Evaluation of 5G NR-Light and NR co-existence network performance at FR2

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Abstract—The grand objective of 5G networks is to support very high data rates in view of the tremendous growth in connectivity and density/volume of traffic that will be required in the near future. However, increasing throughput requires increased device implementation complexity and cost that are not suitable or feasible for mid-market Internet of Things (IoT) devices, such as wearables, video surveillance cameras, and industrial sensors. To address the above market use cases, the research community is exploring a simpler and lighter version of the 5G standard, which is usually referred to as NR-Light. Specifically, NR-Light will need to satisfy higher data rate, improved reliability, and lower latency than current IoT technologies, while guaranteeing lower cost/complexity, longer battery life, and wider coverage than standard 5G solutions.

I. Introduction

The concept of NR-Light devices – also known as reduced-capability (REDCAP) devices – is introduced in Rel-17 [1]. The idea is to give up on extreme low cost and low power features of current IoT devices in order to attain medium data rates and lower latency and higher reliability than the first. In other words, the NR-Light standard will fill the void between IoT and full NR use cases, as depicted in Fig. 1. In particular, a REDCAP User Equipment (UE) can feature a reduction of the minimum user bandwidth, fewer antenna elements, and less transmit power compared to a full NR UE.

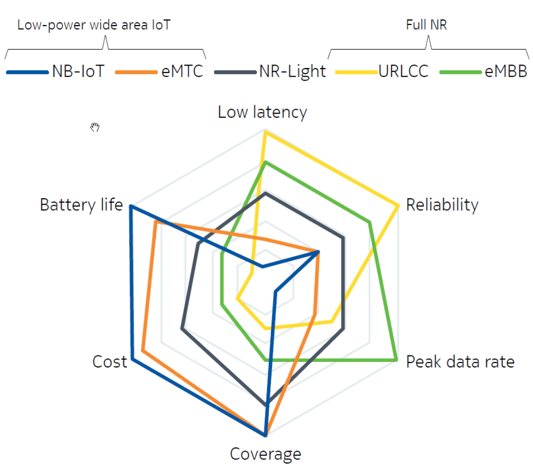


Fig. 1: Expected capabilities of NR-Light devices. [2]

II. Simulation scenario

The aim of this analysis is to evaluate the co-existence of NR and NR-Light devices. In particular, we make use of the network simulator ns-3 to setup a simulation of a cellular environment with a single Next Generation Node Base (gNB) and a fixed number of devices working at millimeter wave (mmWave) frequencies. There are two types of UE: NR devices, which downloads enhanced Mobile Broadband (eMBB)-like traffic, and NR-Light, which are of three classes: Mobile Robot (MR), data sensor, and video alarm. A data sensor device has been equipped with a constant packet size FTP application with rate 500 kbps in Uplink (UL) and a video alarm has been equipped with a constant bitrate UDP application with rate 10 Mbps in UL. Instead, a MR has been equipped with a constant bitrate UDP application with rate 10 Mbps in UL for the video stream and a constant bitrate UDP application with rate 500 kbps in Downlink (DL) to issue commands to the device. First of all, we want to differentiate between the 3rd Generation Partnership Project (3GPP) scenarios, "Sparse High" (SH) and "Dense High" (DH) [3]: in the first case the clutter density is lower than 40%, while in the second it is higher than 40%, but for both of them the gNB is positioned above the obstacles. Then, each simulation has a fixed number of NR-Light and Ultra Reliable and Low Latency Communications (URLLC) devices, while the number of eMBB devices varies in the set $[2, 4, 6, 10]$. The same configuration will be simulated for 15 times. The most important Key Performance Indicator (KPI) of an eMBB UE is the DL throughput, whereas for an URLLC UE the key KPIs are latency and packet loss. In particular, both of them have been implemented in NS-3 as constant bitrate UDP applications, the first with target rate 100 Mbps in DL, whereas the second with desired rate 500 kbps in UL. With this scenario, we simulate three NR-Light configurations, each with different relaxations of the 5G NR specifications and offering different cost and power consumption/performance trade-offs: low, mid, and NR.
Each simulation will have a set of common parameters, that are listed in Table I:

TABLE I: Common simulation parameters.

