Wireless and Mobile Communications Lab
Dept. of Informatics and Telecommunications
University of Peloponnese

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Power consumption in single-cell LTE systems with relays

Ilias Ksirogiannis, Dimitra Zarbouti, George Tsoulos

Abstract

The aim of this thesis is the study of power consumption in a single cellular LTE network with relay nodes (RNs). Our analysis is based on Monte Carlo simulations where the SNR at the user end, the system loading factor, as well as the total power consumption in the network area are calculated. The power consumption calculations were built upon the power models that can be found on FP7 EARTH Project ([1],[2]), while the simulation parameters for the LTE were provided by [3].

Our study regarding the power consumption, rate and SNR was held with respect to the following:

- *the cell layout*
  Seven cell layouts were simulated, one with only the central BS, and six more with 1 up to 6 RNs in the cell. Figure 1 depicts the last scenario with 6 RNs in the cell.
- *the RN location*
  Three different setups were examined regarding the RN distance from the central cell. Specifically, we tested setups where the RNs were placed at R/4, R/2 and 3R/4 from the central base station (*R* is the cell radius).
- *the requested throughput*
  Our system user is considered to request a specific throughput, unless the system can supported, the user is dropped. Three scenarios were investigated with 5, 10 and 20 Mbps of requested throughput.

Simulation Description

Fig. 1 presents an instance of the simulated system cell configuration and in particular, the scenario with 6 RNs in the cell area.

The RNs distance from the BS is defined with respect to the cell radius, i.e. R/4, R/2, 3R/4. While they are uniformly distributed in cell area in a way that the azimuthal angle between them is: $RN_{\varphi} = 2\pi/N_{RN}$.

The system user is served by the either the BS or by an RN according to his channel conditions. Each scenario is analyzed with Monte Carlo simulations. Specifically 10000 iterations were performed where for each iteration a user is randomly generated in the cell area and according to his channel gain he is assigned a server (BS or RN).

For the system simulation, we used the parameters that are shown in Table 1. It should be pointed out that different throughput requirements lead to different cell radii. The cell radius is calculated as the maximum distance that the system can support the requested rate. Apparently, the larger the throughput, the smaller the cell radius.

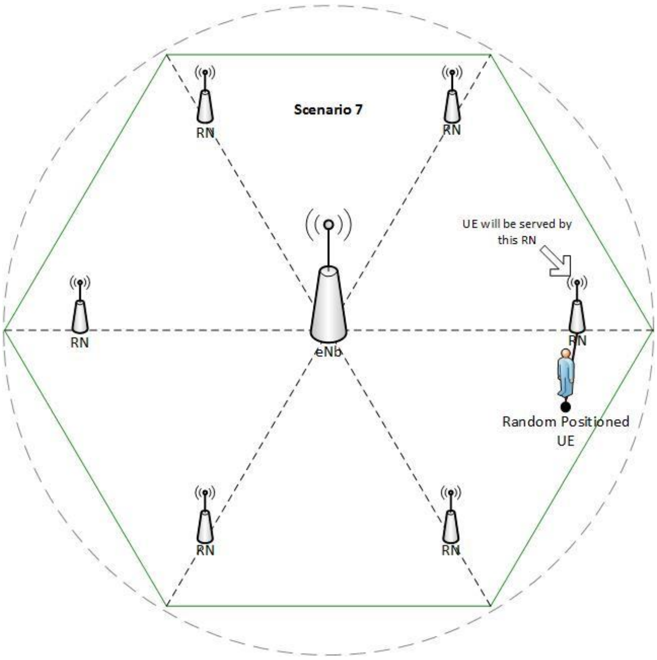

Figure 1: The scenario with an eNB and six RNs. The UE will be served by the node that has the best SNR, relative to the user.

System parameters
F = 2GHz
BandWidth = 20MHz (LTE, 100 RBs)
Cell Radius: **5 Mbps** → 2,697 Km **10 Mbps** → 2,382 Km **20 Mbps** → 1,636 Km
Equipment parameters
eNB Tx Power = 46 dBm
eNB Antenna Gain = 8 dBi
eNB height = 30m
RN Tx Power = 30 dBm
RN Antenna Gain = 5 dBi
RN height = 5m
Propagation
Cost-231 Hata (*eNB->UE*)
Dual slope (*RNs->UE*))(*n* = 3.5)

Table 1 System, equipment and propagation parameters used for the simulations.

