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Analyse de l'efficacité énergétique de JT-CoMP dans les réseaux cellulaires macro/femto

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Dans ce papier, nous avons développé un modèle analytique et simple de l'efficacité énergétique d'un réseau cellulaire dense avec JT-CoMP, en utilisant la modélisation fluide spatiale. Le modèle proposé considère l'impact d'une densité de BSs et tient compte des différents facteurs de puissances associés à JT-CoMP. Les résultats des simulations montrent que le modèle est précis en comparaison avec les résultats de simulation Monté Carlo. L'efficacité énergétique s'améliore en augmentant le nombre de BS en coopération, lorsque la puissance liée au partage des données entre les BSs est constante, mais aussi variable, fonction de la charge du trafic partagé entre les BSs en coopération. Aussi, JT-CoMP est plus efficace dans les réseaux femto (petite cellule) par rapport aux réseaux macro traditionnels, et pourrait donc bien répondre aux besoins des scénarios d'applications spécifiés dans la 5G.

Mots-clés : Energy Efficiency, Spatial fluid modeling, macro/femtocell networks, JT-CoMP

1 Introduction

The energy efficiency (denoted EE), considered as one of the key performance indicators in 5G network, has been attracted much interest in the recent years. Most of advanced techniques launched for Advanced-4G are exploited to improve EE for future 5G networks. Joint Transmission Coordinated Multipoint (JT-CoMP) is a promising technique to improve the network bit rate and fulfill upcoming communication demands [KC17], especially for user equipments (UEs) at the edge. In JT-CoMP technique, data is transmitted to a UE from different BSs simultaneously, to improve the received signal quality. It enhances spectral efficiency by transforming destructive interference into useful one. However, JT-CoMP in practice also brings additional energy cost for sharing data over the backhaul network. Therefore, it is interesting to investigate the EE improvement and to analyse the impact of the backhauling power cost.

In this work, we use the spatial fluid modeling [KCG10] to develop a tractable model of EE of a cellular network with JT-CoMP. We combine our previous work on EE modeling in [HZV18] and on SINR enhancement using JT-CoMP [ZCC⁺16]. We first extend the model in [ZCC⁺16] to compute the total data rate over a network area. Then, we derive the closed-form expression of EE for the JT-CoMP downlink transmission. The effectiveness and the accuracy of the underlying model are presented for both macrocell and femtocell networks, by comparing the results to those of Monte Carlo simulations while considering several path-loss exponents, constant and variable backhauling power cost and varying the number of cooperating BSs.

In the following, the system model is introduced in the section 2, including the definition of the energy efficiency metric and the data rate computation model. Thereafter, a brief recall of the SIR (signal-to-interference ratio) based on the fluid modeling is given when JT-CoMP is applied. The simulation parameters and numerical results are presented in section 3. Finally, we conclude the paper in section 4.

2 System Model

We describe the EE model when JT-CoMP is used within closest BSs, i.e. those belonging to the first ring as shown in Fig.1 (a). The system concerns an OFDMA cellular network, composed of N_{BS} base stations (BSs) and N_u user equipments (UEs) randomly distributed. M_{co} BSs are able to joint transmit data, to improve the signal

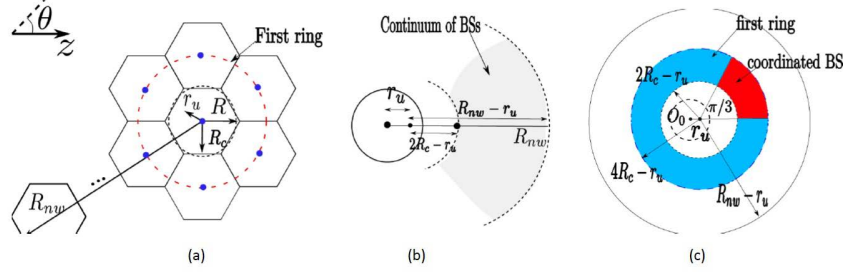

 FIGURE 1: (a). Hexagonal network. (b). Interference area in fluid model. (c). fluid model only one coordinated BS ($n = 1$).

TABLE 1: Value of double linear PCM [HIT12]

| Parameters | $P_{Lx}(W)$ | Δ_P | P_0 | P_1 |
|------------|-------------|------------|-------|-------|
| macro BSs | 80 | 7.25 | 244 | 255 |
| femto BSs | 0.25 | 4.4 | 6.1 | 2.6 |

quality at the UE located at the distance r_u from its serving BS (the central cell in Fig.1 (a)). The network is supposed homogeneous, such that the transmission power P_{Lx} is the same for every BS.

