Sustainable Highways with Shadow Tolls based on VANET Advertising

Position paper

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ABSTRACT

With the advent of vehicular communications and new developments in enhanced reality for Advanced Driver Assistance Systems (ADAS), we present in this position paper a new highway revenue model based on digital advertising super-imposed on physical billboards. We show that there is a strong correlation between economic development and an extensive road network. However, the public support for maintaining and expanding the road network is diminishing since these investments mainly rely on taxation. The common approach is to introduce tolls as a revenue generating method for supporting these investments. We argue that virtual billboards could provide an alternative revenue stream and avoid tolls in highways with high volumes of traffic. The key technologies are vehicular-to-infrastructure (V2I) communications and virtual windshields that already provide enhanced reality for ADAS. The physical billboards would transmit targeted advertising to approaching vehicles that would overlay it on top of the billboard sign. We demonstrate that it is already possible to implement this system with existing technologies. These digital ads would combine the flexibility of Internet advertisement with the high exposure of highway billboards and the willingness to receive them as an alternative to paying tolls. Finally, we show that it is viable to provide advertisement sponsored highway segments with very low cost-per-view values, especially in suburban highways that have a high volume of traffic.

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Advertising, Computer Vision, V2I, VANET

1. INTRODUCTION

Roads in developed countries have become an infrastructure of very large proportions. The United States of America (US) has the largest road network in the world, with more than 7 million kilometres. The European Union (EU) road network has approximately 5.8 million kilometres, but much more densely distributed than in the US. China's road network is rapidly increasing, already totalling more than 3.5 million kilometres in 2007.

An analysis of the statistics in terms of road length, country area and Gross Domestic Product (GDP) shows that, excluding very large countries in area (more than 650,000 km², approximately the size of France), almost all countries in the top 25 GDP list have more than 1 km of road length per km² of surface area. The only exception is Norway, number 25th in 2011 GDP list, with a much smaller ratio between road length and surface area of just 0.29 km²/km². The top place belongs to Belgium (5.03 km²/km²), followed by the Netherlands (3.27 km²/km²) and Japan (3.20 km²/km²). Twenty of the countries in the top 25 list of countries by GDP are also in the top 25 list by length of roads. The exceptions are very small countries in area (South Korea, Netherlands, Switzerland and Belgium), plus Iran and Norway.

It is clear that the economy and society depend heavily on efficient road networks. Approximately 44% of goods transported in the EU go by road. Moreover, people travel mainly by road, with private cars accounting for 73% of passenger traffic in the EU [13]. Despite the importance of roads for economic growth, funds to build and maintain this infrastructure are typically under high political pressure, as they rely mainly on taxation over gas sales. Some US states have even considered introducing a special tax on fuel efficient vehicles in order to compensate for lost revenue. As a result, a 2009 report of the American Association of the State Highway and Transportation Officials concludes that about 50% of the roads in the US are in bad condition [9]. The EU has recently harmonised the level of taxes with minimum excise duties across Europe [14].

Toll roads are a common method of revenue generation for building and maintaining highways. The advantages are that users support most of the costs, even though cars subsidize the degradation caused by heavy transport vehicles. The main disadvantages are that alternative roads are usually burdened by vehicles that avoid paying tolls, with all the associated consequences in terms of accidents, road degradation and increased congestion. In trans-European road trans-
port, some countries that have toll-free highways are especially burdened by traversing traffic from neighbouring countries. Other financing models include public-private partnerships (PPP) where shadow tolls measure traffic and public funds cover the cost of tolls. These models have shown problems in terms of risk sharing mechanisms by placing an unequal burden on the public side [7]. Furthermore, demand for public transportation is also limited by the availability of highways with no cost to the user. Pay-as-you-go schemes as an alternative to circulation tax have been proposed in countries such as the Netherlands, where users would be fitted with a GPS tracker that would charge an amount per distance depending on the road category and time of day. Public opinion has been strongly against this scheme, although similar schemes for car insurance have been welcomed.

In this position paper we propose a novel and disruptive scheme for funding the road network infrastructure, based on revenues from virtual billboard advertising, that would leverage the emerging technologies of augmented reality on windshields and vehicle-to-infrastructure (V2I) wireless communications in the 5.9 GHz band. Our concept is to make virtual outdoor advertising very similar to the ads present in the most popular websites such as Facebook or Google, exploring personalised and contextualised content which greatly increases the added value of a virtual billboard when compared to the physical roadside infrastructure. In our approach, the windshield is seen as a premium website, with a potential share of Internet time that reflects the average three hours of daily windshield exposure of American drivers [8].

