Horus

Enhancing Safe Corners via Integrated Sensing and Communication Enabled by Reconfigurable Intelligent Surface

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1. Introduction
2. System Design
3. Implementation
4. Case Study
5. Conclusion

Integrated Sensing and Communication: A Key Feature in 6G

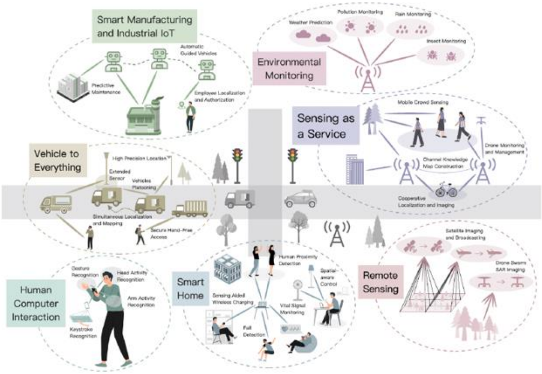


Figure 1: ISAC technology for the future Network [5].

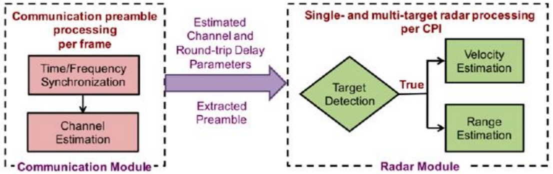
Emerging applications like autonomous driving [8], extended reality (XR) [7] and internet of things (IoT), have urged more advanced and powerful functions in the future-6G wireless networks. The ability to sense in 6G is considered essential as it provides a new paradigm to interact with the environment [2].

Problems:

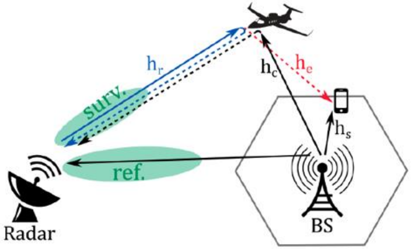
1. Complex devices and extra cost;
2. Consume extra spectrum resources.

Solution: Integrated Sensing and Communication (ISAC)

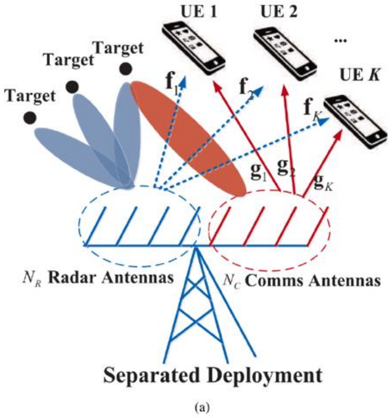
Current Approaches to realize ISAC



Time Division [4]



Frequency Division [1]



Spatial Division [6]

Limitations:

❶ Heterogeneous waveforms for different time/frequency resources [4, 1]⟹Spectrum Consumption

❷ Multiple RF chains in a phased array [6]⟹Energy and Cost

Our Goal: An ISAC system that leverages spectrum resources efficiently at a lower cost.

System Overview

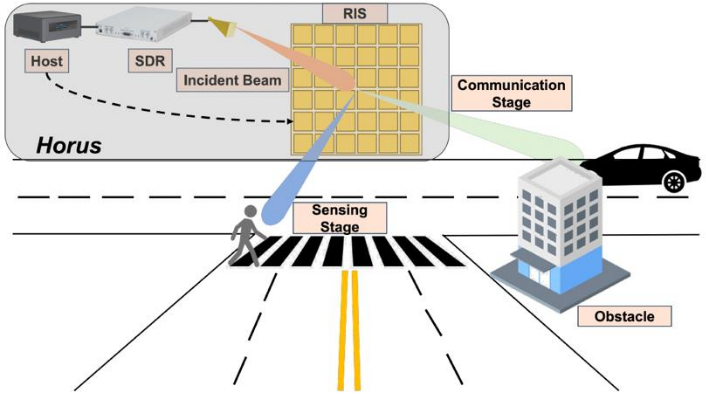


Figure 2: System Illustration of *Horus*

Workflow of *Horus*

1. Baseband signals generation with designed ISAC waveform (Host and SDR)
2. Processed signals up-converted and sent to *RIS-Enabled Transmitter*
3. Host configures RIS to steer the beam for communication or sensing

