

Vehicle-to-Everything (V2X) Communication and IoT in Automobiles: Technologies, Architecture, Applications and Challenges

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ABSTRACT

Vehicle-to-Everything (V2X) communication combined with Internet of Things (IoT) technologies is transforming the modern automobile into an intelligent, connected, and cooperative system. V2X enables vehicles to communicate with other vehicles, infrastructure, pedestrians, cloud networks, and devices for improving safety, traffic efficiency, and driving experience. IoT acts as the backbone by integrating sensors, embedded devices, wireless networks, and cloud platforms to collect and exchange real-time data. This paper presents a comprehensive review of V2X communication models, architecture, enabling technologies, and their integration with IoT in automobiles. It also discusses communication protocols, standards such as DSRC and C-V2X, security challenges, real-world applications, and future research directions. The study highlights how V2X with IoT is a key enabler for autonomous vehicles, smart cities, and intelligent transportation systems. Some technical limitations, cybersecurity threats, and infrastructure requirements are also discussed which still restrict large-scale deployment.

KEYWORDS: *V2X, IoT, Connected Vehicles, DSRC, C-V2X, Intelligent Transportation System, Autonomous Vehicles, Vehicular Networks*

INTRODUCTION

The automobile industry is shifting from mechanical systems to intelligent cyber-physical systems. Modern vehicles are equipped with numerous sensors, controllers, communication modules, and cloud connectivity. This transformation is mainly driven by Vehicle-to-Everything (V2X) communication and Internet of Things (IoT). V2X allows vehicles to exchange information with surrounding environment, while IoT provides the platform for data acquisition, processing, and sharing.

Road accidents, traffic congestion, fuel wastage, and pollution are major issues in urban transportation. V2X communication helps vehicles to share speed, location, road conditions, and hazard warnings in real time. This enables cooperative driving and reduces human errors. IoT integrates vehicles into a larger network of smart infrastructure such as traffic signals, smart parking, toll systems, and weather stations.

The integration of V2X and IoT is playing a very important role in development of autonomous and connected vehicles. However, many technical, infrastructural, and cybersecurity challenges are still present. This paper reviews the technologies, architecture, and applications of V2X with IoT in automobiles.

OVERVIEW OF V2X COMMUNICATION

Vehicle-to-Everything (V2X) communication refers to the wireless exchange of information between a vehicle and any entity that may affect, or be affected by, the vehicle. It is the foundation of connected and cooperative driving where vehicles do not rely only on onboard sensors (camera, radar, LiDAR), but also on shared information from surrounding vehicles, infrastructure, pedestrians, and cloud networks.

Traditional vehicles depend only on driver perception and local sensors. These methods have limitations such as blind spots, poor visibility in fog/rain, and limited sensing range. V2X overcomes these limitations by enabling **cooperative awareness**. Vehicles can “see beyond line of sight” by receiving messages from other road participants.

V2X communication is mainly classified into five categories as shown below.

1. Vehicle-to-Vehicle (V2V)

V2V communication allows vehicles to exchange information such as speed, direction, acceleration, brake status, and location in real time.

Working principle:

Each vehicle periodically broadcasts safety messages (Basic Safety Messages – BSM) containing its dynamic status. Nearby vehicles receive these messages and calculate collision risk.

Applications:

- Forward collision warning
- Emergency brake light warning
- Lane change assistance
- Blind spot warning
- Cooperative overtaking

Example scenario:

If a vehicle ahead applies sudden brakes, it transmits this information to following vehicles even before the driver can visually notice the brake lights.

2. Vehicle-to-Infrastructure (V2I)

V2I communication occurs between vehicles and roadside infrastructure such as traffic lights, road signs, toll booths, parking systems, and road sensors.

Working principle:

Roadside Units (RSUs) installed on roads collect and transmit traffic data to vehicles. Vehicles also send status updates to infrastructure.

Applications:

- Traffic signal timing (Green Light Optimal Speed Advisory)
- Electronic toll collection
- Smart parking guidance
- Road hazard warnings (construction zones, potholes)

- Weather and road condition alerts

Example scenario:

A traffic signal sends remaining time for red/green light to approaching vehicles so drivers can adjust speed and avoid unnecessary stopping.

3. Vehicle-to-Pedestrian (V2P)

V2P communication focuses on safety of vulnerable road users such as pedestrians and cyclists who carry smartphones or wearable devices.

Working principle:

Pedestrian mobile devices transmit location data to nearby vehicles. Vehicles generate alerts if collision risk is detected.

