International Journal of Network and Communication Research
Vol.7, No.1, pp.1-13, 2021
ISSN: ISSN 2058-7155(Print),
ISSN: ISSN 2058-7163(Online)

Trends in Automotive Communication

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Citation: Akhibi, Samuel D. (2022) Trends in Automotive Communication, *International Journal of Network and Communication Research*, Vol.7, No.1, pp.1-13

ABSTRACT: *Modern vehicles are complex cyber-physical systems where communication protocols designed for physically isolated networks are now employed to connect Internet-enabled devices. This paper presents an overview of wireless automotive communication technologies and the Interference Rejection Combining Approach in Vehicle Communication systems with the aim of identifying the strong candidates for future in-vehicle and inter-vehicle automotive applications. The paper first gives an overview of automotive applications relying on wireless communications, with a particular focus on key networking technologies used for in-vehicle and inter-vehicle applications then on Interference Rejection Combining Approach in Vehicle Communication systems.*

KEYWORDS: automotive, communication protocol, networking, technologies

INTRODUCTION

In today's fast-paced world, there is an increasing demand for connected vehicles, which allow automobiles to communicate with one another. Vehicles could be linked to more communication devices in the future to provide a more comprehensive, autonomous, and intelligent driving experience (Kannappan et.al 2022).

Horauer, Zauner, and Schuster (2021) the automotive industry introduces new cars with ever more functionalities and features trying to improve aspects like environmental efficiency, safety, reliability, and comfort. Electronics paired with the respective software is the prevalent innovator in modern cars. In fact, more than 50 electronic control units (ECUs) are state-of-the-art in modern cars. These distributed ECUs are interconnected by different field-bus systems like LIN, CAN, or Flex Ray allowing for a combination of information from different sensors and enabling the control of the respective actors. For example, in this way, it is possible to gather information on the speed of all wheels, and in case of deviations – for instance when one wheel hits the curbs – to react accordingly by braking or accelerating some of the other wheels in order to keep the car stable on the track. Similarly, window lifts can be controlled from different positions in a car by relaying the respective commands to the corresponding actors. The individual networks are separated into several functional domains like chassis, power train, body, and comfort, or telematics. Furthermore, some of these domains are interconnected via gateways to enable centralized access and control.

Testing an entire automotive communication system is a complex, demanding endeavor that can hardly be accomplished with state-of-the-art equipment. In fact, in practice, such a system test is often "felt costly", hence, the focus in practice is typically on the sub-systems alone. Nevertheless, we are confident that with rising functionality and complexity a system test will become indispensable in the future.

There are several applications pushing for the adoption of wireless communications in automotive systems, both within the vehicle (in-vehicle communications) and between the vehicle and its surroundings (inter-vehicle communications). Looking at in-vehicle communications, more and more portable devices, e.g., mobile phones, portable GSM devices and laptop computers could exploit the possibility of interconnection with the vehicle. Also, several new applications will exploit the possibility of inter-vehicle communications, e.g., vehicle-to-vehicle and vehicle-to road side communications. Nolte, Hansson and Bello (2015).

With the advancement of the vehicle communication technology, the intelligent transport system (ITS)communities actively participate in the research and development of vehicle communication related applications and services, including safety service using vehicle to-vehicle(V2V) communication, traffic information service using vehicle-to-infrastructure (V2I) communication, and multimedia service. Seo, Jung and Lee (2014)

Until recently, the U.S., Europe, and Japan were building infrastructures for national level projects and working on their communication standards. In 2004, the IEEE 802.11 committee decided on the American Society for Testing and Materials (ASTM) specification as wireless access in vehicular environments (WAVE) and established Task Group p (TGp) for the standardization. In other words, IEEE802.11p, also known as WAVE, became the radio transmission standard supporting the maximum 27Mbps in vehicles with the maximum 200km/h speed within a radius of one kilometer. WAVE includes a new WAVE basic service set (WBSS) concept, considering the vehicle network's characteristics compared to the conventional IEEE 802.11 networks. IEEE Computer Society (2010)

Alsath, et al. (2015) vehicles could be linked to more communication devices in the future to provide a more comprehensive, autonomous, and intelligent driving experience. This necessitates the use of automotive antennas capable of supporting multiple frequency bands/vehicular wireless services. However, multiple antennas increase the complexity of the transceiver and also require a large space for their integration on the printed circuit board. A multiband antenna, on the other hand, can be designed to combine multiple frequencies into a single antenna and may serve as the foundation for future development in automotive applications.