RIS-Enabled Transmitter: Foundation of *Horus*

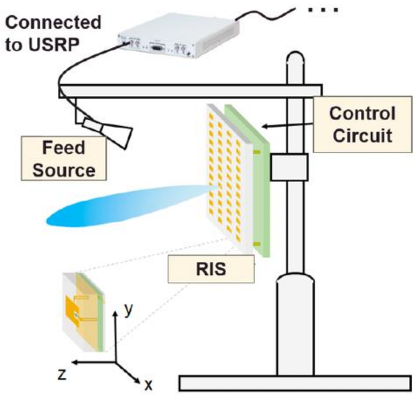


Figure 3: Physical Structure

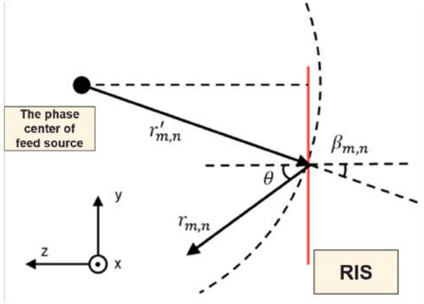


Figure 4: Geometric Structure

❶ A cost/energy efficient solution compared to the traditional phased array

❷ Assume that RIS is on the Y-Z plane, centered by $(0, y_f, z_f)$, for the unit (m, n)

$$E^{in}_{m,n} = \sqrt{\frac{P_{in}}{4\pi(r'_{m,n})^2} \cdot G_{m,n} \cdot S \cdot \beta_{m,n}} \cdot exp(-jk_0 r'_{m,n}) \tag{1}$$

❸ In the far-field direction (θ, ϕ),

$$E_{m,n}(\theta, \phi) = E^{in}_{m,n} \sqrt{|\tau_{m,n}|^2 \frac{1}{2\pi(r_{m,n})^2}} \exp\left(-jk_0 r_{m,n}\right) \tag{2}$$

❹ The reflection beam can be formed by design each unit to meet

$$\arg(\tau_{m,n}) = k_0 r'_{m,n} - k_0 r_{m,n} \tag{3}$$

Design of the *RIS-Enabled Transmitter*

To meet the requirements for communication/sensing tasks in *Horus*, we have the following indices for the *RIS-Enabled Transmitter*.

Requirements	**Parameters**
Operating Frequency	25-27GHz
Number of Units	32*32
Gain	22dBi
Maximum azimuth angle of beam scan	±60*deg*
Maximum elevation angle of beam scan	±10*deg*
Polarization Mode	Linear

Table 1: Requirements of *RIS-Enabled Transmitter* in *Horus*

However, there are some challenges in the design.

1. Hard to control every unit$\Longrightarrow$How to design the macrocell?
2. Determine the position of the feed source
3. Control Circuit Design

For more details, please visit https://luoqinpei.github.io/projects/horus/.

ISAC Waveform Design

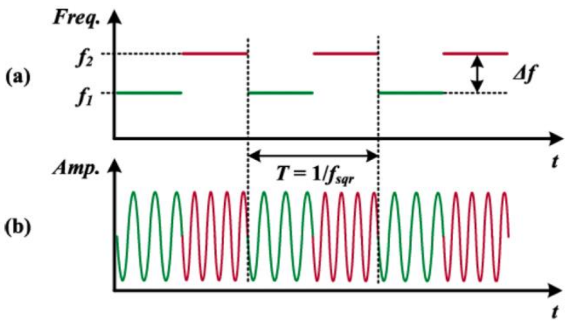


Figure 5: FSK Radar

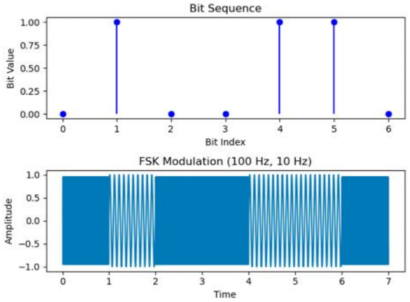


Figure 6: Traditional FSK Modulation

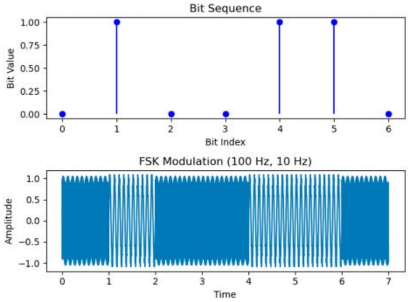


Figure 7: FSK Modulation for ISAC

Brief Preliminary

Frequency shift keying can be used for both sensing (FSK Radar in Fig. 5) and communication (FSK Modulation in Fig. 6).