Applications:

- Pedestrian crossing alert
- School zone warning
- Cyclist proximity detection

Example scenario:

A pedestrian about to cross the road while looking at a phone can still be detected by an approaching vehicle through V2P signals.

4. Vehicle-to-Network (V2N)

V2N communication connects vehicles to cloud servers or internet networks through cellular technologies (4G/5G).

Working principle:

Vehicles send data to cloud platforms for processing, analytics, and storage. Cloud sends navigation updates, traffic information, and software updates back to vehicles.

Applications:

- Real-time navigation and traffic updates

- Over-the-air (OTA) software updates
- Remote diagnostics
- Infotainment services
- Fleet monitoring

Example scenario:

A vehicle receives a map update and traffic rerouting information from the cloud to avoid congestion.

Table: 1

V2X Type	Description	Example Use Case
V2V (Vehicle-to-Vehicle)	Communication between vehicles	Collision warning
V2I (Vehicle-to-Infrastructure)	Vehicle with road infrastructure	Traffic signal timing
V2P (Vehicle-to-Pedestrian)	Vehicle with pedestrians' devices	Pedestrian crossing alert
V2N (Vehicle-to-Network)	Vehicle with cloud/network	Navigation updates
V2G (Vehicle-to-Grid)	Vehicle with smart grid	EV charging optimization

ROLE OF IOT IN AUTOMOBILES

The Internet of Things (IoT) plays a central role in transforming conventional vehicles into **smart, connected, and data-driven systems**. In modern automobiles, IoT is not a single device but a complete ecosystem of sensors, embedded controllers, communication modules, gateways, and cloud platforms that work together to collect, process, transmit, and analyze vehicle data in real time.

Earlier vehicles operated as isolated mechanical machines. With IoT integration, vehicles become part of a larger digital network where they continuously exchange information with other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and cloud services (V2N). This connectivity allows real-time monitoring, predictive maintenance, intelligent navigation, and cooperative safety functions.

IoT enables automobiles to sense the environment, understand internal system health, communicate externally, and take intelligent decisions based on shared data.

1. IoT Architecture in Vehicles

The IoT architecture in automobiles can be viewed in four logical layers:

- **Sensing Layer** – Sensors collect data from vehicle and surroundings.
- **Processing Layer** – ECUs and controllers process raw sensor data.
- **Communication Layer** – TCU and gateways transmit data using V2X technologies.
- **Cloud & Application Layer** – Cloud servers analyze, store, and visualize data.

This layered architecture ensures continuous data flow from the vehicle to the cloud and back to the vehicle.

2. Key IoT Components in Automobiles

a) GPS, LiDAR, RADAR, Cameras

These sensors provide real-time information about vehicle position, speed, surroundings, obstacles, lane markings, and traffic signs.

- **GPS** provides location and navigation data.
- **LiDAR** measures distance using laser pulses for 3D mapping.
- **RADAR** detects object speed and distance in poor visibility.
- **Cameras** recognize lanes, signs, pedestrians, and vehicles.

These sensors generate large volumes of data that are processed locally and shared via V2X when needed.

b) On-Board Diagnostics (OBD)

OBD systems monitor vehicle health parameters such as:

- Engine performance
- Fuel efficiency
- Emission levels
- Battery status (in EVs)
- Fault codes and error logs

OBD data is very useful for **predictive maintenance** and remote diagnostics through IoT platforms.

c) Telematics Control Unit (TCU)

The TCU acts as the **communication gateway** of the vehicle.

Functions of TCU:

- Collects data from sensors and ECUs
- Manages V2X communication (DSRC/5G)
- Sends vehicle data to cloud servers
- Receives OTA updates and commands
- Supports emergency services (eCall)

Without TCU, the vehicle cannot participate in IoT or V2X networks.

d) Cloud Analytics Platforms

Cloud platforms receive data from thousands of vehicles and perform:

- Big data analytics
- Traffic pattern analysis
- Driving behavior analysis
- Fleet monitoring
- AI-based predictions

Cloud intelligence helps in improving navigation, safety algorithms, and system updates.

e) Mobile Applications and Dashboards

End users and fleet operators access vehicle data through mobile apps or web dashboards.

Features include:

- Live vehicle tracking
- Fuel and battery monitoring
- Remote lock/unlock
- Trip history and analytics
- Maintenance alerts

3. Data Flow in IoT-Enabled Vehicles

- Sensors collect environment and vehicle data.

