More Capacity and Less Power: How 5G NR can Reduce Network Energy Consumption

Pål Frenger
Ericsson Research
Ericsson AB
Linköping, Sweden
pal.frenger@ericsson.com

Richard Tano
Ericsson Research
Ericsson AB
Stockholm, Sweden
richard.tano@ericsson.com

Abstract—In this paper we compare the energy consumption of the 3GPP standards 5G New Radio (NR) and Long-Term Evolution (LTE). We show that the energy consumption in an idle network (without user plane traffic) can be up to 9 times lower for an NR stand-alone network compared to an LTE network. The network energy consumption in low or no traffic scenarios is a significant part of the operator OPEX in low traffic areas [1], such as in extreme rural scenarios, and here NR has a clear advantage compared to LTE. To evaluate the energy performance advantage of NR when we have very high traffic, such as in Super-Dense Urban and Urban scenarios, we perform system evaluations. We show that if we increase capacity in an existing LTE network with additional NR micro cells compared to using additional LTE cells, the reduction in network energy consumption is close to 50 percent. If we also upgrade the LTE cells in the macro coverage layer to NR a total energy reduction of up to 70 percent is achievable.

Keywords—5G New Radio (NR), radio network energy consumption, energy efficiency, energy performance, 3GPP Long Term Evolution, LTE.

I. INTRODUCTION

Network energy efficiency is listed as one of thirteen performance requirements for IMT-2020 [2]. Consequently, the recently finalized 5G New Radio (NR) 3GPP Rel-15 standard is designed to enable very low energy consumption, not only in the user terminals, but also in the network equipment. With the introduction of NR [3], new features for energy savings are introduced: Much longer durations and higher ratio of discontinuous transmission (DTX) is supported in NR compared to the 3GPP Long Term Evolution (LTE) standard. Higher transmission rates (primarily due to higher bandwidth and more advanced multi-antenna transmission modes) result in even more DTX as packet transmission times decrease. In addition, the amount of system information (SI) that needs to be broadcasted in NR can be reduced by sending some part of the SI on-demand. NR also support frequency multiplexing of system information and synchronization signals which further increase the DTX of base stations. In the frequency domain the NR standard supports fast bandwidth part (BWP) adaptation and even longer DTX duration (up to 160 ms) on component carriers not used for initial access. In the antenna domain NR is designed for single antenna port operation of mandatory and always-on signals while in LTE the number of antenna ports used for mandatory always-on signals is the same as for data transmissions (up to 4TX ports). These features enable implementation of new hardware deep-sleep states in which the base station can lower its total energy usage significantly.

The combination of new hardware deep-sleep modes and increased throughput in 5G NR will require new design guidelines and trade-offs related to how we build cellular networks with low energy consumption. In previous generation systems, like LTE, WCDMA, and GSM, the network energy usage increased steadily with the number of installed network nodes and the most energy efficient way to serve an area was typically to do it with as few base stations as possible and with as large inter-site distance (ISD) as possible. While this resulted in low network energy consumption it also unfortunately results in low capacity and user throughput. In e.g. [4] and [5] we saw that the network energy consumption of an LTE cellular network can be accurately predicted by only considering the number of, and the type of, base stations deployed. Things like the area covered, the number of subscribers, or the amount of traffic served has a surprisingly small impact on previous generation cellular networks. 5G NR should have the potential to change this and make the network energy much more proportional to the actual network load. In this paper we show that with NR, increasing network capacity by introducing new NR cells in an existing LTE network can reduce the total network energy consumption. Even larger energy reductions are possible if existing LTE cells are upgraded to NR. In this context it is however important to remember that the early NR products that are on the market today does not yet deliver on all these benefits. The main reason is that current NR products are time-to-market optimized and, so far, have only limited support for deep-sleep operation modes that the standard enable. NR products are in some respects still immature compared to LTE products which have had close to a decade of continuous and incremental product development. NR is a completely new radio access technology (RAT) that operate in new frequency bands with much higher bandwidth and many more antennas compared to any previous LTE product. Energy-optimized 5G NR products fully utilizing the 5G NR standard energy saving potential are expected to become gradually available on the market sometime after 2020. A high market pressure from operators may accelerate this development.

