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Network Deployment and RRM Strategies for Green Mobile Communications

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***Abstract*—The RRM strategies and the deployment guidelines to be adopted in a multi-layer heterogeneous mobile network with the goal of the optimization of the Area Power Consumption are presented in this paper: in the considered scenarios, several radio environments are considered, the coverage is guaranteed by different cell types, and the capacity and blockage probability are kept unaltered by the adoption of the green radio approaches with respect to basic configuration. The benefits in terms of energy savings are determined for all possible solutions: within this framework we compare alternative approaches, such as the macro-cell coverage and the strategies which resorts to a higher number of lower power micro-cells to cover the spot.**

I. Introduction

Today, the most dominating trends in the development of wireless and mobile telecommunications can be identified in the continuous growth of the data-rates of the services and in the reduction of cell and spot dimension: these development lines will push towards a huge diffusion of pico and femtocells [1] [2] which will be able to offer also seamless indoor coverage. On the other hand, in the last years also the energy consumption of the actual and future mobile system has become one of the unavoidable challenges to be immediately faced and the energetic sustainability of the proposed systems has already become one of the key points in the assessment of new technologies.

As a result, an unprecedented attention has been recently devoted to the evaluation of the energy efficiency of wireless and mobile communication systems and lots of researchers have tackled this objective by proposing advanced tools and original strategies [3]. Ajmone Marsan *et alii* have proposed an optimization of the cellular networks which is based on the switching-off of the base stations that are not active during the night time [4]. Fettweis *et alii* have connected the energy consumption evaluation to the path loss models and introduced new metrics which are based on the estimation of the area power consumption, so binding the energy absorption to the area where the radio resources are effectively exploited [5].

Together with the low consumption Radio Resource Management (RRM) strategies, the so-called green radio strategies, the energy efficiency should also be taken into account in the deployment phase of the heterogeneous radio networks [3]: in this evaluation also the nature, number and position of the telecommunication infrastructures will have to be considered. Therefore, the telecommunication equipments will be more energy-sober, most likely encompass renewable and alternative energy local generators and the infrastructure have mandatorily to be planned and designed by assuming that energy consumption as another basic constraint, as well as coverage and capacity. In order to consider a realistic scenario, the strategies to be proposed will have to take into account different BTS equipments and cells.

In this paper we present the RRM strategies and the deployment guidelines which can be adopted in a multi-layer heterogeneous mobile network with the goal of the optimization of the Area Power Consumption; the main contribution of this work can be identified in the analysis of the both the network planning and the radio management: these two aspects are jointly considered with the goal a global optimization of the network efficiency. The RRM strategies considered herein are centralized and based on the knowledge of the traffic conditions: the cell traffic is determined for each hour of the day and the necessary radio resources are identified.

In the considered scenarios, several radio environments are considered, the coverage is guaranteed by different cell types, and the capacity and blockage probability are kept unaltered by the adoption of the green radio approaches with respect to basic configuration; by resorting to the guidelines which are defined, two alternative approaches, namely, the macro-cell coverage and the strategy which resorts to a great number of lower power microcells to cover the same spot are compared.

The paper is organized as follows: Section II provides an overview of the system model while Section III describes the metrics which have been adopted. Section IV illustrates the green radio strategies that have been tested in the considered scenario. Section V provides the basic guidelines that allow an energy-efficient deployment of the wireless infrastructure. Finally, conclusive remarks are given in Section VI.

II. System Model

A. Cluster Configuration

Conventionally, the GSM network is modeled as a grid of equal regular hexagons: in the model which is considered herein each hexagon corresponds to a sector of the Macro-cell Base Station (BS). The basic cluster consists of 7 three-sector Macro-cells, as depicted in Fig. 2, which are separated each other by the site distance D and with 2 carrier for sector.

