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Commercial 5G NPN and PN Deployment Options for Industrial Manufacturing: An Empirical Study of Performance and Complexity Tradeoffs

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***Abstract*—As the manufacturing sector adopts Industry 4.0, the need arises for flexible and highly reliable wireless communication networks. 5G has been designed to support these industrial needs, but choosing the right deployment option is nontrivial. In this paper we empirically measure KPIs of three different commercially available 5G deployment options in the Aalborg University 5G Smart Production Lab and compare them in terms of the KPIs and deployment complexity. Option 1 being fully Non-Public Networks (NPN), option 2 using a private RAN connected to a public EPC through a WAN connection, and option 3 using private RAN and public EPC through IPsec. We find that NPN and PN 5G can deliver comparable performance in terms of latency, throughput and packet loss. As such PN 5G are found to be very competitive with NPN solutions, especially when considering upfront costs and complexity of maintenance. NPN is found to deliver best in class latency while having the advantage of total privacy.**

***Index Terms*—5G, Industry 4.0, Non-Public Network, Public Network, Deployment**

I. INTRODUCTION

With the adoption of Industry 4.0, the manufacturing industry seeks to improve efficiency and productivity by utilizing the latest digitization and automation technologies [1]. One important step in this adoption is to establish reliable and ubiquitous stationary and mobile network communication between the various machines involved in manufacturing in order to control the production, collect data and manage the machinery.

For this network communication between machines, the industry has historically utilized wired field bus communication protocols, due to their reliability and determinism. However, Industry 4.0 focuses on re-configurability and flexibility by utilizing the matrix production and the Autonomous Mobile Robot (AMR) concept [2]. This sets new requirements for the factory networks. Instead of simply connecting some Programmable Logic Controller (PLC), the network must now support mobility in order to maintain connections during factory re-configurations and to support previously unseen use cases such as AMR. Because of this, the industry is starting to adopt wireless technologies such as wireless field bus, Wi-Fi and 5th generation cellular network (5G). In 2021, wireless deployments experienced a 21% growth [3] and accounts for 7% of new connected devices in industry. 5G networks are being deployed by telecom operators throughout the world and the technology is built into a large amount of devices by smartphone manufacturers. Leveraging this large scale 5G technology deployment could therefore potentially lower the deployment cost for the manufacturing industry as compared to more specialized technologies such as wireless field bus. Conversely, inherent properties of 5G such as handover and Quality of Service (QoS) support could offer advantages compared to even more common technologies like Wi-Fi, which historically have had poor handover support [4]. In this paper we will test three commercially available 5G deployments in an industrial context and compare them based on Key Performance Indicator (KPI)'s relevant for industrial manufacturing. The KPIs are high percentile roundtrip time latency, throughput and packet losses measured during mobility and when stationary.

The remainder of this paper is structured as follows: In Section II we discuss the challenges of selecting a 5G network for manufacturing, and the state of the art with respect to industrial 5G deployment. Section III describes the experimental setup, which networks will be tested, the KPIs measured and how the measurements were conducted. Section IV presents and discusses the results. Section V concludes on the findings and what they mean in relation to the deployment of wireless communication in manufacturing.

