

## Gossip Networks: The Enabler for Sparsely Populated VANETs

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### ABSTRACT

The future deployment of safety-oriented Dedicated Short Range Communications (DSRC) technology may be hindered due to the so-called “Market Penetration” problem: as a wireless network built from scratch, there is lack of value to consumers who are early adopters. In this paper, we explore potential applications that can be supported during the initial phase of vehicular ad-hoc network (VANET) deployment, i.e., sparsely populated VANETs. We show that delay-insensitive information sharing applications are promising since they only require opportunistic network connections (in contrast to safety applications that require “always on” connectivity). This is done via “gossip spread” information distribution protocols by which DSRC vehicles cache and then exchange the information while in range of other DSRC vehicles or road side units. This approach is especially attractive since the number of communicating vehicles will be very small during early deployment years. Moreover, we find that such a technology framework is adequate to enable several types of information sharing vehicular applications in which vehicles and their drivers/passengers are able to generate, aggregate, process, distribute, and consume the relevant on-the-road information, as nearby vehicles dynamically form virtual groups that share common interests. Using highly popular web-based social networking applications as a basis, we argue that similar vehicular-based applications also have the potential to become valuable applications in the VANET context. Finally, we discuss research and technical challenges as well as business and societal obstacles to be resolved in the future.

### I. INTRODUCTION

Modern vehicles are becoming increasingly connected to a variety of information sources using wireless communication.

On current production vehicles, wireless information may originate from a few meters away (e.g., Bluetooth) or from orbiting space satellites thousands of miles away (e.g., XM radio or GPS). The set of automotive-based wireless applications will soon be extended to include communication from other vehicles or nearby objects. Wireless connectivity in vehicles brings a wide array of information to drivers in the form of applications that can be used to enhance the driving experience. For example, communication with GPS satellites enables navigation and point of interest applications that efficiently guide drivers to locations of interest. Cellular communication with centralized call centers enables a variety of in-vehicle safety and convenience services, from notifying local emergency responders that a crash has occurred to a monthly email that shows the current diagnostic health of a vehicle. Several types of new wireless access technologies are now examined in order to evaluate their applicability to the vehicular domain.

#### DSRC Networks and the Dilemma of Market Penetration:

One emerging technology is Dedicated Short Range Communications (DSRC), which is defined under the IEEE 802.11p standard. DSRC enables vehicles to communicate various types of information (such as safety-critical messages) with other vehicles or road-side units, in a Vehicular Ad Hoc Network (VANET) fashion. Using DSRC, each communicating vehicle on the road periodically broadcasts its current kinematic information (e.g., GPS position, velocity, acceleration, etc.) and other sensor information (e.g., braking, stability control, etc.), to other communicating vehicles that are within communication range (typically 300m). Using a situational awareness algorithm, a receiving vehicle quickly evaluates whether there is a dangerous driving situation caused by other communicating vehicles. In the past few years, DSRC technology has generated a great deal of interest from the automotive

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industry and government agencies because it is widely believed that this emerging technology could significantly improve vehicle related safety [1].

However, the deployment of DSRC systems is currently challenged because consumers will not receive benefits from these systems until there are a substantial number of communicating vehicles. Therefore, there is little incentive for both consumers and OEMs alike to invest in these systems until there is sufficient fleet penetration. The rollout of DSRC in vehicles is likely to be a slow and gradual process. In 2006, there were more than 250 million registered vehicles in the U.S. [1], while the annual U.S. vehicle production volume has peaked at about 16 million vehicles [1]. In an ideal case (where all the new vehicles are DSRC-equipped), the population rate of DSRC-equipped vehicles into the U.S. transportation fleet is about 7%. This implicitly requires that any VANET design under consideration should handle market penetration growth smoothly as it increases over a period of 10-20 years after the initial deployment.