Parameter name	Parameter value
Carrier Frequency	28 GHz
User bandwidth	200 MHz
Number of antennas at gNB	64
Number of antennas at NR UE	16
Number of MRs	2
Number of data sensors	2
Number of video alarms	2
Number of URLLC devices	4
Simulation time	10 s
App cooldown time	1 s

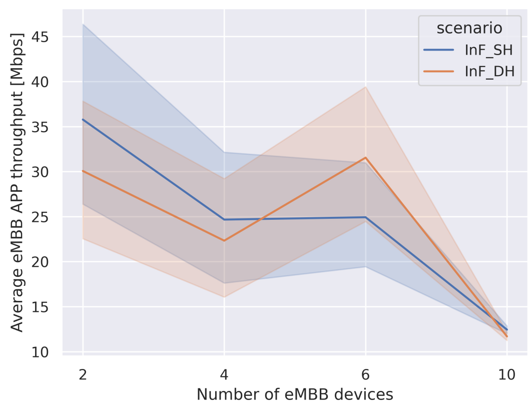
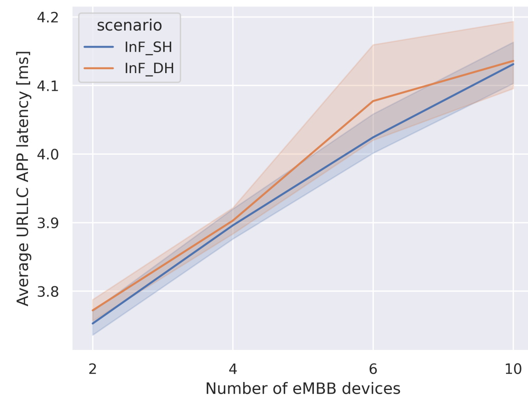
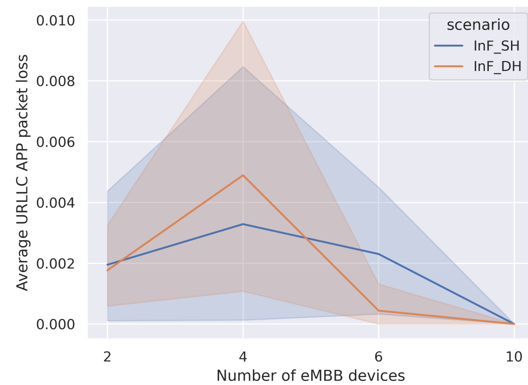


Fig. 2: Average eMBB APP throughput with NR-Light low configuration.



(a) Average URLLC APP latency with NR-Light low configuration.



(b) Average URLLC APP packet loss with NR-Light low configuration.

Fig. 3: URLLC statistics with NR-Light low configuration.

