N\} \mapsto \{1 \dots N\}$.

Using the sequential technique, $\sigma_r = Id_{\{1 \dots N\}}$ for any r, while using the randomised technique, each σ_r is a different random permutation.

As an OBU crosses multiple areas covered by different RSUs, it may experiment more and more duplicate chunks. This phenomenon will alleviate the consequences of packet losses. On the other hand, the download duration will lengthen.

3) At the transport layer: the UDP protocol is used. Each chunk could be sent either in unicast or multicast. However, we have only implemented broadcast in our simulations. We consider a single application transmitting for the whole population. So as far as our results are concerned, there is no difference between multicast and broadcast.

B. Mobility model

As far as we focus on a linear area, we have chosen not to use an external mobility simulator like SUMO. However, we use a very realistic model implementing *Intelligent Driver Model* (IDM), and the *Minimising Overall Braking decelerations Induced by Lane changes* (MOBIL) [12][13]. Some parameters have been tuned to suit our needs (*eg* all the vehicles are sedans with embedded communication means, speed distribution is set according to french rules, …).

C. Physical and link layers model

Multiple channels have been defined in VANETs. In the European profile, the first and second service channels are dedicated to "road safety and efficiency applications" [14]. In this study, we use the second one, called G5SC2, whose main characteristics (a throughput of $12Mbps$, a power of $12dB$ and an gain of $1dB$) have been defined in our simulation model.

Error rate is simulated through the NIST model implemented in NS3 [15] and based on a combined three log distance/Nakagami model. The latter is said to suit VANETs performance evaluation [16][17][18].

It is important here to highlight a significant side effect of the IDM/MOBIL model. In this model, the car flow rate has a direct consequence on the average speed of the vehicles. A high arrival rate leads to a low speed (because of traffic jams). Of course, lower density traffic has less influence on the speed and this impact of vehicle density is more important on longer highway sections.

This property is interesting, because some of our simulations have shown (small) dependences of performance compared to density. These results were unexpected (specially when using broadcast), but are a direct consequence of this property.

D. Implemented strategies

Two different strategies have been implemented for chunks ordering, and two types of transmission : broadcast and "dedicated". A packet is said to be sent as "dedicated" when it has been requested by a vehicle.

An vehicle entering in a RSU area can send to the server a bitmap describing missing packets. In order to limit traffic increase, this should be done by a small proportion of vehicles. The choice between broadcast and dedicated is thus based on τ (the reception ratio for a given vehicle : the number of chunks received divided by N). As far as $\tau > \tau_d$ (where τ_d is a threshold to be defined), the vehicle is allowed to send its bitmap. Dedicated transmissions are then used for this vehicle.

The next question is the throughput sharing between vehicles. If n is the number of vehicles for which dedicated transmissions are used within the transmission area of a given RSU, and m the number of other vehicles in the same area, then let $\alpha = m/(m+n)$. If λ is the available bandwidth for the application on this RSU, then the scheduling strategy will enforce a throughput $\lambda_b = \alpha.\lambda$ for broadcast, and a fair sharing of $(1-\alpha).\lambda$ for dedicated transmissions.

IV. ANALYTICAL ANALYSIS OF THE RANDOMISED OVER BROADCAST SYSTEM

On a purely broadcast system, the behaviour of the randomised technique can be easily (but accurately) modelled so that performance can be analytically exhibited. The only new assumptions (regarding the model used for simulations are a constant speed for a given vehicle, and a uniform distribution of losses within the reception area, with a packet error probability p. As far as chunks are sent in a randomised order, the latter assumption seems reasonable.

Let us call n the maximum number of chunks the vehicle can receive from a single RSU. This value depends on the vehicle speed and on the throughput.

A. Probability of new transmissions

If R is the number of chunks received by a vehicle at time t, the probability that the next RSU send k *new* chunks when the vehicle is within its coverage area is given by the hypergeometric distribution :

$$HG(N, N-R, n, k) = \binom{N-R}{k} . \binom{R}{N-k} / \binom{N}{n}$$

B. Probability of reception

The probability for the vehicle to receive q chunks among these k new chunks is given by :

$$\pi_{k,q} = \binom{k}{q} . p^{k-q} . (1-p)^q$$

It then comes that the probability for vehicle to receive q new chunks ($0 \leq q \leq n$) through the transmission area of a RSU is

$$\Gamma_{N,R,n,q} = \sum_{k=q}^{n} HG(N, N-R, n, k) . \pi_{k,q}$$

C. Probability of i chunks received after b RSUs

Let us define $P_i(b)$ as the probability for a vehicle to receive i different chunks while passing by b consecutive RSUs. With the previous definition of Γ, we have

$$P_i(b) = \sum_{j=max(0,i-n)}^{i} \Gamma_{N,j,n,i-j} . P_j(b-1)$$

If we define $P(b)$ as a vector built with $P_i(b)$ and $G(N,n)$ as a matrix built with $\Gamma_{N,j,n,i-j}$ then we have

$$P(b+1) = G(N,n) \times P(b)$$

Assuming $P(0) = 0$, we can iteratively compute the probability of any reception rate after any number of RSUs. We will compare these results with the ones obtained from simulations.