In this paper we first compare the idle mode energy consumption of LTE and NR in section II. In section III we consider scenarios with very high traffic and compare two options for enhancing the network capacity by adding additional NR cells in and existing LTE network. First, we study the impact of deploying additional micro cells in an existing network with an LTE macro cell deployment and show that if we add LTE micro cells the energy consumption increases significantly while if we add NR micro cells the total energy consumption decreases with approximately 50%. If, in addition, the macro cells are upgraded from LTE to NR even larger energy savings can be achieved. Secondly, we study the option of adding additional NR macro cells on the existing sites, and here we see a significant, but slightly smaller gains, with NR compared to LTE. The paper is then concluded in section IV.

II. IDLE MODE NETWORK ENERGY CONSUMPTION

A. Base station power models

Figure 1 depicts the principle behavior of a radio base station power consumption as function of the RF output power. This simple model is surprisingly accurate, given proper parameterization, and this kind of power model was initially proposed by the European EARTH project when evaluating network power consumption [8].

In this evaluation we will use the power model in Figure 1 together with parameters that was defined in [6]. This model consists of power consumption models for base stations of types 2×2 macro, 4×4 macro, pico, femto, and LSAS (large scale antenna system). The model further defines 4 sleep modes for each base station type, each associated with re-activation times of 71.4 µs (1 OFDM symbol in 15 KHz numerology), 1 ms, 10 ms, and 1 second respectively. Note that the macro power models (2×2 macro and 4×4 macro) provide power consumption number per sector and in this evaluation, we assume that each macro base station consists of 3 sectors. The pico, femto, and LSAS base stations are assumed to consist of 1 sector. The LSAS (large scale antenna system) power model correspond to a massive MIMO base station with a single antenna-panel consisting of 200 antenna elements having a total maximum RF transmission power of 41 dBm.

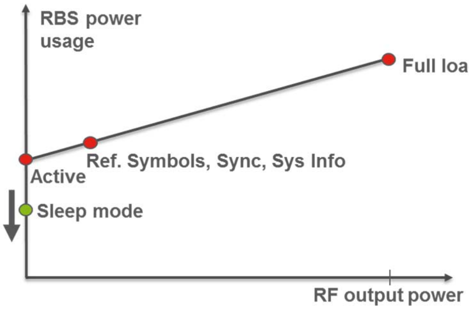

Figure 1: Principle behaviour of the power models used in this evaluation. The power consumption in sleep mode depends on the DTX duration.

B. LTE idle mode reference case

The EARTH project defined an energy efficiency evaluation framework (E3F) for radio networks consisting of base station power models, traffic models, and deployment models [8]. When using that evaluation framework, we noted that the traffic has a very minor impact on the network energy consumption in LTE networks. Most cells in a nationwide network are empty most of the time, if we examine the network on a ms time scale. The impact that the user traffic has on the network energy consumption today is typically in the lower single digit percentage range (in [5] it was estimated to be 1.4% in a nationwide LTE network). This low load-dependence of LTE network energy consumption motivate why we start by examining an idle network with no user plane traffic when comparing the LTE and NR energy consumption.

A 10 ms snapshot of the base station power consumption in an idle LTE cell (i.e. only mandatory reference signals are transmitted and there is no user-plane traffic in the cell) using the power models in [6] is depicted in Figure 2. All sub-frames contain transmissions of cell specific reference signals (CRSs); sub-frame 0 contains the primary and secondary synchronization signals (PSS and SSS) and the physical broadcast channel (PBCH); and system information and PSS/SSS is transmitted in sub-frame 5. In Figure 2 we note that the power consumption peaks reach 725 W. Whenever there is a short duration in which no power is transmitted we can put certain components into sleep-mode. The base station is able to sleep for a few of the OFDM symbols, but it can only reach "sleep mode 1" where the consumption is 3 x 76.5 = 229.5 W [6]. Precisely one OFDM symbol (71.4 µs) before each mandatory transmission of CRS, PSS, SSS, PBCH, or SI occurs the base station need to become active (consuming 3 x 114.5 = 343.5 W). The average power consumption in an "empty" radio frame (with no user plane data transmissions) is calculated to be approximately 400 W when using the 3-sector "2×2 macro" power model defined in [6].

