

I want my MTV!

4G : Content Distribution Re-defined

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ABSTRACT

Vehicular communication networks have been gaining significant popularity and importance recently, primarily to cater to the emerging services involving road safety and a need for data-on-move. Existing content distribution technologies like VANETs, infrastructure based solution or 3G networks suffer from either cost issues, latency, bandwidth or a combination of them. Moreover, they assume that data can tolerate delays and support only non-realtime content distribution.

In this paper, we argue that i) with emergence of new vehicular applications, content delivery will no longer remain a non-realtime operation, and ii) that no current generation wireless communication technology alone is sufficiently powerful to support content distribution for all types of new and emerging vehicular applications. We also discuss possible solutions like i) a hybrid system that makes use of a combination of existing technologies and ii) the next generation 4G system, which presents an attractive solution for vehicular communication, where voice, data and streamed multimedia can be given to users on an “anytime, anywhere” basis.

General Terms

Computer Networks, Communication, Content Delivery

Keywords

VANETs, Infostation, 3G, 4G

1. INTRODUCTION

Wireless vehicular communications has been identified as a key technology for increasing road safety, transport efficiency, and providing Internet access on the move to ensure wireless ubiquitous connectivity. Wireless connectivity allows vehicles to create highly mobile ad-hoc networks that provides communication among neighboring vehicles as well as internet access.

Based on short- and medium-range communication as well as on cellular systems, vehicular inter-networking aims to enable vehicular safety applications (including collision and other safety warnings) as well as non-safety applications like real-time traffic con-

gestion and routing information, high-speed tolling, mobile infotainment, and many others [28]. In the near future, the number of vehicles equipped with computing technologies and wireless communication devices is poised to increase dramatically. Car manufacturers and communication corporations are already investing millions in vehicular communications; among them are General Motors, Daimler Chrysler, Ford Motor Company, Siemens, Honda, Toyota, BMW and Mercedes-Benz.

Although the main advantage of vehicular networks is safety improvements, there are several other benefits. Vehicular networks can help avoid congestions and find better routes by processing real time data. This in return saves both time and fuel and has significant economical advantages. Some vehicular applications may also support infotainment services like web browsing and multimedia content sharing. Most solutions for content delivery utilize one the following mechanisms:

- **VANETs.** Vehicular Ad-hoc Networks or VANETs provide convenience and commercial applications to reduce time on the road and to improve driving experience. A special electronic device is placed inside each vehicle which provides Ad-Hoc Network connectivity for the passengers. This network tends to operate without any infra-structure or legacy client and server communication.
- **Infrastructure based solutions.** Spontaneous communication between vehicles or between vehicles and road-side infrastructure like infostations, mesh and relay networks presents an effective networking solution and is an active research area that a significant number of projects have addressed during the recent years. Examples include Fleetnet [6], NoW [20], CVIS [5] and Safespot [23].
- **3G Networks.** 3G networks are wide area cellular telephone networks which evolved to incorporate high-speed internet access and video telephony. 3G networks enable network operators to offer users a wider range of more advanced services including wide-area wireless voice telephony, video calls, and broadband wireless data. It aims at providing almost “anywhere, anytime” access for multimedia applications in a mobile environment.

The paper is further organized as follows: Section 2 lists a possible classification of vehicular applications and requirements of a content delivery mechanism. Section 3 describes the existing technologies and their advantages and disadvantages. In Section 4, we discuss the possible emerging applications which require new content delivery technologies and Section 5 covers potential replacements to the existing solutions.

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2. CHALLENGES

Next generation vehicular communication networks will provide a wide range of applications with different characteristics. Furthermore some of these applications may require technologies that are not even available now.

2.1 Vehicular Applications

The main motivation for vehicular communication systems is safety and eliminating the excessive cost of traffic collisions. These applications require fast delivery of data (i.e. short latencies) to react in real time when some event happens (e.g., braking the car when the one ahead brakes unexpectedly) and usually exploit only short range communication. On the other hand, vehicular applications may also provide “in-car” infotainment. Such applications offer both voice and multimedia content and can tolerate long delays, but may need long range (i.e. multi-hop) data transmissions. These systems make reliability and in-order data delivery important requirements. We now present a possible classification of vehicular applications:

