Energy effective coexistence of LTE-WCDMA multi-RAT systems

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***Abstract*—As the amount of today's mobile traffic, including internet data and voice calls, highly increases, more effective technologies have to be integrated into the cellular wireless networks to serve the new demands. Actually the "green" networks conception is highly promoted, so the coexistence of radio technologies is very important in terms of energy consumption. By energy effective radio network planning procedure, this paper presents the energy consumption of multi-RAT (Radio Access Technology) structure. During analyses the traffic distribution among RATs is changed representing the user's traffic transition. The primary purpose is to examine the energy consumption in the phases of transition between telecommunication technologies demonstrating the energy efficiency of the multi-RAT systems.**

I. Introduction

The mobile telecommunication is one of the most dynamically developing services in the world. The traffic via mobile networks has exploded in the last few years, so the investments in more effective telecommunication technologies and equipments have become more important to serve the increased size of data. As the occupied bandwidth used by a telecommunication technology is limited and the data transfer conditions over this bandwidth are defined, to follow the increasing traffic the providers have to install more and more equipments in the radio access networks. The total number of mobile subscriptions in the world has passed 5 billion by the end of 2010, more than 70 % of the population of the planet. The number of worldwide base station sites is circa 5.5 million and the total global RAN (Radio Access Network) power consumption is 70 TWh, which equals to the total annual electricity consumption of the countries of Ireland and Portugal together.

The service providers and the largest mobile telecommunications equipment vendors collaborate to research more and more innovative solutions, by which the modern mobile telecommunication systems can be improved. One of the most important criteria is the energy efficiency. Taking the EARTH project for example, which aims to improve the energy efficiency of mobile communication systems, from components over protocols up to the system level. The main target is an average 50 % reduction of electricity consumption of wireless networks [1].

Numerous cellular network planning algorithms are presented in the literature [2], [3], [4], [5], [12], [13], and these can be classified into three major groups. One class uses exact algorithms as core mechanisms. Although exact algorithms are able to find optimal solution, they are often too computationally intensive and time consuming to be applied even to a relatively small data set. The other, more popular class includes the heuristic algorithms, for example simulated annealing, clustering methods, or any others. The disadvantages of these are the long running time, the hard verification as well as the chance of stopping in a local optimum. Our multi-RAT method is the member of this group. Finally the last group is the genetic algorithms, which transform the optimization problem to a simplified representation.

The radio network planning algorithms are the members of location-allocation problems. The target is to find the locations considering to be optimal depending on the pursued objectives, such as minimal transportation costs or maximal accessibility, which are reflected in the location-allocation models used.

The Facility Location Problem (FLP) is a classical question in computer science and one of the NP-complete problems. The capacitated version of FLP (CFLP) contains the capacities of subsets, which is called supplies. The energy efficient cellular network planning can be identified with facility location problem, where the supplies change dynamically taking the signal propagation and the used radio resource management into account.

$$minP_{in} = \sum_{j=1}^{k} P_0(j) + \sum_{j=1}^{k} \Delta * P_{out}(j). \quad (1)$$

where k is the number of sectors, $P_0(j)$ is the static power consumption and $\Delta * P_{out}(j)$ is the dynamic power consumption. In the case of LTE (Long Term Evolution), the P_{out} depends on the used resources near linearly, and $P_0(j)$ is a technology specific value.

Actually the cellular wireless networks are made up of multiple access technologies. This multi-RAT topology is a heterogeneous network including the mixture of different generation standards starting with 2G, 3G and 3.5G technologies. This solution increases the capacity of system, because the different standards use different carrier frequencies avoiding the interferences between technologies. Furthermore, the multi-RAT system represent many generations of mobile technologies, so this heterogeneous wireless network is available for more subscribers. As the traffic increases the data are shared among RANs. The high demands, like internet multimedia service, are served by the highest capacity RAN. The other, low demand services are served by other technologies. The density of stations of actually highest capacity RAN increases more and more following the traffic explosion. The coexistence of multi-RAT systems is an interesting question. The daily

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energy consumption of mobile systems can be reduced by effective base station cooperation [14], [15]. The electricity consumption of an access network can be predicted. This analysis requires a cellular network planning procedure, which determines the positions of necessary stations of every RAT to serve the predefined demand generations. Under demand generation can be understood 2G,3G or 4G subscribers with traffic data.

