

Power Allocation with Max-min Fairness for Multicast in Heterogeneous Network

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Abstract—In this paper, we formulate the problem to guarantee a max-min fairness for multicast in an orthogonal frequency division multiple access (OFDMA)-based heterogeneous network (Het-Net) by managing the power allocation at base stations (BSs) of coexisting macrocell and picocells, where different common messages are, respectively, transmitted from BSs to their served user equipments (UEs) in the same frequency. Due to non-linear and non-posynomial constraint in the problem, it is difficult to solve the problem in a closed form. However, in the case of high operating signal to interference plus noise ratio (SINR) region, we simplify the problem to a corresponding GP problem, which brings forth a suboptimal power allocation algorithm to guarantee a max-min fairness for multicast among the cells in the Het-Net. Simulation results demonstrate the minimum transmission rate for multicast among the cells in Het-Net can be improved efficiently by the proposed algorithm.

Keywords—Multicast, fairness, heterogeneous network, power allocation, OFDMA

I. INTRODUCTION

Due to the robustness to inter-symbol interference, orthogonal frequency division multiplexing (OFDM) has attracted extensive attention for the next generation broadband wireless communication systems, e.g., 3GPP long term evolution (LTE) [1], LTE-advanced (LTE-A) [2], and worldwide interoperability for microwave access (WiMAX) [3], to support high rate service, high power efficiency, and better quality of service (QoS). For the LTE-A, several important technologies have been investigated, e.g., carrier aggregation, inter-cell interference coordination (ICIC), coordinated multi-point transmission and reception, and heterogeneous networks (Het-Net) [4].

According to the report from Cisco, the demand for various QoSs for data traffics will dramatically increase by 66 times by 2013 in future broadband wireless networks [5], in which one of the major issues in the QoS policy is fairness consideration and one of the famous common ideas of fairness is max-min fairness [6]. For Het-Nets, the coexisting macrocells, picocells, and femtocells may work

in the same operating frequency. In this case, the inter-cell interference occurs and the ICIC becomes an essential technology to control the inter-interference for achieving higher operation efficiency in the Het-Net. When multicast is considered for the coexisting cells in the Het-Net, where different common messages are, respectively, transmitted in cells, the max-min fair approach intends to treat all the cells as fairly as possible by making the minimum of all the rates for multicast among cells as large as possible, where the transmission rate for multicast in a cell is determined by the smallest maximum achievable rate among all the UEs in its served area [7]. Owing to the potential of power control or power allocation for improving the operation efficiency and the QoS, numerous works of ICIC had been conducted to enhance the performance in terms of transmission rate, fairness, and served coverage in the Het-Nets [8-12].

Power allocation algorithms in [8,9] had been investigated to increase the transmission rate of UEs or extend the service coverage of Het-Nets by either frequency reuse or dynamic spectrum management. However, the fairness issue and the multicast transmission among cells in the Het-Net were not considered. Though the enhanced ICIC solutions with frame alignment [10], in which the data frame of BSs in Het-Net were aligned and the BSs transmitted data to UEs in an orthogonal manner to avoid the data collision among cells, e.g., different frequency bands were assigned to different BSs in the Het-Net, could be adopted for the multicast among cells in the Het-Net, the fairness issue for multicast among cells was not considered and the orthogonal transmission manner at BSs is inefficient to improve the spectrum efficiency. Although the optimal and suboptimal radio resource management (RRM) algorithms were introduced to achieve the max-min fairness or the proportional fairness for the data transmission to UEs in the Het-Net [11, 12], the multicast transmission among different cells in the Het-Net was not considered and the coexisting cells were assume to be operating in different frequency bands without collision. Thus, all the above algorithms or schemes in [8-12] are invalid to achieve the max-min

fairness for the multicast transmission among cells in the HetNet.

In this paper, we consider the multicast transmission in a Het-Net with one macrocell and multiple picocells, where different common messages are assumed to be, respectively, transmitted in the same operating frequency among the coexisting cells in the Het-Net. We first address a problem to maximize the minimum transmission rate for multicast among cells in the Het-Net under the sum power constraint of BSs. Due to non-linear and non-posynomial constraint in the problem, it is difficult to solve in a closed form. However, we find its suboptimal problem and solve it by the GP, which brings forth a suboptimal power allocation algorithm to achieve a max-min fairness for the multicast among cells in the Het-Net. Simulation results demonstrate the efficiency of the proposed power allocation algorithm.

