UPC – Tsinghua University

MULTIHOP RELAY STATION AND 3 SECTOR CELL ZOOMING USAGE FOR BASE STATION ENERGY SAVING

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1. ABSTRACT

It has been widely discussed the use of different techniques to guarantee the Quality of Service (QoS) in a network when a BS is turned OFF as an energy saving method. In this report, Multi-hop Relay Coverage (MRC) method and Cell Zooming Coverage (CZC) method are compared in terms of QoS and Energy Consumption when a BS is turned OFF. The results show that MRC is more robust in terms of maintaining QoS level when load in the network increases, while CZC show a better energy performance. Therefore, it is proved that the combination of both methods according to the network load level can achieve a better Energy saving performance than the separate use of only one of them.

2. INTRODUCTION

2.1. REPORT INTRODUCTION

The contents of this report are directly based on the paper that has been written after the research and that will be submitted for publication. Therefore, the remainder of this report is organized following that paper model.

A first introduction to the topic, its motivation and its previous research is described in chapter ***2.2. Introduction***. The system model used in the simulations, the energy model and the frame structure and throughput calculation followed in the simulation can be found in chapter ***3. System Descriptions***. Chapter ***4. Case study*** describes the precise cellular model analyzed, the simulation assumptions and presents the simulation results that have been obtained. Finally, chapter ***5. Conclusion*** concludes this report with the most important results found after the simulation.

For better understanding or in case of requiring additional information, references for this project can be found in chapter ***6. References,*** at the end of this report. Also, the initial version of the written paper has been attached together with this report and with all the work that has been done during this research.

2.2. INTRODUCTION

Energy consumption and greenhouse gas emissions are nowadays one of the major worldwide concerns. According to the SMART 2020 study [1], the Information and Communication Technology (ICT) industry is responsible for approximately 2% to 10% of the world energy consumption [2][3]. Moreover, together with the evolution of the communications technologies, there has been a huge increase of the CO_2 emissions; from 530 Megatons in 2002 to 830 Megatons in 2007. That leads many network providers companies, associations and developers to make great efforts on trying to find energy efficient networks [4].

The studies also show that large amount of this energy consumption is due to the Base Stations (BS), rather than the core network. In the case of the UMTS, for example, BS altogether consume up to 60% - 80% of the overall network consumption [5][6]. Also, there is the fact that the number of users is increasing every day, and that they demand higher transmission rates and better performances; which leads to the need of deploying even more BS. Therefore, trying to decrease the total energy consumption by turning OFF some of the BS's in light traffic load is a feasible solution that has been widely studied [7][8][9][10].

However, when a BS is turned OFF, the coverage of the OFF area and a certain level of QoS for those users connected to that BS that has been turned OFF must be guaranteed. In that way, two different approaches have been considered. The first ones are focused on the deployment of Relay Stations (RS) as a way to ensure the coverage and keep a certain level of QoS [8][9][10]. And the other approach is to use the other BS's in the network to cover the OFF zone by increasing their transmitting power; Cell Zooming [7].

In this report a new approach using MRC and CZC is considered. In order to find the best performance using each one of the current energy saving methods, both scenarios have been compared in terms of QoS and Energy saving. Outage, average user throughput in the whole network and average user throughput in the OFF zone are considered as a way of measuring the QoS. This report also shows the performance comparison between this energy saving methods and the ones shown in a typical case in which the network has only BS working, or in which a network has all BS and the RS turned ON. Finally, as a way to show the impact in terms of energy saving that ZCZ case has, 2 different cases of CZC have been studied.

3. SYSTEM DESCRIPTIONS

3.1. SYSTEM MODEL

Our analysis is based on an outdoor Multi-hop Relay cellular network deployment, considering N_C cell sites grouped into a two tier scenario, as shown in (Figure 1). Each cell has a radius of R_{Cell} and is divided into three independent sectors. One BS, situated in the middle of the cell, controls the amount of power that is independently and simultaneously transmitted to each sector; with the main beams at β (60°), β + 120° and β + 240°. A total of N_R more RS per sector are situated symmetrically α degrees at each side of the main BS transmission beam and at a distance of K_R x R_{cell} from the BS.