Our work deals with the multi-RAT energy consumption mentioned above. The analyses are based on a feasible cellular network planning algorithm, which focuses on the energy efficiency. It determines the topologies of radio access networks one by one optimizing the energy consumption of multi-RAT system. The dimensioning phase of planning is not necessary, the algorithm can start with an empty environment placing and configuring the stations of the different RAT layers. When the algorithm plans a radio access network, it is assumed, that the topologies of earlier planned standards (reference system) have already known. So first the reference topology has to be determined by planning algorithm symbolizing the starting state, when only one type of telecommunication technology was installed.

Furthermore, the network planning algorithm determines an effective coexistence of the analyzed technologies. The subscriber attraction by new generation standard affects the other RATs reducing their total traffic, hence these older topologies can be changed by shutting off stations, reducing transmitter power, orientating antenna main lobes, etc..

The rest of this paper is organized as follows. In Section II the models used in this study are presented, and we describe the multi-RAT planning and transmitter power reduction methods, which are used in the analyses. In Section III the results of algorithms are provided, and the conclusion is given in Section IV.

II. System model and used algorithms

This section introduces the system model and the submethods of planning algorithms used for investigation of energy effective coexistence of LTE-WCDMA multi-RAT systems. The examined scenario can be simply described by the set of applicable coordinates over the area and the given traffic amount per generations of technologies (GSM-Global System for Mobile Communications,WCDMA-Wideband Code Division Multiple Access,LTE) over the area, assigned to any subset of the coordinates on the terrain. We suppose that the amount of traffic demands 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:

$$\mathcal{DP}^s = \{\cup_{i=0}^{m} DP_i^s\}; \tag{2}$$

where m denotes the number of DP_i^ss in the traffic environment of s_{th} demand generation. These points are represented by (x_i,y_i,dem_i), where x_i, y_i are the coordinates and dem_i is the traffic demand of DP_i^s, expressed in kbps. DP is an input parameter.

We assume that a base station (BS) operates three cells through three sectorized antennas. The resources are given to the radio access networks by these equipments to serve the users. Some equipment can be shared by different access networks to reduce the installation and energy consumption costs.

The stations are represented by

$$\mathcal{BS}^s = \{\cup_{j=0}^{t} BS_j^s\}; \quad \mathcal{BS} = \{\cup_{s=0}^{n} BS^s\} \tag{3}$$

where t is the number of BS_j^ss in the traffic environment of s_{th} demand generation.

We suppose that base stations cannot be placed arbitrarily, but to given possible (e.g. in an urban environment to rooftops) candidate positions (CP):

$$\mathcal{CP}^s = \{\cup_{j=0}^{r} CP_j^s\}; \quad \mathcal{CP} = \{\cup_{s=0}^{n} CP^s\} \tag{4}$$

where r is the number of CP_j^ss in the traffic environment of s_{th} demand generation.

The stations of other RATs (GSM,WCDMA...) were placed also to any candidate positions.

$$\mathcal{CPE} \subseteq \mathcal{CP}; \tag{5}$$

where CPE denotes the candidate positions of the earlier placed stations (reference topology).

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 [6].

The resources of network can be managed by frequency adaptation and power management. Our planning procedure uses the properties of 3GPP LTE radio resource management (RRM). The relationship between SINR (Signal to Interference plus Noise Ratio) and spectral efficiency is given by the so called Alpha-Shannon Formula which is suggested to be used for LTE networks in [7].