The EARTH power model that we used for estimating the power consumption is described by the following equation [1]:

$$\mathrm{P_{in}} = \begin{cases} N_{TRX} \cdot \left(P_0 + \Delta_p P_{out}\right), & 0 < P_{out} \leq P_{max} \\ N_{TRX} \cdot P_{sleep}, & P_{out} = 0 \end{cases} \quad (1)$$

while the parameters that we used in our analysis for the BS (Macro) and the RN (Relay Urban) environment are summarized in the Table 2. Note that in the previous equation, P_{out} is the transmitted power which depends on the system loading factor, i.e. $P_{out} = P_{max} \cdot LF$.

	Pmax (W)	P_0(W)	Gain(dBi)	Δ_p

Relay Urban	1	19.9	8	5.6
Macro	40	248	5	14.25

Table 2 ENodeB and RN parameters, according to the project EARTH[2].

Next, his SNR is calculated, and with the processes outlined in [4], the number of Resource Blocks (RBs) that are required to satisfy his throughput is derived, RB_u. A user whose rate requirement can't be satisfied, is rejected.

Since we consider an LTE system with 20MHz of bandwidth, 100 RBs are available for the user. Hence, for each iteration the system loading factor is derived: $LF = RB_u/100$. It should be noted that when the user is assigned to an RN, for the backhaul link between the BS and the RN, we have made the weak hypothesis that it presents the same LF as with access link.

Finally, after the LF has been calculated, the total power consumption of the network is estimated:

$$P_{in} = \begin{cases} N_{sec} n_{Tx} \left[P_0 + \left(\Delta_p^{eNB} P_{out}^{eNB}\right)\right] & ,if\ UE \rightarrow eNB \\ N_{sec} n_{Tx} \left[P_{0_{eNB}} + P_{0_{RN}} + \left(\Delta_p^{eNB} P_{out}^{eNB} + \Delta_p^{RN} P_{out}^{RN}\right)\right] & ,if\ UE \rightarrow RN \end{cases} \quad (2)$$

Results

From the Monte Carlo simulations, the ECDFs of the metrics under examination (SNR, LF, Pin) were produced. For instance, Fig. 2 shows the ECDFs for the SNR when the user requests 10Mbps of throughput and the RNs are placed at 3R/4.

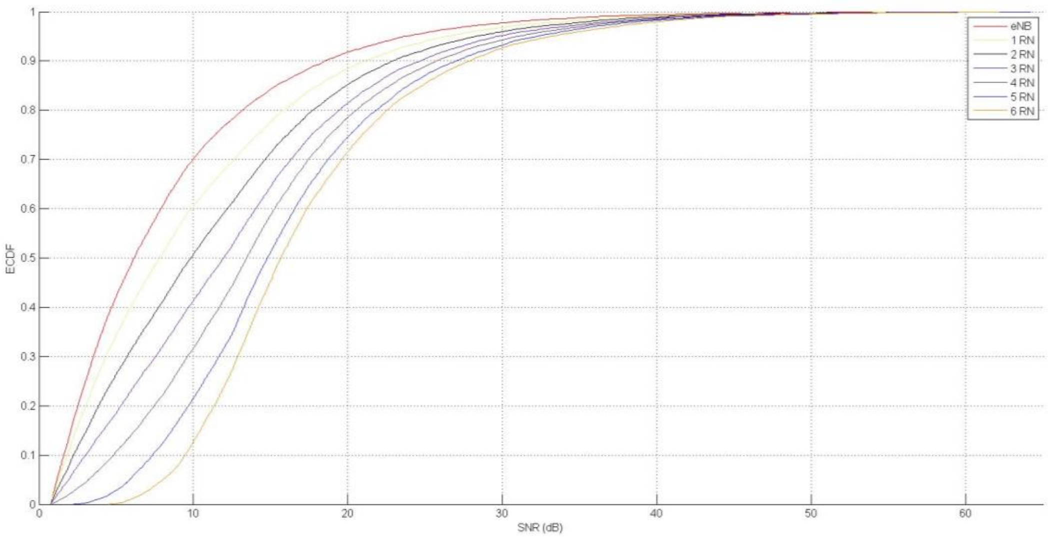

Figure 2 The ECDF for the SNR when the user requests 10Mbps of throughput and the RNs are placed at 3R/4.

However, we used the values of 50% outage in order to produce Fig. 3-5, where the SNR, LF and Pin, are depicted for all different RN locations. As the aforementioned figures suggest, **increasing the number of RNs in the cell as well as placing the RNs closer to the cell edge improve the system performance**. In addition, we notice that when the RNs are placed close to the eNB (R/4) the performance with respect to the power consumption deteriorates (see Fig. 5).

