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Energy performance of 5G backhaul wireless network utilizing hybrid centric-distributed architecture

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ABSTRACT

This paper scrutinizes the influence of deployment scenarios on the energy performance of fifth-generation (5G) network at various backhaul wireless frequency bands. An innovative network architecture, the hybrid centric-distributed, is employed and its energy efficiency (EE) model is analyzed. The obtained results confirm that the EE of the 5G network increases with an increasing number of small cells and degrades with an increasing frequency of wireless backhaul and radius of small cells regardless of the network architectures. Moreover, the hybrid centric-distributed architecture augments the EE when compared with the distributed architecture.

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1. INTRODUCTION

The energy performance of devices part is an important aspect in wireless communications. Whereas smart-phone devices have an extended battery capacity up to 2716 mAh for the iPhone X with wireless and fast charging features [1], the need for high energy performance in the network side has emerged as another significant aspect [2-4]. Particularly, in fifth-generation (5G) networks, the current major concern is the green communications without making a tradeoff with other performance metrics like spectrum efficiency (SE) and latency [5-14]. Millimeter wave (mm-wave) solution is adopted in concentrated-coverage base stations (BSs) for loading the massive backhaul traffic [15-19]. Nonetheless, it is a significant contribution to realize such traffic load in a low energy consumption way [20]. Therefore, enhancing energy efficiency (EE) of 5G networks has become a subject of great interest to academics and industries.

In [21], the EE of small cell backhaul networks has been discussed. In addition, the significance of EE in 5G backhaul wireless networks has been explored in [22], and a functional split solution has been briefly outlined to achieve an expected EE improvement. Further, the EE of mm-wave backhaul is estimated for various spectral bands in [23]. Furthermore, the backhaul throughput and EE of 5G backhaul wireless networks have been evaluated in [24], and the outcomes revealed that the distributed architecture using mm-wave and massive multiple-input multi-output antennas techniques performs better than the centric architecture. Thus, it is worth mentioning that the investigation of the energy performance of hybrid centric-distributed approach will indeed be significant to compare it with the distributed architecture.

The overall framework of the paper is systematized as follows: Section 2 introduces the hybrid centric-distributed network architecture. The derivation of EE model is presented in Section 3, which is then used to assess the energy performance in Section 4. Finally, Section 5 includes the conclusion.

2. NETWORK ARCHITECTURE

The network architecture of hybrid centric-distributed solution is illustrated in Figure 1. Several assumptions are considered as follows:

a) A macrocell base station (MBS) is placed at the center among clusters.
b) The small cell base stations (SBSs) are being homogeneously distributed in a cluster with a similar power of transmission, coverage, SE, and bandwidth.
c) The overhead traffic formed 10 % of user's traffic at S1 interface, which is used to link the specified SBS at each cluster with the MBS.
d) The handoff traffic formed 4 % of user's traffic at X2 interface, which is used for linking SBSs together.
e) Each cluster consists of an equal number of small cells.

A mixture of wireless and wired backhaul is utilized here to make a compromise between implementation cost and complexity. The wireless backhauling is represented by traffic transfer from adjacent SBSs to MBS through a specified SBS by mm-wave links. The MBS forwards the traffic via fiber to core network.

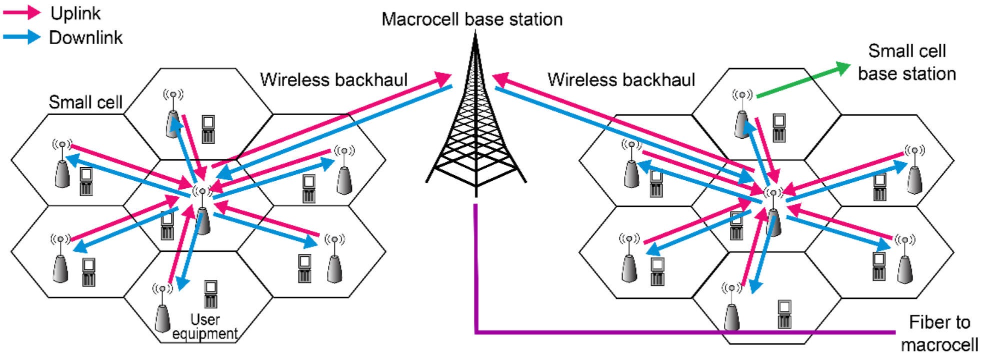

Figure 1. Hybrid centric-distributed architecture

3. ENERGY EFFICIENCY MODEL

Here, we have presented the EE analysis based on the architecture shown in Figure 1 following the same procedure as in [24].

