

# Bringing Wireless Access to the Automobile: A Comparison of Wi-Fi, WiMAX, MBWA, and 3G.

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## ABSTRACT

In this paper, I present a comparison of four next-generation wireless technologies: Wi-Fi (IEEE 802.11), WiMAX (IEEE 802.16), MBWA (IEEE 802.20), and 3G (ITU), in respect to which technology or combination of technologies provides a solution for the creation of a wireless vehicular network. Each technology is evaluated based on performance, coverage area, reliability, security, and mobility. A proposed infrastructure solution is also presented.

## Keywords

Wi-Fi, WiMAX, MBWA, 3G.

## 1. INTRODUCTION

Automobile manufacturers continue to incorporate more and more technological features into their automobiles. One such emerging feature is wireless access. It is estimated that 25 million future vehicles will have wireless access. This creates a need for a wireless vehicular environment.

In the context of this paper, a vehicular environment shall be defined as an environment in which vehicles exist and are traveling at speeds no greater than 80 miles per hour. Most vehicles usually do not exceed the posted speed limit of 55-65 mph on highways in the United States.

In order to support mobility, a network infrastructure will need to be designed and implemented. This infrastructure will need to provide reliable network access to objects traveling at high speeds. The access will need to be similar to what a person currently has at home, if not better. Currently, there are four emerging next-generation wireless technologies that are intended specifically for mobile data access, targeting wireless access in mobile environments such as a vehicle. The four technologies are Wi-Fi (IEEE 802.11p), WiMAX (IEEE 802.16e), MBWA (IEEE 802.20) and 3G.

Wireless Fidelity (Wi-Fi) is a name given to the IEEE 802.11 standard, which was developed to specify an air interface between a wireless client and a base station. The IEEE 802.11 has several working groups of which IEEE 802.11p is one. IEEE 802.11p working group developed a standard, an extension of the IEEE 802.11 standard, to address extending the IEEE 802.11 radio standards that are applicable to automobiles and which provide communication at a higher spectrum allocated to vehicles. The IEEE 802.11p standard also includes better security, mobile operation, identification, and a more sophisticated handoff system.

Worldwide interoperability of microwave access (WiMAX) is a name given to the IEEE 802.16 standard, which was developed to standardize the "last mile" wireless distribution technology. WiMAX is one approach for the metropolitan area to address the "last mile" problem of providing connections to individual homes and offices [8]. Like the IEEE 802.11 standard, the IEEE 802.16 has several working groups. One of the working groups is

developing the IEEE 802.16e standard. The IEEE 802.16e standard is attempting to standardize the technology used to provide wireless network access service for mobile users while maintaining a connection at speeds up to 93 miles per hour.

Mobile broadband wireless access (MBWA) is a name given to the IEEE 802.20 standard currently under development. The standard is hoping to standardize an efficient packet-based air interface that is optimized for the transport of IP-based services. The goal of this standard is to enable worldwide deployment of affordable, ubiquitous, always-on and interoperable multi-vendor mobile broadband wireless access networks [12]. The goal is also to support vehicular mobility up to 155 miles per hour with spectral efficiency (throughput/bandwidth).

Third-generation (3G) is a name given to the third generation of mobile communication. It's a specification /standard developed by International Telecommunication Union (ITU). 3G offers wireless network access for both stationary and moving objects. 3G is intended to replace GSM, which is an open, nonproprietary system dominating cellular technology [13].

Which of the above four next-generation wireless technologies or combination of technologies is best suited for the creation of a wireless access infrastructure? That is, in order to provide ubiquitous wireless network access to moving objects such as cars, what infrastructure is needed and which technology or technologies makes most sense to be incorporated in such an infrastructure?

I envision the infrastructure needed to support a vehicular environment consisting of wireless base stations scattered throughout the topology to which a vehicle, composed of a single access point, shall communicate. This shall be similar to how cell phones work today. The cell phone communicates with the cell tower. In a wireless vehicular environment, a vehicle's access point shall communicate with the network's base station wirelessly. I shall discuss which technology is best suited for implementation of the access point in the vehicle as well as the base stations.

This paper shall provide the technical information on each technology that is relevant to wireless mobile access and discuss the pros and cons of each technology applying it to the creation of a wireless vehicular network.