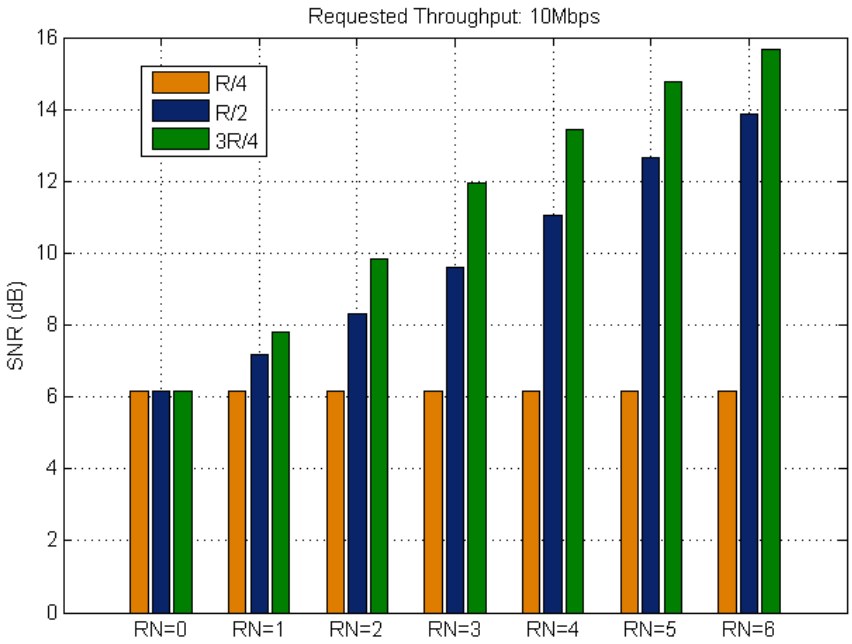

Figure 3: The SNR for 0 to 6 RNs in the cell. The RNs are located at R/4. R/2 and 3R/4 from the central BS.

In order to explain this we have to closely study eq. 2, which suggests that, in the context of our work, any power reduction that comes from employing RNs in the cell area, is due to the lower system loading factor. In other words, the cell edge users when they are served by the BS, experience low SNR regime and require many system Resource Blocks increasing the system loading factor. On the other hand, when RNs are available, the cell edge users will most probably be served by them, demanding fewer system resources, i.e. Resource Blocks, due to the better SNR regime. In this line of thought, when the RNs are placed near the BS, the users that will finally be served by the RNs are also close to the BS, and so neither their SNR is improving, nor the system loading factor is reduced. Practically, the system power consumption is increased from the simultaneous operation of the BS and the RN, without the beneficial impact of RNs to the system loading factor.

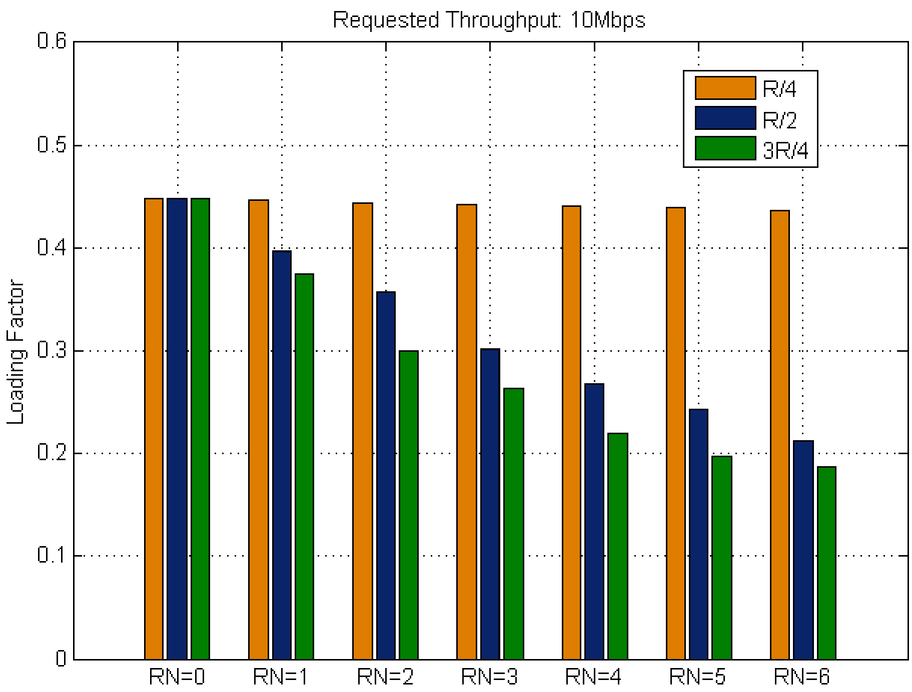

Figure 4: The Loading Factor for 0 to 6 RNs in the cell. The RNs are located at R/4. R/2 and 3R/4 from the central BS.