As previously anticipated, in this paper the term "cell" refers to the union of 3 hexagon; each of them is divided into various subsectors which are respectively identified as A-B-C, D-E-F

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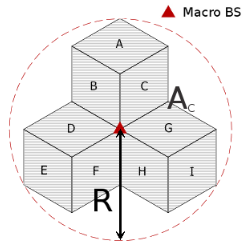


Fig. 1. Macro-cell Geometry

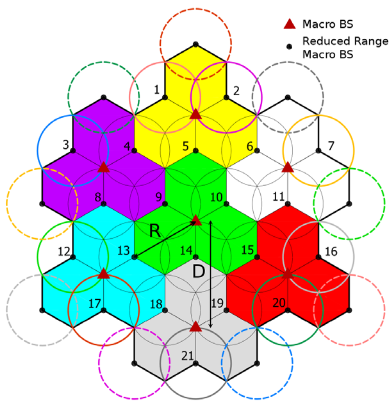
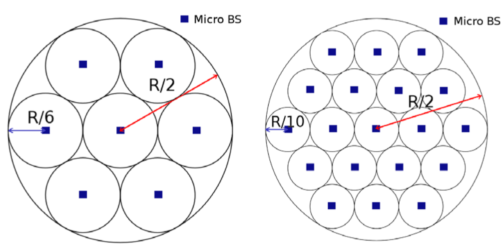


Fig. 2. Cluster Geometry



(a) 7 Micro BS (b) 19 Micro BS

Fig. 3. Micro-cell BS Groups

and G-H-I. The radius of each cell is $R = \frac{2}{3} D$ as shown in Fig. 1 and the area whose coverage is afforded by the Macro-cell BS is $A_C = \frac{9 \cdot \sqrt{3}}{8} \cdot R^2$.

The cluster also includes 21 Reduced Range Macro-cell BS (RR Macro BS) located in 6 of 12 vertices, as shown in Fig. 2. Each Reduced Range Macro BS provides coverage over 3 subsectors so that it is possible to fully cover total cluster by means of 21 RR Macro BSs. By assuming an uniform distribution of the users, this second type of BS shows a lower capacity because it is characterized by omni-directional antenna with only one Transmitted carrier (TRX) over a coverage radius length which is equal to $\frac{R}{2}$.

Finally, we consider the possibility of replacing the Reduced Range Macro BS with group of 7 or 19 Micro BS whose position is graphically depicted in Fig. 3: particularly, in this case the coverage radius of Micro BS will be equal to $\frac{R}{6}$ or $\frac{R}{10}$ in case of group of 7 or 19 Micro BS, respectively.

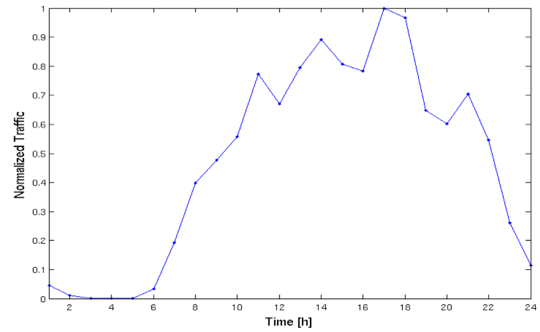


Fig. 4. Normalized Traffic

B. Traffic Load

Typically, in a real mobile network the daily traffic profile is characterized by a periodic pattern [1] . In Fig. 4 a normalized traffic daily profile is shown: it has been achieved from the voice calls of an Italian service provider and then normalized by its maximum value; two peaks are clearly visible in the afternoon when the traffic value is almost 10 times greater than the one experienced in the low traffic hours. As it is known [4], such variations allow a potential energy saving by switching on or off some transceivers accordingly: this task will be carried on by the Green Radio algorithms that will be presented in section IV. The traffic distribution will be assumed uniform in all clusters sectors.

