



Hybrid User Association Algorithm with Optimal Bandwidth Allocation and Power Control for Energy Efficiency Optimization in 5G HetNet

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ABSTRACT

The development and incorporation of an algorithm for power control into the User Association Algorithm with Optimal Bandwidth Allocation (UAAOBA) is presented in this paper. This forms a Hybrid User Association Algorithm with Optimal Bandwidth Allocation and Power Control (HUAAOBAPC) which enables the Base Stations (BSs) to allocate optimal powers and bandwidths to User Equipment (UEs) while satisfying their requirement for minimum data rate. The energy efficiency performance of the developed HUAAOBAPC is compared with that of the UAAOBA. The results show that the developed algorithm has a network energy efficiency improvement of 12.54% with respect to UAAOBA for increasing number of macro BS antennas. Also, when the number pico BSs were increased, the developed algorithm has network energy efficiency improvement of 18.05% with respect to UAAOBA. Finally, the developed algorithm has network energy efficiency improvement of 13.41% with respect to UAAOBA for an increasing number of femto BSs. This implies that the developed algorithm performs better than the UAAOBA in terms of network energy efficiency.

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INTRODUCTION

User association algorithm plays a vital role in enhancing the energy efficiency, throughput fairness and load balancing of a mobile network. It determines the particular BS each UE in the network should be associated with before data transmission and reception commences [1]. The current Maximum Reference Signal Received Power (MaxRSRP) and Maximum Signal-to-Interference-Noise Ratio (MaxSINR) user association algorithms as specified by 3rd Generation Partnership Project (3GPP) result in poor load fairness among BSs in massive MIMO antennas enabled Fifth 5G HetNets and poor throughput fairness among UEs in the network [2]. This result in the decreased energy efficiency of the current Long Term Evolution (LTE) network and degraded Quality of Service (QoS) for active UEs. Subsequently, the energy efficiency of the fifth-generation (5G) mobile network needs to be improved by 10 times compared with that achieved by the current LTE mobile network to cope with the anticipated 1000 times data rate increase [3]. Achieving this requirement for 5G mobile cellular networks requires the development of energy-efficient radio resource management schemes (user association, bandwidth allocation, and power control algorithms) and the integration of emerging mobile cellular network technologies which are HetNets, massive MIMO antennas, and mmWave spectrum [2]. This motivated

Liu *et al.*, (2015) to develop a distributed fair user association in massive MIMO enabled HetNets to maximize the network energy efficiency while guaranteeing the SINR received by the UEs. However, the network energy efficiency of the work can be improved by integrating a power control algorithm into the user association algorithm to adapt the transmit power of the BSs with respect to the traffic load on the BSs [2]. This results in higher network load balancing and energy efficiency. Tang *et al.*, (2018) improved the work of Liu *et al.*, (2015) by developing an energy-efficient joint optimization algorithm for user association and power control in massive MIMO enabled HetNets. However, the maximization of the network sum energy efficiency under load constraint of BS was done not considering the QoS requirements of the UEs. This resulted in unguaranteed receive throughput of the UEs. Also, the power control algorithm does not affect the user association scheme. This caused decreased load balancing in the HetNet and reduced network energy efficiency improvement [5]. It is important to note that the literature that deployed massive MIMO used digital beamforming at the BSs which resulted in increased power consumption of the BS. This is because digital beamforming uses a radio frequency chain per antenna. Obi *et al.*, (2019) developed a user association algorithm with optimal bandwidth allocation for improving the energy efficiency of massive MIMO with hybrid beamforming

and mmWave enabled HetNet [6]. However, the energy efficiency of the work can be improved by hybridizing the UAAOBA with an algorithm for power control. This enables the control of the power variable to enhance the user association algorithm for improved load balancing of the network and subsequent improvement of the energy efficiency of the network. Thus, this paper is an extension of the authors' work in [6].