III. Simulations

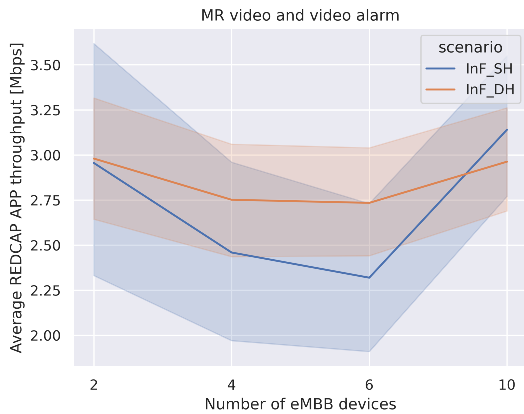
A. NR-Light low configuration

REDCAP devices have: 1 antenna, 50 MHz of bandwidth, 13 dBm of transmit power, and max MCS index 9. As specified in Section II, for eMBB devices we will concentrate uniquely on the DL throughput. Fig. 2 depicts the average Application (APP) throughput with a Confidence Interval (CI) at level 95% for every scenario and configuration. The desired rate is not achieved in any case. In the SH scenario (blue line), with only 2 eMBB devices the average rate is roughly 35 Mbps, with 4 and 6 eMBB UEs it is of 25 Mbps, while with 10 eMBB UEs it collapse to 12 Mbps, roughly. The DH scenario presents a similar curve: it ends up almost at the same point of the SH scenario, but it starts at 30 Mbps. Instead, for an URLLC UE we inspect the latency and the packet loss. In Fig. 3a is represented the average APP latency with CI at level 95%. Here we see that, even though the latency has an increasing trend, it remains under 5 ms, in both scenarios. Instead, In Fig. 3b it is depicted the average APP packet loss with CI at level 95%. The packet loss should be as little as possible, ideally zero, especially for URLLC devices. And in fact we have nearly zero loss rates in both scenarios and with any number of eMBBs. For a NR-Light UE we take into account UL APP throughput, latency and packet loss as KPIs. In Fig. 4a and Fig. 4b it can be seen that the average rate of the MR and video alarm UEs is lower than their target rate, in all cases and scenarios. Some problems can be also noticed in Fig. 4c and Fig. 4d: even though those two KPIs are not crucial in such type of devices, with 10 eMBB devices the latency goes up to almost 500 ms in the SH scenario, whereas in the DH scenario it reaches 700 ms. Moreover, the packet loss is as high as 0.24 and 0.275 in the SH and DH scenarios, respectively.

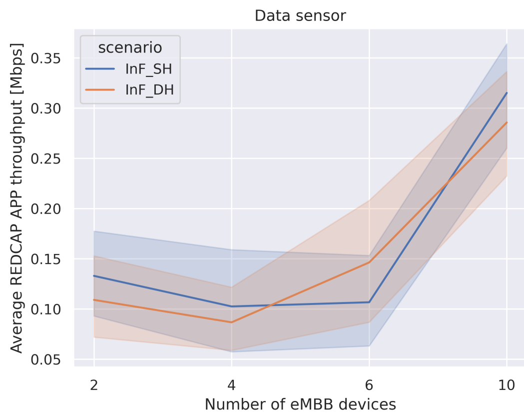
B. NR-Light mid configuration

We repeat the same analysis with REDCAP devices having now: 4 antennas, 50 MHz of bandwidth, 18 dBm of transmit power, and max MCS index 9. By inspecting Fig. 5, it can be seen that now in the SH scenario the average eMBB APP rate is approximately 80 Mbps with only 2 eMBB UEs, with 4 and 6 eMBB devices it stays more or less constant around 70 Mbps, but with 10 eMBB UEs it collapses to roughly 15 Mbps. In the DH scenario this performance degradation is even stronger. Instead, from Fig. 6a, and Fig. 6b, it seems that the URRLC average APP latency and packet loss are similar to the results obtained in the NR-Light low configuration.

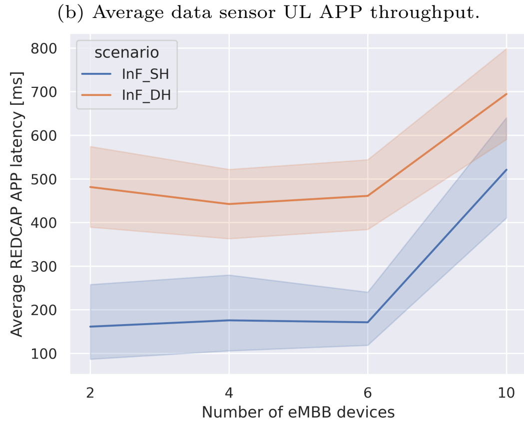
However, if we now take a look at Fig. 7a, the average rate of MR and video alarm devices is much closer to the desired rate in the SH scenario, while the DH scenario the curve is just shifted downwards with respect to the first curve. In Fig. 7b we can see that the MR commands average rate is better than the NR-Light low configuration. Also the latency is significantly lower: in the SH scenario



