# LDPC-based HARQ Design for Optical Satellite-Assisted Internet of Vehicles

**Master's Research Plan Seminar**

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# Outline

1. **Optical Satellite-Assisted Internet of Vehicles**
2. **Challenging Issues**
3. **Possible Solutions: Reliable Methods**
4. **Research Direction & Plan**

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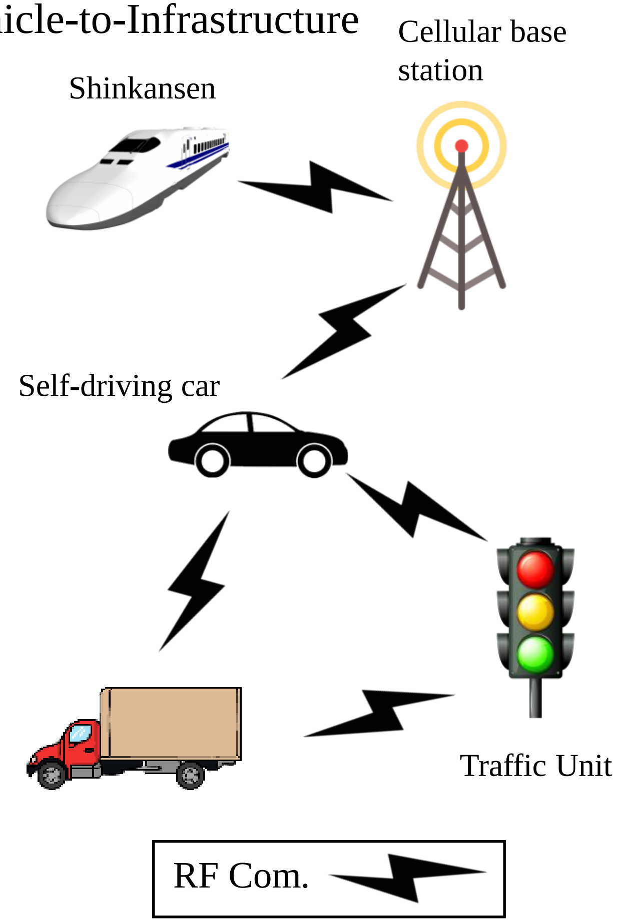
# The Internet of Vehicles (IoVs)

## ❑ Internet of Vehicles (IoVs)

- The network of vehicles and related entities to connect and exchange data over the Internet
- Subclass of the Internet of Things (IoT)
- Includes communication of Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Roadside unit (V2R), …




## ❑ Applications

- **Safety:** emergency call, speed control,…
- **Navigation:** traffic congestion control, real-time information, parking helper,…
- **Business:** high-speed Internet for vehicles, infotainment,…

## ❑ Limitations

*1. Restricted data-rate*

- Based on the radio frequency (RF) band

=> Need higher data rate

*2. Limited coverage area*

- Based on terrestrial infrastructure

=> Need global coverage

# FSO-based Satellite-Assisted IoVs

**1. Data rate issues: *Free-space Optical (FSO)***

- Uses infrared frequency bands (187-400 Thz) to transmit data in free space

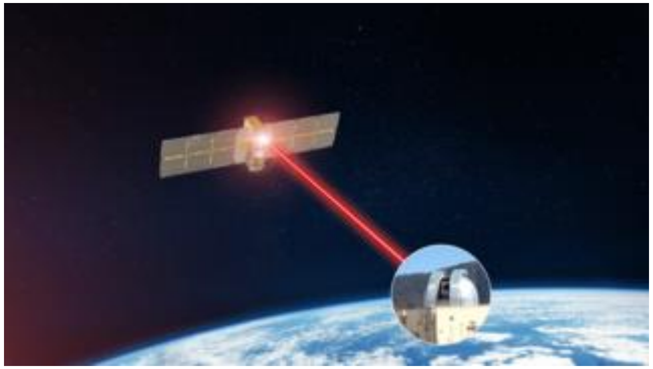
=> <u>Extremely high data rate (~ Gbps or even Tbps)</u>