C. NR idle mode power consumption

The idle mode power consumption for NR depends on the number of SS Blocks that are used in a cell, the sub-carrier spacing, etc. In order to do a reasonably fair comparison, we select the same sub-carrier spacing for NR as we used in the LTE reference case, i.e. 15 kHz. A network energy consumption optimized configuration is to operate NR with a single wide-beam transmitted SSB. We further assume that the system information transmission can occur in the same symbols as the SSB, i.e. using frequency multiplexing. We assume that the power consumption required to transmit the SSB and the system information corresponds to 25% of the total base station power.

In Figure 3 we see the instantaneous power consumption in the base station when applying the same "2×2 macro" power model used in the above example. The SS Block periodicity used in this example is 20 ms, and we note that the NR base station can enter both sleep mode 3 (with an activation delay of 10 ms) and sleep mode 2 (with a 1 ms activation delay). The peak power consumption is slightly higher for NR than for LTE (approximately 785 W in Figure 3) but the average power is significantly lower (approximately 45 W) due to the long sleep modes that are accessible for NR. The reason for why NR has slightly higher peak power is that in this example we assume that NR system information is transmitted at the same time as the SS Block to maximize the DTX duration.

In Figure 4 we show the power consumption gain with NR compared to LTE expressed as $P_{average,LTE} / P_{average,NR}$. We note that for 20 ms SSB periodicity and using the 2×2 macro power model NR is capable of operating with 9 times lower average power consumption compared to LTE. The LSAS power model results in a factor of 6 times lower power consumption for NR compared to LTE for an SSB periodicity of 20 ms and more than 10 times lower for an SSB periodicity of 160 ms.

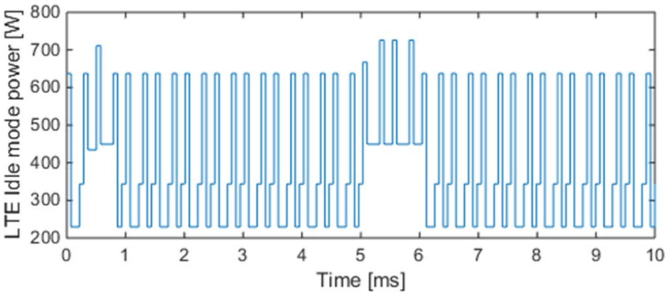

Figure 2: Instantaneous power consumption of a 3-sector "2×2 macro" base station using the power model defined in [6].

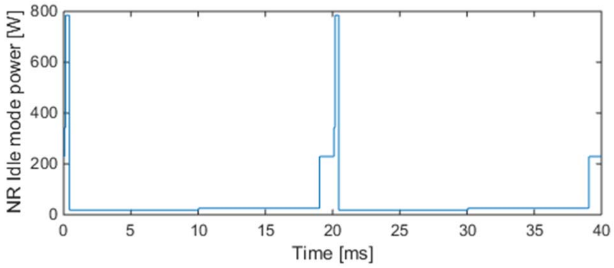

Figure 3: Instantaneous power consumption for NR with a 1 SSB configuration, 20 ms SSB periodicity using the power model “2×2 macro” defined in [6]. In addition to “sleep mode 1” the NR base station can enter both sleep mode 3 (with an activation delay of 10 ms) and sleep mode 2 (with a 1 ms activation delay) in-between each SSB transmission.

In addition to extended sleep time and sleep ratio there are additional benefits with NR that are not addressed here. In LTE the CRS transmissions cover the whole system bandwidth and they are always transmitted from all antenna ports (up to 4 ports) that the base station is equipped with. The SS Block and system information transmissions in NR are only defined for one antenna port covering a limited part of the overall system bandwidth, which makes it possibly to adapt both the bandwidth as well as the number of active antenna ports in NR in a more flexible and energy efficient way. These potential additional benefits are not considered in this assessment.

