Energy consumption of LTE-UMTS multi RAT system using planning algorithms

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Abstract: The optimal base station placement and effective radio resource management are of paramount importance tasks in cellular wireless network planning. The operators can save budget increasing the profit, furthermore, the pollution of carbon dioxide can be decreased by effective planning methods. This paper presents analyses, which introduce the energy consumption of multi RAT systems in terms of demand migration between two technologies. The primary target is to reduce power consumption by means of cooperation of different standards.

1. Introduction

Currently the ICT operator sector uses about 3% of the world electric energy consumption. It might seem an irrelevant factor in percentage, however actually the portion of mobile industry, in particular the cellular radio network parts consume about 60 billion kWh per year, that is roughly equivalent with the consumption of 15-20 million households. So the total amount of electrical energy consumption of wireless networks is very significant and this value raises by 15-20% yearly.

Reducing power consumption and the integration of renewable energy sources in mobile access networks are thus of utmost importance. However the green energy sources do not reduce the energy consumption of wireless systems, but the carbon dioxide pollution can be decreased by this changing. Considerable energy reduction can be achieved by the increment of efficiency of network elements and the effective network planning procedure. So the radio base station is a viable and very important research direction. In 2010 January a new project was started in the European Union, it was called EARTH. The aim of this is an average 50 percent energy decrement in the wireless mobile systems. This target is to be achieved by advanced radio (hardware) solutions as well as by network deployment and management procedures. This work is performed under Earth framework and focuses of cellular network planning and network management taking into account energy considerations.

Nowadays many wireless radio access technologies can be already found in our environment using different standards. These systems are made up of also stations which guarantee the necessary resources. These stations contain the transmitters, power supply, signal processing and cooling systems etc. In case the stations of new standards would be installed in the position of earlier placed stations then the operators shouldn't build a new cooling system (maybe signal processing, power supply). So energy reduction can be achieved by this decision.

Our work using earlier published migration and multi RAT planning methods introduces the energy consumption of multi RAT system in terms of technology conversion. Actually it focusses on the UMTS-LTE conversion.

The rest of this paper is organized as follows. In Section 2. the models used in this study are presented. This part also contains the introduction of the energy optimizing method. In Section 3. we shortly describe the original cellular planning, the used migration and multi-RAT methods. In Section 4. the results of simulations are provided.

2. System model

This section introduces the system model we used for developing the algorithm and during simulation experiments. A scenario can be simply described by the set of applicable coordinates over the area and the given traffic amount per period of day over the area, assigned to any subset of the coordinates on the terrain. We suppose that the amount of traffic demands in different times of the day to be served is given by a set of discrete coordinates (denoted as Demand Positions, DPs), along with the amount of traffic generated at that position. This approach is flexible to describe any kind of traffic distribution (continuous, if every point of the area is a DP, discrete service areas if there are much smaller number of DPs). The set of DPs is denoted by:

$$\mathcal{DP} = \{\cup_{i=0}^{m} DP_i\}; \tag{1}$$

where m is the number of DP_is in the given traffic environment. These points are represented by (x_i,y_i,d_i), where x_i, y_i are the coordinates and d_i is the traffic demand of DP_i, expressed in kbps. During experimentations, we will change the number of DPs and d_i as input parameters.

We suppose that a base station (BS) operates three cells through three sectorised antennas. It's made up of transmitters, cooling system, signal processor, power amplifier and antennas. The model of power consumption is applied in this study accounts for the consumption of these components.

The stations are represented by

$$\mathcal{BS} = \{\cup_{j=0}^{t} BS_j\}; \tag{2}$$

where t is the number of BS_js in the given traffic environment.

If we plan a cellular network in a urban environment then we can't locate the stations everywhere. In consequence we assign candidate positions (CP), where a station can be placed:

$$\mathcal{CP} = \{\cup_{j=0}^{r} CP_j\}; \tag{3}$$

where r is the number of CP_j^ss in the given traffic environment. Actually we can be found more radio access technologies within our environment. The stations of these standards were placed also to a candidate positions.

$$\mathcal{CPE} \subseteq \mathcal{CP}; \tag{4}$$

where CPE signs the candidate positions where the earlier placed stations can be found. We use COST 231 Okumura-Hata path loss model for big city environment in our simulations. This has the advantage that it can be implemented easily without expensive geographical database, yet it is accurate enough, captures major properties of propagation and used widely in cellular network planning. A sector is defined as the set of DPs that are covered by a given transmitter. The "best server" policy is followed within the network, namely a demand is served by the sector whose signal strength is the highest in the position of DP_i [2].