V. SIMULATION RESULTS AND ANALYSIS

With the parameters aforementioned, each RSU can transmit to a distance up to 792 meters. The maximum number of chunks a vehicle can (theoretically) receive from a single RSU is then $N_m = 275$. We will use this value as a reference for the map size in our simulations.

A. Broadcast vs dedicated a single RSU scenario

In this section, a single RSU is used and the file size $N = N_m$. Figure 2 shows the average reception rate for both a pure broadcast system ($\tau_d = 0$) and a pure dedicated one ($\tau_d = 1$).

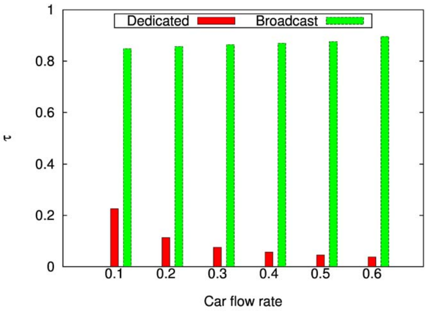

Fig. 2. Reception ratio *vs* car flow rate

Of course, as far as the system is not over provisioned, the dedicated system is inefficient (specially with a single RSU scenario where dedicated behaves like unicast). Density influence on the pure broadcast system has already been discussed.

B. Broadcast behaviour in a multiple RSU scenario

In this section, the number of RSUs is 6, and we will evaluate the performance of a pure broadcast system ($\tau_d = 0$).

1) Sequential ordering: Figure 3 (label "S") shows, for different map sizes, the average reception rate cumulated along multiple RSUs using a sequential ordering. The measured loss rate is around 15 %.

We can notice a surprisingly low value for $N = 1375$. The problem is that with this precise configuration, lots of vehicles suffer a synchronisation phenomenon : starting with RSU number 3 (in this case), most of the received chunks have already been received earlier.

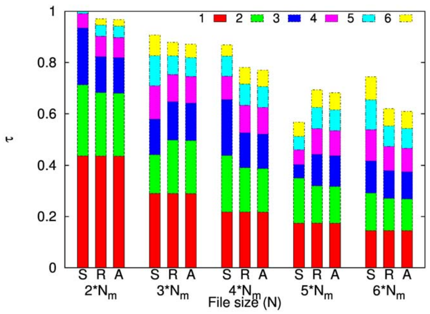

Fig. 3. τ vs N with 6 RSUs and Sequential Scheduler

The sequential ordering turns to be unfair. Whatever the configuration, some vehicles, depending on their speed and other parameters, may receive far less chunks than others.

Concerning the ratio of OBUs achieving a full map download, π_1, table I shows its value for multiple combinations of N and RSU number.

TABLE I
FULL DOWNLOAD RATIO

RSU	1	2	3	4	5	6	Total
Sequential							
275	0.29	27.81	65.07	6.43	0.39	0.01	100
550	0.0	0.0	0.43	6.34	29.44	34.50	70.71
825	0.0	0.0	0.0	0.0	0.0	0.74	0.74
Randomised							
275	0.03	1.06	43.21	43.58	10.15	1.68	99.71
550	0.0	0.0	0.0	0.0	0.0	0.1	0.1

2) Randomised ordering: Figure 3 (label "R") shows the average cumulated reception rate with the randomised ordering. These results can be compared with those obtained through the analytical method previously described and shown with label "A" (using the observed loss rate and average speed). We can notice that this scheme is a bit less efficient, but far more predictable. Moreover, it is more fair that the sequential ordering. However, looking at table I, we can notice that this technique hardly achieves full downloads. This is confirmed by our analytical model.