MATHEMATICAL MODELING AND ALGORITHM DEVELOPMENT

Mathematical Models

This paper adopted the channel model, UE throughput model and network energy efficiency model of the authors' previous work and they are given in equation (1), (2), and (3), respectively as [6]:

$$h_u = \sqrt{\frac{1}{\dots}} \sum_{l=1}^L \dagger_l V_t(\{\xi_l\}) V_r^*([l_l]) \quad (1)$$

where h_u is the channel vector of the u^{th} UE from the BS with L transmitting antennas, \dagger_l is the complex channel gain of the l^{th} path, \dots is the distance-dependent path loss between the BS and UE, $V_t(\{\xi_l\})$ and $V_r^*([l_l])$ are the transmit steering vector and conjugate receive steering vector, respectively. Also, $\{\xi_l$ and $[l_l$ are the angle of departure and angle of arrival of the l^{th} path at the BS and UE, respectively.

$$R_{b,u} = w_{b,u} \log_2(1 + \mathbb{E}_u p_{b,u}) \quad (2)$$

where $R_{b,u}$ is the achievable throughput of the u^{th} UE from the b^{th} BS, $w_{b,u}$ is the bandwidth allocated by the b^{th} BS to the u^{th} UE, $p_{b,u}$ is the power received from the u^{th} UE from the b^{th} BS, and \mathbb{E}_u is the interference to noise ratio at the u^{th} UE.

$$\zeta = \frac{\sum_{b=1}^B \sum_{u=1}^U x_{b,u} (w_{b,u} \log_2(1 + \mathbb{E}_u p_{b,u}))}{\sum_{b=1}^B (pc_b + \frac{1}{\gamma} \sum_{u=1}^U x_{b,u} p_{b,u})} \quad (3)$$

where ζ is the energy efficiency of the network, $x_{b,u}$ is the user association index, pc_b is the static power consumption of the b^{th} BS, γ is the amplifier efficiency of the BS, B is the total number of BSs, and U is the total number of UEs in the network.

Problem Formulation

The system under consideration consists of a macrocell underlaid with picocells and femtocells. The macro BS utilizes massive MIMO in the microwave frequency band. The pico BSs and femto BSs utilize massive MIMO in the mmWave frequencies. The access technology utilized at the BSs is the orthogonal frequency division multiple access (OFDMA) so as to eliminate intra-cell interference between UEs. Let I represent the set of all UEs, J the set of all BSs, X the user association matrix, P the power allocation matrix and L the single row matrix of the total number of UEs connected to each BS.

Therefore, the energy-efficient joint user association and optimal bandwidth allocation with power control problem to be solved is:

$$f(X, P) = \max_{X, P} \sum_{u \in I} \sum_{b \in J} x_{b,u} \log \left(\frac{R_{b,u}}{l_b p_b} \right) \quad (4)$$

Such that the following constraints are satisfied.

$$\sum_{b \in J} x_{b,u} = 1, \quad \forall u \in I \quad (5)$$

$$\sum_{u \in I} x_{b,u} = l_b, \quad \forall b \in J \quad (6)$$

$$\sum_{u \in I} x_{b,u} p_{b,u} \leq p_{\max}, \quad \forall b \in J \quad (7)$$

$$\sum_{b \in J} x_{b,u} R_{b,u} \geq R_{\min}, \quad \forall u \in I \quad (8)$$

$$x_{b,u} \in \{0, 1\} \quad \forall b \in J, \quad \forall u \in I \quad (9)$$

where p_{\max} is the maximum transmit power of each BS, R_{\min} is the minimum data rate that guarantees the QoS received by each UE.

The constraint (5) and (9) means that the u^{th} UE can only associate to the b^{th} BS at a time. Constraint (6) implies that the total number of UEs associated with a BS cannot exceed the maximum load of the BS. Constraint (7) implies that the total transmit power consumed by the UEs associated with the b^{th} BS cannot exceed its maximum transmit power. Subsequently, constraint (8) is used to ensure the quality of service received by the u^{th} UE.