The paper is organized as follows. In Section II, the system model is presented and the problem is formulated to satisfy a max-min fairness for the multicast transmission in the Het-Net. In Section III, the suboptimal algorithm is proposed. In Section IV, the proposed algorithm is evaluated by means of intensive simulations. Finally, the conclusions are drawn in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION FOR MULTICAST IN HETEROGENEOUS NETWORKS

A. System Model for Multicast in Het-Net

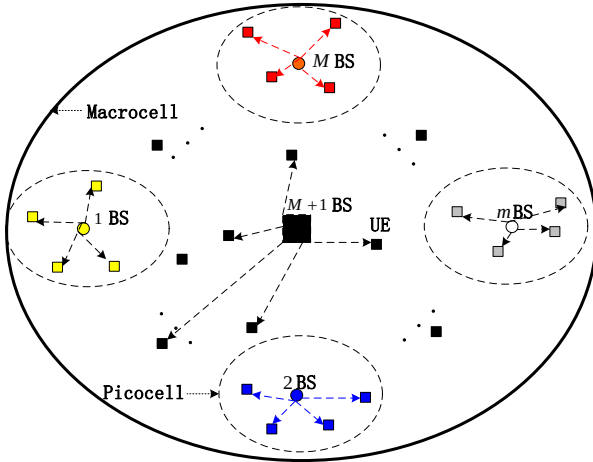


Figure 1. System model for the multicast among cells in a Het-Net

Figure 1 shows the system model for the multicast in an OFDMA-based Het-Net with multiple cells, i.e., one macrocell and M picocells. The BSs of the macrocell and picocells are properly allocated with overlapped service coverage. In general, the macrocell has much larger served area than that of picocell. All the macrocell and picocells are assumed to be operating in the same frequency and the inter-cell interference among different cells exists in the Het-Net. We consider the multicast transmission in the Het-Net, where the BSs, respectively, intend to transmit different common message to their served UEs, e.g., from

the BS of m -th ($m=1,2,\dots,M+1$) cell to its served UEs, where each UE only can connect to one cell, e.g. either the macrocell or the picocell. In addition, the frames of macrocell and picocells are assumed to be aligned [10]. For simplicity, we assumed that there are K UEs for each cell in the Het-Net. The transmit power on the l -th ($l=1,2,\dots,L$) subcarrier at the m -th ($m=1,2,\dots,M+1$) BS is denoted by $P_{m,l}$. The independent and identically distributed (i.i.d.) slow Rayleigh fading channel is assumed among BSs and UEs. The single-side power spectrum density of additive white gaussian noise (AWGN) on the l -th subcarrier of the k -th UEs in the m -th cell is denoted by $n_{m,k,l}$.

Considering the multicast transmission among cells in the Het-Net, the received signal to interference plus noise ratio (SINR) for the signal from the BS of the m -th ($m=1,2,\dots,M+1$) cell to the k -th UE in its served area on the l -th subcarrier, $SINR_{m,k,l}$, can be given as

$$SINR_{m,k,l} = \frac{P_{m,l}\alpha_{m,m,k,l}}{\sum_{\substack{\hat{m}=1 \\ \hat{m} \neq m}}^{M+1} (P_{\hat{m},l}\alpha_{\hat{m},m,k,l}) + n_{m,k,l}}, \quad (1)$$

where $\alpha_{\hat{m},m,k,l}$ denotes the channel gain from the BS of the $\hat{m}$ -th cell to the k -th UE in m -th cell on the l -th subcarrier, due to fading, path loss, and shadowing.

$\sum_{\hat{m}=1, \hat{m} \neq m}^M (P_{\hat{m},l}\alpha_{\hat{m},m,k,l})$ is the interference from the BS of the $\hat{m}$ -th ($\hat{m} \neq m, m=1,2,\dots,M+1$) cell to the k -th UE in the m -th cell on the l -th subcarrier. Thus, the corresponding transmission rate for the k -th UE in the m -th cell, $R_{m,k}$, can be presented as [13]

$$R_{m,k} = \sum_{l=1}^L \log_2(1 + SINR_{m,k,l}). \quad (2)$$

B. Problem Formulation for Multicast in Het-Net.

The problem to guarantee a max-min fairness for multicast transmission among the coexisting macrocell and picocells in the Het-Net under the sum power constraint of BSs can be formulated as