1. **Safety:** Providing safety information is the primary objective of vehicular networks. Sensors present on vehicles detect sudden changes in direction and velocity and inform neighboring vehicles of any impending danger [18].
2. **Traffic Management:** Effective traffic management can be done when traffic information (like speed limits, traffic lights or knowledge of emergency vehicles on road) and routes changes (due to flash crowds, bad weather or emergency) are disseminated to the vehicles. Vehicular applications can make use of vehicular sensors [26] and also assist the driver in making intelligent decisions while changing lanes, parking cars and even recognizing road signs. New applications could be to provide a real-time view of the traffic situation on streets, with vehicles as sensors.
3. **Surveillance:** Police can make use of vehicular communication for surveillance, restricted entries and even communicate with the driver in case of a pull-over.
4. **Travel-related:** Vehicular communication can also assist drivers with positions of gas stations, car service stations, routes and other business locations.
5. **General information services:** Vehicular infotainment is gaining ground and with increase in bandwidth, vehicular applications can be used to connect to the Internet, share files across users [12, 17] or have video / voice conferencing while the users are on the go [25]. Emerging applications would also support IPTV, which is often provided in conjunction with Video on Demand and may be bundled with Internet services such as Web access and VoIP. Such systems would require real-time data transmission with low latencies.
6. **Commerce on-wheels:** This is a new field, where vehicular applications can interact with road side infrastructure and other vehicles and perform e-commerce while the users are on the move [13].
7. **Automated Highways:** This would be the ultimate achievement of vehicular communication where vehicles can run unassisted on a highway negotiating other vehicles all by themselves. Such applications would require continuous inter-vehicle communication to exchange sensitive traffic information among peer vehicles. These applications are bounded by very low latency and high reliability constraints.

Most present solutions for content delivery assume a non-realtime nature of the applications, which would change with new and emerging vehicular applications. Next generation of content distribution technologies for the new applications should therefore have low latency and high throughput, before they can be universally adopted.

2.2 Requirements

Any content delivery technology applicable for the next generation vehicular applications must possess the following characteristics:

1. **Scalable:** Vehicular communication should be scalable, both in terms of the application nodes (or vehicles) it can support and the area it can cover, without much degradation in link quality (due to node mobility) and compromising on “fairness” for use of the transmission channel.
2. **Ease of deployment:** Any potential solution should be easily deployable with minimal equipment addition, both on-ground and on-cars. Cost constraints will always be a factor in the deployment of such a solution and users will resist paying a large price. It must also follow the “anywhere”, “anytime” and “anyhost” paradigm, which means it must seamlessly integrate with all existing solutions.
3. **High Bandwidth, Low Latency:** Most safety applications have stringent latency constraints to enable drivers to take real-time action on reception of any unintended signal. Vehicular communication standards should therefore support low latency communication. On the other hand, content delivery for media requires high bandwidth (like a file sharing application). Such infotainment applications may have additional latency and reliability constraints. IPTV and Video On Demand solutions require low latency mechanisms.

3. CONTENT DISTRIBUTION

In this section, we describe the current content distribution mechanisms. We also discuss the advantages that power their current use (mostly for non-realtime applications) and some shortcomings which fuel the need for development of the next generation of content delivery technology in vehicular networks.

3.1 Vehicular Ad-hoc Networks

A Vehicular Ad-Hoc Network, or VANET, is a form of Mobile ad-hoc network (MANET), aimed at providing communication among near vehicles and between vehicles and nearby fixed equipment, usually described as Road-Side Equipment (RSE). VANETs are self-organizing networks of highly mobile nodes which move relative to each other but within the constraints of the road infrastructure. These networks have minimal or no infrastructure dependency. Each node in the network can act as the source of data, the destination for data and a network router. The nodes are equipped with location tracking (GPS) equipment and may also have 3G and WiFi connectivity. Routing in VANETs can be both proactive or reactive or both. Nodes can choose their routing mechanism to minimize either latency or bandwidth overhead.

• Advantages

1. VANETs offer decreased dependency on fixed infrastructure and thus offer the ease of deployment.
2. Location-oriented services can be provided with little or no running costs to the users.

