

Future Labs with 5G and Beyond

"Turn your 5G ideas into reality virtually and physically at a fraction of the cost."

Hello Everyone!

I hope you are doing well. My name is Shashvat, and I have been associated with the Indian Institute of Technology (IIT) Delhi as a researcher for a long time. Based on my experience, I have designed and arranged virtual, physical, and hybrid low-cost solutions for 5G and beyond, along with various use cases of Easy to use attractive GUI and monitoring tools. These solutions are designed with Different Open sources to help researchers, academia, startups, and students understand and explore the functionalities of 5G and future communication technologies.



The 5G Virtual & Physical Low-Cost Lab brings the power of next-generation networks to your fingertips. By combining virtual simulations with affordable real-world setups, this lab makes advanced 5G experimentation accessible to universities, startups, and innovators without breaking the budget. It bridges the gap between theory and practice. This enables hands-on experimentation in areas like network slicing, IoT, V2X, and private 5G, while keeping infrastructure costs

❖ Key Highlights

- **Virtual + Physical Integration** – Seamlessly move between simulation and hands-on experiments.
- **Affordable Innovation** – Low-cost hardware and open-source software solutions.
- **Future-Ready Testing** – Explore 5G use cases like IoT, V2X, private networks, and edge computing.
- **Education & Research Friendly** – Designed for learning, prototyping, and collaborative R&D.
- **Customizable & Scalable** – Adaptable for classrooms, research labs, or industry pilots.

❖ 5G Virtual & Physical Solutions

a. Virtual Solutions (Software-Based / Cloud-Based)

5G core, RAN ,UE etc. all set up in a virtualized way with VM or Docker.

b. Physical Solutions (Hardware-Based / On-Premise)

Low-Cost 5G Lab Kits Small cells, SDRs (USRP, LimeSDR), Raspberry Pi, mini servers with 5G core and RAN.

C. Full Scale private 5G Lab

Private 5G Network with Highly configured real radio and Rack servers ,designed with different use cases 5G-enabled smartphones, CPEs, IoT sensors.

❖ Virtual Solution with Easy GUI and Monitoring DashBoard

a. Small 5G set up

NRF, AMF, UPF, and SMF, integrated with a Virtual RAN and connected to three UEs along with an external data network. User can perform different tests and can see AI generated log analytics in a single click.