C. Power Consumption Model

Since the cluster is composed of heterogeneous sub-systems, a specific power consumption model for all the different kinds of base stations is required. The consumption in a base station depends on various aspects: the entire radio access network is to be taken into account, comprising of RF signal generation, digital and analogue signal processing, backhaul data link, AC/DC power conversion and cooling [6]. In [7] a model is proposed to achieve this goal considering the power consumption of a Macro-cell BS as function of the transmitted power and of the other parameters by means of the following relation:

$$P_{BS} = N_{sec} \cdot N_{pa} \cdot \left(\frac{P_{tx}}{\mu_{pa}} + P_{sp} \right) \cdot (1 + C_c) \cdot (1 + C_{psbb}) \quad (1)$$

where P_{BS} and P_{tx} denote the average consumed and transmitted power per BS, respectively, N_{sec} and N_{pa} indicate the number of sectors and power amplifiers per sector, the terms μ_{pa} and P_{sp} are the power amplifier efficiency and the signal processing overhead and the coefficients C_c and C_{psbb} account for cooling of site and the battery backup and power supply loss, respectively.

This power consumption model has been used also for the Reduced Range Macro BS whereas for the Micro-cell BS

[1] A periodic behavior can be found in the working days whereas the behavior during holidays is also periodic but according to a different pattern [6].

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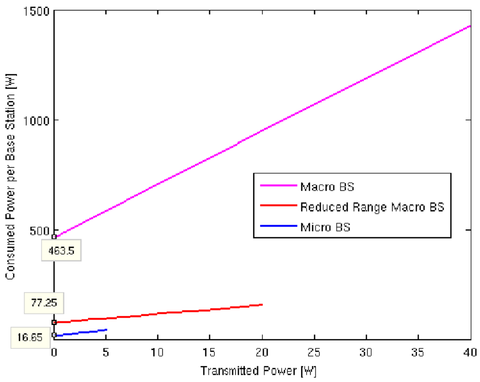

Fig. 5. Power Consumption Models

TABLE I
BS PARAMETERS FOR POWER CONSUMPTION

Parameter	Macro BS	RR Macro BS	Micro BS
N_{sec}	3	1	1
N_{pa}	2	1	1
μ_{pa}	35%	35%	20%
P_{sp}	54.8 W	54.8 W	15 W
C_{c}	27%	27%	0%
C_{psbb}	11%	11%	11%

N_{sec} and N_{pa} will be different. Moreover, the Micro BS are characterized by simpler structures, without cooling, so that their power consumption is inferior. The differences among the various kinds of BS are explained through the parameters in TABLE I. The curves in Fig. 5 show the BS energy consumption as a function of the transmitted power in the three different kinds of BS: it is evident the linearity of the described model and, in particular, a remarkable offset of consumed power for low values of transmitted power. This feature could limit the achievable energy efficiency in the cellular networks because the reduction of the transmitted power (using short inter-site distance by resorting to micro, pico or femto-cell BS) is not proportional to the energy saving.

D. Propagation Model

The propagation of signal is strongly harmed by 3 different phenomena: shadowing (slow fading), multi path (fast fading) and path loss. By using a simple propagation model we can assess the transmitted power which is required to provide coverage. P_{Tx} is the value of transmitted power that allows a signal power on the edge of the cell greater than the sensibility of the GSM mobile terminal $\overline{P}_{rif}$. The propagation model is derived as:

$$P_{Tx} = \frac{P_{rif} \cdot M_{sh} \cdot A_e \cdot A_r \cdot c^2}{G_r \cdot G_e} \cdot (r)^{\alpha} \qquad (2)$$

where: G_e e G_r are the transmission and reception antenna gains, A_e e A_r the attenuation of the cables and the connectors in the BS and in the mobile terminal respectively, M_{sh} is the shadowing margin used to prevent slow fading effects; this value is computed assuming a coverage of 75% [9], [8].