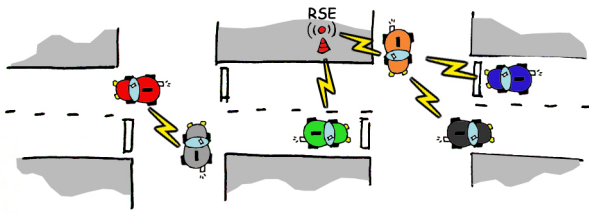


Figure 1: VANETs

3. If vehicle mobility causes links to break, messages are re-routed using a different path.

- **Disadvantages**

1. Rapid topology changes due to high relative speed of vehicles degrade the link quality, which induces moderate delay or even retransmission. A path may cease to exist almost as quickly as it was discovered, thus the application and the transport protocol must ensure reliability.
2. Unlike MANETs where redundancy is critical to providing additional bandwidth, VANETs have limited redundancy both in time and in function.
3. VANETs are subject to frequent fragmentation when chunks of the network are unable to reach nodes in nearby regions.

3.2 Infostations, Meshes and Relays

The primary aim of these infrastructure based solutions is to provide low-cost, low-power access to information services in a mobile environment. They satisfy the needs of many data-intensive applications and result in a new class of drive-by services. The motivation behind their development was that ubiquity of coverage may not be needed, as long as we achieve a sufficiency of coverage to meet users' needs. In contrast to the "anytime, anywhere" service provided by 3G networks, they provide islands of coverage, which greatly reduces the infrastructure and the cost-per-bit for the end user.

The following section discusses the advantages of these solutions:

3.2.1 Info-stations

Info-stations provide inexpensive and high rate wireless data service. As opposed to ubiquitous coverage, infostations offer geographically intermittent coverage at high speed (1Mbps to 1Gbps). The motivation behind such an architecture is that voice cannot handle delays but data on the other hand can often tolerate significant delays. Info-stations were first proposed as extensions to cellular systems that could not offer inexpensive data. A primary feature of info-stations is that they are not shared between users, or just one user must be attached to an info-station at a single instant [10]. A user that enters the coverage region gets the entire bandwidth on offer and thus maximizing system utilization.

- **Advantages**

1. Infostations offer high speed discontinuous coverage as opposed to the moderate rate ubiquitous coverage in cellular systems.
2. It maximizes system capacity since the network link is not shared among users.

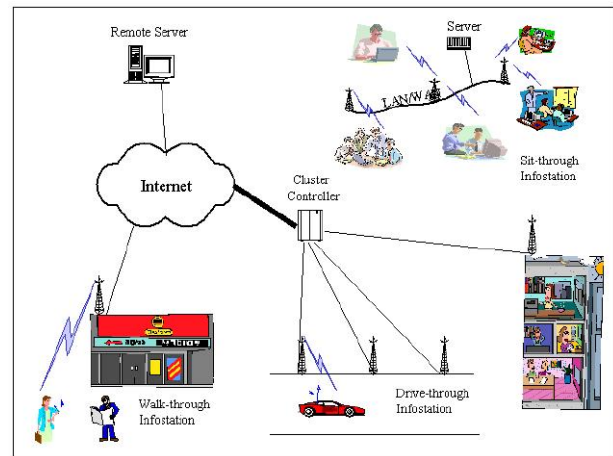


Figure 2: Info-station Network

3. There is no need to coordinate channels among multiple users and thus the overall system design is simple and inexpensive.

- **Disadvantages**

1. It is suitable only for data transmission and may not efficiently handle low latency, real-time VOIP applications that transfer both voice and data together. It relies on bursty nature of data communications and its tolerance of moderate delay.
2. There is no "fairness" criteria for usage among users.
3. Infostation coverage areas are spatially discontinuous.

3.2.2 Meshes

A wireless mesh network is a peer-to-peer multi-hop wireless network in which participant nodes cooperate with one another to route packets. There can be 3 types of mesh networks:

1. *Infrastructure wireless mesh networks*: Mesh routers form an infrastructure for clients eg. MIT Roofnet [1], TFA mesh networks from Rice University and Digital Gangetic Plains project [22].
2. *Client wireless mesh networks*: Client nodes constitute the actual network to perform routing and configuration functionalities.
3. *Hybrid wireless mesh networks*: Mesh clients can perform mesh functions with other mesh clients as well as accessing the network.

Unlike Mobile Ad hoc Networks (MANETs) where every routing node is mobile, routing nodes in mesh networks are stationary. Together these "mesh nodes" form the network's backbone. Other non-routing mobile nodes ("clients") connect to the mesh nodes and use the backbone to communicate with one another over large distances and with nodes on the Internet. The main motivation of developing wireless mesh networks is to provide high-bandwidth network over a specific coverage area.