The SE of a cluster $S_{cluster}$ can be demonstrated as:

$$S_{cluster} = (K-1)S_{sc} \tag{1}$$

where K represents the number of small cells in the cluster and S_{sc} represents the SE of each small cell.

The uplink throughput of cluster $TH_{cluster}^{up}$ can be written as:

$$TH_{cluster}^{up} = 1.14KB_{sc}S_{sc} \tag{2}$$

where B_{sc} is the bandwidth of the small cell.

The downlink throughput of a cluster $TH_{cluster}^{down}$ will be given by:

$$TH_{cluster}^{down} = 1.14KB_{sc}(S_{sc} + S_{cluster}) \tag{3}$$

using (1) – (3), the total throughput of a cluster can be derived as:

$$\begin{aligned} TH_{cluster}^{total} &= TH_{cluster}^{up} + TH_{cluster}^{down} \\ &= 1.14KB_{sc}S_{sc} + 1.14KB_{sc}(S_{sc} + S_{cluster}) \\ &= 1.14KB_{sc}S_{sc} + 1.14KB_{sc}(S_{sc} + (K-1)S_{sc}) \\ &= 1.14KB_{sc}S_{sc} + 1.14KB_{sc}S_{sc}(1 + (K-1)) \\ &= 1.14K(K+1)B_{sc}S_{sc} \end{aligned} \tag{4}$$

For a group of clusters, the total backhaul throughput becomes:

$$TH_{clusters}^{total} = 1.14NK(K+1)B_{sc}S_{sc} \tag{5}$$

where N represents the number of clusters.

Hence, the uplink throughput of a macrocell TH_{mc}^{up} can be expressed as:

$$TH_{mc}^{up} = 0.04B_{mc}S_{mc} \tag{6}$$

where B_{mc} represents the bandwidth of a macrocell and S_{mc} represents the SE of a macrocell.

The downlink throughput of a macrocell TH_{mc}^{down} will be given by:

$$TH_{mc}^{down} = 1.14B_{mc}S_{mc} \tag{7}$$

therefore, the total backhaul throughput of a macrocell is equivalent to:

$$\begin{aligned} TH_{mc}^{total} &= TH_{mc}^{up} + TH_{mc}^{down} \\ &= 0.04B_{mc}S_{mc} + 1.14B_{mc}S_{mc} \\ &= 1.18B_{mc}S_{mc} \end{aligned} \tag{8}$$

From (5) and (8), the total backhaul throughput of the hybrid centric-distributed architecture is:

$$\begin{aligned} TH_{system}^{total} &= TH_{clusters}^{total} + TH_{mc}^{total} \\ &= 1.14NK(K+1)B_{sc}S_{sc} + 1.18B_{mc}S_{mc} \end{aligned} \tag{9}$$

In 5G backhaul wireless networks, both embodied energy and operating energy are accounted in the EE analysis [25].

The embodied energy of macrocell E_{mc}^{EM} includes the maintenance energy $E_{mc}^{ma\,int}$ and the initial energy E_{mc}^{ini}, is

$$E_{mc}^{EM} = E_{mc}^{ma\,int} + E_{mc}^{ini} \tag{10}$$

The embodied energy of cluster $E_{cluster}^{EM}$ is assumed to be 20 % of its total energy consumption.

The operating energy of macrocell E_{mc}^{OP} is given by

$$E_{mc}^{OP} = P_{mc}^{OP}T_{mc}^{lifetime} \tag{11}$$

where P_{mc}^{OP} and $T_{mc}^{lifetime}$ is the MBS operating power and lifetime, respectively.

The oprating power of MBS P_{mc}^{OP} is demonstrated as

$$P_{mc}^{OP} = a_{mc}P_{mc}^{TX} + b_{mc} \tag{12}$$

where P_{mc}^{TX} is the MBS transmission power.

The operating energy of cooperative cluster $E_{cluster}^{OP}$ is written as

$$E_{cluster}^{OP} = KP_{sc}^{OP}T_{sc}^{lifetime} \tag{13}$$

where P_{sc}^{OP} and $T_{sc}^{lifetime}$ denote the operating power and lifetime for SBS, respectively.

The operating power of SBS P_{sc}^{OP} can be written as

$$\begin{aligned} P_{sc}^{OP} &= a_{sc} P_{sc}^{TX} + b_{sc} \\ &= a_{sc} P_{sc}^{O} (r / r_o)^{\alpha} + b_{sc} \end{aligned} \tag{14}$$

where P_{sc}^{TX} is the SBS transmission power, P_{sc}^{O} is the SBS normalized transmission power with normalized coverage radius r_o, r is the radius of coverage, and α is the path loss coefficient.

