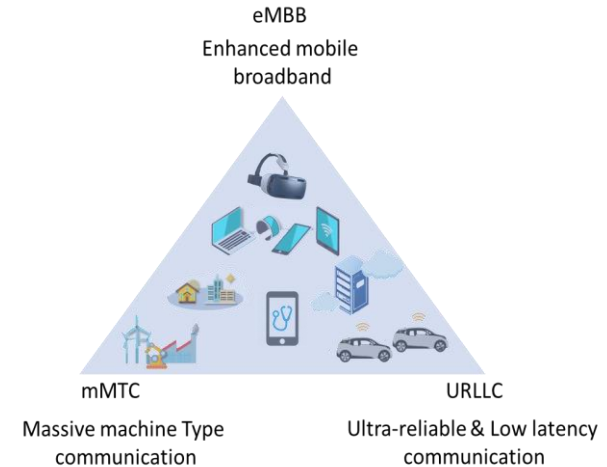# Performance Analysis of a Private 5G SA Campus Network

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Outline

➢ INTRODUCTION

➢ NETWORK AND USER EQUIPMENT

    ○ 5G SA Network Overview

    ○ User Equipment

➢ 5G MEASUREMENT TOOLS AND KPI

    ○ Performance Metrics

    ○ Measurement Applications and Tools

    ○ Measurement Locations

➢ NETWORK PERFORMANCE And EVALUATION

➢ CONCLUSION And FUTURE WORK

➢ 5G has become a reality and there is a strong momentum in the global market as it is growing rapidly

➢ 5G subscriptions are projected to exceed 4.39 billion by end of 2027

➢ Mobile Network Operators (MNOs) around the world are in race to upgrade their networks to 5G stand-alone (SA) operation

➢ To fully exploit 5G's potential, applications need to adapt to appropriately reflect changing user experiences and network speeds

eMBB
Enhanced mobile
broadband

mMTC
Massive machine Type
communication

URLLC
Ultra-reliable & Low latency
communication

➢ In parallel, private campus networks (PCN) are also being built to

trial new applications that were not possible before

➢ Measuring the performance is crucial for the assessments of the

networks as it can influence anything from investment decisions to

legislative measures

➢ **5G SA Network Overview**

    ○ **Topography and Radio Environment**

       ■ The campus of the TU Kaiserslautern

          ● Average urban environment with a flat land but dense development

          ● Located city outskirts - > less interference factor from other bands

   ● Ideal environment for testing 5G SA PCN

➢ **5G SA Network Overview**

- ○ **5G SA Network at TU Kaiserslautern**

  - ■ Supplier -> Smart Mobile Labs (SML)

  - ■ NDAC network from Nokia

  - ■ 4 buildings with Indoor Remote Radio Head (RRH)

  - ■ 3 outdoor RRHs

  - ■ Full Control over RAN but not over Core

  - ■ 3GPP Release 15

  - ■ Core Version - > 7.2022.11.3727

  - ■ RAN Version -> 21B

○ **RAN parameter overview**

■ Frequency -> 3.7 - 3.8 GHz
(100 MHz Bandwidth)

■ Indoor RRH -> 4x4 MIMO

■ Outdoor RRH -> split into 2 sectors
of 2x2 MIMO

■ 40 dBm Tx-Power per channel
(outdoor)