## 2. BACKGROUND

Currently, networks (both wired and static) have only been available in hot-spots, commercial buildings, or homes. Consumers are beginning to demand access any time from any where including an automobile. They want wireless Internet access whether shopping at the mall, waiting at the airport, walking around town, or driving on the highway. They want to have the ability to surf the Web, download files, and have real-time video conference calls and other tasks, through a wireless communication connection to the Internet with the same data rates as their desktop.

The government is encouraging mobile applications with both the Federal Communications Commission (FCC) and the Department of Transportation (DoT) expressing support for a wireless infrastructure that would support safety and traffic management uses. This is definitely a growing industry.

Several manufacturers have already incorporated Bluetooth into their cars to create a personal area network within the car. Saab introduced its 2003 9-3 with Bluetooth and the momentum is continued with the 2004 models from Acura, Audi, Lexus, Lincoln, Mayback, and Toyota, to name a few. Lincoln already has a model with Wi-Fi technology. Toyota is in the process of rolling out an on-board GBOOK terminal, which will be an automotive PDA featuring a Data Communications Module and a Secure Digital card enabling customers to take advantage of the latest network services as easily as they would operate a car radio [14]. Fiat Auto and Microsoft announced a long-term strategic automotive partnership to develop innovative telematics and solutions for motorists [5]. Microsoft's Automotive Business Unit already has a Windows Automotive platform that includes Bluetooth, Wi-Fi and 802.1x wireless technologies.

Analysts are projecting that automobile manufacturers will continue to incorporate wireless features into their automobiles [6]. But current wireless infrastructures cannot furnish the necessary bandwidth and capacity needed to provide the desired services to users traveling at high speeds. Therefore, a wireless infrastructure, aimed specifically toward providing Internet access at high speeds, will need to be put in place to support the 25 million vehicles estimated to have wireless access by 2008 [15].

## 2.1 Benefits

Vehicular wireless access has many benefits. It can be used in vehicle safety and traffic management applications, consumer applications for convenience, and mobile computing.

A possible safety and traffic management application can be a system that could sense traffic backups and change the timing of the traffic lights and/or issue an automatic warning, alerting a vehicle of approaching traffic congestion. The network infrastructure can also be used by the Department of Transportation for warning purposes such as work zone warning, traffic signal violation warning, stop sign warning, road condition warning, curve speed warning, etc.

Along with the safety benefits there are also some possible consumer convenience benefits. Such applications can consist of obtaining the latest weather report, viewing a restaurant's menu, getting directions, checking email, downloading music, streaming video for passenger entertainment, on the go shopping, drive-through payment, point of interest information, etc.

Such a network would also benefit the mobile office. People whose work requires them to be in a car traveling from place to place would find great benefits in being able to access the Internet via their cars. This would allow such a person to access their company email and stay connected as well as access files and download files from their company website. This would allow such a person essentially to create a mobile office.

The possibilities are endless. As we become more mobile and more reliant on electronic information and devices, this type of network shall become essential.

## 3. METHODOLOGY

### 3.1 Approach

This investigation centers on the hypothesis that no one wireless technology provides a better solution and that no combination of technologies provides a better solution either. I shall investigate whether one wireless technology provides a better solution than any other or whether a combination of technologies is needed to provide the desired characteristics.

The key characteristics for which I shall evaluate each of the four emerging next-generation wireless technologies for vehicular network applications are: performance, coverage area, reliability, security, and mobility. These five characteristics are the standard characteristics applied to Internet applications.

#### 3.1.1 Performance

Performance is assessed from measured bandwidth and latency, with values obtained from previous research conducted on each technology.

Performance is an important measure because it determines what type of applications can be run on a network. A low-bandwidth network can only feasibly support simple data such as text files. A higher bandwidth network can potentially support streaming video and more powerful applications.

For real-time applications like voice, latency is critical. Latency should be kept below 20 ms, as anything above this would warrant the deployment of additional features such as echo cancellation.

#### 3.1.2 Coverage Area

Coverage area is evaluated from the measured distance needed between base stations, the number of devices required to support the infrastructure, and whether the technology has the ability to switch/hand-off between base stations without loss of coverage. The distance needed as well as the ability to switch/hand-off between base stations was obtained from previous research conducted on each technology and the number of base stations required is an estimate based on the allowable distance between them.

Coverage area is an important characteristic because it determines how large a contiguous wireless area can be. Also, a wireless technology's cell coverage area is important with respect to cost, since operators can reduce their initial capital expenditures if they can serve the same area with fewer base stations.