**2. Coverage issues: *Satellite Communication***

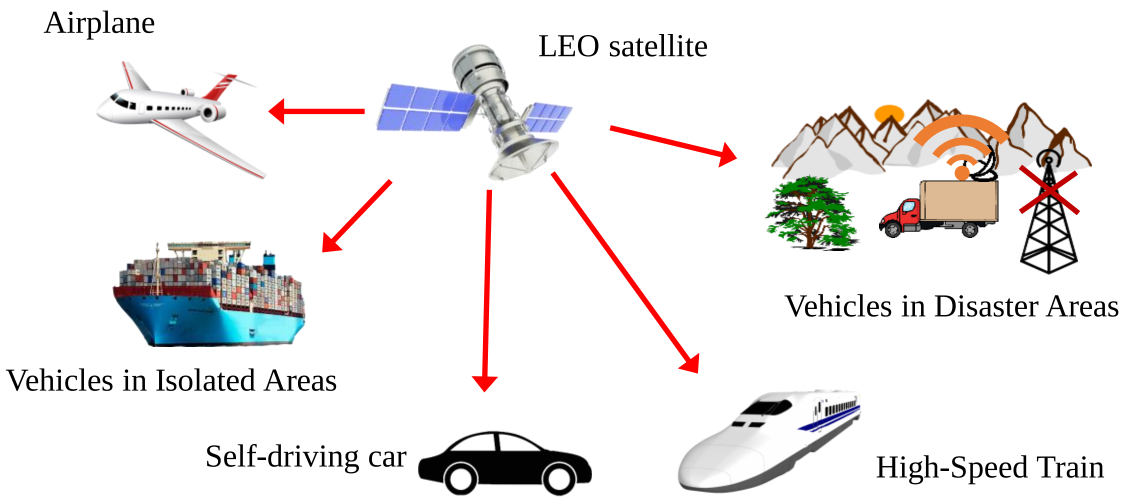
- Use low-earth orbit (LEO) satellites
- Popularity (E.g., Starlink (3000 LEO satellites), SpaceX, Telesat,…)

=> <u>Global coverage area</u>

**FSO-based Satellite systems** is expected to be a key technology to support the IoVs.



The **TeraByte InfraRed Delivery** (TBIRD) launched on May 25, 2022, by NASA, achieved **200 Gbps** downlink speed.



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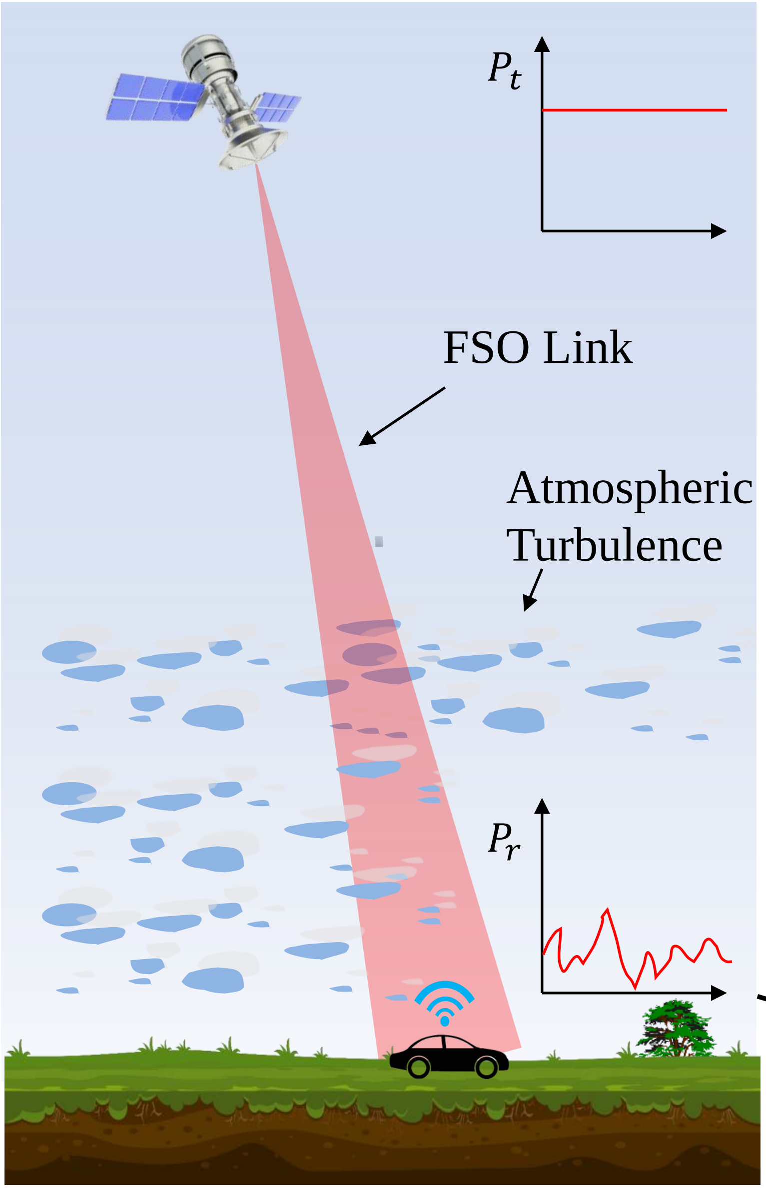
# Challenging Issues (1)