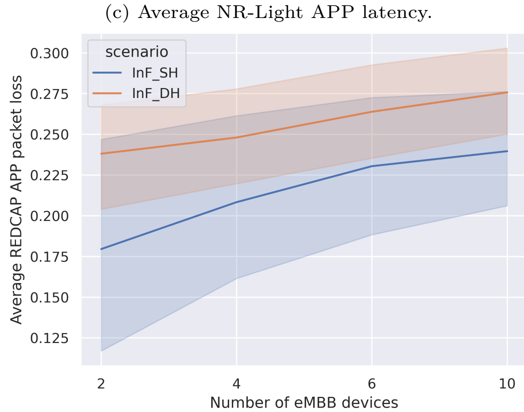
(a) Average MR and video alarm APP throughput.



(b) Average data sensor UL APP throughput.



(c) Average NR-Light APP latency.



(d) Average NR-Light APP packet loss.

Fig. 4: REDCAP statistics with NR-Light low configuration.

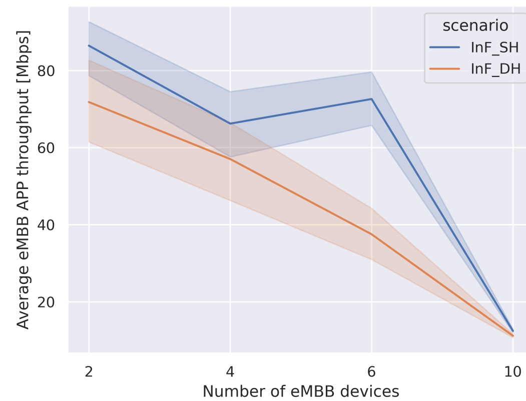
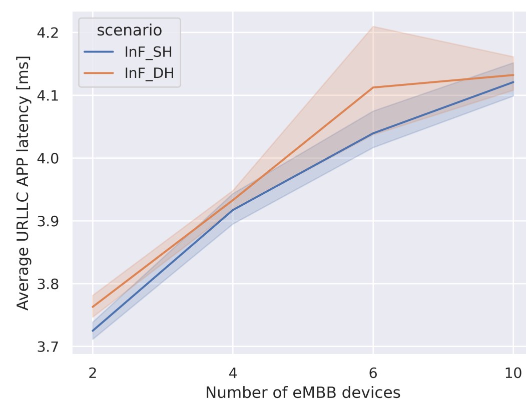
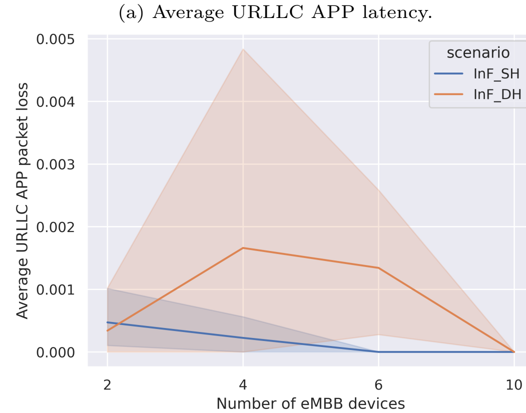


Fig. 5: Average eMBB APP throughput with NR-Light mid configuration.



(a) Average URLLC APP latency.



