Communication Systems

In Autonomous Vehicles

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Learning Objectives

- Explain the fundamental principles of communication systems and their role in AVs
- Differentiate between wired and wireless communication
- Describe internal communication within AVs
- Describe external communication between AV and its environment
- Identify real-world applications
- Recognize cybersecurity and privacy challenges

What Is Communication?

- **Communication** is the process of transmitting information from one entity to another through a medium. A communication system includes:
  - **Transmitter** – Generates and encodes information
  - **Channel (Medium)** – Carries the signal
  - **Receiver** – Decodes and interprets the information
- In Transportation Systems vehicles, traffic signals, roadside units, control centers and pedestrians communicate through networks.
- In Avs, communication occurs *inside the vehicle* and *between vehicle and its environment.*

The Physical Backbone of Communication Infrastructure

- Communication requires infrastructure, just like transportation requires roads.
- Two main categories:
  - ❖ **Wired Communication**
  - ❖ **Wireless Communication**
- Both are critical for connected transportation systems.

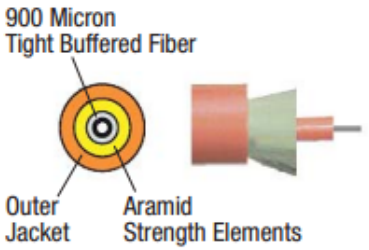
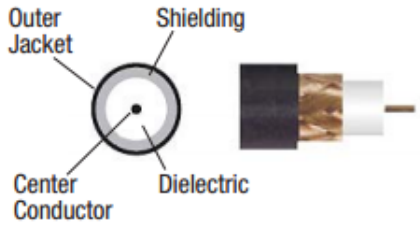
Wired Communication Medium

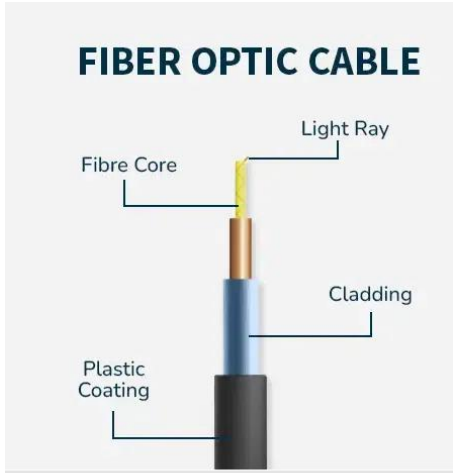
- A **communication medium** is the physical path that carries information from one location to another.
- In wired systems, common media include:
  - **Fiber optic cables:** Transmit data using light signals, very high bandwidth, long-distance communication, Low signal loss
  - **Copper cables (Ethernet, twisted pair):** Shorter distances, used inside cabinets and buildings
  - **Coaxial cables:** Sometimes used for CCTV and legacy systems
- These are **physical infrastructure components**, just like pavement or bridges—

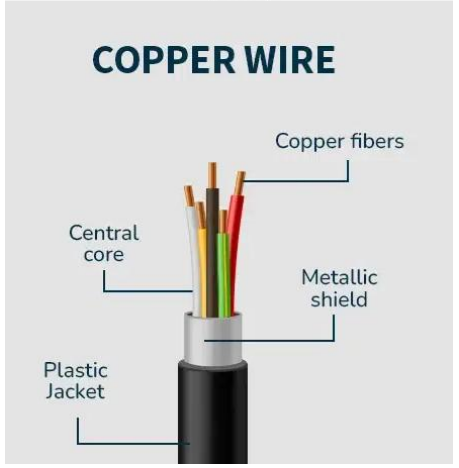
  they must be designed, installed, protected, and maintained.

Wired Communication Medium

Tip ***Bandwidth and application differences, between copper and fiber optic cabling***

Type:	Fiber Optic Cabling	Unshielded Twisted Pair Cabling (Copper)	Coaxial Cabling (Copper)
			
Typical Bandwidth:	<10 GHz	<100 MHz (cat 5E)	<1 GHz (RG6)
Typical Use:	Data communication Broadcast	Structured wiring in local area networks	Cable TV / Broadcast Test and instrumentation
Benefits:	Most bandwidth. Fastest transmission speeds. Immune to EMI/RFI.	Inexpensive, relatively easy to install and terminate	Inexpensive, relatively easy to install and terminate. Can span longer distances than UTP.
Limitations:	Difficult to terminate. Most expensive cost / foot.	Maximum distance of 100m. Can be affected by EMI/RFI.	Can be affected by EMI/RFI.