II. 5G FOR INDUSTRIAL MANUFACTURING

The 5G technology is designed to be flexible in its deployment and configuration [5]. However, from a manufacturing industry perspective, this flexibility naturally raises questions about which specific deployment and configuration should then be chosen for a specific factory [6]. Key factors are not only of technical nature, such as latency and throughput, but also the commercial availability, the complexity of deploying the solution and the price of it. As an example, a green-field deployment of a private 5G core and associated radio facilities at a factory will naturally be more complex and time-consuming than leveraging already established, publicly available infrastructure provided by telecom operators. This is discussed by [7] where the use of NPN are weighed against hybrid deployments. The author highlights that 5G deployments can vary in complexity and price depending on the needs of the factory, ranging from full NPN with built-in edge compute to public networks with public cloud off-loading. [8] covers the various deployment options of 5G, including the considerations regarding trust and security when using public and shared infrastructures. Depending on industry, a factory may have strict confidentiality needs which leans towards usage of NPN or cooperation with trusted network operators. In addition, the author discusses the issues of frequency allocation. Depending on the country, rules regarding frequency availability and bandwidth varies greatly. However, spectrum sharing and subleasing from existing network operators along with unlicensed 5G NR-U are presented as viable and more economical alternatives to full-fledged frequency leasing. At the time of writing, commercial 5G NR-U products are still multiple years away, and can therefore not be considered yet. 5G rollout is now reaching a point of maturity where operators and manufacturers start offering managed NPN and shared spectrum solutions. However, there is a gap in the literature on the performance numbers of such solutions. Until now, most work has focused either on full NPN solutions like in [9] and [10], where private 5G SA and NSA networks are evaluated in terms of baseline performance KPIs, or measurements on public infrastructure [11]. In this paper we seek to fill this gap, by comparing a NPN solution to two commercial, public core solutions currently provided by Telenor Denmark.

The focus will be on KPIs relevant for industrial manufacturing and AMR: high percentile roundtrip time latency, throughput and packet loss. The KPIs will be measured both in stationary and mobile conditions in an indoor industrial environment. During the tests, our measurement device is the only device on the networks, such that the maximum obtainable performance is measured. The primary contribution of this paper is therefore concrete latency, throughput and packet loss measurements that show what can realistically be expected as best case in practice, with and without mobility, from three different, commercially available 5G deployments.

III. EXPERIMENTAL SETUP

A. Test environment and setup

The tests are conducted inside the AAU 5G Smart Production lab, which consists of approximately 1200 m^2 open industrial workshops and laboratories located in Aalborg, Denmark. The lab is equipped with a commercial 5G network operated in collaboration with Nokia and Telenor Denmark. The network consists of an in-house Nokia Mxie 5G SA core, a Nokia airscale baseband unit and 2x3 Nokia AirScale indoor Radio (ASiR). 3 ASiR are used for transmitting the 5G NR and 3 are for Telenor's 4G. The ASiR are mounted in the ceiling, approximately 6 meters above the ground. Each radio is positioned to cover roughly 1/3 of the factory floor and receives and transmits signals from/to 4 different 4G cells with 4 different EARFCN (E-UTRA Absolute Radio Frequency Channel Number) as well as from/to one 5G cell in Band N78. As all 5G radios emit the same cell, handovers will never occur during mobility. Fig. 1 shows a Light Detection And Ranging (LiDAR) floor plan of the lab where the physical location of the radios are highlighted in green rectangles.

The 5G baseband unit is configured to use the in-house 5G SA core in parallel with Telenor's public EPC. This makes it possible to host two 5G networks which coexist in the same N78 (3710 MHz) frequency space as a Multi-Operator Core Networks (MOCN). With such a configuration we can fairly compare multiple 5G deployments, since we can utilize the same Radio Access Network (RAN) for all tests. The in-house 5G SA core provides a private network for AAU, while the public EPC provides access to Telenor's public network. The 5G RAN is configured as Time Division Duplex (TDD) with an UL/DL slot ratio of 3/7 and 100 MHz bandwidth.