Internet advertising generates enough revenue for keeping free most of the online content, while paywalled websites usually struggle to generate sufficient revenue. The virtual billboards could provide a similar revenue model since they exhibit the same flexibility and targeted advertising of mobile ads without the constraints of the screen size, while typically reaching an adult audience with a reasonable purchasing power.

2. AUGMENTED REALITY ON THE WINDSHIELD

Augmented reality on the windshield exists even prior to the invention of electronic displays. The rear-view mirror centrally placed on the windshield has been invented to augment the forward-looking perspective of drivers with rear-view images, improving safety as a result of improved perception. Some people might argue that such a purely optical system cannot be considered as an augmented reality (AR) system, as it lacks the integration of computer-generated elements with the real world environment. In fact, modern rear-view mirrors can already be fitted with electronically-controlled auto-dimming features, which is technically an electronic based manipulation of a real-world reflection. Furthermore, some side mirrors already superimpose visual alerts when a vehicle is detected in the driver’s blind-spot [1].

Aside from the mainly optical rear-view mirrors, GPS navigators are probably the earliest examples of systems that use the windshield as an AR display. The earliest units used the windshield to mount a portable electronic display that obscured the driver’s vision. To solve this problem, some systems use a rear-facing video camera on the portable device to merge navigational images with the real-time video stream [16]. This is known as video-see-through AR. In addition to the displays for navigational information, some instrument consoles include an embedded screen that displays the view from a vehicle-mounted infrared or thermal camera, implementing a night vision driver assistance system, capable in some cases of identifying and highlighting pedestrians. The idea is that these small screens can augment the perception of drivers when the visibility through the windshield is low, in a similar fashion to rear-view mirrors.

In modern high-end vehicles, the windshield is actually used as a transparent canvas over which the navigational images are projected [16]. Optical see-through AR in the context of driving has the major advantage of allowing the augmented content to be superimposed over a very large and ideally placed screen, which is the glass-based virtual windshield. Laser holographic projection is an emerging technology being applied in this context. The company Light Blue Optics (LBO) has been developing laser-based virtual image displays capable of displaying high brightness signage at high resolution and in full-colour [17]. LBO’s laser projection engine explores the process of two-dimensional diffraction to create pictograms that are always in-focus and can be projected on curved surfaces, such as a windshield. A preview of the pictography that can be displayed on a windshield using LBO technology is shown in Fig. 1A. Another example of an augmented reality system also based in laser projection is the Virtual Cable system, being developed by a company called Making Virtual Solid, LLC (MVS) [3]. The idea is to have navigation information being displayed to the driver in the form of a virtual 3D cable that appears to be hanging over the road, providing a guideline that the driver just has to follow to reach the destination. Figure 1B provides a snapshot of the functioning of this Virtual Cable.

Optical see-through AR can also be implemented through transparent Liquid Crystal Displays (LCD), embedded in the windshield. In [20] we have implemented an overtaking assistant, known as the See-Through System (STS) [19], which combines such AR technology with low-latency video streaming transmitted between two vehicles using Dedicated Short-Range Communications (DSRC). The result is the transformation of long and vision-obstructing vehicles into see-through tubular objects, which greatly facilitates the overtaking manoeuvre. Figure 1C shows a snapshot of the functioning of STS implemented using a transparent LCD. A video of a test-drive with this system is available at [6].

Several manufacturers have presented augmented reality glasses that can also be used to create the driver’s augmented vision of the road. These have some important advantages that results from the wearable nature of such equipment: while eye-point alignment calibration or eye-tracking systems are typically necessary with windshield-based AR technology, wearable displays overcome this problem by their very nature. Nonetheless, their drawbacks are the need to wear glasses while driving and the still limited resolution achieved by these very small displays.

3. INTERNET ADVERTISING

Since the early days of the Internet, there has been an exponential growth of both quantity and diversity of available content. This growth gained attraction from advertisers, that saw an immense opportunity to attract new customers to their businesses. Contrasting to the traditional out-of-home billboards or radio and TV advertising, the on-
of a website, the content of a search performed in a search engine, the history of a specific user or its localization, are the base for the selection of a specific advertisement. Often, the advertising services use a cookie that tracks the history of a user, which websites he/she visited and ads that he/she saw or clicked before. In the case that users are using an account that is associated with a provider of these kind of services, the ads will be targeted with improved information such as their tastes or recent purchases.

Recently, with the advent of the evolution of smartphones, the advertising model has suffered some evolutions. Mobile advertising surpasses the Internet advertising in terms of contextual advertising. The inherent mobility increases the localization factor to select the best advertising to display. Furthermore, the different ecosystems that exist in smartphones such as iOS, Android or Windows Phone, enhance the advertisers with more rich data about the user tastes in terms of which applications, websites or places are being visited the most. However, the screen real estate is a serious issue within the mobile advertising, where there is a limited size available for the advertising banner. Another serious concern, are the unbearable costs associated with the Internet traffic inside the cellular network. In the past, FCC addressed a similar issue with the prohibition of the FAX spam that proliferated in the 1980’s [15], which implicated high costs to the user. The recent trends show that smartphones have already surpassed the traditional computers in terms of units sold. Therefore, it is expected that the growth of mobile advertising will level the internet advertising and eventually overcome it.