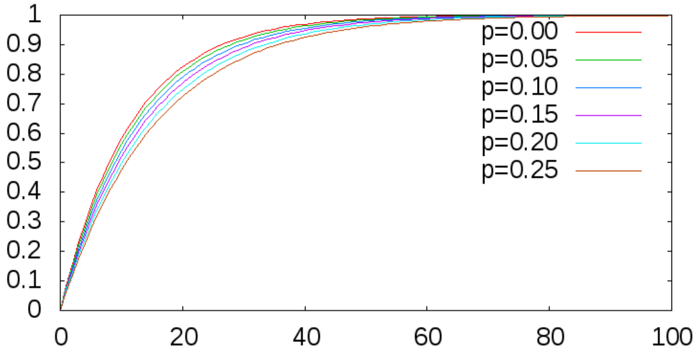

Fig. 4. Reception ratio vs RSU number

Both simulations and analytical analysis also show that, with the help of duplicated transmissions, the packet loss rate has little influence on the results. Figure 4, for example, shows the average reception ratio (analytically evaluated) for a 3300 chunks map as a function of the number of RSUs for multiple packet loss rates. A chosen π_1 ratio can be reached with a number of RSUs linearly dependent on the map size. This ratio increases sharply near this number of RSUs, then increases very softly.

We will then try to determine if dedicated transmission could help accelerate this final increase.

C. Multiplexing broadcast and dedicated transmission

Dedicated transmissions are clearly inefficient, except with a lightly loaded system. With a pure broadcast system, on the other hand, sequential ordering can induce unpredictable and unfair behaviour, while achieving in most cases a good rate of full download. A randomised ordering leads to more predictable and more fair results, but with a (slightly) lower average reception rate and a lower rate of full download.

1) Some results: We ran simulations sharing the throughput λ between broadcast and dedicated transmissions with the help of the aforementioned parameter α and threshold τ_b.

The main idea is that dedicated transmissions, while consuming some throughput that could be used for broadcast, can help some vehicle to fulfil their download, increasing the global efficiency and fairness.

We noticed in our results that low threshold values dramatically reduce the bandwidth available for broadcast. As the threshold is low, indeed, most of the missing chunks have not even been sent to the vehicles. Hence there is a large correlation of packets received by different vehicles.

On the other hand, high threshold values also proved useless, as most of the vehicles would not reach the threshold.

Finally, any decrease in broadcast throughput has more significant consequences on the results than the increase provided by the corresponding use of dedicated transmission.

2) Side effect of the model: The linear highway model used in our simulations seems to induce a bias in the previously described results. It comes from the fact that all the RSUs are not used the same way. Those close to the highway entrance/exit are used by cars with a high or very low ratio of received chunks, while those in the middle of the highway are used by cars with a medium ratio.

In order to check the consequences of this bias, we ran simulations with a beltway model. The results we obtained are a bit different, but the main conclusion remains : dedicated transmissions will not improve performances.

D. Broadcasting most wanted chunk first

In order to clarify the opportunity to improve broadcast performance, we also implemented a "most wanted first" strategy. In such a scenario, every vehicle sends its bitmap every time it enters a new RSU area. We think that this is not a good technique as this will significantly increase the traffic.

Our results show a significant increase of the average received ratio but also highlight some challenges that should be addressed in such a system. First of all, our simulations show, indeed, that this technique is much more sensitive to the packet loss ratio than broadcast. This is because packets are sent mainly for vehicles entering the area, that means for vehicles suffering a high packet loss. Another drawback is that the same packet can be sent several times in a short period, because new cars entering the area can increase again its priority. This will lead to a non optimal use of resources.

As a consequence, even if this strategy could be faster than pure broadcast to download a high ratio of the map, a high probability of full download is still difficult to achieve. For this reason, we did not explore this idea further, and we did not even simulate the contention phenomenon that could decrease its performances.

VI. CONCLUSION AND FUTURE WORKS

We believe that the use of some RSUs scattered along the road should be of great help to a VANET peer to peer content download application, specially in sparse scenarios. In this paper, we have studied the use of such a network infrastructure. We have shown that a simple broadcast system can achieve a previously defined level of performance, evaluated either by the average reception ratio or by the proportion of cars enjoying a full download.

Depending on the performance criterion, we have shown that a sequential or a randomised packet ordering is more suitable. The performance of the latter is highly predictable with the help of a simple analytic model.

Of course the RSU density, the available bit rate and the data size are fundamental parameters. Our results have shown however that, with the help of multiple transmissions through multiple RSUs, the most important parameter is not the packet loss rate, but the number of (useless) retransmissions.

Our conclusions are the following. Unicast is obviously not a scalable solution. Broadcast can be tuned to achieve a high delivery ratio but can hardly guarantee a high level of full downloads, mostly because of unneeded duplicates. Any use of resources to send packets in a more specific way would decrease performance. Basically, using feedback to avoid some retransmissions would turn the system to be (partly) unicast and thus not scalable.

We believe that network coding could be of great help to alleviate the probability of unfortunate retransmission. Our very first results on this area are very promising. We are also working on the evaluation of the combined use of RSU broadcast and OBU peer to peer communications in a content delivery application.

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