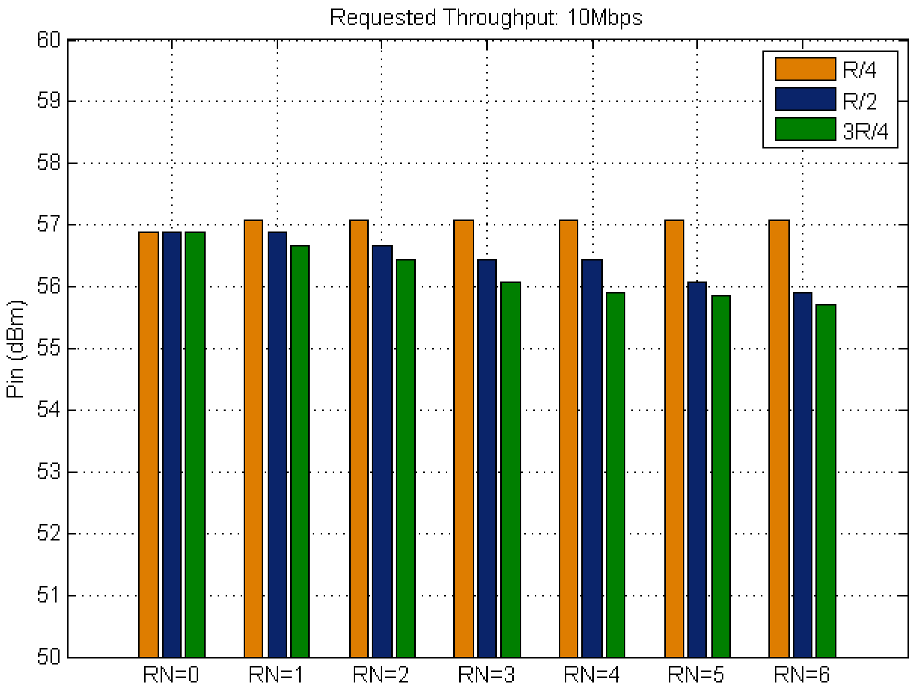

Figure 5: The P_{in} for 0 to 6 RNs in the cell. The RNs are located at R/4. R/2 and 3R/4 from the central BS.

Regarding the requested throughput, as expected, higher throughput requirements lead to higher loadings and higher power consumptions. For instance, Fig. 6 and 7 present the LF and power consumption for the scenario with 6 RNs in the cell for the three throughput requirements examined.

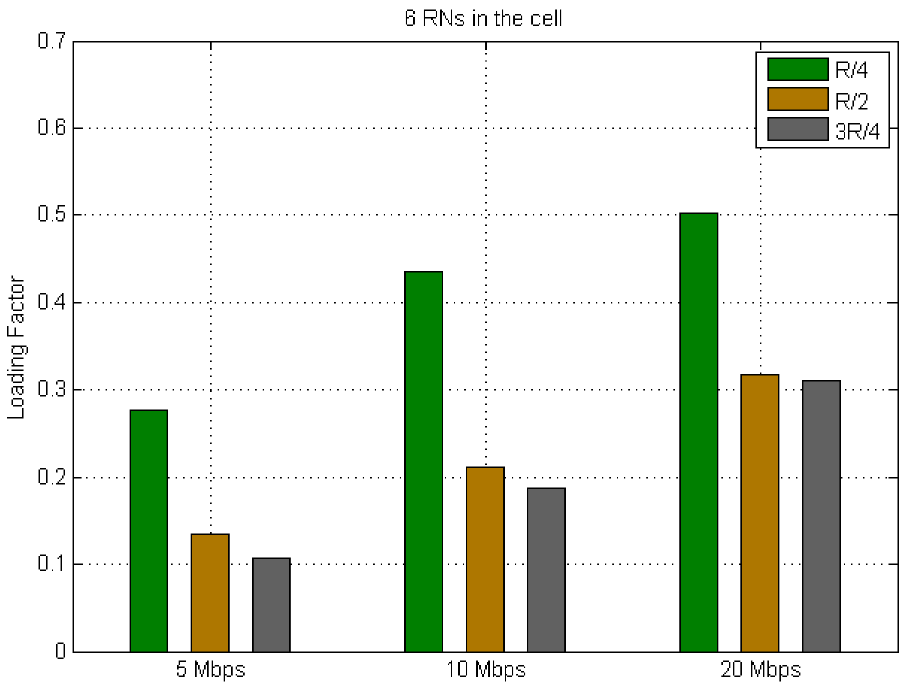

Figure 6: The Loading Factor for 6 RNs in the cell. The RNs are located at R/4. R/2 and 3R/4 from the central BS.