TABLE II
LINK BUDGET PARAMETERS

Parameter	Macro BS	RR Macro BS	Micro BS
P_{max}	$40\,W$	$20\,W$	$5\,W$
G_e	$15\,dB$	$5\,dB$	$3\,dB$
r	R	$\frac{R}{2}$	$\frac{R}{6}$ or $\frac{R}{10}$
G_r	$2\,dB$		
A_e	$7\,dB$		
A_r	$2\,dB$		
M_{sh}	$5\,dB$		
P_{rif}	$-104\,dBm$		
c	$\frac{4\pi}{\lambda}$		

TABLE III
PATH LOSS EXPONENT IN DIFFERENT SCENERIES

Sceneries	Path loss exponent α
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

This model permits to compute the transmission power as function of the inter-site distance[2] and of the path loss exponent α; the transmitted power has different upper limits P_{max} according to the kinds of BS. All link budget parameters are reported in TABLE II: all these value are achieved by real devices. The value of path loss exponent depends on the considered scenario and are shown in TABLE III.

III. METRICS

A. Area Power Consumption

A metric which is generally used to measure the energy efficiency of a cellular networks is the consumed energy over the number of information bits in [Joule/bit]. This metric, even if binds the cost in term of energy consumed by the entire network to the total network capacity, i.e., the number of information bits, is suitable to assess the energy efficiency only in the case of full load [6]. In order to assess the power consumption in all operating conditions we use the metric of the area power consumption which is defined as total power consumed by the entire cluster divided by the cluster area $(7 \cdot A_c)$. We will use this metric to evaluate the deployment's efficiency as function of the inter site distance and the path loss exponent. The total power consumed by the entire cluster depends on the number of active carriers of all BS computed by the green radio algorithms: as a matter of fact, when no green radio approach is used, the network is redundant with a very high energy consumption.

B. Energy Saving

In order to fairly compare the energy efficient solutions that will introduced in the following, another metric has been considered: particularly, we also consider the energy saving defined as the percentage gain with respect to the total power

[2]As anticipated, this value is related to the radius of each kind of BS

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consumption which is typical of all the 7 Macro BS of the cluster under full load conditions.

IV. Green Radio Strategies

In this Section the Green Radio strategies which have been studied and adopted are thoroughly described: they allow energy efficient Radio Resource Management (RRM) without any drawback in terms of blockage or admission control; particularly, 5 different algorithms have been considered in order to manage the cluster resources according to the traffic profile and to different optimization strategies. It is important to note that the strategies that are considered in this paper are centralized and based on the ideal knowledge of the traffic conditions: therefore, they can give an upper bound for the energy savings which can be achieved with realistic implementation.

1) Solution 1: Macro-cell BS with Dynamic Carrier Allocation: The first solution is based only on the use of the Macro-cell BSs that are able to dynamically allocate carriers: basically, the cell traffic is measured every hour of the day and the required number of carriers is determined. The steps of this procedure are the following: when the traffic load is low, it is allocated only over the channels that are provided by one TRX per sector. Conversely, when middle traffic is experienced both the two carriers are used. Finally, if the system present a high traffic load, the channels of both the two carriers are eventually switched to the half-rate mode. For the traffic value considered in the study and for a cluster which is composed of only Macro BSs the solution 1 is able to guarantee the service with blockage probability equal to 0.5% even if the network has to face a very large traffic increase, e.g., up to the 90%.

2) Solution 2: Conventional and Reduced Range Macro-cell BSs: In solution 2 Reduced Range Macro-cell BSs are used together with Macro BS. The algorithm flow chart is depicted in Fig. 6; it refers to a generic subsector where the access is guaranteed only by one RR Macro BS ($RR\ MA$) and one Macro BS sector, whose carriers are MA_1 and MA_2. As can be seen in the chart, $RR\ MA$ is switched on if and only if no Macro BS carrier is active in the area and n_{RRC} is lower than C_{RRMA}, with n_{RRC} and C_{RRMA} equal to the number of requested radio channels into the 3 subsectors covered by $RRMA$ and the RR Macro BS capacity in terms of number of radio channels, respectively. As a result, the RR Macro BSs are switched on only if they are able to serve the whole traffic in that hour. Otherwise, as in case of middle or high traffic, only the Macro BSs will be used as in Solution 1.

