A Survey of VANET Technologies

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ABSTRACT

Recent advances in wireless communication technologies and automobiles have fuelled the growth of Intelligent Transport System (ITS) which addresses various vehicular traffic issues like traffic congestion, information dissemination, accident etc. Vehicular Ad-Hoc Network (VANET), a distinctive class of Mobile Ad-Hoc Network (MANET), is an integral component of ITS in which moving vehicles are connected and communicate wirelessly. Wireless communication technologies play a vital role in supporting both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication in VANET. This paper surveys some of the key vehicular wireless access technology standards such as 802.11p, P1609 protocols, Cellular System, CALM, MBWA, WiMAX, Microwave, Bluetooth and ZigBee which serve as a base for supporting both safety and non-safety applications. It also analyses and compares the wireless standards using various parameters such as bandwidth, ease of use, upfront cost, maintenance, accessibility, signal coverage, signal interference and security. Finally, comments on some of the issues associated with the interoperability among those protocols are provided.

Keywords: ITS, VANET, V2V, V2I, DSRC, WAVE, IEEE 802.11p, CALM

1. INTRODUCTION

A VANET is a distinctive class of a MANET in which moving vehicles act as either a node or a router to exchange messages between vehicles, or an Access Point (AP). Typically, it can connect to vehicles within the range of 100 to 900 meters if using 802.11p. It is aimed to support both V2V and V2I communication over infrastructure-less network. It is essential to realize that the ITS aims to improve road safety and provides a comfortable travel experience to driver and passengers [1][8]. There have been numerous research initiatives such as COOPERS, CVIS, SAFESPOT, PREVENT, Wireless Access in Vehicular Environments (WAVE) and Advanced Safety Vehicle Program (ASV) carried out across Europe, US and Japan to turn ITS into a reality.

VANETs are used to support critical applications and non-safety infotainment or entertainment based applications. Safety applications such as collision avoidance, pre-crash sensing or lane changing are aimed at minimizing road accidents by using traffic monitoring and management applications. Non-safety applications, on the other hand, enable passengers to access various services like Internet/World Wide web, interactive communication, online games, payment services and information updates while vehicles are on the move. The key difference between safety and non-safety applications is that the safety applications are capable of sending and processing messages in real time [3]. The driver and passengers can access both kinds of services from the nearby infrastructure seamlessly using wireless access technologies [7].

VANET and MANET have many similarities such as dynamic topology, multi-hop data transmission, distributed architecture and Omni-directional broadcast. In both networks, mobile nodes are able to route or relay data to the destination by itself. However, there are some notable differences between VANET and MANET. Since the vehicles are moving along the road, the mobility of nodes in VANET is predictable unlike MANET [5]. Furthermore, there is no limitation of storage and processing capability and battery power of nodes in a VANET. Due to the fast movement of nodes the topology of network formed tends to become highly dynamic. In addition, network density in VANET varies significantly over time and location [10].

Typically, a VANET consists of four major components viz: Vehicles, Devices/Sensor such as GPS enabled devices, Road-side Info-Station and Traffic Management Centre (TMC) [2][11]. All these components communicate using wireless standards/protocols that determine the various aspects of communication such as data transmission range and rate, latency and security. Perhaps, data delivery is considered as the key challenge due to the fast topology change, frequent signal disruptions, and contact opportunities of VANET [9]. In principle, a VANET could use a host of networking technologies such as WAVE IEEE P1609, DSRC IEEE802.11p, WiMAX IEEE 802.16, Bluetooth IEEE 802.15.1, MBWA IEEE 802.20, Infrared and Cellular to facilitate ad-hoc communication among the vehicles [4][7]. This paper describes the characteristics of wireless access standards and their limitations as well as their suitability for VANETs.

The paper is organized as follows. Section 2 describes the various wireless standards used in VANETs. Section 3 compares the communication technologies to find out their suitability for VANET applications. Finally, Section 4 concludes the paper.
2. WIRELESS ACCESS STANDARDS

In VANET, vehicles employ a number of wireless access technologies to communicate with other vehicles and roadside base stations [6]. Generally, this is to improve traffic management and monitoring and to enable the driver and passengers to access infotainment/entertainment services. These protocols are broadly classified into five categories: Cellular systems, WLAN/Wi-Fi Standards, DSRC/WAVE Standard, CALM Standard and miscellaneous standards including Bluetooth, ZigBee, and Infrared. These protocols can also be grouped into three categories based on their range as shown in Fig.1. This section describes the design principles and technical features of some key data communication protocols.