#### 3.1.3 Reliability

Reliability is characterized by the average number of dropped packets, average number of disconnects, and whether the technology is affected by environmental factors such as line of sight, weather, etc. All of these metrics were obtained from previous estimates or research conducted on each technology.

Reliability is important because it can potentially affect the functioning of an application. Some applications may require a reliable connection. If a connection is not reliable, packets are being dropped; the speed of the network connection will decrease. This would adversely affect the performance of the applications, thereby limiting the types of applications that can be used.

### 3.1.4 Security

Security is evaluated from the level of encryption and the device authentication provided by each technology.

Most applications will require a secure connection in order to transmit sensitive information. They will not want to expose themselves to the potential of being altered or the information being viewed by unauthorized individuals. Connection to a company's internal network will require a secure connection as well.

### 3.1.5 Mobility

Mobility is the speed of the mobile access point at which the technology can connect and remain connected without packet loss or service interruption.

Naturally, a wireless vehicular environment will need to be mobile. The network must sustain connection at vehicular speeds.

## 3.2 Candidate Technologies

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### 3.2.1 Wi-Fi (802.11p)

Wi-Fi was developed by the IEEE 802.11 working group and was initially designed to be used indoors at close range but has recently ventured into mobility. It includes the approved 802.11a, b, g, n, and p specifications. Wi-Fi is the first high-speed wireless technology deployed in areas such as hotspots, homes, offices, airports, etc. Wi-Fi hotspots have become quite popular and have allowed mobile users to remain productive while on the go. Wi-Fi, however, is limited by its range; users must remain within 300 feet (for 802.11a) or 1000 feet (for 802.11p) of a base station.

The following is a diagram of a Wi-Fi network (Figure 1):

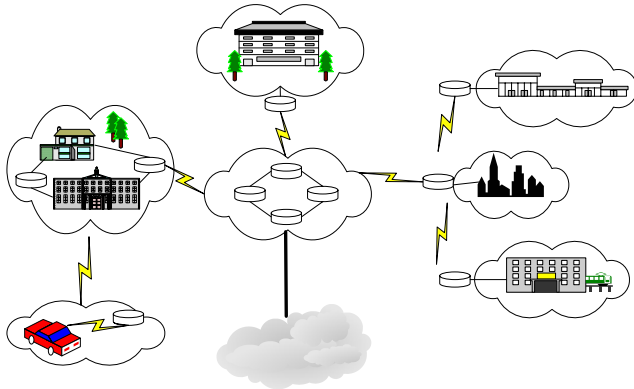


Figure 1. Wi-Fi Network

### 3.2.2 WiMAX (IEEE 802.16e)

WiMAX is the latest wireless technology to be approved by the IEEE 802.16 working group. It is a standard for point-to-multipoint wireless networking. It's intended to deliver "last mile" broadband connectivity to individual home or business locations and its data rates are comparable with cable and Digital Subscriber Line (DSL) rates. Phone companies are hoping it will be a replacement for their aging legacy wired networks. In fact, it

is seen as the wireless replacement for a wired broadband connection. It has the ability to allow users to connect to a wireless Internet service provider even when they roam outside their home or business office.

WiMAX is a point-to-multipoint (PMP) technology that operates in the 10 to 66GHz and sub1GHz wavelengths. At higher frequencies, line of sight is a requirement and it is compatible with technologies such as asynchronous transfer mode (ATM) and internet protocol (IP). It can provide service over distances up to 30 miles. The standard covers both media access control (MAC) and physical (PHY) layers for combined fixed and mobile operation in licensed frequency bands. The MAC layer is optimized for longer distances because it was designed specifically to tolerate longer delays and delay variations. WiMAX-based voice service can work on either traditional Time Division Multiplexed (TDM) voice or IP-based voice, also known as Voice over IP (VoIP).

The IEEE 802.16e version is an extension of the IEEE 802.16 standard that was drafted specifically to deal with mobility. It is backward compatible with all IEEE 802.16 standards. And while IEEE 802.16 was conceived as a back-end technology, IEEE 802.16e has the capacity to be adapted for individual computers, and has the quality of service features to support voice. It provides connectivity for high-speed data in both stationary and mobile situations. It will enable mobile users to maintain their network connection while moving at speeds up to between 75-93 miles per hour. The upper speed limit depends on the distance of the access point from the base station as well as other transmission quality issues, i.e., air density, solar flares, electromagnetic radiation, etc.