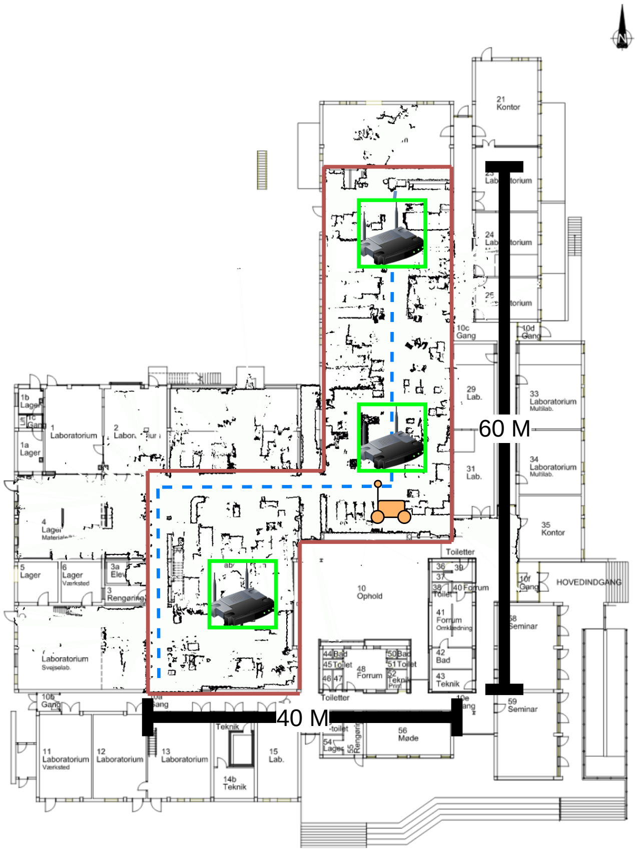

Fig. 1. Floor plan including clutter. The lab floor area is highlighted in red. Ceiling mounted 5G cell locations are marked in green boxes. The AMR stationary location is marked as an orange car. AMR route is marked as a dotted blue line.

The 5G network in the lab is thereby configured to operate in 3 different deployments, which are illustrated in Fig. 2. The options are listed in order of decreasing deployment complexity and cost:

1) NPN 5G SA - Red line: User- and control-plane traffic is terminated directly at the in-house 5G core. User plane data is then routed into the lab network. The radio spectrum is shared between this 5G SA in-house core and the public EPC, i.e. defining a typical MOCN Private Network scenario, where user- and control-plane traffic and subscriber data remain inside the premises, but a generic Telenor customer SIM card can still use the same radio resources to access the public EPC.

2) PN 5G Non-Stand-Alone (NSA) (WAN) - Black line: User- and control-plane traffic is routed via a dedicated fiber line outside the lab, to Telenor's closest site. The traffic then travels along Telenor's private fiber network until it is terminated in the Telenor public core, approximately 5 km from the lab. From there, the user-plane traffic is returned along Telenor's private fiber network into the lab via a Multiprotocol Label Switching (MPLS) solution, along the same path it exited. In this deployment, the user-plane traffic is never routed via the internet.

3) PN 5G NSA (IPsec) - Teal line: The User- and control-plane traffic follows the same route as described in the previous scenario until it reaches the public core. From there, the user-plane data is then routed from the core into a secure IPsec tunnel back to the lab over the internet.

In an SA deployment, both user-plane traffic and control-plane traffic is handled by the 5G layer. In a NSA deployment, the control-plane traffic is handled by the 4G layer, and only user-plane data is handled by the 5G layer. Currently, the public core from Telenor is an 4G EPC and therefore does not support SA operation. 5G on the Telenor network will therefore run in NSA mode.

Access Point Name (APN) selection by the UE is used to control both the IP address allocation pool for the UE and the routing towards either the WAN or IPSec route for the two 5G NSA deployments. The experiments in this paper uses the indoor RAN in the lab only, which means that no Telenor customers outside the building will interfere with the indoor RAN or use its capacity. The PN 5G NSA deployments do not have any special QoS applied.

The User Equipment (UE) used to perform all measurements was an embedded single board computer from Gateworks, the GW6400[12] running Ubuntu 22.04 with Linux kernel 5.10.18[13]. The GW6400 is equipped with a Simcom SIM8202G-M2 5G multi-band modem and dual SIM cards. One SIM card is for the NPN 5G SA network, while the other SIM card is for the PN 5G NSA networks. Only one SIM will be active at any given time during the tests, and switching between the PN 5G NSA deployments is done through APN configuration on the UE.

