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Abstract

We evaluate the performance of an energy efficient algorithm that controls power emissions and the number of powered cell sites (eNBs) in overlaid Long Term Evolution (LTE) networks. Simulations are carried out in OPNET Modeler and we investigate cells cites designed to meet peak hours traffic demand, as there is a high potential for reducing the transmission power when resource utilization becomes low. The eNBs must be aware of configuration updates in neighboring cells and make automated decisions to respond to changes in the network. The effectiveness of the algorithm is represented as a number of powered off eNB sites.

Introduction

In today's economical climate it is common to come across discussions that target the tender questions of information society. The ever increasing demand for data exchange and high throughput data services put the weight on service providers shoulders to meet the needs of the, as the user pattern shows, mobile information society as well as competitively offer lower prices. The prediction of exponential mobile data traffic growth that has been done in the last several years [1], has now shown its truthfulness.

However, the increase of mobile data exchange demand has its own downsides. The energy consumption has become one of the main challenges for network operators. Due to the decreasing profit per bit there is a need to approach networks from a holistic point of view and look for optimization on a global, long term and large scale. The energy consumption composes legitimate amount of operational expenditures (OPEX) and in addition, the rates of increasing energy demand and ever growing carbon dioxide (CO_2) emissions are signaling a threat for sustainable living and prosperity of the planet. Therefore it is of major importance to undertake legitimate actions at various energy related industrial fields, where Information and Communication Technology (ICT) industry is no exception. The estimated CO_2 emissions generated by ICT sector in 2007 contributed with a fraction of 2% of global CO_2 emissions, where telecom sector represents 25% of that fraction [2]. Nevertheless the contribution of mobile communications has been predicted to grow nearly three times from the year 2002 (64 Megatons) to 2020 (178 Megatons), which points to long term commitment of reducing the carbon footprint [4].

In mobile sector, the major energy consumption comes from radio access technology where base stations are contributing approximately 80% [6]. Reduction could be achieved by minimizing the number of energy demanding network elements, or in this case the base station sites. This, however, stands in conflict with network requirements to support coverage, capacity and quality of service for increased throughput using existing Radio Access Network (RAN) technologies. Moreover, in practice the tendencies are quite the opposite. The number of base stations being installed is increasing. This is done in order to meet throughput demand of today and future mobile applications. This approach creates multilayer, heterogeneous networks, with increased energy consumption, because the technologies are implemented in a redundant manner, and specifically designed for supporting services during the periods of the highest demand (rush hours). As a result network management becomes complex and expensive, and network optimization field of high interest.

Networks that are capable of dynamically adjusting their resources according to the demand, that optimally utilize the electrical power with required service level and the least of waste, that are capable of self configuration, self optimization and self healing are the networks of the future. Moreover, self organizing networks (SON) comes in handy to address the previously described network energy issues.

In this paper the model for testing Energy Efficiency (EE) algorithm is discussed and the proposed EE algorithm is tested. The paper is organized as follows. The next section introduces the centralized EE algorithm, that controls the number of powered on eNB sites. Later the simulation model set up, including model components and their key functionalities are presented, finishing with the discussion of results, conclusion and future work.

Centralized energy efficiency algorithm

The key aim of the algorithm is to switch off as many eNBs as possible, during the periods of low traffic. With the current algorithm setup the maximum number of eNBs in power off state does not exceed half of the total number of eNBs in the network, where the assumption is that each powered off eNB must have a compensating base station to accommodate the traffic and cover for the emerging coverage hole. The energy efficient (EE) algorithm is triggered when the load at the eNB surpasses one of the two thresholds: *eNB threshold high* or *eNB threshold low*. *eNB threshold low* is the threshold determining load level below which the eNB is underutilized and could be powered off. We consider maximum eNB load at the peak hours L_{max}, then *eNB threshold low* is 20% of L_{max}. *eNB threshold high* is the threshold that determines load level 20% below the maximum load; it equals 80% of L_{max}. If this threshold condition is met, and if eNB is in compensating state, the powered off eNB shall be powered on in order to avoid possible overload at the compensating eNB. Consider a situation when the eNB traffic load reduces to *eNB threshold low* level (Figure 1). In such case the eNB triggers the centralized eNB power off algorithm by sending the signalling message to the central node, informing about the eNB ID, where the load threshold condition is met, and what type threshold was reached. In the central node, the list of all the eNBs in the network is maintained. The list is sorted in ascending manner according to the load and list entity in total contains 10 information fields that stores information about particular eNB. These fields are presented in Table 1.