Note that drivers are the main target audience of a radio advertising, especially daily commuters. However, it cannot provide localized and targeted advertising that is possible on the Internet. This could change in the near future with the integration of Internet radio in connected vehicles, or the already announced Spotify services embedded in vehicles.

4. MODELLING HIGHWAY BILLBOARDS

In order to propose virtual billboards, it is necessary to understand how these are distributed along highways. We identified all the billboards present in the A3 highway (Porto-Valença) on both directions, using a GPS logger and a webcam recording of the trip. The highway operator periodically reports on the volume of traffic data per segment of the highway. We obtained the linear regression model for the number of billboards per segment. The latter presented a symmetrical pattern, so we collapsed the 5 higher bins into the lower ones, which allowed us to increase the data set and simplify the model to only half of the segment. Finally, we ran a distribution fitting algorithm and obtained the parameters for the closest model, which in this case was a negative binomial distribution with the parameters $r = 1.604$ and $p = 0.06374$. In Fig. 2 we compare the billboard data with the obtained distribution model.

With these two models we are able to estimate the billboard placements in other highways and create simulation...
models for the highway infrastructure in Portugal. Furthermore, it provides an insight into the rationale behind the placement of these billboards, namely that their number for each highway segment is proportional to the volume of traffic. Moreover, billboards tend to be placed just after an entrance and just before an exit. This rationale is consistent with the billboards content since they are usually advertising local products and services that can be found at subsequent exits of the highway.

5. BILLBOARD ADVERTISING

The physical billboards placed on the roadside of an highway are exposed to thousands of visualizations per day. Nevertheless, most of these billboards display advertising that do not capture drivers attention, and mostly due to the lack of targeting. The virtual billboard aims to provide an advertising that is relevant to the drivers by displaying a more contextual and targeted advertising tailored for each driver. In this section, we first describe the technical characteristics of outdoor billboards and then introduce the concept of a virtual billboard.

5.1 Outdoor Billboard

Outdoor billboards are also known in the advertising industry as bulletins. Due to its nature, a bulletin must comply to certain specifications. According to the Outdoor Advertising Association of America (OAAA) [4], the size of a bulletin must fit within 11-21 meters in width and 3-6 meters in height. Often, the shape of the billboard is modified in order to visually enhance some specific characteristic on the displayed advertising. Ads placed on these billboards usually stay in place during long periods, typically more than one month, and in Portugal such advertising costs about 700€/month. Digital billboards were introduced to provide a more flexible way to display advertising on a bulletin. While their format resembles the traditional billboard, their content can change more frequently, such as weekly, daily or even hourly. Furthermore, displayed ads are more dynamic, having the possibility to have embedded video and multiple layouts, within the limits imposed by local regulations.

To maximize the profitability of both billboard and the displayed ad, the placement of billboards takes into account its exposure time, in terms of visibility and number of different views. Usually, billboards are placed at the roadside of a highway, near to populous areas, or on top of buildings. Still, the proliferation of billboards has been a real concern due to its visual pollution. Some U.S. states such as Alaska or Hawaii do not allow outdoor billboards, and in 2007 the city of São Paulo prohibited all outdoor advertising [2].

In terms of market share and exposure time, as shown in Fig. 3, out-of-home advertising represents a 27% of the consumer exposure time, even though it only generates 4.4% of the revenue. The information provided by [4] aggregates all out-of-home advertising and not just billboards. However, this further emphasises the disparity between exposure time and revenue.

5.2 Virtual Billboard

The architecture of the virtual billboard is built upon V2I communication between the vehicle and the billboard, as presented in the Fig. 4. To keep backward compatibility with existing roadside billboards architecture, the virtual billboard virtually superimposes existing billboards with the virtual advertising. Both vehicle and billboard must have a DSRC radio, and the billboard must be connected to the Internet. Internet connection can be available on each billboard or clusters can be formed in order to share a single Internet connection for cost reduction purposes. By having each billboard connected to the advertising network, there is an unlimited number of advertisements to display. This advertising network will retain all the relevant information about each registered driver.