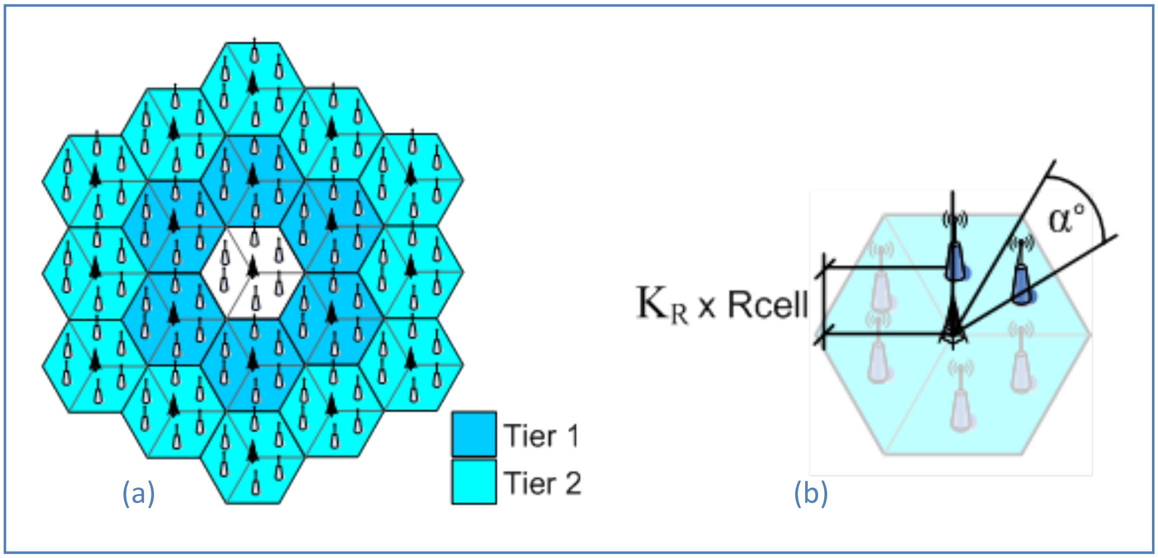

Figure 1. Multi-hop relay cellular network layout. (a) 19 cell site case grouped into two tier scenario. (b) BS and RS deployment.

Users are dropped non-uniformly in the whole area and, once dropped, every user is assigned either to a BS or to a RS according to their SINR level. That is, if the highest SINR level received comes from a certain BS, this MS is directly assigned to that BS. Otherwise, if it comes from a RS, the MS is assigned to a RS. In that case, the communication is considered to be Multi-hop, as there is one communication hop between the MS and the RS and, at least, another one between the RS and its BS. Furthermore, according to a scenario in which a BS is turned OFF, it is also possible to have a 3 hop communication; MS-RS1, RS1-RS2 and RS2-BS, as shown in (Figure 2).

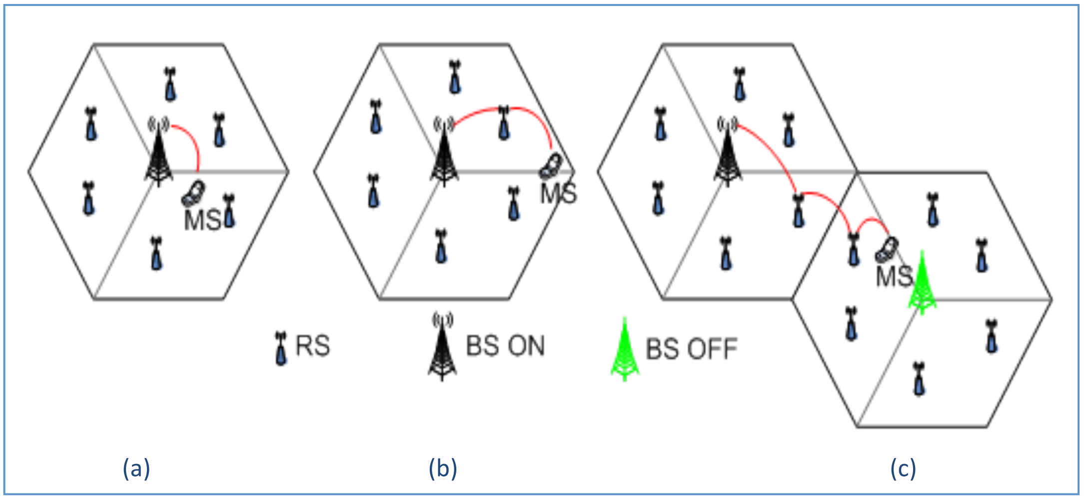

Figure 2. Multi-hop cases. (a) One hop. (b) Two hops. (c) Three hops.

Frequency reuse is considered in every cell and RS act in non-transparent mode. Also, a different frequency bandwidth is used between the transmission BS-MS and RS-MS and the transmission BS-RS. This allows a RS to transmit and receive data simultaneously and, therefore, throughput can be increased in a two-hop or three hop communication, when a MS is linked to RS's.

In our analysis, four different scenarios modes have been considered according to the load of the network and the possibility of turning OFF some of the RS and some of the BS:

- **All-ON case**: A first scenario in which all BS and all RS are turned ON.
- **BS-ON**: A second case in which only the BS are turned ON.
- **RS-Coverage**: A third case in which some BS are turned OFF and the RS are used to cover the cells which have their BS turned OFF.
- **Cell-Zooming-Coverage**: A fourth scenario in which all RS are turned OFF, some BS are turned OFF, and the BS that are ON increase the power transmitted by some of their sectors in order to cover the cells which have a BS turned OFF.

By switching between these four cases, then, the best throughput-energy saving scenario can be chosen. That is, in case of having very low traffic load in the network, the BS with less traffic load can access the OFF mode. In that case, and according to the QoS expected from the users, either *RS-Coverage* or *Cell-Zooming-Coverage* can be chosen. This allows the whole system to save the energy consumed by those BS that are turned OFF, while keeping a certain QoS for the users that are in the network.

Moreover, if *Cell-Zooming-Coverage* is used, not only it is possible to save the energy of all the RS and the BS that are turned OFF, but also the power transmitted by each sector can be adjusted to increase the energy saved, as shown in (Figure 3).