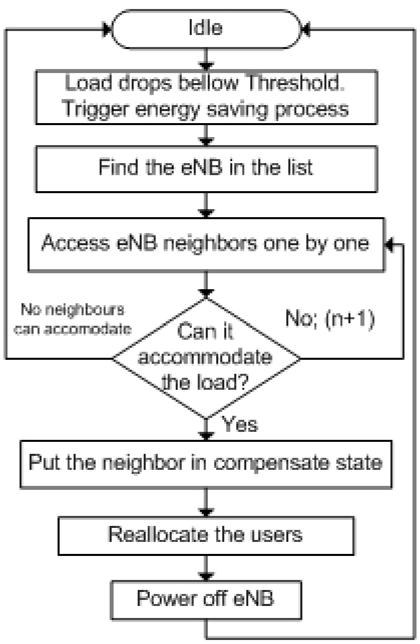

Figure 1: Centralized EE algorithm flow diagram

Table 1: Information about eNB

Field	**Characteristics**
eNB ID	A unique ID that is assigned to the nodes in the beginning of the simulation.
Number Of Users	Stores the number of users that are currently in the coverage area of that particular eNB.
Users List	Stores user IDs that are currently in the coverage area of that particular eNB.
Load	Total traffic load that is generated by the users that are currently connected to a particular eNB.
Threshold High	The maximum load that can be accommodated by the eNB also considering a 20% security margin which makes it 80% of total eNB capacity.
Neighbors List	Stores the neighboring eNBs IDs, which are the eNB within the Inter Cite Distance (ICD) limit.
Power State	Stores a binary digit: 1 for the eNB being in ON state, and 0 for the eNB in OFF state
Compensate State	Stores 1 if the eNB is in compensate state and 0 if eNB is operating normally
Compensating eNB	By default this field has a value of a 0. It is used to create bonds between the eNBs that are affected by the energy efficient algorithm. If the eNB is powered off it stores the Compensating eNB ID, that is the eNB that accommodates the users of the one that is powered off
Powered off eNB	By default this field is set to 0. It is used to create bonds between the eNBs that are affected by the energy efficient algorithm. If the eNB is in compensating state it stores the eNB ID of powered off eNB.

This is the information that describes the eNB and serves as criteria map for decisions made by the energy efficient algorithm.

Simulation setup

The simulations are carried out in OPNET modeller. Although OPNET provides models that support various wireless standards, such as LTE, we have instead used a custom built model with reduced complexity, that focuses on specific EE aspects.

Network topology

A network topology example is depicted in Figure 2. The eNBs are arranged to form a hexagonal grid, with base station located in the center of each cell. To consider inter site distance 500m we use cell radius R=289 m for full coverage. The yellow dashed line represents logical eNB connection to the central node, and in OPNET simulation environment the communication between these network entities is done using *op_pk_deliver* command.