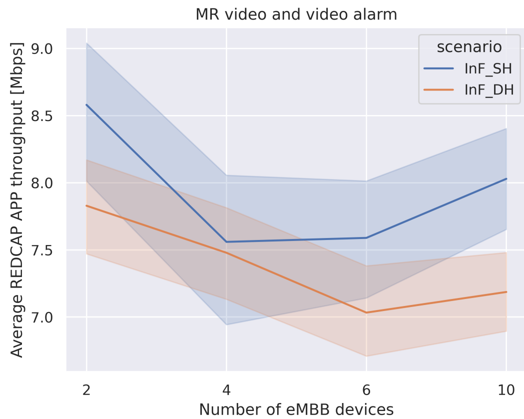
(b) Average URLLC APP packet loss.

Fig. 6: URLLC statistics with NR-Light mid configuration.

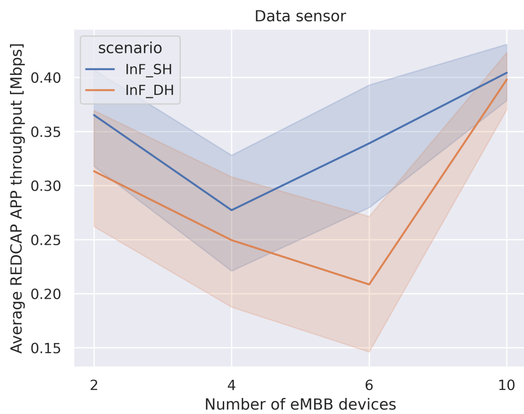
it starts from as little as 25 ms and it remains stable until 6 eMBB devices before jumping to nearly 120 ms with 10 eMBBs. In the DH scenario the curve is just shifted upwards, reaching about 225 ms in the worst case. Finally, the packet loss is improved, too: in the SH scenario it remains under 0.03, while in the DH scenario it stays below 0.06 in the worst case.

C. NR-Light High configuration

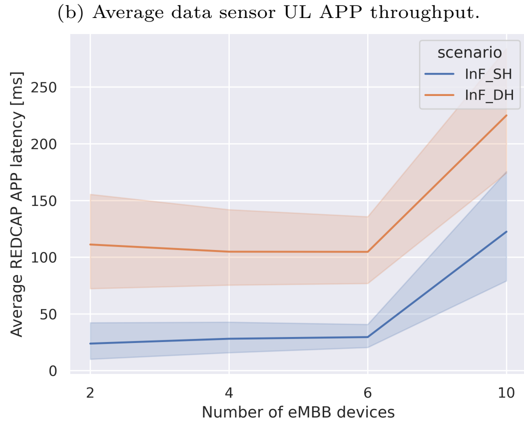
Finally, we inspect the performance of the REDCAP high configuration which features the same characteristics



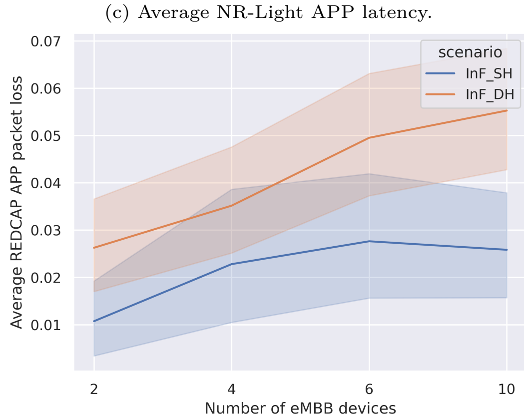
(a) Average MR and video alarm UL APP throughput.



(b) Average data sensor UL APP throughput.



(c) Average NR-Light APP latency.



(d) Average NR-Light APP packet loss.

Fig. 7: REDCAP statistics with NR-Light mid configuration.