Automotive Ethernet (AE) offers a superior bandwidth to other automotive protocols, thus applications requiring more resources can provide better passengers experiences. Fast technological development allows highly demanding protocols therefore Ethernet may be the future in automotive communications. There are several studies and implementations for Ethernet in Automotive communications Varun and Kathiresh (2014)., including some focused-on communication between Ethernet and other protocols like CAN and Flex Ray Postolache, Neamtu and Trofin, (2013). Ethernet is efficient in terms of bandwidth and interoperability, providing faster transfer rates and larger payloads than other automotive protocols, hence, the physical layer standard BroadR-Reach has emerged as the future of automotive applications. Through OPEN Alliance, the automotive industry has standardized the BroadR-Reach point-to-point physical layer (PHY) as the standard for Ethernet communication in vehicles [143]. BroadR-Reach uses bidirectional communications similar to 1000BASE-T Ethernet, where both interfaces communicate simultaneously over the same twisted pair cable. Bernardini, Asghar and Crispo (2017).

In this paper we will focus on trends and emerging automotive communication systems used for vehicle intra and interconnected communication.

LITERATURE REVIEW

The concept of an automotive communication system

The increasing adoption of advanced driver assistance systems and infotainment solutions, often connected to the public Internet, makes modern vehicles similar to mobile networks of computing devices. These technologies can increase the safety of the vehicle and pave the way for novel solutions and business models, such as the European eCall initiative (European Parliament).

Wireless Automotive Communications

UWB

Kannappan et.al (2022) automotive multiband antennas are required for a variety of applications in intelligent transportation systems (ITS), such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2E) communication. The automotive antenna may play a role in the advanced driver assistance system (ADAS), which is a collection of active safety systems that allow drivers to take timely control of their vehicles by warning them of potential road hazards. In the context of automobiles, the ADAS system includes autonomous parking, congestion avoidance via re-routing and blind spot detection. The Internet of things (IoT) facilitates this ADAS system. The term “automotive IoT” refers to the incorporation of IoT technologies into automotive systems in order to develop new applications and solutions that can make vehicles smarter and more intelligent, resulting in safer, more efficient, and more comfortable driving. Vehicle IoT technology enables applications such as autonomous driving, braking, automatic parking, traffic tracking, route and driver control.

Recently, a few ultra-wideband (UWB) antennas with integrated multi-standard bands have been reported for automotive applications. Despite the numerous advantages of UWB technology, multipath propagation and fading degrade system performance by decreasing the signal to interference ratio. The fading problem can be alleviated by introducing a diversity scheme. Diversity improves signal reliability by obtaining replicas of the information signal across multiple pathways. The combination of multiple-input-multiple-output (MIMO) and UWB technologies can improve system robustness by avoiding the effects of fading and multipath propagation. MIMO transmits and receives uncorrelated signals while increasing channel capacity by forming parallel resolvable channels. However, the main challenges in MIMO antenna design are high inter-element coupling and compact size suitable for integration with other high-frequency devices Kabiri, Borja, Kelly, and Xiao (2019).

Li, Zhai, Li, Ma, and Liang (2013) a UWB antenna with GSM, WCDMA, and WLAN integrated bands were presented. The ground plane of the antenna was modified with capacitively loaded line resonators. The multi-band operation was achieved without increasing the size of the antenna, but the antenna showed single polarization. Bod, Hassani, and Samadi Taheri, (2012) a rectangular patch antenna with multiple standards was reported, where an octagonal-shaped slot was used to integrate multiple bands. Ali, Mohammad Saadh, Biradar, Andújar, and Anguera (2018) slots were introduced in the ground plane to achieve multiple band resonance without increasing the physical size of the antenna. A compact UWB monopole antenna with a notch and resonating strips were designed to achieve the quad-band performance Foudazi, Hassani, and Mohammad Ali Nezhad (2012)

