On the Impact of Backhaul Network on Distributed Cloud Computing

Jessica Oueis
CEA, LETI
F-38054 Grenoble, France
jessica.oueis@cea.fr

Emilio Calvanese-Strinati
CEA, LETI
F-38054 Grenoble, France
emilio.calvanese-strinati@cea.fr

Antonio De Domenico
CEA, LETI
F-38054 Grenoble, France
antonio.de-domenico@cea.fr

Sergio Barbarossa
Sapienza University of Rome
Roma, Italy
sergio.barbarossa@uniroma1.it

***Abstract*—Nowadays, heterogeneous networks are seen as a key enabler to meet the challenging performance required for the evolution of LTE networks. At the same time, cloud computing is an emerging trend that outsources computing and storage resources, and extends mobile handsets capability of processing large data amounts. Cooperation in heterogeneous networks allows better (improved) network management by reducing power consumption, enhancing network coverage, and reducing deployment and communication costs. Within the cloud paradigm, federating femtocells in clusters not only helps with network management, but also opens the possibility to use these clusters for both communication and computation. Clusters of femtocells with virtual machine hosting capabilities is a novel disruptive paradigm which adds a dimension to cooperative management of heterogeneous networks. However, effective cooperation among geographically neighboring femtocells is prone to backhauling energy costs and delay limitations. In this paper, we propose a framework for evaluating backhauling performance in a femto-cloud architecture, considering several backhaul technologies and topologies. Our simulations explicit the limitations of clustering in femto-cloud imposed by backhauling.**

I. Introduction

Heterogeneous cellular networks are the main candidate solutions to meet the ever increasing data rate requirements of future generations of wireless communications. In such networks, small cells coexist with macrocells in the same geographical area. Due to the reduced distance between base station and end users, signal and service quality are improved. Femtocells were first introduced as a tool to improve network capacity and guarantee better indoor coverage. Today, because of their lower power consumption, they are primarily viewed as a low-cost tool to offload macrocell traffic. Deployment of femtocells is a growing trend in wireless cellular communication. In 2011, the number of deployed femtocells was nearly 3 millions, it is expected to reach 49 millions by 2014 [1].

Another growing trend at the moment, is mobile cloud computing. Mobile computation offloading to the cloud has been attracting attention in recent years especially for its ability to extend the battery life of mobile devices. It provides users access to greater computing power and storage space. Typically, mobile computations are offloaded to the cloud through a wide area network (WAN). However, the interaction latency between mobile users and the cloud is a severe bottleneck since it cannot be easily controlled. In the current revolution of Internet where people and smart objects live connected in smart environments, mobile applications are getting more resource demanding and time critical. The European project TROPIC [2] recently proposed a networking architecture, named as *femto-cloud*, where both trends, femtocells and computation offloading to the cloud, are merged in a single framework. The idea is to form server farms of femtocell access points providing cloud services. In the proposed context, femtocell access points are characterized by computation and storage capacities, and they are referred to as Home cloud enhanced Node B (HceNB). A set of femtocells grouped together plays the role of a cloud. Users will be able to utilize pooled resources at a closer distance, and thus, with smaller latency and power consumption.

Cooperation of femtocells has been already proposed in literature for energy saving and interference management. Introducing discontinuous transmission (DTX) in cooperative open access femtocells limits the network power consumption by adapting the femtocell activity to traffic scenarios [3]. Pantisano et al. have proposed to use interference alignment techniques to mitigate co-channel interference in cooperative femtocell scenarios [4].

In femto-cloud, the cooperation of femtocells through cluster formation merges cooperation for communication and energetic purposes with computation offloading. The cloud network boosts the computational capacity of mobile terminals, and its proximity to users' equipments reduces the end-to-end latency. To enhance the computation and storage capacities of a single femtocell, HceNBs should be backhauled together and able to exchange data. Accordingly, when an application is offloaded to the femto-cloud, one or more HceNBs could contribute in the data processing and computing. In the framework of femto-cloud, the cluster management process, i.e., choosing the cluster size and the set of cooperative HceNBs, depends on multiple constraints such as, latency and power consumption. Another important parameter is the backhaul type through which the HceNBs are connected. Nevertheless, there is a lack of studies that investigate these relationships. With the dependency on several parameters, getting the optimal number of base stations to include in a cluster would request more analysis.