3G/UMTS (Universal Mobile Telecommunications System) operates in the band from 1.8 GHz to 2.5 GHz. It uses more advanced adaptive modulation techniques such as Quadrature Phase Shift keying, or 64 QAM (QPSK). Differential phase shift keying (DPSK), Bipolar Phase Shift Keying (BPSK) and Pulse Modulation (PM). It provides data transfer speeds up to 2 Mbps. 3G HSPA (High-Speed Packet Access) offers a downstream data transfer rate of 14 Mbps and an upstream data transfer rate of 5.74 Mbps. In contrast, 3G HSPA+ (Evolved HSPA) achieves 42 Mbps in the downlink and 11 Mbps in the uplink. 3G HSDPA (High-Speed Downlink Packet Access) technique was developed to meet the requirements of bandwidth-intensive applications such as large file transfers, and fast Web browsing. It is an ideal technology to support real time application due to its low latency (70 to 100ms). It can support data transfer speed of up to 14.4Mbps. [15]

The Fourth Generation (4G) technologies were developed to offer high speed, broadband, cheaper mobile services. They support high mobility through soft handoffs and seamless switching [16]. 4G/ LTE (Long Term Evolution) network uses the 1700 MHz and 2100 MHz frequency bands, and its data transfer speed is up to 129Mbps. 3G Cellular network has already been used for timely data dissemination to support VANET applications such as accident prevention and traffic jam avoidance [47].

2.1 LONG RANGE PROTOCOLS

2.1.1 CELLULAR SYSTEMS (2G/3G/4G):

Cellular system uses radio waves to transmit data over long distances. They have been used to provide mobile services since the 1970s. They use a concept of “frequency reuse” to increase coverage area and also for multiple transmissions simultaneously [12]. In the first generation (1G), analog signals were used to transmit data. The Second Generation (2G) supports secure, digital transmission unlike its predecessor 1G. It has various forms such as the Global System for Mobile communications (GSM), digital AMPS (D-AMPS), Code-Division Multiple Access (CDMA), and Personal Digital Communication (PDC). Among them GSM is predominately used. It uses Frequency Division multiple access (FDMA) along with Time Division Multiple Access (TDMA) technique and operates in fourteen frequency bands. Presently many countries use two variants of GSM known as GSM-900 and GSM-1800 versions. GSM-900 uses 890–915 MHz for uplink and 935–960 MHz for downlink whereas GSM 1800 uses 1,710–1,785 MHz for uplink and 1,805–1,880 MHz for downlink. Those frequency bands are divided into several channels in order to transmit data [13]. GSM supports a data transfer rate of 9.6 Kbps. Its extension, called General Packet Radio Service (GPRS), introduces a packet oriented, mobile data service. It improves the data transfer rate through efficient bandwidth utilization as compared to GSM. GPRS and GSM together are called 2.5G. They support a data transmission speed of up to 170 Kbps and enables internet access [14]. Enhanced Data Rates for GSM Evolution EDGE)/Enhanced GPRS (EGPRS), uses eight state Phase Shift Keying (8-PSK) in combination with Gaussian Mean Shift Keying (GMSK) modulation techniques to achieve a higher data rate. It can be operated on any GSM frequency band and increases the data rate up to 384Kbps [15]. It is a more suitable standard to support email, wireless multimedia, video conferencing and web based infotainment applications than GPRS.

2.1.2 WiMAX STANDARD

WiMax (Worldwide Interoperability for Microwave Access) provides Internet access at the distance of up to 50km with a speed of 70Mbps. As it uses higher frequency band (2.5 GHz) compared to LTE, it provides high bandwidth which in turn increases throughput. The new standard, WiMax Mobile (IEEE 802.16m), uses advanced modulation techniques such as Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeat Request (HARQ) and Fast Channel Feedback (CQICH) to offer broadband access to mobile users [17]. It can offer downlink data rates of up to 63 Mbps and uplink data rates of 28Mbps. J.S
Huang et al [48] have used WiMax for implementing road safety applications by streaming real time videos.