Mobile measurements are performed using a MiR200 [14] AMR, with the GW6400 placed on top. The MiR200 is a commercially available AMR, designed for indoor transport and logistical tasks. It can carry a payload of up to 200 kg and autonomously navigate using LiDAR, encoders and inertial measurement units. For these tests, we use the AMR as a mobile test platform to provide power for our GW6400 and for programmable and repeatable movement through the laboratory. During the measurements, the MiR200 will traverse the Smart Production lab at 1 m/s in a loop, following the path indicated by the blue line on Fig. 1. One round trip of the lab takes approximately 3 minutes and 30 seconds. Measurements are done resembling operational conditions in a real factory. The stationary case resembles, for example, the connectivity of a PLC in a stationary production module; the mobile case is representative of a real AMR performing autonomous transportation of goods across the factory hall.

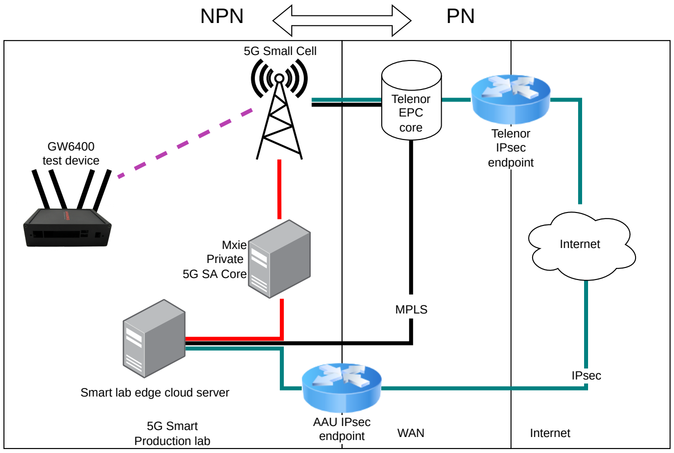

Fig. 2. Block-diagram showing the three network deployments and how the data paths between the GW6400 measuring device and the Smart lab edge cloud server.

B. KPIs used to characterize network performace

The KPIs measured during this campaign are as follows:

Throughput: Iperf3 [15] is used to generate and measure the transport layer throughput performance of the 5G network deployments. This will be used to measure both downlink and uplink throughput independently. An iperf3 server is configured on the edge cloud server, and the GW6400 acts as a client, initiating all tests. To test the raw available throughput, iperf3 is configured to perform throughput tests using User Datagram Protocol (UDP), and use the default packet size of 1460 bytes. In UDP mode, the user must provide a target throughput which iperf3 will try and achieve if possible. For our measurements, we set the target throughput to 1 Gb/s since the back haul on both the private and public core networks are limited to 1 Gb/s. The throughput measurements of downlink and uplink have a runtime of 1 hour each, which provides 3600 samples due to iperf3 reporting throughput over 1 second intervals.

Latency: Using the ping utility from iputils [16] we measure roundtrip latency from the GW6400 to our edge cloud server, and back. The tool is configured to transmit Internet Control Message Protocol (ICMP) echo requests at 100 Hz, with a payload size of 64 bytes and preload of 100 packets. A request frequency of 100 Hz ensures that the 5G modem does not enter low power mode between requests, which would negatively impact measurements. Preloading 100 packets instructs ping to keep up to 100 packets in flight at a given time. This helps ping keep a constant 100 Hz packet frequency when long delays are encountered. To ensure statistically significant measurements, we run the measurements until ping has transmitted at least 1 million requests.

Packet loss: Based on packet statistics from the latency measurements, we count how many packets were lost during any given measurement campaign. Packets loss is counted by reading the output from the ping utility after a completed measurement. This includes how many ICMP packets were sent and how many replies have been received. Based on the difference we can determine how many packets was lost.

IV. RESULTS AND DISCUSSION

In this section we will present the measured results in the following order: Throughput, latency and packet loss statistics.