- FSK communication and sensing leverage the information from amplitude and phase, respectively;
- Maintain the two sources of information by simultaneously transmitting signals with two frequencies but with different amplitudes to encode the information (Fig. 7)

Analysis of the waveform

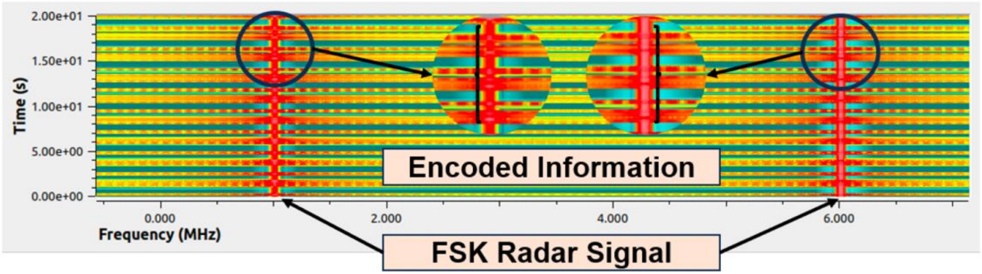


Figure 8: FSK Radar

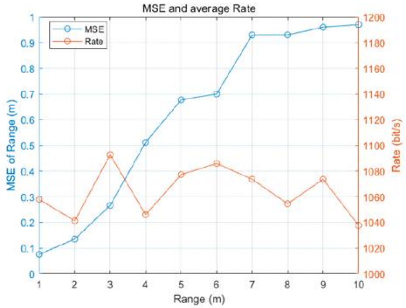


Figure 9: Traditional FSK Modulation

- Multi-path fading⟷Frequency selectiv fading⟷Coherence bandwidth
- From the measurement in [3], 11.2 GHz⟶18.3MHz, 62.4 GHz⟶32.8MHz
- *Horus* adopts the center frequency of 26 GHz, with the FSK signals spacing of 6 MHz⟶Flat-fading
- Simulation in *Gnuradio* verifies the robustness of the designed ISAC waveform for both sensing and communication.

Frame Structure

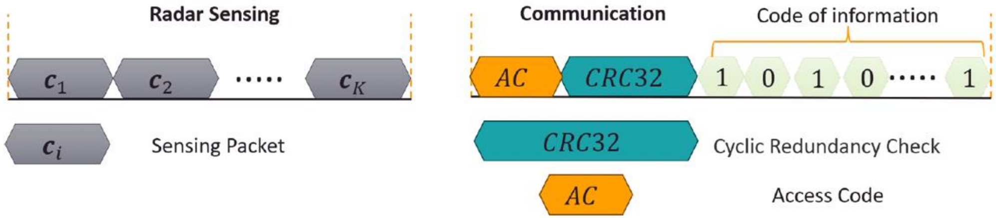


Figure 10: Frame Structure of *Horus*

1. Each sensing frame includes K sensing packets, in which each consists of a fixed number of sampling points of the FSK signals ⟶ Range and velocity information
2. Communication packet: Access code + CRC + code of data
3. Two frames are generated simultaneously, and each communication packet can consist of multiple sensing packets.