The selection of an advertising is similar to current methods used on the Internet, using the driver’s own personal preferences, advertising history, driving history, etc. This implies that each advertising displayed will have different variables to process, ultimately leading to different advertisements displayed on each vehicle that is within the visibility range of a specific physical billboard. In order to correctly create the virtual billboard, an accurate localization of both vehicle and physical billboard is needed. The vehicle can be in the communication range of the physical billboard but not in the visibility range since the visibility range can be affected not only by terrain obstacles like trees and hills, but also by environmental issues such as dense fog and rain.

The communication protocol relies on the periodic beacons enabled in the DSRC radios, defined as Cooperative Awareness Message (CAM) [18]. Each vehicle periodically advertises its advertising network’s user ID and its location. Upon receiving each beacon, the physical billboard evaluates
if the vehicle is or will be in its visibility range. In that case, the user ID will be used to automatically select the best advertisement to be displayed on this particular vehicle. After this selection, the advertisement will be sent to the vehicle in order to be displayed on its windshield. Computer vision in the vehicle visually detects the position of the physical billboard in terms of the driver’s point-of-view, and creates the virtual billboard by overlapping the physical billboard with the targeted advertising.

6. PROOF-OF-CONCEPT

Taking the concept of a virtual windshield discussed in Section 2, we envisioned the transparent LCD as the perfect way to enable the augmented reality within the vehicular environment. Based on this concept and in order to create a proof-of-concept, we performed an experiment based on video recording, computer vision and image overlapping. As the concept on this paper focus on highways, this experiment was performed on the same highway as in Section 4. We filmed the driver’s perspective of the highway with a camera, with a resolution of 1280x720 at a frame rate of 30fps. This video allowed us to virtually reproduce the driving experience with a high degree of realism.

For this proof-of-concept, we created digital advertisements that superimpose on the existing roadside physical billboards. We assume that the physical billboards can either use a chromatic key technique or near-infrared markers that are easily detected by digital camera sensors. This billboard would then be detected using computer vision, assisted by GPS information and other characteristics transmitted by the billboard over DSRC. In each video frame, we replaced the physical billboard with a pink coloured billboard. We used the OpenCV library to programmatically detect it. By using the segmentation technique we are able to detect where the physical billboard is placed and then virtually replace it by a digital advertising. A sample snapshot of this representation can be seen in the Fig. 5.

We can observe the digital advertising correctly superimposed on the physical billboard, being seamless to the driver. The proof-of-concept can be seen in video in [5].

7. BILLBOARD SPONSORED HIGHWAYS

In order to analyse the viability of billboard sponsored highways, we first obtain the toll-based revenue followed by an analysis of the advertising-based revenue necessary to replace these tolls. The equivalent cost per billboard for each highway segment was obtained by splitting the toll-based revenue by the number of billboards. This number was estimated by applying the model obtained in Section 4 to the A1 highway (Porto-Lisboa), which has 19 segments and about 300km. In Fig. 6, we present the daily cost per billboard for the actual toll values and compare it with the fixed price of 0.08€/km, which is defined by law as the reference toll price/km in Portugal. The values are ordered from lowest to highest in order to observe the number of highway segments that could become fully sponsored for different threshold values.

![Figure 6: Equivalent cost per billboard for toll based revenue.](image)
billboard advertising cost per vehicle based on the number of vehicles for each highway segment. Furthermore, we analyse different scenarios in terms of the impact of switching from toll-based revenue to billboard sponsored revenue. First, it is reasonable to assume that removing tolls would increase the volume of traffic, since the inverse happened when Portuguese highways with shadow tolls switched to real tolls [12], with reductions up to 50% in the volume of traffic. Second, the billboard sponsored highway segments can either maintain the same revenue and absorb the increased traffic or reflect this increase in the billboard sponsorship, thereby generating an higher revenue. In Fig. 7, we present these different metrics for obtaining the advertisement cost per vehicle. We used the same order of highway segments as in Fig. 6 in order to provide better comparison.

![Figure 7: Advertising cost per vehicle for billboard sponsored highways.](image)

These results show that 11 out of 19 highway segments could become fully sponsored and therefore free to users with advertising costs as low as 0.01€/vehicle. In Fig. 7, we observe that 11 segments stay below the threshold when considering a 50% increase in traffic due to providing toll-free highways. Even when considering a 30% increase in traffic and charging advertisers for this extra traffic, the threshold would be around 0.02€/vehicle.

8. CONCLUSIONS

In this position paper we present virtual billboards that combine the flexibility of Internet advertising, the contextual awareness of mobile advertising and the high exposure of roadside billboards. We present an architecture based on DSRC V2I communications and enhanced reality displays that allows for digital ads to be superimposed on existing physical billboards. We demonstrate the concept of virtual billboards using current technologies and present a video illustrating the system. Finally, we present the feasibility analysis of billboard sponsored highways and show that many highways with high volume of traffic could be supported from the advertising revenue alone.

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10. REFERENCES