■ 3:7 upload to download ratio
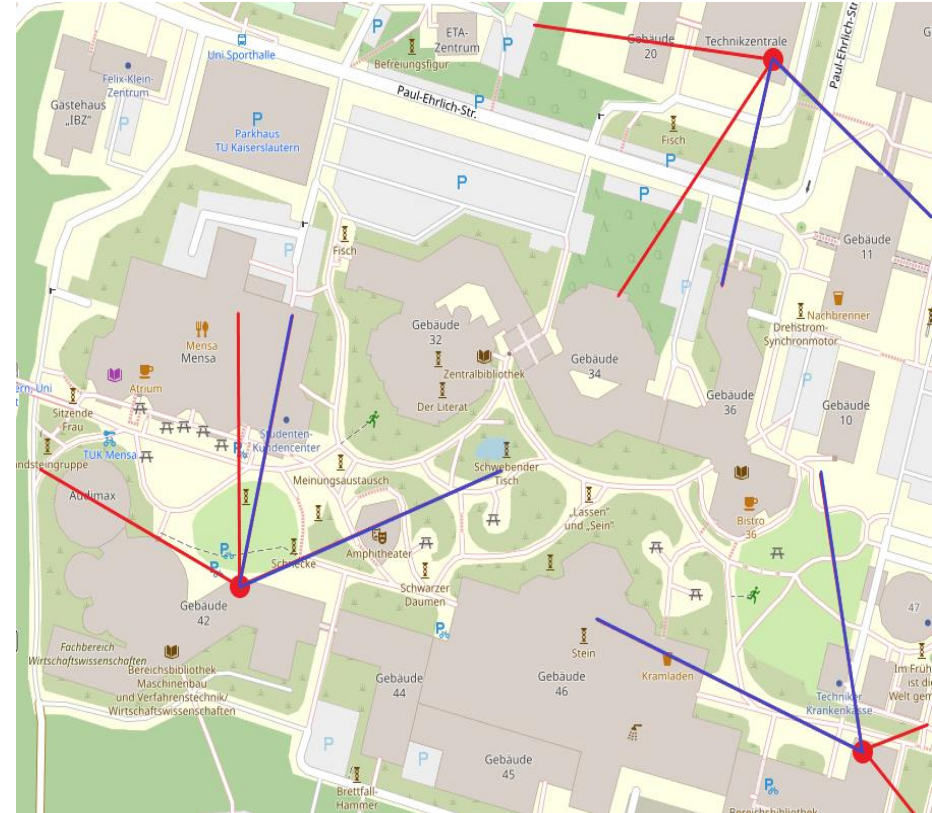
- ➤ User Equipment
  - ○ 5G UE's are more complex than LTE or 4G UE's in terms of Antennas to modems and Physical layer to MAC layer co-design
  - ○ Few 5G UEs -> Setback for initial 5G Use Cases
  - ○ Few Commercial UEs available for CPN
  - ○ Commercial Mobile phones -
    - ■ Samsung S21 (Exynos, Specific build versions only)
    - ■ Huawei P40 (Balong 5000)
    - ■ Nokia 8.3 5G (Qualcomm x55)
  - ○ 5G Modules (Qualcomm x55 based)
    - ■ Sierra EM9191
    - ■ Quectel RM500Q-GL , RG500-L, RM520N-GL (Rel 16 compliant)
    - ■ Telit FN980 series

➢ Performance Metrics

    ○ Throughput

    ○ Latency

    ○ Jitter

    ○ Radio Parameters

        ■ Synchronization Signal reference signal received power (SS-RSRP)

        ■ Synchronization Signal signal-to-noise and interference ratio (SS-SINR)

        ■ Received Signal Strength (RSS)

➢ Speedtest Servers
   ○ External Speedtest server
      ■ speedtest.net (Multi link, TCP)
   ○ Internal Speedtest server
      ■ Librespeed server (Single link, TCP)
➢ External Measuring device
   ○ Rohde and Schwarz
      ■ TSMA6 test drive scanner
      ■ ROMES drive test software
      ■ ROMES is used in combination with scanners or test mobile phones

Measurement Locations

➢ Care was taken to ensure that the choice of measurement points was balanced

➢ At least one measuring point per RRH as serving cell

➢ The handover areas between two RRHs

➢ 5 outdoor Measurement points

➢ 1 indoor measurement point

Signal Strengths from Different Measurement Points

Outdoor → (MP1 -MP5)