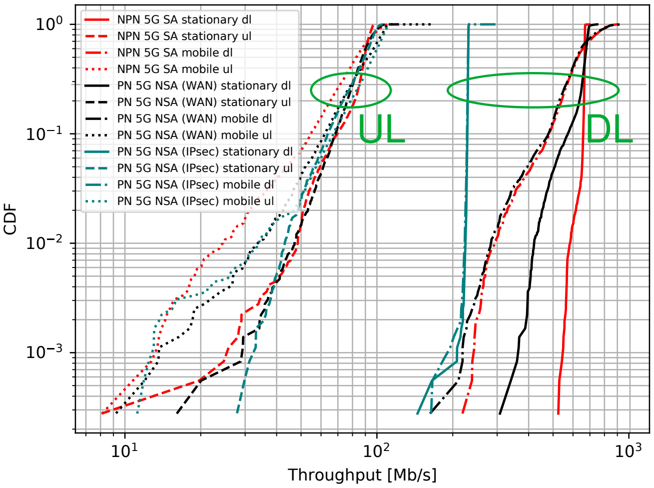

Fig. 3. Throughput results.

TABLE I
THROUGHPUT. ALL RESULTS ARE GIVEN IN MEGABITS PER SECOND

Deployment	Min	Median	99%	Max
NPN 5G SA stationary dl	524.64	666.69	584.72	697.92
NPN 5G SA stationary ul	8.08	89.28	48.52	99.68
NPN 5G SA mobile dl	218.49	626.66	294.24	903.11
NPN 5G SA mobile ul	8.12	82.75	24.51	110.77
PN 5G NSA (WAN) stationary dl	307.79	671.01	420.80	748.37
PN 5G NSA (WAN) stationary ul	16.07	87.45	47.15	123.69
PN 5G NSA (WAN) mobile dl	162.43	621.30	283.91	950.78
PN 5G NSA (WAN) mobile ul	9.22	92.13	33.89	165.65
PN 5G NSA (IPsec) stationary dl	144.91	230.11	224.66	231.67
PN 5G NSA (IPsec) stationary ul	27.85	89.21	43.17	105.46
PN 5G NSA (IPsec) mobile dl	164.18	229.95	223.15	296.63
PN 5G NSA (IPsec) mobile ul	11.19	96.54	34.04	112.55

A. Throughput

Let's first analyze the throughput results, as observed for the tests of the 5G deployment combinations. We will describe the results for each deployment individually with respect to stationary and mobile throughput, then we will compare the throughput values observed between the different deployments. Fig. 3 shows a CDF of each measurement campaign, which consists of 3600 throughput samples. During the mobile tests the robot completed 15 full round-trips of the lab. The results are summarized in Table I.

1) NPN 5G SA: NPN 5G SA shows a high degree of consistency in DL throughput when stationary with a minimum throughput of 524.64 Mb/s. The uplink throughput while stationary is significantly less with a minimum of 8.08 Mb/s. This is partly due to the TDD uplink/downlink slot ratio, which is configured to 3/7 in the baseband unit and partly because the Simcom 8300 modem does not support UL multiple-input and multiple-output (MIMO). When mobility is introduced we observe higher variability in the throughput of 5G SA, which is expected due to more dynamic propagation conditions. This results in higher maximum throughput. Conversely, mobility causes a significant reduction in 99% throughput.

2) PN 5G NSA (WAN): The PN 5G NSA (WAN) deployment shows similar DL throughput as the NPN 5G SA deployment in the stationary tests in terms of maximum and median throughput. Some deviation is observed in the tails where the PN 5G NSA (WAN) falls to 420.80 Mb/s at the 99%. In terms of UL throughput, PN 5G NSA (WAN) shows similar results to 5G SA, with a 99% throughput value of 47.15 Mb/s. Likewise, when mobility is introduced, the observed results appear to follow the same trend as seen on the NPN 5G SA deployment. The high similarity is expected, since both PN 5G NSA deployments uses 5G for user plane data transport and should therefore perform similarly, all things being equal.

