VANET: Superior System for Content Distribution in Vehicular Network Applications

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Abstract

Vehicular connectivity can be fairly considered a future killer application, adding extra value to the car industry and operator's services. Its main feature is to provide car safety and passenger comfort. Thus the issue of content distribution for these emerging vehicular applications needs to be handled carefully. In this paper we have done comparative study of different systems that can be used for distributing data in vehicular network applications and shown that Vehicular Ad hoc Network (VANET) is the most suitable solution for this purpose.

1.Introduction

About half of the 43000 accidents each year on U.S. highways result from vehicles leaving the road or traveling unsafely through intersections. Traffic delays waste more than a 40-hour workweek for peak-time travelers [22]. Taking into account the constant growth of automotive market and the increasing demand for the car safety, also driven by regulatory (governmental) domain, the potential of car-to-car connectivity is immense. Such system should be suitable for a wide spectrum of applications, including safety-related, traffic and fleet control, and entertainment. First, some issues concerning architecture, content distribution, routing, performance or QoS need to be investigated.

Thus Vehicular computing is one of the most emerging research areas and extensive research is going on concentrating on different issues of this field. However, we shall focus on only content distribution for vehicular network application. Vehicular applications require large amount of different types of data. These applications require data that can be either delay sensitive and delay-tolerant. Thus efficient data distribution is of utmost necessity for these applications. In this paper we have compared VANET [4], Infostations [1], Cellular network using 3G/4G [10], three potential systems to handle content distribution in an effective and efficient way. Through various analysis based on different criteria- availability of data, data delivery delay, security, cost of delivery we have shown that VANET (Vehicular Ad hoc Network) is most appropriate for vehicular applications.

The rest of the article is organized as follows: section 2 gives an overview of the vehicular applications. Section 3 gives details description of VANET and its features. Two other systems – 3G cellular network and Infostations that are probably suitable for providing vehicular network applications along with their comparison with VANET are presented in the following section. Section 5 concludes the paper.

2. Vehicular Network Applications

Vehicular network applications require wireless mobile communications. Currently, there are several possible paradigms for wireless mobile communication, for example, cellular, ad hoc, wireless LAN, and Infostations [1, 2]. Clearly, the choice of technology depends on the application that the network is intended to support. For this reason we need to have a clear insight into these applications and their requirements.

Integrating a network interface, GPS receiver, different sensors and on-board computer gives an opportunity to build a powerful car-safety system, capable of gathering, processing and distributing information. Numerous applications can be deployed in a network established with such equipped vehicles and proper infrastructure. Generally, from the connectivity point of view they could be divided into four main groups: car-to-car traffic, car-to-infrastructure, car-to-home and routing based applications. These applications are either safety-related or comfort-related (commercial).

A. Safety-related Applications

Safety-related applications may be grouped in three main classes: assistance (navigation, cooperative collision avoidance, and lane-changing), information (speed limit or work zone info) and warning (post crash, obstacle or road condition warnings). They usually demand direct communication due to their delay-critical nature. One such application would be emergency notifications, e.g. emergency braking alarms. In case of an accident (the airbag trigger event) or sudden hard breaking, a notification is sent to the following cars. That information could also be propagated by cars driving in the opposite direction and, thereby, conveyed to the vehicles that might run into the accident.

Another, more advanced example is cooperative driver assistance system, which exploits the exchange of sensor data or other status information among cars. The basic idea is to broaden the range of perception of the driver beyond his field of vision and further on to assist the driver with autonomous assistance applications. By transmitting this data to cars following on the same road, the drivers get information about hazards, obstacles or traffic flow ahead, resulting in more efficient and safe driving. Some applications of this kind are only applicable if the penetration of VANET enabled cars is high enough.

B. Comfort (commercial) Applications

The general aim of these applications is to improve passenger comfort and traffic efficiency. That could include nearest POI (Points Of Interest) localization, current traffic or weather information and interactive communication. All kinds of applications, which may run on top of TCP/IP stack might be applied here, e.g. online games or instant messaging.

