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Planning Criteria to Improve Energy Efficiency of Mobile Radio Systems[1]

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Abstract – *The cellular layout of a mobile radio system has an impact on its performance (in terms of both coverage and capacity) as well as on its economical and environmental sustainability in terms of power consumption and of exposure of population to electromagnetic field.*

In this paper we study different cellular coverage strategies to identify which solutions better meet the constraints on the above mentioned parameters. Both an idealized, 2D case and a more detailed urban layout case are considered in the work: in the latter case a 3D ray tracing tool is used as propagation model. Generally, a trade-off is required to reach the best performance in terms of radio coverage, system throughput and energy efficiency.

1 Introduction

In Europe the telecommunications market accounts for 8% of the total energy consumption and for the 4% of CO2 emission. The problem of increasing energy consumption and CO2 emissions in different industrial sectors led the European Commission to identify the so-called 2020 objectives which foresee to reach the 20% of renewable energy production, to improve energy efficiency by 20% and to decrease by 20% CO2 emissions by the end of the year 2020.

In both fixed and mobile Telecommunication sectors, the access network is responsible of a large part of the energy consumption. As an example, in a typical mobile radio network, up to about 80% of total power consumption occurs at base stations. It is worth noting that the power consumption in cellular networks is steadily increasing due to growing demand of broadband wireless internet access through the usage of new mobile terminals such as smartphones, tablets and other high-end terminal devices, as well as laptops with cellular connectivity.

On the other hand, the cost of energy production is increasing due to the larger demand experienced particularly in emerging markets, which causes an increased price of natural resources such as gas and oil.

The combined effect of these two trends is causing an augmented cost for operators, which also have to face a reduction of ARPU in most markets. As a consequence, the effect of energy consumption on operators bottom lines may become excessive and, in some cases, even unbearable.

In order to attain a significant reduction in the energy balance (and hence both in the carbon footprint and in the OPEX) of mobile radio networks, different strategies such as a smart cellular

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coverage, the usage of new base station equipment (single RAN: UMTS and GSM) and MIMO smart antennas can be envisaged.

We show two directions to follow in order to reduce the power consumption of cellular networks, namely the study of innovative and “smart” cellular architectures and the improvement of energy efficiency by means of hardware and software solutions for the base stations.

As already stated in [1] an optimum planning should be able to maximize the overall system efficiency, which requires a trade-off between the bandwidth and power efficiencies, where the former η_B is the ratio between the achievable bit rate and the available bandwidth and the latter η_P is the number of bits per thermal energy unit.

One more aspect that we need to consider in this evaluation is the fact that cellular structure allows to reuse the spectral resources over the service area, thus introducing a third dimension to the problem, i.e. the spatial efficiency that gives account of how the spectral resources are reused over the territory. As it is well known, the received power S decreases with distance from the Base Station according to different path loss factors which depend on cell size and on the propagation environment (e.g. urban, suburban). We will analyze and compare different coverage solutions (e.g. macrocellular and microcellular BSs) in order to identify the best configuration which guarantees an appropriate trade-off between spectral and power efficiencies.

Of course, for a complete network planning analysis, it is very important to consider jointly all aspects.

In [2] a study of different coverage strategies for a mobile radio system in a real urban area is presented.

Focusing on the indoor coverage analysis, it is shown that macrocellular coverage guarantees high signal levels at higher floors, but extremely poor at ground floor, while the opposite occurs with the pure microcellular deployment, where the covered fraction sharply decreases at higher floors. Furthermore, in the former case increasing the transmitter power is not sufficient to cover lower floors, while in the latter case in order to increase the percentage to 90% and 95% the transmitter power should be increased by 11 dB and 14 dB respectively. Apart from exposure levels concerns, this would imply an extremely high increase of energy consumption.

A combined use of both cellular layers was therefore suggested to guarantee the required coverage while keeping the field exposure levels within the values imposed by law: this idea is further developed in this work with the help of a 3D ray tracing tool. Moreover, a theoretical investigation is carried out on an idealised cellular layout case with a dual slope propagation model to determine the dependence of emitted power spatial-density on cell radius.

2 The considered coverage scenarios

In this paper different coverage strategies are investigated in order to identify the influence of cellular architecture parameters (e.g. cell radius) on both coverage and power consumption. We focus our attention on Base Station emitted power levels which guarantee service in the considered area.

The minimum power consumption is assumed to correspond to the minimum BS transmitted power needed to provide data coverage over a given percentage of the cell area.

Two different scenarios have been considered: a theoretical single cell scenario with a uniformly varying cell radius and a Manhattan environment with macrocellular and microcellular coverage architecture.