Kumar, Ansari, Kanaujia, Kishor, and Kumar (2020) a compact-sized UWB antenna with band-notched characteristics was developed. The antenna offered good isolation, but its polarization was limited. Maurya and Bhattacharya (2020) a dual-polarized UWB MIMO antenna with integrated 1.9 GHz and 2.4 GHz were presented. Wu, et.al. (2019) a MIMO antenna was designed with good isolation for IEEE 802.11 a/b/g/n applications; however, only single-polarization was obtained. The band-notched multiband antennas were designed in10–12. Suriya and Anbazhagan (2019) a UWB MIMO antenna with improved isolation and dual-polarization were proposed. Srivastava, Kumar, Kanaujia, Dwari and Kumar (2019) a quad-port UWB antenna with an integrated GSM band was proposed without increasing the overall antenna size. The antenna offered horizontal and vertical polarization.

Huang, Liu, Zhang, and Gong (2015) a uniplanar four-port differently driven UWB antenna was presented, where high isolation and low cross-polarization were achieved through different feeding mechanisms. Srivastava, Kumar, Kanaujia, Dwari, and Kumar (2018) a UWB antenna integrated with Bluetooth and WLAN bands was presented, where ring slots were loaded in the patch for achieving multiband characteristics. However, the overall size of the antenna element was larger. Srikar and Anuradha (2019) the antenna elements were located perpendicular to each other, and good isolation was obtained without any isolation technique.

Evolution of the UWB antenna element

Kannappan et.al (2022) the proposed UWB monopole antenna element is depicted in Fig. 1. The overall size of the antenna element is 30 × 30 mm2. The antenna element is designed on the FR-4 substrate with relative permittivity of 4.4, loss tangent of 0.025, and thickness of 1.6 mm. The design equation for the UWB planar monopole antenna is given as

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Publication of the European Centre for Research Training and Development -UK

Vol.7, No.1, pp.1-13, 2021
ISSN: ISSN 2058-7155(Print),
ISSN: ISSN 2058-7163(Online)

$$f\,l = \frac{7.2}{l + r + p \text{-} \times k}$$

Where fl is the lowest resonating frequency of the antenna and p is the distance between the patch and the ground plane, and the empirical constant k is calculated as

$$k = \sqrt[4]{\varepsilon eff}$$

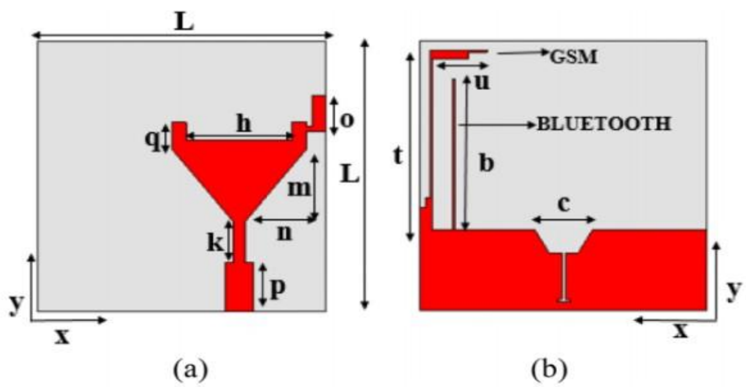

Figure1. Proposed antenna element: (a) front view and (b) back view.

In this section three Personal Area Network (PAN) standards for in-vehicle communications are presented: Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4). Also, one Wireless Local Area Network (WLAN) for inter-vehicle communications is presented: Wi-Fi (IEEE 802.11a/b/g). All these technologies are possible candidates for wireless real-time control systems found in automotive systems. Important issues not discussed in this paper are safety and security. In general, concerning safety, a wireless link is more sensitive to interference compared with a wired one. Also, from a security perspective, the wireless medium makes the system reachable from outside, possibly subject to intrusion. Moreover, it is still an open issue whether wireless networks introduce health risks for the driver of the vehicle.