Our goal is to open of a new vision of dynamic optimization of the number and the choice of HceNBs that participate in a femtocell cluster. To this end, we study and evaluate the

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different tradeoffs of base stations clustering in a femto-cloud network. In this paper, we focus on evaluating the backhaul influence on cluster size and characteristics. First, we analyze the cluster performance in terms of latency and power consumption for different computation efforts. Then, we compare through simulation three different backhaul topologies and three different backhaul technologies.

II. System Model

In this paper, we consider a cellular deployment model of hexagonal compartments of radius of 5m. Each cell is assumed to be equipped with a deployed HceNB (see Figure 1). We consider an LTE system with K mobile users and M femtocells. Users are served by a femtocell base station within a distance d. We consider a connection channel of bandwidth B between UE and the serving base station. Instantaneous bit rate is maximized based on adaptive modulation and coding scheme (AMC) [5]. A parameter Γ in the channel model indicates the SNR margin to guarantee the minimum error rate. We adopt a Rayleigh channel model with path loss exponent β, noise power N_0, and fading channel coefficient h_k. We assume perfect estimation of the channel coefficients h_k and the channel fading is assumed constant for a whole transmission period. The maximum information rate that can be achieved through this channel is calculated using the following equation:

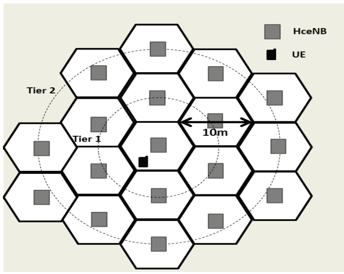

Fig. 1: Cellular deployment of HceNBs.

$$R = Blog(1 + aP_{Tx}) \tag{1}$$

where $a = \frac{|h_k|^2}{\Gamma d^{\beta} N_0}$, B is the channel bandwidth, and P_{Tx} is the transmission power. We consider that user k asks for the computation of an application instruction block of size W to the femtocell it is connected. We assume that the number of bits to be transmitted through uplink and downlink communications is proportional to W: $N_{UL} = W\beta_{UL}$ for uplink and $N_{DL} = W\beta_{DL}$ [6], where the constants β_{UL} and β_{DL} account respectively for the overhead due to the uplink and downlink communications and for the ratio between output and input bits associated to the execution of the instruction block at the HceNB. The uplink and downlink transmission length are expressed respectively as: $\Delta_{UL} = \frac{N_{UL}}{R_{UL}}$ and $\Delta_{DL} = \frac{N_{DL}}{R_{DL}}$, where R_{UL} and R_{DL} are the instant maximum rate that can be achieved in uplink and downlink transmissions, evaluated with Equation 1.

We denote the latency constraint of the application as L_{app}, and the cluster overall latency as $\Delta_{cluster}$. For the application latency to be respected, we should have:

$$L_{app} \geq \Delta_{UL} + \Delta_{cluster} + \Delta_{DL}$$

Finally, the power consumption of the overall process can be formulated as:

$$P = P_{Tx}^{UL} + P_{com} + P_{comp} + P_{Tx}^{DL}$$

where P_{Tx}^{UL} and P_{Tx}^{DL} are, respectively, the radiated power of uplink and downlink transmissions. P_{com} and P_{comp} represent the power consumed in the cluster for communication and computation respectively. In the rest of this paper we aim to model $\Delta_{cluster}$ and P_{com} and their relations with the cluster characteristics such as, size, backhaul topology, and backhaul technology.

III. Latency models

To guarantee an acceptable quality of experience (QoE), applications latency constraints must be respected. In this work, we identify three major latency components: the transmission duration from user equipment (UE) to the connected HceNB, the overall cluster latency due to the data sharing amongst HceNBs of the cluster and computation), and data transmission from the HceNB back to UE. Data transmission between UE and HceNB depends on the channel quality and on the amount of data to be transmitted. The cluster latency depends on both communication and computation latencies. Particularly, data processing latency depends on the number of HceNBs in the cluster, the amount of computing tasks assigned to each one of them, and their computational capacity. Data transport inside the cluster depends on the cluster size, the backhaul topology used to interconnect the base stations, and the backhaul technology.