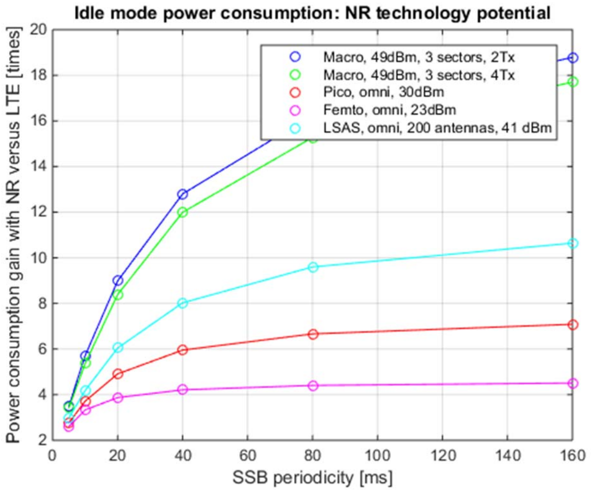

Figure 4: Power consumption gain with NR versus LTE for different power consumption models and SS Block periodicities.

III. NETWORK CAPACITY ENHANCEMENT EXAMPLES

In the previous section we showed that NR has significantly lower idle mode power consumption than LTE and consequently NR networks will consume far less energy in very low traffic scenarios compared to LTE networks when deployed in the same way. However, it is perhaps more interesting to compare LTE and NR in a scenario with a very large amount of traffic and see if the advantages are still there or if they disappear. In this section we therefore focus on comparing the radio network energy consumption of NR and LTE in Super Dense Urban (SU) and Urban (U) scenarios. According to Ericsson Mobility Report [7] the maximum peak-hour traffic load for these scenarios is estimated to reach 750 and 40 Mbps/km2 respectively in 2020. Furthermore, the data traffic varies from 10-100% of the maximum traffic load during the day which can be modelled by applying a European average daily traffic profile as defined in [8]. In such scenarios LTE is already deployed today and we therefore study the impact of a common capacity enhancement solution which is to add additional cells to the existing network with macro sites. One option we will consider is the impact of adding between 1 to 4 additional LTE or NR micro cells per macro site sector. Another option is to add an extra macro layer of NR or LTE cells to the existing macro sites. In both options the impact of replacing the existing LTE macro cells with NR cells is also evaluated.

A. Senario Setup

System simulations are performed in hexagonal multi-user and multi-cell scenarios with both macro and micro cell deployments. The macro layer consists of 3-sector sites using 3GPP antenna models [9] with 2 antenna elements. The micro layer consists of 1 to 4 additional nodes with omni antennas located inside each of the macro-site sectors. The macro layers transmit power is 40 W (46 dBm) per sector while the micro layer is 20 W (43 dBm) per micro cell.

Two frequency bands are used, the lower band is configured on the macro layer and the higher band is configured either on the micro layer or on an additional macro layer. The low band is situated at 0.9 GHz with 10 MHz bandwidth and the high band is at 3.5 GHz with 40 MHz bandwidth. Both the macro layer and the micro layer operate in frequency division duplex (FDD) mode. Users are stationary and randomly distributed across simulation area with an indoor probability of 80%. The traffic type is FTP (file transfer protocol) and all users try to download a 2 Mb file. The propagation model used is the 3GPP spatial channel model (SCM) [10].

B. Super Dense Urban and Urban scenarios: Network densification using additional micro layer

Figure 5, Figure 7, Figure 8 and Figure 8 show results for the Super Dense Urban (SU) scenario. Figure 5 shows the traffic load for heterogeneous (hetnet) network deployments consisting of a macro layer and up to 4 micro-cells per macro sector. It is obvious from looking at Figure 5 that the single macro deployment is not able to reach the 2020-year target traffic load expected of a Super Dense Urban scenario (i.e. 750 Mbps/km2, se above). It can also be noted that the “1 micro” deployment performs worse than the other hetnet deployments. This is further visualized in Figure 6 that going from 1 to 2 micros greatly increases the performance, especially for the worst performing users (10th percentile). However, adding more than 2 micros doesn’t give any significant additional performance increase. suggesting that for this scenario and configuration “2 micros” is a suitable deployment.

Shown in Figure 7 is the daily power usage curve for hetnet network deployments with LTE macros and NR micros. In the low load traffic point (6h), addition of micro cells increases the power consumption. In the high traffic load point (22h) the increase in power consumption with each addition of micro cells (and hence more capacity) get smaller. In fact, in this case the “2 micro” deployment consumes less than the “1 micro” deployment. At first it may seem counter-intuitive that by adding additional NR cells we can reduce the total network energy consumption, but this is the effect of higher throughput resulting in more DTX operation in the network nodes.