Bluetooth

(IEEE 802.15.1) Bluetooth currently provides network speeds of up to 3 Mbps. Originally devised for PAN deployment for low-cost, low-power, short-range wireless ad hoc interconnection, Bluetooth technology has fast become very appealing also for the automotive environment, as a potential automotive wireless networking technology. In response to interest by the automotive industry, in December 1999 the Bluetooth Special Interest Group (SIG) formed the Car Working Group. The Hands-Free profile was the first of several application level Specifications from the Car Working Group. Using the new Hands-Free profile, products that implement the Bluetooth specification can facilitate automatic establishment of a connection between the car’s hands-free system (typically part of its audio system) and a mobile phone. Bluetooth wireless products incorporating these new enhancements enable a seamless, virtually automatic interface between the car and wireless products.

Today, Bluetooth allows hands-free use of a mobile phone either through the car's audio system or wireless headsets, resulting in better sound and control, and a safe solution to legislation banning mobile phone use while driving. The Bluetooth SIG, in November 2004, laid out a three-year roadmap for future improvements to Bluetooth. Prioritized targets include Quality of Service (QoS), security, power consumption, multicast capabilities, and privacy enhancements. Long-range performances improvements are expected to increase the range of very low power Bluetooth enabled sensors to approximately 100 meters.

ZigBee

(IEEE 802.15.4) ZigBee is a new low-cost and low-power wireless PAN standard, intended to meet the needs of sensors and control devices. Typical ZigBee applications do not require high bandwidth, but do impose severe requirements on latency and energy consumption. Despite the number of low data rates proprietary systems designed to fulfill the above-mentioned requirements, there were no standards that met them. Moreover, the usage of such legacy systems raised significant interoperability problems which ZigBee technology solves, providing a standardized base set of solutions for sensor and control systems.

The ZigBee Alliance with over 120 company members, ratified the first ZigBee specification for wireless data communications in December 2004. ZigBee provides network speed of up to 250Kbps, and is expected to be largely used in home and building automation (e.g., for fire detection, security and access monitoring, heating, lighting and environment control), and in industrial process monitoring and control systems (e.g., for use in monitoring and control of industrial processes and equipment, especially in hazardous environments inaccessible to normal wired systems).

Wi-Fi

(IEEE 802.11) Wi-Fi (wireless fidelity) is the general term for any type of network. Examples of 802.11 networks are the 802.11a (up to 54 Mbps), 802.11b (up to 11 Mbps), and 802.11g (up to 54Mbps). These networks are used as WLANs. The three 802.11 standards differ for the offered bandwidth, coverage, security support and, therefore, the kind of applications supported. 802.11a is better suited for multimedia voice, video and large-image applications in densely populated user environments. However, it provides relatively shorter range than 802.11b, which consequently requires fewer access points for coverage of large areas. The 802.11g standard is compatible with and may replace 802.11b, partly due to its higher bandwidth and improved security.

Interference Rejection Combining Approach in Vehicle Communication Systems for Throughput Enhancement

With the advancement of the vehicle communication technology, the intelligent transport system (ITS)communities actively participate in the research and development of vehicle communication related applications and services, including safety service using vehicle to-vehicle(V2V) communication, traffic information service using vehicle-to-infrastructure (V2I) communication, and multimedia service. Seo, Jung and Lee (2014)

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In a WAVE system, it is critical to achieve a high capacity for sustainable data transmission. In the case of typical traffic conditions, groups of vehicles' transceivers communicate simultaneously. Due to the heavy network traffic, only a few vehicles can achieve a high transmit data rate. Especially in heavy traffic conditions, the data traffic performance could severely deteriorate because of significantly low SINR caused by other adjacent vehicle interference. This low performed data throughput at heavy traffic is one of the severe bottlenecks of the WAVE system, and specific techniques for SINR improvement need to be present to resolve this issue.

The interference rejection combining (IRC) scheme became widely popular in the mobile communication areas Srinivasan and Renfors (2018), due to no prior knowledge requirement of the interference. In cellular networks, the IRC scheme was widely studied as an example of inter-cell interference suppression Zhang, et.al, (2020), non-orthogonal modulation scheme Usman, et.al, (2021), and backhaul links since the surging demands of network capacity with interference cancellation. Since IRC was investigated primarily on cellular communication, the IRC scheme must be considered in the vehicle communications, including WAVE Jaffry, et.al (2020). In particular, the existing vehicle communication studies do not consider the vehicle environments for IRC schemes, and implementing IRC schemes in the WAVE system can promise potential opportunities to improve WAVE communication.

