An Energy Efficiency Assessment for Indoor Small Cells Using Copper-Based Backhaul

Albert Richard Moraes Lopes, Fabrício S. Farias, and João Crisóstomo Weyl Albuquerque Costa

***Abstract*—Heterogeneous networks (HetNets) are being adopted as the main alternative for reducing the energy consumption in wireless network. This adoption forces the backhaul architectures expansion, and consequently it increases the overall network energy consumption. In the last years, copper technology has been disregarded to backhaul indoor small cells. However, lately the copper-based technology turned out as an effective option due to the femtocell technology based on wireless over cable (FemtoWoC). In this paper, it was assessed two backhaul architectures, using copper in the last mile, to connect FemtoWoC in the network. It was also evaluated the energy-effiency achieved compared to the results in scenarios using conventional femtocells.**

***Index Terms*—Energy efficiency, mobile backhaul, small cells.**

I. Introduction

The acceleration of wireless data traffic demand motivated by both LTE development and unprecedented popularization of mobile devices has caused a direct impact on mobile wireless power consumption. This impact is led by the network densification, i.e., new base stations (BSs) being deployed in order to guarantee coverage and new capacity requests, which aggravates the concerns about carbon footprint [1]. Recently, energy savings is a hot topic on mobile communication. The initial efforts tried to reduce BSs energy consumption by using renewable energy resources [2], adopting BSs with standby technology for discontinuity [3], improving the power amplifier efficiency [4], or comparing homogeneous networks based only on one kind of BSs (e.g., macro BSs) versus heterogeneous networks (HetNets) based on different types of BSs (e.g., macro-,pico-and femto-cells) [5]-[9].

Among all attempts to tailor the network through reducing gas emissions and operational costs, HetNets are highlighted as the most attractive option. Authors in [7] show that HetNets based on macro-cells and femto-cells may reduce dramatically the energy consumption of wireless networks. Moreover, papers [8]-[10] present advantages, such as the improvement of QoS, bandwidth, coverage and reduction of power consumption, due to the small cells installation instead of macro BSs densification. On the other hand, the use of HetNets also brings drawbacks, e.g., increase in both backhaul energy consumption and investments on new equipment/infrastructure.

The usage of HetNets caused an inverse impact on backhaul power consumption. Different of the wireless part, composed by BSs, the backhaul is a new concern. Paper [7] shows that if the wrong backhaul is chosen its energy consumption may reach up to 50% of the overall network consumption. In order to reduce the backhaul energy impact on HetNets, many papers investigated which backhaul technology is the most efficient [7]-[9], i.e., testing fiber-, microwave-, and copper-based backhaul. The results presented fiber as the most energy-efficient technology and microwave as the worse one [7], [9].

It is known that copper is the most spread broadband technology with approximately 1.3 billion copper phone lines connection all over the globe [11]. The main technological gap of the copper-based backhaul is associated to the bandwidth, i.e., lower capacity to transmit 100 Mbps up to 300 meters [12]. However, for dense urban areas where all users are connected through fixed broadband and the capacity requirements are respected, copper in the last mile is still an alternative.

In this paper, a test-proof is presented in order to show if copper-based backhaul can still play as a big hole. The impact caused by different small cells on both backhaul and overall network energy consumption is investigated. For this purpose, a dense urban scenario is introduced covered by macro cells and either conventional femtocell or femtocell Wireless Over Cable (femtoWoC)-cells and backhauled by two options: one based on Fiber-To-The-Node (FTTN), composed by Fiber Switches (FS), Digital Subscriber Line Access Multiplexer (DSLAMs) and residential modems, and another based on Fiber-To-The-Building (FTTB), composed by Fiber Switches (FS) and either a Gigabit Ethernet Switch (GES) or Multi-cell BS.

The remainder of this study is presented as follows: Section II details the methodology used. Section III presents the wireless network dimensioning treating the model for femtoWoC. Section IV shows the backhaul power consumption, and Section V summarizes and discusses the numerical results obtained. Finally, Section VI presents the conclusions.