The total energy consumption E_{system}^{total} is demonstrated as

$$\begin{aligned} E_{system}^{total} &= E_{cluster}^{EM} + E_{cluster}^{OP} + E_{mc}^{EM} + E_{mc}^{OP} \\ &= 1.25 K P_{sc}^{OP} T_{sc}^{lifetime} + E_{mc}^{maint} + E_{mc}^{ini} + P_{mc}^{OP} T_{mc}^{lifetime} \end{aligned} \tag{15}$$

Finally, the EE of the hybrid centric-distributed architecture is given by

$$EE_{system}^{total} = \frac{TH_{system}^{total}}{E_{system}^{total}} \tag{16}$$

4. RESULTS AND DISCUSSION

This section presents the results of EE performance of hybrid centric-distributed architecture in comparison to the distributed architecture by utilizing MATLAB software. The parameters listed in Table 1 are used in the mathematical calculation.

Table 1. Parameters Used in Calculated Analysis

Symbol	Backhaul wireless frequency bands		
	5.8 GHz	28 GHz	60 GHz
a_{mc}	21.45	21.45	21.45
b_{mc}	354 W	354 W	354 W
B_{mc}	100 Mb/s	100 Mb/s	100 Mb/s
S_{mc}	10 b/s/Hz	10 b/s/Hz	10 b/s/Hz
E_{mc}^{maint}	10 GJ	10 GJ	10 GJ
E_{mc}^{ini}	75 GJ	75 GJ	75 GJ
$T_{mc}^{lifetime}$	10 years	10 years	10 years
B_{sc}	100 Mb/s	100 Mb/s	100 Mb/s
S_{sc}	20 b/s/Hz	20 b/s/Hz	20 b/s/Hz
a_{sc}	7.84	7.84	7.84
b_{sc}	71 W	71 W	71 W
P_{sc}^{TX} (radius is 50 m)	6.3 mW	147 mW	675 mW
P_{sc}^{OP} (radius is 50 m)	71 W	72 W	76 W
$T_{sc}^{lifetime}$	5 years	5 years	5 years

Figure 2 plots the EE against number of small cells for five clusters of 5G backhaul wireless networks at different frequency bands and deployment scenarios. The MBS transmission power is fixed to 40 W with radius of coverage equals is equals to 1 km. It can be obviously seen that the hybrid centric-distributed architecture provides a higher EE than the distributed architecture for all frequency bands. Another interesting observation from Figure 2 is that when the number of small cells is constant, the EE performance degrades with an increasing frequency of wireless backhaul. Additionally, the increase in the number of small cells increases dramatically the EE of 5G backhaul wireless networks since the total throughput is increased.

