

5G Implementation in Defect Inspection Facility

5G Network Foundation Course Finals



Inspection Facility

- Focus in Automotive parts
- Have 5 Inspection Line

Scenario Information: What we working on?

Parts to be Inspect



Piston



Gearbox Housing



Suspension Rods

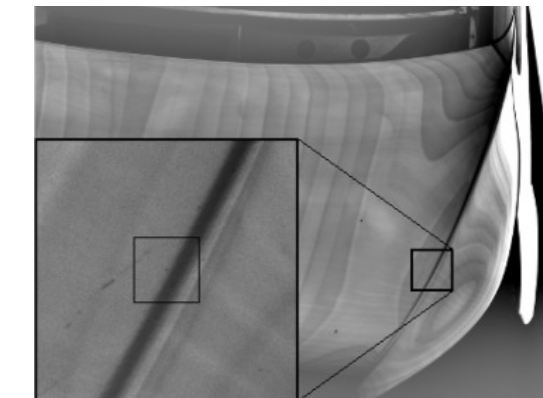
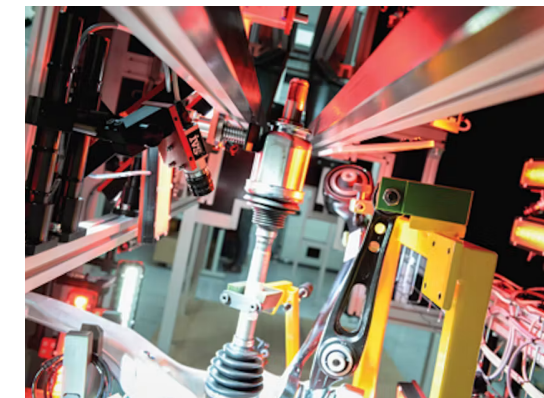
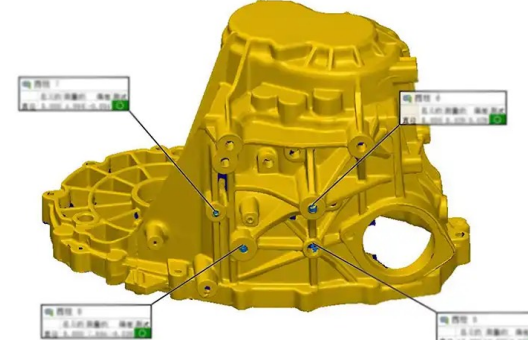


Body Panel



Wheel Rim

Inspection Requirements



Detection Surface				
6 (4 in High Res)	6 (2 in High Res)	8 (3 in High Res)	4 (1 in High Res)	6 in Normal Res
Minimum Defect Size				
1 mm/pixel	1 mm/pixel	1 mm/pixel	1 mm/pixel	3 mm/pixel
Detection Details				
<ul style="list-style-type: none">• High resolution indicates 1920x1080 / Normal resolution is 800x600 (pixel).• Camera record in 30 Frame per Second (fps) is capable to detect defects accurately.• All the recordings and detection results have to sent to central database for QC reports.				

Quality of Service (QoS) in the Scenario

- key performance that the network must satisfy, including *Latency*, *Reliability*, and *Throughput* (bitrate).
- In the Defect Inspection scenario, different camera streams have vastly different requirements for image quality and latency:
 - **High Resolution** : Used for Critical Inspection → Requires low latency and high reliability, otherwise it will affect real-time alerts and decision-making.
 - **Normal Resolution** : Used for **Non-Critical Inspection** → Can tolerate higher latency and may use a more relaxed eMBB channel.

Slice Type	Use Case	Resolution / Bitrate	Latency	Reliability
URLLC	Critical Inspection	1920x1080 @ 30fps (19.9 Mbps)	$\leq 10\text{ ms}$	$\geq 99.999\%$ (Packet-Loss $\leq 10^{-5}$)
eMBB	Non-Critical Inspection	800*600 @30fps (4.6 Mbps)	$\leq 50\text{ ms}$	Best-Effort

Project Objectives: Trade-offs

- **Design and validate URLLC network slices** to meet sub-10 ms latency for high-precision streams.
- **Integrate Multi-Access Edge Computing (MEC)** nodes at the factory floor to offload inference and minimize core-network latency
- **Benchmark open-source 5G stacks** under mixed URLLC/eMBB traffic replicating our five inspection lines.