II. Methodology

This paper aims to study the impact caused by different small cells on backhaul architectures and overall network

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energy consumption. The work methodology is summarized as follows.

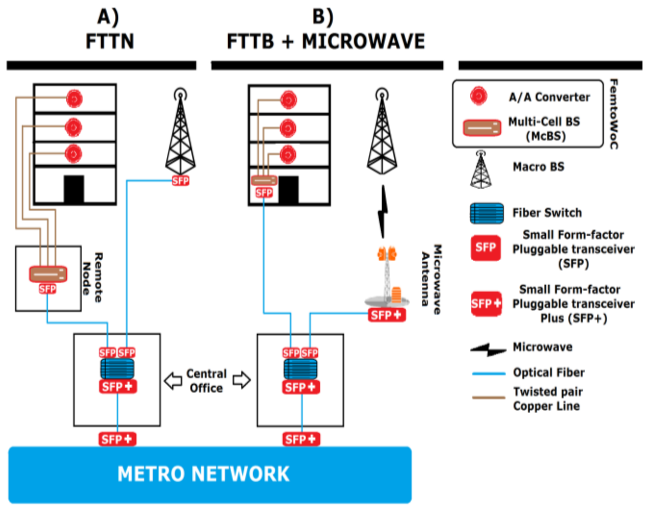

Fig. 1. FemtoWoC BSs backhauled by two backhaul architecture: A) Fiber-to-the-node (FTTN); B) Fiber-to-the-building (FTTB).

The first step is defining the *network model*. Here, it was determined the city architecture (e.g., defining the area dimension, number of buildings, number of floor and apartments per building). Thereafter, it was modeled a population distribution for indoor and outdoor environments. More details are presented in [7].

The second step is *Traffic Forecast*. This phase generates an estimation of the average area traffic demand for a dense urban area in a rush hour. This traffic estimation is based on network service usage, e.g., habits from the subscribers, and long term large-scale traffic models, which provides a data forecast. The details regarding this phase are provided in [7].

The third step is the *Wireless Network Dimensioning*. In this stage, it is estimated the number of each base station type covering the city. The result of this step as a function of the traffic forecast obtained using the results of first and second phase. All the details regarding this phase are presented in [7] and Section III.

The Fourth step is the *Backhaul Network Dimensioning*. This phase provides the number of equipment composing the backhaul architectures. The result of this step is in function of the wireless network dimension. Details are presented in [7] and Section IV.

Finally, in the last step the total power consumption of the overall wireless access network, considering both the wireless and the backhaul segment, is computed. The calculations are based on the power consumption models presented in [7] and discussed in Section IV.

III. Wireless Network Dimensioning

For the indoor wireless network dimensioning, it was only considered the implementation of conventional femtocells base stations or *femtocells Wireless over Cable* (*femtoWoC*) in indoor. Each conventional femtocell is a standalone device configuring a BS. In [13], the femtoWoC is presented as a solution for indoor BS compared to convencional femtocell. The femtoWoC consists of a *Analog to Analog converter*. (A/A) Converter and *Multi-cell Base Station* (McBS). For this study, it was considered that the A/A Converter as a femtoWoC BS. In outdoor are implemented macro BSs. Thus, it was prepared two scenarios.

- Scenario 1: Conventional femtocell + macro BS;
- Scenario 2: FemtoWoC + macro BS.

Scenario 1 is described in [7]. Whereas, in Scenario 2, it is assumed that femtoWoC BSs are randomly deployed indoor to serve the end user in their apartments. The number of deployed femtoWoC BSs ($N_{femtoWoC}$) is calculated as a function of femtoWoC BS penetration rate (η), total number of building and number of floors per building:

$$N_{femtoWoC} = N_{building} \times N_{floor} \times \eta \quad (1)$$

Since the macro BS needs to serve the remaining active users (i.e., which are not covered by femtoWoC BSs) in the rush hour, the required number of macro BSs (N_{macro}) in a given network area A can be computed as described in [7].

