Lecture Note: Communication Systems in Autonomous Vehicles

1. Introduction

This lecture is the final component of the AV system pipeline:

- Signals & Systems → data representation
- Sensors → data collection
- Sensor Fusion → data integration
- Control Systems → decision execution
- **Communication Systems → data exchange and connectivity**

Communication connects **all components inside and outside the vehicle** and enables **cooperative and intelligent transportation**.

2. Learning Objectives

After this lecture, students should be able to:

- Explain fundamentals of communication systems
- Differentiate:
  - Wired vs. wireless communication
- Understand:
  - Internal communication (inside AV)
  - External communication (AV ↔ environment)
- Identify real-world applications
- Recognize cybersecurity and privacy challenges

3. What is Communication?

Definition

Communication is:

The process of transmitting information from one entity to another through a medium

3.1 Components of Communication System

1. **Transmitter**
   - Generates and encodes information

2. **Channel (Medium)**
    - Carries the signal
3. **Receiver**
    - Decodes and interprets information

3.2 Communication in Transportation

Entities that communicate:

- Vehicles
- Traffic signals
- Roadside units
- Control centers
- Pedestrians

Communication occurs:

- Inside the vehicle
- Between vehicle and environment

4. Communication Infrastructure

Communication requires infrastructure (like roads in transportation):

Two main types:

- **Wired communication**
- **Wireless communication**

5. Wired Communication

5.1 Definition

- Uses physical medium (cables)

5.2 Types of Wired Media

1. Fiber Optic

- Uses light signals
- Very high bandwidth
- Long distance

- Low signal loss

2. Copper Cables

- Ethernet, twisted pair
- Short distance

3. Coaxial Cable

- Used for CCTV and legacy systems

5.3 Comparison (from slide page 6)

Medium	Speed	Distance	Cost
Fiber optic	Highest	Long	High
Coaxial	Medium	Medium	Medium
Twisted pair	Lower	Short	Low

5.4 Applications in Transportation

- Traffic Management Centers (TMC)
- Adaptive signal control
- CCTV traffic monitoring

Used where:

- High speed is required
- Infrastructure is fixed

6. Wireless Communication

6.1 Definition

- Transmits data through air using electromagnetic waves

6.2 Importance

- Essential for moving vehicles
- Enables real-time interaction

Vehicles cannot use cables → must use wireless communication

6.3 Wireless Technologies

1. Wi-Fi

- Short range, high speed

2. Bluetooth

- Very short range, low power

3. DSRC

- Low latency
- Safety-critical communication

4. Cellular (4G/5G, C-V2X)

- Wide area coverage

5. Satellite (GPS/GNSS)

- Global positioning and timing

6.4 Key Trade-Off

Type	Range	Latency	Use
Short-range (DSRC)	Low	Low	Safety
Long-range (Cellular)	High	Higher	Data, cloud

7. Internal Communication in AVs

Definition

Communication inside the vehicle between:

- Sensors
- Perception system
- Planning system
- Control system

- Actuators

Technologies

- CAN Bus
- Automotive Ethernet
- In-vehicle networks

Requirements

- Ultra-fast
- Reliable
- Low latency

Enables real-time operation of the vehicle

8. External Communication in AVs

Definition

Communication between vehicle and environment:

- Vehicles
- Infrastructure
- Pedestrians
- Network/cloud

Key Concept

External communication:
Extends perception beyond onboard sensors

Technologies

- DSRC
- Cellular (5G, C-V2X)
- Satellite (GPS)

9. Vehicle-to-Everything (V2X)

Definition

V2X is a communication framework connecting:

- V2V (vehicle-to-vehicle)
- V2I (vehicle-to-infrastructure)
- V2P (vehicle-to-pedestrian)
- V2N (vehicle-to-network)

Purpose

- Improve safety
- Improve efficiency
- Enable cooperative driving

Important Note

V2X:

- Supports **perception and planning**
- Does **not directly control actuators**

10. V2X Categories

10.1 Vehicle-to-Vehicle (V2V)

Data exchanged

- Speed
- Position
- Direction
- Acceleration

Applications

- Collision warning
- Blind spot detection
- Lane change alerts
- Emergency braking alerts

10.2 Vehicle-to-Infrastructure (V2I)

Communication with

- Traffic lights
- Roadside units
- Sensors

Benefits

- Reduced collisions
- Improved traffic flow
- Eco-driving strategies

10.3 Vehicle-to-Pedestrian (V2P)

Data exchanged

- Pedestrian location
- Movement direction

Purpose

- Protect vulnerable users
- Improve awareness

10.4 Vehicle-to-Network (V2N)

Features

- Cloud connectivity
- Large-area communication

Data

- Maps
- Traffic data
- Fleet management

Note

- Not used for immediate control

11. Communication for Safety

Communication enhances safety by enabling:

- Early warnings from other vehicles
- Signal timing information
- Hazard alerts
- Pedestrian detection

Complements onboard sensors

12. Communication for Efficiency

Benefits include:

- Reduced congestion
- Optimized signal timing
- Speed adjustment
- Platooning coordination
- Real-time routing

Leads to smarter transportation systems

13. Smart Infrastructure (Civil Engineering Link)

Traditional vs Smart Infrastructure

Traditional	Smart
Fixed signals	Adaptive signals
Static signs	Digital signs
Manual data	Real-time data

Civil Engineering Role

- Design:
  - Smart intersections
  - Connected corridors
  - Roadside units

Infrastructure becomes **intelligent and connected**

14. Cybersecurity in AV Communication

Threats

- Message spoofing
- Denial-of-service attacks
- Unauthorized access
- Signal interception

Protection Methods

- Encryption
- Authentication
- Public Key Infrastructure (PKI)
- Intrusion detection systems

15. Privacy Concerns

Must protect:

- Driver identity
- Location history
- Travel patterns

Essential for user trust and safety

16. Key Takeaways

- Communication connects all AV components
- Two types:
  - Wired → internal, high speed
  - Wireless → external, mobility
- V2X enables:
  - Safety
  - Efficiency
  - Cooperation
- Cybersecurity and privacy are critical challenges

17. Final System Integration

Complete AV pipeline:

1. **See** → Sensors
2. **Think** → AI + Planning
3. **Act** → Control
4. **Connect** → Communication

18. Course Summary

This course covered:

- Signals & Systems
- Sensors
- Sensor Fusion
- Control Systems
- Communication Systems

Together, they form the **foundation of autonomous vehicle systems**