2.1 Energy efficiency expression

We use the common definition of EE such as the ratio of total data rate over a network area D_{area} , to the total power consumption Eq. (1) as in [ZZAL16, PHB17] :

$$EE = \frac{D_{area}}{M_{co} \times P_{exp}^{CoMP} + (N_{BS} - M_{co}) \times P_{exp}}. \quad (1)$$

P_{exp}^{CoMP} and P_{exp} are respectively the total energy expenditure per coordinated BS and per BS respectively. The power consumption of a coordinated BS, $P_{exp}^{CoMP} = N_{ant}(\Delta_P P_{Lx} + P_0) + P_1 + K_{CoMP}$, depends on the antennas number N_{ant} , the transmitting power P_{Lx} and the backhauling power cost K_{CoMP} . P_1 , Δ_P and P_0 account for the direct/alternating current (DC/AC) converter, and some circuit power consumption as in Table. 1.

K_{CoMP} can be a constant for simplification, or proportional to the backhaul requirement C_{bh} as in [FMF10] :

$$K_{CoMP} = \frac{P_{bh}^0 C_{bh}}{C_{bh}^0} = \alpha_{bh} C_{bh}, \quad (2)$$

P_{bh}^0 is the backhauling power when supporting the maximum data rate C_{bh}^0 . $\alpha_{bh} = P_{bh}^0 / C_{bh}^0$ is the power coefficient of backhaul equipment, and C_{bh} is the backhaul traffic for every BS. $\alpha_{bh} = 5 \times 10^{-7} \text{ Joules/bit}$ for a macro BS and $\alpha_{bh} = 4 \times 10^{-8} \text{ Joules/bit}$ for a femto BS [LY16]. Obviously, without JT-CoMP, the BS power consumption is as P_{exp}^{CoMP} without the K_{CoMP} part.

2.2 Total data rate D_{area}

The fluid paradigm assumes a continuum number of transmitters over the network [KCG10]. Therefore, the neighbors interfering power is supposed as a continuum field, the shaded area in Fig. 1 (b), over rings with radii $2R_c - r_u$ and $R_{nw} - r_u$, respectively, and centered at the user's position. R_{nw} is the network radius, R_c is the half distance between two BSs.

Neglecting noise, a UE u at the distance r_u from its serving BS b , and receiving data from the coordinated BSs as shown in Fig. 1 (a), experiences an enhanced signal quality, Γ_u^{CoMP} as

$$\Gamma_u^{CoMP} = \frac{p_{u,b} + p_{u,CoMP}}{p_{u,ext} - p_{u,CoMP}}. \quad (3)$$

$p_{u,b}$ and $p_{u,CoMP}$ denote the received powers at u from the serving BS and the coordinated BSs, respectively. $p_{u,ext}$ is the sum of received interference power.

There are n BSs, $n = \{1, \dots, 6\}$ (Fig.1 (a)), in the first ring to jointly transmit data with the central BS. The fluid-based expression of $p_{u,CoMP}$ over the cooperation area limited between $[2R_c - r_u, 4R_c - r_u]$ and $[0, \frac{n\pi}{3}]$ (Fig.1 (c)), is computed as $p_{u,CoMP} = \frac{n\pi}{3} \frac{\rho_{BS} P_{tx}^A}{\eta - 2} [(2R_c - r_u)^{2-\eta} - (4R_c - r_u)^{2-\eta}]$ (see [ZCC⁺16] for details).

According to Shannon's formula, the maximum theoretical achievable data rate $D_u(r)$ can be computed as $D_u(r) = B_u \times \log_2(1 + \Gamma_u^{CoMP}(r))$, where B_u is the UE's bandwidth. Hence, the total data rate D_{area} over a network area of radius R_a , can be computed as :

$$D_{area} = \frac{B\pi}{\sqrt{3}R_c^2} \int_0^{R_a} r \log_2(1 + \Gamma_u^{CoMP}(r)) dr. \quad (4)$$

When $R_a = R_e$, the above equation is evolved to compute the total data rate over the cell, D_{cell}^{CoMP} .

3 Simulation and Results

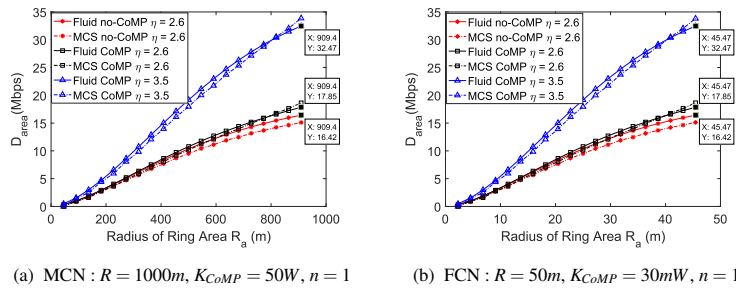
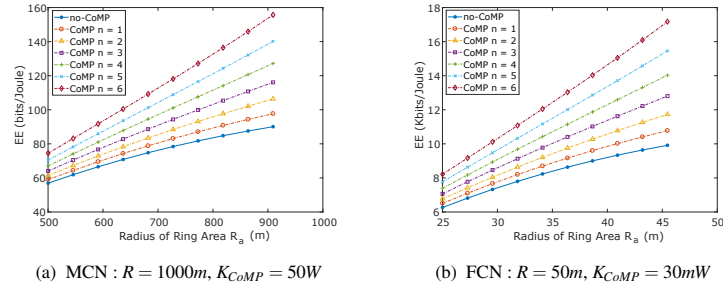


