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Automotive Wireless Communication

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Abstract

This study offers a comprehensive examination of wireless communication technologies in the automotive sector, aiming to pinpoint the most promising options for future vehicle-based applications, both within and between vehicles. The research begins by surveying automotive applications that rely on wireless communications, with a particular emphasis on telematics. Subsequently, the study identifies and compares the primary networking technologies employed in intra-vehicle and inter-vehicle applications. It also highlights upcoming challenges in the field of wireless automotive communications, specifically focusing on real-time aspects.

Introduction

In the automotive communications sector, two areas are currently receiving the most focus: protocols and technologies that support x-by-wire applications, such as Flexray [3], and those related to telematics and wireless applications. Automotive telematics encompasses any vehicle information or communication service that relies on wireless communication.

Various applications are driving the adoption of wireless communications in automotive systems, both inside the vehicle (in-vehicle communications) and between the vehicle and its environment (inter-vehicle communications). Within the vehicle, an increasing number of portable devices, including mobile phones, portable GSM devices, and laptop computers, could benefit from interconnection with the vehicle. Additionally, numerous new applications will utilize inter-vehicle communications, such as vehicle-to-vehicle [2] and vehicle-to-roadside communications.

This study examines the most widely adopted wireless protocols for communication within vehicles and between vehicles in the automotive sector, as well as those anticipated to be utilized in the near term. Following a summary of typical telematics services and applications in Section 2, the paper discusses relevant wireless automotive networking technologies for in-vehicle and Section 3 examines and contrasts various inter-vehicle communication methods, highlighting aspects related to real-time performance. The paper concludes with a summary in Section 4.

Telematics

The integration of wireless communication technology into vehicles through automotive telematics has paved the way for numerous innovative services and applications. This advancement enhances the vehicle's capabilities and expands the range of services available to users. Some examples of telematics-based services and applications include:

- **Navigation and traffic information systems:** Vehicles equipped with telematics units can guide drivers to their desired destinations while providing up-to-date traffic information for the chosen route.
- **Voice recognition and wireless Internet connectivity:** Drivers and passengers can send and receive voice-activated emails while traveling.

- **Safety systems:** These encompass collision avoidance systems, unsafe driving behavior monitoring, and intelligent airbag deployment mechanisms. They also facilitate communication between the vehicle and its environment, such as other vehicles and roadside objects. Additional features include automatic airbag deployment notification, as well as accident and roadside assistance. An illustration of this is the General Motors Advanced Automatic Crash Notification (AACN) system, which is available on many GM OnStarTM-equipped vehicles.
- **Security systems:** These include anti-theft measures and stolen vehicle tracking services. OnStarTM-equipped vehicles offer tracking capabilities and remote door unlocking features.

Monitoring and support services - Systems for remote vehicle diagnostics and/or servicing, as well as tracking of vehicle performance and driver behavior.

3 Wireless automotive communications

This segment introduces three Personal Area Network (PAN) standards for in-vehicle communications: Bluetooth (IEEE 802.15.1) [1, 5], ZigBee (IEEE 802.15.4) [8, 5], and Ultra Wide Band (UWB/IEEE 802.15.3a) [7, 5]. Additionally, it presents one Wireless Local Area Network (WLAN) for inter-vehicle communications: Wi-Fi (IEEE 802.11a/b/g) [4]. These wireless technologies are potential candidates for real-time control systems in automotive applications. While safety and security concerns are not addressed in this paper, it is worth noting that wireless connections are generally more susceptible to interference than wired ones. Furthermore, the wireless medium potentially exposes the system to external intrusion, raising security concerns. Lastly, the potential health risks associated with wireless networks for vehicle drivers remain an unresolved issue.

3.1 Bluetooth

Bluetooth (IEEE 802.15.1) [1, 5] currently offers network speeds reaching 3 Mbps. Initially conceived for Personal Area Network (PAN) implementation as a cost-effective, energy-efficient, and short-range wireless ad hoc connection solution, Bluetooth has rapidly gained traction in the automotive sector as a potential wireless networking technology. Recognizing the automotive industry's interest, the Bluetooth Special Interest Group (SIG) established the Car Working Group in December 1999. The group's first application-level specification was the Hands-Free profile. Products incorporating this new Bluetooth specification can enable automatic connection between a vehicle's hands-free system (typically integrated into the audio system) and a mobile phone. Bluetooth wireless products with these enhancements facilitate a smooth, nearly automatic interface between vehicles and wireless devices. Currently, Bluetooth enables hands-free mobile phone usage through either the car's audio system or wireless headsets, providing improved sound quality, control, and a safe solution to comply with laws prohibiting mobile phone use while driving.

In November 2004, the Bluetooth SIG outlined a three-year plan for future Bluetooth enhancements. Key focus areas include Quality of Service (QoS), security, power consumption, multicast capabilities, and privacy improvements. Long-term performance enhancements are anticipated to extend the range of ultra-low power Bluetooth-enabled sensors to approximately 100 meters.