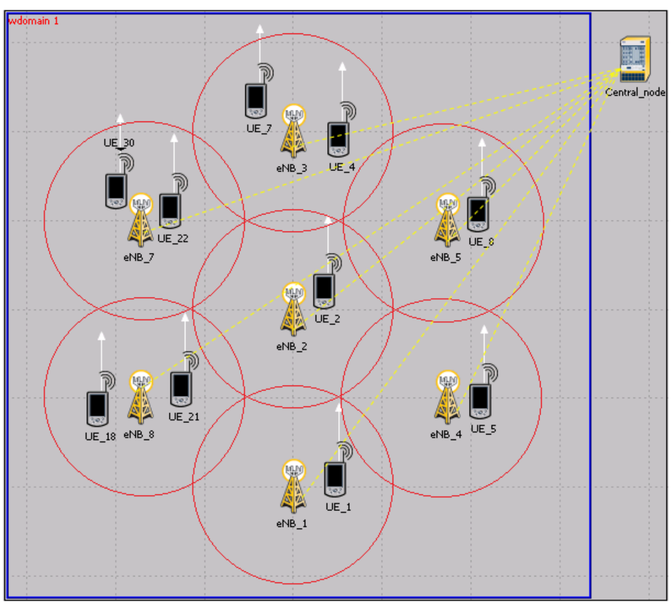

Figure 2: Network topology example

Our simulation model is slightly bigger than the example presented in Figure 2. It consist of 19 sites with 500 meters inter site distance. The user equipments (UEs) transmit on 10 MHz bandwidth operating at 2.1 GHz carrier frequency. It is assumed no interference in the network and each UE is associated with one eNB at a time. Packets that are sent to non-associated eNBs are filtered out in the sink of the eNB.
To model a realistic traffic profile we follow the derivative made in [5], such that in Europe the number of active subscribers during the peak hours corresponds to approximately 10 users with active data connections in a typical urban cell. The daily traffic profile reference values provided by EARTH project are depicted in Figure 3. The vertical scale represents the percentage of the traffic load in relation to the peak load during the rush hours. This traffic profile is closely followed by scaling the number of active users, while the traffic generation at UE remains according to the data type as in Table 2.

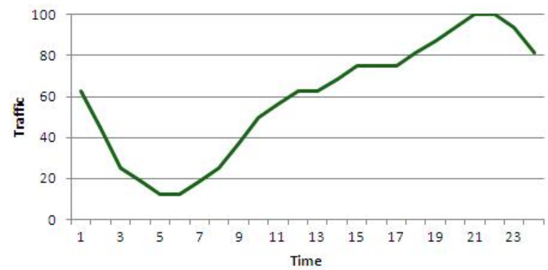

Figure 3: Data traffic average daily profile in Europe [3]

As it was mentioned before, we assume no interference in the network. This has been done in order to simplify the user reallocation to another eNB once some of the eNBs are powered off. To achieve no interference and avoid loosing the packets in wireless media the pipeline stages at the receiver end has been disabled except the error correction (stage 13) where *default ecc* is used.

eNB node model

The base station (eNB) node model consist of traffic *Generator*, *Transmitter*, *Antenna*, *Receiver*, *Sink* and *SON* modules (Figure 4). All the modules are connected by the packet streams, except one statistical wire that connects *SON* module to *Sink*. It provides statistical interrupts to the *SON* module based on the received traffic load.

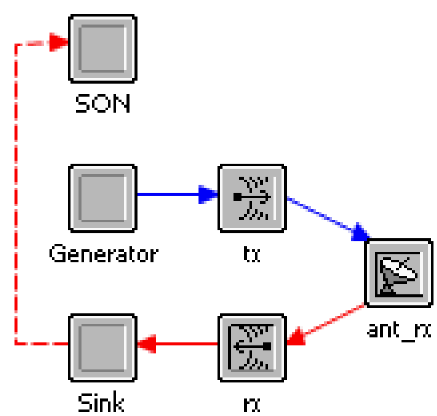

Figure 4: eNB node model

The traffic generated at the eNB is steady 1024 bit and it is a good indication of when and for how long the eNB is in power off state. The *Generator* process model is depicted in Figure 5. This is an adapted version of the *Simple source* process model. The transition between the *stop* or *generate* states is controlled by the central node, which delivers the *Power OFF* or *Power ON* commands.

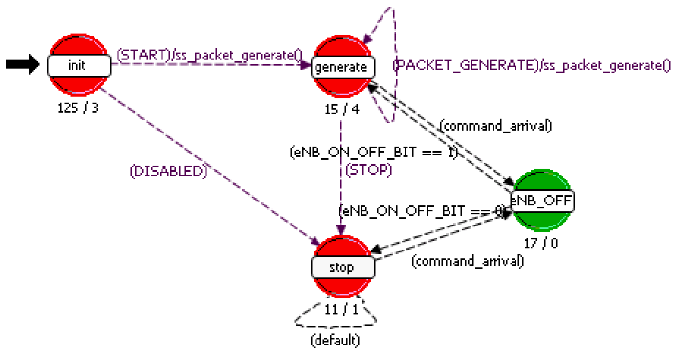

Figure 5: eNB generator state diagram

The *Sink* process model is depicted in the Figure 6.

- **PROCESS** state is responsible for filtering out the packets that are not dedicated to particular eNB, and then updating statistics. In this state the received traffic load at the particular eNB is measured. If the value of the statistics reach our defined load thresholds in the statistical wire, the statistical interrupts are generated to *SON* module. For example if the load drops below the *eNB threshold low* level the statistical interrupt initiates energy saving algorithm by triggering events in the intelligent eNB *SON* module.