The problem of equation (4) subjected to the constraints from equations (5) through (9) is a mixed-integer non-linear optimization problem which lacks convexity due to the objective function of logarithmic utility and the user association indicator binary nature. This makes the problem NP-hard. To solve the problem,

the user association indicator is relaxed as $x_{b,u} \in [0,1]$ and the Lagrangian dual analysis of the problem is presented with the view to making the problem convex. The Lagrangian L, therefore, associated with the optimization problem is given as:

$$L(X, P, \sim, \}, \epsilon) = \sum_{u \in I} \sum_{b \in J} x_{b,u} \log \left(\frac{R_{b,u}}{l_b P_b} \right) + \sum_{b \in J} \sim_b \left(\sum_{u \in I} x_{b,u} - l_b \right) - \sum_{b \in J} \} _b \left(P_{\max} - \sum_{u \in I} x_{b,u} P_{b,u} \right) - \sum_{u \in I} \epsilon_u \left(\sum_{b \in J} x_{b,u} R_{b,u} - R_{\min} \right) \quad (10)$$

where, $\sim = [\sim_1, \sim_2, \dots, \sim_B]^T$, $\} = \{ \}_1, \}_2, \dots, \}_B]^T$ and $\epsilon = [\epsilon_1, \epsilon_2, \dots, \epsilon_U]^T$ are the Lagrange multipliers used to relax the coupled constraints.

The dual problem of the optimization problem with respect to the dual variables is written as:

$$\min_{\sim, \}, \epsilon} g(\sim, \}, \epsilon) = \begin{cases} \max_{X, I, P} L(X, \sim, \}, \epsilon) \\ \text{s.t.} \\ \sum_{b \in J} x_{i,k} = 1, \quad \forall u \in I \\ 0 \leq x_{b,u} \leq 1, \quad \forall b \in J, \forall u \in I \\ \sim, \}, \epsilon \geq 0 \end{cases} \quad (11)$$

The optimal user association matrix that maximizes equation (4) is given as:

$$x_{b,u} = \begin{cases} 1, & \forall b = b^* \\ 0, & \forall b \neq b^* \end{cases} \quad (12)$$

where

$$b^* = \underset{u}{\operatorname{argmax}} \left(\log(R_{b,u}) - \sim_b + \} _b P_{b,u} - \epsilon_u R_{b,u} \right) \quad (13)$$

Equation (13) is the judgment criterion for UE to determine the BS providing the best service.

Similarly, the optimal load condition for maximizing equation (4) is given as [6]:

$$l_b^* = \frac{e^{-\sim_b - 1}}{P_b} \quad (14)$$

In solving the dual problem of equation (11), a closed-form expression for the optimal solution cannot be obtained directly. This is because of the second derivative of the dual function $g(\sim, \}, \epsilon)$ with

respect to \sim_b , $\} _b$, and ϵ_u are all less than zero. Therefore, the subgradient method is employed to update the Lagrangian variables as follows [7]:

$$\sim_b(t+1) = \sim_b(t) - u(t) \left(l_b(t) - \sum_{u \in I} x_{b,u}(t) \right), \quad \forall b \in J \quad (15)$$

$$\} _b(t+1) = \} _b(t) - u(t) \left(P_{\max} - \sum_{u \in I} x_{u,b}(t) P_{u,b}(t) \right), \quad \forall b \in J \quad (16)$$

$$\epsilon_u(t+1) = \epsilon_u(t) - u(t) \left(\sum_{b \in J} x_{b,u}(t) R_{b,u}(t) - R_{\min} \right), \quad \forall u \in I \quad (17)$$

where t represents the iteration index and $u(t)$ is the step size.

The step size is made to be adaptive at every iteration. By updating the Lagrange multipliers $\mu_b(t)$, $\lambda_b(t)$, and $\nu_u(t)$ using the respective equations of (15), (16) and (17), $x_{b,u}(t)$ is updated accordingly using equation (12) and (13). This enables the dual problem to converge to the global optimum since it is convex.

Development and Integration of a Power Control Algorithm into the UAAOBA

From the Lagrangian function given in equation (10), the power optimization function is given as:

$$f(p_{b,u}) = \sum_{b \in J} \sum_{u \in I} x_{b,u} \log \left(\frac{R_{b,u}}{l_b P_b} \right) - \sum_{b \in J} \} _b \left(P_{\max} - \sum_{u \in I} x_{b,u} P_{b,u} \right) \quad (18)$$

The total power consumption of the b^{th} BS P_b is given as:

$$P_b = p c_b + \frac{1}{y_b} \sum_{u=1}^U x_{b,u} P_{b,u} \quad (19)$$

Substituting equation (19) into (18) gives:

$$f(p_{b,u}) = \sum_{b \in J} \sum_{u \in I} x_{b,u} \log \left(\frac{R_{b,u}}{l_b \left(p c_b + \frac{1}{y_b} \sum_{u=1}^U x_{b,u} P_{b,u} \right)} \right) - \sum_{b \in J} \} _b \left(P_{\max} - \sum_{u \in I} x_{b,u} P_{b,u} \right) \quad (20)$$