3.2 ZigBee

ZigBee (IEEE 802.15.4) [8, 5] is a recently developed wireless PAN standard that offers reduced costs and power consumption, designed to address the requirements of sensor and control devices. While typical ZigBee applications don't demand high bandwidth, they have stringent requirements for latency and energy efficiency. Although numerous proprietary systems with low data rates were created to meet these needs, no standards existed that could satisfy them. Furthermore, the implementation of such legacyZigBee technology addresses significant interoperability challenges that previous systems encountered, offering a standardized foundation for sensor and control systems. In December 2004, the ZigBee Alliance, comprising over 120 companies, approved the initial ZigBee specification for wireless data communication.

With a network speed reaching 250 Kbps, ZigBee is anticipated to be widely adopted in residential and commercial automation applications. These include fire detection, security and access monitoring, as well as heating, lighting, and environmental control. Additionally, ZigBee is expected to play a crucial role in industrial process monitoring and control systems, particularly in hazardous environments where traditional wired systems are impractical. It will be utilized for overseeing and managing industrial processes and equipment in such settings.

3.3 UWB

Ultra Wide Band (UWB), defined by IEEE 802.15.3a [7, 5], presents a possible alternative to IEEE 802.11 standards. While UWB primarily focuses on home multimedia networking, 802.11 networks are designed for data networking across various settings, including homes, public spaces, and businesses. In the wireless Personal Area Network (PAN) sector, currently led by Bluetooth, UWB offers a higher bandwidth solution. Theoretically, UWB can achieve network speeds of several hundred Mbps, though initial implementations are more likely to reach up to 100 Mbps.

UWB technology employs low-power, brief radio pulses to transmit data across a broad range of frequencies. This wide frequency spectrum enhances its resilience to interference, making it well-suited for the noisy environment found in automotive applications.

3.4 WiFi

The term Wi-Fi, short for wireless fidelity, encompasses various types of IEEE 802.11 networks [4]. These include 802.11a, 802.11b, and 802.11g, which offer maximum speeds of 54 Mbps, 11 Mbps, and 54 Mbps respectively. Such networks are utilized as WLANs.

Each of the three 802.11 standards has distinct characteristics in terms of bandwidth, range, security features, and supported applications. The 802.11a standard is particularly well-suited for applications involving multimedia voice, video, and large images in areas with high user density. However, it has a shorter range compared to 802.11b, which means fewer access points are needed to cover extensive areas with 802.11b. The 802.11g standard, which is backward compatible with 802.11b, may eventually replace it due to its enhanced bandwidth and improved security measures.

Technology Comparison

From a broad perspective, the primary distinctions among the wireless technologies discussed stem from the specific applications they were designed to optimize. Bluetooth was created for voice-related uses, eliminating the need for short-range cables. It is well-suited for hands-free audio, synchronizing mobile phones with PDAs, transferring files, and creating ad-hoc networks between compatible devices. These applications require network ranges of about 10-30 meters and speeds of 1-3 Mbps, which Bluetooth delivers.

In contrast, ZigBee is tailored for sensors, control systems, and other applications involving brief messages. ZigBee applications typically comprise numerous devices that need small data packets with a streamlined protocol and compact protocol stack. Network speed is less crucial for ZigBee compared to other technologies discussed here, currently offering 250 Kbps. ZigBee nodes can be distributed across a slightly larger area than Bluetooth.

UWB, despite its historical roots in the 1960s, is an emerging technology that provides remarkably high network speeds and robust communication using a wide frequency spectrum. This technology is most effective at very short ranges (a few meters) compared to the others, but its bandwidth (up to 480 MBps) is significantly higher than the other technologies.

WiFi was developed as a replacement for wired Ethernet, primarily used in residential and office settings. To ensure mobility, WiFi aims for the highest possible network speeds and range. It offers 54 Mbps and maintains effectiveness up to about 50 meters.

Regarding power consumption, both ZigBee and UWB require minimal power for operation. Bluetooth, while considerably more efficient than WiFi (which was not primarily designed for low power usage), still consumes approximately 50 times more energy than UWB to transmit a single bit.

Conclusion:

This study has examined current and emerging wireless networking technologies for automobiles, as well as identified fundamental wireless applications that rely on these technologies. Several challenges remain unresolved. Firstly, it is necessary to determine which automotive wireless applications depend on real-time systems and explore how existing research in wireless real-time communications can support these applications. Additional crucial considerations involve the integration of wireless networking technologies and potential interoperability issues within the automotive sector. Lastly, there is a need to discuss the integration of these wireless technologies into the existing communications framework, which encompasses various network protocols such as CAN, LIN, and MOST. Furthermore, the potential expansion of this framework to include a wireless infrastructure should be evaluated.