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Applications of Wired Communication in Transportation

- **Traffic Management Centers (TMCs):** Central control facilities, monitor traffic conditions, control traffic signals, coordinate corridor timing, Manage incidents
- **Adaptive Signal Control Systems:** Real-time signal timing adjustments, communication between intersections, data exchange with control center
- **CCTV & Traffic Monitoring:** Video feeds transmitted through fiber network, used for incident detection and congestion monitoring

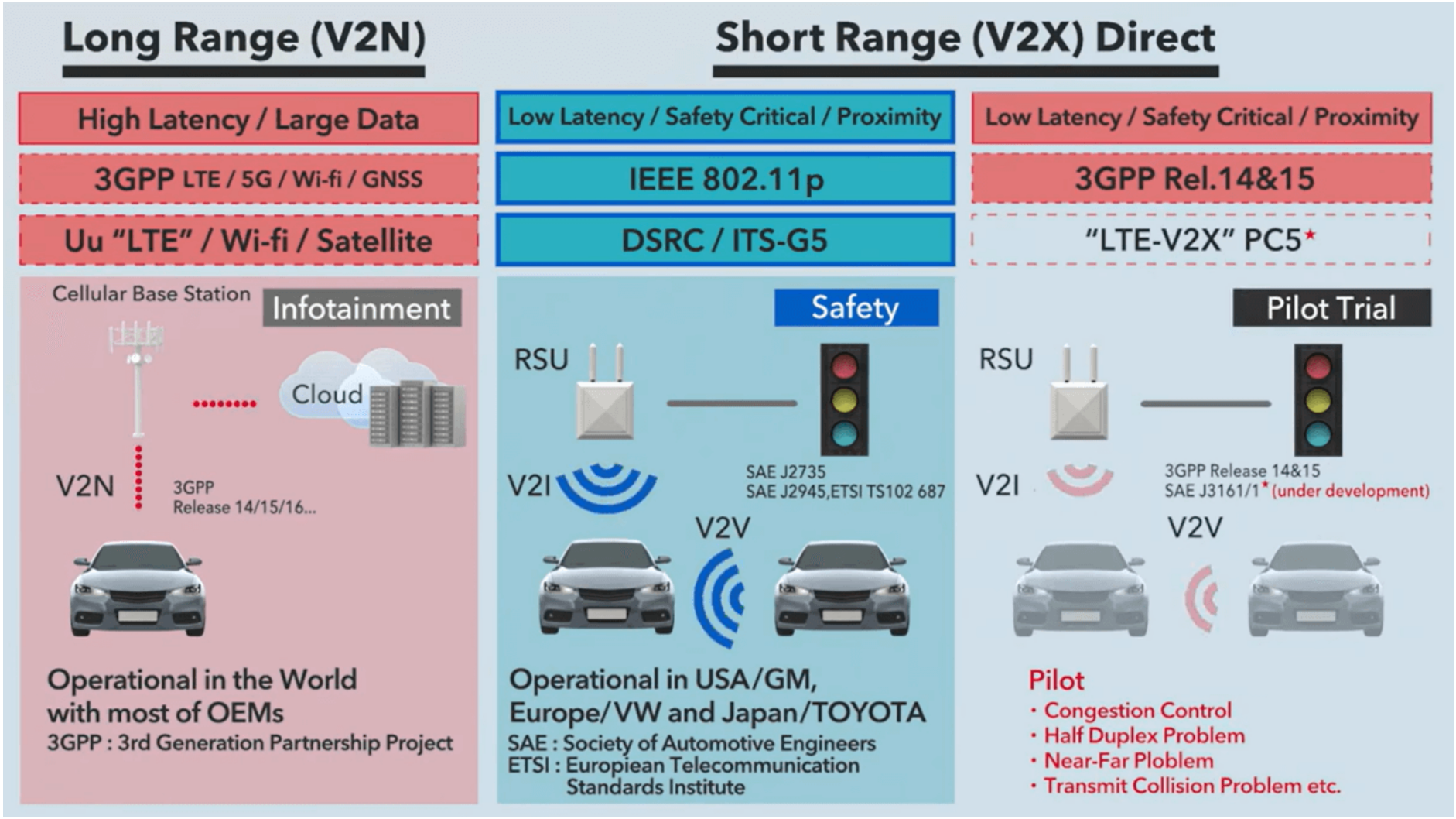
Wireless Communication Infrastructure

- **Wireless communication** is the transmission of information between devices *without physical cables*, using electromagnetic waves (radio waves). Instead of fiber or copper carrying signals through a conduit, wireless systems transmit data through the air.
- In transportation systems it enables moving vehicles to exchange information and infrastructure to broadcast traffic data and real-time safety alerts
- It is essential because vehicles are mobile and cannot be physically connected to cables while driving.

Wireless Communication Technologies

- Each wireless technology uses different frequencies, ranges, and purposes.
- **Wi-Fi:** Short-range, high-speed wireless communication typically used for local data exchange and infrastructure connectivity.
- **Bluetooth:** Very short-range, low-power communication mainly used for device-to-device connections.
- **DSRC (Dedicated Short-Range Communication):** Low-latency vehicle communication technology designed specifically for safety-critical scenarios.
- **Cellular (4G / 5G / C-V2X):** Wide-area wireless communication using cellular networks to connect vehicles to infrastructure, cloud systems, and other vehicles.
- **Satellite Communication (GNSS/GPS):** Global satellite-based communication that provides precise vehicle positioning, navigation, and timing information essential for autonomous vehicle localization.