- **LOAD** state stores the load as a variable that is read from a SON module and later passed to the central node as part of the information describing the eNB. This load variable value is an average of the received traffic that is updated every 5 s.

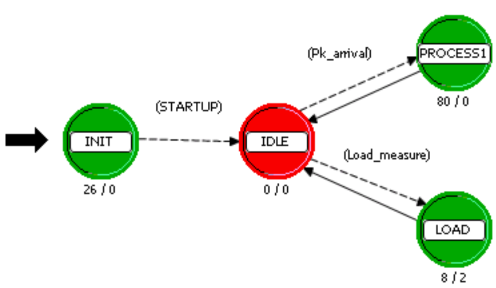

Figure 6: eNB sink state diagram

The SON module is the intelligent part of the eNB (Figure 7). This module is responsible for regular (every 10 s) information exchange with the central node, as well as triggering the EE algorithm in the central node when the statistical interrupts from the *Sink* module occur. Here are the states in more detail:

- **Init** is the initial state of SON process module where variables and timers are set. Variables include eNB thresholds (load, distance), eNB power state bit, compensate state bit, etc. In this state the users within the eNB coverage as well as the neighbouring eNBs are identified. Once the users are identified, they are informed of the eNB ID, to which they shall send the traffic. There are two timers set: one specifies how often information is exchanged with the central node and the other specifies how often the users are identified within the coverage, thus allowing user mobility.

- **Power ON** state is when eNB operates normally or in compensate state.

- **Power OFF** state is when eNB is put to sleep.

- **UE SETUP** state is accessed every 120 seconds and runs the function that identifies the users within eNB coverage area and informs them to send their packets to this particular eNB.

- **GenPacket** state periodically generates the packet that exchanges the eNB describing information with the central node. The packet is filled with structure that has information fields previously described in energy efficient algorithm section.

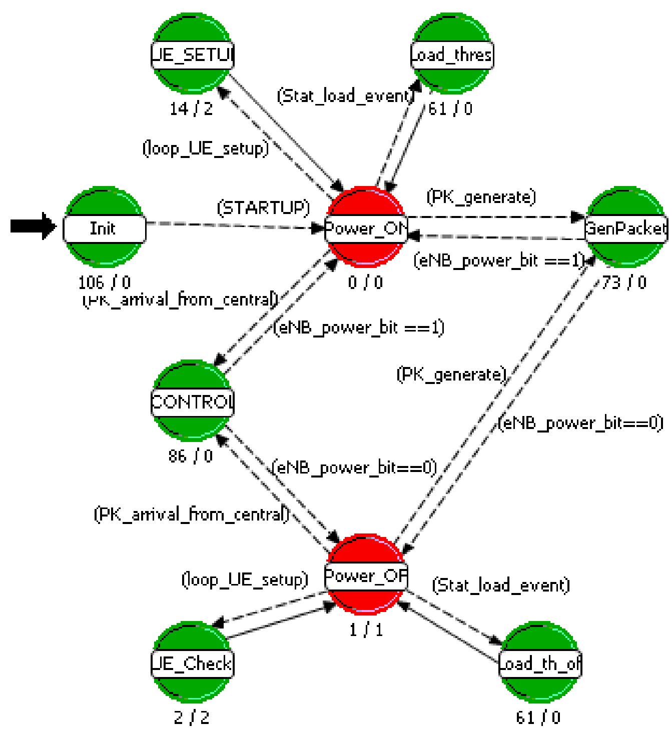

Figure 7: eNB SON state diagram

- **Load thresh** is the state that is accessed with statistical interrupt from the sink when one of the load threshold levels are reached. Depending what threshold condition was met, either the eNB power off or eNB neighbour power on triggering messages are sent to the central node.

- **CONTROL** is a transitional state, that identifies the messages received from central node, and either powers off or powers on the eNB.
- **UE Check** state is similar to the UE SETUP state such that it periodically identifies the users within eNB coverage area. However in this case, since eNB is in powered off state, it informs its users to send packets to the compensating eNB, rather than itself. The UE informing mechanism that is implemented currently must stay active during the powered off time, because of user mobility: if a user from an active cell arrives to powered off cell coverage it must connect to the eNB that is compensating for that area. In reality, the powered of eNB should consume very little power, the only active device should be one that controls the powering mechanism. Thus the previously described processes of power off state should be implemented and performed by compensating eNB.
- **Load th off** for power off state. The statistical load threshold interrupts still happen but they are cancelled out in this forced state.