	SS-RSRP [dBm]			SS-SINR [dB]			RSS [dBm]
	RRH (Serving Cell)	RRH (Neighbor Cell 1)	RRH (Neighbor Cell 2)	RRH (Serving Cell)	RRH (Neigbor Cell 1)	RRH (Neighbor Cell 2)	RRH
MP1	-72,37	-85,3	-97,57	15,1	-15,8	-27,4	-66,6
MP2	-69,4	-88,56	-91,22	10,9	-20,3	-25,9	-65,7
MP3	-76,07	-92	-100,5	14,5	-16,1	-24,7	-50,33
MP4	-64,6	-95,9	-97,4	31,1	-35,4	-35,3	-61,24
MP5	-79,16	-83,89	-102,3	8,3	-9,4	-23,2	-54,32
Indoor	-90,15	-110,42	-112,99	16,15	-20,31	-23,31	-62,2

NETWORK PERFORMANCE

➢ Outdoor 5G Performance ->
  w.r.t External Server
  ○ Best
    ■ Download : ~870 Mbps
    ■ Upload : ~110 Mbps
    ■ Latency : ~7 ms
  ○ Best of Avg.
    ■ Download : ~850 Mbps
    ■ Upload : ~102 Mbps
    ■ Latency : ~ 8 ms

Outdoor 5G Network Performance with external Server					
User Equipments			Download [Mbps]	Upload [Mbps]	Latency [ms]
Quectel RM500Q-GL	MP1	Best	718,1	78,3	7,5
		Avg.	708,1	68,3	9,1
	MP2	Best	102,2	73,4	8
		Avg.	78,6	58,7	9,6
	MP3	Best	693,2	53,9	7
		Avg.	671,1	52,2	8,9
	MP4	Best	726,8	75,4	8
		Avg.	707,4	70,3	9,3
	MP5	Best	501,2	57,7	8
		Avg.	487,3	55,3	10,5
Huawei P40 Pro	MP1	Best	707	83,8	8,5
		Avg.	697,4	77,1	7
	MP2	Best	283	70,2	7
		Avg.	279,2	65,8	8,6
	MP3	Best	474	51,6	9,5
		Avg.	320,2	47,9	10,1
	MP4	Best	870	110	8
		Avg.	850,6	102,8	9
	MP5	Best	456	36,4	9
		Avg.	413,4	30,4	9,8
Telit FN980	MP1	Best	353,1	75,8	11
		Avg.	350,6	66	13,6
	MP2	Best	169,6	67,5	10
		Avg.	161,4	64,4	11,6
	MP3	Best	357,8	60,5	9,5
		Avg.	353,3	53,4	11,3
	MP4	Best	353,8	64,7	9
		Avg.	347,7	61,3	11,5
	MP5	Best	354,9	43	10
		Avg.	330	34,7	11,6

NETWORK PERFORMANCE

➢ Outdoor 5G Performance ->
w.r.t Internal Server
- Best
    - Download : ~746 Mbps
    - Upload : ~126 Mbps
    - Latency : ~8 ms
    - Jitter: ~0.5 ms
- Best of Avg.
    - Download : ~740 Mbps
    - Upload : ~111 Mbps
    - Latency : ~9 ms
    - Jitter: ~2 ms

User Equipment			Download [Mbps]	Upload [Mbps]	Latency [ms]	Jitter [ms]
Quectel RM500Q-GL	MP1	Best	739	115	9,1	3,3
		Avg.	727,6	74,7	10,8	4,9
	MP2	Best	98,2	84,5	13,4	1,3
		Avg.	92,2	76,6	14,9	2,7
	MP3	Best	731	59,2	13,4	2,3
		Avg.	718,6	53,9	13,6	3,5
	MP4	Best	747	104	10,4	1,6
		Avg.	738,4	82	11,4	3,7
	MP5	Best	543	68,8	11,2	1,9
		Avg.	526,4	62,7	11,5	3,2
Huawei P40 Pro	MP1	Best	738,2	90,1	9,1	3,4
		Avg.	731,3	83,7	10,1	5,3
	MP2	Best	296,1	102,6	9,1	1,3
		Avg.	293,9	90,6	9,7	2,1
	MP3	Best	602,4	79	8,7	1,8
		Avg.	517,8	59	9,5	3,4
	MP4	Best	746,3	126,6	9,1	2,6
		Avg.	740,2	111,1	9,2	3,3
	MP5	Best	513,2	39	8,5	4,7
		Avg.	473	28,6	10,4	28,4
Telit FN980	MP1	Best	375	74,2	9	3
		Avg.	373,8	69,5	9,5	6
	MP2	Best	177	57,4	12,5	1,2
		Avg.	170	50,3	13,8	3,7
	MP3	Best	376	62,7	9,4	0,5
		Avg.	372,8	57	11,8	2
	MP4	Best	375	74,1	8	4,4
		Avg.	372,8	65,4	9	5,7
	MP5	Best	374	37,5	11,3	1,7
		Avg.	371,6	36	12,3	2,7