Defect-Detection Performance Requirements

Default 0.32

$$\text{Bitrate (bps)} = \text{Width (px)} \times \text{Height (px)} \times \text{Frame rate (fps)} \times \text{BPP}$$

Critical inspection faces (1920x1080)

- End-to-end latency ≤ 10 ms
- Packet-loss rate $\leq 10^{-5}$

$$1920 \times 1080 \times 30 \times 0.32 \approx 19,907,712 \text{ bps} \approx 19.9 \text{ Mbps}$$

Non-Critical inspection faces (800x600)

- Support $\geq N$ simultaneous streams
- Average one-way latency ≤ 50 ms

$$800 \times 600 \times 30 \times 0.32 \approx 4,608,000 \text{ bps} \approx 4.6 \text{ Mbps}$$

Mapping to 5G QoS

URLLC slice

- Latency Budget: ≤ 10 ms
- Reliability $\geq 99.999\%$ (packet-loss $\leq 10^{-5}$)
- Guaranteed Bitrate

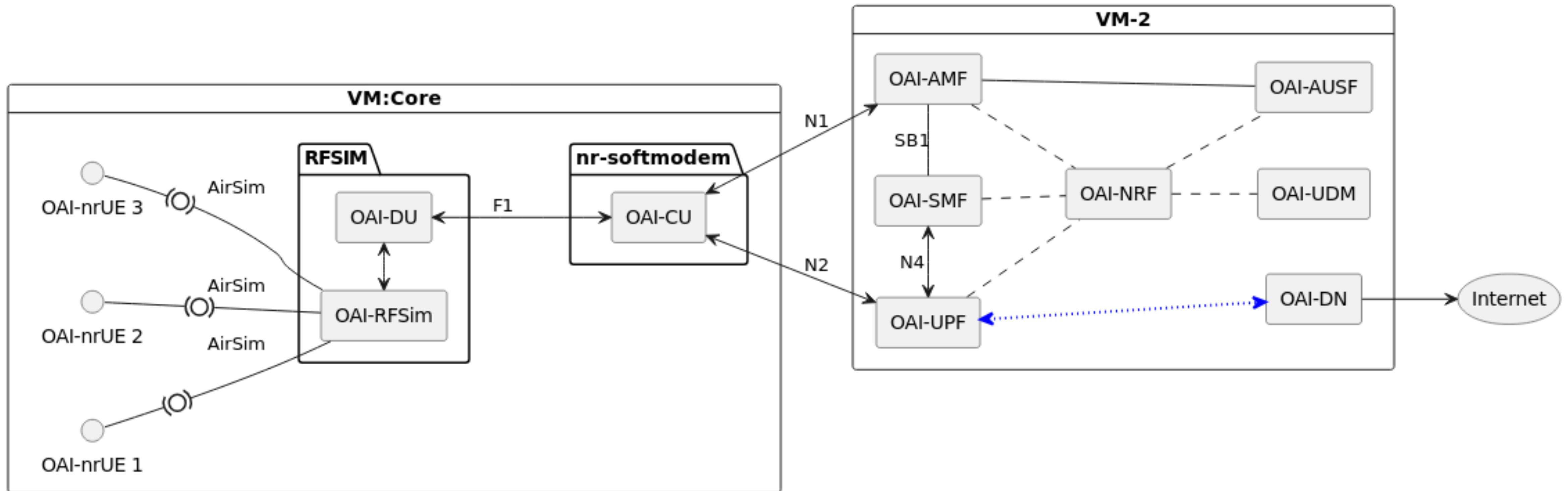
eMBB slice

- Throughput 5 Mbps per 600p stream
- Latency Target: ≤ 50 ms
- lower than URLLC but above standard best-effort

Overall System Architecture

- This diagram illustrates the complete architecture of our 5G network system, showing the interconnections between different network components and layers.