$$\max_{p_{m,l}} \min_{m=1,\dots,M} \gamma_m \quad (3a)$$

$$\text{subject to } R_{m,k} > \gamma_m, \forall k, m, \quad (3b)$$

$$\sum_{m=1}^{M+1} \sum_{l=1}^L P_{m,l} \leq P_{tot}^C, \forall k, m, \quad (3c)$$

$$0 \leq P_{m,l}, \forall l, m. \quad (3d)$$

To achieve the max-min fairness for the multicast in the Het-Net, the objective function in (3a) is designed to maximize the minimum of γ_m , which is the auxiliary variable and represents the achievable rate for multicast in the m -th cell, among all the cells in the Het-Net by optimally allocating $p_{m,l}$ to all the subcarriers of the BSs. Constraint (3b) implies that the transmission rate for multicast in the m -th cell, γ_m , is achievable for all the K UEs in the served region of the m -th cell. Constraint (3c)

denotes the sum power constraint for BSs, where P_{tot}^C is the maximum sum power for all the BSs in the Het-Net. In order to efficiently manage the received signal power at the receiver side and control the potential interference to the neighbor cell, we consider the sum power constraint at BSs instead of the individual power constraint at each BS in the paper.

III. PROPOSED POWER ALLOCATION ALGORITHM FOR MULTICAST IN HET-NET

Geometric programming (GP) is well studied to solve the nonlinear, nonconvex optimization problems [14]. For the GP problems, there is no local optimal solution. However, a global optimal solution exists, since a GP problem is possible to be represented by an equivalent convex reformulation.

Due to the nonlinear constraint of (3b), the problem (3a)-(3d) is difficult to solve in a closed form. Moreover, it is also infeasible to transform the problem directly into a GP problem, since $R_{m,k}$ in constraint (3b) is not a posynomial. However, for the high operating SINR region, e.g., $SINR_{m,k,l} \gg 1$, $(1 + SINR_{m,k,l})$ is approximately equal to $SINR_{m,k,l}$. Thus, we can have the approximation as

$$R_{m,k} = \sum_{l=1}^L \log_2(1 + SINR_{m,k,l}) \approx \sum_{l=1}^L \log_2(SINR_{m,k,l}). \quad (4)$$

By introducing another auxiliary variable, γ , as a target minimum rate for multicast among the cells in the Het-Net, we can simplified the problem in (3a)-(3d) as

$$\min \frac{1}{P_{m,l} \gamma} \quad (5a)$$

$$\text{subject to } \sum_{l=1}^L \log_2(SINR_{m,k,l}) > \gamma, \forall k, m, \quad (5b)$$

$$\sum_{m=1}^{M+1} \sum_{l=1}^L P_{m,l} \leq P_{tot}^C, \forall k, m, \quad (5c)$$

$$0 \leq P_{m,l}, \forall l, m. \quad (5d)$$

Since $SINR_{m,k,l}$ is a posynomial with variables, $P_{m,l}$, the product of $SINR_{m,k,l}$, i.e., $\log_2(\prod_{l=1}^L SINR_{m,k,l})$, is also a posynomial. In this case, we simplify the problem of (3a)-(3d) to a GP problem as in (5a)-(5d). Thus, a sub-optimal power allocation algorithm (called "SubOpt") is proposed to satisfy the max-min fairness for the multicast transmission among cells in the Het-Net as follows:

Suboptimal power allocation algorithm

- 1) Macro-BS collects the channel gains $\alpha_{m,k,l}$.
- 2) Macro-BS solves the optimization problem in (5a)-(5d) to get $P_{m,l}^*$ by GP, where $P_{m,l}^*$ denotes the optimal power allocation at the l -th subcarrier of the m -th BS.
- 3) Macro-BS informs the Pico-BSs of the allocated power vector, $P_{m,l}^*$.