The RRM of LTE is modelled in our case by a semi dynamic frequency allocation strategy. It is the so called C/I scheduler. 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^s 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). 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 (6).

The transmitter output power, P_{out} can be described by

$$P_{out} = \frac{usedPRB}{allPRB} * P_{max} \quad (6)$$

where P_{max} 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 subframe, e.g. a 20 MHz bandwidth configuration typically means 100 PRBs in every 1 ms subframe.

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. Furthermore, it is assumed, that the P_{out} depends on the allocated resources also linearly in the cases of the other standards (GSM,WCDMA).

The power consumption of the base station follows the linear model:

$$P_{Cons} = P_0 + \Delta * P_{out} \quad (7)$$

where the first part (P_0) describes the static power consumption. Depending on the load situation, a dynamic power consumption ($\Delta * P_{out}$) part adds to the static power. The factor Δ is mainly due to the power amplifier inefficiency and feeder loss.

A. Base station placement and multi-RAT planning methods

This subsection deals with the base station placement and multi-RAT planning methods. To analyze the energy consumption of multi-RAT system, first the network topology has to be planned. These methods determine the quasi optimal station position and configuration for every RAN and reduce the number of applied equipments. The explaining of these algorithms are necessary to understand the numerical results.

The base station placement 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 input parameters are the used bandwidth, maximum transmit power parameters of transmitters as well as the DP scenario of every demand generation. The geographical area is fixed. The output data are the base station topology (BS) [9].

1) Base Station Placement Algorithm (BSPA): This algorithm determines a base station topology, which guarantees the serving and coverage criteria on the given demand scenario.

The BSPA is based on K-means dynamic clustering method. The clusters are the sites of stations including the covered subscribers. The criterion function of K-means, which has to be minimized, is the sum of squared Euclidean distances

Algorithm 1: K-means

Input: K is the number of centroids/clusters.
M is the number of objects.
$O = \{\cup_{i=0}^{M} o_i(i, x, y)\}$ is the set of position of objects.
I is the number of iterations.
map is the $max_x * max_y$ scenario.
Output: C is the set of positions of centroids after clusterization.

```
begin
    Initialization Step:
    C = {∪_{j=0}^{K} c_j^0}
    ∀c_j^0.x ← random(max_x)
    ∀c_j^0.y ← random(max_y)
    S = {∪_{k=0}^{K} S_k}
    ∀S_k ← ∅
    Iteration Step:
    for t ← 0 to I do
        Reassignment Step:
        ∀S_k ← ∅
        for i ← 0 to M do
            min ← ∞
            id ← −1
            for j ← 0 to K do
                if distance(o_i, c_j) < min then
                    min ← distance(o_i, c_j)
                    id ← j
                end
            end
            o_i joins to the S_id
        end
        Update Step:
        for k ← 0 to K do
            c_k^(t+1) ← (1 / #S_k^t) Σ_{i⊂S_k^t} o_i
        end
    end
end
```

between the locations of demands and the position of serving base station.

K-means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem. It is a dynamic clustering method which attempts to directly decompose the data into disjoint clusters. The number of clusters (K) is fixed a priori. The different located centroids of clusters cause different results, so the algorithm has to be started with different initial states and run as much as possible.

Briefly overview the K-means, it can be composed of the following steps:

1. Place K (parameter) points into the space represented by the objects that are being clustered.

2. Assign each object to the group (cluster) that has the closest centroid. (Reassignment step)

3. When all objects have been assigned, recalculate the properties of the K centroids. (Update step)

4. Repeat Steps 2 and 3 until the centroids no longer move

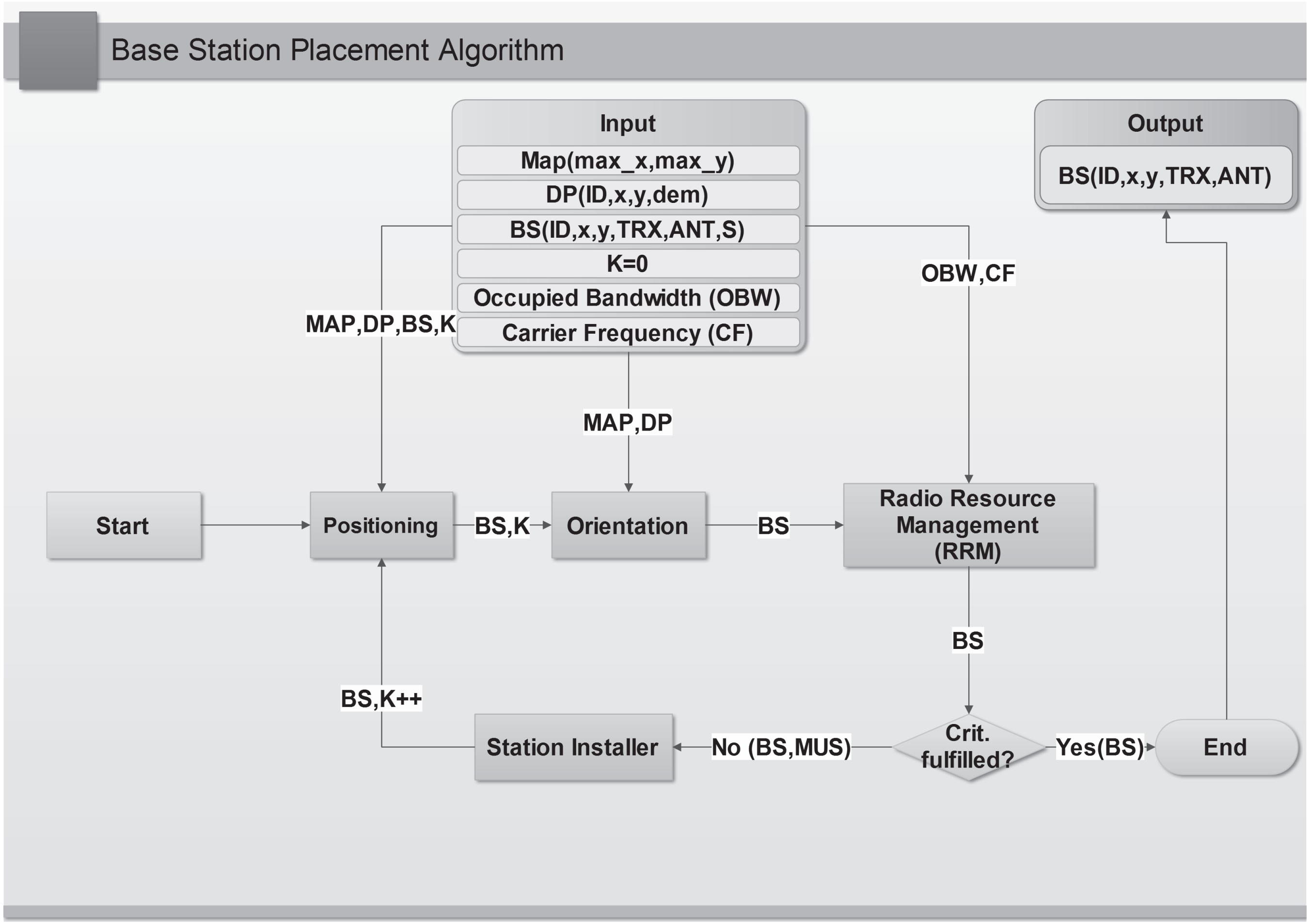

Fig. 1. State chart diagram of Base Station Placement Algorithm

or the counter of iteration expire.