Setup End-to-End



Network Configuration Setup

- Detailed view of the network configuration parameters and settings required for establishing the 5G network connections.

Context: greign-smo
Cluster: microk8s-cluster
User: admin
K9s Rev: v0.32.5 ⚡ v0.50.6
K8s Rev: v1.27.16
CPU: 54%↓
MEM: 65%

<0> all
<1> default

<a> Attach
<ctrl-d> Delete
<d> Describe
<e> Edit
<?> Help
<shift-j> Jump Owner

<ctrl-k> Kill
<l> Logs
<p> Logs Previous
<shift-f> Port-Forward
<z> Sanitize
<s> Shell

<o> Show Node
<f> Show PortForward
<t> Transfer
<y> YAML

Pods(all)[13] </site-00>

NAMESPACE↑	NAME	PF	READY	STATUS	RESTARTS	CPU	MEM	%CPU/R	%CPU/L	%MEM/R	%MEM/L	IP	NODE	AGE
site-00	e2e-mysql-5dbff6b9f-chspc	●	1/1	Running	0	9	444	4	4	86	86	10.1.248.37	smo-nnag	72m
site-00	oai-amf-84dcc5c68-4scwr	●	2/2	Running	0	28	5	n/a	n/a	n/a	n/a	10.1.248.38	smo-nnag	72m
site-00	oai-ausf-599cc96c5d-d5vql	●	2/2	Running	0	50	3	n/a	n/a	n/a	n/a	10.1.248.10	smo-nnag	72m
site-00	oai-cu-644cb9c49-46q9d	●	2/2	Running	0	1	128	n/a	n/a	n/a	n/a	10.1.248.62	smo-nnag	72m
site-00	oai-du-f6658ddd6-6b4hp	●	2/2	Running	0	1152	1088	n/a	n/a	n/a	n/a	10.1.248.42	smo-nnag	72m
site-00	oai-nr-ue-00-6d9c98d886-rmbn6	●	1/1	Running	0	439	477	n/a	n/a	n/a	n/a	10.1.248.22	smo-nnag	72m
site-00	oai-nr-ue-01-c87c7d566-djx2f	●	1/1	Running	0	447	475	n/a	n/a	n/a	n/a	10.1.248.45	smo-nnag	72m
site-00	oai-nrf-5b6f9bb56-s4h7f	●	2/2	Running	0	50	3	n/a	n/a	n/a	n/a	10.1.248.29	smo-nnag	72m
site-00	oai-smf-57695c9f8d-6ngwk	●	2/2	Running	0	20	5	n/a	n/a	n/a	n/a	10.1.248.2	smo-nnag	72m
site-00	oai-traffic-server-6d9d9b44d9-2gh9l	●	1/1	Running	0	5	2	n/a	n/a	n/a	n/a	10.1.248.7	smo-nnag	72m
site-00	oai-udm-555d58587c-c755c	●	2/2	Running	0	46	3	n/a	n/a	n/a	n/a	10.1.248.32	smo-nnag	72m
site-00	oai-udr-5b75b99c74-r8w92	●	2/2	Running	0	42	4	n/a	n/a	n/a	n/a	10.1.248.43	smo-nnag	72m
site-00	oai-upf-56d669ddf9-p85vg	●	3/3	Running	0	18	6	18	n/a	4	n/a	10.1.248.31	smo-nnag	72m

Network Topology

- Visual representation of how different network elements are connected, including the relationship between Central Units (CU) and Distributed Units (DU).