For comparative purpose, the case with equal power allocation (EPA) is also considered. In the EPA, the total available power of P_{tot}^C is equally shared among all the subcarriers of BSs, e.g., $P_{m,l} = P_{tot}^C / ((M+1) \cdot L)$. Thus, according to the Eq. (1), the corresponding transmission rate for the k -th UE in the m -th cell, $R_{m,k}^{epa}$, can be given as

$$R_{m,k}^{epa} = \sum_{l=1}^L \log_2 \left(1 + \frac{P_{tot}^C \alpha_{m,m,k,l}}{\sum_{\substack{m=1 \\ m \neq m}}^{M+1} (P_{tot}^C \alpha_{m,m,k,l}) + (M+1) \cdot L \cdot n_{m,k,l}} \right). \quad (6)$$

Thus, the minimum transmission rate for multicast among the macrocell and picocells in the Het-Net for the case of EPA, R^{epa} , can be given as

$$R^{epa} = \min_{\substack{m=0,1,\dots,M+1 \\ l=1,2,\dots,L}} (R_{m,k}^{epa}). \quad (7)$$

IV. SIMULATION AND RESULTS

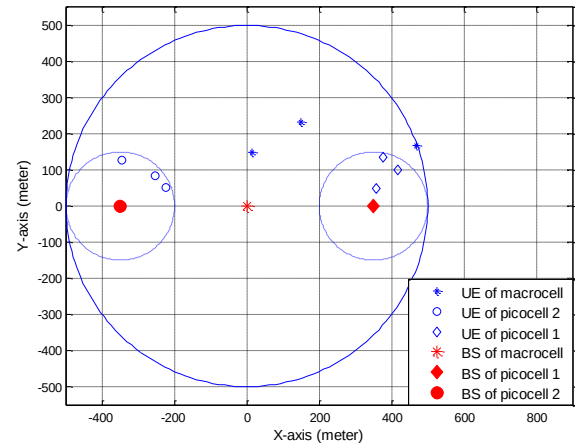


Figure 2. Simulation model for the multicast among cells in a Het-Net

Fig. 2 shows the simulations model for the multicast transmission in the Het-Net. BSs of a macrocell and two picocells simultaneously transmit different common message to their served UEs, respectively. The BSs and UEs are deployed within a 2-dimensional region ($1\text{km} \times 1\text{km}$). The BSs of macrocell and picocells are, respectively, fixed at the coordinates (0,0), (0,350), and (0,-350). The service coverage of macrocell is 500m and that of picocell is 150m. For simplicity, a simple path loss model of $(1/d^2)$, where d is the Euclidean distance in meters between transmitting and receiving devices, is considered and shadowing is not considered [7, 15]. Additionally, i.i.d. block Rayleigh fading channels are assumed among BSs and UEs. The (fast Fourier transform) FFT size of 128 is considered. The AWGN powers at UE(s) are assumed to be identical at $N = -40\text{dBm}$. In the

simulations, the software package in [15] is utilized for solving the GP problem.

Fig. 3 compares the averaged minimum transmission rate for multicast among cells of the Het-Net in the cases of EPA and SubOpt with different power constraint of P_{tot}^C . With a low sum power consumption at BSs, e.g., $0 \leq P_{tot}^C \leq 25\text{dBm}$, the noise dominates the SINR, thus, a quit small transmission rate for multicast is observed for both SubOpt and EPA as shown in Fig. 3. Since the received SINR_k is an increasing function of $P_{m,l}$, the minimum transmission rate for multicast among cells for both of EPA and SubOpt is increased with a higher P_{tot}^C , e.g., $P_{tot}^C \geq 25\text{dBm}$. Moreover, owing to the effective power allocation with full CSI, the minimum transmission rate for multicast in the Het-Net in the case of SubOpt increases more quickly than that of EPA. In addition, with a different number of UEs, e.g., $K=8$, the similar performance trends can be observed for both SubOpt and EPA compared to those with $K=3$. Thereby, compared with EPA, the minimum transmission rate for multicast among all the cells in the Het-Net can be greatly improved to satisfy a max-min fairness by the proposed SubOpt.