Another application is reception of data from commercial vehicles and roadside infrastructure about their businesses ('wireless advertising'). Enterprises (shopping malls, fast foods, gas stations, hotels) can set up stationary gateways to transmit marketing data to potential customers passing by. Furthermore, these services could be integrated with electronic payments.

The important feature of comfort/commercial applications is that they should not interfere with safety applications. In this context traffic prioritizing and use of separate physical channels is a viable solution.

3. VANET : Overview and Why it is Suitable for Vehicular Network Applications

A Vehicular Ad-Hoc Network, or VANET [4], is a form of Mobile ad-hoc network, to provide communications among nearby vehicles and between vehicles and nearby fixed equipment, usually described as roadside equipment. Thus in other words, it is combination of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

The main goal of VANET is providing safety and comfort for passengers as shown in *figure 1*. To this end a special electronic device will be placed inside each vehicle which will provide Ad-Hoc Network connectivity for the passengers. This network tends to operate without any infra-structure or legacy client

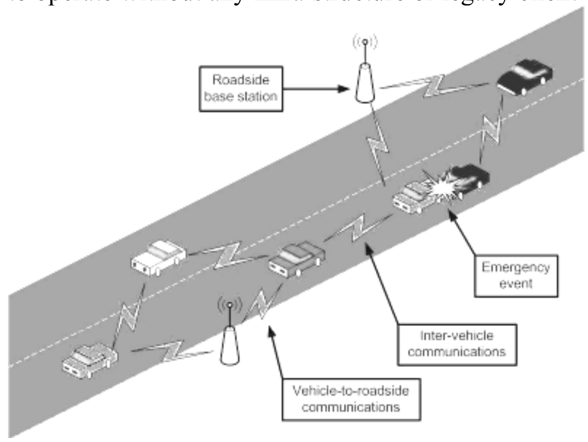

Figure 1: A VANET consists of vehicles and road-side base stations that exchange primarily safety messages to give the drivers the time to react to life-endangering events.

and server communication. Each vehicle equipped with VANET device will be a node in the Ad-Hoc network and can receive and relay others messages through the wireless network. There are also multimedia and internet connectivity facilities for passengers, all provided within the wireless coverage of each car. Automatic payment for parking lots and toll collection are other examples of possibilities inside VANET.

Most of the concerns of interest to MANETs are of interest in VANETs, but the details differ. Rather than moving at random, vehicles tend to move in an organized fashion. The interactions with roadside equipment can likewise be characterized fairly accurately. And finally, most vehicles are restricted in their range of motion, for example by being constrained to follow a paved highway.

3.1 Features

When deploying of a vehicular networking system, several issues have to be resolved, ranging from applications development up to economical issues. These unique characteristics of these networks are as follows:

- rapid topology changes and frequent fragmentation, resulting in small effective network diameter
- virtually no power constrains
- variable, highly dynamic scale and network density
- driver might adjust his behavior reacting to the data received from the network, inflicting a topology change

Here we briefly mention some of the core research challenges that need to be addressed.

A. Wireless Access technology

There are several wireless access standards that could be used as a base for VANET connectivity. In general the aim is to provide a set of air interface protocols and parameters for high-speed vehicular communication using one or more of several available media. Some of the core technologies include:

a) IEEE 802.11p based technology: IEEE is working on a variation of 802.11 standard that would be applied to support communication between vehicles and the roadside, or, alternatively, among vehicles themselves, operating at speeds up to 200 km/h, handling communication ranges as high as 1,000 meters. PHY and MAC layers are based on IEEE 802.11a, shifted to the 5.9 GHz band (5.850-5.925 GHz within US). Estimated deployment cost is foreseen to be relatively low due to large production volumes.

b) Combined wireless access: One of the most significant efforts in combining wireless access technologies is done by ISO TC 204 WG16, called CALM M5 (Continuous Air Interface for Long and Medium range). It builds on the top of IEEE 802.11p, incorporating a set of additional interface protocols. Currently supported standards include: Cellular Systems: GSM/HSCSD/GPRS (2/2.5G) and UMTS (3G), Infrared Communication and wireless systems in 60 GHz band. Using all those interfaces in a single, uniform system would result in increased flexibility and redundancy, thus improving applications' performance.