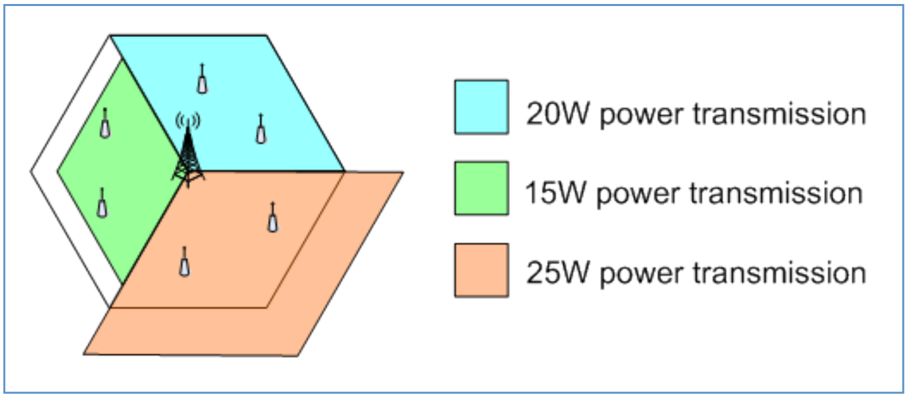

Figure 3. Three sector independent power adjusting.

3.2. ENERGY MODEL

As both BS and RS not only consume that power needed for the transmission, but also the power needed for processing the data, cooling the system or other static consumptions, a model which assumes static energy consumption and dynamic energy consumption is considered (1).

$$E_{consumption} = E_{Static} + E_{Dynamic}, \qquad (1)$$

Then, assuming that the BS is always transmitting; either directly to a MS or to a RS (in a multi-hop communication), considering each sector of a BS as an independent module, and also assuming that ON RS only transmit when they are connected to a MS; either 2 hop or 3 hop communication, the energy consumption of the network can be written by:

$$\begin{aligned} E_{consumption} &= \sum_{j=1}^{N_{BS}} \sum_{s=1}^{3} BS_{static}(j,s) T_{Total} + N_{ON-RS} RS_{Static} T_{Total} \\ &+ A_m T_{Total} \sum_{j=1}^{N_{BS}} \sum_{s=1}^{3} BS_{Tx}(j,s) + A_r \sum_{i=1}^{N_{ON-RS}} RS_{Tx} T_{Tx}(i) \end{aligned}, \qquad (2)$$

Where the power consumption model in [6] has been applied and

- N_{BS} is the total number of BS; each one with 3 independent sectors.
- $BS_{Static}(j,s)$ is equal to 354.44W if *sector s* of *BS j* is turned ON, and is equal to 0 if it is turned OFF.
- T_{Total} is the total operation time.
- $N_{ON\text{-}RS}$ is the number of RS that are turned on.
- RS_{Static} is 71.5W for the ON RS.
- A_m = 21.45 is a scaling factor for the radiated power of a BS.
- $BS_{Tx}(j,s)$ is the power transmitted by the *sector s* of the *BS j* .
- A_r = 7.84 is a scaling factor for the radiated power of a RS.
- $T_{Tx}(i)$ is the transmission time of the i_{th} RS and can get values from 0 to T_{Total}.

3.3. FRAME STRUCTURE AND THROUGHPUT CALCULATION

Relay structures in [11] for non-transparent RS mode are used in the simulation cases in which RS are ON. That is, according to their SINR, one frame of 5 *ms* of duration is assigned to one MS at a time. Each frame is divided into two main parts; downlink and uplink, and each part has a header before transmitting the data. In case of having a multi-hop communication, that frame is first transmitted to a RS and, on the next frame, that RS transmits it to the linked MS; following a two-hop case. In case of having a three-hop communication, the transmission adds an extra additional step between the first RS and the second one, as shown in (Figure 4). Only downlink is considered for our analysis.