2.1.3 MBWA STANDARD

The IEEE 802.20 or Mobile Broadband Wireless Access (MBWA) was developed to provide wireless Internet access to highly mobile devices. While it attempts to provide various features such as low latency, high data rate of up to 4.5 Mbps, support for mobility up to vehicular speeds of 250 km/h, it operates in licensed 3.5 GHz and is optimized to support IP packet transmission. It also supports seamless and fast handoffs [41].

2.1.4 MICROWAVE

This standard (IEEE 802.15.4) uses a frequency between 0.3 GHz and 300 GHz and transmits data up to 16 Gbps over long distance. Unlike infrared, it provides broad bandwidth and supports high transmission rate. It is already used in RADAR, Microwave Ovens and Satellite Communications. Moreover, it is used to build wireless LAN that spans multiple cities. The key limitation of microwave is that it requires Line of Sight (LoS) communication [37]. Like infrared, it can be used to support both safety and infotainment applications but only with the LoS constraint.

GSM based 2G is inefficient for short data transactions. Moreover, the key limitation of GPRS or EDGE is that they cannot transfer voice and data simultaneously. As a result, 2G cannot be used to support time-critical, safety applications in a VANET. Because of high latency and low data rates, both GSM and GPRS could not be used to support infotainment applications. Generally, Cellular Systems such as 3G and 4G can be used for long range data communications in ITS. The 3G enables constant access to infotainment services through the Internet irrespective of the high mobility of vehicles. However, it reduces the data rate to 144 Kbps while moving and covers only up to 12 km range. 4G Standards promise to support a speed of 100 Mbps for high mobility and 1 Gbps for low mobility. The LTE Advanced Standard is expected to provide high performance during mobility of 15 to 120 kph and capable of supporting mobile speeds of up to 500 km/h. [44] WiMAX Mobile can provide more reliable communication over long distances. It can support high-speed, handoffs and smart antenna technologies such as MIMO and beamforming. WiMAX Mobile (IEEE 802.16m), supports mobility up to 350 kph and increases the data transfer rate up to 1 Gbps. [45]

A hybrid approach, combining Wi-Fi and 3G services, can be used to support VANET applications. But, it will lead to frequent handoffs and discontinuous connection due to low-speed 3G [18]. Hence, 4G standards are mostly preferred for VANET over 3G due to high throughput and low loss rates. As 4G is expected to minimize the latency, it is a potential alternative to Dedicated Short Range Communication (DSRC). However, the availability of 4G is the biggest issue today. It is expected that the combination of GPS, DSRC and 4G will revolutionize the ITS in the near future [19].

2.2 MEDIUM RANGE PROTOCOLS:

2.2.1 WLAN/Wi-Fi STANDARDS:

Wireless local area network (WLAN) or wireless fidelity (Wi-Fi) standards are widely used to create ad-hoc networks due to their low cost, high data transfer rates and ease of deployment. These consist of several standards including 802.11a, 802.11ac, 802.11b, 802.11e, 802.11g and 802.11n. The IEEE 802.11b operates in the unlicensed 2.4 GHz frequency band and achieves data rates of up to 11 Mbps using DSSS. IEEE 802.11a operates in the licensed 5 GHz frequency band and supports high data rate of 54 Mbps. This standard is incompatible with 802.11b and costlier. 802.11g, an extension of 802.11b, has the same data rate of 802.11a through using an OFDM modulation technique. Like 802.11b, it is also vulnerable to air interferences from Bluetooth devices and cordless phones due to usage of unlicensed 2.4 GHz frequency band [12]. 802.11n is backward compatible with 802.11a and 802.11b and operates in both the 2.4 GHz and 5 GHz bands. It significantly increases data transmission rate up to 100 Mbps using channel bonding. Unlike 802.11g, it improves reliability and performance using MIMO. It can support bandwidth intensive applications such as VoIP and video streaming over long distances [13]. 802.11e defines the rules to improve QoS of WLAN through modifying the MAC Layer [39].