- **Advantages**

1. Mesh networks extend high-speed local area networking services to the wide area.

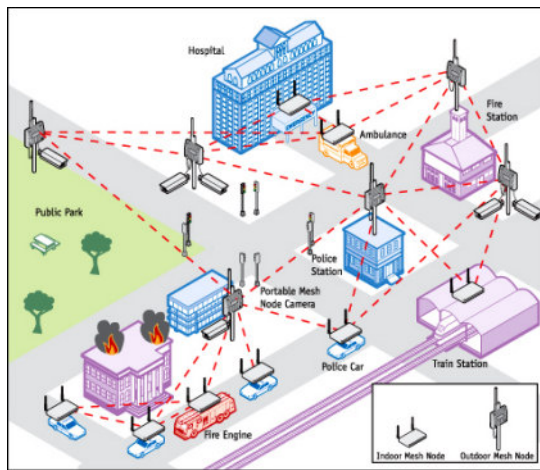


Figure 3: Mesh Network

2. This type of infrastructure can be decentralized (with no central server) or centrally managed (with a central server), both are relatively inexpensive.
3. Alternate paths in case of failure or performance degradation and so resilient to node failures.
4. They are an attractive low-cost technology option for robust broadband communication for:
 - City-wide Broadband Internet Coverage.
 - neighborhood Community Networks.
 - All-Wireless Offices
 - Rural Networks.

• **Disadvantages**

1. Increased delay introduced by multiple hops.
2. Increased complexity of protocols (MAC, routing, management, security).
3. Increased complexity of planning of initial coverage (network seeding).

3.2.3 Relays

A “relay” relays data between remote base stations, wireless clients or other relay stations to either a main or another relay base station. The relay network is arranged in a tree structure and the head always connects to the base station. It works in as store-and-forward mechanism. The relay node stores those packets, waits for another transit bus, and then exchanges packets with that bus, propagating packets from mobile node to mobile node. A relay can either be stationary or mobile.

• **Advantages**

1. Relays avoid the constraints of mesh wireless connectivity and the costs of base station wiring.
2. Relay networks provide coverage extension and high throughput.
3. Relays help decrease the cost since they are much cheaper than base stations.

• **Disadvantages**

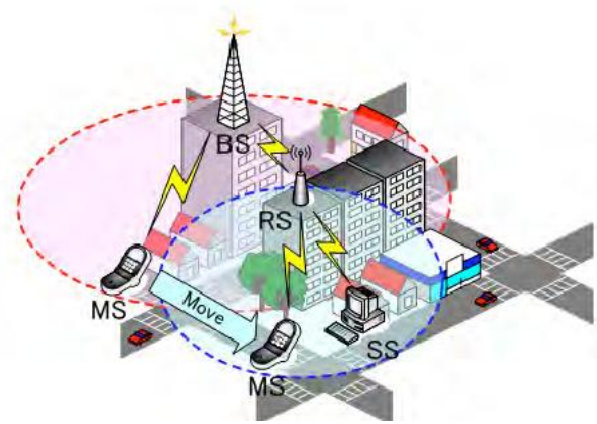


Figure 4: Relay Network

1. Data transmission through stationary relays can take extremely long durations and this delay increases with every increasing hop.
2. Fixed relays use simple routing protocols. Routing protocols for mobile relays are complex.

Another form of relay networks include the use of disconnected relays to store packets, for delivery to other relays or mobile nodes, and propagate information towards the final destination using a mobile client node that comes within the range.

3.3 3rd Generation Cellular Networks

Third generation or 3G networks is the term used to describe the current mobile networks and services. It leverages the on the developments in cellular technology and complements the existing fixed line networks and the Internet, to provide a general purpose network that provides flexibility and support for almost any kind of service (voice, video or data or a combination of all) in any location. It is the current generation of wireless network technology that provides high speed bandwidth (maximum of 2.05 Mbps) to handheld devices over a large coverage area. The main motivation behind 3G networks was to provide “anytime, anywhere” service, for which extensive infrastructure setup is required, therefore base stations based wireless solution sit at the top of the cost hierarchy in all infrastructure solutions.

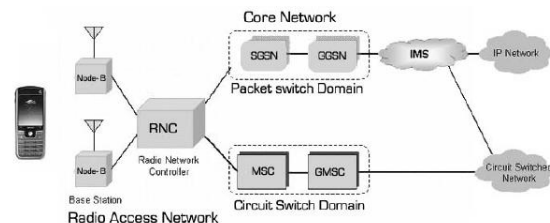


Figure 5: 3G Architecture

• **Advantages**

1. 3G uses IP connectivity and thus reduces call cost as compared to previous 2G networks.
2. It ensures backwards compatibility with almost every other telecommunication network.