UE node model

The UE node module is depicted in Figure 8 and similarly to eNB consist of: Traffic *Generator*, *Transmitter*, *Antenna*, *Receiver*, *Sink* and *UE SON* modules.

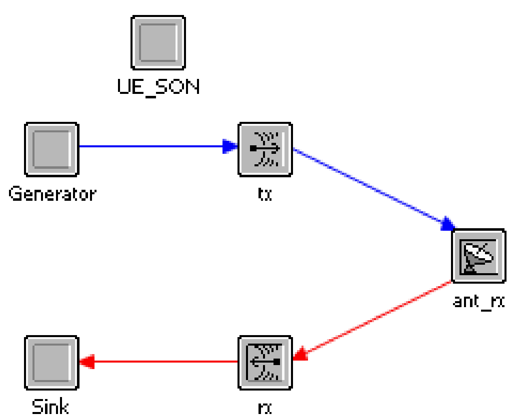

Figure 8: UE node model

The UE traffic *Generator* (Figure 9) is a modified version of the *Simple Source* and adjusted to support three traffic types that are summarized in Table 2 [7]. The traffic type for the UE can be set prior the simulation, by editing generator module attributes and choosing one of the three traffic types. To enable the ON/OFF periods for the VoIP traffic a transitional VoIP state that is forced by scheduled self interrupts is added to the Simple Source process model. The unforced OFF state is the state used to switch off any traffic generation for example, during the low traffic hours.

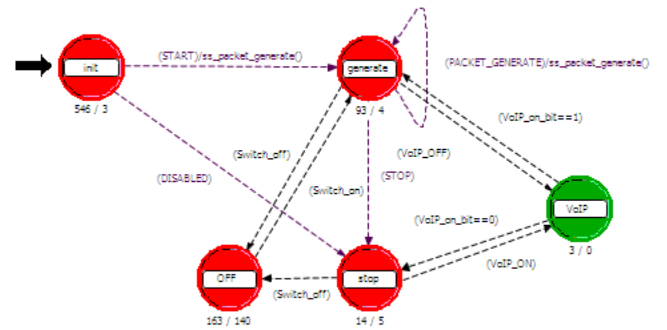

Figure 9: UE generator state diagram

The UE SON module (Figure 10) performs the function of receiving the packets sent from eNB SON with information of the serving eNB, i.e. the eNB ID to which the traffic from this UE must be sent to. The eNB ID is stored as variable and the UE generator marks all the packets with this particular eNB ID prior sending.

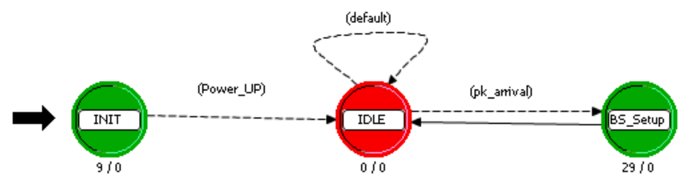

Figure 10: UE SON state diagram

Table 2: Traffic characteristics

	Characteristics	Distribution
Video	Packet size	Log-normal (mean 4.9 bytes, st. dev 0.75 bytes)
	Interarrival time	Normal (mean 0.033 s., st. dev. 0.01 s.)
VOIP	Packet size	Constant 66 bytes
	Interarrival time	Constant 0.02 s.
	ON time	Exponential (mean 1.34 s.)
	OFF time	Exponential (mean 1.67)
WWW	Packet size	Pareto (mean 81.5 bytes shape 1.1)
	Interarrival time	Normal (mean (0.0277 s. st. dev. 0.01 s.)
	Session size	Normal (mean 25 packets, st. dev. 5 packets)
	Reading duration	Exponential (5 s.)

Central node

The central node is responsible for monitoring the performance of the network. It collects the information from all the eNBs, and is the fundamental element of the centralized energy efficient algorithm coordination. Because the communication to and from central node is made using *op_pk_deliver* command, the node model does not require receivers and consist only of one processor module Figure 11.