The number N of femtocells in the cluster should be set in order to satisfy the following constraint:

$$N = \{n \in \mathbb{N} / \Delta_{cluster}(n) \leq L_{app} - \frac{N_{UL}}{R_{UL}} - \frac{N_{DL}}{R_{DL}}\}$$

We now model the cluster latency when using the ring, binary tree, and full mesh topologies (see Figure 2). As for transmission technologies we consider fiber backhaul, microwave backhaul, and over the air (OTA) LTE wireless backhaul. As already discussed, the cluster latency is due to the communication latency between HceNBs and the computation latency at each HceNB. Hence, in the full mesh case, the cluster latency can be written as:

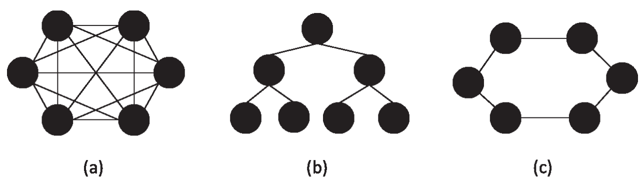

Fig. 2: Wireless backhaul topologies: (a) full mesh topology, (b) tree topology, and (c) ring topology.

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \delta_{Tx,bh}(n) + \delta_{Tx,bh}^{r}(n)) \tag{2}$$

where W_n is the computation task assigned to each base station, f_n its computational capacity, $\delta_{Tx,bh}$ the one way communication latency through the backhaul between the

HceNB connected to the user and other HceNBs, and $\delta^r_{Tx,bh}$ the communication latency for the reverse way.

Considering LTE wireless backhaul, $\delta_{Tx,bh}(n) = \frac{N^n_{in}}{R^n_{in}}$ and $\delta^r_{Tx,bh} = \frac{N^n_{out}}{R^n_{out}}$, where $N^n_{in} = W_n\beta_{UL}$ is the number of bits sent to base station n, and $N^n_{out} = W_n\beta_{DL}$ is the number of bits that base station n should send back. R^n_{in} and R^n_{out} represent the rates of data transmission achieved in downlink and uplink through the channel between base station n and the base station connected to the UE. So, for LTE wireless backhaul, Equation 2 can be rewritten as:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \frac{N^n_{in}}{R^n_{in}} + \frac{N^n_{out}}{R^n_{out}}) \tag{3}$$

For fiber and microwave backhaul, the latency of a transmission is assumed to be load independent because of the high throughput than can be achieved using these technologies. A categorization of non-ideal backhaul latency based on operator inputs can be found in [7]. Therefore, in both cases the total cluster latency can be formulated as the following:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + 2\delta_{Tx,bh}) \tag{4}$$

In the tree topology case, for the data to reach base station n at level l_n, it should be transmitted through l_n base stations (The HceNB connected to the user is considered of level $l = 0$). Therefore, the total cluster latency can be formulated as:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \sum_{l=1}^{l_n} \delta_{Tx,bh}(n) + \sum_{l=1}^{l_n} \delta^r_{Tx,bh}(n))$$

For LTE wireless backhaul, $\delta_{Tx,bh}$ and $\delta^r_{Tx,bh}$ depend respectively on the number of bits to be sent in uplink and downlink, and on the channel capacity at the transmission time.

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \sum_{l=1}^{l_n} \frac{N^n_{in}}{R^l_{in}} + \sum_{l=1}^{l_n} \frac{N^n_{out}}{R^l_{out}}) \tag{5}$$

where R^l_{in} and R^l_{out} are the transmission rates in downlink and uplink at the base station backhauling the traffic at level l.

For fiber and microwave backhaul cases, as the transmission latency is constant, $(\delta_{Tx,bh}(n) = \delta^r_{Tx,bh}(n) = \delta_{Tx,bh}$), the total latency can be represented as:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + 2l_n\delta_{Tx,bh}) \tag{6}$$

In the ring topology case, the total cluster latency can be formulated as:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \sum_{h=1}^{h_n} \delta_{Tx,bh}(n) + \sum_{h=1}^{h_n} \delta^r_{Tx,bh}(n))$$

where h_n is the number of hops needed for HceNB of index n to reach the HceNB connected to UE. Similar to the tree topology case, LTE wireless backhaul latency depends on the data load and channel conditions, and for fiber and microwave backhaul backhaul transmission time is constant. So the equation for LTE wireless can be written as:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + \sum_{h=1}^{h_n} \frac{N^n_{in}}{R^h_{in}} + \sum_{h=1}^{h_n} \frac{N^n_{out}}{R^h_{out}})$$

and for fiber and microwave backhaul:

$$\Delta_{cluster} = \max_{n=1}^{N}(W_n f_n + 2h_n\delta_{Tx,bh}) \tag{7}$$

Given the latency formulas for different backhaul topologies, we can distribute the computational load across the distributed cloud in order to minimize latency. In all previous cases, for any set of computational rates f_n and channel states, the optimization problem can be cast as:

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & \max_{n=1}^{N}(W_n f_n + L_n) \\ \text{subject to:} \quad & \sum_{n=1}^{N} W_n = W \\ & W_n \geq 0 \end{aligned} \tag{8}$$

Where L_n is the delay associated to communications across the computing nodes. Some numerical results comparing the optimal load distribution and the simple equal load distribution will be presented in section V.

IV. Power consumption models

Another important issue in the formation of the HceNBs cluster, is the power consumption. Cloud computing leads to increases in the network traffic, and thus in the power consumption. Power consumption in transport and switching can be a significant percentage of total power consumption in cloud computing [8]. This section presents power consumption models for data transport inside the cluster of HceNBs. The cluster power consumption depends on the number of base stations forming the cluster, the backhaul technology, and topology. All traffic from the base stations is assumed to be backhauled through the HceNB connected to the UE, playing the role of a hub node. In our work, it is assumed that any base station can be a hub node. If more than one backhaul link originates at any HceNB, the base station is assumed to be equipped with a switch. The equations in this section are based on the study done in [9]. The equations below assume that the backhaul topologies are height balanced (formed with the lowest possible level depth).

For LTE wireless backhaul transmissions between base stations, the total power consumption is expressed as [10]:

$$P = \sum_{n=1}^{N} \sum_{j=1}^{N^n_{ant}} (P_0 + \Delta p P^{n,j}_{Tx})$$

In this equation, N^n_{ant} is the number of active antennas at HceNB n, P_0 the base station power consumption at zero load, Δp is the slope of the load-dependent power consumption, and $P^{n,j}_{Tx}$ the transmission power used to transmit at base station n through antenna j.

Considering constant transmission power P_{Tx} for all base stations, the total power consumption for the different types of backhaul topology can be modeled as the following:

Full mesh topology: The base station connected to UE will transmit to all the $N-1$ base stations in the cluster, that will transmit back once computing tasks are accomplished. Then, the total number of transmissions in this case is $2(N-1)$, and the power consumption can be formulated as:

$$P = 2(N-1)(P_0 + \Delta p P_{Tx})$$

Tree topology: The number of base stations that will transmit through two antennas to two different base stations is

$\lfloor\frac{N-1}{2}\rfloor$, and thus, the number of base stations that will transmit through only one antenna is $(N-1)-2\lfloor\frac{N-1}{2}\rfloor$, which is equal to 1 if N is even and 0 if odd. All $(N-1)$ base stations transmit back when computing tasks are accomplished. Therefore, the total power consumption is expressed as:

$$P = \begin{cases} (2\lfloor\frac{N-1}{2}\rfloor + N)(P_0 + \Delta p P_{Tx}), & \text{if } N \text{ is odd} \\ (2\lfloor\frac{N-1}{2}\rfloor + N - 1)(P_0 + \Delta p P_{Tx}), & \text{if } N \text{ is even} \end{cases}$$

Ring topology: Only the base station connected to the user will transmit through two antennas to two different base stations. In addition, $N-1$ base stations will transmit back after accomplishing computing tasks. The total number of transmissions in this case is $2(N-1)$, and the total cluster power consumption is:

$$P = 2(N-1)(P_0 + \Delta p P_{Tx})$$

For fiber backhaul, the communication power consumption in the small cell cluster is formulated as:

$$P = N_{UL}P_{UL} + N_{DL}P_{DL} + \sum_{n=1}^{N} N_s^n P_s$$

with $N_s^n = \begin{cases} 0 & \text{if } N_{ant}^n = 1; \\ \lceil \frac{N_{ant}^n}{max_{dl}} \rceil & \text{otherwise} \end{cases}$

where N_s^n is the number of switches needed at base station n and max_{dl} is the maximum number of interfaces available at one switch. For the different types of backhaul topology considered here, the total power consumption can be modeled as:

Full mesh topology:

$$P = (N-1)(P_{DL} + P_{UL}) + \lceil \frac{N}{max_{dl}} \rceil P_s \tag{9}$$

Tree topology:

$$P = (N-1)(P_{DL} + P_{UL}) + \lfloor \frac{N-1}{2} \rfloor \lceil \frac{2}{max_{dl}} \rceil P_s \tag{10}$$