**Disconnected Gossip-Spread Network:** Designing a self-sustainable DSRC deployment is a challenging task that the industry currently faces. In this paper, we discuss the issues that are associated with a sparse deployment and propose means to deliver value to the consumers under extremely low penetration rates. We also explore the underlying network architecture of such networks as well as a potential application portfolio that could provide sustainable growth and increased functionality as the vehicle penetration increases.

The key contribution of this paper is that our proposed use cases employ a technique of limited, opportunistic network connectivity, or ‘disconnected gossip-spread network’. A disconnected delay-tolerant network (shown in Fig 1) contains nodes that have limited, opportunistic connectivity to other nodes during temporary encounters on the roadway. For example, in a vehicle environment, DSRC-equipped vehicles would have connectivity only when other DSRC-equipped vehicles are within the communication range, which is typically 300 meters. Only during these brief encounters can data be exchanged between the nodes. This opportunistic exchange of data is most useful in applications that can tolerate delays between the time when the data is disseminated and when the data is consumed. This type of data is referred to as Delay Tolerant Data (DTD) and networks that employ limited connectivity are referred to as Delay Tolerant Networks (DTN). Unless otherwise stated, we use the terms “Delay Tolerant Networks”, “disconnected network” and “gossip-spread networks” interchangeably in this paper.

**Delay Tolerant Data and Its Usage in Automotive Industry:** There are many real world examples of Delay Tolerant Data. A simple example is a radio station that

delivers weather and traffic at specified intervals, such as “weather and traffic on the 5’s”. In this case, the consumer will not have to wait any longer than 5 minutes to receive the weather and traffic information. Another example is Sirius/XM weather and traffic channels where information about the weather and traffic is cycled. XM radio, for example, communicates Detroit and Las Vegas data over the same channel. A listener in Detroit may have to wait until the Las Vegas weather and traffic information has been communicated before receiving the Detroit information. In both of these examples, the delivery network was always available (e.g., FM and XM radio) but the data was not. It is also interesting to note that in the case of weather, and possibly traffic, that new information (e.g. new weather forecasts) is only available at certain intervals.

Moreover, there are also use-cases where the network itself is a Delay Tolerant Network. Slacker Radio is an example of a service that employs limited periods of connectivity to deliver hours of audio entertainment and information to the user. A typical slacker radio consumer configures a list of preferred stations they wish to listen to using the Slacker Radio website. When the consumer is within range of a wireless hot spot, the consumer’s device will be automatically refreshed with new data from the Slacker Radio server. The consumer can playback the information later, even when not connected to the network.