3) Solution 3: RR Macro-cell BSs with Support of Macro-cell BSs: Conversely, the solution 3 mostly resorts to the channels of the RR Macro BSs which are activated either for low or high traffic load. As can be seen in the flow chart in Fig. 7, the normal Macro-cell BSs ends up being active only when the capacity which is provided by the RR Macro BSs is not enough for the load requests. The first action performed in the algorithm is to switch on the $RRMA$; then one or both MA will be used if and only if the number of further requested channels $n_{RRC} - C_{RR\,MA}$ is greater than 0 . As a matter of fact this solution changes the typical behavior of a mobile network, namely Macro BSs provide coverage and Micro BS provide capacity.

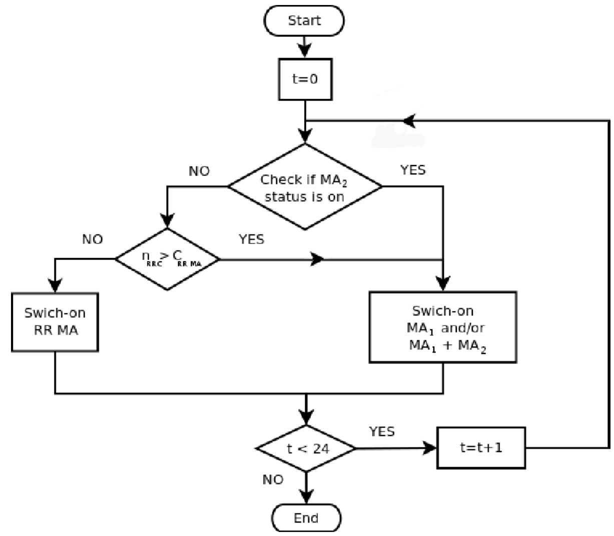

Fig. 6. Solution 2 Algorithm Flow Chart

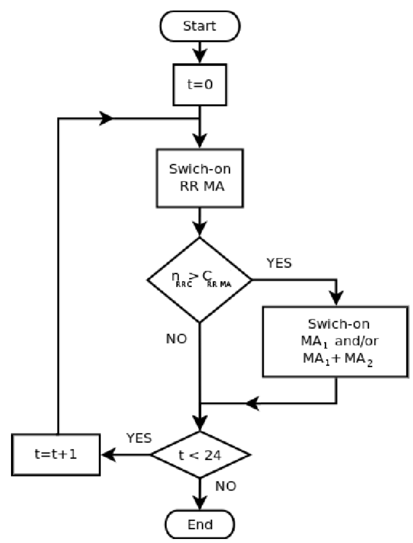

Fig. 7. Solution 3 Algorithm Flow Chart

4) Solution 4 and 5: 7 or 19 Micro-cell BSs with support of Macro-cell BSs: Solutions 4 and 5 are based on a generalization of the algorithms of solution 3; however, in this case the use of groups of 7 or 19 Micro BSs substitute the RR Macro BSs. We will show that in this case, the scheme is suitable only when short Micro-cell BS inter-site distances (up to 200 m) are considered: particularly, this parameter has to be lower than 2250 m or 3750 m for solution 4 or 5 respectively, according to the power limitations which have indicated by the government and the coverage area limitation which is normally given by the service provider.

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V. Efficient Deployment

In this section the guidelines to be followed to realize an energy efficient network deployment are provided for different scenarios, e.g. urban and shadowed urban environment; as in the previous section, we aim at optimizing the area power consumption: the minimization of this parameter indicates that the energy required to cover an area is used in an optimal way.

In the cluster configuration which has been described in Sec. II, the inter-site distance D is assumed to range from 0 to 5 km. The traffic is independently identically distributed in all cluster's sectors.