FIGURE 2: D_{area} vs radius of the network

Two main purposes are exposed here : 1) the accuracy of the EE expression proposed earlier regarding Monte Carlo (MC) simulations of a hexagonal network. 2) the impact of the coordinated BSs number on EE improvement as well as the backhauling power consumption. For MC simulations, we consider 7 rings of hexagonal cells around a central hexagon such that $R_{nw} = 15R_c$. N_u UEs are generated uniformly and attached to the BS located at the center. We compute Γ_u (without JT-CoMP), Γ_u^{CoMP} (in case of JT-CoMP), for each UE, then sum the achievable data rate for all the UEs depending on $D_u = B_u \times \log_2(1 + \Gamma_u)$ or $D_u = B_u \times \log_2(1 + \Gamma_u^{CoMP})$, respectively to obtain the total data rate D_{area} . Obtained results are averaged over 5000 independent iterations of MC trials. The other simulation parameters are set up according to Table 1 for the power consumption model. Fig. 2a and Fig. 2b confirm that the proposed model is effective and match well with MC results, whatever the network type and η values. Moreover, D_{area} increases with the network radius R_a when JT-CoMP is applied, as defined in Eq. (4). Alternatively, we observe that D_{area} is similar regardless the network type. Indeed, D_{area} is related to $R_a/R_c, R_{nw}/R_c$ ratios and η as demonstrated in [HZV19], so that same data rate can be obtained in MCN and FCN (Macro/Femto Cell Networks), if same path-loss exponent and same bandwidth are set up together with the same distance ratios.

Fig. 3a and Fig. 3b show the variation of EE depending on the number of coordinated BSs n , for $\eta = 2.6$ when $R/2 < R_a < R_e$, in a MCN and a FCN, respectively. EE is improved as the growth of n for a fixed R_a , since the data rate D_{area} increases with n . Here, a constant backhauling power cost is considered, i.e. $K_{CoMP} = 50W$ for a MCN and $K_{CoMP} = 30mW$ for a FCN as in [DPZC14]. In MCN, the EE enhancement reaches $66bits/Joule$ when 6 BSs are used to joint transmit data, against $26bits/Joule$ in case of 3 BSs. The EE improvement is more substantial in a FCN, about $2.9Kbits/Joule$ when 3 BSs are considered and reaches $7.3Kbits/Joule$ in case of 6 coordinated BSs. Although the same data rate D_{area} is observed in MCN and FCN, the EE improvement is higher in FCN than MCN, thank's to the smaller backhauling power cost in FCN. Therefore, JT-CoMP is more effective in small cellular networks and bring high improvement than macrocell. Moreover, it is important to emphasize that the EE improvement is very light and can be neglected when $R_a < R/2$, since UEs are closer to their serving BS and experience a great signal quality. Due to the limited page number, the numerical results are not presented here but are available in [HZV19].

Based on Eq. (2), we investigate the variation K_{CoMP} along with n in both MCN and FCN. K_{CoMP} in FCN increases slightly with the raise of n , regarding the MCN case. For example, K_{CoMP} is about $26W$ for $\eta = 3.5$

FIGURE 3: EE improvement depending on n , $\eta = 2.6$

and $n = 6$ in MCN, whereas, it is about $2W$ in FCN, since the femtocell has a lower power dissipation compared to macro ones. Moreover, we find that the EE enhancement are almost the same as those obtained with constant K_{CoMP} , (see [HZV19]). Therefore, considering constant is reasonable choice, it does not compromise the results presented above.

4 Conclusion

In this paper, we proposed a tractable expression of the energy efficiency (EE) based on fluid modeling of the downlink transmission network while considering the JT-CoMP approach. Then, we investigated the EE enhancement in both types of cellular networks : macro (MCN) and femto (FCN), through a comparison with the baseline case where no coordination is applied. Results show the EE model accuracy and that the data rate is the same in the both types of cellular networks, whereas the EE in a FCN is larger than the ones in a MCN. JT-CoMP induces a slight additional backhauling cost in FCNs making the coordination more efficient. Therefore small cell deployments are more suitable and fit with the main 5G scenarios characterized by high nodes density and short transmission range.

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