Context: greign-smo

Cluster: microk8s-cluster

User: admin

K9s Rev: v0.32.5 ⚡ v0.50.6

K8s Rev: v1.27.16

CPU: 60%↑

MEM: 65%

<0> tail

<1> head

<2> 1m

<3> 5m

<4> 15m

<5> 30m

<6> 1h

<shift-c> Clear

<c> Copy

<m> Mark

<ctrl-s> Save

<s> Toggle AutoScroll

<f> Toggle FullScreen

<t> Toggle Timestamp

<w> Toggle Wrap

Logs(site-00/oai-amf-84dcc5c68-4scwr)[tail]

Autoscroll:On

FullScreen:Off

Timestamps:Off

Wrap:Off

init-udr Ncat: 0 bytes sent, 0 bytes received in 3.59 seconds.

amf [2025-06-02 05:52:09.738] [amf_sbi] [info] Receive Update NF Instance Request, handling ...

amf [2025-06-02 05:52:09.738] [amf_sbi] [info] Send HTTP message to http://oai-nrf:80/nnrf-nfm/v1/nf-instances/1220adeb-3748-4dd0-87f6-7cf054f04573

amf [2025-06-02 05:52:09.738] [amf_sbi] [info] HTTP message Body: [{"op":"replace","path":"/nfStatus","value":"REGISTERED"}]

amf [2025-06-02 05:52:09.741] [amf_sbi] [info] Get response with HTTP code (204)

amf [2025-06-02 05:52:09.741] [amf_sbi] [info] Could not get JSON content from the response

amf [2025-06-02 05:52:16.916] [amf_app] [info]

-----gNBs' Information-----

Index	Status	Global Id	gNB Name	PLMN
1	Disconnected	0x00		,
2	Connected	0xE000	oai-cu	001,01

-----UEs' Information-----

Index	5GMM State	IMSI	GUTI	RAN UE NGAP ID	AMF UE NGAP ID	PLMN	Cell Id
1	5GMM-REGISTERED	001010000000100	0010101004100000001	0x01	0x01	001,01	0xE00000
2	5GMM-REGISTERED	001010000000101	0010101004100000002	0x02	0x02	001,01	0xE00000

CU / DU Socket Connection Diagram

- Specific illustration of the Central Unit socket configuration, showing the connection parameters and communication protocols used.

```
root@oai-cu-644cb9c49-2gmkv:/opt/oai-gnb# netstat -apn4
Active Internet connections (servers and established)
Proto Recv-Q Send-Q Local Address           Foreign Address          State        PID/Program name
sctp           0      0 10.1.248.62:38472        *:*                      LISTEN       1/nr-softmodem
sctp           0      0 10.1.248.62:37795        10.1.248.39:38412        ESTABLISHED  1/nr-softmodem
udp            0      0 10.1.248.62:2152        0.0.0.0:*                 1/nr-softmodem
udp            0      0 10.1.248.62:2153        0.0.0.0:*                 1/nr-softmodem
root@oai-cu-644cb9c49-2gmkv:/opt/oai-gnb#
```

- Detailed representation of the Distributed Unit socket setup, demonstrating the interface configurations and data flow paths.

```
<<K9s-Shell>> Pod: site-00/oai-du-f6658ddd6-485mx | Container: gnbdu
root@oai-du-f6658ddd6-485mx:/opt/oai-gnb# netstat -apn4
Active Internet connections (servers and established)
Proto Recv-Q Send-Q Local Address           Foreign Address          State        PID/Program name
tcp           0      0 0.0.0.0:4043            0.0.0.0:*                LISTEN       1/nr-softmodem
tcp    122904 185958 10.1.248.45:4043        10.1.248.40:39770        ESTABLISHED  1/nr-softmodem
tcp    245808  58572 10.1.248.45:4043        10.1.248.22:43670        ESTABLISHED  1/nr-softmodem
sctp           0      0 10.1.248.45:54523        10.1.248.35:38472        CLOSE       1/nr-softmodem
udp            0      0 10.1.248.45:2153        0.0.0.0:*                 1/nr-softmodem
root@oai-du-f6658ddd6-485mx:/opt/oai-gnb#
```