The 802.11ac is an emerging standard which provides high data rate of up to 1 Gbps only in the 5 GHz frequency band. It has many attractive features like beamforming and Multiuser MIMO as opposed to 802.11n. Wi-Fi Standards are used to create an Independent Basic Service Set (IBSS) in VANET. However, when the number of vehicles increases significantly it affects the performance of the Wi-Fi network. Most of the Wi-Fi standards operate in unlicensed 2.4 GHz band. Hence, they are susceptible to interference with other standards such as Bluetooth. Though some standards use 5 GHz band, they can support short range communications. Generally, Wi-Fi needs more access points and provides less secure and unreliable communications for VANETs than Cellular Systems. The Vehicle tracking system (VETRAC) uses IEEE 802.11 b/g for tracking and locating a moving vehicle [58].

2.2.2 DSRC/WAVE (IEEE 802.11p Wi-Fi FAMILY PROTOCOLS):

Dedicated Short Range Communication (DSRC / IEEE 802.11p) was exclusively developed to meet the requirements of VANETs such as self-organizing, self-configuring, high mobility and dynamic topology. DSRC works using a 75 MHz spectrum in 5.9 GHz frequency band in US whereas in Europe and Japan it operates on 30 MHz
spectrum in the 5.8 GHz band. It can provide services to both V2V and V2I up to 1 km and supports data rate of up to 27 Mbps. As shown in the Fig.2 the spectrum comprises a 5 MHz guard band, one 10 MHz Control Channel (CCH) and six 10 MHz Service Channels (SCHs). The CCH is dedicated to transmit only safety-related messages. However, SCHs are used to support both safety and non-safety applications. The DSRC allows combining two SCHs to form 20 MHz channels in order to support high data rates of 54 Mbps [26][25].

<table>
<thead>
<tr>
<th>Operating Channel No.</th>
<th>172</th>
<th>174</th>
<th>176</th>
<th>178</th>
<th>180</th>
<th>182</th>
<th>184</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel f in GHz</td>
<td>5.860</td>
<td>5.870</td>
<td>5.880</td>
<td>5.890</td>
<td>5.900</td>
<td>5.910</td>
<td>5.920</td>
</tr>
<tr>
<td>Channel Purpose</td>
<td>SCH</td>
<td>SCH</td>
<td>SCH</td>
<td>CCH</td>
<td>SCH</td>
<td>SCH</td>
<td>SCH</td>
</tr>
</tbody>
</table>

**Figure 2:** DSRC Channels [24]

In DSRC, the Road Side Unit (RSU) and On Board Unit (OBU) communicate using either 802.11p or Wireless Access in Vehicular Environment (WAVE) standard. Usually DSRC and WAVE terms are used interchangeably. The notable difference is that DSRC includes IEEE 802.11p, an amendment of 802.11a MAC and PHY whereas WAVE standard focuses on the upper layers. Furthermore, DSRC can use the WAVE Short Message Protocol (WSMP) to support V2V and V2I safety applications. The following Fig.3 shows the Layered architecture of DSRC [24][29]. The MAC Layer is divided into two layers: MAC sub layer and Logical Link Control (LLC). The MAC sub layer allows Stations (STAs) to share the spectrum more effectively and uses IEEE1609.3 standard to support multichannel operations of DSRC by extending MAC functions, LLC uses 802.2 along with Sub Network Access Protocol (SNAP) to provide services required by higher layers including 1609.3. Based on the requirements of VANET applications, the Network and Transport Layers use protocols such as IPv6, TCP, UDP and WSMP to facilitate wireless connectivity. Typically, it uses WAVE Short Message Protocol (WSMP) for single hop transmissions and the remaining protocols for supporting multihop transmissions. Its architecture can support both safety and non-safety applications using WSMP and TCP/IPV6 respectively. The P1609.3 standard provides networking services and defines WSMP and WAVE Service Advertisement (WSA). The application layer comprises applications and some other services to support interoperability among the safety applications.

As shown in the Fig.3, DSRC comprises the following sub standards.

- IEEE P1609.1 - Resource Manager
- IEEE P1609.2 - Security Services for Applications and Management Messages
- IEEE P1609.3 - Networking Services
- IEEE P1609.4 - Multi-Channel Operations

DSRC is widely and chiefly used for road safety applications due to its reliability, secure data transmission and low latency. DSRC standard is still a draft because of some technical issues that need to be addressed before the full adaption for VANETs. For example, it has been observed that the current specification of DSRC performs poorly in high density and mobility conditions [27]. Protecting safety-related and application messages against abuses is another issue in DSRC [28]. Also, seamless ubiquitous non-safety TCP/IP based services remains to be addressed. DSRC is currently mostly used for Electronic Toll Collection (ETC) in various countries such as Italy and Germany [56][57].