The objective function is the total energy consumption of access network.

$$min\ P(\mathcal{BS}) = min \sum_{j=1}^{k} (P_0(j) + \Delta * P_{out}(j)). \quad (8)$$

The objective function has four changeable parameters to reduce the total power consumption. Δ and P_0 depend on the type of BSs, so these parameters are independent from BSPA, because the algorithm places only one type of stations. The k is the number of sites in the wireless network. As it is pointed out in the related work section, the minimization of installed stations (sites) is the first priority target. $P_{out}(j)$ is the output power of j_{th} site. This parameter is the function of allocated resources depending on the network topology. So the k and $P_{out}(j)$ parameters can be reduced by BSPA.

The BSPA, including station positioning, antenna beam orientation, RRM and station installer, can be realized as a closed loop (Figure 2). Starting with an empty environment (K is 0), it places the stations (K=1,2,3,4...) iteratively until the mentioned criteria are fulfilled.

Positioning:

The BS positioning algorithm is based on the mentioned K-means procedure. The centroids of clusters are the BSs and the assignment step is the procedure of sector creation. One cluster is made up of three sectors of BSs. In the update step the position of covered DP (x_i) is weighted by the demands of DP (dem_i) determining the positions of stations. So the modified objective function of K-means is

$$min\ Z = \sum_{j=1}^{k} \sum_{DP_i \in S_j} dem_i * ||DP_i^{(j)} - BS_j||^2 \quad (9)$$

where dem_i is the demands of i_{th} subscriber, and $||DP_i^{(j)} - BS_j||$ is the Euclidean distance between subscriber (Demands positions) and the serving station. $S_j = \cup_{h=1}^{N} S_{j,h}$, where N is the number of sectors per BS [9].

Orientation:

The antenna beam orientation is also based on K-means clustering. Our aim that the directions of covered DPs with higher demand are subtended smaller angle with the main direction of serving antenna. The assignment step is also the procedure of sector creation. In the update step, x_i is the included angle between the direction of covered DP_i within the sector and the main direction of serving transmitter weighted by the dem_i. This mechanism determines the beam directions of antennas[9].