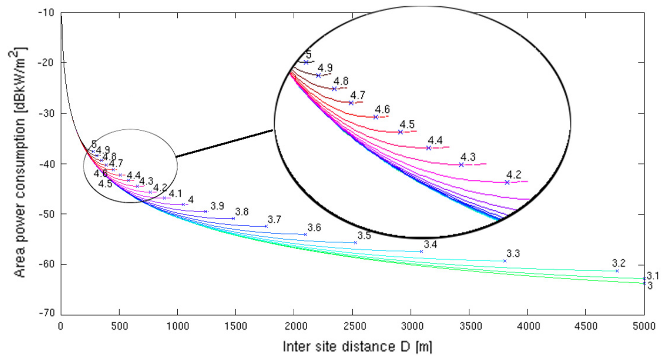
The simulation procedure, that we have realized in the MATLAB environment, allows to determine the status of all the carriers of each BS in the cluster according to the Green Radio strategies which have been previously explained. Therefore, the overall cluster energy consumption has been determined accordingly as a function of inter-site distance D and of the path loss exponent α by means of relation 2 and 1. Hence, the Area Power Consumption has been minimized, with respect to D, with the goal of the determination of the optimum iter-site distance. If this value of D is adopted in the infrastructure deployment, the network is energy efficient and the deployment is optimal.

A qualitative analysis of the optimization procedure is described in the following: Fig. 8(a) and 8(b) show the area power consumption in urban and shadowed urban areas, respectively, when solution 3 is adopted. A family of curves is represented, each one related to a specific path loss exponent α, as a function of the inter-site distance D. Each curve presents a minimum value for a specific inter-site distance, as highlighted by the zoom area in the graph. When a small distance D is considered, the area power consumption remains high because of the offset of consumed power which is a constant contribution. As the distance D increases, the curves which are relative to solutions 4 and 5 are interrupted: the transmission power which is required for the signal propagation, would be higher than the real limits. Even if the Fig. 8 has been achieved for solution 3, analogous trends can be found in all other solutions; the main difference is to be identified in the value of the inter-site distance for an optimal deployment which is different for all the cases.

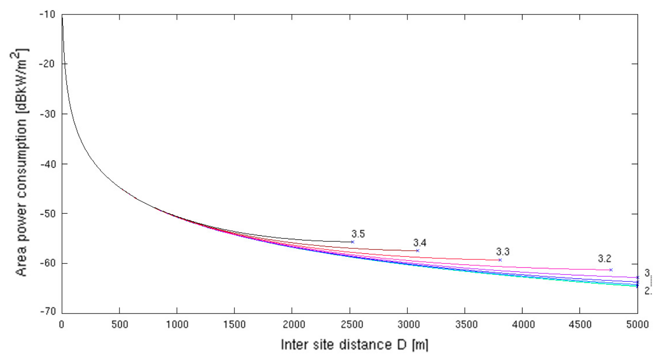
The energy saving which can be achieved in each situation is also determined: in Fig. 9(a) and 9(b) the energy saving is depicted as a function of the inter-site distance and of the path loss exponent for solutions 2 and 3 [3], respectively. It is worth underlining the quick increase of the gain when higher path loss indices are considered. On the other hand we can see that, as the inter-site distance increases, after an initial grow, the gain presents an horizontal asymptote.

It is worth noticing that each solution is characterized by a specific energy saving: in order to provide a fair comparison, it's necessary to evaluate the energy savings together with the optimal inter-site distance. The curves obtained are shown

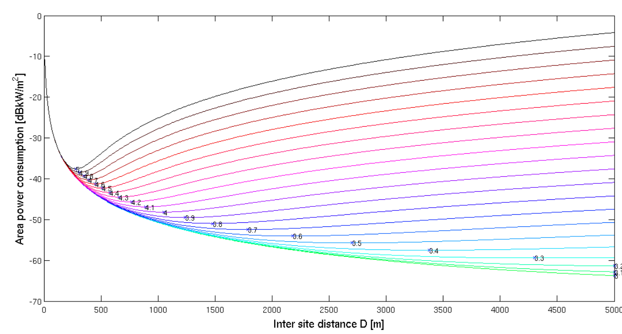
[3]Solution 2 and 3 are relative to the case Conventional and Reduced Range Macro-cell BSs and RR Macro-cell BSs with Support of Macro-cell BSs



(a) Shadowed Urban Area



(b) Urban Area



(c) Shadowed Urban Area without Power and Distance Limitation

Fig. 8. Area Power Consumption

in Fig. 10: since the comparison has been performed for an optimized deployment, in the caption of the successive figures we have indicated the optimal energy savings. By comparing all the different curves, we can conclude that:

The Solution 1 presents a constant energy saving of about 20% in both scenarios: since this solution uses only Macro BS, the achieved saving depends merely on the adaptive and dynamic management of the TRX.