**Table:** DSRC Architecture [29]

- **Safety Applications**
  - Safety Application Sublayer
  - Message Sublayer
  - Network & Transport Layer
  - P1609.3
  - LLC Sublayer
  - IEEE 802.2
  - MAC sublayer Extension
  - IEEE P1609.4
  - PHY Layer

- **Non-Safety Applications**
  - Application Layer
  - HTTP
  - Network Layer
  - TCP/UDP
  - IPv6

**Figure 3:** DSRC Architecture [29]

**2.2.3 CONTINUOUS AIR-INTERFACE, LONG AND MEDIUM RANGE (CALM):**

CALM is being developed by Working Group 16 (WG16) of Technical Committee 204 (TC204) of ISO. Like the WAVE standard, it also operates in the 5.9 GHz band. Basically it is a collection of standards, procedures and management processes. It is intended to provide continuous and transparent communication across multiple communication standards and application interfaces. CALM media are classified into five categories: 5 GHz wireless LAN systems (IEEE 802.11 Wi-Fi/802.11p/CALM M5), Cellular systems, (GSM/HSDS/4GPRS and 3G UMTS), 60 GHz systems, Infrared communication and a Convergence Layer, supporting DSRC, broadcast and positioning [21][23]. It is capable of selecting a transmission media based on the location and OBU of the vehicle. For short to medium distances, it recommends infrared, millimetre waves and microwave communications whereas for long distances, it prefers cellular systems. It also uses satellite communication to provide services to vehicles in mountainous and rural areas. Consequently, CALM can support all kinds of ITS applications including safety applications and comfort applications. As it is able to
provide uninterrupted internet services through IPv6 with mobility features like Network Mobility (NEMO). It handles media handoffs more effectively than the WAVE standard [21]. It depends on IETF IPv6 protocols for vertical handovers and media specific protocols for horizontal handovers. It can support three modes of communication V2V, V2I and Infrastructure-to-Infrastructure (I2I) communication. Unlike DSRC, CALM supports five communication scenarios: V2I Non-IPv6 communications, V2I/V2V Local IPv6, V2I MIPv6, V2I NEMO and V2V Non-IPv6. CALM has seven sub working groups that work on various CALM related standards concerning architecture, networking, application management, non-IP networking and security.

To support low latency, real time applications, data management of multiple applications and multiple network routing protocols, the CALM architecture was revised in 2007. Fig.4 shows the key components of the new, flexible architecture of CALM [22]. Its management is governed by three components: CALM / Application Management Entity (CME), Network Management Entity (NME) and Interface Management Entity (IME). The CME is responsible for meeting the requirements of ITS applications. It interacts with the IME to perform media selection and instruct the NME to establish the connection. NME performs transparent media handoffs whereas IME monitors the various Communication Interface (CI) and records the quality of various channels including CALM Infrared, CALM M5 and CALM Millimetre. In the lowest Physical and MAC Layer, CALM has multiple CI for wired (Ethernet/Fibre) and wireless networks. The CALM Network Layer comprises network and transport protocols such as CALM FAST networking, CALM geo-routing. IPv6 to support both CALM based and non-CALM based applications that run in the topmost level. Service Access Protocols (SAPs) are used to access a particular component in CALM. Since this architecture is open, futuristic communication standard will be integrated into the CALM standard easily.

The CALM standard is not widely used since it is still under development. Some projects have used CALM standards to enhance interoperability among networks and applications. The Cooperative Vehicular Infrastructure Systems (CVIS) project, funded by the EU, has tried to use CALM to develop various ITS applications. CALM is used by Germany’s LKW-MAUT project and applied to develop applications for in-vehicle internet access, dynamic navigation, safety warnings, and collision avoidance, Curve-Warning, Hazard-Warning, Traffic information [20]. As it attempts to support heterogeneous networks, it gets into a lot of implementation issues. Moreover, CALM has to store and manage huge amount of management data. Like other communication standards, several issues concerning architecture, routing, user acceptance, data privacy and security, system openness and interoperability need closer examination. There are projects like Cooperative Vehicle-Infrastructure Systems (CVIS) [20], Co-operative Systems for Intelligent Road Safety (COOPERS) [54], and SAFESPOT [55] that have used CALM architecture to implement both road safety and non-safety applications.