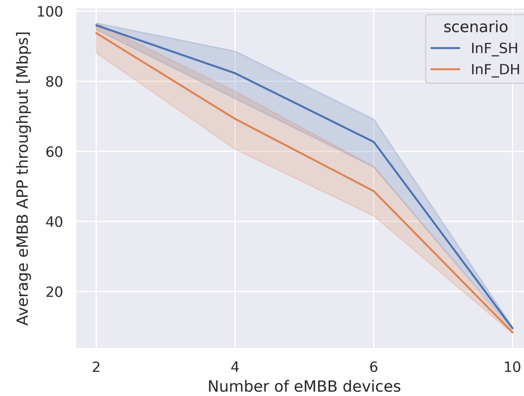


Fig. 8: Average eMBB APP throughput with NR-Light high configuration.

of NR devices, that are: 16 antennas, 200 MHz of bandwidth, 23 dBm of transmit power, and max MCS index 28. Judging by Fig. 8, eMBB UEs can achieve higher rates with respect to the NR-Light mid configuration, in general. For example, with only 2 eMBB devices the average throughput is approximately 90 Mbps, quite close to the target rate. However, the eMBB data rate with 10 of them seems to be slightly less than the NR-Light low and mid configurations. Instead, MRs and video alarms also are almost reaching their target rate with only 2 eMBB devices in the SH scenario, as shown in Fig. 10a. Moreover, the latency of the NR-Light UEs is now below 15 ms overall, and their packet loss is generally almost zero. The URRLC statistics are practically the same, instead.

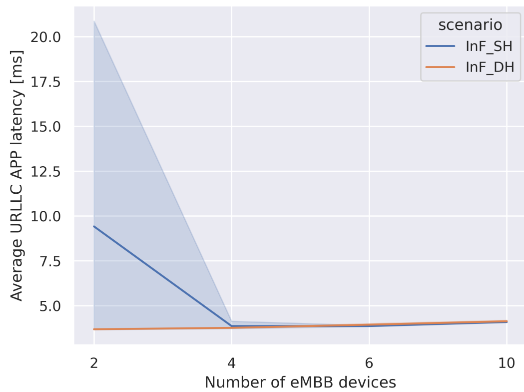
IV. Conclusions

In this article we simulated a use case in which the REDCAP and NR devices co-exist in the same bandwidth in order to find an NR-Light configuration that reduces the cost and complexity of such devices but that provides good enough throughput, latency, and packet loss, while not interfering too much with present NR devices at the same time.

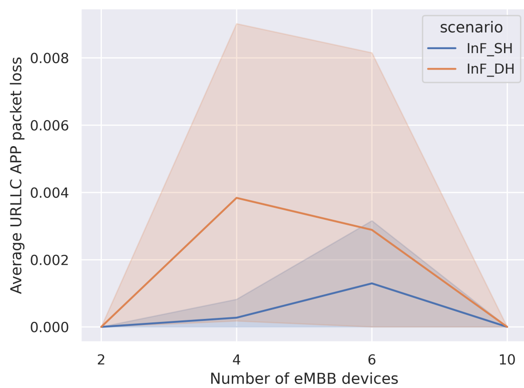
The results show that with the extreme set of reductions, the actual average rate of the MR and video alarm devices is lower than the desired rate and in addition the average APP packet loss is quite high in both scenarios, especially with 10 eMBBs. This is due to the fact that most of the transmitting power, which is already low, is not directed towards the intended receiver, due to the lack of beamforming.

On the other hand, NR-Light mid devices feature an increased transmission power and 4 antenna elements. Now the transmitting power can be directed along a certain direction. Thanks to this, the packet loss is quite small in every case, the latency is reduced by about 3 times in the worst case (10 eMBB in DH scenario) compared to the previous configuration, and the NR-Light throughput is closer to the desired rate.

Finally, NR-Light devices which do not feature any reduction of capabilities with respect to a typical NR UE



(a) Average URLLC APP latency.



(b) Average URLLC APP packet loss.

Fig. 9: URLLC statistics with NR-Light high configuration.