Ring topology:

$$P = (N-1)(P_{DL} + P_{UL}) + \lceil \frac{2}{max_{dl}} \rceil P_s \tag{11}$$

For microwave backhaul, the communication power consumption in the small cell cluster is formulated as [9]:

$$P = \sum_{n=1}^{N} \sum_{j=1}^{N_{ant}^n} (P_{agg}^{n,j}(C_{n,j}) + P_{ss}^n) \tag{12}$$

$$P_{agg}^{n,j}(C_{n,j}) = \begin{cases} P_{low-c}, & \text{if } C_{n,j} \leq Th_{low-c} \\ P_{high-c}, & \text{otherwise} \end{cases}$$

$$P_{ss}^n = \begin{cases} 0, & \text{if } N_{ant}^n = 1 \\ P_s \lceil \frac{C_{n,j}}{C_{switch}^{MAX}} \rceil, & \text{otherwise} \end{cases}$$

Where $P_{agg}^{n,j}$ is the power consumption for transmitting and receiving the aggregate backhaul traffic through base station n via antenna j. This power consumption is modulated as a two steps function that depends on whether the backhauled capacity traffic through the same antenna ($C_{n,j}$) is low or high. The capacity traffic is considered as high if it exceeds a defined threshold (Th_{low-c}), and considered as low otherwise. P_{ss}^n is the function that accounts the necessary switch power consumption that depends on the backhauled capacity and the maximum capacity of a switch (C_{switch}^{MAX}).

V. Numerical Evaluation

In this section we evaluate the backhaul cluster latency and communication power consumption, using the models proposed in Sections III and IV. Our evaluations compare latency and power consumption for the different considered backhaul technologies and topologies, in function of the cluster size. We adopt the same system model described in Section II, considering a single user ($K = 1$) at the cell edge of its serving base station. All M HceNBs are assumed to have the same computing capacity $f^{-1} = 2.10^7$ instructions/sec. We assume that the total number of instructions is equally distributed on the cluster HceNBs. Tables I,II, and III resume the parameters used for LTE wireless, fiber, and microwave backhaul respectively. As assumed in section IV, backhaul

B [MHz]	β	N_0	T_c[s]	$P_{Tx}[W]$	P_0[W]	Δ_p
20	5	10^{-3}	1	1	6.8	4

TABLE I: LTE wireless backhaul parameters[10] [11].

$\delta_{Tx,bh}$[ms]	P_{DL}[W]	P_{UL}[W]	P_s[W]	max_{dl}
5	2	1	300	12

TABLE II: Fiber backhaul parameters [7][9].

$\delta_{Tx,bh}$ [ms]	P_{low-c} [W]	P_{high-c} [W]	Th_{low-c} [Mbps]	P_{ss} [W]	C_{switch}^{MAX} [Gbps]
15	37	37	500	53	36

TABLE III: Microwave backhaul parameters [7][9].

topologies are assumed to be balanced. For the whole mesh topology, we assume that a cluster of N is formed with the HceNB connected to the UE and the $N-1$ closest HceNBs. We consider three different sizes of application instruction blocks W corresponding to 1MB, 50MB, and 100MB traffic, representing low, medium, and high traffic load scenarios.

A. Cluster latency comparisons

As already shown in Equation 3, the cluster latency for the LTE wireless backhaul depends on the traffic load. In both tree and ring topology, the cluster latency for wireless LTE backhaul will be greater than the full mesh case. In fact, not every HceNB is reachable via a direct link, and thus, cluster HceNBs will have to backhaul traffic for farther base stations which increases the overall cluster latency. For lack of space, we show simulation results on the effect of traffic load on cluster latency only for a full mesh topology (Figure 3). As the assumption in our simulations is to always form the cluster with the closest HceNBs to the UE, the cluster latency will be subject to a brutal increase with the increase of cluster radius (distance between the HceNB connected to the user and the farthest HceNB in the cluster).We notice that for low load scenarios, including more HceNBs in the cluster will not have an effect on the latency since the computation time with only one HceNB is already low. However, for higher load scenarios, including more HceNBs in the femtocell cluster will decrease the overall latency since the tasks are distributed on different computing entities.