Wireless Communication Technologies

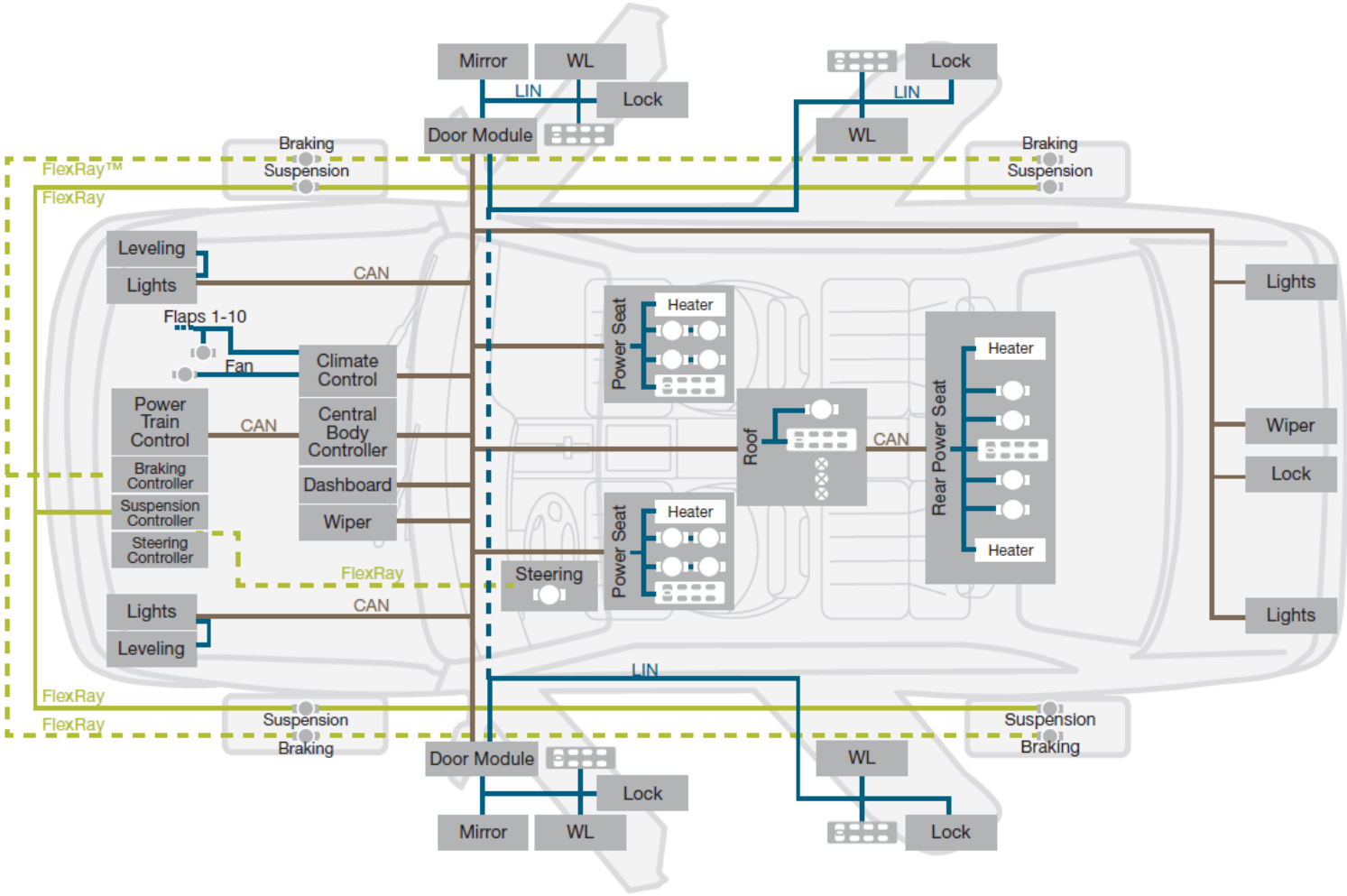


https://poynting.tech/articles/newsletter-articles/aug-2024/driving-the-future-v2x-systems-and-the-role-antennas-play/

Internal Communication in AVs

- **Internal Communication (Inside the Vehicle):** Communication between sensors, perception system, planning system, control system and actuators such as brakes, steering and throttle. This enables real-time vehicle operation and control.
- **Internal Communication Media:** CAN bus (Controller Area Network), Automotive Ethernet, In-vehicle networks
- Internal Communication must be **ultra-fast**, **highly reliable** and **with less latency**.