B. Spectrum issues

VANETs are based on short-range wireless communication (e.g., IEEE 802.11) between vehicles. The Federal Communications Commission (FCC) has recently allocated 75 MHz in the 5.9 GHz band for licensed Dedicated Short Range Communication (DSRC) [23] aimed at enhancing bandwidth and reducing latency for V2V and V2I communication.

C. Routing issues

Frequent network partitioning in VANETs requires the 'carry and forward' idea, where, if no direct route exists, a packed is carried by a node until it could be forwarded to a node being closer to the destination [3]. The 'carry and forward' concept can be combined with one of the 3 main routing algorithm categories suitable for VANETs: opportunistic forwarding, trajectory based forwarding and geographic forwarding. Also a hybrid solution, mixing 2 or 3 different approaches, could be developed. In opportunistic forwarding works efficient in broadcasting mode, but fails when the target is a single node.

D. Broadcasting and Message Dissemination

The foreseen applications will require a vast amount of information to be broadcasted, thus several broadcasting techniques are taken into account. Broadcasting appears to be an attractive solution due to its low cost and large potential volumes of data. There are already some services available that, based on DAB broadcast and TPEG protocol, offer real-time traffic information.

Location-aware broadcasting would limit the broadcast range only to the site of interest, thus reducing overhead (avoiding the broadcast storm problem) [3]. Clustering is another approach to optimize the message dissemination process: neighbor nodes form clusters, manageable units that limit the broadcasting range. E.g. in a clustering method called Local Peer Groups (LPGs) is proposed, where nodes can either form static or dynamic clusters.

a)V2V Data Distribution

An important problem that has to be solved in VANETs is how to exchange traffic information among vehicles in a scalable fashion. In some applications information is disseminated proactively using broadcast (push model), while in others the information is obtained on-demand (pull model). It is believed that broadcast-based applications have the potential of bootstrapping vehicular ad-hoc networks.

The goal of the data push communication model is to exchange information (e.g., position, speed) among a set of moving vehicles in order to enable each individual vehicle to view and assess traffic conditions in front of it. Two main mechanisms could be used to achieve this goal: flooding and dissemination. In the flooding mechanism, each individual vehicle periodically broadcasts information about itself. Every time a vehicle receives a broadcast message, it stores it and immediately forwards it by rebroadcasting the message. This is useful for delay sensitive applications. However , this mechanism is clearly not scalable due to the large number of messages flooded over the network, especially in high traffic density scenarios. Several techniques to avoid the broadcast problem have been proposed. Timer based, Hop limited simple forwarding, Map based or geographic forwarding, opportunistic forwarding are the examples.

Several Network coding protocol has been proposed to solve the problem of scalability related to flooding. Network coding improves the performance of content distribution by mitigating the scheduling problem given only a local knowledge of the network. Code torrent outperforms Car-torrent [21] as has been shown in *figure 2* and it requires almost 200 seconds to deliver a 1MB file when there are 80 mobile nodes interested in the same file.

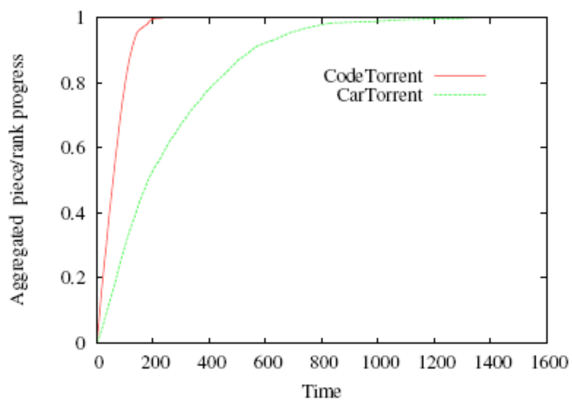

Figure 2: Aggregated downloading progress (200 nodes moving with the maximum speed of 20 m/s. The popularity index is set to 40% meaning that the number of interested nodes is 80 nodes.)

In the dissemination mechanism, each vehicle broadcasts information about itself and the other vehicles it knows about. Each time a vehicle receives information broadcasted by another vehicle, it updates its stored information accordingly, and defers forwarding the information to the next broadcast period, at which time it broadcasts its updated information. The dissemination mechanism is scalable, since the number of broadcast messages is limited, and they do not flood the network.