The Solutions 2 and 3 show excellent result, providing energy saving value between 30% (Solution 2 in urban area) and 55% (Solution 3 in urban shadowed area). These results can be justified by two facts: the reduced radius of the RR Macro BS allows to lower the transmitted power and the capacity offered by only RR Macro BS is enough to fully manage and control the users for a large part of the day.

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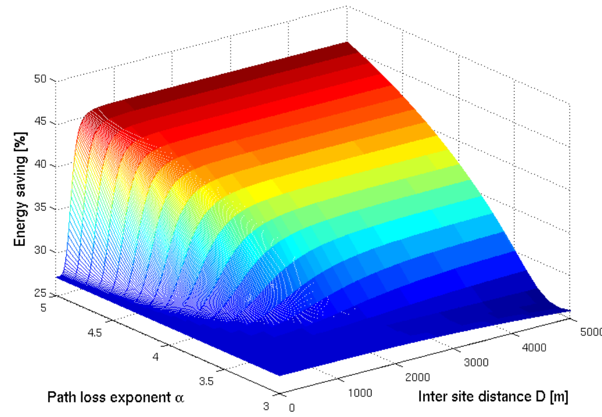
The Solutions 4 and 5 are related to groups of 7 or 19 Microcell BSs, respectively: since the coverage of a single micro-cell is limited to 200 meters, the groups cannot be used for inter-site distance greater than the 2250 and 3750 m. The results show that these schemes are effective for path loss indices which are greater or equal than 3.5; for lower path loss values, the Micro-cell solution performance collapses.

On the other hand, when the D values are lower, the Micro-cell BSs are characterized by opposite results: the solution 4 is the best with energy saving of about 60% while solution 5 is worse than solution 1: these behaviors can be understood by recalling that the solutions with Micro-cell BSs allow to reduce the transmission power to a high number of BSs while maintaining the power consumption typical to a low transmission power and increasing the coverage. Therefore, with the solution 5 a high number of Micro BS with lower transmission power is used: in this case, anyway, the overall power is higher; conversely, the solution 4 presents a valid trade-off between dimension of the cells and number of BS. As depicted in Fig. 10(b) and Fig. 10(a), the Micro-cell BS solutions experienced a break-down of the energy saving; this strong reduction is caused by the limitations in the transmitted power and inter-site distance which are typical of the Micro-cell BS configurations: the limitations prevent this architecture from selecting the inter-site distance which allows the optimization of the Area Power Consumption and, therefore, originates the break-down. A deeper insight in the behaviour of the energy saving protocols can be obtained by assuming unlimited transmitted power and inter-site distance for the different BS types: the area power consumption and the energy saving which are obtained under these hypotheses are represented in Fig. 8(c) and Fig. 10(c) [4]. As for the Area Power Consumption, the minimum points are achieved for a higher value of the inter-site distance with respect to the limited power case: this increase causes a growth of the energy saving - see Fig. 10(c) - which is remarkable for Micro-cell Architectures, namely Solutions 4 and 5; particularly, the latter greatly benefits from the lack of limitation for the transmitted power, becoming the best solutions for all the scenarios. Nonetheless, the extremely high inter-site distance and transmitted power make these sets of parameter not suitable for any practical applications, only exploitable for a theorethical analysis.