Internal Communication in AVs

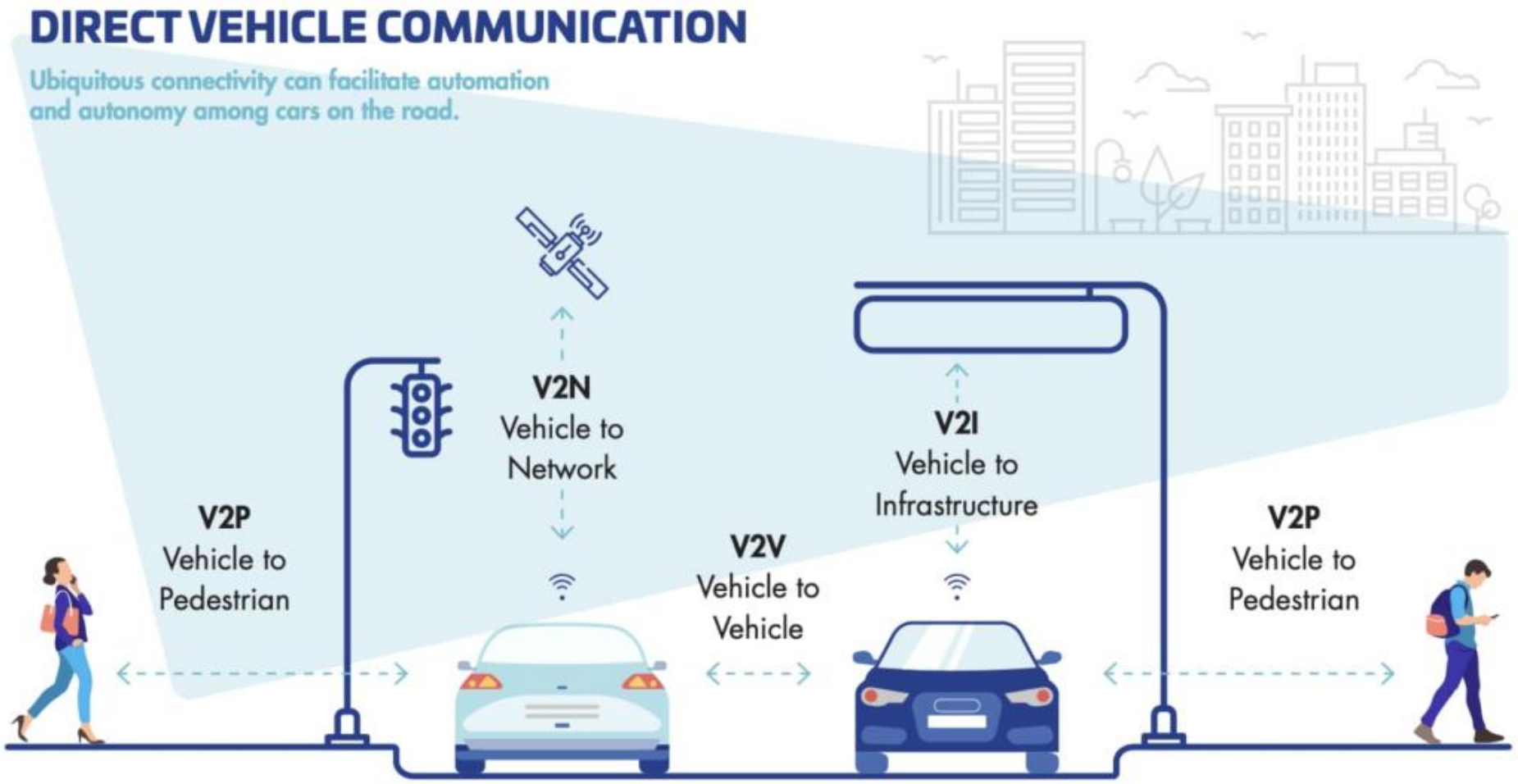


https://www.eeworldonline.com/communications-protocols-proliferate-in-the-drive-toward-autonomous-vehicles/

External Communication in AVs

- **External Communication (Vehicle with Environment):** Communication between vehicle and: other vehicles (V2V), infrastructure (V2I), pedestrian (V2P), network/cloud (V2N). This enables connected and cooperative driving mechanism. Some applications include Forward collision warning, Signal Phase & Timing (SPaT), Work zone alerts, Traffic congestion updates, HD map updates, Fleet coordination
- **Communication Media (External):** DSRC, Cellular (4G/5G, C-V2X), Satellite (GPS / GNSS)
- Extends perception beyond onboard sensors.

External Communication in AVs



https://portal.phenikaa-x.com/enhancing-autonomous-vehicle-safety-the-power-of-communication-systems-in-v2x-connectivity/

Communication in Transportation

- Traditionally, Civil Engineers design roads, intersections, bridges, traffic signals, pavement markings.
- But modern transportation systems now require:
  - **Data exchange between vehicles and infrastructure**
  - **Real-time signal control**
  - **Traffic monitoring and Safety alerts**
  - **Smart corridor management**
- Communication transforms **static infrastructure** into **intelligent infrastructure.**