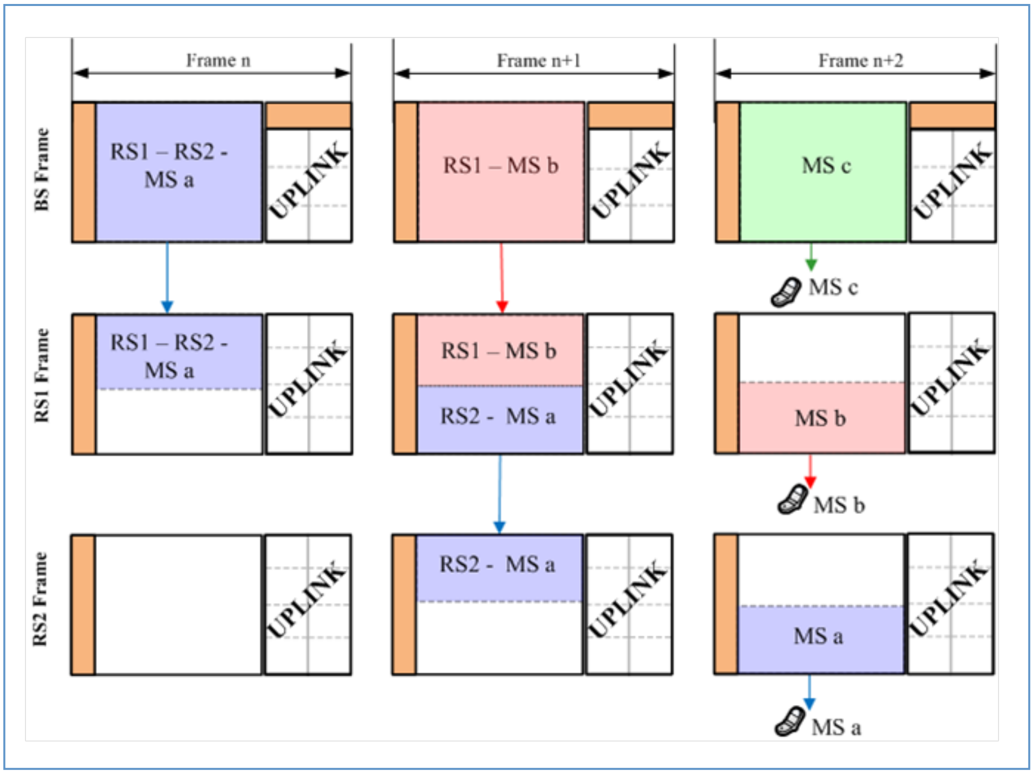

Figure 4. Frame structure. (a) MS c linked to a BS, (b) MS b linked to one RS and (c) MS a linked to two RS

For each frame, and according to the SINR between the current MS and the linked RS('s) or BS, different channel modulations can be chosen. Using the channel modulation and the code rating of the modulation, then, the number of bits transmitted in one frame can be directly calculated

$$N_{bit}(j) = C_{rate} Nb_{\mathrm{mod}} Ns_{symb} Nsymb_{user}, \qquad (3)$$

And knowing the total number of frames transmitted to one MS, the number of bits transmitted in each frame and the duration of the simulation, then, throughput can be calculated as follows

$$Mbps(userx) = \frac{\sum_{j=1}^{N_{frame}(userx)} N_{bit}(j)}{T_{frame} N_{frames}} \frac{1}{1 \times 10^6}, \qquad (4)$$

Where the final result has been adjusted to Mbps and

- N_{frame}*(user x)* is the number of frames transmitted to user x.
- N_{bit}*(j)* is the number of bits transmitted in frame j.
- T_{frame} is the frame time duration (5 ms).
- N_{frames} is total number of frames transmitted.
- C_{rate} is the code rating ($0 \le C_{rate} \le 1$).
- Nb_{mod} is the number of bits transmitted per subcarrier.
- NS_{symb} is the number of subcarriers per symbol.
- $Nsymb_{user}$ is the number of available symbols for a user in a frame period.

4. CASE STUDY

4.1. CELLULAR MODEL

The practical cellular model parameters considered in our simulation are the ones in TABLE I.

Description	Parameter values
Cell radius (R_{cell})	1500 [m]
Configuration	2 tiers, N_C =19 cells, 3 sectors/cell
BS main beam directions	BS main beams are located at β = 60° for the sector 1, at 180° for sector 2 and at 300° for sector three.
RS location	Symmetrically at α = 30° at each side of the main beam and at distance $0.8xR_{Cell}$ [m] from BS
BS/RS/MS height	30 / 30 / 1.5 [m]

TABLE I. CELLULAR MODEL SIMULATION PARAMETERS

Also, a two-steps user dropping method is used. Firstly, up to 40% of the total number of MS is dropped uniformly on the whole network area. Then, the 60% remaining users are dropped in four different hotspots according to a normal distribution with mean = 0 and variance = 1. That is, a part from the homogenous drop previously distributed, two hotspots also contain, each one, 20% of the total number of users, and the two other hotspots contain, each one, 10% of the total number of users dropped in the network, as shown in (Figure 5).

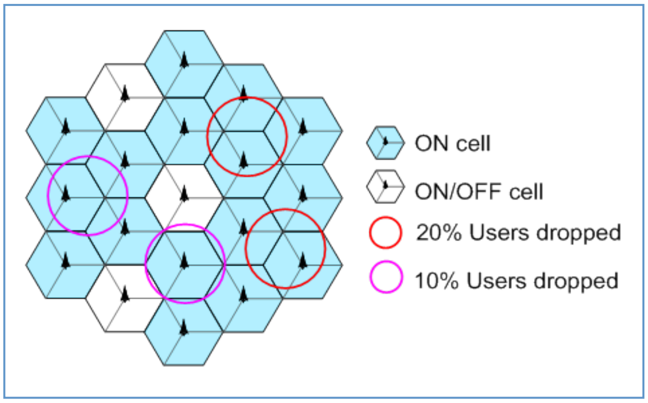

Figure 5. Non-homogeneous user distribution; 40% homogenous + 60% in four different hot spots. Always ON cells and switching ON/OFF cells.

The difference between the cases of energy saving and the normal cases remain on the fact that 3 BS can be turned OFF, as shown in (Figure 5). That is, following the cases described in Section 3.1. System model, those 3 BS are the only ones that are turned OFF.

Finally, two different cases of Cell-Zooming coverage have been considered. A first case in which each BS transmits 20 W per sector when it is in ON mode. And a second case in which those BS sectors that have to extend their coverage to other BS-OFF-cells increase their transmitted power up to 25 W, while the rest decrease it to 15 W, as shown in (Figure 3). In all the other scenarios, ON BSs transmit 20 W per sector while ON RS transmit 5 W omnidirectionally.

A total of 5 different scenario simulations are, then, considered:

- ***All ON*** case.
- ***BS ON*** case: BS ON and RS OFF.
- ***RS – Coverage*** case: 3 BS OFF, 16 BS and all RS ON.
- ***Cell Zooming 20 W*** case: only 16 BS ON.
- ***Cell Zooming 15 W – 25 W*** case: only 16 BS ON with power adjusting.