Figure 11: Central node node model

The process model of central node is shown in Figure 12. The *SORTING* state is responsible for receiving the information packets from the eNBs SON modules and maintaining the list of all the eNBs structures that are present in the simulation setup. The list is sorted according to the eNBs load in the ascending manner, and updated periodically. Upon the EE triggering message arrival from the eNB the process transits to *Spec eNB* state where the EE algorithm is performed using the already described list.

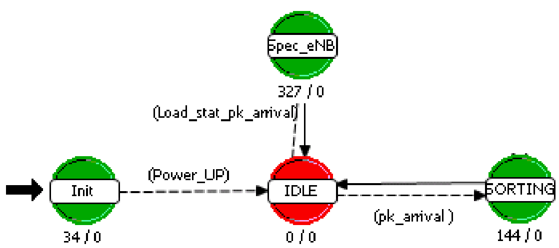

Figure 12: Central SON state diagram

Simulation results

In this section we evaluate performance of the algorithm. In Figure 13 the modeled traffic profile of the network is presented in bits/s over time.

The eNB thresholds (low and high) are chosen by evaluating the average eNB traffic profile, where the maximum received load is registered and threshold derived from that L_{max} value. The L_{max} value is retrieved by running a test simulation, in order to measure the maximum eNB load during the simulation. In current simulation setup $L_{max} = 118000$ bits. With this foundation the algorithm takes effect during the low traffic period which is between 1 am. and 12 pm. During this period up to 8 out of 19 sites can be powered off (Figure 14) without compromising user throughput.

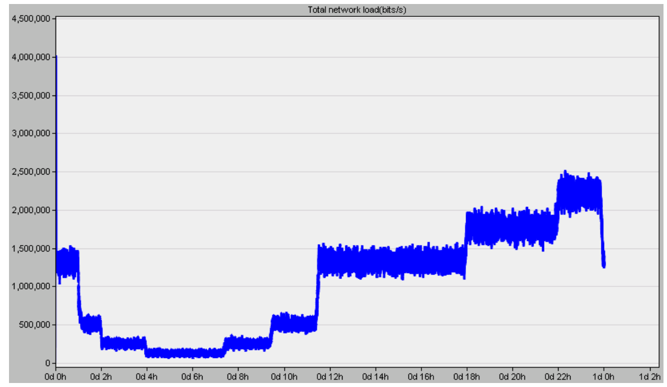

Figure 13: Network model traffic profile

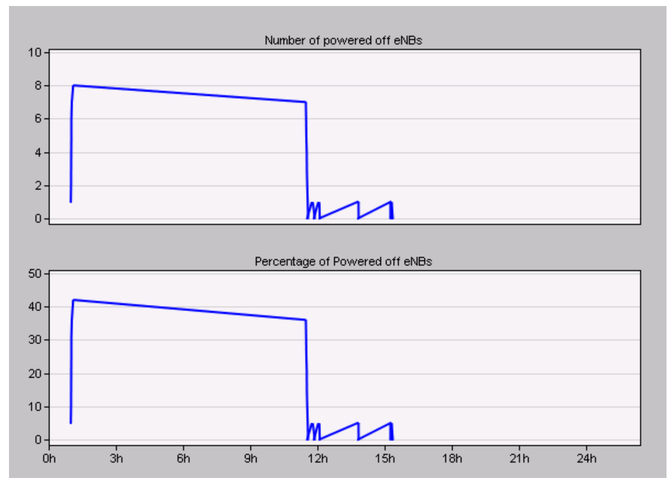

Figure 14: Number and percentage of powered off eNBs during low traffic hours

Conclusion

In this work we tackle the energy efficiency issues in mobile networks. We propose and analyse the performance of centralized energy efficiency algorithm that allows power savings by reducing the number of powered on base station sites during low traffic hours. It is important that the power savings are achieved without compromising the user throughput. The reduction of power consumption presented as a number of powered off base station sites propose that even slightly over 40% of energy can be saved when considering only the number of powered off sites during low network utilization periods.

Future work

Currently the power savings are presented as a number of powered off eNBs in time. In order to have more accurate results power model should evaluate the power increase in compensating eNBs, that are covering for the emerging coverage holes. In addition, the eNB powering on, and powering off procedure time should be considered, as it could influence the power saving results. Moreover there is high potential for algorithm optimization, such as e.g., changing the compensating schemes where one eNB can compensate for more than one powered off eNBs.

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