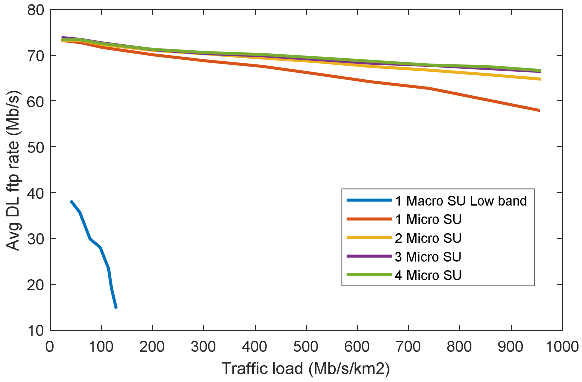

Figure 5: Super Dense Urban (SU) hetnet, traffic load curves. Note that the performance of the Macro only deployment is not sufficient to serve an expected 2020 peak hour traffic of 750 Mbps/km^2.

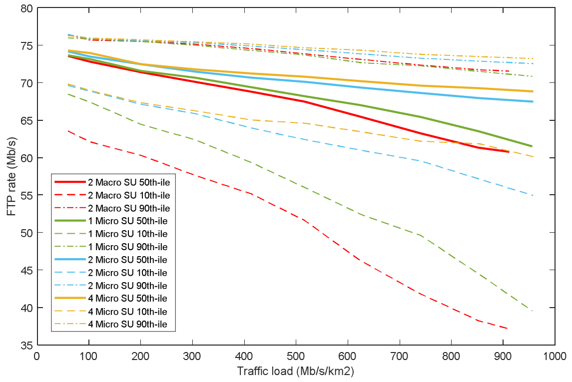

Figure 6: Super Dense Urban (SU) hetnet and macros, FTP rate percentile curves.

In Figure 8 the total daily average power usage is shown for three different types of deployments that can fulfill the 2020 traffic requirement: (1) LTE macros with LTE micros; (2) LTE macros with NR micros; and (3) NR macros with NR micros. At the top of each bar in the graph we show the power consumption in the micro layer in red, while the power consumption in the macro layer is shown in different colors at the bottom of each bar. In all deployment examples, the power usage of the macro layer decreases with addition of micro cells that gives a capacity and throughput boost and thus offloads the macro layer traffic. As expected with LTE micros, the total power consumption increases with more micro cells despite the positive impact they have on the macro layer power consumption.

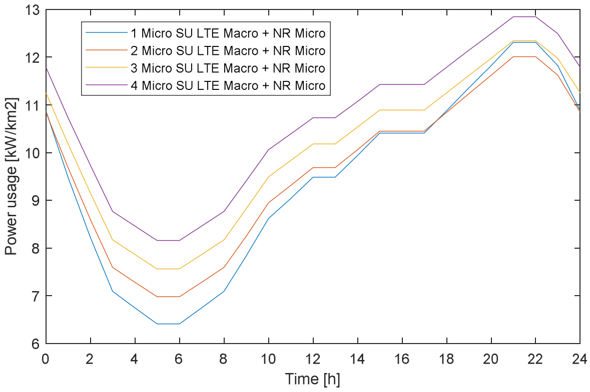

Figure 7: Super Dense Urban (SU) hetnet, daily power usage curves.

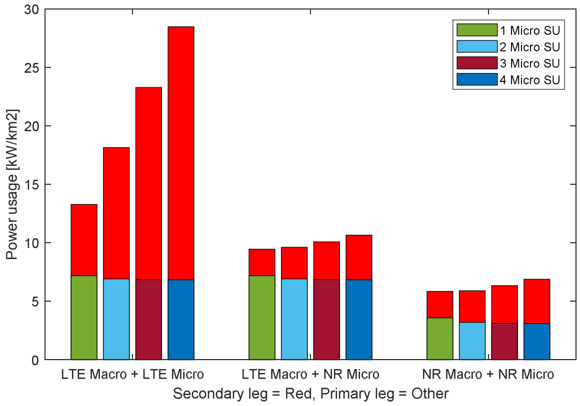

Figure 8: Super Dense Urban (SU) hetnet, total daily power consumption.