4.2. CELLULAR MODEL

Practical system-level simulation parameters have been simulated, as shown in TABLE II. and an OFDMA system is considered, with 10 MHz carrier bandwidth, 720 data subcarriers and 11.6 kHz of subcarrier spacing. Also, the same MCS levels between BS and RS and between RS and MS are used for simulation simplicity.

Description	Downlink
Frame structure	IEEE 802.16e, 16j non-transparent
Path loss type (BS-RS / BS, RS-MS)	Urban, LOS / NLOS [12]
Multipath type	ITU-R Pedestrian A (3 km/h), B (10 km/h), Vehicular A (60 km/h), B (120 km/h)
Shadow modeling	Spatial correlation, cross correlation [12]
Shadow std. deviation	Type E: 8 [dB] [12]
Antenna structure	1 × 1 (SISO)
Transmit power	20 / 5 [W] (BS/RS)
Maximum antenna gain	14 / 10 / 0 [dBi] (BS/RS/MS)
Noise figure	9 [dB]
DL/UL ratio	2:1 (DL = 28 symbols, UL = 14 symbols)
Scheduling/traffic model	Round robin / full buffer
Modulation and coding scheme (MCS)	QPSK (1/12, 1/8, 1/4, 1/2, 3/4), 16QAM (1/2, 3/4), 64QAM (3/4) with convolutional turbo code (CTC)
β values for each MCS	1.6, 1.6, 1.6, 1.7, 5.4, 8.2, 16.5, and 30

TABLE II. SYSTEM LEVEL SIMULATION PARAMETERS

4.3. SIMULATION RESULTS

The simulations results are obtained after averaging 30 simulations of each one of the cases stated in Section 4.1. Cellular Model. In each simulation, network and system level parameters are kept constant, while number of users of the network increases from 57 to 1995. Results are also separated into two different blocks for better understanding; those related to the global network, and those related to the OFF cell zones. Finally, different traffic loads zones can be considered according to the number of users deployed in the network:

- ***Very low traffic load***: below 200 users.
- ***Low traffic load***: below 400 users.
- ***Moderate traffic load***: below 800 users.
- ***Moderate-high traffic load***: below 1200 users.
- ***High traffic load***: above 1200 users.

Firstly, global QoS performance of the five different cases is analyzed. For that, Figure 6 and Figure 7 show us, respectively, a comparison between the five cases of the total Outage in the network (considering in outage all those users with throughput rate below 5 kbps) and the total user average throughput.

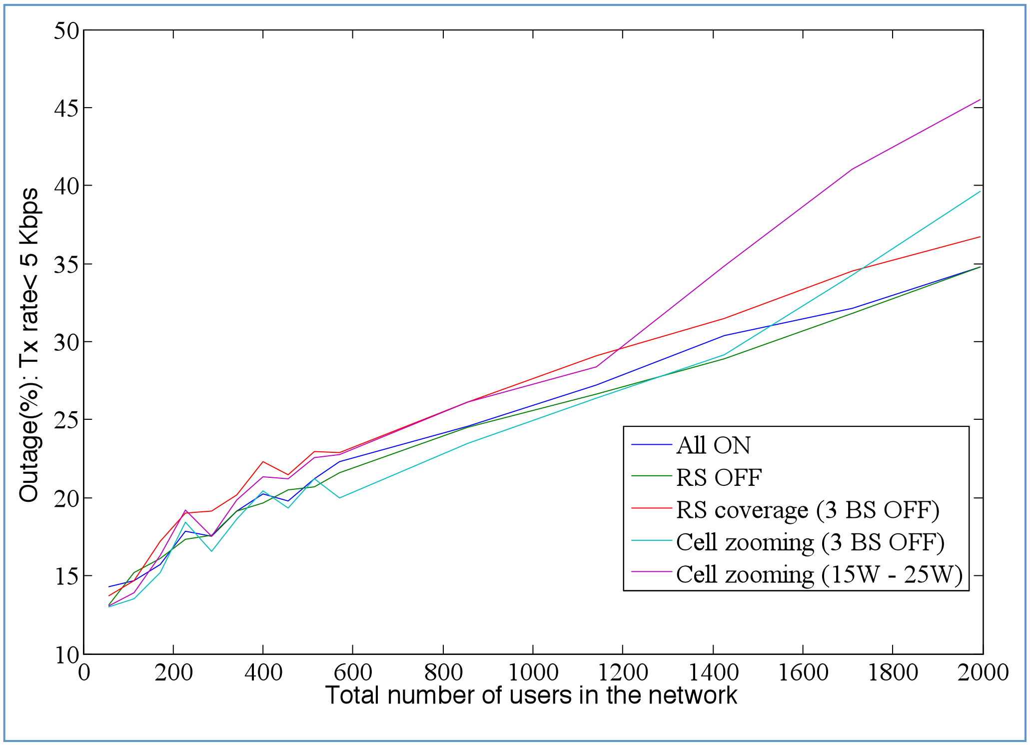

Figure 6. Comparison of the total outage (user throughput rate below 5 kbps) in the network when load increases [Outage vs Total number of users]