- ECUs process the data locally for immediate decisions.
- TCU transmits important data via V2X or cellular network.
- Cloud analyzes aggregated data and sends insights/updates.
- Driver or fleet operator monitors vehicle via mobile app.

This continuous loop creates an intelligent feedback system.

4. Benefits of IoT in Automobiles

- Real-time vehicle monitoring
- Predictive maintenance and reduced breakdowns
- Enhanced safety through shared data
- Smart navigation and route optimization
- Remote diagnostics and OTA updates
- Improved fleet efficiency
- Integration with smart city infrastructure

5. IoT and V2X Integration

IoT provides the **data**, while V2X provides the **communication channel**.

For example:

- A vehicle detects slippery road using sensors (IoT data).
- This information is sent to nearby vehicles through V2V (V2X communication).
- Cloud updates traffic map and warns other vehicles (IoT + V2N).

Thus, IoT and V2X together enable cooperative and intelligent transportation.

6. Challenges of IoT in Automobiles

- Handling massive sensor data in real time
- Data privacy and cybersecurity risks
- Interoperability between different manufacturers
- Network latency and reliability
- High cost of sensors and communication modules

V2X COMMUNICATION TECHNOLOGIES

1. Dedicated Short Range Communication (DSRC)

DSRC is based on IEEE 802.11p standard. It operates in 5.9 GHz band and provides low latency communication. It is mainly used for safety applications.

Advantages:

- Low latency
- Reliable for short range
- Mature standard

Limitations:

- Limited range
- Infrastructure cost

2. Cellular V2X (C-V2X)

C-V2X uses LTE and 5G cellular networks. It supports both direct communication and network-based communication.

Advantages:

- Long range
- High data rate
- Future ready with 5G

Limitations:

- Network dependency
- Spectrum allocation issues

SYSTEM ARCHITECTURE OF V2X WITH IoT

The architecture consists of four layers.

- **Perception layer** collects vehicle and environment data.
- **Edge layer** processes data locally.
- **Communication layer** transmits data using V2X.
- **Cloud layer** performs analytics and storage.

APPLICATIONS OF V2X AND IoT

1. Road Safety

- Forward collision warning
- Blind spot alert
- Emergency electronic brake light
- Intersection movement assist

2. Traffic Management

- Adaptive traffic signals
- Congestion avoidance
- Smart routing

3. Autonomous Driving

Autonomous vehicles depends heavily on V2X for situational awareness beyond sensor range.

4. Smart Parking and Toll Collection

Vehicles communicate with parking infrastructure and toll booths automatically.

5. Fleet Management

Real-time tracking, fuel monitoring, predictive maintenance using IoT data.

COMMUNICATION PROTOCOLS AND STANDARDS

Table: 1

Protocol/Standard	Purpose
IEEE 802.11p	DSRC communication
SAE J2735	Message sets for V2X
3GPP Release 14/16	C-V2X standards
MQTT	IoT data transfer
IPv6	Addressing large devices

CYBERSECURITY CHALLENGES

V2X networks are highly vulnerable because they are wireless and open.

Common attacks:

- Spoofing of GPS or vehicle identity
- Denial of Service (DoS)
- Malware injection

- Unauthorized access to vehicle ECU

Security solutions:

- Public key infrastructure (PKI)
- Encryption and authentication
- Intrusion detection systems
- Blockchain for trust management

CHALLENGES IN IMPLEMENTATION

- High infrastructure cost
- Standardization issues
- Spectrum regulation
- Data privacy concerns
- Interoperability between manufacturers

FUTURE TRENDS

- Integration with 5G and 6G
- Edge AI for real-time decision
- Blockchain based vehicular networks
- Integration with smart city platforms
- Quantum resistant security algorithms

COMPARATIVE ANALYSIS

Table: 1

Feature	DSRC	C-V2X
Range	Short	Long
Latency	Very low	Low
Infrastructure	Roadside units	Cellular towers
Scalability	Limited	High
Future scope	Moderate	Very high

DISCUSSION

The integration of V2X and IoT is not only improving vehicle intelligence but also changing transportation ecosystem. Still, deployment in developing countries is slow due to cost and policy issues. Collaboration between automobile manufacturers, telecom companies, and government agencies is required.

CONCLUSION

V2X communication and IoT in automobiles is a revolutionary technology for intelligent transportation. It enhances safety, reduces congestion, and supports autonomous driving. DSRC and C-V2X both have advantages and suitable for different scenarios. However, cybersecurity, standardization, and infrastructure challenges must be solved before mass adoption. Future developments in 5G, edge computing, and AI will further strengthen V2X ecosystems.

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