Communication in Transportation

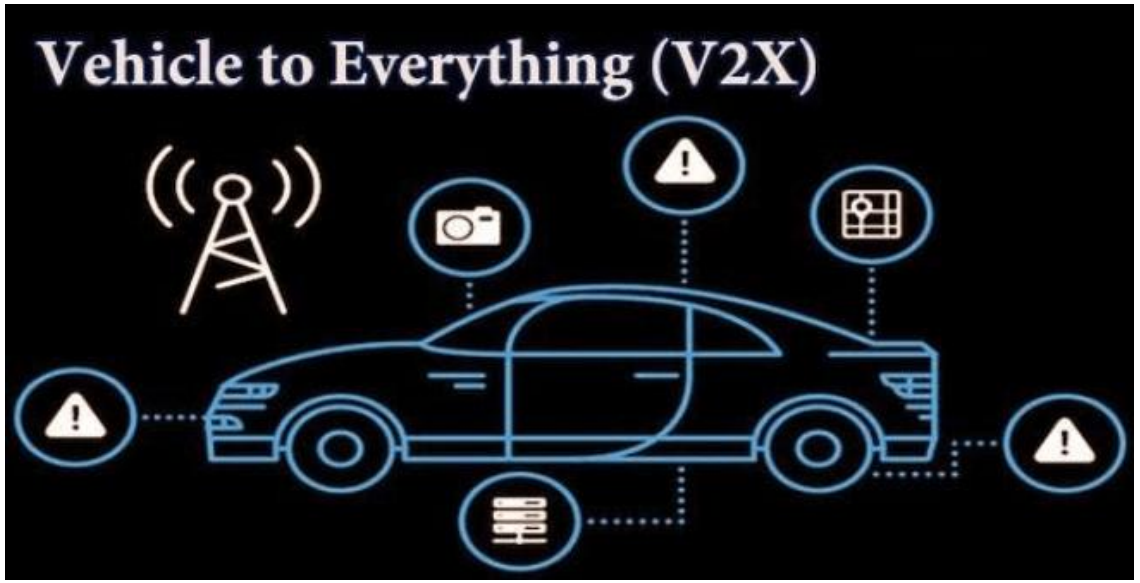
Traditional Infrastructure	Smart Infrastructure
Fixed signal timing	Adaptive signal control
Static signs	Digital message boards
Manual traffic studies	Real-time traffic data
Road geometry only	Road + data networks

Civil engineers now design:

- Signal Phase & Timing (SPaT) systems
- Roadside Units (RSUs)
- Smart intersections
- Connected corridors

Vehicle-to-Everything (V2X): The Big Picture

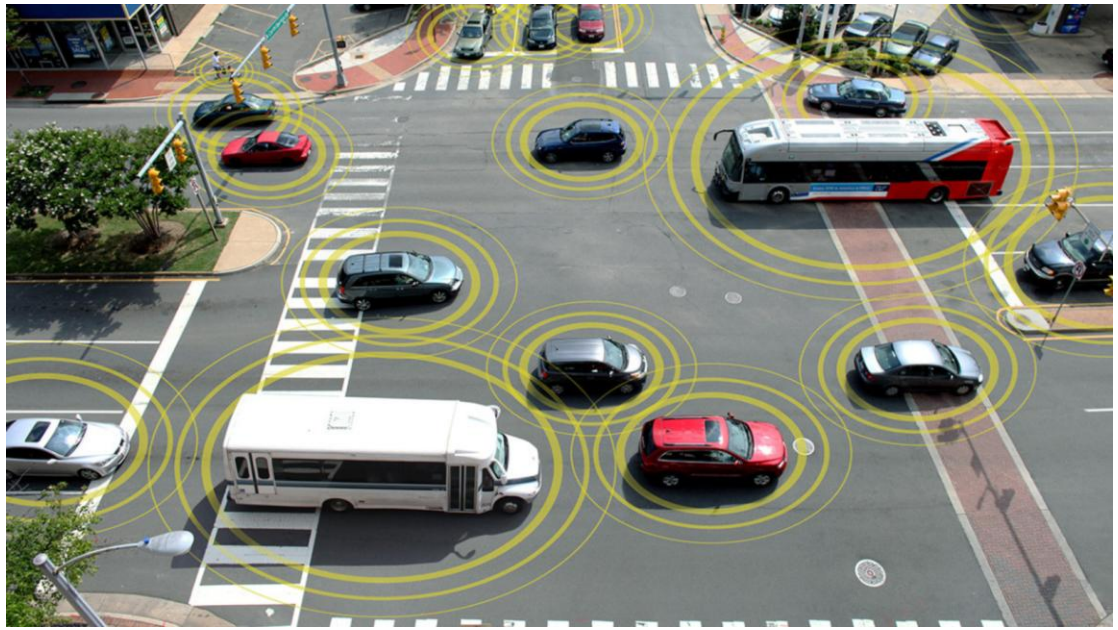
- A communication framework that enables vehicles to **exchange information** with:
  - Vehicles
  - Infrastructure
  - Pedestrians
  - Networks and cloud services.
- Purpose of creating such a communication framework was to **improve safety, traffic efficiency**, and **overall enable cooperative** and **connected driving.**
- Fit in AV stack: Supports perception & planning stage
- Does not directly control actuators but enhances decision making