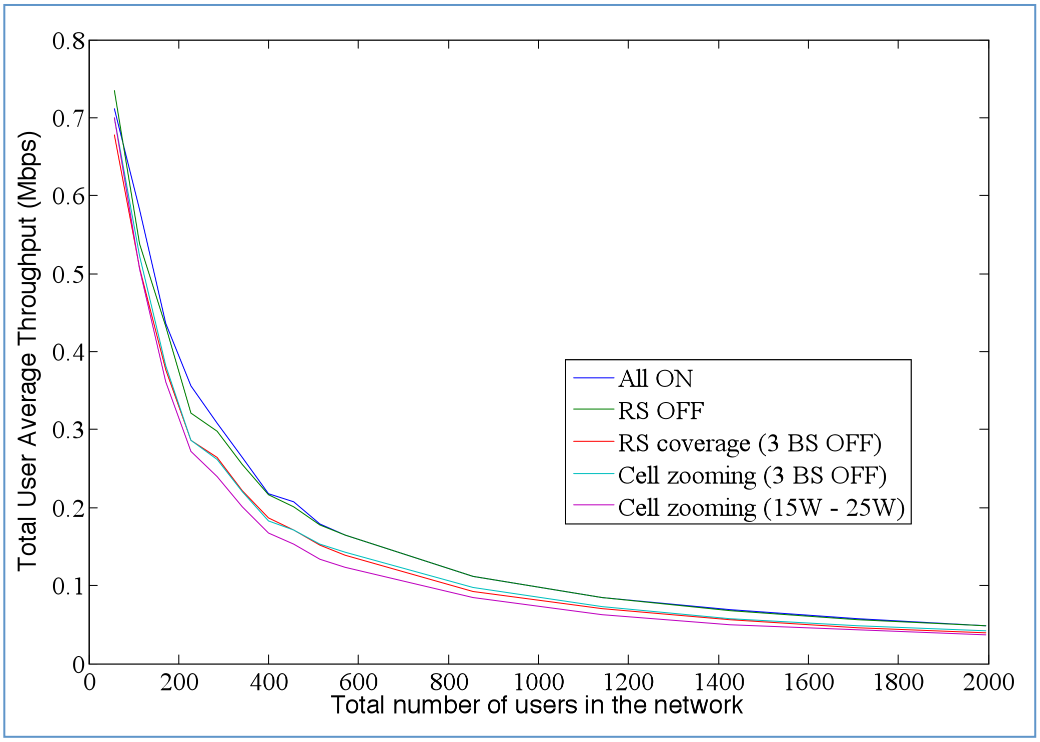

Figure 7. Comparison of the total average user throughput when load increases [Mbps vs Total number of users]

Considering the difference between the five different cases, we can see that both CZC (pink and light blue) and MRC (red) have always a lower QoS performance than that of a normal network case with all the BS turned ON (dark green) or with all the RS and BS turned ON (dark blue). However, that difference between CZC and MRC, and the normal network cases is, when they are under high traffic loads scenarios, always below 10% in terms of outage performance, and always below 100 kpbs in terms of user average throughput.

In terms of energy consumption, however, Figure 8 shows that the difference between the five different cases studied is much bigger than that seen in their general QoS performance. By using CZC, for example, we can see that the energy consumption can be reduced up to the 32% of the total energy used in the normal All ON case, if CZC without power adjusting is used, or up to about 53%, when CZC with power adjusting is used. This results show, as we can see in Figure 9, that CZC is more energy efficient per unit of average user throughput than the rest of the cases.

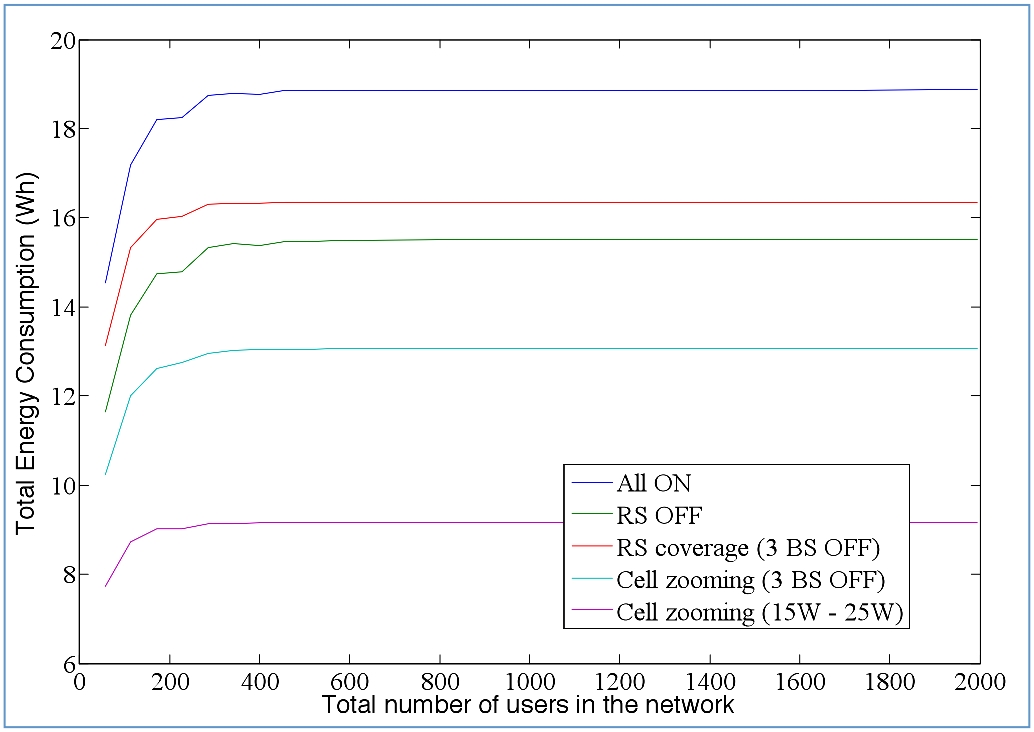

Figure 8. Comparison of the total energy consumption when load increases [Wh vs Total number of users]