IV. Backhaul Power Consumption Model

In [7], it is detailed the mathematical for calculating power consumption of HetNets. The only difference is that it was attributed a value, according to [14], [15] for the power consumption of conventional femtocell instead of calculating. In the same way, it was assigned power consumption value of femtoWoC.

In this section, it was define the following backhaul architectures: FTTN and FTTB + Microwave, Fig. 1. In order to assess the energy efficiency, it was applied both architectures on Scenario 2. For the Scenario 1, it was reproduced the architectures from paper [7], whereas for Scenario 2, it was obtained new results explained in the Section V.

A. Architecture 1: Fiber-to-the-Node (FTTN)

The first backhaul architecture is shown in Fig. 1A) and is given by the use of fiber and copper. Here, femtoWoC BSs are backhauled using femtoWoC signal from femtoWoC to McBS. The femtoWoC signal is similar to VDSL, with power spectral density equals to -60dBm/Hz over the entire bandwidth [13]. In this scenario, the twisted-pair copper lines are fully dedicated to ensure the largest capacity of this technology. Each femtoWoC is connected to a McBS over copper. The McBSs are located in a remote node, which is usually placed inside a street cabinet, called remote node (RN) closed to the user premises. McBSs and macro BSs are connected to a number of Fiber Switch (FSs) using 1 Gbps point-to-point optical links. For transmitting and receiving the optical signal small form-factor pluggable transceivers (SFPs) are used. The FSs aggregate the traffic from wireless network before sending it towards the metro network (MN) via 10 Gbps fiber links and SFP+ modules. The power consumption is obtained through the following formula:

$$\begin{aligned} P_{bh}^{FTTN} &= N_{McBS}(P_{McBS} + 2P_{sfp}) + N_{fs}P_{fs} \\ &+ 2N_{macro}P_{sfp} + 2N_{ul}P_{sfp+} \end{aligned} \quad (2)$$

where P_{McBS}, P_{fs}, P_{sfp}, and P_{sfp+} are power consumption values of McBS, FS, SFP and SFP+, respectively. On the other hand, N_{McBS} and N_{fs} are the number of McBS and FS, respectively. N_{McBS} is as a function of the ports numbers per McBS (N_{ports}^{McBS}), i.e., $N_{McBS} = \left\lceil \frac{N_{femtoWoC}}{N_{ports}^{McBS}} \right\rceil$. Similarly, N_{fs} depends of the ports numbers of a FS (N_{ports}^{fs}), i.e., $N_{fs} = \left\lceil \frac{N_{McBS} + N_{macro}}{N_{ports}^{fs}} \right\rceil$. Finally, N_{ul} is the total number of uplink interfaces used to connect the metro network (MN), whereas P_{sfp+} is the power consumption of a SFP+ used to transmit the backhauled traffic to the MN. N_{ul} depends on the total aggregate traffic collected in the FSs, i.e., $Ag_{tot} = \tau \times A$, and on the maximum transmission rate of an uplink interface ($U_{\max}$). N_{ul} can be computed as $N_{ul} = \max\left(N_{fs}, \left\lceil \frac{Ag_{tot}}{U_{\max}} \right\rceil \right)$.

B. Architecture 2: Fiber-to-the-Building (FTTB) Plus Microwave

The second backhaul solution is shown in Fig. 1(B). It is a hybrid architecture that employs both fiber and microwave. The femtoWoC are connected to a McBS using copper cables. The McBS connects to a FS using 1 Gbps optical point-to-point links. SFP transceivers are used in the McBS and in the FS to transmit and receive the optical signal. The The FSs are connected to the MN using 10 Gbps optical links and SFP+ transceivers. In order to compare with paper [7], it was kept the macro BSs being backhauled with microwave. It was considered a point-to-point star topology where several microwave antennas are directly connected to a hub. The hubs are equipped with switches to aggregate traffic from the macro BSs. Additionally, the hubs are connected to the MN using 10 Gbps optical links and SFP+ modules. The power consumption of Architecture 2 can be defined as:

$$\begin{aligned} P_{bh}^{FTTB+Microwave} &= N_{building}(P_{McBS} + 2P_{SFP}) \\ &+ N_{macro}P_{low-c} + N_{fs}P_{fs} \\ &+ N_{hub}(P_{hugh-c} + P_{sfp}) \\ &+ N_s^{MW}P_S^{MW} + N_{ul}P_{sfp} \end{aligned} \tag{3}$$

P_S^{MW} is the power consumption of a switch inside a hub. P_{low-c} and P_{high-c} are represent respectively as the lowest and highest power consumption region of the microwave antennas. Finally, $n_{\sup}^{MW}$ is the max number of microwave links that a hub can support. More details are found in paper [7].