3. 3G networks provide an improvement in bit-rate over other previous communication technologies. The higher bit-rate capabilities have allowed service providers to indulge into producing many bandwidth intensive applications like video telephony and other VoIP applications.
4. 3G packet based networks will allow users to be online all the time, since coverage area for such networks is very large.

- **Disadvantages**

1. The cost of installing the infrastructure i.e. the base stations and other cellular infrastructure is very high. The next generation applications need very high data rates. Thus, to increase the data throughput in 3G networks to support the emerging applications, would involve installing more base stations and additional investment.

$$\begin{aligned}
 \text{Data rate} &\propto 1/\text{distance} \\
 &\Rightarrow \text{High density of cell towers} \\
 &\Rightarrow \text{High cost}
 \end{aligned}$$

2. 3G systems suffer from high latency problems, due to which their use in safety applications is avoided.

4. DISCUSSION

In this section we argue that the existing content distribution technologies alone are not sufficient for the needs of the new emerging vehicular applications. We present a set of applications that would be common in future vehicular networks and evaluate the feasibility of using existing content distribution mechanisms

4.1 IPTV and VoD

Internet Protocol Television (IPTV) is a system where a digital television service is delivered using Internet Protocol over a network infrastructure [30]. The idea is to provide users with both standard definition and high-definition content via the Internet. Most cable and telecommunication based television providers also offer Video on Demand (VoD) along with IPTV. Video-on-Demand (VoD) allows users to select and watch/listen to video or audio content on demand. VoD applications have high bandwidth, low latency requirements and service providers instead provide either Near Video on Demand or Push Video on Demand.

Typically, IPTV video broadcast as MPEG-2 (the current standard for digital television and DVD) takes 4-6Mbps, whereas newer, advanced codecs (e.g. MPEG-4 H.264, VP6, VC-1) are designed to consume 1-2.5Mbps [11]. The offered bitrate for VoD services ranges from 1-3Mbps [31]. Content distribution technologies supporting IPTV and VoD should therefore have a minimum bandwidth of at least 1Mbps.

- Infrastructure based content distribution methods discussed in section 3.2, provide high bandwidth and can therefore support both IPTV and VoD. But, they suffer from 2 major problems. Firstly, these infrastructure are mostly deployed only in an urban setting, which greatly reduces their utility for real-time entertainment¹. Secondly, infostations on highways have intermittent connectivity and at high vehicle speeds, application buffering cannot cover-up for lost connectivity.

¹We make an assumption that most people would prefer to use their in-car infotainment (not including radio/FM services) over long distances i.e. while driving over highways than while driving within city limits.

- Content distribution and sharing in VANETs is supported by technologies like CarTorrent [12], CarTel [9], Cabernet [7], etc. They make opportunistic use of ad-hoc networking among vehicles to download large multimedia files. The main idea in CarTorrent is to find peers who can share the same content, whereas CarTel uses data-muling and opportunistic use of WiFi, Bluetooth and 3G to achieve the purpose. All these systems work on the assumption that data can tolerate bounded delays and so are not applicable for vehicular applications providing IPTV and / or VoD services.

- 3G wireless networks support the following maximum data transfer rates [24]:

- 2.05 Mbps to stationary devices.
- 384 Kbps for slowly moving devices, such as a handset carried by a walking user.
- 128 Kbps for fast moving devices, such as handsets in moving vehicles.

This clearly indicates that 3G networks are unsuitable for providing IPTV and VoD services to fast moving vehicles on highways. Most current solutions [27, 16] that provide in-car IPTV services enable connection to the Web either by EVDO [21] or WiMAX [32] technologies, which provide higher bandwidths than 3G.