Since the 1st and 2nd order partial derivative of $f(p_{b,u})$

with respect to $P_{b,u}$ exists, the variable $P_{b,u}$ is updated using the Newton's method as follows [8]:

$$P_{b,u}(t+1) = P_{b,u}(t) - u(t) \Delta P_{b,u} \quad (21)$$

where $\Delta P_{b,u}$ is given as:

$$\Delta P_{b,u} = \frac{\left| \frac{\partial f}{\partial P_{b,u}} \right|}{\left| \frac{\partial^2 f}{\partial P_{b,u}^2} \right|} \quad (22)$$

The 1st derivative of equation (20) with respect to $P_{i,k}$ is given as:

$$\frac{\partial f}{\partial P_{b,u}} = \sum_{b \in J} \sum_{u \in I} x_{b,u} \left(\frac{\epsilon_u}{(1 + \epsilon_u) \ln 2 \log_2(1 + \epsilon_u P_{b,u})} - \frac{\sum_{u \in I} x_{b,u}}{y_b \left(p c_b + \frac{1}{y_b} \sum_{u \in I} x_{b,u} P_{b,u} \right)} \right) + \sum_{b \in J} \} _b \sum_{u \in I} x_{b,u} \quad (23)$$

And the 2nd derivative of equation (21) with respect to $P_{b,u}$ is given as:

$$\frac{\partial^2 f}{\partial p_{b,u}^2} = \sum_{b \in J} \sum_{u \in I} x_{b,u} \left(\frac{\epsilon_u \left(\frac{(1+\epsilon_u)}{\ln 2 \left((1+\epsilon_u p_{b,u})^2 \log_2(1+\epsilon_u p_{b,u}) + \frac{\epsilon_u}{(1+\epsilon_u p_{b,u})^2 \ln 2 (\log_2(1+\epsilon_u p_{b,u}))^2} \right)} \right)}{\left(y_b \left(p_{c,b} + \frac{1}{y_b} \sum_{u \in I} x_{b,u} p_{b,u} \right) \right)^2} \right) \quad (24)$$

The minimum transmit power for the BS required to achieve the updated BS transmit power of equation (22) is derived by substituting equation (2) into QoS constraint of equation (8) to give:

$$\sum_{b \in I} x_{b,u} w_{b,u} \log_2(1 + \epsilon_u p_{b,u}^*) \geq R_{\min} \quad (25)$$

But for user association with optimal bandwidth allocation, the following expression is obtained [5]:

$$w_{b,u} = \frac{W_b}{\sum_{u \in I} x_{b,u}}, \quad \forall b \in J \quad (26)$$

Substituting equation (26) into equation (25) gives:

$$p_{b,u}^* = \frac{1}{\epsilon_u} \left(2^{\frac{R_{\min}}{W_b}} - 1 \right) \quad (27)$$

Now, if the transmit power, $p_{b,u}$ is less than the minimum transmit power, $p_{b,u}^*$, then:

$$p_{b,u} = p_{b,u}^* \quad (28)$$

The integration of the power control algorithm into the UAAOBA forms the Hybrid User Association Algorithm with Optimal Bandwidth Allocation and Power Control (HUAAOBAPC) which enables the updating of the transmit powers of the BSs to adapt to the number of UEs connected to the respective BSs and leads to the improved load balancing and energy efficiency of the network. The power control algorithm allocates the minimum transmit power to the UEs while satisfying the QoS requirement in order to achieve a better energy efficiency of the network. The flowcharts for integrating the power control algorithm into the user association algorithm with optimal bandwidth allocation algorithm is shown in Figure 1. Also, the power control algorithm flowchart is provided in Figure 2.