System Overview and Models

System Model

We assume our system model to be based on a WAVE system. Figure 1 show the system model composed of a group of vehicles. In the group, we consider vehicles of three types: serving vehicle, target vehicle, and neighboring vehicle. A serving vehicle acts as a WAVE system transmitter, and a target vehicle receives the signal from the serving vehicle. Neighboring vehicles generate interference to the link between the serving vehicle and the target vehicle. As far as the vehicle position is concerned, we consider that there should be a direct line of sight between the serving vehicle and the target vehicle. IEEE Computer Society (2010).

Vol.7, No.1, pp.1-13, 2021

ISSN: ISSN 2058-7155(Print),

ISSN: ISSN 2058-7163(Online)

In this scenario, the vehicle communication between the serving vehicle and the target vehicle can be interfered with via wireless nodes from the neighboring vehicles. Hence, the signal-to-interference and noise ratio (SINR) should be considered. Although scenarios of multiple neighboring vehicles are possible, the complexity of wireless communication within heavy traffic is significant in the multiple vehicles' cases. In this sector, we start on the single antenna port for transmit and transmit antenna diversity for simplicity before explaining the case of multiple antenna ports. Schmidt-Eisenlohr (2010)

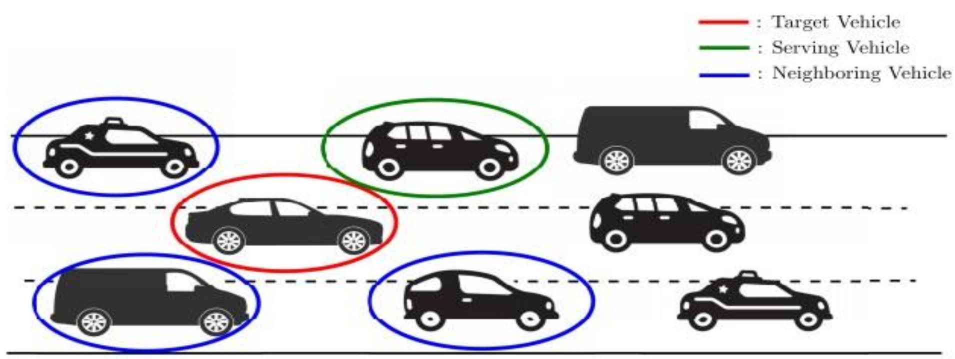

Figure 2. System model with multiple vehicles

WAVE Physical Layer

The physical layer of WAVE is defined in IEEE802.11p standard. IEEE802.11p is the transformed form of the existing wireless local area network (WLAN) standard from IEEE 802.11. It operates in the frequency band of 5.850–5.925 GHz with the partly overlaying industry, science, and medical (ISM) band of the conventional WLAN standard. It also uses the 10 MHz bandwidth for a channel with OFDM modulation. Given that channel bandwidth, the range of data rate supported is 3–27Mbps with the various modulation schemes, including BPSK, QPSK, 16QAM, etc. The OFDM signal comprises 64 subcarriers with 48 data, four pilots, and 12 direct currents (DC). In this paper, we consider the 6 Mbps data rate for simulation. Table 1 shows the parameters of the OFDM signal defined in IEEE 802.11p standard. IEEE Computer Society (2010)

Table1. Properties of OFDM signal in IEEE 802.11p.

Parameter	Value
Bandwidth	10 MHz
FFT Size	64
Subcarrier Interval	0.15625 MHz
Signal Bandwidth	8.28 MHz
IFFT / FFT Interval	6.4us
Guard Interval	1.6us
Symbol Interval	8.0(6.4 + 1.6) us

Table2. Show a transmission mode of an OFDM signal by the data rate. Note that each modulation and coding bit type depends on the data rate. In summary, the IEEE 802.11p standard has a narrow band transmission spectrum as compared to the conventional wireless LAN standard and is defined to transmit the maximum transmission power of 44.8dBm IEEE Computer Society (2010).

Table2. Transmission modes of OFDM signal according to the data rate in IEEE 802.11p.

