Modelling the Energy Efficiency of Microcell Base Stations

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***Abstract*—The power consumption of wireless access networks will become a major issue in the coming years. Therefore, it is important to have a realistic idea about the power consumption of each element in those access networks. In this paper, an energy efficiency model for microcell base stations is proposed. Based on this model, the energy efficiency of microcell base stations is compared for various wireless technologies, namely mobile WiMAX, HSPA and LTE. The power consumption of microcell base stations is about 70-77% lower than for macrocell base stations but a macrocell base station is more energy-efficient than a microcell base station for the same bit rates. However, for the considered case and assuming our parameters are correct, a reduction in power consumption can be obtained by using microcell base stations to fill coverage holes.**

***Keywords*-energy efficiency, green wireless access networks, microcell base station, power consumption.**

I. Introduction

Looking at the complete life cycle (production, use and end-of-life) tells us that ICT is responsible for 4% of the worldwide primary energy consumption [1]. Without any precautions, this percentage will even double within the next 10 to 15 years. 9% of this ICT consumption is caused by radio access networks [2]. Within these networks, 10% of the energy is consumed by the user terminals, while 90% is caused by the base stations. These numbers indicate that the power consumption of wireless access networks is going to become an important issue in the next few years. To model and optimize the power consumption in those networks, the focus should therefore be on the base stations.

An operator's wireless access network has a hierarchical structure of different cell types. Three different cell types can be found: macrocell, microcell and picocell. A macrocell has the highest possible coverage range. A microcell has a smaller coverage range and is often used in densely populated urban areas. A picocell is much smaller than a microcell and is mostly used for indoor coverage in large office buildings, shopping centres or train stations. To determine the power consumption of the whole wireless access network, the power consumption of the macrocell, microcell and picocell base stations have to be modelled. In [3][4], an energy efficiency model for the macrocell base station is proposed. The aim of this study is to model and compare the energy efficiency between microcell and macrocell base stations for various wireless technologies. The same approach as in [3][4] is followed: the power consumption of a microcell base station is first modelled and related to the range to determine the energy efficiency. The wireless technologies considered are: mobile WiMAX (Worldwide Interoperability for Microwave Access) [5], HSPA (High Speed Packet Access) [6] and LTE (Long Term Evolution) [7].

Few work has been done about the energy efficiency of microcell base stations. The most valuable contribution to this topic can be found in [8] where the power consumption of different equipment is combined into three parameters. This makes it difficult to investigate the influence of the different components on the base station's power consumption, as well as the influence of possible dependencies between the components. Furthermore, only one wireless technology is considered, while our work shows that there are significant differences in energy efficiency between the wireless technologies.

The remainder of this paper is organized as follows. In Section II the power consumption of a microcell base station is modelled and related to the coverage. Section III describes some results obtained with the model proposed in Section II. Section IV presents our conclusions.

II. Method

In this section, a power consumption model for a microcell base station is proposed.

A. Energy-efficiency of a microcell base station

Just like for a macrocell base station, the power consumption PC_{area} per covered area of a microcell base station is defined as (in W/m^2) [3][4] :

$$PC_{area} = \frac{P_{el/micro}}{\pi \cdot R^2} \quad (1)$$

with $P_{el/micro}$ the power consumption (in Watt) and R the range (in meter) of the microcell base station. The next sections discuss how $P_{el/micro}$ and R are determined. The lower PC_{area}, the more energy-efficient the technology is.

1) Power consumption of a microcell base station: A base station is here defined as the equipment needed to communicate with the mobile stations and with the backhaul network. The microcell base station consists of several power consuming components, which are shown in Fig. 1.

 ISBN: 978-1-61208-136-6

The following components are found: the transceiver (responsible for sending and receiving of signals to the mobile stations and includes the signal generation), digital signal processing (responsible for system processing and coding), the power amplifier, the AC-DC converter or rectifier, and the air conditioning (if present). In contrary to a macrocell base station, a microcell base station supports only one sector and each component is therefore used once. This assumption is based on the confidential information retrieved from an operator.