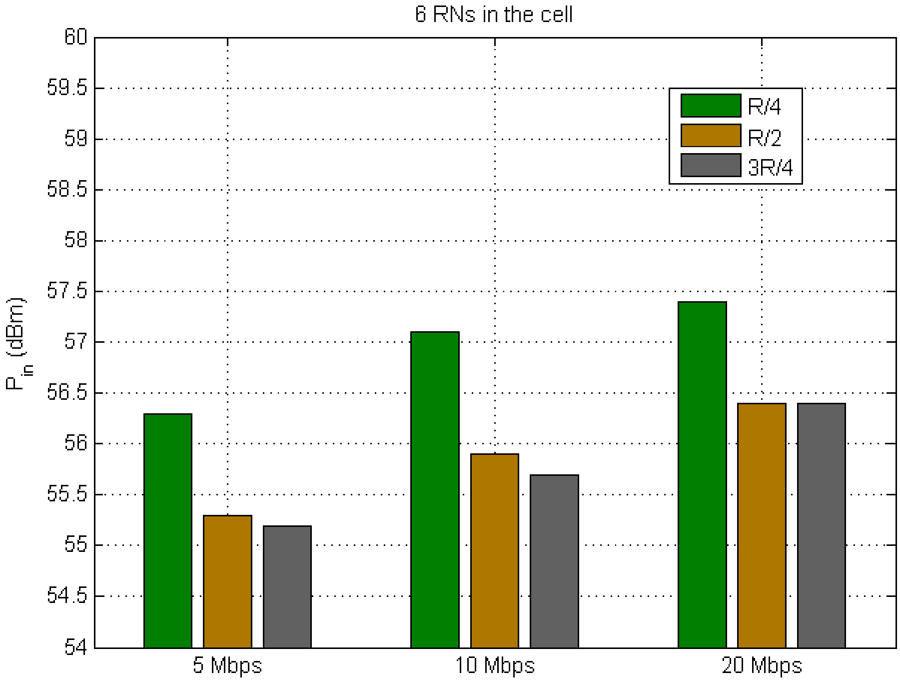

Figure 7: The P_{in} for 6 RNs in the cell. The RNs are located at R/4, R/2 and 3R/4 from the central BS.

Conclusions

In this work the performance of a single cell LTE network employing relays, with respect to the SNR, loading factor and power consumption was examined, via Monte Carlo simulations. Firstly, our results conclude that when the access and backhaul link operate with the same system loading factor, the reduction of power consumption from employing RNs are practically trivial. Secondly, regarding the placement of RNs in the cell area, the results suggest that when the relays are placed near the BS there is no improvement in the system performance (SNR and Loading Factor), in addition there is an obvious deterioration of the consumed power. On the contrary, the system performance is boosted when the RNs are placed near the cell edge (~10dB gain in the SNR when 6 RNs are employed in the cell). Finally, the user throughput requirements have a minor impact on the total power consumption, i.e. an ~1dB power increase is noted every time the user throughput request is doubled.

References

[1] EARTH WP2: '*Energy efficiency analysis of the reference systems, areas of improvements and target breakdown*', Deliverable D2.3, 31/01/2012 (updated)

[2] EARTH WP3: "*Final Report on Green Network Technologies*" Deliverable D3.3, 16/07/2012

[3] H. Holma, P. Kinnunen, I. Kovacs, K. Pajukoski, K. Pedersen,and J. Reunanen (2009), *Performance*. In H. Holma and A. Toskala (Eds.), *LTE for UMTS - OFDMA and SC-FDMA Based Radio Access* (pp. 213–257). John Wiley & Sons, Ltd.

[4] G.E. Athanasiadou. D. Zarbouti, G.V. Tsoulos, 'Automatic Location of Base-Stations for Optimum Coverage and Capacity Planning of LTE systems,' EuCAP 2014, Hague, Netherlands, 6-11 April 2014.