3) PN 5G NSA (IPsec): Lastly, the PN 5G NSA (IPsec) deployment clearly shows that we are hitting a throughput limitation in the DL results close to 230 Mb/s. This is evident both in stationary and mobile tests. This limitation is caused by the AAU router where the IPsec tunnel terminates and is caused by a capacity limitation. Because of this limitation, we do not see a significant difference between stationary and mobile tests in the DL direction, since the connection is throughput-limited to a value below what the radio link can handle. UL results for PN 5G NSA (IPsec) are similar to the other tested deployments. In the UL case, the radio link throughput is well below the IPsec limitation, and we are able to measure the true throughput like for the previous two tests.

4) Summary: Overall, the throughput observed from both the NPN 5G SA and PN 5G NSA (WAN) deployments are similar. This is expected because all three deployments share the same baseband unit, radio spectrum and bandwidth. In the PN 5G NSA (IPsec) deployment we observed a bottleneck which limited high throughput. The limitation was not inherently caused by 5G NSA or IPsec, but rather a capacity limitation in the IPsec endpoint at AAU. The PN 5G NSA (IPsec) deployment would be expected to deliver similar throughput results as the other two 5G deployments, however practical limitations prevents us from reaching these high throughput numbers. For an end-user with high DL throughput requirements, either deployment option will fit well and will provide near identical performance. While the results show

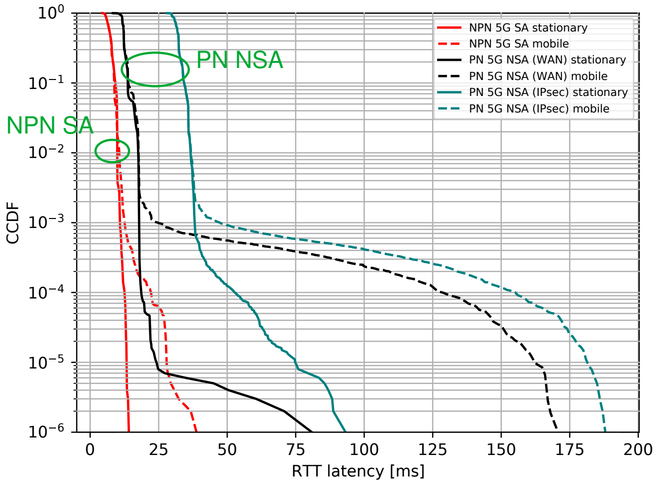

Fig. 4. Latency CCDF.

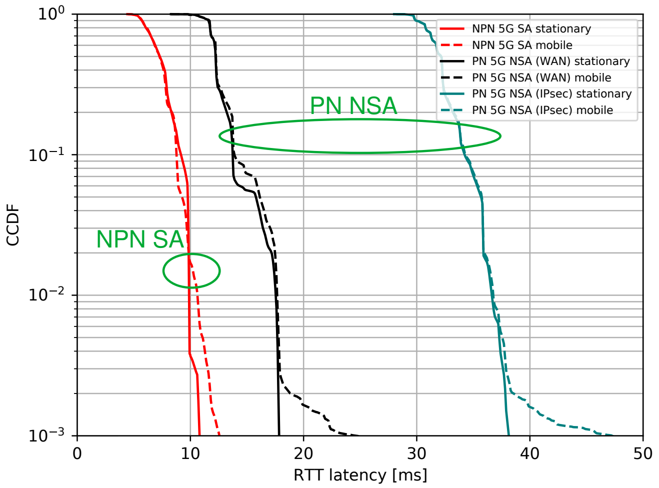

Fig. 5. Latency CCDF with focus on the top 99.9%.

limited throughput for PN 5G NSA (IPsec) it does deliver a consistent throughput because of the underlying 5G NSA radio link. From performance-complexity point of view, PN 5G NSA (WAN) and PN 5G NSA (IPsec) are enticing options, because of the competitive performance and lower complexity when compared to the NPN 5G SA deployment.