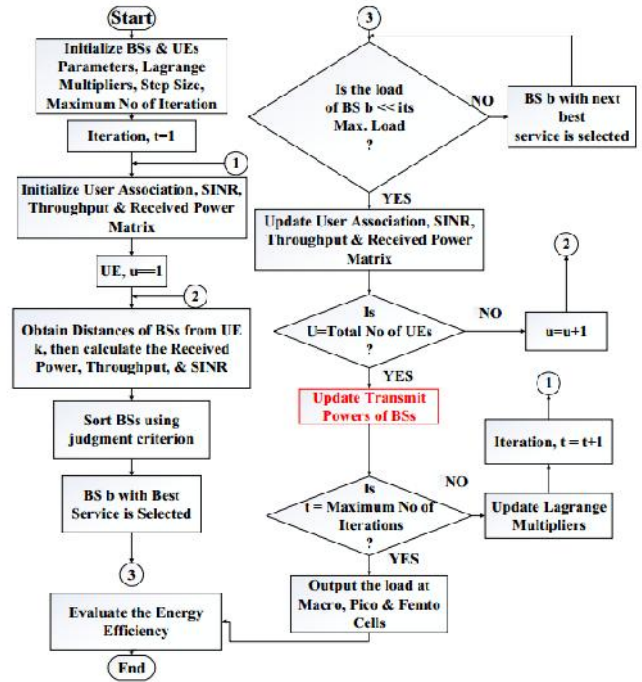


Figure 1: Developed HUAAOBAPC

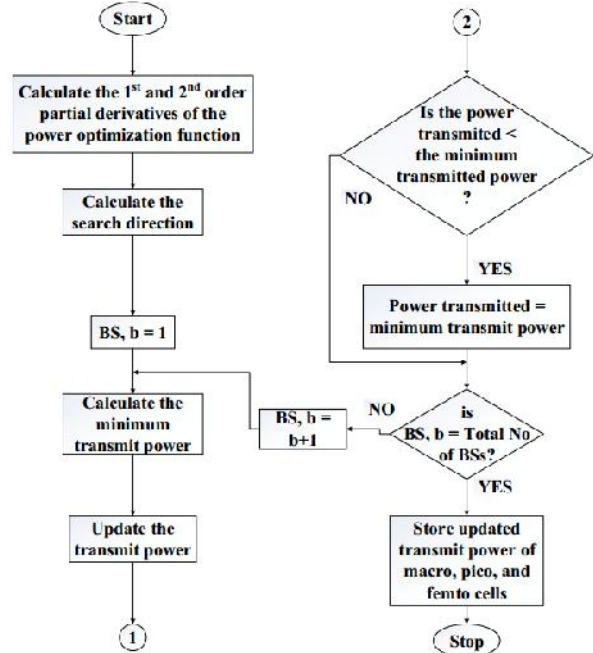


Figure 2: Algorithm for Power Control

Simulations

The performance of the developed HUAAOBAPC is evaluated by simulation. The minimum number of macro BS (one) which can be deployed in a HetNet is considered. The macrocell is under-laid with picocells and femtocells to form a three-tier HetNet. The cell radii of the picocells and femtocells are 0.1 km

and 0.01 km, respectively as specified by 3GPP [9]. The standard parameters used for the simulation are shown in Table 1, which are consistent with the simulation scenario used in a system-level simulator for 5G mobile networks [10].

Table 1: Standard Simulation Parameter

Parameters	Values
Macro BS bandwidth	20 MHz
Macro BS frequency	2 GHz
mmWave BS bandwidth	5 GHz
mmWave BS frequency	38 GHz
Macro BS transmit power	20 W
Pico BS transmit power	1 W
Femto BS transmit power	0.1 W
Noise power density	-174 dBm / Hz
Minimum UE data rate	1 Gbps

The circuitry power of the different BS is also simulated using parameters shown in Table 2 [11].

Table 2: Circuitry Power of the Different BSs Components

BS Type	Baseband Power	Radio Frequency Chain Power	Phase Shifter Power	Power Amplifier Efficiency
Macro BS	100W	5W	1W	0.7855
Pico BS	0.5W	0.25W	0.05W	0.8500
Femto BS	0.2W	0.12W	0.02W	0.9000

RESULTS AND DISCUSSION

The performance of the HUAOBAPC is first given in terms of time of convergence of the network energy efficiency with respect to the UAAOBA. The optimal solutions of the algorithms are taken at convergence. Consequently, the performance of the HUAOBAPC using the network energy efficiency with respect to the UAAOBA is analyzed for increase number

of macro BS antennas, pico BSs, and femto BSs. This is to ascertain the algorithm with the best performance.