Blockchain Autonomous Vehicles: Securing V2X Data

Vehicle-to-Vehicle (V2V): Cooperative Safety

- **Vehicle-to-Vehicle (V2V)** communication allows vehicles to wirelessly exchange information such as: Speed, Position (GPS location), Direction of travel, and Acceleration/braking.
- **Goal:** Vehicles working together to prevent crashes.
- **Examples of Cooperative Safety Applications:**
  - **Forward Collision Warning –** alerts if a vehicle ahead brakes suddenly
  - **Intersection Movement Assist –** warns of cross-traffic you cannot see
  - **Blind Spot/Lane Change Warning**
  - **Emergency Electronic Brake Light Warning**



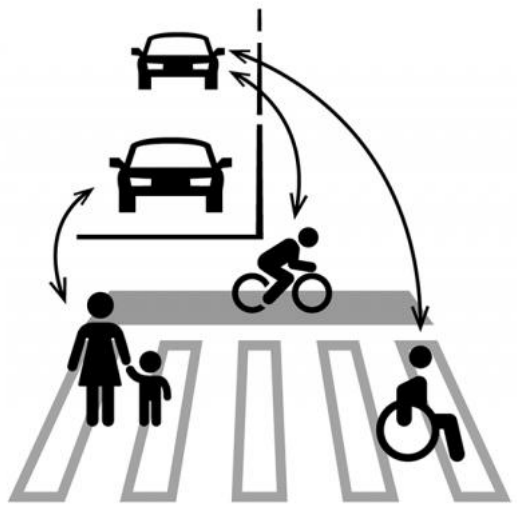
What is V2V Technology in Cars? Understanding the Future of Connected Vehicles - Millionaire Garage

Vehicle-to-Infrastructure (V2I)

- **Vehicle-to-Infrastructure (V2I):** Enables vehicles to exchange real-time information with intelligent roadway infrastructure.
- **Information exchanged**: Roadside units (RSUs), Message signs, Toll systems, Highway sensors
- Impact of V2I:**Reduces** intersection collisions, **optimizes traffic** flow, and enables **eco-driving strategies.**

Vehicle-to-Pedestrian (V2P)

- **Vehicle-to-Pedestrian (V2P)** communication allows vehicles to detect and communicate with pedestrians using wireless signals through smartphones or wearable devices.
- Information shared consists of **pedestrian location** (GPS), **direction of movement**, and **trajectory estimates.**
- **V2P** protects vulnerable road users and provides awareness



V2X Technology | V2X VPN | V2X Automotive

Vehicle-to-Network (V2N)

- **Vehicle-to-Network (V2N)** enables vehicles to communicate with cloud and cellular networks for wide-area data exchange.
- Data exchanged in V2N includes Map updates, Traffic and congestion data, Fleet management data
- V2N extends communication beyond local range and supports cloud-based system and intelligence in AVs.
- V2N is not typically used for immediate critical control.

Communication for Traffic Safety

- Communication for traffic safety refers to **vehicles, infrastructure, and road users exchanging real-time information** to prevent crashes and reduce roadway risks.
- Rather than relying only on onboard sensors (cameras, radar, LiDAR), vehicles can:
  - Receive warnings from other vehicles
  - Receive signal timing information from intersections
  - Detect pedestrians through **V2P** alerts
  - Receive weather or hazard warnings

Communication for Mobility & Efficiency

- Communication for mobility and efficiency focuses on improving **traffic flow, reducing congestion, and optimizing transportation systems.**
- Vehicles and infrastructure exchange data to:
  - Optimize traffic signal timing
  - Adjust speed to avoid red lights
  - Coordinate vehicle platooning
  - Provide real-time congestion routing
  - Support network-wide traffic management

Cybersecurity and Privacy in AV Communications

- **Cybersecurity** protects vehicle communication systems from:
  - Message spoofing (fake safety messages)
  - Denial-of-service attacks
  - Unauthorized access
  - Signal interception
- **Protection Method:** Digital signature & authentication, Public Key Infrastructure (PKI), Encryption, Secure hardware modules, and Intrusion detection systems.
- **Privacy** in AV communication ensures that vehicle communication does not expose: Driver identity, Location history, and Personal travel patterns.

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