➢ Indoor 5G Performance ->
w.r.t Internal Server
- Best
  - Download : ~749 Mbps
  - Upload : ~232 Mbps
  - Latency : ~6 ms
  - Jitter : ~ 1.2 ms
- Best of Avg.
  - Download : ~741 Mbps
  - Upload : ~228 Mbps
  - Latency : ~8 ms
  - Jitter: ~1.5 ms

User Equipment		Download [Mbps]	Upload [Mbps]	Latency [ms]	Jitter [ms]
Quectel RM500Q-GL	Best	749	97	11,4	1,6
	Avg.	741,2	40,9	14,4	3,4
Huawei P40 Pro	Best	732,58	232,6	6,4	1,2
	Avg.	679,7	228,8	7,9	1,5
Telit FN980	Best	376	221	9	3,5
	Avg.	372,8	68,8	9,4	4,4

NETWORK PERFORMANCE

➢ Indoor 5G Performance ->
w.r.t External Server
- Best
  - Download : ~812 Mbps
  - Upload : ~230 Mbps
  - Latency : ~7 ms
- Best of Avg.
  - Download : ~786 Mbps
  - Upload : ~205 Mbps
  - Latency : ~8.7 ms

User Equipment		Download [Mbps]	Upload [Mbps]	Latency [ms]
Quectel RM500Q-GL	Best	812,9	58,8	8,5
	Avg.	786,4	41,9	10,5
Huawei P40 Pro	Best	650	230	7,5
	Avg.	593,6	205,8	8,7
Telit FN980	Best	354,3	36,7	10,5
	Avg.	353,5	29,3	12,2

Evaluation

- ➢ From every measurement point five measurements were made

- ➢ A maximum indoor data throughput of

  - 813 Mbit/s (Quectel chip with external server) in the downlink

  - 232 Mbit/s (Huawei P40 with internal server) in the uplink

- ➢ A maximum outdoor data throughput of

  - peak download rate of 870 Mbit/s (Huawei P40- MP4 - external server)

  - peak upload rate of 126 Mbit/s (Huawei P40- MP4 - internal server)

➢ Data throughput at MP2 is worst despite with good SS-RSRP and SS-SINR

➢ MP5 has the worst signal strength and MP4 has the best signal strength

➢ Throughput reflected accordingly for MP4 but not MP5

➢ Factors that influenced our measurement campaign are

  ○ User related considerations, such as chip set feature integration, antennas(MIMO supported or not) and firmware release

  ○ Network Software versions (both Core and Radio Units)

  ○ Type of UE, Antennas, Weather, Interference from neighbor cells of same network and other network

Summary and future work

➢ A maximum indoor data throughput of 812 Mbps in the downlink and 232 Mbps in the uplink

➢ A maximum outdoor data throughput of 870 Mbps in the downlink and 127 Mbps in the uplink

➢ The measured values are highly dependent on the measurement location and the user equipment

Future work:

➢ To run stress tests on the network by connecting multiple devices to the same cell and stream high definition videos

➢ Throughput test for different download and upload ratios available (currently 4:1 and 7:3, but 6:4 will be possible in the future)

➢ Apart from throughput and test, the network will also be tested with respect to different ongoing use cases at TU Kaiserslautern (Video Streaming, low latency communication for automated guided vehicles and autonomous unmanned aerial vehicles)

Thank you for your attention.

Questions?
OR
Write to us "mallikarjun@eit.uni-kl.de"