Convergence Behaviour of Algorithms

The performance of the HUAOBAPC with respect to UAAOBA is first illustrated by analyzing its convergence behavior and computational cost in terms of network energy efficiency as shown in Figure 3. The convergence analysis is carried out to ensure that the algorithm converges and therefore provides an optimal solution for energy efficiency.

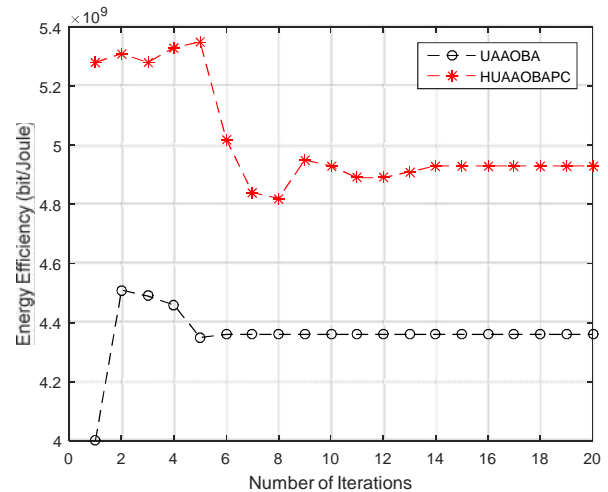


Figure 3: Algorithms Convergence Behaviour of Energy Efficiency

From Figure 3, it is observed that the UAAOBA obtains an optimal solution for energy efficiency after the sixth iteration as against the HUAOBAPC that obtains an optimal solution after the fourteenth iteration. This is because, in the UAAOBA, the algorithm iterates for optimal user association with the subgradient method to provide for the best quality of service of UEs using equation (13) as the judgment criterion. While the HUAOBAPC iterates simultaneously to obtain an optimal user association and transmit powers of BSs using the subgradient method and Newton method, respectively. Subsequently, the HUAOBAPC obtains a higher energy efficiency at convergence with respect to UAAOBA. The maximization of the network energy efficiency in the HUAOBAPC is attributed to the BS transmit power updates algorithm that minimizes the transmit power of the BSs and efficiently coordinates cross-tier interference and inter-tier interference. Therefore, the HUAOBAPC enables the UEs in the network to receive better throughput distribution and load balancing as against the UAAOBA, which therefore leads to the better energy efficiency of the network. Therefore, the HUAOBAPC cannot only achieve an optimal solution, but it also provides a load balancing property that

avored HetNet deployment in order to maximize the network energy efficiency under the QoS requirements.

Performance of Algorithms with Increasing Number of Macro BS Antennas

Secondly, the performance of the HUAAOBAPC with respect to UAAOBA is illustrated by evaluating the energy efficiency of the network with an increasing number of Macro BS massive MIMO antennas while keeping the number of antennas at the pico BS and femto BS constant at 400 (this is because of their same carrier frequency). In evaluating the network energy efficiency with the increasing number of macro BS antennas, the number of macro BS antennas is set to be less than or equal to the mmWave BS antennas (that is, the antennas at the pico BS and femto BS). This is because the number of massive MIMO BS antennas is a function of its carrier frequency and the mmWave BSs utilizes higher carrier frequency than that of the macro BS. In these simulations, two pico BSs and twenty femto BSs each are randomly deployed in the macro cell coverage area while maintaining the simulation parameters shown in Table 1 and 2. The results obtained for the energy efficiency of the network with the varying number of massive MIMO antennas at the macro BS using equation (3) for the HUAAOBAPC with respect to UAAOBA is as illustrated in Figure 4.