As in Figure 7 a trend where addition of NR micros only generates a small power consumption increase is seen in Figure 8. With NR the “2 micro” deployment have almost as low total daily energy consumption as the “1 micro” deployment, which is a result of the reduction in power consumption of the macro layer. When adding more than 2 micro cells per macro cell the decrease in power consumption of the macro layer doesn’t make up for the increase in power consumption of the micros resulting in small increases in the total power consumption. For the deployment with 2 micros, which seems to be a reasonable deployment choice for this scenario, a reduction of 47% in energy consumption between the LTE micro and NR micro deployment is seen. When also switching the macro layer from LTE to NR another 38% of energy efficiency gain is achieved. The total energy saving when going from LTE-only to NR-only in the “2 micro” deployment is 67%. We note that the energy saving difference between NR and LTE in Figure 8 is higher for the micro-cell layer than for the macro-cell layer. One reason for this is that in this scenario the traffic density is very high which leaves little time for DTX in the network nodes. Furthermore, each UE is always served by both layers (macro and micro) in a dual cell configuration. Hence each time a micro cell serves a UE the macro cell also becomes active, and this further reduce the DTX time in the macro layer.

In Figure 9 and Figure 10 the performance and power consumption of hetnet network deployments in the Urban scenario is shown. Similar results as for the Super Dense Urban scenario is seen; switching from LTE to NR deployments lowers the total power consumption significantly. In this scenario with larger cell sizes increased number of micros have a bigger impact on the coverage and performance (Figure 9). Thus, for the Urban (U) scenario it is even possible to see a small decrease in power consumption when increasing from 1 to 2 NR micros. Comparing Figure 8 and Figure 10 we see that the relative gain of introducing NR in the macro layer is larger for the Urban (U) scenario than for the Super-Dense Urban scenario (SU), up to 6% more energy savings is possible when switching from LTE to NR giving a total energy saving of 73% in the “2 micro” deployment. This difference is due to the significantly lower area traffic density in the Urban case (40 versus 750 Mbps/km2) resulting in less load in the network nodes overall, and consequently more energy savings by DTX.

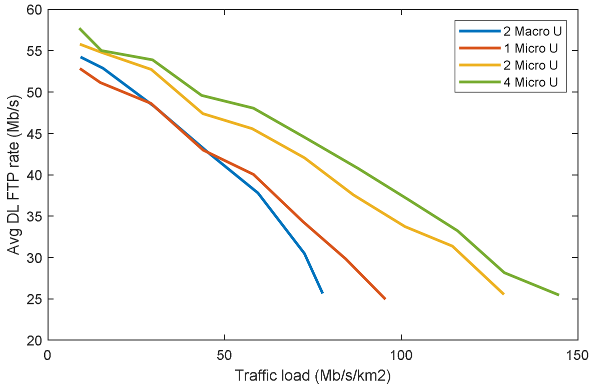

Figure 9: Urban (U) hetnet and macros, traffic load curves.

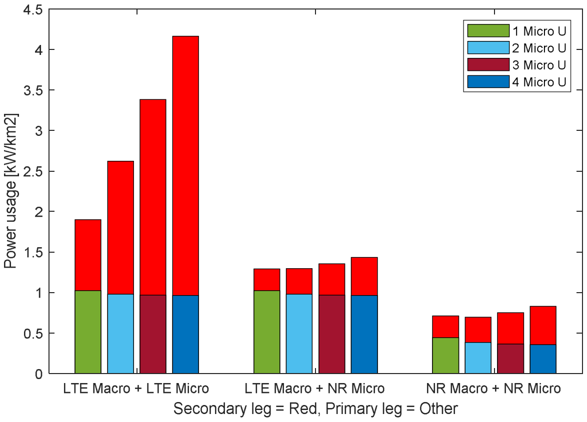

Figure 10: Urban (U) hetnet, total daily power consumption.