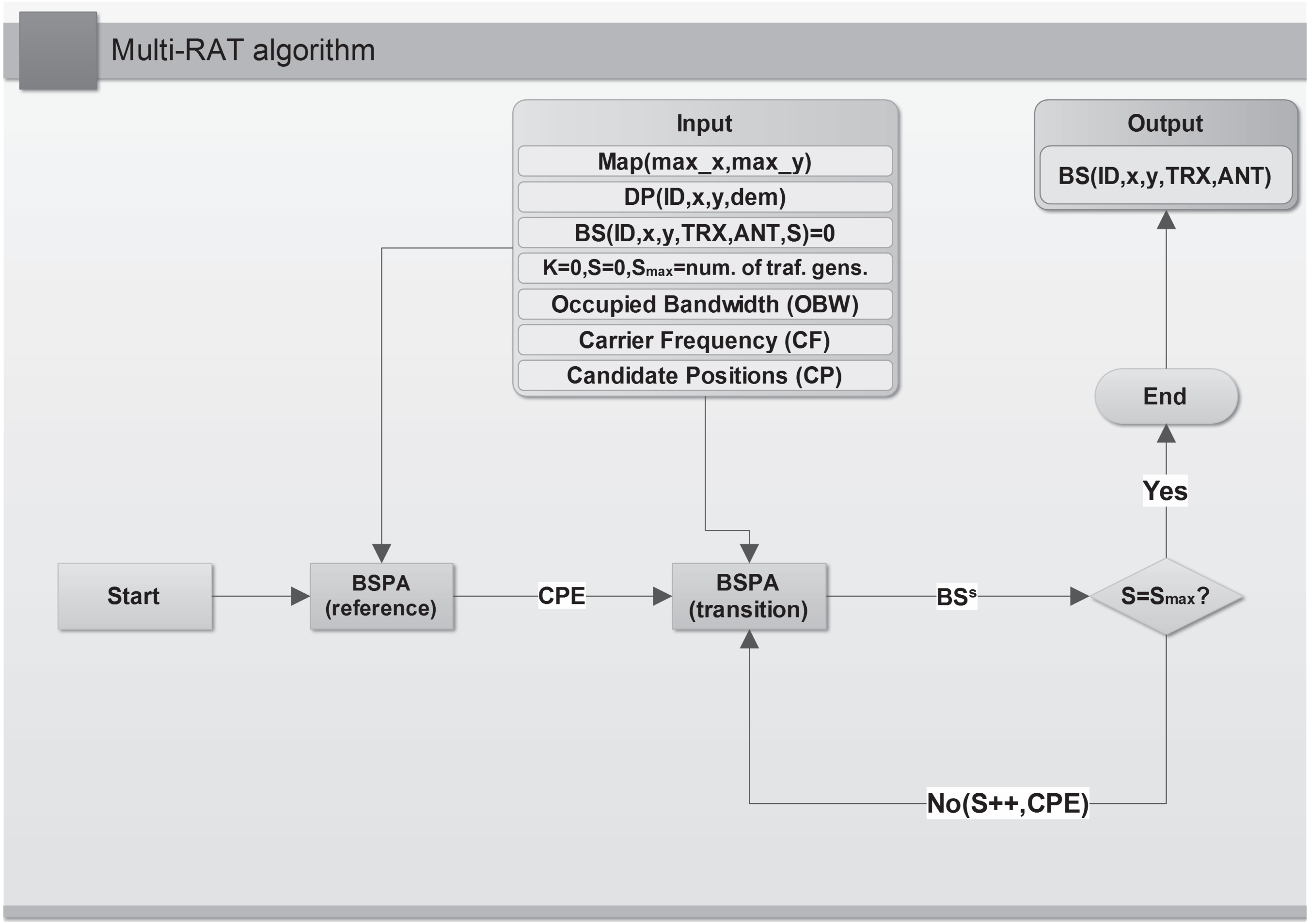

Fig. 2. State chart diagram of Multi-RAT planning

Radio Resource Management:

The radio resource management is described in model section as a parameter. In our investigations, the RRM is a max C/I scheduler. It is executed after base station positioning and antenna beam orientation to analyze the loads of sectors. The radio resource management is an input parameter of BSPA. The target of this method is to determine the required/used number of PRBs per sector and to give these informations to the station installer as results.

Station Installer:

After RRM the most unserved sector (MUS) has to be found, which is the sector with the highest total unserved traffic (DPs with not enough PRBs allocated to) under its coverage. If the number of required PRBs is less than the number of available PRBs within all sectors 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. So our clustering algorithm is an increasing number of K-means (X-mean) [11].

Figure 3 shows the mentioned station movement, as the algorithm runs iteratively. Actually the black sector is the MUS, so the station installer places the new station near the serving antenna of this.

The complexities of BSPA is $O(IK^2NM)$, where I is the fix number of iterations, N is the number of DPs, K is the number of BSs in the final state, and $O(M)$ is the operation cost (signal propagation).

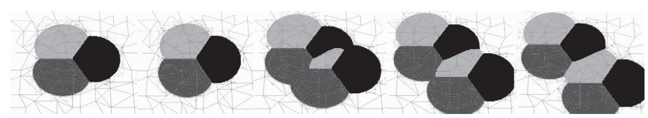

Fig. 3. Station movement within placement algorithm

2) Multi-RAT planning method: This method uses the BSPA to plan an energy effective multi-RAT topology. First it plans a reference network topology using an older telecommunication standard (WCDMA,GSM). As the subscribers are attracted by new standard, the stations of reference RAN can be shut off, because the reduced overall demands can be served by fewer capacities. Furthermore, the high demands, like internet multimedia service, connect with the highest capacity RAN (LTE).

The reference system contains the stations of older topology determining the candidate positions of transition phases (CPE). The second procedure is the planning of transition cases. The traffic scenarios contains the demand generations ($DP_i{}^s$) starting with the reduced number of subscribers of older generation and ending with the new generation demands.