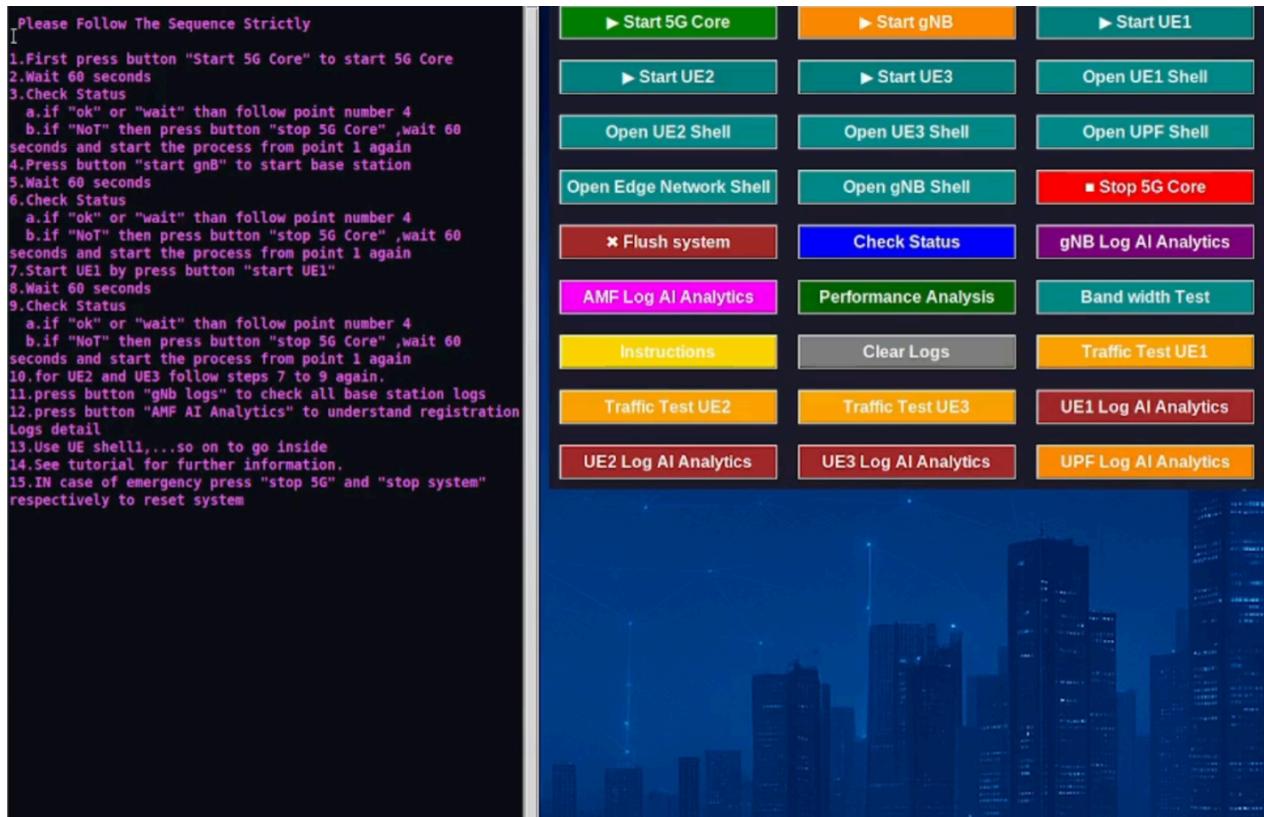


Figure: Small 5G with Easy GUI

b. Advance 5G

An advanced 5G setup is designed with a broader set of core components, including **NRF, AMF, advanced UPF, SMF, UDM, UDR, AUSF, and PCF**. It is integrated with a **Virtual RAN (vRAN)** and supports connectivity to multiple UEs, external data networks, and monitoring tools. Users can perform various tests and instantly view **AI-generated log analytics with a single click**.

c. Slice 5G

A **network slice in 5G** is a virtual, end-to-end network built on top of a shared physical infrastructure. Each slice is fully isolated, customizable, and optimized to meet the requirements of a specific service or customer.

In this setup, a 5G slice is designed with a comprehensive set of core components, including **NRF (multiple instances)**, **AMF**, **UDM**, **UDR**, **AUSF**, **PCF**, **UPF (multiple instances)**, and **SMF (multiple instances)**. Each component is configured according to the specific needs of the slice.

The slices are integrated with a **Virtual RAN (vRAN)** and connected to multiple UEs within each slice. External data networks are also mapped to their respective slices and supported with **dedicated monitoring and analytics tools**.

Users can run different tests on these slices and instantly view **AI-powered log analytics** with a **single click**.