WiMAX-based solutions include many advantages, such as robust security features, good quality of service, and mesh and smart antenna technology that will allow better utilization of the spectrum resources.

The WiMAX-based solutions are set up and deployed like cellular systems using base stations that service a radius of several miles/kilometers. The most typical WiMAX-based architecture includes a base station mounted on a building and shall be responsible for communicating on a point to multi-point basis with subscriber stations located in business offices, homes, and even automobiles. The following is a diagram of a WiMAX network (Figure 2):

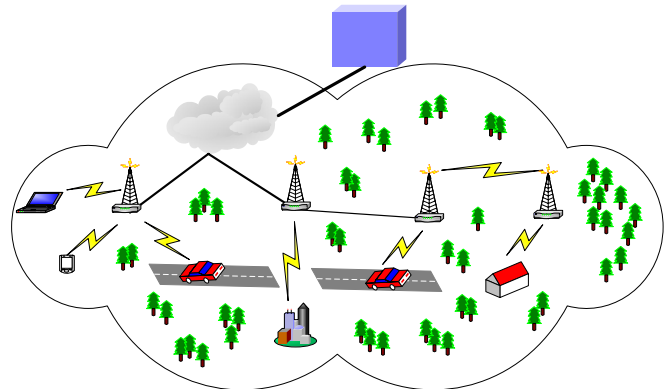


Figure 2. WiMAX Network

### 3.2.3 MBWA (IEEE 802.20)

MBWA is being developed by the IEEE 802.20 working group and is still in its infancy. It is intended to be a mobile broadband technology, targeting high-speed mobile networks. The standard is specifically targeting creation of a reliable, high-speed, wireless voice and data link to be used in high-speed trains and cars traveling up to 155 miles per hour. It seeks to boost real-time data transmission rates in wireless MANs (metropolitan area networks) to speeds that rival DSL and cable connections. It is being designed to operating in small chunks of spectrum, meaning that the required channel bandwidth is small. It has an approximate base station range of 9 miles. It has already demonstrated a successful hand off between 802.20 networks and 802.11-based LANs (local area networks) [1,12].

The following is a diagram of a MBWA network (Figure 3):

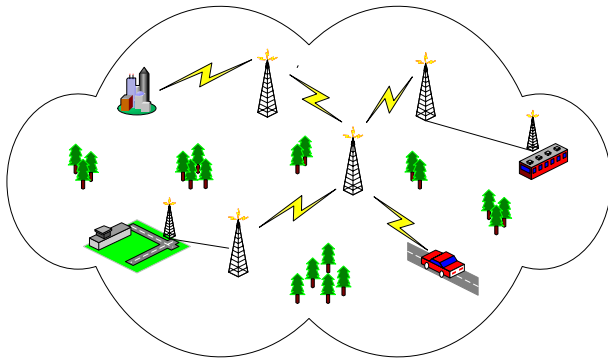


Figure 3. MBWA Network

### 3.2.4 3G

3G is an ITU specification for high-speed wireless communications. 3G is a cellular technology that aims to provide a long-range wireless access canopy for voice and data. The hope is to create broad coverage for data access across wide geographic areas, providing the greatest mobility for voice communication and Internet connectivity.

## 4. EMPIRICAL DATA

Table 1. Empirical Data - Performance

	Bandwidth	Latency	Max. Bit rate
<i>Wi-Fi</i> <i>802.11p</i>	54 Mbps at 20 MHz	50 ms	54 Mbps
<i>WiMAX</i> <i>802.16e</i>	70 Mbps at 14 MHz >5 MHz	25-40 ms	100 Mbps
<i>MBWA</i> <i>802.20</i>	3.2 Mbps at 1.25 MHz (downlink) 16 Mbps at 5 MHz (uplink) <5 MHz	10-30 ms	16 Mbps
<i>3G</i>	<2 Mbps (typically 300-600 Kbps) <5 MHz	500 ms	2 Mbps

Table 2. Empirical Data – Coverage Area & Mobility

	Range	Mobility
<i>Wi-Fi</i> <i>802.11p</i>	Up to 1000 feet	<100 mph
<i>WiMAX</i> <i>802.16e</i>	Up to 30 miles (LOS) Up to 5 miles (NLOS)	<75-93 mph
<i>MBWA</i> <i>802.20</i>	Up to 9 miles	<155 mph
<i>3G</i>	Typically 1-5 miles	310 mph at 144 Kbps 75 mph at 384 Kbps 6 mph at 2 Mbps