In [8] a formal model of data dissemination in VANET is presented and analyzed how VANET characteristics, mainly the bidirectional mobility on well defined paths, affect the performance of data dissemination. Three data dissemination models: same − dir, opp − dir, and bi − dir have been compared in the context of TrafficView [6,7], a system for scalable traffic data dissemination and visualization in VANETs.

To study the effects of vehicle density, the average speed of vehicles was fixed to 30m/s and the average periodic broadcast to 2 seconds. The average gap between each consecutive car was changed from 100m (dense traffic) to 500m (regular traffic) to 1000m (sparse traffic).

By means of analysis and simulations, it has been shown that the data dissemination model that uses only vehicles in the opposite direction for propagating data shows best performance.

Figure 3 confirms the previous observations in which *bi-dir* model has higher latency than *opp-dir* model which indicates that the vehicle's information received through data propagation in the same direction is received later than the propagation through the opposite direction. From those figures, we can see that the difference between opp-dir and bi-dir models is signified with the increase of the gap distance because the relative propagation speed between the opposite direction and the same direction increases with the gap distance. *Figure 4* shows the utilization rate for the three models. As expected, the utilization rate increases with the gap distance and opp-dir has the highest utilization.

b)V2I / I2V dissemination

It can be wither Push based or Pull based. Studies have shown that vehicle-to-infrastructure communication is feasible [18,19]. Push based station pushes out the data to everyone.. This is useful for the popular data like Traffic alerts, Weather alerts and here is no cross traffic resulting in low contention. Its drawback is that everyone might not be interested in the same data. In Pull based communication, a Request – Response model is followed. This is useful for unpopular / user-specific data like Email, Webpage requests. Its drawback lays in lots of cross traffic that result in Contention, Interference, Collisions.

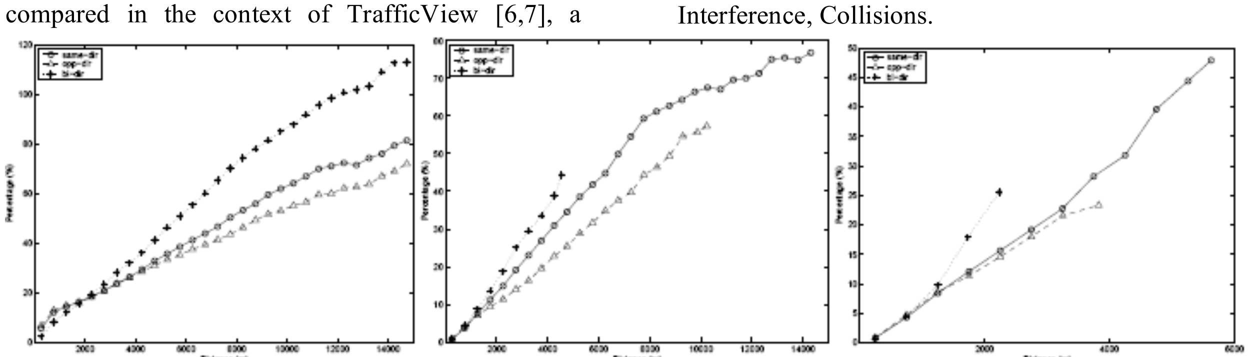

Figure 3: Latency graph: (a)Gap=100m, (b)Gap=500m, (c)Gap=1000m

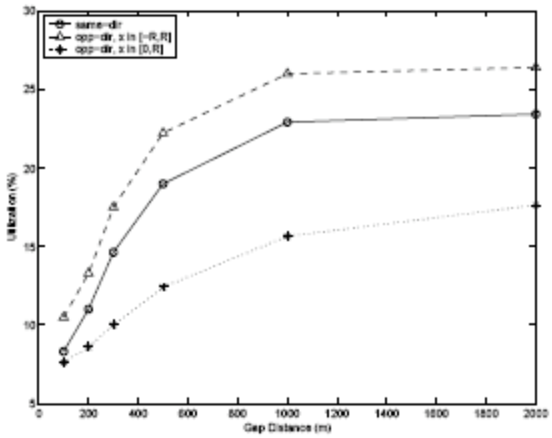

Figure 4: Broadcast Utilization for different dissemination models (Simulation results)