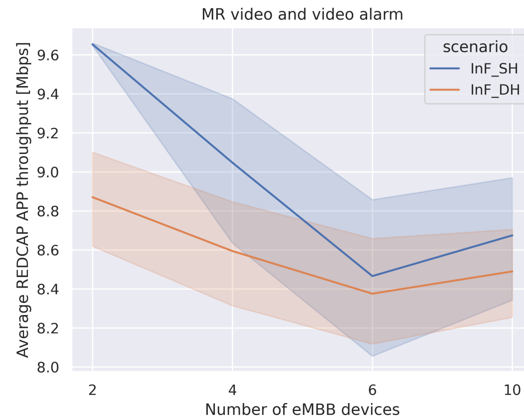
can satisfy their Quality of Service (QoS) requirements. Moreover, since we do not make use of CA anymore, REDCAP and NR devices do not interfere one with the other. Thus, the average eMBB rate is higher with 2, 4 and 6 of them, while for 10 eMBB devices the average throughput is slightly worse than the two previous configurations. This is due to the fact that now the NR-Light devices are now enjoying a greater data rate. However, this configuration might be too costly and too power hungry for a NR-Light use case. Therefore, the ideal configuration for such devices is the NR-Light mid, which offers the best trade-off between performance and complexity.

References

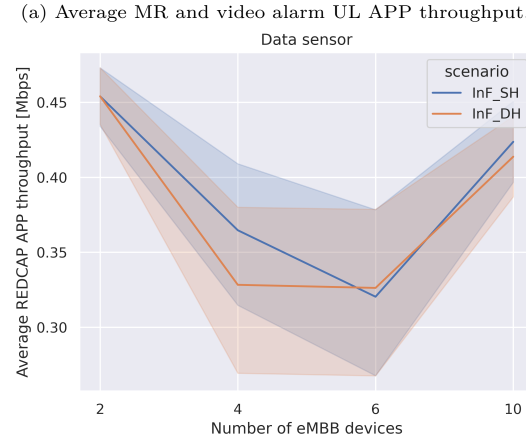
[1] 3GPP, “Study on support of reduced capability NR devices,” 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.901, Mar 2021, version 16.1.0.

[2] Nokia Bell Labs, “5G releases 16 and 17 in 3GPP,” 2020. [Online]. Available: https://www.bell-labs.com/institute/white-papers/5g-releases-16-and-17-3gpp/

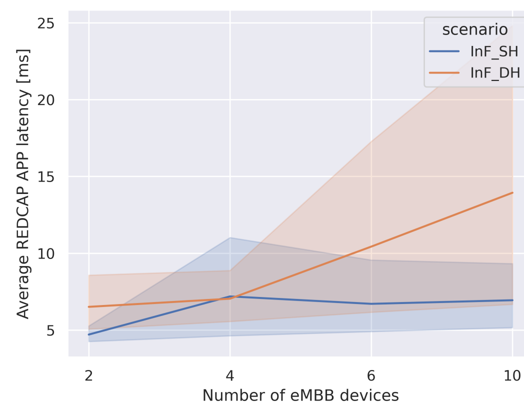
[3] 3GPP, “Study on channel model for frequencies from 0.5 to 100 GHz,” 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.901, Dec 2019, version 16.1.0.



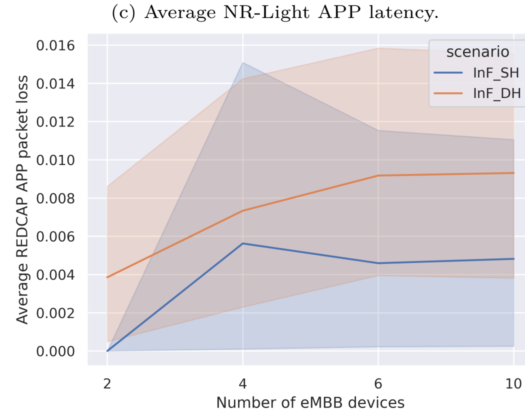
(a) Average MR and video alarm UL APP throughput.



(b) Average data sensor UL APP throughput.



(c) Average NR-Light APP latency.



(d) Average NR-Light APP packet loss.

Fig. 10: REDCAP statistics with NR-Light high configuration.