❑ The FSO link is adversely affected when propagating through the atmosphere.

1. **Atmospheric Attenuation**
   - Caused by molecular absorption and aerosol scattering
   - Happens mostly in the range below 20 km

=> Reduction in the received power

2. **Atmospheric Turbulence**
   - Caused by inhomogeneity in temperature and pressure along the propagation path

=> Fluctuation in the received signal

The received signal is fluctuating and low in power.

# Challenging Issues (2)

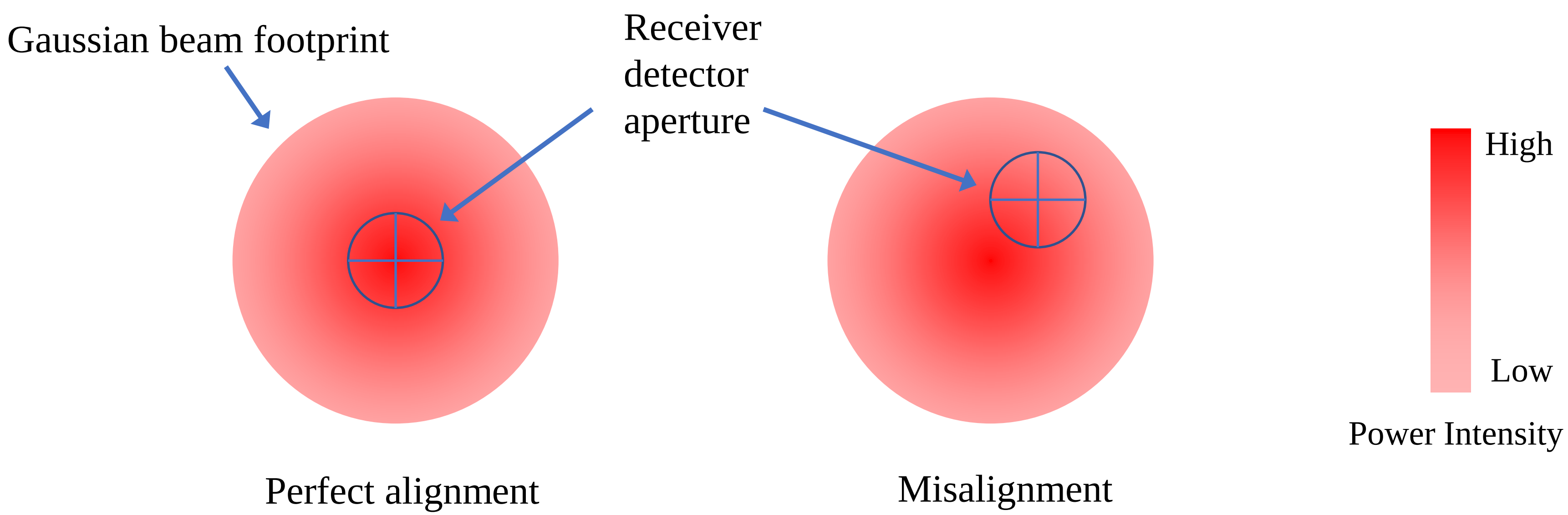
**3. Geometric Loss:** Beam divergence caused by diffraction

=> Only a fraction of power is received

**4. Pointing Error:** Misalignment between the center of beam footprint and the center of the receiver detector

=> Reduction in received power

The channel of optical satellite systems is unreliable.