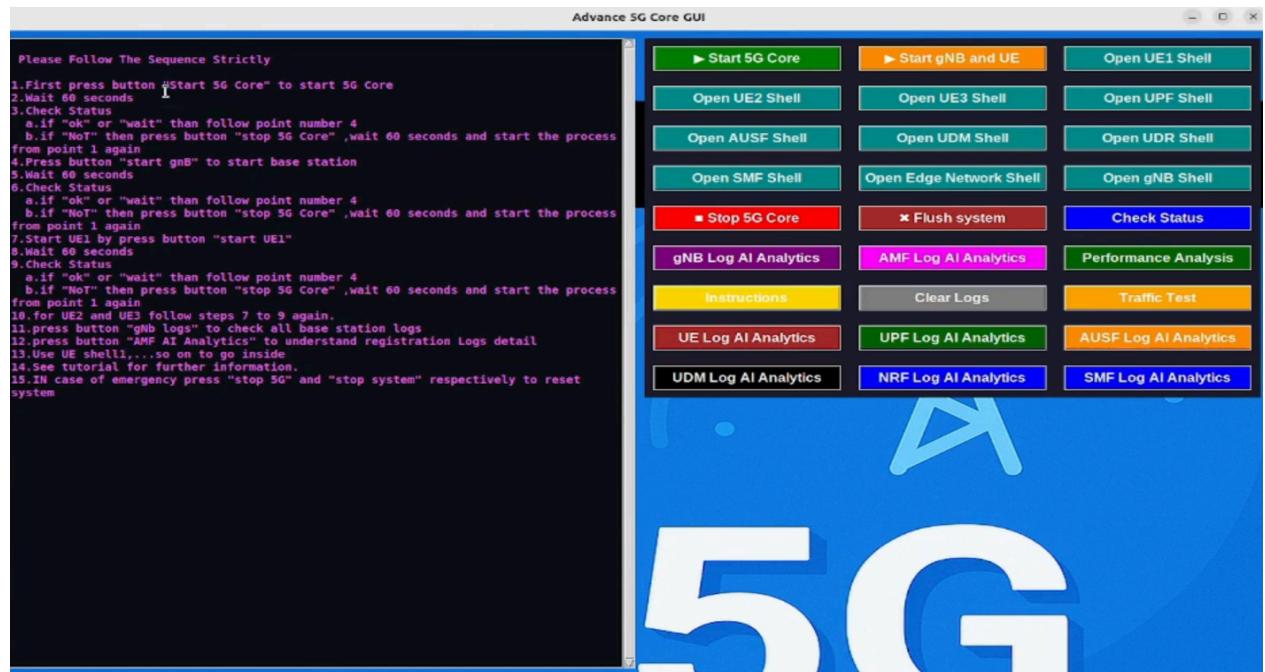


Figure: Advance 5G with Easy GUI

d. Edge 5G

Edge 5G is a virtual, end-to-end network built on top of a shared physical infrastructure.

Edge computing in this setup is fully isolated, customizable, and optimized to meet the requirements of specific services or customers, particularly to achieve **low latency**.

This Edge 5G setup includes a comprehensive set of core components: **NRF, AMF, UDM, UDR, AUSF, PCF, SMF, UPF (Edge UPF and Cloud UPF), ULCL, Edge LCM, Edge Orchestrator, and Edge Host**. Each component is configured to meet low-latency demands.

The slices are integrated with a **Virtual RAN (vRAN)** and connected to multiple UEs through the edge network. External data networks are also mapped with the edge networks and supported by **dedicated monitoring and analytics tools**.

Users can run different tests on these slices and instantly view **AI-powered log analytics with a single click**.