It should be noted that in the Fig. 1(B) architecture there are two types of aggregation points, i.e., (i) microwave hubs (summing the $n_{\sup}^{MW}$), and (ii) FSs (summing the N_{ports}^{fs}). Due to the fact that only macro BSs use microwave backhauling, the total number of hubs required in this architecture can be computed as $N_{hub} = \left\lceil \frac{N_{macro}}{n_{\sup}^{MW}} \right\rceil$. Whereas the number of FS is calculated as $N_{fs} = \left\lceil \frac{N_{building}}{n_{ports}^{fs}} \right\rceil$. The total number of switches inside the hubs are calculated as a function of the aggregated outdoor traffic only $Ag_{tot}^{outdoor}$, i.e., $N_s^{MW} = \max\left(N_{hub}, \left\lceil \frac{Ag_{tot}^{outdoor}}{C_{switch}^{MW}} \right\rceil \right)$. C_{switch}^{MW} is the maximum capacity of a switch inside a hub. On the other hand, the number of uplink interfaces (N_{ul}) are calculated based on the total aggregated traffic collected at the fiber switches and hubs, i.e., $N_{ul} = \max\left(N_{hub} + N_{fs}, \left\lceil \frac{Ag_{tot}}{U_{\max}} \right\rceil \right)$.

TABLE I: EQUIPMENT PARAMETERS — POWER CONSUMPTION AND NUMBER OF PORTS

Equipment	Power Consumption	Ports
Femtocell	9 W	1
FemtoWoC	6 W	1
McBS	70 W	8
SFP	1 W	1
SFP+	2 W	1
Fiber Switch	300 W	24
P_{low-c}	37 W	-
P_{high-c}	92.5 W	-
P_{ul}	2 W	-
P_{dl}	1 W	-
n^{MW}_{sup}	-	16

V. NUMERICAL RESULTS

In this section, the numerical results achieved from the comparison of femtoWoC and conventional femtocell are presented. It is assumed the same scenario defined in [7]. The scenario under discuss is composed by a 10km × 10km dense urban area with 100.000 apartments and 3000 users/km^2. For the conventional femtocells, it was adopted and recreated the same setup described in [7]. Fig. 2(A) and Fig. 2(B) present the curves reproduced from FTTN and FTTB architectures respectively.

In order to compare the results, it is assumed that the user demand is satisfied by a macro+femto deployment strategy where the penetration rate (eta), for both femtoWoC and conventional femtocell BS, varies between 0.1 and 0.6. Also, it was compared two new architectures (FTTN and FTTB using femtoWoC BS) with their respective backhaul architectures proposed in [7]. The detailed system and power consumption parameters are listed in Table I.

A. Fiber-to-the-Node (FTTN)

In Fig. 2(A), it is observed that HetNets using copper-based backhaul are more attractive only when the throughput is higher than 600 Mbps/km^2. Whereas, Fig. 2(B) shows that the intersection point (i.e., when HetNets become more energy-efficient than homogeneous networks) can be shifted to the left side, as a result achieving approximately 100Mbps/Km^2.