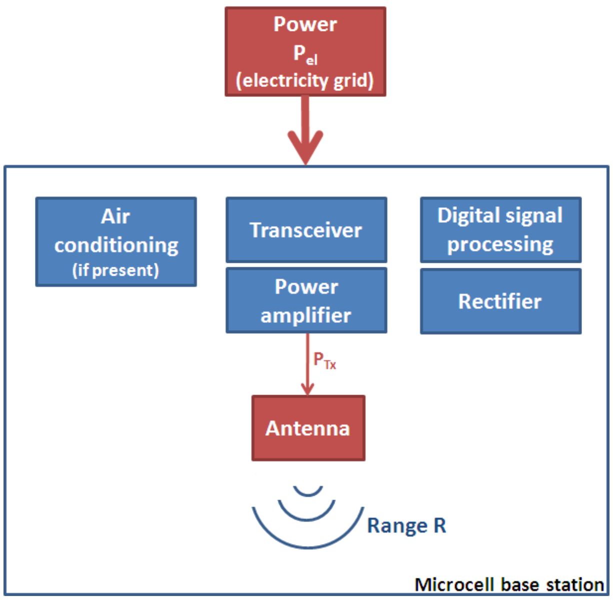

Figure 1. Block diagram of microcell base station equipment.

The power consumption of each component is constant (in Watt), expect for the air conditioning and the power amplifier. The air conditioning's power consumption depends on the internal and ambient temperature of the base station cabinet. Assuming an internal and ambient temperature of 25° C gives also a constant power consumption for the air conditioning. However, an air conditioning is not always necessary for a microcell base station. In this paper, the worst case for the power consumption, which includes the air conditioning, is investigated. The power consumption $P_{e/amp}$ of the power amplifier depends on the required input power P_{Tx} of the antenna and is determined as follows [9]:

$$P_{el/amp} = \frac{P_{Tx}}{\eta} \tag{2}$$

with P_{Tx} the input power of the antenna (in Watt) and η the efficiency of the power amplifier, which is the ratio of RF output power to the electrical input power [9]. The RF output power corresponds with P_{Tx} as indicated in Fig. 1.

Once the power consumption of each component is known, the power consumption $P_{el/micro}$ of the entire microcell base station can be determined (in Watt):

$$P_{el/micro} = P_{el/amp} + P_{el/trans} + P_{el/proc} + P_{el/rect} + P_{el/airco} \tag{3}$$

with $P_{el/amp}$, $P_{el/trans}$, $P_{el/proc}$, $P_{el/rect}$, $P_{el/airco}$ and $P_{el/link}$ the power consumption of, respectively, the power amplifier, the transceiver, the digital signal processing, the rectifier, and the air conditioning. Table I summarises the typical power consumption of the different components for the technologies considered. These values are retrieved from data sheets of various network equipment manufacturers and are very similar to those of the macrocell base station [3][4], except for the air conditioning. The air conditioning's cooling power is significant lower for the microcell base station, resulting in a lower power consumption for the microcell base station (60 W versus 225 W for the macrocell base station, based on confidential information from an operator).

Table I
POWER CONSUMPTION OF THE DIFFERENT COMPONENTS OF THE MICROCELL BASE STATION.