C. *Super Dense Urban and Urban scenarios: Adding an additional macro cell*

In this section the network energy consumption of using two macro layer deployments is evaluated. Figure 11 show the total daily power usage in Super Dense Urban and Urban scenarios. As in the hetnet scenario a reduction in energy consumption is achieved when switching from LTE to NR deployments, 50% for the Super Dense Urban (SU) and 53% for the Urban (U) scenario. Compared to the hetnet deployments the total energy consumption is higher. Furthermore, in this scenario the energy savings when using NR compared to LTE is smaller, up to 20% less than in the hetnet scenario. This is partly due to the very high traffic and the fact that the capacity and performance for this deployment scenario is lower than in the previously studied hetnet scenario (seen in Figure 6 and Figure 9, the “2 macro” deployment performs worse than the “1 micro” deployment), resulting in higher load on the base stations and less time for DTX overall. Also impacting the results is that all UEs are always served by both cells in a dual connectivity configuration. Even if users could have been served by e.g. only the lower frequency band cell, we always use both the high frequency cell and the low frequency cell to serve each user. This further reduce the DTX duration of the cells in the networks, resulting in a smaller difference between NR and LTE power usage in this scenario.

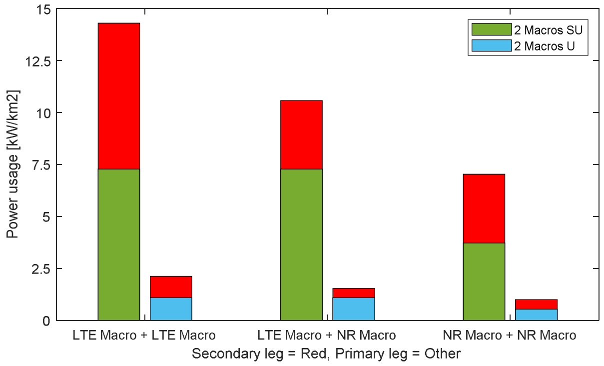

Figure 11: Super Dense Urban (SU) and Urban (U) with 2 macros, total daily power consumption.

IV. SUMMARY AND CONCLUSIONS

With the new idle mode operation features introduced in NR where longer DTX duration and deeper sleep states is available large gains in energy efficiency is achievable. In very low-traffic or no-traffic scenarios (e.g. extreme rural scenarios) the energy consumption of NR can be reduced with up to a factor of 9 (see Section II). In scenarios with very high traffic we note that by switching deployments from LTE to NR it is possible to reduce the overall network energy consumption with up to 70% (see Section III). In the system level simulations, we did not optimize for energy efficiency, and there are room for further improvement, e.g. by optimizing when to activate dual connectivity when we have two frequency layers. Also, NR provides several additional capacity-enhancing benefits over LTE, such as support for much higher bandwidth and significantly enhanced multi-antenna transmission modes that were not considered here. In summary we conclude that NR provide very high energy saving gains in very low traffic scenarios and that, with proper deployment, significant energy savings are also achievable in scenarios with extremely high traffic, making usage of NR a preferred option in the construction of green networks.

REFERENCES

[1] GSMA, “Green Power for mobile: The global telecom tower ESCO market overview of the global market for energy to telecom towers in off-grid and bad-grid areas,” December 2014, (available 2018-10-15), https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2015/01/140617-GSMA-report-draft-vF-KR-v7.pdf

[2] ITU-R, “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” Nov. 2017, (available 2018-10-15), https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

[3] E. Dahlman, S. Parkvall, and J. Sköld, *5G NR: The Next Generation Wireless Access Technology*, Academic Press, 2018.

[4] P. Frenger, Y. Jading, and J. Turk, “A Case Study on Estimating Future Radio Network Energy Consumption and CO2 Emissions,” in *Proc. IEEE PIMRC*, 2013.

[5] P. Frenger and M. Ericson, “Assessment of Alternatives for Reducing Energy Consumption in Multi-RAT Scenarios,” in *Proc. IEEE VTC-Spring*, 2014.

[6] C. Desset, C. Debaillie, and F. Louagie, “A Flexible and Future-Proof Power Model for Cellular Base Stations”, In *Proc. IEEE VTC-Spring*, 2015.

[7] Ericsson, “Ericsson mobility report: On the pulse of the networked society,” Nov. 2014, (available 2018-10-15), https://www.ericsson.com/assets/local/news/2014/11/ericsson-mobility-report-november-2014.pdf

[8] M. Olsson, S. Tombaz, I. Godor, and P. Frenger, “Energy performance evaluation revisited: Methodology, models and results,” in *Proc. IEEE STWiMob*, 2016.

[9] 3GPP TR36.819 Annex A, “Coordinated multi-point operation for LTE physical layer aspects”.

[10] 3GPP TR38.901, “Study on channel model for frequencies from 0.5 to 100 GHz”.