Simulation

- Camera I specification
- Camera II specification

Python

iperf3 -c 12.1.1.1 -b 19.9M -u -t 10 -l 188 -P 1 -p 5201

Python

iperf3 -c 12.1.1.1 -b 23M -u -t 10 -l 1400 -P 1 -p 5202

infidel@XPG-Fedora 6 1:k9s* 17:48:46 2025-06-02

[5]	16.00-17.00	sec	959 KBytes	7.85 Mbits/sec	0	2.16 MBytes
[5]	17.00-18.00	sec	984 KBytes	8.06 Mbits/sec	0	2.33 MBytes
[5]	18.00-19.00	sec	1.29 MBytes	10.8 Mbits/sec	0	2.33 MBytes
[5]	19.00-20.00	sec	1.17 MBytes	9.85 Mbits/sec	0	2.33 MBytes
[5]	20.00-21.00	sec	1.22 MBytes	10.2 Mbits/sec	0	2.33 MBytes
[5]	21.00-22.00	sec	1.02 MBytes	8.57 Mbits/sec	0	2.33 MBytes
[5]	22.00-23.00	sec	1.01 MBytes	8.48 Mbits/sec	0	2.33 MBytes
[5]	23.00-24.00	sec	1.23 MBytes	10.3 Mbits/sec	0	2.33 MBytes
[5]	24.00-25.00	sec	1.23 MBytes	10.3 Mbits/sec	0	2.33 MBytes
[5]	25.00-26.00	sec	1.20 MBytes	10.1 Mbits/sec	0	2.33 MBytes
[5]	26.00-27.00	sec	1.10 MBytes	9.23 Mbits/sec	0	2.33 MBytes
[5]	27.00-28.00	sec	1.18 MBytes	9.94 Mbits/sec	0	2.33 MBytes
[5]	28.00-29.00	sec	1.25 MBytes	10.4 Mbits/sec	0	2.33 MBytes
^C[5] 29.00-29.41 sec 433 KBytes 8.74 Mbits/sec 0 2.33 MBytes						

[ID]	Interval		Transfer	Bitrate	Retr	
[5]	0.00-29.41	sec	32.9 MBytes	9.39 Mbits/sec	0	sender
[5]	0.00-29.41	sec	0.00 Bytes	0.00 bits/sec		receiver
iperf3: interrupt - the client has terminated						
root@oai-nr-ue-00-6d9c98d886-4cnjr:/opt/oai-nr-ue#						

[7]	26.00-27.00	sec	295 KBytes	2.42 Mbits/sec	0	2.39 MBytes
[9]	26.00-27.00	sec	272 KBytes	2.23 Mbits/sec	0	2.46 MBytes
[11]	26.00-27.00	sec	135 KBytes	1.11 Mbits/sec	0	2.36 MBytes
[13]	26.00-27.00	sec	232 KBytes	1.90 Mbits/sec	0	2.40 MBytes
[SUM]	26.00-27.00	sec	956 KBytes	7.83 Mbits/sec	0	

[5]	27.00-28.00	sec	260 KBytes	2.12 Mbits/sec	0	2.47 MBytes
[7]	27.00-28.00	sec	64.3 KBytes	525 Kbits/sec	0	2.43 MBytes
[9]	27.00-28.00	sec	21.9 KBytes	179 Kbits/sec	0	2.47 MBytes
[11]	27.00-28.00	sec	206 KBytes	1.69 Mbits/sec	0	2.49 MBytes
[13]	27.00-28.00	sec	271 KBytes	2.21 Mbits/sec	0	2.58 MBytes
[SUM]	27.00-28.00	sec	823 KBytes	6.72 Mbits/sec	0	

[5]	28.00-29.00	sec	306 KBytes	2.52 Mbits/sec	0	2.67 MBytes
[7]	28.00-29.00	sec	13.7 KBytes	112 Kbits/sec	0	2.44 MBytes
[9]	28.00-29.00	sec	279 KBytes	2.29 Mbits/sec	0	2.65 MBytes
[11]	28.00-29.00	sec	232 KBytes	1.91 Mbits/sec	0	2.63 MBytes
[13]	28.00-29.00	sec	68.4 KBytes	562 Kbits/sec	0	2.62 MBytes
[SUM]	28.00-29.00	sec	900 KBytes	7.39 Mbits/sec	0	