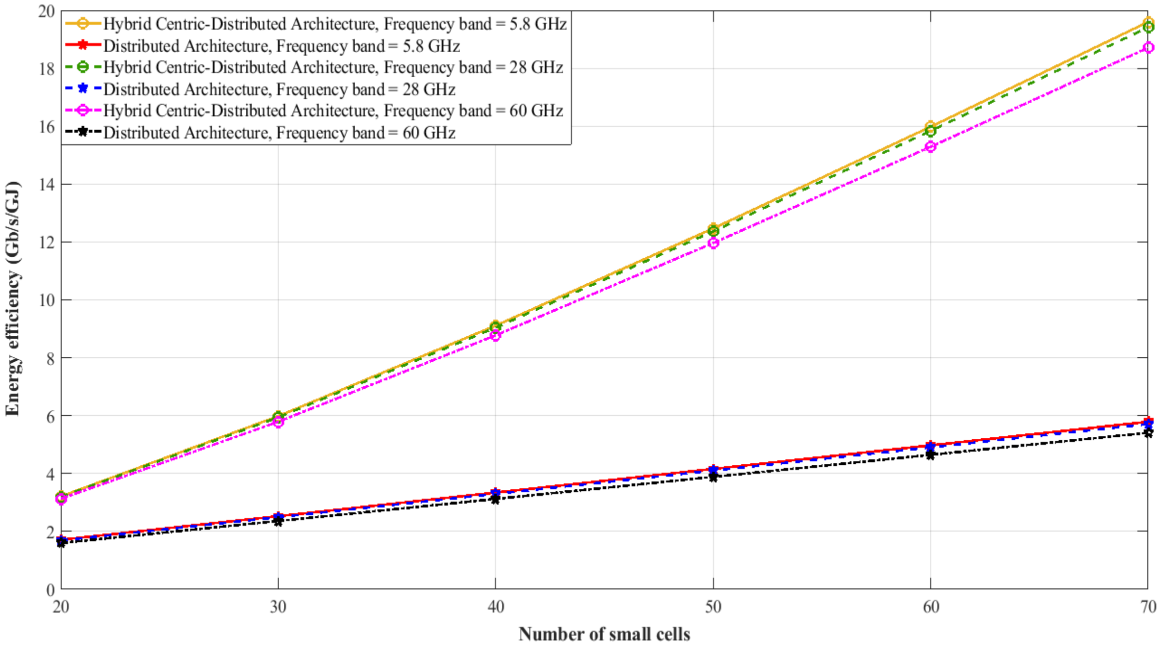

Figure 2. EE versus number of small cells considering various frequency bands

Figure 3 shows the variation in EE with radius of small cells considering various path loss coefficients. The number of small cells is fixed to 30. It is observed that the EE slightly increases with an increasing path loss coefficient when radius of small cells is less than or equal to 50 m. This is because the influence of attenuation on the wireless capacity is less when the path loss coefficient is increased. However, the EE degrades with an increasing path loss coefficient when radius of small cells is greater than 50 m due to the increased impact of attenuation on the wireless capacity when the path loss coefficient is increased. For similar path loss coefficient and radius of small cells, the hybrid centric-distributed architecture provides better EE than the distributed architecture.

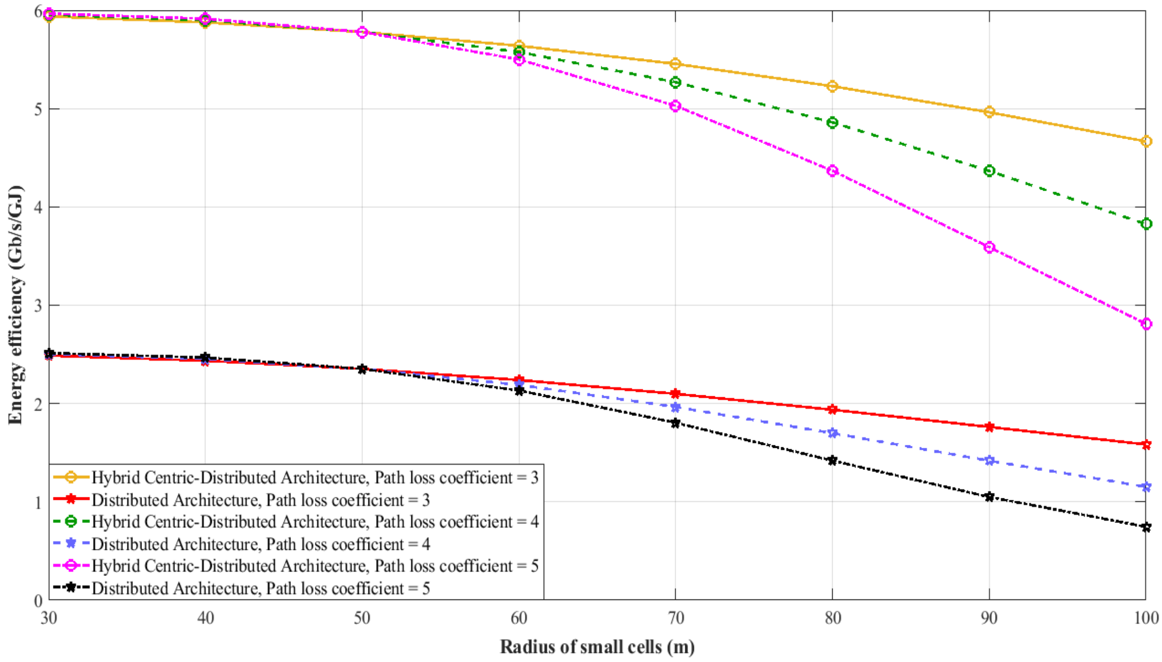

Figure 3. EE against radius of small cells considering various path loss coefficients

5. CONCLUSION

In this work, we focused on a recent subject in communications engineering i.e. 5G backhaul wireless networks. The presented enhancement by the proposed hybrid centric-distributed scheme optimize the energy consumption. Furthermore, it has been shown that the EE is strongly influenced by several factors, such as number of small cells, frequency of wireless backhaul, path loss coefficient, radius of small cells, as well as network architecture.

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