Table 3. Empirical Data – Reliability & Security

	Line of Sight /Non-Line of Sight	Security
<i>Wi-Fi</i> <i>802.11p</i>	NLOS	WEP (Wired Equivalent Privacy)
<i>WiMAX</i> <i>802.16e</i>	NLOS LOS	Implemented
<i>MBWA</i> <i>802.20</i>	NLOS	Implemented
<i>3G</i>	NLOS	Based on GSM with enhancements

## 5. ANALYSIS

### 5.1 Overall Comparison

#### 5.1.1 *Wi-Fi (IEEE 802.11p)* vs. *WiMAX (IEEE 802.16e)*

Although the fundamental technology is the same, the biggest difference between Wi-Fi and WiMAX is in coverage area. This translates into more base stations required for Wi-Fi, which means the deployment of the vehicular network infrastructure would be more costly.

Wi-Fi was really optimized for indoor use and for short ranges. Wi-Fi may be a good solution for toll collection, drive-through windows, etc., where you can have a fixed receiver and the transmitter is known to be a given distance away. WiMAX was optimized for use outdoors. Wi-Fi technology was really actually designed and optimized for Local Area Networks (LAN), whereas WiMAX was designed and optimized for Metropolitan Area Networks (MAN).

Wi-Fi base stations cannot support as many users as WiMAX base stations. Wi-Fi was only designed to support one to ten users per base station with a fixed channel size of 20 MHz per base station. WiMAX was designed to support one to no more than five hundred users per base station, each with a variable channel size from 1.5 MHz to 20 MHz [7].

There are also frequency band differences. WiMAX uses licensed spectrum whereas Wi-Fi uses unlicensed spectrum. WiMAX uses one of the unlicensed frequencies, but also supports two other frequencies that are licensed. What that means is that

you can turn up the output power and broadcast longer distances. This also makes WiMAX a better choice because Wi-Fi only works in unlicensed spectrum and only has a 20 MHz channel bandwidth. That means it's contention-based, so if one person is on that channel another person getting on would have to share the same capacity. Therefore, it's much more limited in its ability for going long range. As you get more users, the bandwidth is divided up among the users.

Also, WiMAX was designed to be a carrier-grade technology, which requires a higher level of reliability and quality of service than is now available in typical Wi-Fi implementations.

### 5.1.2 Wi-Fi (IEEE 802.11p) vs. MBWA (IEEE 802.20)

Wi-Fi and MBWA are not directly comparable. Wi-Fi was initially intended and designed for indoor use with a small number of users per base station. MBWA is intended and designed specifically for wireless broadband access, so it is inherently capable of a greater bit rate, larger coverage area, and support for moving objects at greater speeds.

### 5.1.3 WiMAX (IEEE 802.16e) vs. MBWA (IEEE 802.20)

WiMAX (IEEE 802.16e) and MBWA (IEEE 802.20) are very similar. Some have argued that they address the same market space, and thus overlap. Both technologies are attempting to address the wireless mobile use case, but in different ways. For WiMAX the highest priority is throughput while the highest priority for MBWA is mobility. That is why WiMAX has a higher throughput compared to MBWA. WiMAX is backward-compatible with all 802.16 standards; therefore the technology may be used for both stationary and mobile applications. However, WiMAX was not initially designed with mobility in mind. Mobility was added as an enhancement; therefore WiMAX is not optimized for mobility. MBWA, on the other hand, is a "clean slate" design, starting from scratch to be optimized for maximum mobility. So both technologies have advantages or disadvantages, depending on the intended application. If the application is mobile access in a vehicle, Table 4 shows each technology's pros and cons:

**Table 4. WiMAX and MBWA Comparison**

WiMAX (IEEE 802.16e)		MBWA (IEEE 802.20)	
Pros	Cons	Pros	Cons
Backward compatible with stationary networks	Possible interference issues	Designed specifically for mobile use	Three years behind WiMAX in development
Maximum bandwidth of 100 Mbps		Maximum bandwidth of 16 Mbps	
75-93 mph		Up to 155 mph	
Low Latency (as low as 20ms)		Low Latency (as low as 10ms)	
local/regional mobility, hand-off and roaming support		global mobility, hand-off and roaming support	
Available 2005			Available 2006
Stronger support			Lacks support,

from key vendors			standards forum ridden with political turmoil, key vendors hostile toward standard
Proven technology since 802.16e is an enhancement to the 802.16 standard.			Technology is new, started from a clean slate.
	Needs to be backward compatible with all 802.16 standards	Started from clean slate, able to target specific market	

Clearly MBWA supports higher speeds. MBWA is specified up to 150 mph relative to the antenna, while WiMAX is only specified for "vehicular speeds" and works up to about 90 mph in simulation [17]. MBWA provides very low latency (as low as 10 ms) but at much lower data rates than WiMAX. MBWA's guaranteed low latency may also make it more appropriate for voice communications, and some have even suggested that it may be able to act as a replacement for the existing cellular network [17].