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# Possible Solutions: Reliable Methods (1)

- *To cope with unreliable problems*, **reliable transmission protocols** are implemented.
  - Ensure the reliability of data over an uncertainty channel
  - Two common methods: **Automatic Repeat reQuest (ARQ)** and **Error Correction Code (ECC)**

*Retransmission* | *Error Correction*

- **Automatic Repeat reQuest (ARQ):**
  - Retransmit erroneous frames.
- In a time-varying channel
  - ⇒ Increase the frequency of retransmissions (noisy)
  - ⇒ Increase the delay, especially *in satellite systems.*

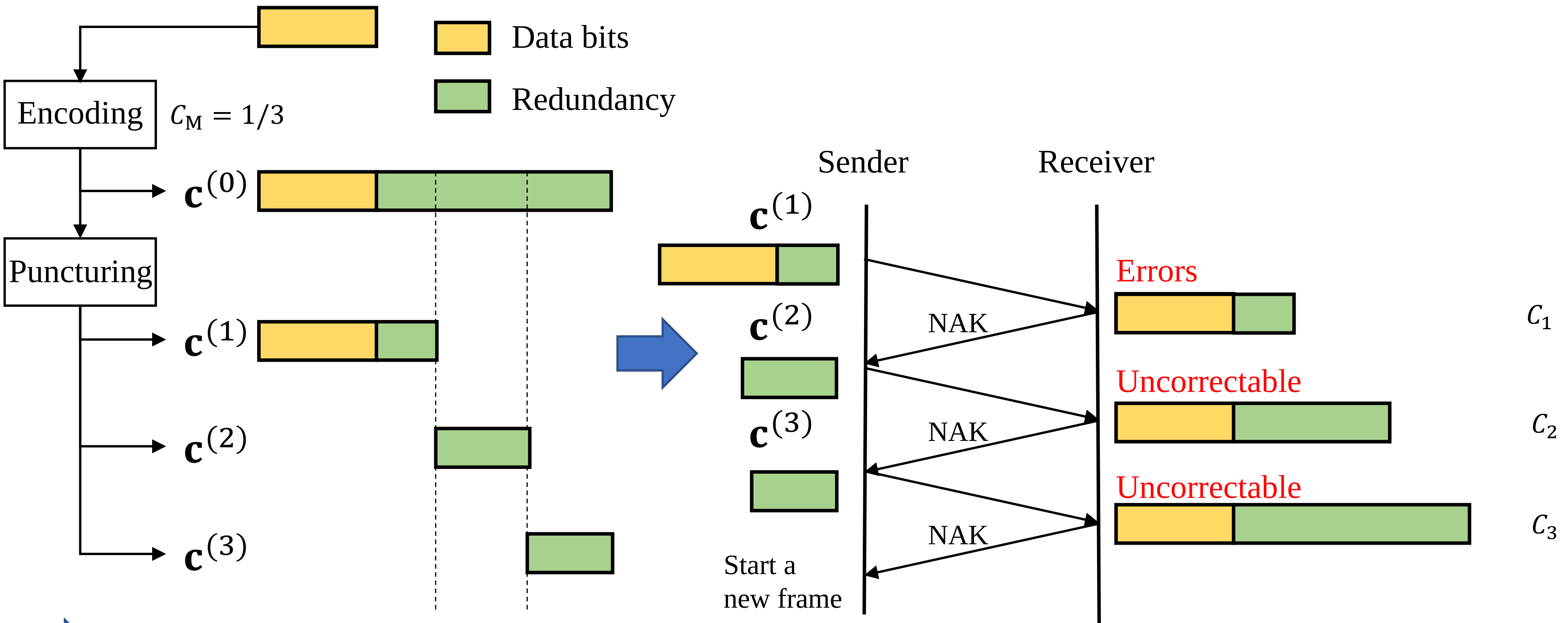
- **Error Correction Code (ECC):**
  - Add redundancy to correct errors.
- In a time-varying channel,
  - ⇒ Inefficient throughput due to the redundancy (less noisy)
  - ⇒ Lose the reliability once the frame is uncorrectable (noisy)

# Possible Solutions: Reliable Methods (2)

## ❑ Hybrid ARQ (HARQ)

- Combination of **ARQ** and **ECC**
- Mitigate the problems of both protocols
- Data is encoded by **ECC** and used for (re)transmissions.