F. Security and Privacy

Security is an issue that needs to be carefully assessed and addressed in the design of the vehicular communication system. Several threats potentially exist, including fake messages causing disruption of traffic or even danger, compromising drivers' private information, etc. The issues to be addressed include trust (vehicles are able to trust the messages they receive), resiliency (resiliency for interference, easy maintenance) and efficiency, e.g. real-time message authentication.

Privacy is also a major issue that will need to be addressed. Anonymity must be preserved - the communications should not make the vehicle tracking or identification possible for non-trusted parties. The lack of taking into account the privacy concerns at the early design stage could result in multiple law suits after the network is deployed.

If, as it is in the networking world, each node (vehicle) would carry a unique, permanent MAC address, then it could be possible to trace such a car and its driver. For that reason IEEE 802.11p introduces dynamically assigned MAC addresses, along with a mechanism for duplicate MAC address discovery.

Integrating security is a big challenge for high speed communication as well as group communication. Since most security schemes include some cryptographic calculations the latency will be increased, thus limiting the speed for data exchange. Moreover, if a key agreement needs to be done further delay will be added. Depending on the operations, an additional delay of around 50 ms will be added for each node due to the cryptographic mechanisms. For secure group communication (e.g. for platooning) the group key agreement is the biggest bottleneck [9]. Thus content distribution is affected if security is taken into account.

In the decentralized MANETs, the use of a PKI and certificates to introduce trust is not an obvious choice. Especially the continuously changing connectivity to different neighbors and the not guaranteed access to an Internet gateway node make the use of certificates a challenge. A security framework LKN-ASF is a first approach using certificates to secure VANETs. The performance evaluation proved the feasibility of the approach [14]. However, simply installing a PKI to introduce trust is not sufficient. A certificate management is needed which can validate and revoke certificates. With the limited access to the Internet and hence the PKI backend servers, this management is difficult to realize in VANETs.

Two approaches to solve this challenge have been presented in [15]. Both a conventional certificate revocation list approach and a concept using validation tickets proved to be quite efficient for the certificate management in distributed network environments.

Many solutions have been published concerning secure routing protocols [16]. A secure version of the popular AODV routing protocol is AODV-SEC. Our evaluation of AODV-SEC [17] was based on simulations using the network simulator ns-2 implementing the full protocol with all cryptographic extensions. This evaluation demonstrated the feasibility of secure routing, however it also pointed out several scalability and performance limits.

3. Other Solutions

The drawbacks of VANET regarding security issues, lack of consistent connection may encourage peoples to support other possible solutions for providing vehicular applications. In this section we shall discuss two other contender 3G/4G cellular systems [10] and Infostations [1,2] and point out why there are less appropriate than VANET.

3.1 3G/4G Cellular Network:

Third generation (3G) [10] is the next generation of wireless network technology that provides high speed bandwidth (high data transfer rates) to handheld devices. The high data transfer rates will allow 3G networks to offer multimedia services combining voice and data. Specifically, 3G wireless networks support 128 Kbits/second for fast moving devices, such as handsets in moving vehicles. This data rate is for one user hogging the entire capacity of the base station. This data rate will be far lower if there is voice traffic (the actual data rate would depend upon the number of calls in progress).

Some characteristics of 3G services that have been proposed are:

- Always-on connectivity. 3G networks use IP connectivity, which is packet based.
- Multi-media services with streaming audio and video.
- Email with full-fledged attachments such as PowerPoint files.
- Instant messaging with video/audio clips.
- Access to corporate applications
- Fast downloads of large files such as faxes and PowerPoint files.

3G networks offer users advantages such as:

- New radio spectrum to relieve overcrowding in existing systems.
- More bandwidth, security, and reliability. Interoperability between service providers.
- Fixed and variable data rates.
- Asymmetric data rates.
- Backward compatibility of devices with existing networks.
- Always-online devices. 3G will use IP connectivity, IP is packet based (not circuit based)
- Rich Multimedia services

From these characteristics one may assume 3G is suitable for wireless communication in vehicular applications. But careful investigation shows that 3G cannot be the sole mean of wireless mobile communications for these applications.