TABLE II
LATENCY. ALL RESULTS ARE GIVEN IN MILLISECONDS

Deployment	Min	Median	99.99%	Max
NPN 5G SA stationary	4.43	7.32	12.60	14.8
NPN 5G SA mobile	4.50	7.28	22.20	43.2
PN 5G NSA (WAN) stationary	8.28	12.30	18.70	91.0
PN 5G NSA (WAN) mobile	8.27	12.30	129.00	176.0
PN 5G NSA (IPsec) stationary	28.00	32.20	52.81	93.7
PN 5G NSA (IPsec) mobile	28.20	32.20	156.00	191.0

B. *Latency*

We will now present the latency results obtained. Fig. 4 shows CCDF plots of the latency measurements and the key values are summarized in Table II. Fig. 5 shows a zoomed in CCDF plot, of the latency measurements down to 10^{-3}.

1) NPN 5G SA: Generally, NPN SA delivers the lowest round-trip latencies both when stationary and mobile. This is expected, since the end-to-end data path is significantly shorter than for the other tested 5G deployments. The latency when stationary is highly consistent, never exceeding 14.8 ms. During mobility tests we observe higher variance in the lower percentiles, which is expected due to the more dynamic radio conditions.

2) PN 5G NSA (WAN): PN 5G NSA (WAN) delivers the second-lowest latencies, with the minimum being 8.28 ms when stationary and 8.27 ms during mobility.

In the stationary test we observe similar trends as for the NPN SA, but with a constant latency offset due to the longer end-to-end data path and PN NSA deployment. As the data path is only increased by less than 10 km and as less than 10 additional router hops are introduced, the latency offset is expected to contribute less than 1 ms to the results. In case the AAU and the Telenor public core were located further away geographically, this latency would have been higher.

With mobility, we observe larger tail latencies below 10^{-}3. It is unknown what causes these increased latencies, but they can be caused by reconfiguration or handovers on the LTE layer. Since we only see this tail during mobility we can conclude it is unlikely to be related to the back haul, and instead likely caused by unintended interactions between the modem and RAN. We expect this to be a bug which can be fixed in future software releases.

3) PN 5G NSA (IPsec): The trends we see in the PN 5G NSA (IPsec) deployment are similar to the PN 5G NSA (WAN), but with an additional constant offset in latency on approximately 20 ms. This offset is expected for the specific path, as the Telenor and AAU networks only exchange Internet traffic in the far end of Denmark. This causes the traffic to travel over a larger geographical distance than in the NSA WAN deployment, which is important latency wise as light in fiber only travels approximately 200 km/ms. This is, however, not an unrealistic scenario for a practical deployment where traffic is exchanged between different operators.

Once again we see the same large latency tail during mobility. The trends appear similar to the PN 5G NSA (WAN) deployment and are therefore likely to have the same root cause.

4) Summary: In both stationary and mobile tests, NPN 5G SA delivers the lowest latency and the lowest jitter. As mentioned before, this is expected since the whole network is hosted in-house. Fig. 5 shows that PN 5G NSA follows the same trends as NPN 5G SA down until 10^{-}3. The two PN 5G NSA deployments, show larger tail latencies which can affect latency sensitive applications. We expect the tails to be caused by LTE handovers during mobility or software issues in the modems which can be fixed in the future. For end-users with strict latency requirements, NPN 5G SA is the best option, with PN 5G NSA (WAN) as a strong second when stationary and in the upper percentiles. For mobility the root cause of the longer latency tails will need to be identified and solved. The PN 5G NSA (IPsec) deployment benefits from the same low jitter as the two other options, however the base latency is significantly higher, due to a much longer data path. From this we can conclude that the internet has little impact on jitter.

TABLE III
PACKET LOSS STATISTICS

Deployment	Sent	Received	Loss
NPN 5G SA stationary	1001000	1000999	1
NPN 5G SA mobile	1000002	999999	3
PN 5G NSA (WAN) stationary	1000000	999997	3
PN 5G NSA (WAN) mobile	1065641	1065637	4
PN 5G NSA (IPsec) stationary	1000000	999989	11
PN 5G NSA (IPsec) mobile	1017085	1017076	9

C. *Packet loss*

Lastly, we will present the packet loss statistics. These are obtained from the statistics summary output by the ping utility.