4.2 Internet P2P Games

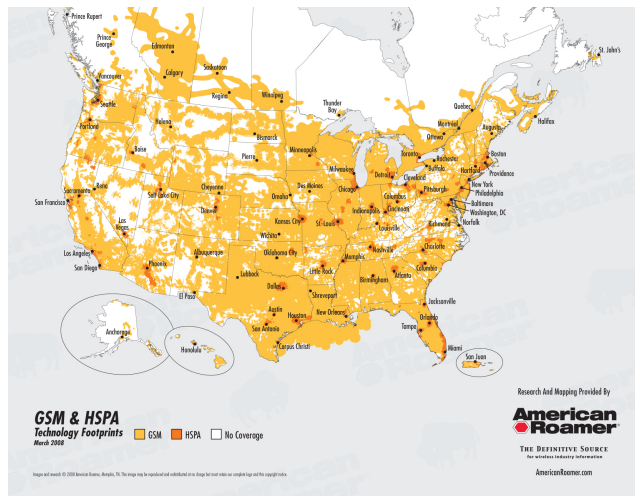
Most automobile giants are planning to provide internet connectivity in their upcoming models [4, 2]. Increase in network bandwidth could open doors for passenger gaming applications. Such applications would have high bandwidth and low latency (< 25ms) constraints, both of which are unavailable to high speed vehicles using content distribution technologies discussed in section 3.

4.3 RealTime Street-view

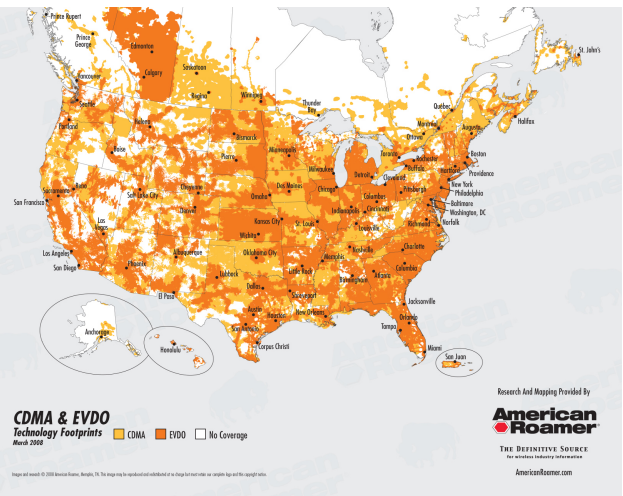
People have proposed traffic probing using smartphones, but the output of these systems is merely a number, a congestion metric. Pictures / videos of traffic crossroads are much more informative than a metric value and most people would prefer seeing live pictures / videos of a congested road to make their route decision, instead of deciding on the basis of metric values like “80% congestion”. The current state of the art systems include NJ DOT’s **Live Cameras** [19]. These have real-time data (still images that are refreshed every 30-60 secs) but the data is not presented well enough and the coverage is very sparse. On the other hand, there is Google’s Street View, which covers lots of places but has stale (not real-time) data. With high bandwidth and low latency networks, the next generation of vehicular applications can capture real-time traffic conditions and stream it to a central server or send it to a requesting node directly, enabling the receiver to observe a “near real-time” view of the traffic condition. Such applications cannot work with low bandwidth and intermittent connectivity. Traffic probing using VANETs is supported by their dynamic and self-organizing nature, but is restricted by frequent fragmentation of the network which causes delay in data transmission. Thus, real-time content transmission is not guaranteed. Infostations cannot be used because their coverage is discontinuous. Meshes and relay suffer from long bounded delays, while 3G networks have low bandwidth and high latency issues.

4.4 Mobile Net Meeting

There already are a number of live streaming cellular video services like Qik, Bambuser, Flixbus and other streaming services



(a) HSPA



(b) EVDO

Figure 6: Coverage Maps

like Ustream, Stickam, Justin.tv. With increasing carrier bandwidth and decreasing latency, these could be the preferred means of conducting mobile Net Meetings and share office presentations and other data.

4.5 Vehicular Automation

Vehicular automation is set to be the next big thing in the automobile industry. It would allow vehicles to travel independently without driver assistance and communicate with other peer vehicles to exchange sensitive security data. In fact driverless cars have already been tested [29] but fully automated highways is still left to be achieved. Automated vehicles would interact with both the road-side equipment (like traffic lights) and the peer vehicles. Usually, inter-vehicle communication can do without high bandwidth but not low latency, but we believe that such applications would also need to share information like road maps, location of gas stations, etc (for full automation) and therefore a high bandwidth, low latency medium is required. An infrastructure based mesh network is not sufficient due to its intermittent coverage, while use of 3G [3] (where latency is > 350ms, whereas in WiMAX it is < 50ms) could delay reception of an important safety message from a peer vehicle, when travelling at high speeds on highways.

The above discussion clearly suggests that most existing content delivery mechanisms cannot efficiently support vehicular applications with high bandwidth and low latency demands and the need for a new content delivery medium is imperative.