3.1.1 Why VANET is Better than 3G

First of all, as it is previously stated that is data rate for moving vehicles is maximum 128 Kbit/s. though some real time application like audio/video chat can be benefited from 3G but principle vehicular applications such as- safety applications need to handle larger amount of data as V2V communication is required. 3G with its limited bandwidth cannot provide this.

Another strong reason against 3G is its high cost. Cellular systems are designed primarily for voice and therefore aim for anytime, anywhere service. To setup and maintain the significant infrastructure required for such near-ubiquitous coverage comes at great cost, often exceeding hundreds of millions of dollars [11].

On the other hand, VANET is cost effective. Unlike infrastructure-based networks (e.g., cellular networks), these networks are constructed on-the-fly and do not require any investment besides the wireless network interfaces which will be a standard feature in the next generation of vehicles. Thus VANET provides much lower cost per bit than cellular systems, at the expense of reduced coverage.

Constant Connectivity is not given by VANET. However many common applications, such as email, transferring pictures or video, and bulk downloads, can already tolerate significant outages between periods of connectivity. This relieves the need for ubiquitous coverage, allowing for a much less expensive access paradigm that still provides the ability to transfer large amounts of data. In [12] experiments, shows that, a vehicle traveling past an 802.11 roadside access point at 80 km/h is able to transfer up to 50 MB of data, the equivalent of approximately 20 songs, 15 minutes of low quality video, or 125 high quality digital photographs.

3.2 Infostations

Infostations [1,2] is a new system concept proposed to support "many time, many where" wireless messaging services. Three basic scenarios, sit-through, walk-through, and drive-through are used to describe the user mobility in Infostations. In the Infostation model [13], users can connect to the network in the vicinity of ports (or Infostations), which are geographically distributed throughout the area of network coverage. The Infostation architecture includes low-power base stations. Infostations provide strong radio signal quality to small disjoint geographical areas as shown in *figure 5* and, as a result, offer very high rates to users in these areas. However, due to the lack of continuous coverage, this high data rate comes at the expense of providing intermittent connectivity only.

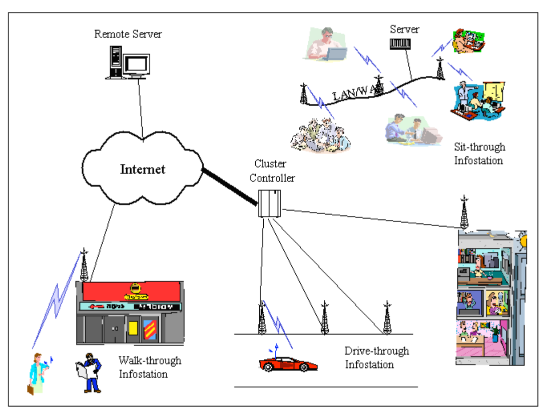

Figure 5*: The Infostation Network.*

In [14], it has been shown that, in “Tours in One Dimension: The Highway Scenario” delay in file delivery does not depend on coverage area, but depends on file size F, distance between stations d, vehicle constant velocity v, that the wired backbone transmits at a rate of *R* bits/sec. and the delay D, in seconds, is given by:

$$D <= \sqrt{\frac{d^2}{4v^2} + \frac{2Fd}{Rv}} + \frac{d}{2v}$$

Another interesting fact is that the delay decreases as the velocity increases. Thus, it behooves the mobile to move rapidly, passing through a large number of infostations. In this way, the network-to-infostation bottleneck is essentially removed by spreading the communication over many slow links. A near optimum algorithm [1] is proposed that minimizes the delay when the vehicle is not restricted to move in only one direction, rather it moves randomly. *Figure 6* shows the average delivery delay. The system transmits C infestations to the right and C infestations to the left , in total 2C+1 infostations. As can be seen, reducing the value of C to 3, for example, increases considerably the efficiency and does not affect as much the delay performance. That shows that it may be possible to accommodate more users without affecting very much the system performance.