Also, WiMAX products for mobile users are expected to appear before MBWA-based devices, potentially giving WiMAX a further edge.

### 5.1.4 WiMAX (IEEE 802.16e) vs. 3G

WiMAX may become a complementary technology to 3G because they both tend to address two different market sectors. WiMAX is primarily geared toward data services and was designed to support such. 3G is primarily geared toward voice services and was designed for them. Both are capable of doing both voice and data but were not originally designed to do so.

3G has been built on the foundation of a voice network and the 3G community is adding data capability to it. The objective of WiMAX is to be a high-speed data service that can be used to extend and complement 3G service. There are several 3G service providers that are worried that as data use grows they will not have enough spectrum for both their voice customers and their data customers. So they have become interested in WiMAX as a complementary data service technology that they can deploy with their 3G voice service [3].

WiMAX presents a serious threat to 3G because of its broadband capabilities, distance capabilities, and ability to support voice effectively with full QoS (quality of service). This makes it an alternative to cellular in a way that Wi-Fi can never be, so that while operators are integrating Wi-Fi into their offerings, looking to control both the licensed spectrum and the unlicensed hotspots, they will have more problems accommodating WiMAX [2].

### 5.1.5 MBWA (IEEE 802.20) vs. 3G

MBWA may become a direct competitor to 3G wireless cellular technologies [4]. Both technologies are fully mobile, although 3G is primarily aimed at voice users who require data services whereas MBWA is designed specifically for data services but has

the capability of carrying voice. MBWA is meant to target IP-based mobile data applications which are more closely associated with Internet access via laptops, PDAs, etc., as opposed to data-enabled cell phones.

The MBWA group cites a low latency of 10 ms whereas 3G is about 500 ms. This is one main differentiating feature. Another significant difference is that MBWA can cover a radius of approximately 9 miles which is more than 3G's coverage area of 1-5 miles. MBWA was intended for use in devices traveling at high speeds and therefore can generally provide a much higher data rate. Finally, the business model for MBWA services may prove more attractive to providers because a base station dedicated to IP data services should be simpler than a standard 3G base station and consequently less expensive to build and maintain.

## 5.2 Summary

The metrics used to compare the four technologies were described in section 3.1: performance, coverage area, reliability, security, and mobility. Using the empirical data, we can see which technology has the best performance, coverage area, reliability, security, and mobility:

- Performance is measured as bandwidth and latency. WiMAX (IEEE 802.16e) has the best performance with a maximum bandwidth of 100Mbps and a low latency of 25-40 ms.
- Coverage area is the measured distance between base stations. MBWA (IEEE 802.20) has the greatest coverage area, which will translate into fewer base stations.
- Estimates of reliability are best obtained by simulating a network. Since there are many different types of vehicular networks that can be simulated, no consistent data was available for all four technologies. All technologies are attempting to minimize dropped packets and decrease the number of disconnects. None of the technologies requires a line of sight connection. Without comparable simulations of an actual vehicular network using all four technologies, assessment of this characteristic is inconclusive.
- Security comprises the level of encryption and the device authentication provided by each technology. Each technology has some level of security. Both Wi-Fi and 3G are more secure because both have enhanced or built on previously deployed security models. Therefore, both technologies have been able to address perceived weaknesses in their security models.
- Mobility is the speed at which the technology can connect and remain connected. MBWA (IEEE 802.20) is capable of supporting connections at higher speeds, up to 155 miles per hour. This measure has already been proven to work on a high-speed train. Although 3G is capable of supporting speeds up to 310 miles per hour, the bit rate is significantly decreased at high speeds, whereas MBWA is capable of more than 1 Mbps at 155 miles per hour. Therefore, MBWA offers a better mobility solution.

From this summary it is apparent that no one technology is best in all categories.