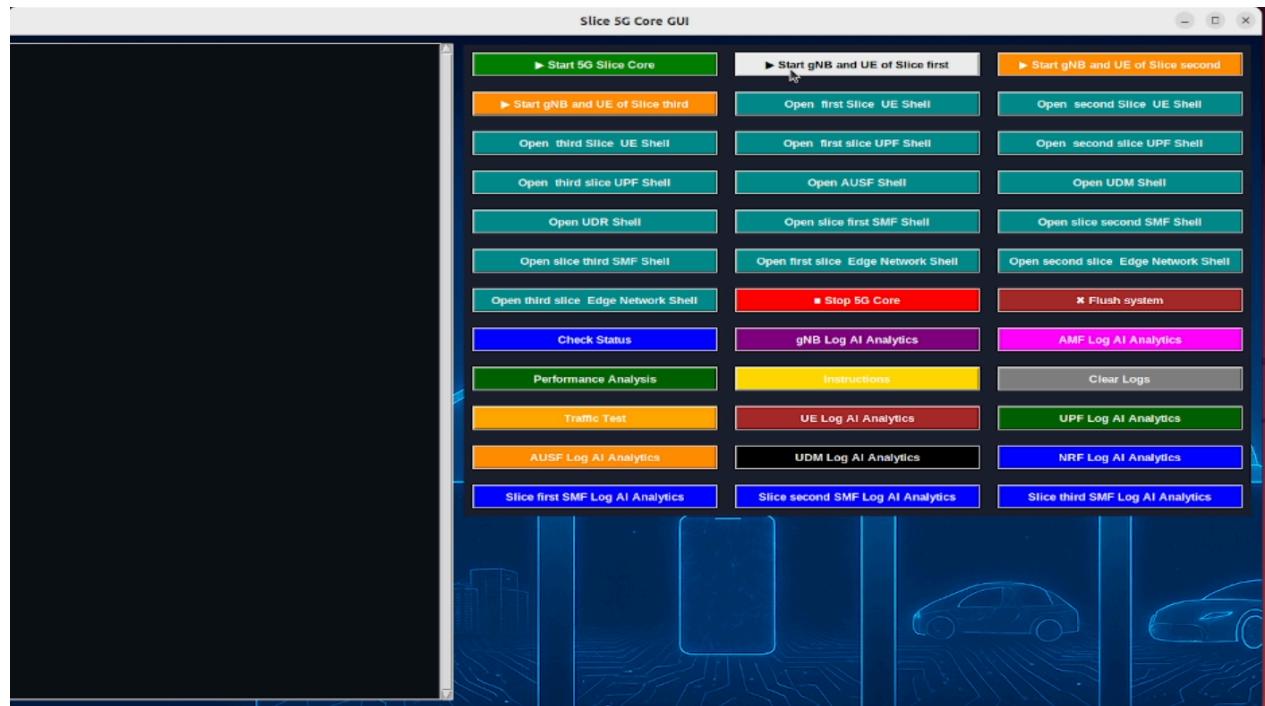


Figure: Slice 5G with Easy GUI

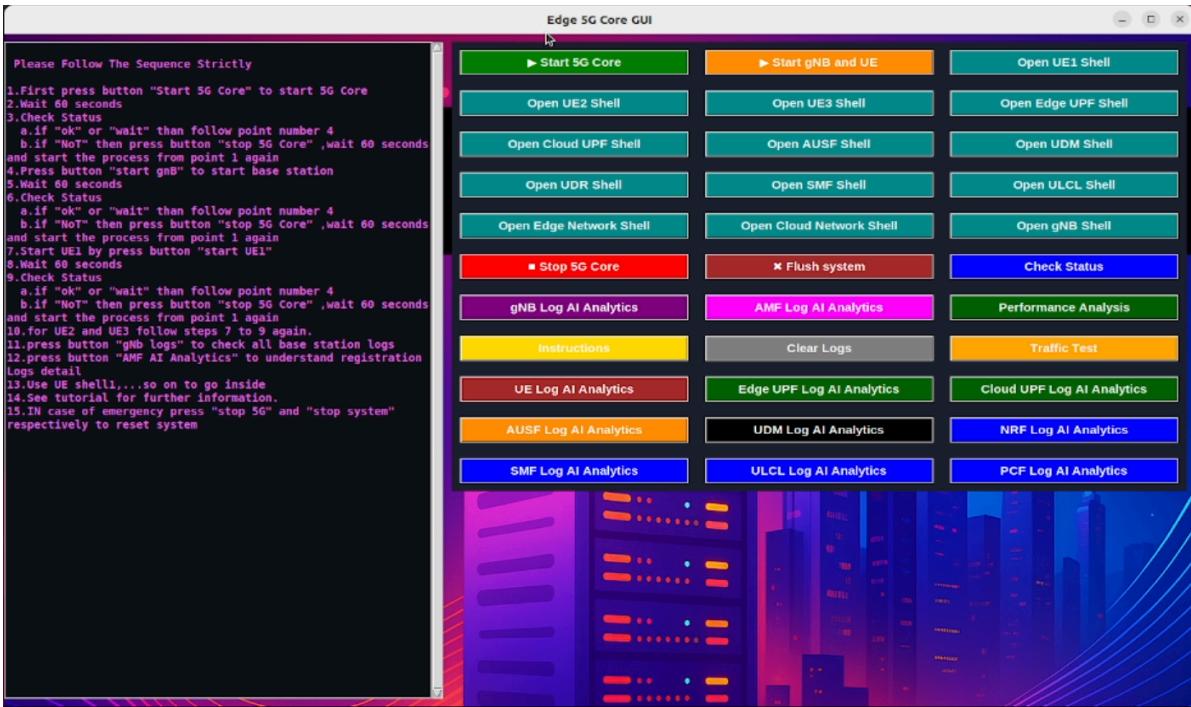


Figure: Edge 5G with Easy GUI

❖ Physical Solution with Easy GUI and Monitoring DashBoard

Diagram: Desktop (RAN + 5G Core) with Edge Network connected to UEs

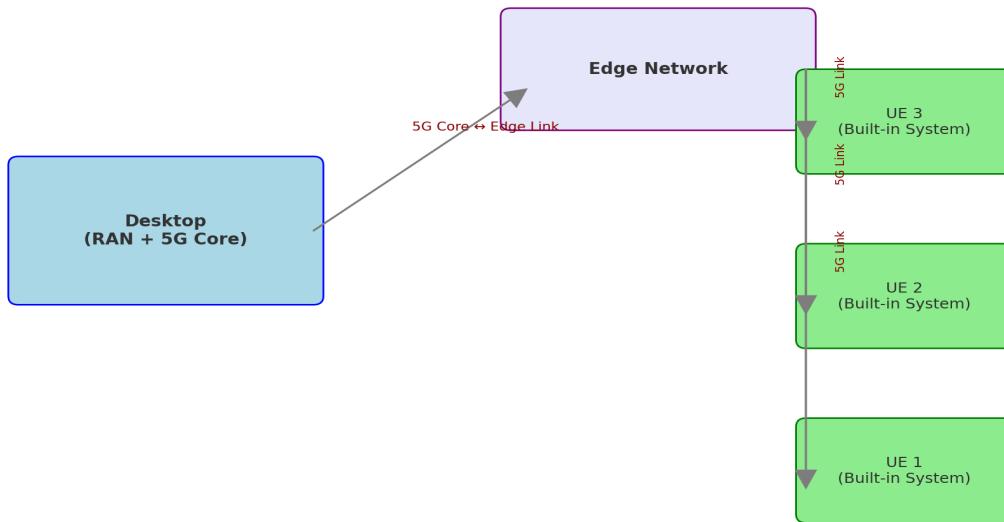


Figure: Physical 5G with Easy GUI

Physical setup work with Binary files (NOT virtual) with or without SDR (software define radio) , It contain 5G core with EPC (evolve packet core that is 4G and 5G hybrid) ,RAN and number of UE integrated with different use cases under edge computing capabilities.All the setup designed with open source.

```
[2025-10-05 05:52:24.853] [nas] [info] UE switches to state [MM-DEREGISTERED/PLMN-SEARCH]
[2025-10-05 05:52:24.853] [rcc] [debug] New signal detected for cell[1], total [1] cells in coverage
[2025-10-05 05:52:24.853] [nas] [info] Selected plmn[001/01]
[2025-10-05 05:52:24.853] [rcc] [info] Selected cell plmn[001/01] tac[1] category[SUITABLE]
[2025-10-05 05:52:24.853] [nas] [info] UE switches to state [MM-DEREGISTERED/PS]
[2025-10-05 05:52:24.853] [nas] [info] UE switches to state [MM-DEREGISTERED/NORMAL-SERVICE]
[2025-10-05 05:52:24.853] [nas] [debug] Initial registration required due to [MM-DREG-NORMAL-SERVICE]
[2025-10-05 05:52:24.853] [nas] [debug] UAC access attempt is allowed for identity[@], category[MO_sig]
[2025-10-05 05:52:24.853] [nas] [debug] Sending Initial Registration
[2025-10-05 05:52:24.853] [nas] [info] UE switches to state [MM-REGISTER-INITIATED]
[2025-10-05 05:52:24.853] [rcc] [debug] Sending RRC Setup Request
[2025-10-05 05:52:24.854] [rcc] [info] RRC connection established