Equipment		Value
Digital signal processing	$P_{el/proc}$	100 W
Power amplifier	η	12%
Transceiver	$P_{el/trans}$	100 W
AC-DC converter	$P_{el/conv}$	100 W
Air conditioning	$P_{el/airco}$	60 W

2) Calculation of the range of a microcell base station: To determine the coverage of a microcell base station a link budget has to be determined. Table II-A2 summarises the link budget parameters for the coverage calculations of the microcell base stations. The same parameters as for the macrocell base stations are usable, however, some of these parameters will have a different value such as the input power of the antenna and the antenna gain. The typical input power of the antenna P_{Tx} for a microcell base station is 2 W or 6 W. In this investigation, we use P_{Tx} equal to 2 W, which corresponds with 33 dBm [8]. As mentioned above, a microcell base station has only one sector, therefore, an omnidirectional antenna is used. The antenna gain for this type of antennas and the base station considered varies from 4 to 6 dB depending on the technology. The other parameters remain the same because these parameters are either technology dependent (such as the frequency, bandwidth, etc.) or mobile station dependent (such as antenna gain of mobile station, feeder loss of the mobile station, etc.) or fixed assumptions (such as the yearly availability, fade margin). Note that the cell interference margin assumed might be too optimistic because the same cell interference margin is used for both the macrocell and the microcell base station just like in [8].

In Table III, the characteristics of the scenario considered are presented. A suburban area is assumed with a height of

 ISBN: 978-1-61208-136-6

Table II
LINK BUDGET TABLE FOR A MICROCELL BASE STATION FOR THE TECHNOLOGIES CONSIDERED.

Parameter	Mobile WiMAX	HSPA	LTE
Frequency [MHz]	2500	2100	2600
Maximum input power of base station P_{Tx} [dBm]	33	33	33
Effective input power of base station P_{Tx}^{TCH} [dBm]	33	13.8	33
Antenna gain of base station [dBi]	6	5	4
Antenna gain of mobile station [dBi]	2	0	0
Soft handover gain [dB]	0	1.5	0
Feeder loss of base station [dB]	0.5	0	2
Feeder loss of mobile station [dB]	0	0	0
Fade margin [dB]	10	10	10
Cell interference margin [dB]	2	2	2
Bandwidth [MHz]	5	5	5
Receiver SNR [dB]	[6, 8.5, 11.5 15, 19, 21][1]	[-3.1, 0.1, 3.4 6, 7.1, 9.6 15.6][2]	[-1.5, 3, 10.5 14, 19, 23 23, 29.4][3]
Number of used subcarriers	360	—	301
Number of total subcarriers	512	—	512
Noise figure of mobile station [dB]	7	9	8
Implementation loss of mobile station [dB]	2	0	0
Duplexing	TDD		
Building penetration loss [dB]	8.1	8.1	8.1

(1) [1/2 QPSK, 3/4 QPSK, 1/2 16-QAM, 3/4 16-QAM, 2/3 64-QAM, 3/4 64-QM]

(2) [1/4 QPSK, 1/2 QPSK, 3/4 QPSK, 3/4 8-QAM, 1/2 16-QAM, 3/4 16-QAM, 3/4 64-QAM]

(3) [1/3 QPSK, 1/2 QPSK, 2/3 QPSK, 1/2 16-QAM, 2/3 16-QAM, 4/5 16-QAM, 1/2 64-QAM, 2/3 64-QAM]

1.5 m for the mobile station and a coverage requirement of 90%. The antenna of the microcell base station is placed typically at a height of 6 m, which corresponds with the height of the roof-gutter of a three-storied house (i.e., 2 m per floor). The base stations are placed outdoor and for the mobile stations an indoor residential scenario is considered with a Wireless Network Interface Card (WNIC) for a laptop.

The Walfisch-Ikegami (W-I) model is used as propagation model for microcells [10]. The Erceg-model, which is used for macrocell base stations, is not suitable for microcell base station heights [11].

Table III
SCENARIO TABLE.

Parameter	Value
Area type	Suburban
Height of base station	6 m
Height of mobile station	1.5 m
Coverage requirement	90%
Path loss model	W-I
Shadowing margin	12.8 dB

III. RESULTS

In this section, some results obtained with the model from Section II are discussed.