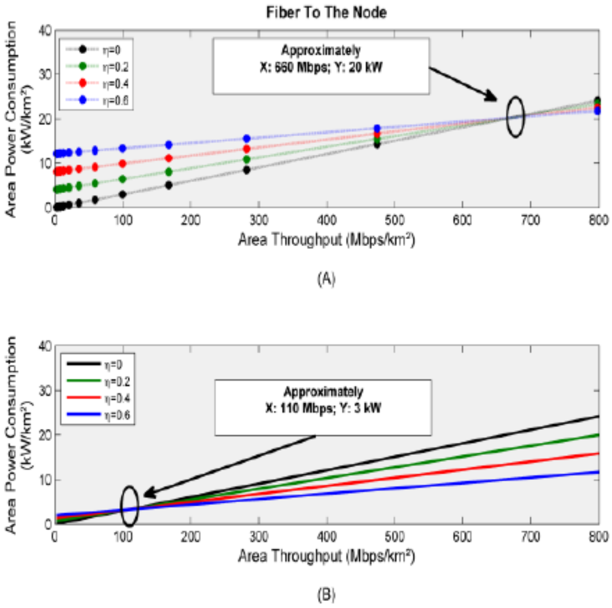

Fig. 2. Area power consumption per throughput for the FTTN case. (A) Using the backhaul architecture planned to provide capacity to conventional femtocell. (B) Using the new backhaul architecture planned to provide capacity to femtoWoC.

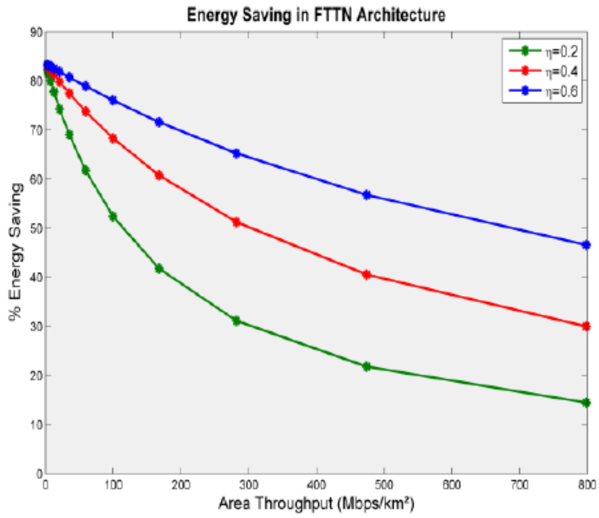

Fig. 3. Energy efficiency achieved by changing convencional femtocell to femtoWoC (FTTB case).

This energy saving is mainly caused by three factors: first, the addition of McBS instead of DSLAMs; second, the VDSL2 modems removal; and third, the lower energy consumption from femtoWoC compared to conventional femtocell.

Fig. 3 presents the savings percentage according to the data traffic increase. In this Figure, it is observed that the use of femtoWoC over conventional femtocell can reduce up to 80% of the overall network energy consumption when the penetration rate is 0.6 and the data traffic is lower than 100 Mbps/km^2. Moreover, in the worst case, when a penetration rate of 0.2 is chosen, the gain can be, approximately, of 50% under 100 Mbps/km^2 and 20% when 800Mbps/Km^2 is requested.

B. Fiber-to-the-Building (FTTB) + Microwave

In Fig. 4(A), it is observed that HetNets are more effective only when the throughput is higher than 520 Mbps/km^2. Whereas, Fig. 4(B) shows that the intersection point goes to approximately 425Mbps/km^2.

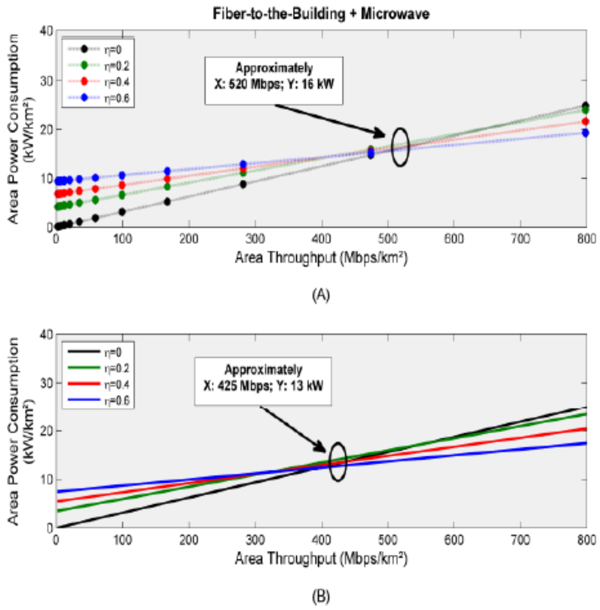

Fig. 4. Area power consumption per throughput for the FTTB case. (A) Using the backhaul architecture planned to provide capacity to conventional femtocell. (B) Using the new backhaul architecture planned to provide capacity to FemtoWoC.