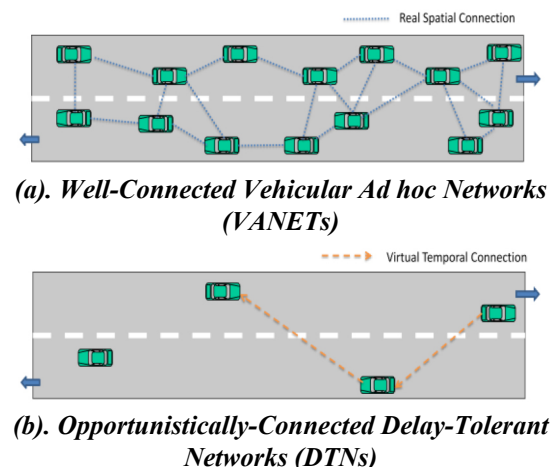


**Fig. 1. Vehicular Peer-to-Peer Networks (VANETs and DTNs)**

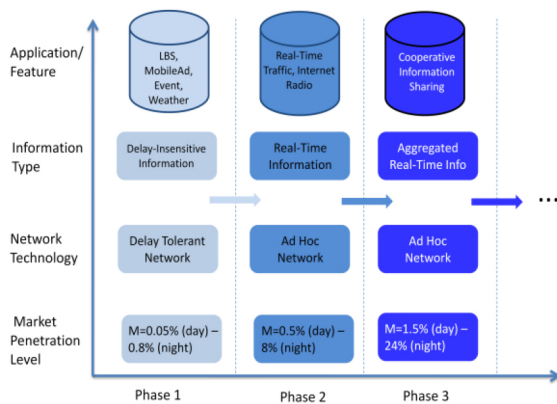


**Fig.2. Evolution of Vehicular Networks and Applications**

This paper will focus on how a DSRC network, under extremely low penetration rates, can deliver delay tolerant data over delay tolerate networks. We have found that many automotive services are well suited for DTD over DTNs. In addition to the weather and traffic examples that were described above, many Location Based Services (LBS) and social networking applications can be enabled over DTNs. Some of these services have the potential to generate revenue and could offer opportunities for OEMs to enter previously unexplored markets.

**Organization of the Paper:** The remainder of this paper is organized as follows: We lay out the motivation for forming a disconnected network which has only opportunistic connectivity among vehicles in Sec II. After describing the network architecture of a vehicular DTN in Sec III, we explore a DSRC application portfolio that could provide sustainable growth and increased functionality during the different phases of the deployment in Sec IV. We point out a number of technical and business challenges that this type of vehicular network might face during the implementation phase in Sec V and Sec VI, respectively. We conclude the paper in Sec VII.

## II. MOTIVATION

The motivation for providing use cases that create new value propositions to customers (in addition to safety applications) during the early phase of DSRC deployment are two-fold:

1. To create value for customers before the vehicle safety application benefits take effect:

Dedicated Short Range Communications (DSRC) can be used to reduce vehicle accidents and improve vehicular traffic management. To enable these types of applications, the number of vehicles equipped with DSRC will need to be significant. Therefore, these types of applications will offer limited benefits during the early stages of DSRC deployment when the vehicle penetration is low. In a safety-oriented

deployment of DSRC, early adopters of the technology need to pay for the additional vehicle hardware, but receive little value until the population of vehicles has reached substantial levels. This is a classic ‘chicken or the egg’ dilemma; the consumer will be reluctant to pay for the DSRC hardware until there is sufficient consumer value, but the value cannot be realized until enough consumers purchase DSRC hardware.

Thus far, DSRC deployment strategies have been unable to resolve the early deployment value proposition, and in the end, it is likely that a viable business model will be required for the successful deployment of DSRC. Fundamentally, a business model must demonstrate that the value of the deployed hardware and services is greater than the cost: On the cost side, there is limited ability to reduce the cost of the DSRC communication system - an antenna, radio, microprocessor, vehicle LAN and software are all required and the cost of these components are relatively fixed; on the value side, as indicated previously, early adopters receive little value from the safety applications and traffic management functions during the early phases of DSRC deployment.

In order to successfully deploy a DSRC network, it is necessary to create value from a sparsely populated DSRC vehicle network. We refer to this as ‘Day Zero’ value proposition, which metaphorically refers to the DSRC ecosystem at the point in time when the first equipped vehicles are introduced into the market and the total fleet penetration is less than 1 percent. Clearly, at these low penetration rates vehicles safety application will not be effective. To derive value, it is necessary to look beyond the safety applications to other possible use cases for DSRC. We therefore investigate other types of services (e.g., non-safety applications or social networking applications) that could be offered in an environment where there is less than one percent DSRC vehicle penetration.

2. To provide an alternative low-cost, high-bandwidth data pipe for mobile data users:

In the past few years, consumer's appetite for mobile data continues to grow exponentially. It is reported that the average monthly data usage for U.S. consumers was about 30 MB in 2005, 1 GB in 2009 and is expected to exceed 14 GB by 2014 [5]. A recent Cisco report predicts that the mobile data usage is expected to increase by 39 times from 2010 to 2014, forming a “Mobile Data Tsunami” that will affect the existing mobile infrastructure [6]. The significant growth of AT&T's mobile data access (by approximately 5,000% in the past 3 years) is solid evidence that demonstrates the trend of mobile data growth [7]. While network operators are currently investing billions of dollars to enhance mobile connectivity and implement future systems such as 4G, there is still some concern about system capacity limits. A well-