## 6. INFRASTRUCTURE RECOMMENDATION

The infrastructure I propose for the creation of a wireless vehicular environment consists of roadside-installed base stations which would essentially be Internet gateways that are integrated into a vehicular network. Some of the base stations might be wired underground for connection to the Internet backbone. Other stations might be connected to another base station wirelessly.

Based on the preceding analysis, a combination of technologies appears to be best suited for construction of such a wireless vehicular network.

I propose the wireless vehicular network consist of both WiMAX (IEEE 802.16e) and MBWA (IEEE 802.20), as well as 3G. Since WiMAX was initially intended to replace existing phone lines, WiMAX should be used both to replace these lines, as well as provide a base station for traveling vehicles. WiMAX would be deployed primarily in residential and metropolitan areas since that is where it is best suited and for what it was originally intended. MBWA would be used along highways and roads since it can support high speeds and has a lower latency. At times this would provide overlapping coverage with WiMAX, but would primarily emphasize provision of connections for vehicles that are on these roads and highways. 3G would provide coverage where WiMAX and MBWA are not yet deployed and where cellular towers already exist. Figure 4 illustrates such a network.

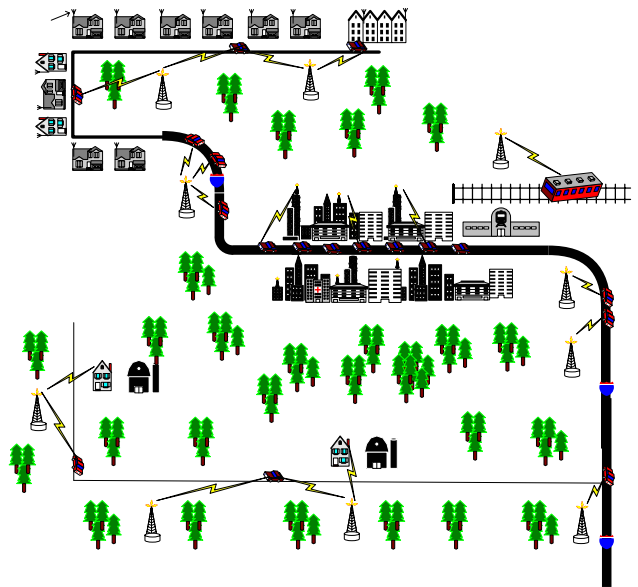


Figure 4. Vehicular Network

To support the proposed vehicular network, base stations will need to be installed along roadways and throughout various residential and commercial areas. These base stations will require electricity as well as connectivity to a backbone network, and are likely to be installed and supported by both government agencies and private companies. Government would be interested in this type of network primarily to provide safety features. Private companies are more likely to be interested in this type of network for the purpose of selling Internet-based services to mobile users.



## 6.1 Deployment

The business model for such a network to be successful must address the following:

1. ongoing communication costs must be controlled
2. investments in infrastructure must be recoverable in a reasonable period of time
3. public and private entities have (some) very different cost/benefit functions
4. good goals – safety and congestion relief are important to all

System management issues that need to be resolved include:

1. be responsible for the network
2. ensure long term stability of the network
3. management of network by automotive OEMs
4. management of network by public entities
5. management and financing of upgrades and extensions

## 7. CONCLUSION

This paper has studied four emerging wireless networking technologies; Wi-Fi (IEEE 802.11p), WiMAX (IEEE 802.16e), MBWA (IEEE 802.20), and 3G in terms of how they could be applied to the creation of a wireless vehicular network. Technical data was obtained on each technology and each technology was compared using five measures: performance, coverage area, reliability, security, and mobility. It was determined that no single technology can provide a complete solution for the creation of a vehicular network. The solution consists of a combination of the technologies. This allows the network to use aspects from the current network infrastructure. Essentially, each technology was designed and created to complement another, not compete with it. Therefore there are several different combinations that can be used to support mobility. ABI Research has predicted that all high-speed wireless technologies will coexist, working in tandem to meet service provider and customer needs for truly mobile computing and communications across the globe [16]. No single technology will become dominant or ubiquitous [16]. In fact, the most feasible wireless solution shall use a combination of technologies to enable increased mobility and eventually seamless roaming. The devices that are integrated into the vehicles must support multiple technologies and provide seamless handovers. The solution proposed in this paper for creation of a wireless vehicular network, in fact, uses three of the technologies: WiMAX, MBWA, and 3G.

## 8. ACKNOWLEDGMENTS

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