3.1.1 Why VANET is Better than Infostations

Form *figure 6*, we can see that average delay for a file containing 20 segments is 10 seconds. Assuming the wired backbone transmission rate is 56000b/s, and only one node is served is one station at a time, the download-delay for 1MB file is approximately 100 seconds which is half of that shown in figure 2. But there are problems with this delay measurement. It has been assumed that velocity is constant between two stations, but in reality the time spent traveling between two infostations is a random variable. And only one mobile node is contending for the same file while it is 80 nodes in *figure 2.*

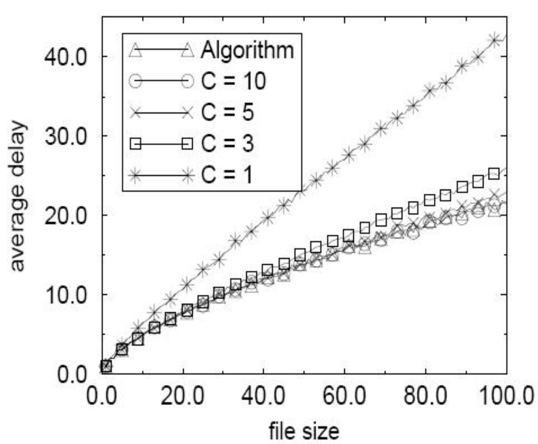

Figure 6: Average Delivery Delay, 100 trials

It was assumed that the bottleneck of the system was the wired backbone and that the radio was always capable of transmitting all the segments to the mobile during the time the mobile is in the coverage area. It is necessary to consider imperfections over the wireless channel, such as errors and retransmissions, which may cause some file segments to be probabilistically missed at any given infostation.

Some vehicular applications like- braking alert is delay sensitive and in this type of applications v2v communication is much more efficient than infostations . Because then the data will suffer delay as it has to bypass a station. More specifically, the *Infostation* network architecture should be used for applications which can tolerate significant delay. Since a node that wishes to transmit data may be located outside the *Infostations*' coverage areas for an extended period of time and must always transmit to an *Infostation* directly, large delays may result. Upon arrival in a coverage zone, the node can transmit at very high bitrates. Thus, *Infostations* trade connectivity for capacity, by exploiting the mobility of the nodes. In the *Infostations* model, network diversity due to mobility of nodes is exploited by allowing the nodes to transmit at times with larger signal quality to get the improved throughput at the expense of potentially large delays.

Moreover it has been shown in [5] that throughput increases when mobile nodes act as mobile infostations. This case occurs when all nodes have common interest in all files cached in the fixed info-stations. In addition to downloading files from the fixed infostations, nodes act as mobile infostations and exchange files when they are in proximity. Thus a social contract is stipulated such that an exchange occurs only when each node can obtain something it wants from the exchange. We show by analysis and simulations that network performance depends on node density, mobility and the number of files that are being disseminated. Results point to the existence of data diversity for mobile infostation networks. As the number of files of interest to all users increases, the achievable throughput increases. Moreover, each user has a fairer share of the total network throughput. In particular, when the number of files of shared interest is large, the transmission of each channel is only limited by contention, indicating this strategy achieves near optimum resource utilization.

This is what VANET supports i.e. content sharing between mobile nodes**.** VANETs enable a new class of applications that require time-critical responses (less than 50 ms) or very high data transfer rates (6-54 Mbps)[8].

4. Conclusion

In this paper, we have discussed VANET, 3G, Infostations – three possible systems for providing content distribution in vehicular network applications and compared them based on different criteria. While 3G is more secured and provides continuous connectivity, the relatively high cost, together with limited bandwidth and latency make it impossible to use as a main communication means. Though Infostations supports higher data rate, VANETs outperforms it with by delivering data with less delay for delay-sensitive applications, with sufficient bandwidth and in a low cost. Thus VANEt is superior to both of them. Actually it is not a surprise that VANET is most suitable for delivering content in vehicular applications. After all the network is solely design for vehicular applications while the main intention of 3G is to carry voice traffic and for Infostations to provide higher bandwidth in wireless communication.

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