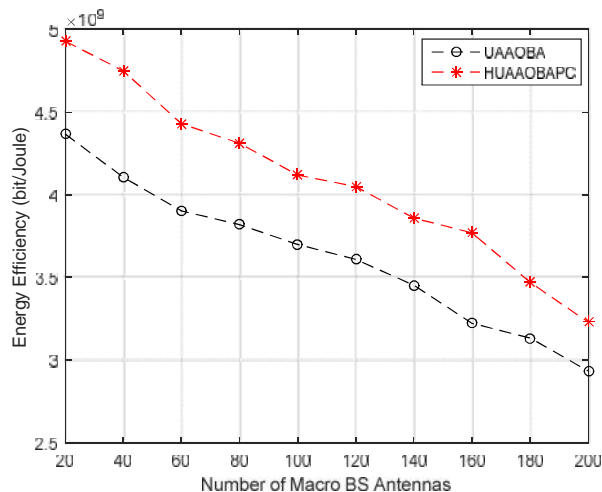


Figure 4: Energy Efficiency for increase Number of Macro BS Antennas

As observed in Figure 4, the energy efficiency of the network for both algorithms decreases with an increased number of massive MIMO antennas at the macro BS. This is because increasing the number of antennas at the macro BS results in an increase in the number of UEs associated with it. This leads to the decrease of the energy efficiency of the HetNet due to

the higher transmit power of the macro BS. This is attributed to the fact that the high transmit power of macro BS leads to an increase in the receive powers of UEs at different distances from the macro BS. The increase receives powers of the UEs cause increase power radiation by the macro BS to its serving UEs which corresponds to the increase of the dynamic power consumption of the macro BS. This contributes to the overall increase in the power consumption of the network and a subsequent reduction in the energy efficiency of the network. Also, increasing the number of antennas of a BS result to a corresponding increase of the static power consumption of the BS. This leads to the overall power consumption of the network and subsequently, causes a decrease in the energy efficiency of the network. Consequently, it is observed that regardless of the number of macro BS antennas, the HUAAOBAPC achieves better energy efficiency than the UAAOBA. The average energy efficiency for the HUAAOBAPC and UAAOBA from Figure 4 is computed as 4.0992×10^9 bit/Joule and 3.6424×10^9 bit/Joule, respectively. Thus, the HUAAOBA has network energy efficiency performance improvement of 12.54% with respect to UAAOBA. This is because the HUAAOBAPC maximizes the network energy efficiency by coordinating the load fairness and the throughput fairness of the network.

Performance of Algorithms with Increase Number of Pico BSs

Similarly, the energy efficiency of the network is evaluated for an increased number of pico BSs. This is to ascertain the performance of the HUAAOBAPC with respect to UAAOBA when increasing the number of pico BSs in the three-tier HetNet. In this simulation, the number of macro BS and mmWave BSs (pico BSs and femto BSs) massive MIMO antennas are arbitrarily set as 20 and 400 respectively. This is because the mmWave BSs is operating at a higher frequency than the macro BS with a frequency ratio of 1:20. Hence, the mmWave BSs support larger number antennas. The results obtained for the energy efficiency of the network with a varying number of pico BSs with the constant deployment of 20 femto BSs is as shown in Figure 6.