2.1 Single cell layout

A single cellular layout coverage is addressed assuming a circular coverage area. A minimum received signal level P_R of -90 dBm is imposed in order to guarantee service coverage at the cell border. Similarly to what done in [3], the BTS transmitted power P_T is calculated as a function of the cell radius R based on a "dual-slope model":

$$P_T = P_R \left(\frac{\pi d_o}{\lambda} \right)^2 \frac{1}{G_{T\,\max} G_m} \left(\frac{R}{d_o} \right)^{\alpha} \quad (1)$$

where Pr is the minimum received signal strength at the cell edge (-90 dBm), R is cell radius, α is the power-decay exponent after the reference distance d_o, G_T and G_m are respectively the transmitter and the receiver gains, and λ the wave length. According to this propagation model, if the cell radius R is lower or equal to the reference distance d_o a free-space (α=2) propagation applies, otherwise a stronger attenuation law with α>2 is considered. The transition distance d_o depends on transmitter and receiver heights and on other parameters according to the expression identified in [3].

A typical BS antenna diagram and gain have been adopted [3] and an empirical law has been assumed to identify suitable BS heights h as a function of the cell radius: $R=0.0257\,h^3+11.5\,h^2-40.4$

In table 1 the parameter values adopted for the single cell case are shown.

Table 1: Single Cell layout parameters	
λ	0.16
R	150 m- 6 Km
Gt	20 dB
Gr	1 dB
a	2-6

The power P_T emitted by a single BTS cell for one single carrier is assumed to be equal to the power P_{Tmin} which guarantees the minimum received power P_{Rmin} = -90 dBm on cell border. P_{Tmin} is evaluated for different cell radius R and as a function of the path loss exponent. Energy consumption is then assessed as the *emitted power density [W/km²]*, i.e. the emitted power per square kilometre obtained by dividing the obtained P_{Tmin} values by the coverage area, πR^2.

2.2 Regular Manhattan layout

We subsequently examined a regular Manhattan-like scenario, depicted in Figure 1.

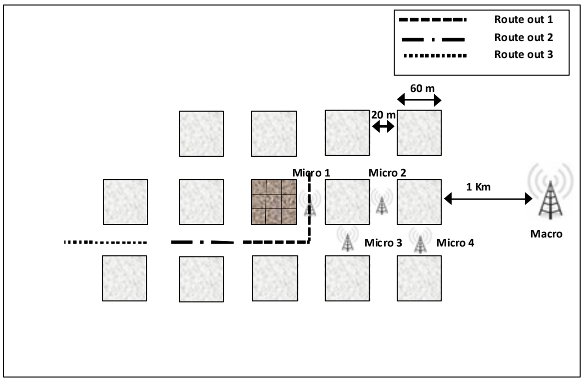

Figure 1. Manhattan cellular layout

The city is composed of a regular grid of square building blocks, with side equal to 60 m, separated by 20 m wide streets. The buildings have a random number of floors, which can be 9 or 11 with equal probability; as each floor is supposed 3 m high, the building height can be 27 or 33 m.

The figure also shows the simulated routes along which the terminal moves. We also evaluated indoor coverage within the building highlighted in dark grey.

Field prediction is made by a full 3D ray-tracing model developed in our laboratory ([4], [5]).

We simulated one macrocellular base station, 40 m high and is located 1 Km away from the considered area. Furthermore, we considered 3 m high microcellular base stations in various positions with a transmitted power of 200 mW.

We evaluated the macrocellular power necessary to guarantee 75% of locations in outdoors environment, and 50% for indoor locations, above the threshold of -90 dBm. This value was imposed assuming that the simulated area lies at the cell border.

For microcells, we imposed a coverage probability of 90% over the whole cell area in outdoors and 50% in indoors. In order to determine cell shape and size in the microcellular case, different BS positions and receiver routes are considered. Base stations have been placed along the city block side (in the centre of the street), as this solution maximizes inter-cell isolation and therefore overall system capacity.

In both the macro- and micro-cellular cases the emitted power density is then computed as the ratio between BS's emitted power and cell area.

3 Simulation Results

Simulations results are shown for the first theoretical single cell scenario, as a function of the cell radius.