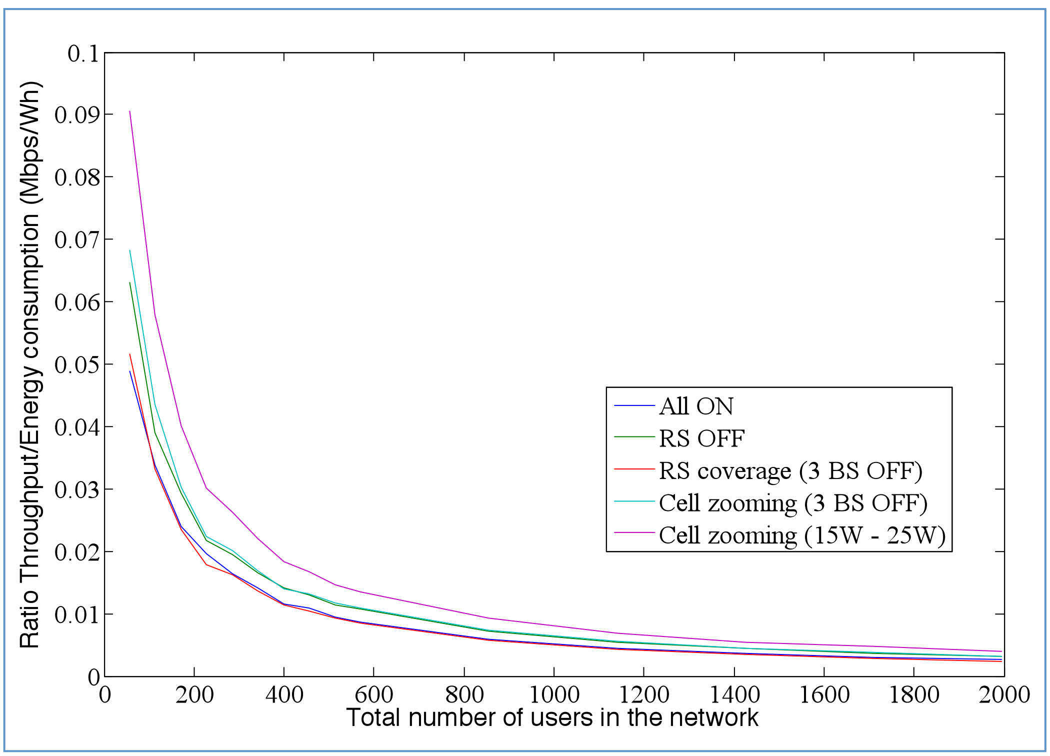

Figure 9. Comparison of the global energy efficiency when traffic load increases [unit of user average throughput transmitted by each unit of energy consumed vs Total number of users]

If the OFF zone is studied, however, QoS performance is worse than that found for the whole network, as we can see in Figure 10 and Figure 11. In this case, the outage difference between the CZC cases and the normal cases is kept below the 10% only for very low traffic loads while MRC can keep this difference for loads a little bit higher (below 900 users). In terms of user average throughput, the difference is bigger for low loads (up to 1 Mbps), but this difference decreases below 200 kbps as load increases (above 900 users). However, Figure 11 also shows that both CZC cases and MRC can guarantee an OFF-zone average user throughput in low traffic cases better or equal to that guaranteed by normal networks above high load traffic cases. That means that if CZC is used for low traffic scenarios, MRC is used for moderate traffic scenarios, and normal network cases are used for higher traffic loads, a certain threshold of user average throughput can be guaranteed; both in the general network and in the OFF zones.