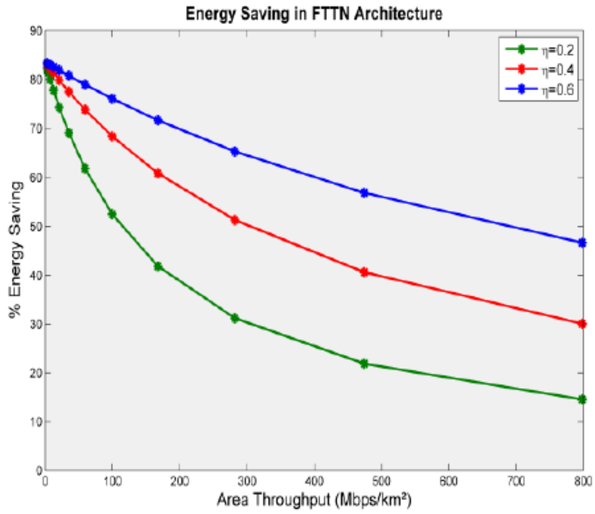

Fig. 5. Energy efficiency achieved by changing convencional femtocell to femtoWoC (FTTB case).

This energy saving is mainly caused by two factors: first, the addition of McBS instead of GES; and, second, the lower energy consumption of femtoWoC compared to conventional femtocell.

Fig. 5 presents the savings percentage according to the data traffic increase. In this case, the use of femtoWoC may decrease the overall network energy consumption in approximately 20% when the data traffic is under 100 Mbps/km^2 and the penetration rate is 0.6. Moreover, in the worst case (i.e., when the penetration rate of 0.2 is chosen), the gain can be, approximately, of 10% under 100 Mbps/km^2 and 5% when 800Mbps/km^2 is requested.

Comparing the FTTN and FTTB cases, it is observed that FTTN using copper-based backhaul for small cells highlights as an effective option in order to provide high broadband capacity for femtoWoC. The main advantage on FTTN instead of FTTB is for the reason that when the equipment is placed outside the building its full capacity can be used, i.e., connecting the equipment in all available ports, whereas in FTTB some ports may not be used due to the maximum length that copper-based backhaul can reach providing the minimum necessary capacity. Another advantage from FTTN is the DSLAMs replacement by McBS. This equipment change prevents the addition of modems, i.e., the femtoWoC connects straight to the McBS, resulting in the energy consumption reduction.

VI. Conclusion

In this paper, two new backhaul alternatives for indoor small cells were presented. Also a comparison between two small cells technologies (conventional femtocell and femtoWoC) was performed. The main goal is energy saving in the overall networks through the use of new backhaul architectures connecting femtoWoC small cells.

Different from the previous work, this paper claims that HetNets using copper-based backhaul can still play an important role specially where copper is already deployed and there is not either fiber nor microwave infrastructure.

In terms of energy-efficiency, it is still interesting to keep copper-based backhaul connected to the last mile (remote node to the end-user). Moreover, it is observed that the equipment replacement, e.g., changing GES to Multi-cell BS may represent energy-efficiency gains.

The introduction of femtoWoC and Multi-Cell BS decreases the overall energy consumption. Moreover, the usage of Multi-Cell BS controlling sets of femtoWoC, i.e, aggregating the processing, enabled the HetNets based on cable to become more economical.

The results demonstrate that copper-based backhaul is still an effective option to provide mobile requested capacity. Different from the previous paper, this work presented HetNets based on copper as more energy-efficient network than homogeneous networks for a large range area throughput, and at the same time it warns that the backhaul architectures must be chosen .

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