2.3 SHORT RANGE PROTOCOLS

2.3.1 BLUETOOTH

The ISM (Industrial Scientific and Medical) radio bands based Bluetooth (IEEE 802.15.1) protocol is used to transfer data at the rate of up to 1 Mbps to 4 Mbps over a distance of 10m. Bluetooth operates in the 2.4 GHz band and uses Frequency Hopping Spread Spectrum technique to overcome signal interference [30]. Though Bluetooth Version 3 can work on 6 GHz to 9 GHz frequency band, it uses 2.4 GHz band to communicate with other devices. Though Bluetooth 4.0 uses low energy for transmission, it is not compatible with earlier versions [31]. It is predominately used to create a Personal Area Network (PAN). Bluetooth technology can be used to support both V2V and V2I applications [32]. As compared to other Wi-Fi standards, it requires low power. However, it cannot be used to build safety applications because of slow transfer rate, short coverage area and vulnerability to air inferences. It is not suitable for bandwidth intensive infotainment applications such as VoIP and web browsing. Frank et al [51] have used this technology to exchange data between two cars while moving.

2.3.2 ZigBee

ZigBee (IEEE 802.15.4) uses the license-free 2.4 GHz band to transfer data at the rate of 250 Kbps up to 70 meters. It also uses lower frequency bands 915 MHz (US) and 868 MHz (Europe) to supports data transmission rates of 40 Kbps and 20 Kbps respectively. This technology uses low powered radio signals to transfer data up to 100m using Offset Quadrature Phase Shift Keying (O-QPSK) modulation [33]. Since it uses low-power and low-latency, it is widely used in PANs, remote controls, transport
monitoring, and sensor networks. It is simpler and cheaper than Wi-Fi and Bluetooth standards. Moreover, it can support more mobile nodes simultaneously and has self-healing capability [34]. Like Bluetooth, it can be used to support V2V and V2I applications [36]. However, it is not suitable for bandwidth intensive infotainment applications such as VoIP, web browsing [35]. Bhargav et al used ZigBee to track the vehicular positional coordinates during rescue missions of vehicular accidents [52].

2.3.3 INFRARED

It is another popular wireless access technique which uses invisible light to transfer data. It operates in the frequency band between 300 GHz and 400 THz. This broad spectrum is divided into three sub-bands: near-infrared, mid-infrared and far-infrared. Based on the type of sub-band, it can transfer data from 115kbps to 4Mbps. Since infrared signals are affected by obstacles, it is mainly used for short range communication [43]. Though it uses low power, it supports low data rate as compared to other standards such as Bluetooth. Many peripherals equipped with infrared capabilities are used to form indoor wireless LANs. This technique is able to transmit voice, data, and video information more securely. It can be used to support safety application due to its ability to support high network traffic and large bandwidth. Japan’s most successful application Vehicle Information and Communication System (VICS) uses radio-wave beacons on the expressway and infrared beacons on the arterial routes [38].

2.3.4 ULTRA WIDEBAND (UWB)

UWB, which operates on unlicensed frequency band between 3.1 and 10.6 GHz, can support a STA with mobility of 10 kph [46]. It support low power operation, low power dissipation, robustness for multi-path fading and higher throughput of up to 480 Mbps. Like Bluetooth, it has a transmission range of 10m. In VANET, it can be used for collision avoidance. This standard and differential GPS (DGPS) together were used to determine the relative position of a vehicle [53].

3. COMPARATIVE ANALYSIS

The suitability of various wireless access standards to support VANET applications including infotainment applications are compared in terms of Bandwidth, Signal Coverage, Signal Interference, Accessibility, Maintenance, Upfront Cost and Security. The data transmission rate determines the amount of data transmitted between the ends of communication at a time. Infotainment applications such as large data transfers, video chat, VoIP needs more bandwidth. Signal coverage which determines the service area is essential for the deployment of specific standard. It is measured using signal strength and propagation path loss caused by factors like multi-path propagation, reflection, absorption and diffraction. Signal interference decreases coverage range and throughput. Many devices including Direct Satellite Service (DSS), external electrical sources such as power lines, electrical power stations, Wireless speakers, microwaves ovens, cameras, wireless devices that operate in the same frequency band affect the data transmission. Accessibility determines the number of simultaneous data transmission of multiple users so as to improve bandwidth utilization. Maintenance deals with the life of network whereas upfront cost covers the total costs of acquisition. The last parameter addresses how wireless standard protects communications over a shared wireless medium.