5. SOLUTIONS

In this section, we propose the following solutions, which could be the preferred content delivery technology for the next generation vehicular networks.

- **4th Generation Networks:** 4G (also known as Beyond 3G), an abbreviation for Fourth-Generation, is used to describe the next complete evolution in wireless communications. These networks are expected to provide real-time and internet-like

services. 4G networks would achieve the following objectives:

- fully IP-based, scalable mobile networks, with global mobility and service portability.
- high speed (capable of providing between 100 Mbps and 1 Gbps speeds both indoors and outdoors), high capacity and low cost per bit.
- support for interactive multimedia, voice, video, wireless internet and other broadband services.
- seamless switching, variety of services based on Quality of Service (QoS) requirements.
- sub-5ms latency for small IP packets [15].

With high bandwidth and assured QoS, 4G networks can be used to deliver IPTV and VoD over vehicular networks. Applications requesting real-time content can also be assured of a minimum quality of service, thus satisfying the latency constraints for safety and other infotainment applications. A 4G system will be able to provide a comprehensive IP solution where voice, data and streamed multimedia can be given to users on an “Anytime, Anywhere” basis, and at higher data rates than previous generation networks. 4G would also support the various kinds of vehicular applications discussed in section 4.

The only obstacle in upgrading to 4G would be the cost. Expectation is that high-quality video to a handset (along with audio) will consume on the order of 20 times that much bandwidth, an amount that will severely limit the number of video subscribers on a 3G base station sector to no more than a handful. Successful mobile video will require at least an order of magnitude more base stations per square kilometer (to provide stronger signal to users and thus provide higher data rates) than what can be provided by traditional networks. This would require considerable investment in infrastructure.

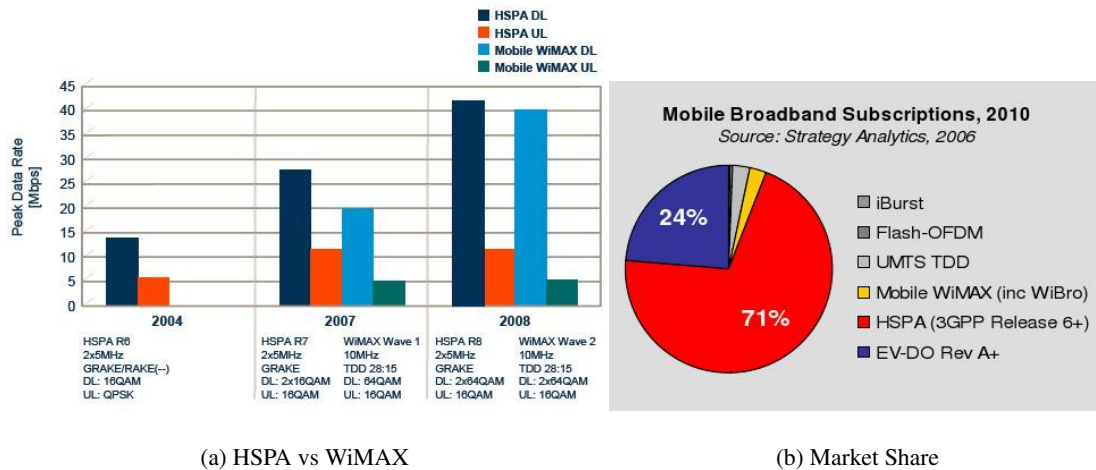


Figure 7: HSPA vs WiMAX

- **Hybrid Solution:** We propose a **hybrid** solution that exploits the capabilities of both the GSM HSPA+ and CDMA EVDO networks.

GSM HSPA (High Speed Packet Access) refers to both the improvements made in the UMTS downlink, often referred to as High Speed Downlink Packet Access (HSDPA) and the improvements made in the up-link, often referred to as High Speed Uplink Packet Access (HSUPA). HSDPA provides improved down-link performance of up to 14.4 Mbps while HSUPA provides improved up-link performance of up to 5.76 Mbps. The round-trip delay time is 60 ms [8] meaning that many real time interactive services can be delivered over HSPA. Evolved HSPA (or HSPA+), defined in 3GPP release 7, introduces a simpler IP-centric architecture for the mobile network bypassing most of the legacy equipment and boosts peak data rates to 42 Mbps on the downlink and 22 Mbps on the up-link. and reduced latency with 20 ms to 40 ms of round trip delay.