[2025-10-05 05:52:24.854] [rcc] [info] UE switches to state [RRC-CONNECTED]
[2025-10-05 05:52:24.854] [nas] [info] UE switches to state [CM-CONNECTED]
[2025-10-05 05:52:24.856] [nas] [debug] Authentication Request received
[2025-10-05 05:52:24.856] [nas] [debug] Received SQN [0000000000A1]
[2025-10-05 05:52:24.856] [nas] [debug] SQN-MS [000000000000]
[2025-10-05 05:52:24.859] [nas] [debug] Security Mode Command received
[2025-10-05 05:52:24.859] [nas] [debug] Selected integrity[2] ciphering[0]
[2025-10-05 05:52:24.863] [nas] [debug] Registration accept received
[2025-10-05 05:52:24.863] [nas] [info] UE switches to state [MM-REGISTERED/NORMAL-SERVICE]
[2025-10-05 05:52:24.863] [nas] [debug] Sending Registration Complete
[2025-10-05 05:52:24.863] [nas] [info] Initial Registration is successful
[2025-10-05 05:52:24.863] [nas] [debug] Sending PDU Session Establishment Request
[2025-10-05 05:52:24.863] [nas] [debug] UAC access attempt is allowed for identity[@], category[MO_sig]
[2025-10-05 05:52:25.072] [nas] [debug] Configuration Update Command received
[2025-10-05 05:52:25.095] [nas] [debug] PDU Session Establishment Accept received
[2025-10-05 05:52:25.095] [nas] [info] PDU session establishment is successful PSI[1]
[2025-10-05 05:52:25.102] [app] [info] Connection setup for PDU session[1] is successful, TUN interface[uesintun0, 10.45.0.2] is up.
```

Figure 5G ,gnB and UE Core inside desktop

❖ Deployment Mode

All The Solution deployed with high configurable Laptop or Desktop or Mini PC (i7 or i9 processor ,SSD and 32 GB RAM) , Cloud deployment also possible with migrated vm machine in Amazon or Google Cloud.