As shown in Table 1, many wireless standards operate in either the 2.4 GHz or 5 GHz frequency band. It is observed that wireless standards that operate on high frequencies are less affected by air inferences. Cellular Systems, WiMAX, MBWA are used to provide services to large coverage over a wide geographical area. Though contention based protocols allow collisions, they enable fast access to the service. Wireless standards that support long range transmissions have high upfront cost whereas standard that supports short range communication have low maintenance cost. Although wireless standards use encryption and authentication to ensure secure communications, they are still vulnerable to security breaches. Most of the wireless standards like Cellular Systems, CALM and DSRC now provide highly secure data transmissions.

Cellular systems such as 3G/4G, Mobile WiMAX and MBWA can be used to provide infotainment services over long distances. Though 3G supports high mobility of STA, it reduces the data rate to 144 kbps. Similarly, Mobile WiMAX (IEEE 802.16e) can support a Mobile Station (MS) with the speed of 60 kph but it drops the data rate to 10Mbps over 2km. MBWA and 4G LTE can provide highest spectrum efficiency, STA mobility up to 250 kph and fast mobile-IP connectivity. It is noted that 4G, DSRC/ MBWA/WiMAX with 3G are adequate to support all types of VANET applications including multi-hop infotainment applications such as Internet access and video streaming.

The Wi-Fi based protocols such as DSRC and CALM are more suitable for VANET due to their support of low latency and broad coverage area compared to other Wi-Fi standards. These standards are already used to implement V2V and V2I applications particularly safety related applications. It is observed that protocols like DSRC were chiefly designed and developed to support road safety applications. Safety applications demand low latency and high reliability, whereas infotainment applications require high throughput, high resource utilization and low packet loss. One of the biggest challenges in VANET is data dissemination which is the key component of infotainment applications [42]. To provide fair data dissemination, a VANET must use different wireless protocols. Switching from one standard to another either to provide backward
compatibility or to adapt the available protocol in the service area affects throughput and increases packet loss. Moreover, providing seamless handoffs and ubiquitous service coverage is difficult in a VANET due to high mobility of vehicles. VANETs use MIPv6, Hierarchical Mobile Internet Protocol (HMIPv6) and Network Mobility (NEMO) for IP assignment and reassignment to achieve soft and vertical handoffs. These protocols must be used along with wireless protocols to handle mobility in VANET. Furthermore, the impact of several handoffs on throughput should also be investigated in future.

Bluetooth, Zigbee, Infrared and UWB standards are now used to create Wireless Personal Area Networks. These technologies support high transmission rates over short distances. They are mostly preferred in comfort (service related) applications like Parking Spot Locator, Parking Availability Notifications and Electronic Toll Tax Collection. Most OBUs are already equipped with these capabilities to enable in-vehicle communications. Wi-Fi protocols are very common and popular for wireless Local Area Networks (WLAN). Most of the Wi-Fi standards particularly 802.11n support higher throughput, reasonable range and link quality. Moreover, they ensure high network utilization and availability.