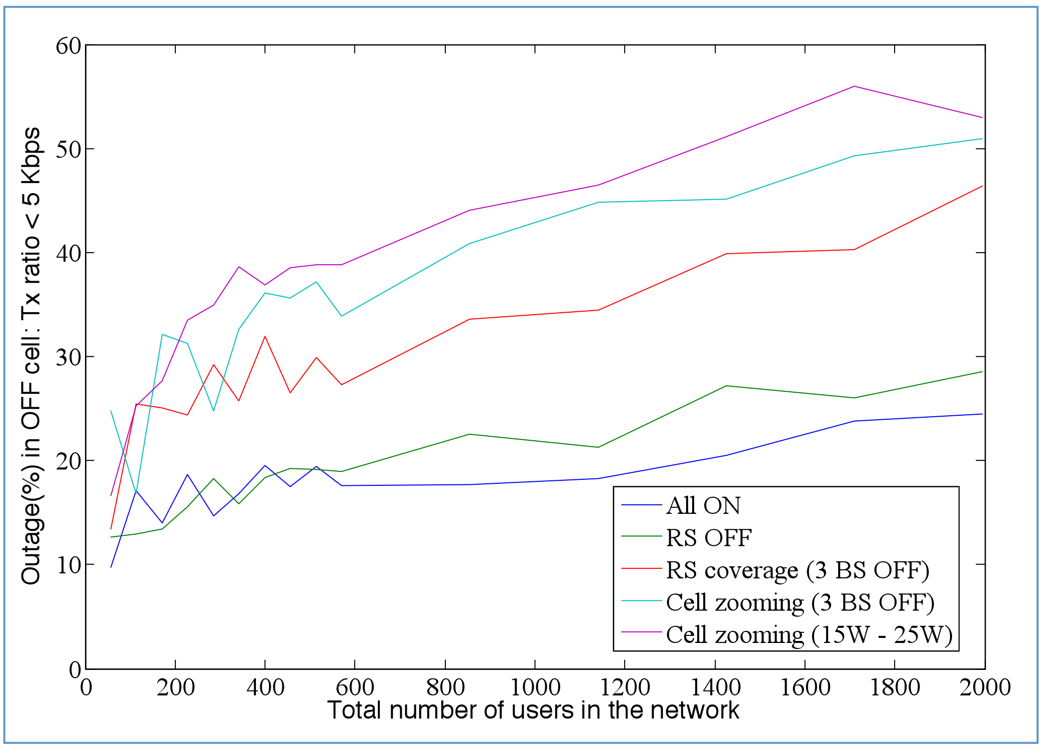

Figure 10. Comparison of the outage (user throughput rate below 5 kbps) in the OFF zones when load increases [Outage vs Number of users in OFF zones]

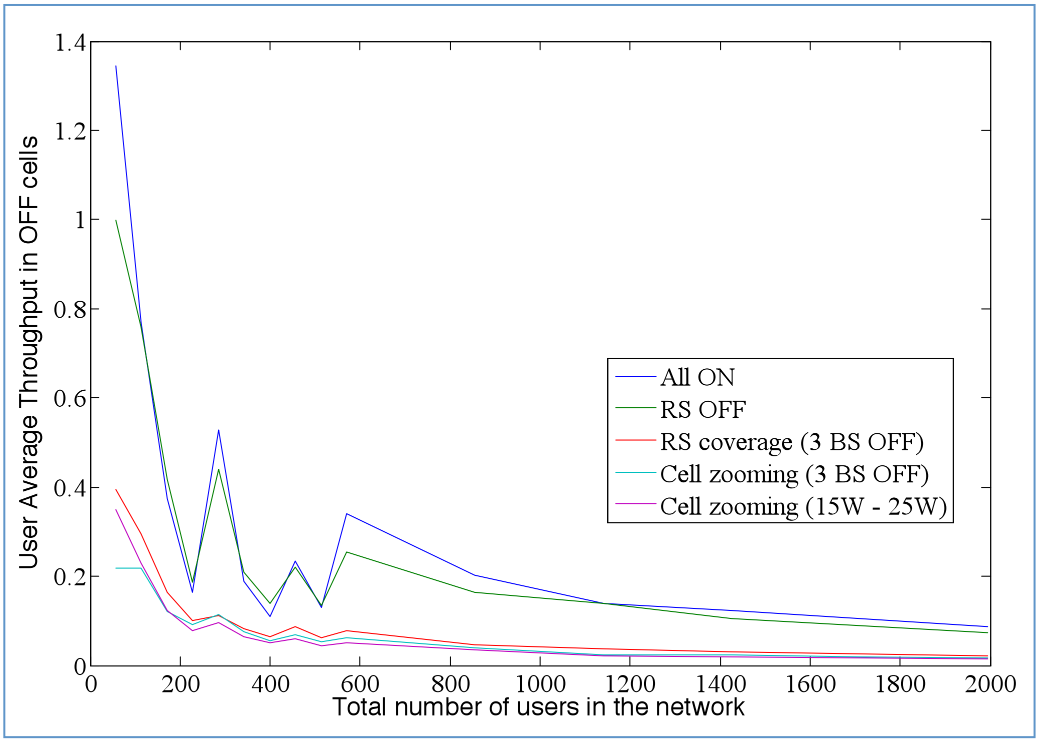

Figure 11. Comparison of the average user throughput in the OFF zones when load increases [Mbps vs Number of users in OFF zones]

5. CONCLUSION

In this report it was proposed a new approach to energy saving methods in which both Multihop Relay coverage and Cell Zooming Coverage are used when a Base Station is turned off. Normal network cases with all the BS turned on, or with all the Base Stations and the Relay Stations turned on, have been compared to MRC and to two different types of CZC; one of them with energy adjustable sectors, and the other one without it. The comparison has been carried out in terms of general outage and outage in the off zones, general average user throughput and average user throughput in the off zones, and total energy consumption. After studying the results, we have found that:

1- CZC can always guarantee an outage performance that is less than 10% worse than normal network cases in low and very low traffic loads.
2- MRC can always guarantee that the outage performance is less than 10% worse than normal cases in moderate, low and very low traffic loads.
3- Using CZC for low and very low traffic loads, MRC for moderate traffic loads, and normal cases for moderate and high traffic loads, it is guaranteed that user average throughput is always above a certain threshold.
4- CZC with independent sector power adjusting can save up to 53% of the energy consumed by a normal network in which all the relays and base stations are turned on.

Through our analysis, then, it is proved that the combination of different energy saving methods according to the network load can achieve even a better energy saving performance than the usage of these methods separately, while still keeping the Quality of Service of the users.

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