CDMA EVDO (Evolution-Data Optimized) is a mobile broadband cellular network which offers peak speeds of 3.1 Mbps on the downlink (base-station to user) and 1.8 Mbps on the uplink (user to base-station) for both mobile and stationary users [14], with average latency being 100-200ms and sometimes hit as low as 70ms.

In our hybrid solution, we opportunistically use wireless networks similar to the CarTel model [9]. Nodes use both EVDO and HSPA for data transmission choosing whichever has higher signal strength (a higher signal strength signifies higher available data rates). All vehicles must be equipped with dual radios for both GSM and CDMA channels. As figure 6 suggests, EVDO presently has a much higher network coverage than HSPA (which is mostly concentrated in urban areas), thus the nodes use HSPA+ in urban settings and switch to EVDO when moving on highways. Application nodes can also make use of both the radios simultaneously (wherever possible) to achieve even higher bandwidths. With the reduced latency and high bandwidth in the “always available” HSPA networks and increased range of EVDO, the hybrid solution would achieve the best available throughput with

minimum latency.

Even though VoIP traffic is much cheaper than WCDMA traffic, a hybrid solution involving **WiMAX** (in place of HSPA) is not a good choice for the following reasons:

1. HSPA+ has a much larger coverage area than WiMAX, which requires Line of Sight connectivity for longer connections and higher data rates.
2. WiMAX has lower peak data rates (for mobile users) than HSPA+ (fig 7.a).
3. Industry analysis of the current technologies (fig 7.b) projects a much lower market share for WiMAX as compared to HSPA. Thus, investing in a better and dominant technology is more cost efficient. While it’s been theorized that the cost of mobile WiMAX base stations will be less than that of corresponding cellular equipment, the real costs in operating any wireless network are in spectrum (it’s auctioned to the highest bidder), real estate and customer-related functions like marketing, sales and support. WiMAX won’t have any advantage in these.

We believe this hybrid solution would work for the following reasons:

- Much more coverage with higher bandwidth and low latency available than with any of the earlier solutions.
- Use of dual channels increases the available bandwidth, and with both EVDO and HSPA networks having reduced latency, hybrid networks can support most of the emerging vehicular applications, including internet gaming, real-time street view, IPTV and VoD.
- Both EVDO and HSDPA have QoS and traffic prioritizing, so different applications with different QoS can be effectively serviced.
- Less cost burden since HSPA/HSPA+ and EVDO are already being deployed worldwide.

The use of either of the above technologies will have benefits in all interactive applications [8]:

1. **High-Speed Internet Access:** With HSDPA offering similar speeds to most DSL connections and the added value of ubiquitous mobility, UMTS can be expected to become a preferred connection medium for a range of users, whether it be via a laptop or a handheld terminal.
2. **Voice over IP :** Voice is clearly not a new application but when delivered over IP and coupled with other interactive media such as video and text will become very attractive.
3. **Multi-player Gaming :** The improved interactivity of the networks is expected to have a significant impact on the mobile gaming industry. Multi-user games, whether broadband or narrowband will benefit from the real time interactivity that will be possible and the end user experience will be significantly enhanced.
4. **IPTV and VoD :** With the increased capacity of 4G / HSPA / EVDO networks, more streaming services can be offered to more and more users. These mobile TV streaming services have already shown themselves to be extremely popular in many markets and this trend can be repeated and improved on with HSPA.
5. **Video Telephony and Conferencing :** Video conferencing or the delivery of multiple video streams to a single terminal will become more feasible now that the video services can be delivered using an IP stream.
6. **Automated Highways :** 4G networks have large coverage and extremely low latency, which makes it an attractive option for real-time communication and sensitive data transfer between vehicles.

6. CONCLUSION

The arguments presented in sections 3 and 4 clearly establish that existing content distribution mechanisms like VANETs, Infostations or 3G networks will not suffice the needs of the new emerging vehicular applications with both low latency and high bandwidth constraints. They also explain that content distribution will no longer remain non-realtime and we require a new content distribution technology that has low latency, high bandwidth and good coverage. We present two solutions i) use of upcoming 4G networks or ii) a hybrid solution that creates an opportunistic use of CDMA EVDO and the GSM HSPA networks. Both these solutions would support new and emerging vehicular applications, some of which are a cornerstone of the envisioned Intelligent Transportation Systems (ITS). By enabling vehicles to communicate and share data with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Roadside-to-Vehicle Communication (RVC), vehicular networks will contribute to both safety and entertainment of passengers.

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