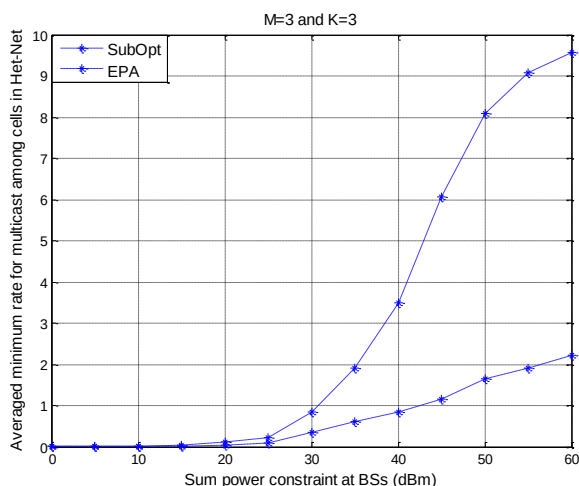


Figure 3. Average minimum rate for multicast among cells in Het-Net

V. CONCLUSIONS

In this paper, we consider the max-min fairness for multicast transmission in the Het-Net, where BSs in the Het-Net, respectively, transmit different common message to their served UEs. We first addressed the problem to maximize the minimum transmission rate for multicast in Het-Net. Due to the difficulty from the non-linear and non-positynomial constraint, it is hard to solve the problem directly. Instead, with the assumption of high SINR region, we find its suboptimal problem and solve it by the GP. Thus, a suboptimal power allocation algorithm is proposed to achieve a max-min fairness for multicast among cells in the Het-Net. Simulation results showed that with the

proposed algorithm the minimum transmission rate for multicast among cells in the Het-Net can be greatly improved compared to the EPA.

In addition, in this paper, only the case with a high operating SINR region is assumed. So if a low or medium SINR region is considered, the proposed algorithm may not be accurate. The optimal and suboptimal power allocation for low or medium SINR region may be an interesting and valuable topic and is left for future study.

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REFERENCES

- [1] E-UTRA and E-UTRAN Overall Description; Stage 2 (Release 8), 3GPP Technical Specification TS 36.300 V9.1.0, Sep. 2009. Available: <http://www.3gpp.org>.
- [2] Further Advancements for E-UTRA Physical Layer Aspects (Release 9), 3GPP Technical Specification TR 36.814 V0.4.1, Feb. 2009. Available: <http://www.3gpp.org>.
- [3] WiMAX Forum, "Mobile WiMAX- part I: A technical overview and performance evaluation," White Paper, Aug. 2006.
- [4] Further Advancements for E-UTRA Physical Layer Aspects (Release 9), 3GPP TR 36.814, v. 2.0.0, Mar. 2010.
- [5] Y. S. Huang, S. W. Mao, and Y. H. Li, "Downlink power allocation for stored variable-bit-rate videos," *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering (LNICTST)*, vol. 74, pp. 423-438, 2011.
- [6] D.P. Bertsekas and R.G. Gallager. Data Networks. Prentice-Hall, Englewood Cliffs, 1992.
- [7] P. Gong, P. Xue, D. Park, and D. K. Kim, "Optimum power allocation in a non-orthogonal amplify-and-forward relay-assisted network," *IEEE Trans. Veh. Technol.*, vol. 60, no. 3, pp. 890-900, Mar. 2011.
- [8] A. L. Stolyar and H. Viswanatha, "Self-organizing dynamic fractional frequency reuse in OFDMA systems," in *Proc. IEEE INFOCOM*, Phoenix, AZ, U.S.A., Apr. 13 - 18, 2008, pp. 691 - 699.
- [9] M. Bohge, J. Gross, and A. Wolisz, "Optimal power masking in soft frequency reuse based OFDMA networks," in *European Wireless Conference*, Aalborg, Denmark, May 17 - 20, 2009, pp. 162 - 166.
- [10] R1-104661, Comparison of Time-Domain eCIC Solutions, 3GPP Std., Madrid, Spain, Aug. 2010.
- [11] P. Xue, P. Gong, J. H. Park, D. Y. Park, and D. K. Kim, "Max-min fairness based radio resource management in fourth generation heterogeneous networks," in *Proc. IEEE ISCIT*, pp. 208-213, Sept. 2009.
- [12] P. Xue, P. Gong, J. H. Park, D. Y. Park, and D. K. Kim, "Radio resource management with proportional rate constraint in the heterogeneous networks," accepted and to be published in *IEEE Transactions on Wireless Communications*, 2011.
- [13] S. Görtzen, A. Schmeink, Visualization and analysis of the OFDMA downlink capacity region, in *Proc. International OFDM-Workshop (InOWo)*, Hamburg, S.1-4, Sep. 2009.
- [14] M. Chiang, C. W. Tan, D. Palomar, D. O'Neill, and D. Julian, "Power control by geometric programming," *IEEE Trans. Wireless Commun.*, vol. 6, pp. 2640-2651, July 2007.
- [15] M. Grant and S. Boyd, CVX: Matlab software for disciplined convex programming (web page and software), <http://stanford.edu/~boyd/cvx>, Feb. 2008.