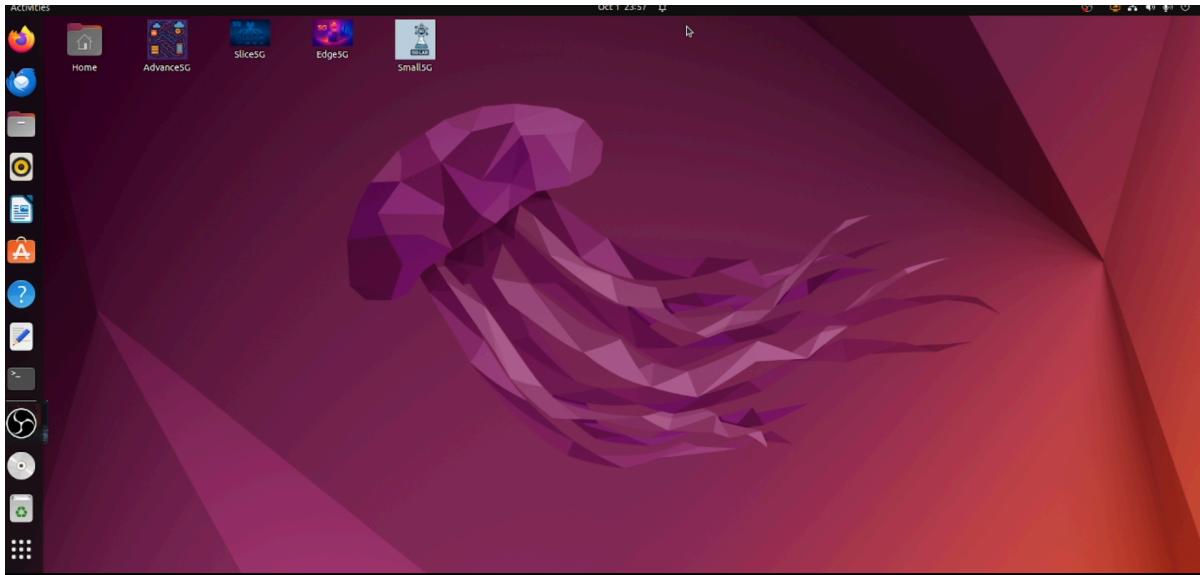


Figure:5G Desktop Lab

❖ Use Cases

a. Video analytics

Video analytics ties in beautifully with 5G labs and edge computing, since 5G provides the high bandwidth + low latency needed for real-time video analysis. Video analytics types are Object Detection & Tracking, Facial Recognition etc.

b. V2X Communications

V2X (Vehicle-to-Everything) is a communication system where vehicles exchange data with each other and with surrounding infrastructure to improve safety, efficiency, and automation.

User sending video stream sending video stream Edge platform receiving video stream from UE