The resources of network can be managed by frequency adaptation and power management. Our planning procedure uses the properties of 3GPP LTE (Long Term Evolution) radio resource management (RRM). The relationship between SINR and spectral efficiency is given by the so called Alpha-Shannon Formula which is suggested to be used for LTE networks in [1].

The RRM of LTE is modelled in our case by a semi dynamic frequency allocation strategy. The sectors allocate Physical Resource Blocks (PRBs) to the demands in the order of decreasing SINRs. The frequency allocation simultaneously deals the PRBs one by one in every sector. Note that the amount of traffic a PRB can carry is determined from the SINR by the alpha-Shannon formula. If a sector is ready (serves all DP^g sets) then it won't transmit on the remaining PRBs (hence the SINR on these PRBs will be better for the neighbours). This method is very fast and reasonably high SINR values can be achieved by cell borders as well. It has to be emphasized, that any RRM algorithm can be supposed for our planning mechanism, RRM function is actually an input to the planning (and thus affects final results). The described simple RRM is just an example, used in the evaluation of the planning algorithm. In practice LTE base stations are transmitting with constant power spectral density (regardless the number of PRBs actually used), hence using less PRBs require proportionally less transmit power, as described below in (5).

The transmit power of a sector, P_{tr} hence can be described by

$$P_{tr} = \frac{usedPRB}{allPRB} * P_{tr0} \tag{5}$$

where P_{tr0} is the maximum top of cabinet output power of transmitter, $usedPRB$ and $allPRB$ are the number of actually used PRBs and all PRBs respectively. This latter depends on the configured bandwidth of the system, that is also a parameter of the deployment method. Namely, as a PRB is a 180 kHz wide chunk of the channel, in a 1 ms timeslot, e.g. a 20 MHz bandwidth configuration typically means 100 PRBs in every 1 ms slots.

The power consumption of the base station follows the linear model [5] (adopted by the Earth project as well):

$$P_{Cons} = P0 + \mu * P_{tr} \tag{6}$$

where the first part ($P0$) describes the static power consumption (used even in case of no transmission). Depending on the load situation, a dynamic power consumption ($\mu * P_{tr}$) part adds to the static power. The factor μ is mainly due to the power amplifier inefficiency and feeder loss.

3. Base station placement and multi RAT planning methods

This section deals with the base station placement and multi RAT planning methods. The main tasks of these are the positioning of the base stations and the determination of the direction of antennas taking into account the earlier installed systems in terms of energy consumption. The method can be configured for given coverage (in terms of percentage of the area covered by at least a minimum signal strength) and service (in terms of percentage of total traffic requirements served) criteria. The default is 100% for both. The main input parameters are the used bandwidth and transmit power parameters of BSs as well as the DP. The output data are the base station topology (BS) and the set of used candidate points (CP) [4].

3.1 Objective Function of placement method

Our optimization procedure can be describe by minimizing the objective function

$$O(\mathcal{BS}, \mathcal{DP}) = min \sum_{i=1}^{k} \sum_{\forall DP_j} d_j * ||x_j - BS_i||^2, \tag{7}$$

where d_j is the size of DP_j in kbps, x_j is the position of DPU_j as well as $||vector||$ is the length of $vector$, BS_i is the location of i_{th} station. The main idea behind is that the base stations are to be positioned near the highest demands. This results in high SINRs for high demands, allowing the use of more effective modulation and coding (that is higher spectral efficiency) resulting in lower number of required PRBs [3],[4].

3.2 Placement algorithm

So the goal is to place a number of base stations over the area that minimizes (7). This can be achieved by K-means clustering method. The cluster here will be the set of DPUs allocated to a cell. The algorithm is composed of the following steps:

1. Place K points into the space represented by the DPUs that are being clustered. These points represent initial guess of BSU positions (group centroids in clustering terminology).
2. Assign each DPU to the group that has the closest centroid. (Assignment step)
3. When all DPUs have been assigned, recalculate the properties of the K centroids. (Update step)

$$m_i^{(t+1)} = \frac{1}{\#C_i^t} \sum_{x \subset C_i^t} x_j \tag{8}$$

where $\#C_i^t$ is the number and x is the location of DPU within i^{th} cluster (C_i).