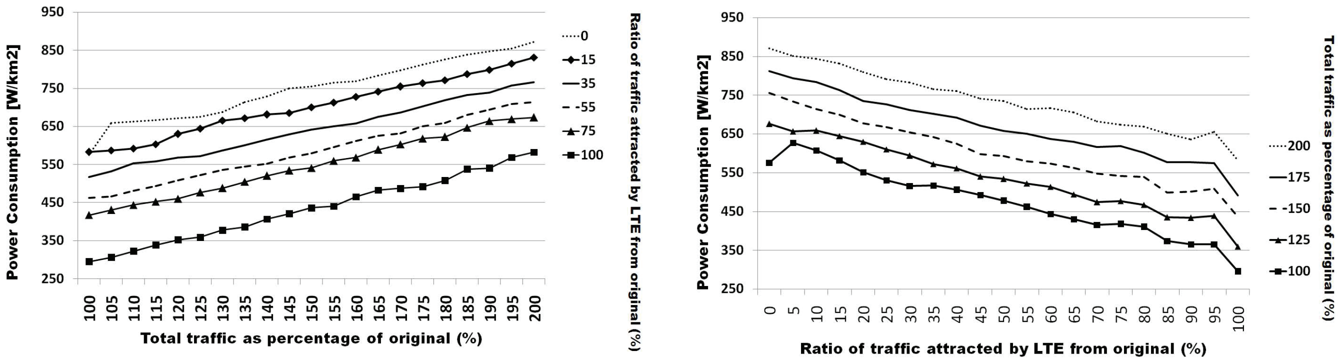

Fig. 4. The power consumption of multi-RAT systems as a function of the increase in the traffic demands and demands migration between standards (WCDMA,LTE).

The BSPA installs the stations only to the reference candidate positions (CPE), which denote base stations of reference topology, so the new multi-RAT structure reuses the elements of older topology. If a CPE is empty on every scenario, then the station can be removed. If the number of CPE is not enough in the case of new generation demands, then the set of CPE need to be complemented with the rest of candidate positions ($CP \setminus CPE$).

III. Numerical results

The analyses discussed below use the multi-RAT planning algorithm. The geographical topology is constant, the sizes of total demands and the ratio of traffic attracted by LTE from WCDMA (reference) are changed illustrating the phases of transition between telecommunication technologies. The multi-RAT planning algorithm gets the WCDMA and LTE demand scenarios as input parameters and gives back a WCDMA-LTE multi-RAT topology. Table III shows the main input parameters of algorithm derived from [16].

Input parameters

Carrier frequency	2 GHz
Occupied bandwidth of WCDMA	5 MHz
Occupied bandwidth of LTE	10 MHz
Frequency reuse factor	1
Static power of stations	300 W
Max top of cabinet output power of tx	30 W
Inefficiency of power amplifier	3
Size of environments	$9km^2$
Default traffic	85 Mbps/$9km^2$

The analyses were run with same parameters on the studied scenario and the results were averaged.

Figure 4 shows total power consumption of multi-RAT networks as a function of size of traffic demands (left) and a function of the ratio of traffic attracted by LTE from WCDMA (right). The new demands always connect with the LTE system. The different lines of the figures represent the horizontal axis of other one, and vice versa. The curves can not intersect each other, because more data traffic requires more stations increasing the power consumption of system. The reasons of high steps (left figure dotted line 100 % and right figure at the end of lines) are caused by the establishment of new technology and the complete removing of the other one. In the establishment phase the service providers have to place many new transmitters to guarantee the coverage criterion of new telecommunication technology. In the complete removing phase the transmitters of WCDMA system can be switched off totally, reducing the energy consumption. These simulation results show that the LTE system is more effective than the WCDMA (wider bandwidth) one, so the service providers can save the budget of energy consumption if the users change over from 3G to 4G.