❑ **Example:** The operation of a variant of HARQ, namely HARQ Incremental Redundancy




**HARQ** performs better than the standalone **ARQ** and the standalone **ECC**.

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# Literature Review: HARQ in Optical Satellite Communication

❑ Survey of Major Studies of HARQ designs for optical satellite systems.

| Reference | Main Contributions |
|---|---|
| [1] – 2016 | The performance of HARQ with adaptive rate **Reed-Solomon (RS)** code in inter-HAPs channel is evaluated under the effects of delayed CSI. |
| [2] – 2021 | A novel design of cooperative HARQ using the **puncturing RS** is proposed for FSO-based satellite-HAP-Vehicle system. |
| [3] – 2022 | The study considered the design of HARQ with sliding window and **the rate-compatible convolutional code (RCPC)** for FSO-based satellite-to-ground systems. |

➡ The ECCs of current designs mainly focuses on **Reed-Solomon** and **convolutional code**.

[1] S. Parthasarathy, A. Kirstaedter, and D. Giggenbach, “Performance analysis of adaptive hybrid ARQ for inter-HAP free-space optical fading channel with delayed channel state information,” in *Proc. IEEE Photon. Netw.*, 2016, pp. 1–7.
[2] H. D. Nguyen, H. D. Le, C. T. Nguyen, and A. T. Pham, “Throughput and delay performance of cooperative HARQ in satellite-HAP-vehicle
FSO systems,” in *Proc. IEEE Veh. Technol. Conf.*, 2021, pp. 1–6.
[3] H. D. Le and A. T. Pham, “On the design of FSO-based satellite systems using incremental redundancy hybrid ARQ protocols with rate adaptation,” *IEEE Trans. Veh. Technol.*, vol. 71, no. 1, pp. 463–477, Jan. 2022.

# Problem Statement

- *In the context of IoVs*, one of the most critical issues in HARQ designs is having a proper ECC satisfying
  - Low complexity decoding due to *the constrained computational capability of vehicles*
  - High efficiency to *serve the long-distance and noisy channel of satellite systems*

- **Convolutional code**
  - Decoding complexity increases exponentially with code length

  ⇒ Inefficient due to *the constrained computational capability of vehicles*

- **Reed-Solomon code**
  - Has lower coding gain compare to other ECCs

  ⇒ Inefficient in *the long-distance and noisy channel of satellite systems*

➡ It is necessary to have a proper design of ECC for HARQ in optical satellite-assisted IoV systems.

# Low-density Parity-check Code

- **Low-density Parity-check (LDPC),** a class of high performance ECCs, *have not been considered for the optical satellite networks.*
- **Advantages**
  - High coding gain
  - Low decoding complexity
- **Real-life Applications**
  - WiMAX (IEEE 802.16)
  - Wifi 6 (IEEE 802.11ax)
  - 5G New Radio (NR)

➡ It is necessary to have an LDPC-based HARQ design for optical satellite-assisted IoV systems.

# Research Goals

1. **Propose** an LDPC-based HARQ design for the FSO-based satellite-assisted IoVs systems.

2. **Evaluate the performance of the proposed design in terms of**
   - **Average throughput:** The average number of successfully transmitted data bits over a period of time
   - **Average frame delay:** The average time required to deliver a data frame
   - **Energy efficiency:** The ratio between the average number of successfully transmitted data bits and the average consumed power over a period of time

3. **Compare the design's performance** with other types of ECCs

# Research Method & Schedule

**Dec.** (2023)
Propose an LDPC-based HARQ design

**March**
Model the design by simulations

**May**
Validate simulation results by mathematical analysis

**Sep.**
Compare the design's performance with other ECCs

**Nov.**
Write and edit thesis

**2023** **2024**

Thanks you for your attention