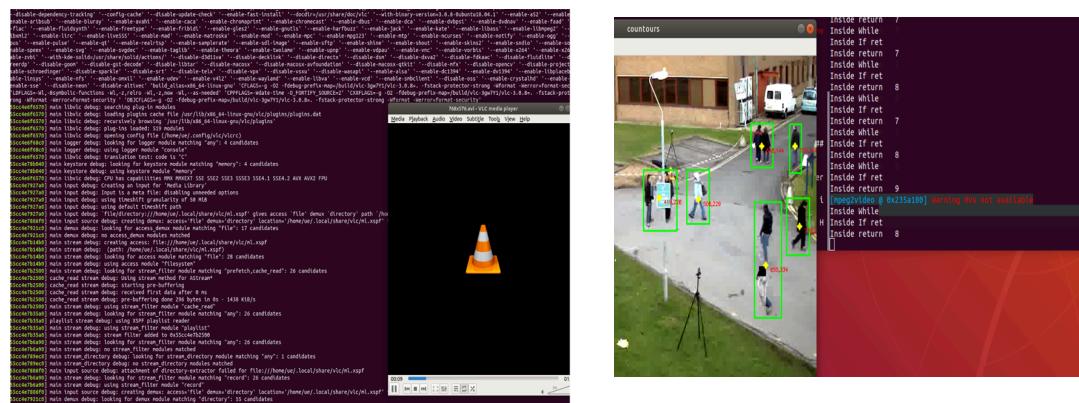


Figure: Video analytics with edge

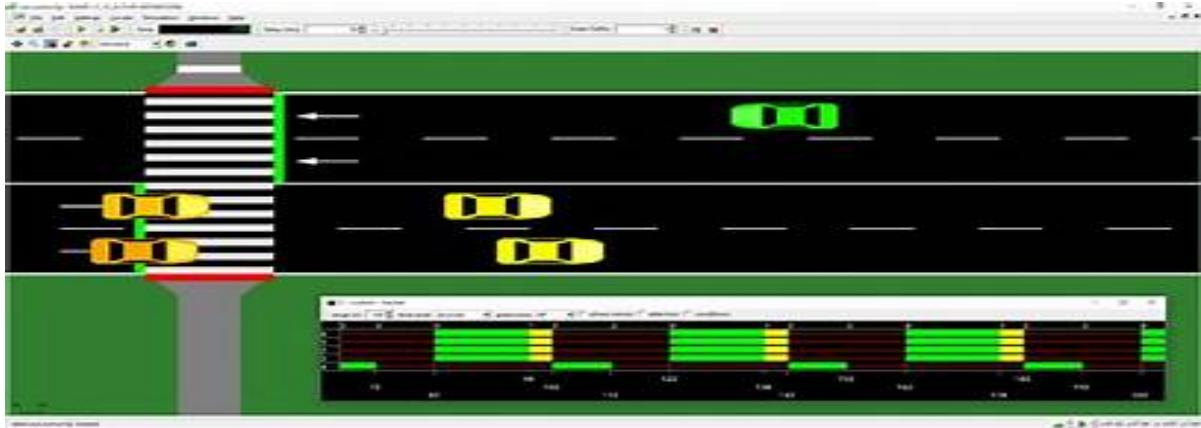


Figure: Traffic Simulation with SUMO for V2X

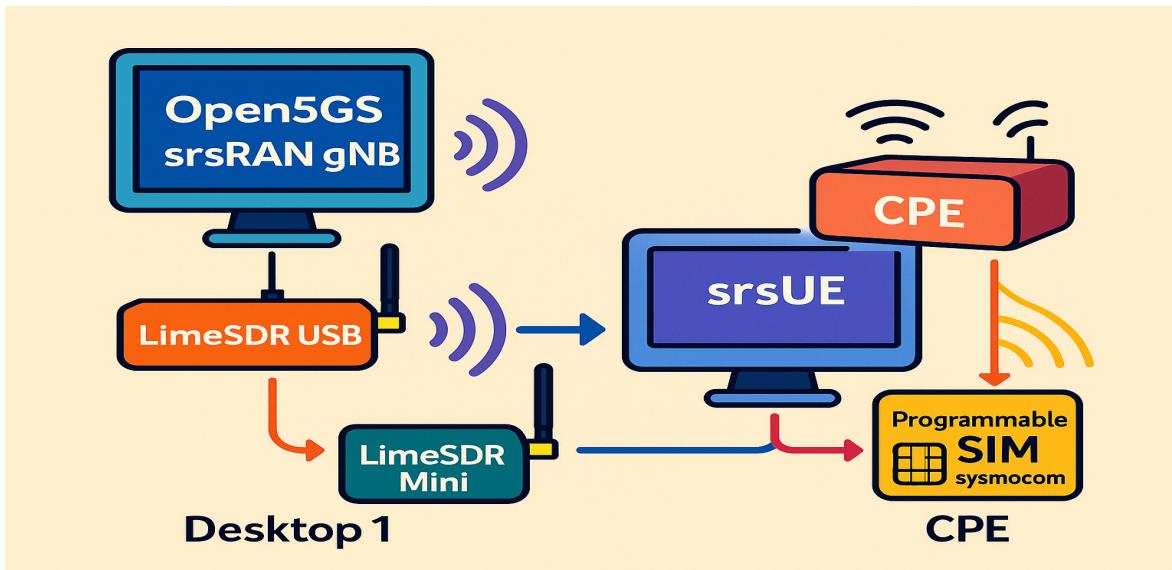
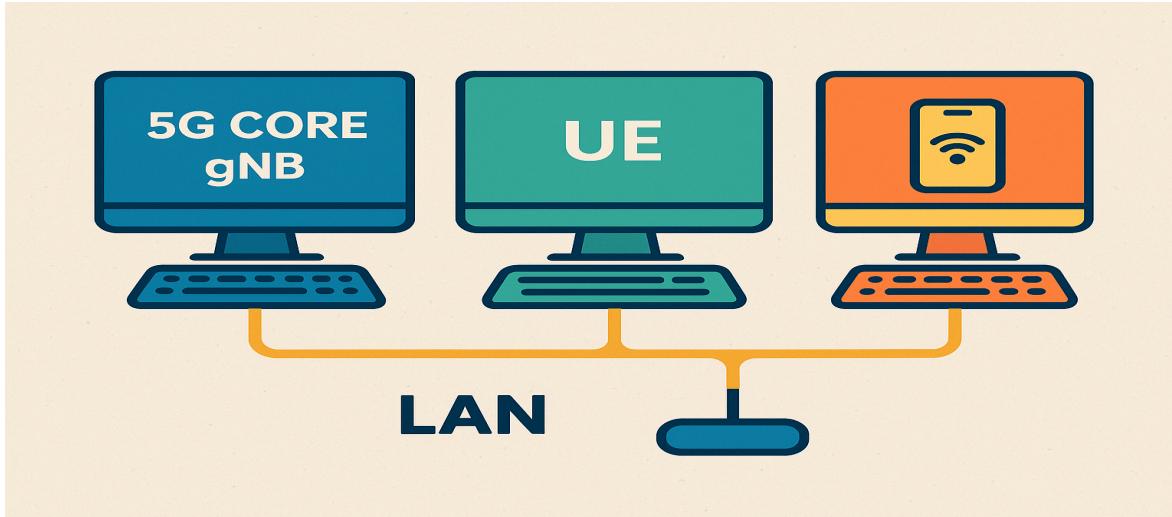
❖ Tutorials