IV. Conclusion

In this paper we examined the energy consumptions of multi-RAT network topologies focussing on WCDMA-LTE coexistence. In the analyzed cases it was assumed, that the future demands would connect with the new LTE network, furthermore, some percents of 3G users would change technology. The results showed that the energy consumption of cellular system could be reduced by LTE technology. Assuming same overall demands, the energy efficiency of network increased as the LTE gains ground.

Acknowledgment

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References

[1] Gergely Biczók, Jens Malmodin, Albrecht Fehske, "INFSO-ICT-247733 EARTH Deliverable D2.1", Economic and Ecological Impact of ICT (2011)

[2] Omar H. Karam, Lamia Fattouh, Nourhan Youssef, Ahmad E. Abdelazim, "Employing Clustering Techniques in Planning Wireless Local Loop Communication Systems: PlanAir",11th International Conference On Artificial Intelligence Applications Cairo, Egypt, February 23-26, (2005)

[3] Harish Ramamurthy, Abhay Karandikar: "B-Hive: A cell planning tool for urban wireless networks", 9th National Conference on Communications, (2003)

[4] Kurt Tutschku, ”Demand-based Radio Network Planning of Cellular Mobile Communication Systems”, INFOCOM, pp. 1054–1061 (1998)
[5] Hurley, S., ”Planning effective cellular mobile radio networks.” IEEE Trans. Vehicular Technol. v51 i2. 243-253. (2002)
[6] Les Barclay, ”Propagation of Radiowaves, p. 194, The Institution of Electrical Engineers”, London (2003)
[7] Abdul Basit, ”Dimensioning of LTE Network, Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface” (2009)
[8] O. Arnold, F. Richter, G. Fettweis, and O. Blume, ”Power consumption modeling of different base station types in heterogeneous cellular networks” in Proc. of 19th Future Network & MobileSummit 2010, Florence, Italy, (June 2010)
[9] István Törős, Péter Fazekas, ”Automatic Base Station Deployment Algorithm in Next Generation Cellular Networks”, Accessnet 2010 Budapest (2010)
[10] J. B. MacQueen, ”Some Methods for classification and Analysis of Multivariate Observations, Proceedings of 5-th Berkeley Symposium on Mathematical Statistics and Probability”, Berkeley, University of California Press, 1:281-297 (1967)
[11] Dan Pelleg, Andrew Moore, ”X-means: Extending K-means with Efficient Estimation of the Number of Clusters”, Proceedings of the 17th International Conf. on Machine Learning 2000
[12] Gonzlez-Brevis P., Gondzio J., Fan Y., Poor H.V., Thompson J.S., Krikidis I., Chung P., ”Base Station Location Optimization for Minimal Energy Consumption in Wireless Networks.”, In VTC Spring(2011)1-5
[13] Z. Zheng, S. He, L. X. Cai, X. Shen, ”Constrained Green Base Station Deployment with Resource Allocation in Wireless Networks”, Handbook on Green Information and Communication Systems, Editors M. S. Obaidat, A. Anpalagan, and I. Woungang, John Wiley & Sons, Inc., 2012.
[14] F. Han, Z. Safar, W.S. Lin, Y. Chen, and K.J.R. Liu, ”Energy-efficient cellular network operation via base station cooperation”, ;in Proc. ICC, 2012, pp.4374-4378.
[15] István Törős, Péter Fazekas, ”Planning and network management for energy efficiency in wireless systems”, In Future Network & Mobile Summit (FutureNetw), 2011
[16] Gunther Auer (DOCOMO), Oliver Blume (ALUD), Vito Giannini (IMEC), Istvan Godor (ETH), Muhammad Ali Imran (UNIS), Ylva Jading (EAB), Efstathios Katranaras (UNIS), Magnus Olsson (EAB), Dario Sabella (TI), Per Skillermark (EAB), Wieslawa Wajda (ALUD), ”INFSO-ICT-247733 EARTH Deliverable D2.3”, Energy efficiency analysis of the reference systems, areas of improvements and target breakdown (2012)

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