In the cases of fiber and microwave backhaul, as can be seen in Equations 4, 6, and 7, the cluster communication latency

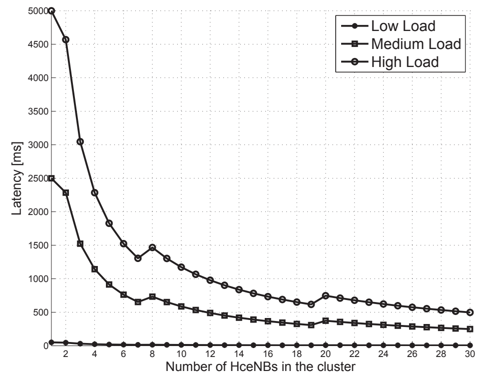

Fig. 3: Wireless LTE full mesh backhaul cluster latency for different traffic loads.

does not depend on the traffic load. The load will only have an effect on the computation latency in the cluster through $W_n f_n$.

Figure 4 shows cluster latency for medium traffic load for different backhaul topologies and technologies. As can be seen, wireless LTE backhaul is the most time costly for lower cluster sizes. Full mesh is the topology less time consuming for both fiber and microwave backhaul, followed by tree and then ring topologies. As the tree and ring topologies are assumed height balanced, we can see a step when a level is added to the topology (every 2 HceNBs for ring topology, every 2^n for tree topology). We notice that we always gain in latency for a cluster of size N over a cluster of size $N-1$ when the addition of the N's base station does not increase the cluster radius. However, adding too much base stations can result in more time consuming as can be seen for the fiber ring backhaul. In fact, when the number of base stations increases, the task computation delays at each base HceNB decrease. When computing delay becomes less than the transmission time between two HceNBs, the addition of new base stations to the cluster will increase the total latency.

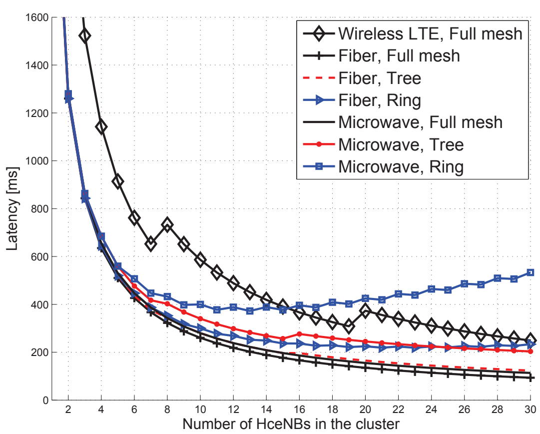

Fig. 4: Cluster backhaul latency for different backhaul technologies and topologies for medium traffic load.

Figure 5 compares between the adopted assumption of equal load distribution and the optimal load distribution among cluster base stations for full mesh wireless LTE and tree fiber backhaul. Same kind of results goes for other technologies and topologies. We notice that the optimal load distribution is optimal for the fiber tree backhaul, and can outperform equal load distribution in the case of wireless LTE backhaul. This is due to the fact that in the latter case the transmission latency is highly affected by the distance. The Major difference of performance is noticed when the cluster radius changes, elsewhere, it is close to the full performance. In particular, it reaches 27.5% for 2 HceNBs, and 24.8% for 8 HceNBs.

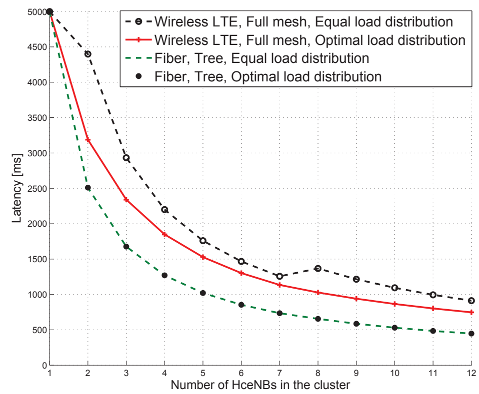

Fig. 5: Equal load and optimal distribution comparison.

B. Cluster communication power consumption comparisons

The cluster communication power consumption for the wireless LTE backhaul depends on the transmission power P_{Tx}. If this transmission power is kept constant, as in our simulations, traffic transport power consumption will be a linear function of the number of HceNBs in the cluster, however, it will consume more time as seen in V-A.