4. Repeat Steps 2 and 3 until the centroids no longer move or our counter of iteration expire.

The positioning algorithm is based on this K-means procedure. The centroids of clusters are the base stations. The assignment step is the procedure of sector creation, and one cluster is made up of three sectors of stations. Before the update step the algorithm creates a dynamic environment, which can contain elements form different DP^s. The method has to choose in every sector the demands of s_{th} traffic environment that would load the given sector to the greatest extent. In the update step the positions of demands of new environment (x_i) is weighted by the size of demands(d_i). After this step we shift the stations to the nearest candidate position.

The antenna rotation algorithm is also based on K-means clustering. Our aim that the directions of covered DPUs with higher demand are subtended smaller angle with the main direction of serving antenna. The assignment step is also the procedure of sector creation. After this we have to also create the dynamic environment. In the update step x_i is the subtended angle between the direction of covered demands within the sector and the main direction of serving transmitter weighted by the d_i. This is followed by the PRB RRM on all s_{th} environments.

After this we have to find the most unserved sector (MUS), which is the one with the highest total unserved traffic (demands with not enough PRBs allocated to) under its coverage. If the number of required PRBs is less than the number of available PRBs of the given sectors in all traffic environments then there is no MUS and the algorithm stops. Otherwise the algorithm locates a new base station near the serving antenna of MUS in the main direction and runs the positioning, rotation and RRM mechanisms again [3],[4].

3.3 Migration method

This method combines the placement algorithms to plan an energy effective topology. The most important task of this method is to minimize energy consumption of the union of demand scenarios (UMTS,LTE,GSM). The main idea is the following: for each traffic environment, minimal power network layout is determined. It is assumed that base stations can be reconfigured or switched off, when not part of the actual optimum layout. Network management handles the transition between the different optimal layouts. The next pseudocode introduces the proposed algorithm.

1.
$DPU \leftarrow \cup_{i=0}^{s} DP^i$
$CPU \leftarrow \cup_{i=0}^{s} CP^i$
$BSU, CPU \leftarrow Placementalgorithm(DPU, CPU)$
$BS, CP \leftarrow BSU, CPU$

2.
for all $i \in environments$ **do**
  $DPU \leftarrow DP^i$
  $CPU \leftarrow CP$
  $BSU, CPU \leftarrow Placementalgorithm(DPU, CPU)$
  $BS^i, CP^i \leftarrow BSU, CPU$
  $Transmitterpowerreductionmethod(BS^i, DPU)$
end for

At the beginning we define DPU and CPU, which are $DPU = \cup_{i=0}^{s} DP^i$ and $CPU = \cup_{i=0}^{s} CP^i$. In the first segment the method gives the necessary number of stations and candidate points, which can serve all traffic environments. The positions of stations are known, where they have to be placed. Every station will be used at least in one environment, so it is expedient to save which is the environment wherethrough the given station placement becomes necessary. After this segment we remove the unused CPs. Summarizing the remaining CPs shows the positions of necessary stations, sufficient to serve all demands in each traffic environment. But this topology would be inefficient, because spatial and temporal demand changes can be observed during a day, so it's possible that we do not have to use all stations in the given time period.

In the next step we run the planning algorithm sequentially on each traffic environments. These steps use the reduced number of CPs, so the algorithm only shifts the stations to remained CPs. This procedure determines the necessary stations for the given traffic environment (the rest are assumed to be turned off). After placement we run the transmitter power reduction method which optimize the transmitter power.