<table>
<thead>
<tr>
<th>Wireless Standard</th>
<th>f in GHz</th>
<th>Data Transmission Rate</th>
<th>Max Signal Coverage</th>
<th>Signal Interference</th>
<th>Maintenance</th>
<th>Accessibility</th>
<th>Upfront Cost</th>
<th>Security</th>
<th>Mobility Support km/h</th>
<th>Suitable for Safety Applications</th>
<th>Suitable for Non-Safety Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Systems</td>
<td>Operator Dependent</td>
<td>≈ 384 Kbps - 129 Mbps</td>
<td>50 km</td>
<td>Low</td>
<td>Difficult</td>
<td>Contention based</td>
<td>High</td>
<td>High</td>
<td>100-250</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>WiMAX 802.16m</td>
<td>2.3/2.5/3.5</td>
<td>≈ 75 - 300 Mbps</td>
<td>50 km</td>
<td>High</td>
<td>Difficult</td>
<td>Schedule based</td>
<td>High</td>
<td>High</td>
<td>60-250</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>MBWA 802.20</td>
<td>3.5</td>
<td>≈ 4.5 Mbps</td>
<td>15 km</td>
<td>High</td>
<td>Easy</td>
<td>Schedule based</td>
<td>High</td>
<td>High</td>
<td>100-250</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Microwave</td>
<td>1-3</td>
<td>≈ 16 Gbps</td>
<td>30 km</td>
<td>High</td>
<td>Difficult</td>
<td>Contention based</td>
<td>High</td>
<td>Low</td>
<td>--</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wi-Fi 802.11a</td>
<td>5.1/5.8</td>
<td>≈ 54 Mbps</td>
<td>100 m</td>
<td>Low</td>
<td>Easy</td>
<td>Contention based</td>
<td>High</td>
<td>Low</td>
<td>40-120</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wi-Fi 802.11b</td>
<td>2.4</td>
<td>≈ 11 Mbps</td>
<td>100 m</td>
<td>High</td>
<td>Easy</td>
<td>Contention based</td>
<td>Moderate</td>
<td>Low</td>
<td>40-150</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wi-Fi 802.11g</td>
<td>2.4</td>
<td>≈ 54 Mbps</td>
<td>140 m</td>
<td>High</td>
<td>Easy</td>
<td>Contention based</td>
<td>Moderate</td>
<td>Low</td>
<td>40-120</td>
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<td>No</td>
</tr>
<tr>
<td>Wi-Fi 802.11n</td>
<td>2.4/5</td>
<td>≈ 100 Mbps</td>
<td>250 m</td>
<td>High</td>
<td>Easy</td>
<td>Contention based</td>
<td>High</td>
<td>High</td>
<td>40-120</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>DSRC 802.11p</td>
<td>5.8/5.9</td>
<td>≈ 27 Mbps</td>
<td>1 km</td>
<td>Low</td>
<td>Easy</td>
<td>Contention based</td>
<td>Moderate</td>
<td>High</td>
<td>40-150</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CALM M5</td>
<td>5</td>
<td>≈ 6 Mbps</td>
<td>10 km</td>
<td>High</td>
<td>Difficult</td>
<td>Contention based</td>
<td>High</td>
<td>High</td>
<td>40-150</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Infrared</td>
<td>300 GHz - 400 THz</td>
<td>≈ 115 Kbps - 4 Mbps</td>
<td>100m</td>
<td>Low</td>
<td>Easy</td>
<td>Contention based</td>
<td>Low</td>
<td>High</td>
<td>250</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Bluetooth 802.15.1</td>
<td>2.4 GHz</td>
<td>≈ 1-24 Mbps</td>
<td>100 m</td>
<td>High</td>
<td>Easy</td>
<td>Schedule based</td>
<td>Low</td>
<td>Low</td>
<td>20-30</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ZigBee 802.15.2</td>
<td>868/915 MHz /2.4 GHz</td>
<td>≈ 250 Kbps</td>
<td>100 m</td>
<td>High</td>
<td>Easy</td>
<td>Schedule based</td>
<td>Low</td>
<td>High</td>
<td>10-20</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>UWB 802.15.3</td>
<td>3.1-10.6 GHz</td>
<td>&lt; 100 Mbps</td>
<td>10 m</td>
<td>Low</td>
<td>Easy</td>
<td>Contention based</td>
<td>Low</td>
<td>High</td>
<td>10-20</td>
<td>No</td>
<td>No</td>
</tr>
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</table>

Table 1: Comparison of wireless access technologies

4. CONCLUSION

The Intelligent Transportation System (ITS) has recently attracted both academia and industry as it has the potential to save lives and environment, time and money and can even transform our social life! A VANET is an important component of ITS which employs multiple wireless communication protocols in order to support applications for both V2V and V2I. In VANET, the choice of access protocols is an important issue since it determines the transmission range, data rate, security and reliability.

This paper has presented an overview of wireless access technologies which could be used in VANETs. For each standard, it discusses the limitations and support for safety and non-safety applications. It also compares wireless communication standards through various parameters including bandwidth, service coverage and signal interference. VANET requires multiple wireless protocols to support constant communication connectivity in multi-hop environment. Hence, interoperability issues between wireless standards need to be investigated. DSRC/WAVE is
considered to be best suited for safety-critical applications though its efficiency to support ubiquitous connectivity based application needs to be addressed.

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