In all tests we observe very low packet loss, which is expected from the favorable radio conditions and built in re-transmissions of 5G. In all test cases we see similar losses, with PN 5G NSA (IPsec) topping out at 11 lost packets. However, the loss is generally low and we do not believe this difference is significant, nor can be generalized.

1) Summary: The 3 different deployments perform similarly in all tested conditions, with the IPsec deployment as a slight outlier. In all cases we see remarkably low packet losses which bodes well for the use of 5G in high reliability situations. In addition, it is positive to see that a public core does not significantly affect reliability, despite having to share resources with other customers.

D. *Overall recommendations*

For use cases and applications with strict throughput-, latency- and packet loss-requirements, PN 5G is a strong option. In terms of throughput, PN 5G delivers the same capacity as NPN 5G. For latency, we see a small difference in minimum and median latency, between NPN 5G SA and PN 5G NSA (WAN), however this difference is so small that it is unlikely to matter in most real world applications. It is worth keeping in mind that our latency measurements on PN 5G NSA (WAN) are close to ideal, due to the lab's close geographical proximity to Telenor. Real world deployments may be less fortunate and experience higher back-haul latencies. Lastly, in terms of packet losses, we see no significant difference between the deployments in terms of reliability of packet delivery where all solutions exhibit low packet losses. With much of the network managed by the public operator, up front costs will be low, and the installation will be simple. Overall, the PN 5G deployments delivers good performance for the complexity. However, we do see that NPN 5G SA delivers best in class latency, independent of network operators, which makes this deployment type best suited for the strictest latency requirements. In addition, it is important to acknowledge that NPN 5G provides better privacy since all communication stays inside the premises. In a PN 5G deployment, traffic will necessarily have to go through a third party transit network, i.e. the network operator. For some industries with extremely strict privacy requirements, such as R&D or, weapons development this may not be acceptable and NPN 5G will be a necessity.

V. CONCLUSION

In this paper, we have empirically compared the network KPIs of three different, commercially available 5G deployments in stationary and mobile scenarios. The data is obtained in an industrial lab environment which guarantees physical manufacturing operational conditions.

Our results show that the three tested 5G deployments perform similarly in terms of throughput. The type of access technology, whether being NPN 5G SA or 5G NSA, appears to have little to no impact on the observed throughput. PN 5G NSA (IPsec) showed the lowest DL throughput due to a bottleneck in the VPN tunnel. This is expected to be specific to the setup used in our tests and therefore not an inherent characteristic of the PN 5G NSA (IPsec) deployment. For applications purely focusing on throughput heavy tasks, any of the three tested deployments are strong options for providing wireless access to a factory.

In terms of latency we generally observed similar trends across the compared deployments. NPN 5G SA and PN 5G NSA (WAN) generally performed very similar while PN 5G NSA (IPsec) had a higher constant latency delay added due to the longer data path. During mobility the 5G NSA deployments show longer latency tails. This is expected to be anomalies and caused by the testing equipment. For latency critical tasks, either NPN 5G SA or PN 5G NSA (WAN) are good options and will generally perform similarly, while PN 5G NSA (IPsec) will generally show longer latencies and therefore is a weaker option for latency critical tasks.

Finally, in terms of packet losses all three deployments showed high levels of reliability and thus low packet losses. The access technology and core back haul does not matter here, and all deployments show good performance in this area. This means all three deployments can be recommended for high reliability tasks where consistent data delivery is important.

In summary, NPN 5G SA shows very strong performance in the measured KPIs however it is also by far the most complex and expensive solution for end users. PN 5G NSA (WAN) comes close to deliver the same performance for a significantly lower price point and complexity level. PN 5G NSA (IPsec) likewise shows very strong performance in terms of throughput and reliability, but suffers longer latencies due to the longer data path. Generally this shows that a public core configuration is quite competitive with NPN solutions even when the public network uses an EPC.

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