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Horus & Vehicle

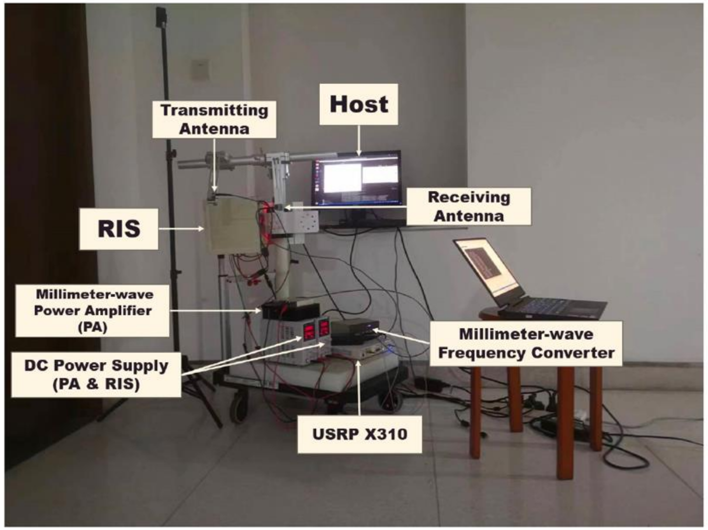

Figure 11: Prototype of *Horus*

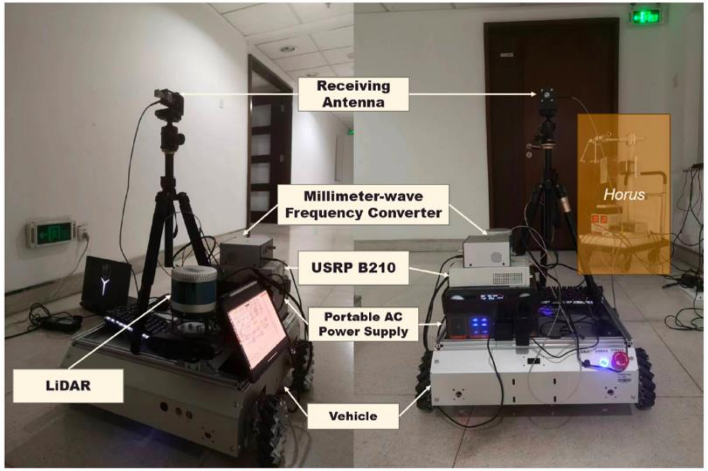

Figure 12: Prototype of Vehicle for Case Study

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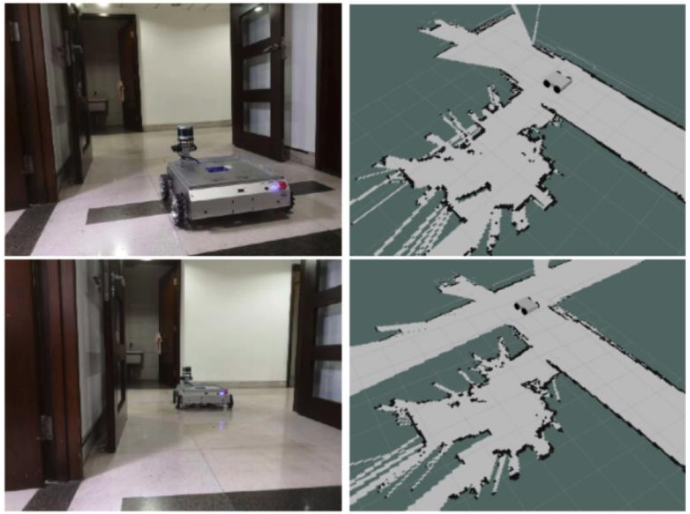
Multi-Modal Sensing

Figure 13: *Horus* aided multi-modal sensing

- Indoor environment
- Vehicle-mounted sensors (Camera, Lidar) are blocked.
- Two working stages of *Horus*:
  1. Sensing stage: Scans the space by changing the configuration of RIS and computing the range from radar echo signals.
  2. Communication stage: Configures the RIS to direct the beam toward the vehicle and transmits the generated point cloud.
- Offers scalability for applications like SLAM of the home robot.

Around-Corner Radar Early Warning



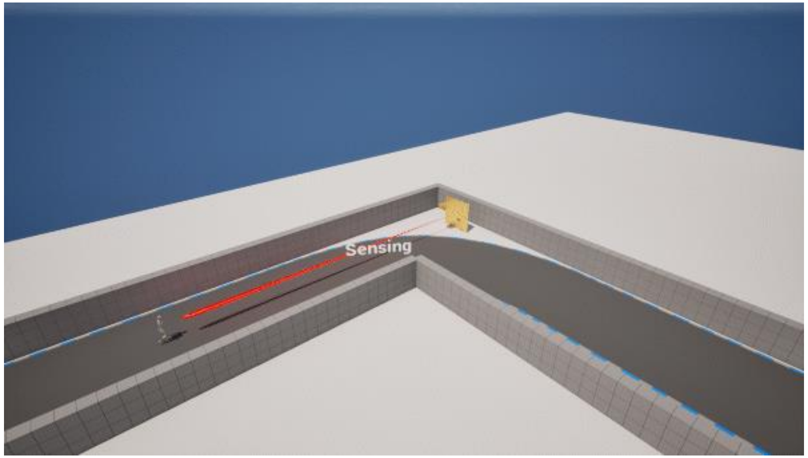


Figure 14: Scenario where Vehicle-Mounted LiDAR is limited

- Vehicle is navigating in the corridor and turning around the corner at a fixed speed
- Pedestrian is approaching the corner from the other direction
- The system should detect the coming pedestrian and send an alarm to the vehicle if a collision happens.

Demo Video

Conclusion

- *Horus*, an ISAC system prototype providing an efficient solution for sensing and communication.
- Thanks to the designed *RIS-Enabled Transmitter*, it is able to beam-scan a wide range of space to achieve ISAC at a relatively lower cost compared to the MIMO array.
- With the proposed ISAC protocol based on FSK, it can leverage the same channel for both sensing and communication to save spectrum resources.
- Two case studies verify its capability of providing a new sensing paradigm with communication ability, which has the potential for advanced applications such as indoor SLAM and intelligent roadside units in vehicular networks.

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Thanks for Listening!

Q & A