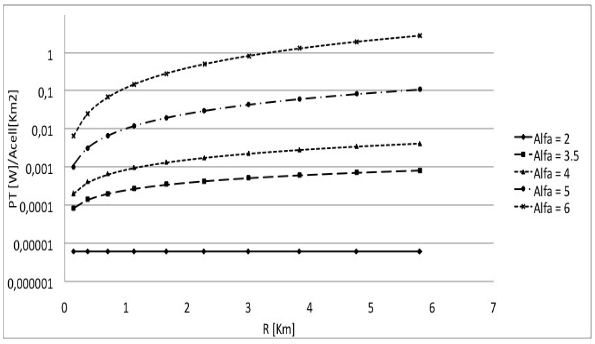

Figure 2. Single cell Base Station transmitted power density as a function of the cell radius

In Figure 2 the emitted power density is plotted as a function of cell radius and path loss exponent, for various propagations conditions varying from LOS (α=2) to high NLOS (α=6). The higher the α, the more substantial is the reduction of total power owing to the introduction of microcells (small radius) in this very simple scenario.

In order to analyze the effect of cellular layout in spectral and power efficiency we then considered a regular Manhattan-like scenario, described in Section 2.2.

In macrocellular scenario, if we only consider outdoor coverage requirements (75% of locations above the -90 dBm threshold) we need a power density of 0.8 W/Km^2, but in this case only 8.8% of indoor location at the 9th floor are above the -90 dBm threshold and the percentage of covered indoor locations at 1st floor falls to 0%. In order to reach at least a 50% covered indoor locations at 9th floor we increase the power level to 2 W/ Km^2, in this case the percentage of outdoor covered locations reaches 88%, but is not sufficient to increase the number of covered indoor locations at 1st floor, which remain at 0%. To increase the percentage of indoor covered locations at 1st floor up to 50%, we need to augment the transmit power up to 81.4 W/Km^2, which is a quite high value. Table 2 summarises the power density and the corresponding percentage of covered locations.

Table 2

Power Density (W/Km^2)	Percentage of covered locations
0.8	75% outdoor
	0% indoor 1st floor
	8.8% indoor 9th floor
2	88% outdoor
	0% indoor 1st floor
	50% indoor 9th floor
81.4	98.5% outdoor
	50% indoor 1st floor
	98.2% indoor 9th floor

As the power density needed to reach a 50% of indoor covered locations at 1st floor is not achievable we analyse a microcellular layout to cover the same Manhattan-like scenario.

In table 3 the indoor coverage percentages evaluated at the 1st and 9th floor of the central Manhattan building are shown for each different microcell location, assuming the same transmitted power P_T equal to 200 mW.

Table 3: Indoor microcellular coverage (P_T = 200 mW)		
Microcell	1st floor	9th floor
1	100%	75.4%
2	8.7 %	0%
3	70.1 %	35 %
4	24.5 %	8.7%

As it can expected, a good coverage is obtained at the first floor especially for microcells 1 and 3 which are located near the building while in the higher floors (9th floor) only microcell 1 provides a significant percentage of covered points.

Less critical coverage situations occur in the outdoor microcellular environment as shown in Table 4. In this case, apart from microcell 2, microcells 1, 3 and 4 guarantee high coverage percentages in the 3 different routes.

Table 4: Outdoor microcellular coverage (P_T = 200 mW)			
Microcell	Route 1	Route 2	Route 3
1	100%	100%	56.5%
2	52.5%	0%	0%
3	100%	100%	100%
4	82%	100%	100%

If we assume an outdoor microcellular coverage requirement of 90 % and a minimum indoor coverage of 50 %, it is possible to evaluate the microcell coverage area and calculate the corresponding power density. The extension of the coverage area is equal to about a square area of 0.22x0.22 Km^2 and the power density is 4.13 W/Km^2. In this case only in the central building coverage at the last floor is higher than 50%. In order to serve the higher floors also for the other buildings of the square area 0.22x0.22 Km^2, the microcell 1 transmitted power should be increased by 18 dB which corresponds to an unacceptable power density of 260.7 W/ Km^2.

4 Conclusions

In this paper we have shown that power consumption of a mobile radio network is strictly related to the cellular deployment strategy.

Some preliminary indications result from a theoretical single cell layout: for high values of the path loss exponent α, which are typical for a urban environment, a microcellular layout with small cell radius leads to lower power consumption. This effect tends to disappear as the power attenuation law approaches free space propagation.

Then a Manhattan environment with macrocellular and microcellular coverage architecture has been considered and results show that macrocells are power efficient for outdoor coverage and indoor, high floor locations, but become extremely inefficient when a coverage in indoor locations at 1st floor is needed. Conversely microcellular layout is efficient for outdoor coverage and indoor location at 1st floor, but inefficient for coverage at high floors. Thus the maximum efficiency (i.e. the minimum transmitted power density per Km^2) is achieved by combining the micro- and the macrocellular architecture: using macrocells for indoor coverage at high floors and for outdoor coverage, acting as umbrella cells, and using microcells as gap fillers for outdoor coverage and for indoor coverage at lower floors.

Further studies will address the evaluation of power efficiency of mixed cellular layouts.

5 References

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