Training Video available on following Topics

- RF basics
- 1G to 5G basic concept
- 5G architecture and Functionality details
- Radio access network (RAN)
- Edge Computing concepts with Use case Integration and testing
- Network Slicing

❖ Summary

Setup Name	5G Components	Remarks
Small 5G	AMF, SMF, NRF, UPF (basic), Single gNB, 3 UEs, External Data Network	Minimal component design using Docker. Easy to use with GUI. Suitable for beginners. Includes AI-based log analysis, network testing, and monitoring tools.
Advanced 5G	AMF, SMF, NRF, PCF, AUSF, UDM, UDR, UPF (advanced), 1 gNB, 5 UEs, External Data Network	More comprehensive 5G component design using Docker. Easy to use with GUI. Suitable for advanced learners. Includes AI-based log analysis and network testing.
Slice 5G	Three network slices with individual UPF, SMF, NRF. Common components: AMF, PCF, AUSF, UDM, UDR. Dedicated gNB and UE per slice (scalable). External Data Network for each slice.	Slice-based 5G design with Docker. Easy to use with GUI. Useful for researchers and students exploring network slicing. Includes AI-based log analysis, network testing, and monitoring tools.
Edge 5G	Edge and Cloud UPFs with uplink classifier, plus AMF, SMF, NRF, PCF, AUSF, UDM, UDR. Single gNB, multiple UEs. Dedicated cloud and edge data networks.	Edge network design with Docker. Easy to use with GUI. Useful for researchers and students studying edge computing. Includes AI-based log analysis, network testing, and monitoring tools.
Physical 5G (without SDR)	Build files (non-virtual binaries) for 5G Core, EPC (4G/5G), gNB, and multiple UEs. Integrated edge network based on standard use cases.	Alternative to SDR-based 5G. Good for application testing, performance analysis, and private network design.
Physical 5G (with SDR)	Build files (non-virtual binaries) for 5G Core, EPC (4G/5G), gNB, and multiple UEs. Connects with SDR hardware (USRP, LimeSDR). Integrated edge network based on standard use cases.	Lab-scale private 5G with real radio and edge computing. Good for application testing, analysis, and realistic network evaluation.
Full-Scale 5G Environment	Full-scale 5G with MIMO, rack servers, smartphones, and CPE devices. Private 5G with real radio and edge computing.	Suitable for enterprise/private lab deployments. Enables full-scale application testing, analysis, and real-world cellular environment experiments.



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