Data Rate (Mbits/s)	Modulation	Coding Rate	Coded Bits per Subcarrier	Coded Bits per OFDM Symbol	Data Bits per OFDM Symbol
3	BPSK	1/2	1	48	24
4.5	BPSK	3/4	1	48	36
6	QPSK	1/2	2	96	48
9	QPSK	3/4	2	96	72
12	16-QAM	1/2	4	192	96
18	16-QAM	3/4	4	192	144
24	64-QAM	2/3	6	288	192
27	64-QAM	3/4	6	288	216

DISCUSSION

Nolte, Hansson and Bello (2015) Looking at the automotive context, Bluetooth is built into many vehicles today. Hence, it is currently the most widely used automotive wireless technology. The frequency hopping modulation technique is also suitable in harsh environments often found in automotive applications. The availability of Bluetooth in vehicles and cell phones, means that it already today provides a technology for telematics applications. In a Bluetooth-enabled vehicle, the car audio system takes over the phone function. In addition, other Bluetooth devices can easily interconnect within a Bluetooth enabled car: for example, portable devices, such as DVD, CD,

MP3 players, can be connected to speakers. Moreover, hand-held computers and diagnostic equipment can interface to the car and access services provided by the onboard diagnostic and control systems through Bluetooth interfaces. Beyond entertainment and phone calls there are other emerging possibilities, including remote starting to warm-up the car in the winter or start the air conditioning in summer, iPod or MP3 players streaming to the audio system, a remote parking garage or home garage door controller, and payment for gas at the pump and toll road payments.
ZigBee on the other hand, fills a gap not provided by the other technologies, namely the interconnection of wireless sensors for control. ZigBee is expected to be used in monitoring and control applications, related to temperature and humidity measurement as well as heating, ventilation, air-conditioning and lighting control. There are also quite novel and original ways of using ZigBee for the driver's benefit. One of them is rental car monitoring. A ZigBee-enabled monitoring system could allow customers to quickly drop off a rental car without waiting for the attendant to check gas or mileage. Other interesting automotive applications are tire-pressure monitoring and remote keyless entry. Further proposals involve attaching a ZigBee device to anything which should not be lost (e.g., car keys), so that, whenever the device goes out of range, an alert signal is generated from a ZigBee-equipped phone.

(Ultrawidebandplanet.com) UWB is the newcomer in this area, possibly providing robust communications thanks to its usage of a broad spectrum of frequencies. We are likely to see UWB in applications requiring high bandwidth, such as interconnection of multimedia devices. Other automotive applications are collision-detection systems and suspension systems that respond to road conditions. (Car2Car Communication Consortium) however, UWB being a young technology, no such applications are available to date. For inter-vehicle communications, Wi-Fi is the most interesting technology today, partly due to its extensive usage in office and home networks, but also due to its availability. Hence, it is often used in pilot research projects. Wi-Fi is used for inter-vehicle communications by, e.g., the Car2Car Consortium, a non-profit organization initiated by European vehicle manufacturers.

Applications here are advanced drive assistance reducing the number of accidents, decentralized floating car data improving local traffic flow and efficiency, and user communications and information services for comfort and business applications to driver and passengers. Research projects working in this area are, e.g., the European Network-on-Wheels (NoW) project.

CONCLUSION

The constant progress of technology has impacted current vehicles which have more and more sensors, electro-mechanical devices, and electronic control units, which allow them to have more functionality and provide drivers with more services. From a real-time point of view, most telematics applications do not feature real-time requirements in the strict sense. Navigation and traffic information systems require position and Internet-like communications formation and directions. Voice applications have slightly higher requirements on QoS, e.g., real-time voice processing and recognition.

However, some safety-systems do have real-time requirements, e.g., communications between the vehicle and other vehicles or roadside objects, implementing collision detection/avoidance systems or active suspension systems that respond to road conditions. Moreover, diagnostics and service tools could make real-time data available during operation of the vehicle. Also, real-time requirements are put by the usage of wireless technologies as a redundant link between nodes linked with wired type of networks. None of the wireless technologies presented in this paper provide hard real-time guarantees, since they are not as deterministic as wired technologies and messages are more likely to be corrupted. However, they can make use of real time dependability concepts to provide as good service as possible in the area of wireless automotive real-time communications.

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