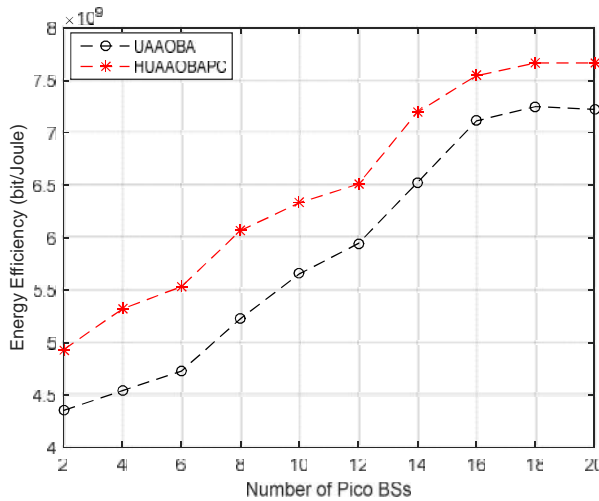


Figure 6: Energy Efficiency for Increasing Number of Pico BSs

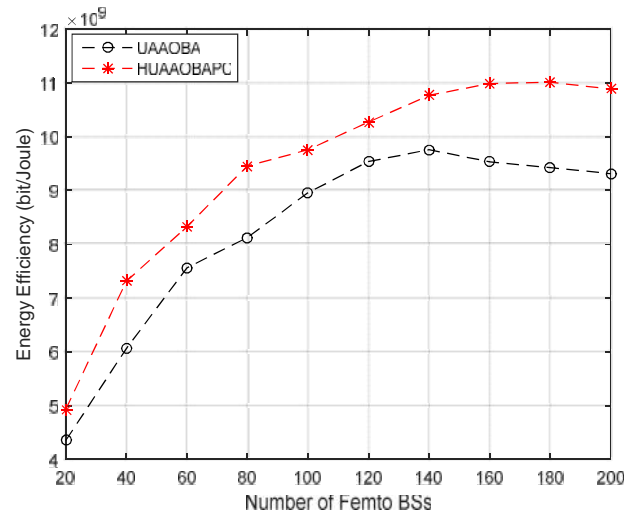


Figure 7: Energy Efficiency for Increasing Number of Femto BSs

As shown in Figure 6, the energy efficiency of the network for HUAOBAPC and UAAOBA increases with the number of Pico BSs up to 18 pico BSs per macrocell. Thereafter, for both algorithms, the network energy efficiency remains fairly constant with increasing number of pico BSs. This is attributed to the increase of the power consumption of the HetNet as the pico BSs increases. For the HUAOBAPC, as the number of pico BSs increases, the algorithm as compare to UAAOBA has higher load fairness which leads to the increase sum rate of the network and a corresponding increase of the throughput fairness of the network. This, therefore, causes a subsequent increase in the energy efficiency of the network due to the decrease of the dynamic power consumption of the network. The average energy efficiency of the HUAOBAPC and UAAOBA for an increasing number of pico BSs are computed as 6.9142×10^9 bit/Joule and 5.8567×10^9 respectively. Therefore, the HUAOBAPC has network energy efficiency improvement of 18.05% as compared to UAAOBA.

Performance of Algorithms with Increase Number of Femto BSs

Consequently, the energy efficiency of the network is evaluated with an increased number of femto BSs. The results obtained for the energy efficiency of the network of varying number of femto BSs with the constant deployment of 2 Pico BSs is shown in Figure 7.

As shown in Figure 7, the energy efficiency of the network for UAAOBA increases with the number of femto BSs per macrocell for a number of femto BSs up to 140 femto BSs. Thereafter, the energy efficiency of the network began to decrease. But, for HUAOBAPC, the energy efficiency of the network increases with the number of femto BSs per macrocell up to 180 femto BSs and decreases thereafter. The decrease of the energy efficiency beyond these values of femto BSs for both algorithms is attributed to the increase of the power consumption of the HetNet as the femto BSs increases which then leads to the overall reduction of the energy efficiency of the network. For the HUAOBAPC, as the number of femto BSs increases, the algorithm as compare to UAAOBA has higher load fairness which leads to the increase sum rate of the network and a corresponding increase of the throughput fairness of the network. This, therefore, causes a subsequent increase in the energy efficiency of the network due to the decrease of the dynamic power consumption of the network. The average energy efficiency of the HUAOBAPC and UAAOBA for an increasing number of femto BSs are computed as 9.3701×10^9 bit/Joule and 8.2619×10^9 bit/Joule, respectively. Therefore the HUAOBAPC has network energy efficiency improvements of 13.41% as compared to UAAOBA.

CONCLUSION

The paper presents the development of a hybrid user association algorithm with optimal bandwidth allocation and power control for energy efficiency optimization in 5G HetNet integrating massive MIMO and mmWave with hybrid beamforming. The developed



algorithm provides for an optimal solution for user association, bandwidth allocation, and power allocation to UEs simultaneously. This leads to the maximization of the network energy efficiency by the coordination of the load fairness and throughput fairness of the network while guaranteeing the quality of service requirement of the UEs. The developed algorithm outperforms the user association algorithm with optimal bandwidth allocation in terms of network energy efficiency for increasing number of massive MIMO antennas, pico BSs, and femto BSs. The results show that the developed HUAAOBAPC has network energy efficiency performance improvement of 12.54%, 18.05%, and 13.41% with respect to UAAOBA for increase number of macro BSs antennas, pico BSs, and femto BSs per macrocell, respectively. However, the HUAAOBAPC incurred more computational and signaling overhead when compared to the UAAOBA due to its more convergence time.

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