A. Energy-efficiency of microcell base stations

In this section, the wireless technologies considered are compared for a bandwidth of 5 MHz. The parameters given in Tables I, II-A2 and III are used. Fig. 2 shows the power consumption PC_{area} per covered area (in W/m^2) as a function of the bit rate (in Mbps).

In general, Fig. 2 shows that each technology becomes less energy-efficient for higher bit rates as PC_{area} increases for increasing bit rates. The higher the bit rate, the higher the receiver SNR (Signal-to-Noise Ratio) as given in Table II-A2. Furthermore, a higher receiver SNR corresponds with a smaller range for the same power consumption P_{el} resulting in a higher value for PC_{area} (eq. (1)) and thus a lower energy efficiency.

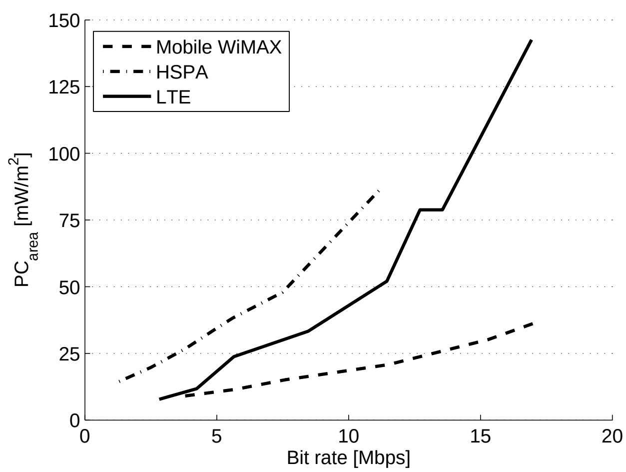

Figure 2. Energy efficiency of a microcell base station for different bit rates in 5 MHz channel.

A microcell base station consumes about 376.6 W for each technology (Table I). However, the range R differs between the technologies considered. For a bit rate of 10 Mbps, R equals to 76.0 m, 37.0 m and 48.0 m for mobile WiMAX, HSPA and LTE respectively. A higher R for the same P_{el} results in a lower PC_{area} and thus in a higher energy efficiency.

Fig. 2 shows that mobile WiMAX is the most energy-efficient technology for bit rates higher than 3.8 Mbps (lowest PC_{area} of 20.8 mW/m^2 at 10 Mbps versus 87.6 mW/m^2 and 52.0 mW/m^2 for HSPA and LTE respectively). For the bit rates considered, mobile WiMAX performs better than HSPA and LTE due to its higher antenna gain for both the base station and the mobile station (Table II-A2). Moreover, mobile WiMAX has a higher effective input power of the antenna P_{Tx}^{TCH} than HSPA. P_{Tx}^{TCH} is the power reserved by the base station for the traffic channels and is lower for HSPA because it uses a W-CDMA (Wideband Code Division Multiple Access) based multiple access technique, while mobile WiMAX uses OFDMA (Orthogonal Frequency Division Multiple Access).

The bit rates between 2.8 Mbps and 3.8 Mbps are only supported by HSPA and LTE. In this case, LTE is the most energy-efficient due to its higher P_{Tx}^{TCH} (PC_{area} of

 ISBN: 978-1-61208-136-6

2.8 mW/m^2 versus 19.7 mW/m^2 for a bit rate of 2.8 Mbps). Bit rates below the 2.8 Mbps are only supported by HSPA (PC_{area} = 14.5 mW/m^2 for 1.3 Mbps).

B. Energy-efficiency of microcell base stations versus macrocell base stations

In this section, the energy efficiency of a microcell base station is compared to that of a macrocell base station for the technologies considered and in a 5 MHz channel. For the macrocell base station, the same settings as in [4] are used. Fig. 3 presents the power consumption per covered (PC_{area}) as a function of the bit rate (in Mbps) for both the macrocell and the microcell base station.