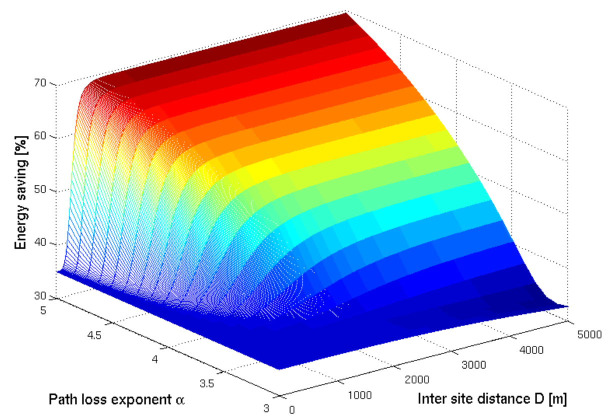
VI. Conclusion

In this paper, the RRM strategies and the deployment guidelines which can be adopted in a multi-layer heterogeneous mobile networks have been presented; these techniques permit to optimize the Area Power Consumption which is calculated by means of the capacity of the cell and the energy which is used to maintain the links active. The heterogeneous network deployment has been shown to be highly efficient when supported by the green radio strategies. A comparative evaluation of the possible alternative approaches, namely, the macro-cell coverage and the strategy which resorts to a great number of lower power microcells to cover the same spot has been also provided: the microcell strategy is shown effective only for radio environments with high propagation loss and only for a moderate number of micro-cells inside the spot.

[4]In comparison with the results reported in Fig. 8(a) no other change of working conditions is assumed



(a) Solution 2



(b) Solution 3

Fig. 9. Energy Saving

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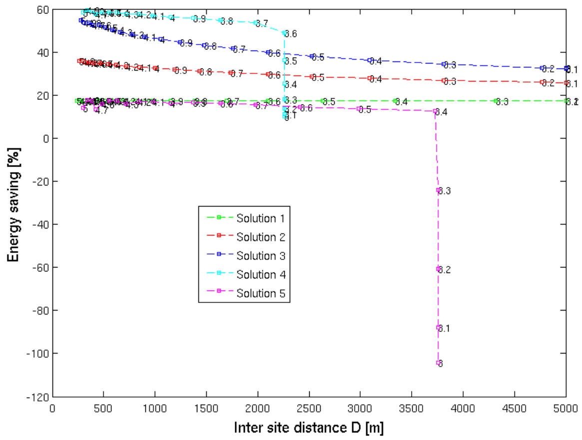
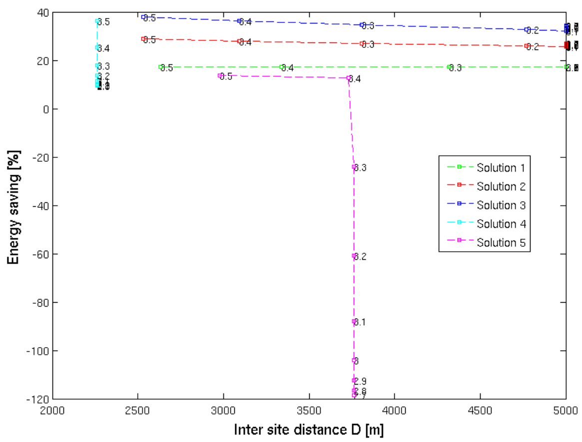
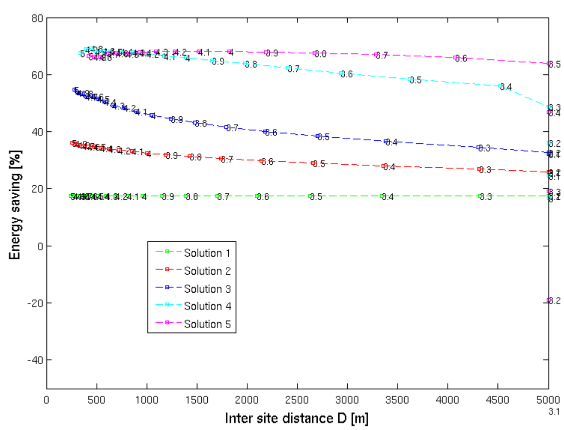


(a) Shadowed Urban Area



(b) Urban Area



(c) Shadowed Urban Area without Power and Distance Limitation

Fig. 10. Optimal Energy Saving

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