3.4 Multi RAT planning method

As it was earlier mentioned, the operators should not build again some systems of new stations if these were installed to the position of CPE, by which the static consumption of stations can be reduced. The proposed multi RAT planning method runs after each iteration of the placement algorithm (PA). The output datas of PA are the actually best positions of stations (BP) which are not necessarily candidate positions. So one of our tasks is to shift the stations to the positions of subset of CP. The logical decision would be the nearest CP element which is the best position in terms of signal propagation. But it is impossibly that the nearest CPE element is more optimal in terms of energy consumption because of static power reduction. So our main target is to choose between the nearest CP and nearest CPE elements. The key idea is to be taken a new fictive user at the position of nearest CPE which would demand the static consumption gain power as serving power. The changing equation is

$$Num_{PRB} = \frac{maxNum_{PRB} * gain}{P_{tr}} \tag{9}$$

where $maxNum_{PRB}$ is the number of overall packet resource blocks, $gain$ is the static consumption gain and P_{tr} is the maximum top of cabinet output power of transmitter.

After this changing procedure the PA runs again and the K-means procedure shifts the stations toward the nearest CPE. After some iteration the nearest CP or CPE will be the correct position of station.

This mechanism can be also focussed on the infrastructure cost. In this case the changing equation has to be modified. The $gain$ is the infrastructure cost reduction which can be achieved by a replacement from cost to power value.

4. Numerical results

The mentioned analyses use the multi-RAT planning and migration algorithms. The geographical topology is constant, the sizes of total demands and the rate of migration are changed. The equipment of new technology can be only placed on the roofs, where UMTS stations can be found. The reduction of installation cost is aimed by this conception. The migration algorithm gets the UMTS and LTE demand scenarios as input parameters and combining it with multi RAT planning method gives back a UMTS-LTE multi RAT topology.

The spectrum allocation is 20 MHz and the frequency reuse factor is 1. All transmitters can use the whole spectrum (100 PRBs per msec). The static power consumption value of BSs is assumed to be 300W, the maximum top of cabinet output power of transmitter is 30W, and the inefficiency factor (μ) is 3. The size of the environment is $9km^2$. We run simulations with same parameters on the studied scenario and the results are averaged.

Figure 1 shows total power consumption of network in the functions of the ratio of demand migration between standards (horizontal axis) and increment of total size of demand (vertical curve shifting). The new demands always connect with the LTE system. The curves can't intersect each other, because more data traffic demands more stations, so the power consumption of systems are increased. Theoretically only die-away curves should be seen on this graph, but in some cases the curves increase. The reason of these situations, that the stations have static and dynamic energy consumptions, so because of demand migration new stations have to be installed in the new LTE system (increase static cons.) and in the other (actually UMTS) system we can reduce only the dynamic energy consumption (can't shut down station). This figure shows that the LTE system (wider bandwidth) is more effective than the UMTS one, so the service providers can save the budget of energy consumption if the users change over from 3G to 4G.

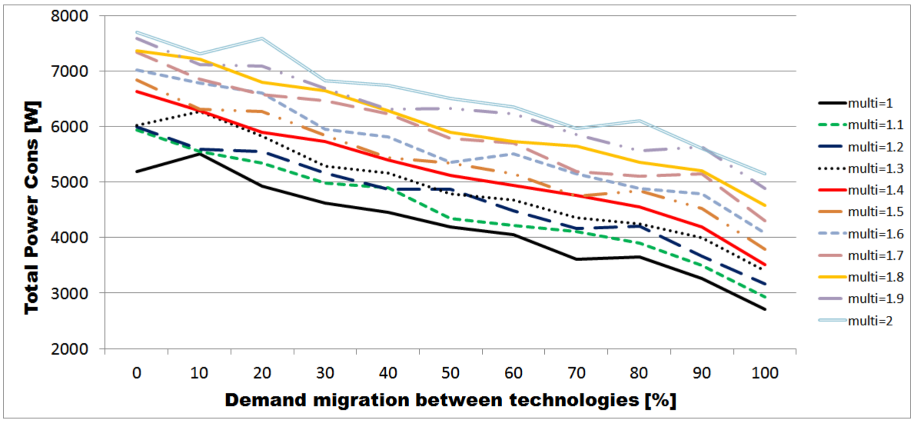

Figure 1: The total power consumption of multi-RAT systems in the function of demand increment and demand migration between standards

5. Conclusions

In this paper we have analyzed the energy consumtions of multi-RAT network topologies focussing on UMTS-LTE conversion. In these simulations it is assumed, that the future demands will connect with the new LTE network, furthermore, some percents of 3G users will change technology.

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