Fig. 3 shows that, in general, the macrocell base stations are more energy-efficient than microcell base stations as PC_{area} is lower (about 82 to 93%). The power consumption P_{el} of the microcell base station is about 70.6% lower for mobile WiMAX and about 77.5% lower for HSPA and LTE compared to the corresponding macrocell base stations (Table IV). However, a macrocell base station has a significant higher range (297.0%, 346.3% and 498.4% for mobile WiMAX, LTE and HSPA respectively) resulting in a higher energy efficiency.

Furthermore, for the macrocell base station, it was found that HSPA is the most energy-efficient technology until a bit rate of 2.8 Mbps (which corresponds with the results for microcell base stations), LTE is the most energy-efficient for bit rates between 2.8 Mbps and 11.5 Mbps (versus 2.8 Mbps and 3.8 Mbps for microcell base stations) and mobile WiMAX is the most energy-efficient for bit rates higher than 11.5 Mbps (versus 3.8 Mbps for microcell base stations).

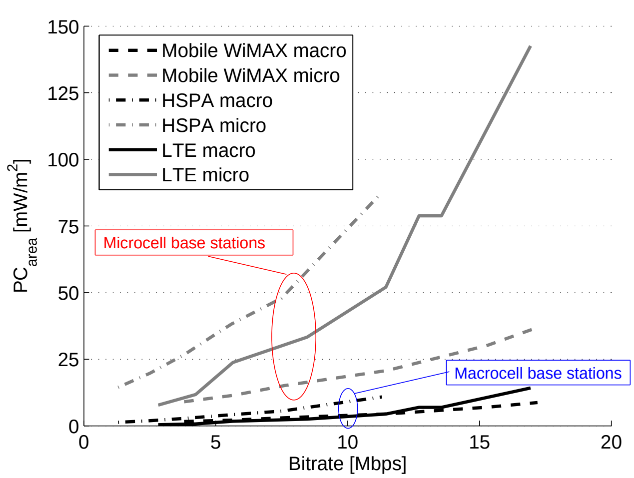

Figure 3. Comparison of the energy efficiency of a macrocell base station and a microcell base station for different bit rates in a 5 MHz channel.

Table IV
COMPARISON OF THE POWER CONSUMPTION P_{el} AND THE POWER CONSUMPTION PC_{area} PER COVERED AREA FOR MACROCELL AND MICROCELL BASE STATIONS IN A 5 MHZ CHANNEL AND A BIT RATE OF (APPROXIMATELY) 10 MBPS.

Technology	**Macrocell**			**Microcell**		
	P_{el} [W]	R [m]	PC_{area} [mW/m^2]	P_{el} [W]	R [m]	PC_{area} [mW/m^2]
Mobile WiMAX	1279.1	301.7	4.5	376.6	76.0	25.2
HSPA	1672.6	346.3	10.9	376.6	48.0	106.2
LTE	1672.6	221.4	4.4	376.6	37.0	63.1

C. Microcell base stations in realistic network deployments

Based on the results mentioned above, one might ask if it is interesting to use microcell base stations in real network deployments. The answer to that question is positive. Microcell base stations can be used to increase the capacity of a macrocell base station in a certain area. Furthermore, microcells can also be used to solve coverage holes. In this section, a simple example is given where a benefit can be obtained by using microcell base stations to solve coverage holes.

Fig. 4(a) shows the example considered. An operator has to cover an area of 4 km^2 for 100% with mobile WiMAX base stations. A bit rate of 3.8 Mbps is considered. Seven macrocell base stations are placed in the area and these sites have to be re-used. Five of these base stations have an input power P_{Tx} of 35 dBm (blue circles), which corresponds with a range of 499.0 m and a power consumption of 1279.1 W; the other two have a P_{Tx} of 31 dBm (red circles) resulting in a range of 399.0 m and a power consumption of 1234.5 W. The current situation has a power consumption of 8.9 kW:

$$P_{el,curr} = 5 \cdot 1279.1\ W + 2 \cdot 1234.5\ W = 8864.5\ W \quad (4)$$

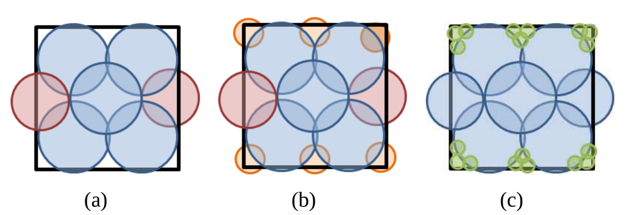

Figure 4. Possible solution to cover coverage holes: start situation (a), only macrocell base stations are used (b), and both macro- and microcell base stations are used (c).

In Fig. 4(b), the coverage holes are filled by using only macrocell base stations. Six macrocell base stations are introduced. Each macrocell base station added has a P_{Tx} of 18 dBm corresponding with a range of 193.0 m and a power consumption of 1206.5 W. The total power consumption $P_{el,1}$ to cover the area is in this case:

$$\begin{aligned} P_{el,1} &= 5 \cdot 1279.1\ W + 2 \cdot 1234.5\ W + 6 \cdot 1206.5\ W \\ &= 16104\ W \end{aligned} \quad (5)$$

 ISBN: 978-1-61208-136-6

The network in Fig. 4(b) consumes thus about 16.1 kW.

In Fig. 4(c), the coverage holes are filled by placing microcell base stations (green circles). 18 microcell base stations are needed to cover the area considered. Each of these base stations have a P_{Tx} of 33 dBm, which corresponds with a range of 115.0 m and a power consumption of 376.6 W. The total power consumption $P_{el,2}$ to cover the area is then approximately 15.6 kW:

$$P_{el,2} = 5 \cdot 1279.1\ W + 2 \cdot 1234.5\ W + 18 \cdot 376.6\ W = 15643.0\ W \quad (6)$$

The solution with both macrocell and microcell base stations consumes about 461 W less. This is a power consumption reduction of 3% than the solution where only macrocell base stations are considered. It is thus interesting to add microcell base stations in a realistic network deployment.

IV. Conclusion

In this paper, an energy efficiency model for microcell base stations is proposed. Based on this model, the energy efficiency of microcell base stations is compared for various bit rates and wireless technologies, namely mobile WiMAX, HSPA and LTE. Furthermore, the energy efficiency between a microcell and macrocell base station is investigated. The base stations were placed outdoor in a suburban environment and for the mobile stations an indoor scenario was considered with a WNIC for a laptop. A bandwidth of 5 MHz was assumed. For the parameters considered, a microcell base station has ranges from 40 m to 80 m for a power consumption of approximately 377 W.

Mobile WiMAX is the most energy-efficient technology for bit rates higher than 3.8 Mbps, LTE for bit rates between 2.8 Mbps and 3.8 Mbps and HSPA for bit rates lower than 2.8 Mbps. HSPA is the only technology which supports bit rates lower than 2.8 Mbps. Mobile WiMAX support only bit rates higher than 3.8 Mbps. The power consumption P_{el} of the microcell base station is 70.6% lower for mobile WiMAX and 77.5% lower for HSPA and LTE but a macrocell base station is more energy-efficient than a microcell base station due to the higher ranges of the macrocell base stations.

However, it is interesting to use microcell base stations in real network deployments. In this paper, a solution was presented to fill coverage holes by using only macrocell base stations and by using both macrocell and microcell base stations. The latter showed a reduction in power consumption compared to the solution with only macrocell base stations for the case considered and assuming our parameters are correct.

In the future, the power consumption model should be validated with measurements and will be added in the GRAND (Green Radio Access Network Design) tool, which is a deployment tool we developed for green wireless access networks.

Acknowledgment

The work described in this paper was carried out with support of the IBBT-project GreenICT.
W. Joseph is a Post-Doctoral Fellow of the FWO-V (Research Foundation Flanders).

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