For the microwave backhaul, the communication power consumption depends on the traffic load through Equation 12. For this reason, a full mesh topology in this case would be the most interesting. Indeed, a previous study on microwave backhaul power consumption in [9] shows that the ring topology is the most costly in terms of power, followed by the tree topology. Figure 6 shows the variation of power in function of the number of base stations. In the case of low traffic load the HceNBs are always operating in the low consumption regime (P_{low-c}) and the total consumption is a linear function of the number of HceNBs in the cluster. In the case of high and medium traffic loads, we notice that the power consumption is reduced when the cluster size exceeds the values of 9 and 19 HceNBs. This is due to the fact that the traffic backhauled through each base station decreases with the increase of the cluster size. And at a certain point, the traffic backhauled through each base station gets lower than $Th_{low,c}$, and thus, the base stations switch from operating at a higher power consumption P_{high-c} to a lower power consumption P_{low-c}.

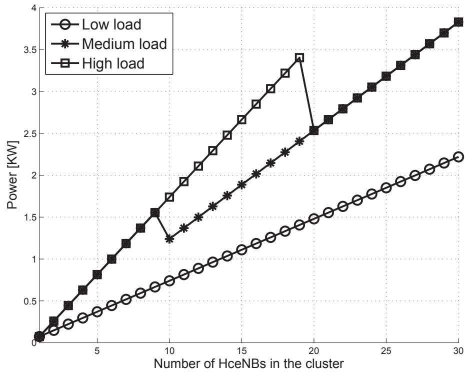

Fig. 6: Microwave backhaul traffic power consumption for different traffic loads.

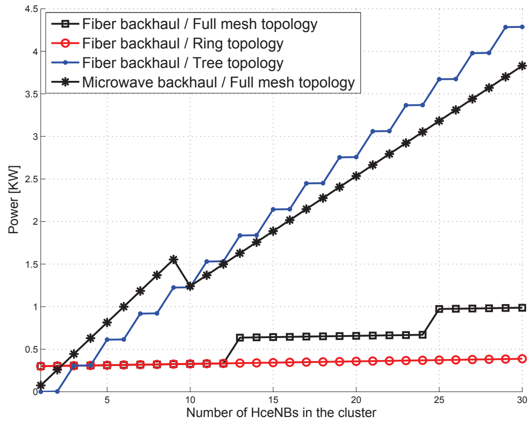

Fig. 7: Cluster backhaul power consumption for different backhaul topologies and technologies.

In the case of fiber backhaul, the communication power consumption in the cluster does not depend on the traffic load. As shown in Equations 9, 10, and 11 it depends on the number of HceNBs in the cluster. Figure 7 shows the power consumption for the three topologies for fiber backhaul, and for the full mesh topology for microwave backhaul. It can be seen that fiber backhaul consumes less power than microwave backhaul in a full mesh topology. Fiber backhaul power consumption for a full mesh topology increases by a step each max_{dl} base stations, because an extra switch is needed. Ring topology is the less consuming since it requires the least number of switches which consumes the major part of the total power consumption. For the tree topology, at each addition of two base stations an additional switch is needed. For this reason, it is the most power consuming.

A comparison of different backhaul technologies characteristics are summarized in table IV.

Criterion	**Wireless LTE**	**Fiber**	**Microwave**
Load dependent latency	Yes	No	No
Load dependent power consumption	Yes	No	Yes
Topology with lowest latency	Full mesh	Full mesh	Full mesh
Topology with lowest power consumption	Full mesh	Ring	Full mesh
Latency classification	⋆	⋆⋆⋆	⋆⋆
Power consumption classification	⋆	⋆⋆⋆	⋆⋆

TABLE IV: Comparison of backhaul technologies.
(⋆⋆⋆-the best,⋆-the worst)

VI. Conclusion

This paper presents a study and an evaluation framework of the impact of backhaul network on cooperative cluster of small cells. Three backhaul technologies (Wireless LTE, fiber and microwave) and three backhaul technologies (full mesh, tree, and ring) are considered. The presented results give a preliminary vision on the small cell cluster backhaul that has not been given much attention in the paradigm of small cell clustering. This paper presents a new lead in this paradigm that allows to consider backhaul latency and backhaul power consumption as important issues in the clustering process. As future work, we intend to analyze more characteristics that may affect the backhaul technology and topology choice such as deployment cost and coverage capacity. Furthermore, we will study other important issues that affects the choice of the cluster base stations in order to develop a framework for dynamic cluster optimization in femtocloud.

VII. Acknowledgment

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