Load Balancing Scheme with PTM Mode for Multicast Services Between MBSFN

Min Wang, Jijuan Wu, Qiaoyun Sun & Shuguang Zhang
Information School, Beijing City University, Beijing, China

Yinlong Liu & Yu Zhang
Institute of Information, Engineering Chinese Academy of Sciences, Beijing, China

ABSTRACT: In long term evolution (LTE) networks, the multicast services can be transmitted by single frequency network (SFN) mode or point-to-multipoint (PTM) mode, and the unicast services are delivered with point-to-point (PTP) mode. To avoid the network congestion in the LTE networks with the multicast and unicast mixed services, a load balancing (LB) scheme with PTM mode is proposed to minimize the demanded radio resources of the maximum load cell. The system model of the demanded radio resources is based on the signal to interference noise ratio (SINR) of multicast services with SFN mode and PTM mode. Then the minimization problem is solved by means of simulated annealing (SA) heuristics. It selects the optimal transmission mode between SFN and PTM for multicast services. Simulation results show that the proposed LB needs less demanded radio resources of the maximum load cell than SFN mode for all the multicast services.

Keywords: single frequency network; point-to-multipoint; point-to-point; load balancing; simulated annealing

1 INTRODUCTION

In long term evolution (LTE) networks, the single frequency network (SFN) is introduced to be a transmission mode for multicast and broadcast in the multiple cells [1], while unicast services are delivered with point-to-point (PTP) mode. A multicast broadcast single frequency network (MBSFN) area is a region within which all base stations (BSs) are synchronized and send the same multicast services in a SFN fashion. Thus SFN mode can achieve diversity gain and have high signal to interference noise ratio (SINR) [2]. However, the same time-frequency radio resources are needed in all the cells of the MBSFN area for a given multicast service though those cells do not need the multicast service. Furthermore, multicast services can be also provided by point-to-multipoint (PTM) mode in the single cell. PTM mode has no diversity gain, but it only allocates the radio resources for those cells which need the multicast service. Therefore, it is essential to select the optimal transmission mode between SFN and PTM for multicast services to minimize the demanded radio resources of the maximum load cell.

The work on load balancing in wireless system is inherited from the adaptation of resource allocation [3]. In order to guarantee diverse quality of service (QoS) demands, the dynamic resource allocation solutions [4] and the adaptive load distribution [5] are introduced for load balance. Joint packet scheduling and dynamic resource allocation [6] are proposed in orthogonal frequency division multiple access (OFDMA) system. Furthermore, the load balancing is proposed with the game theoretical approach in LTE networks [7]. According to the user association, the cell load balancing [8] is adopted for the heterogeneous wireless networks. Another local resource allocation for load balance in WLAN takes advantages of the cell breathing and adaptively controls the transmission power for the indications to minimize the maximum load [9]. A user association scheme with quality of service support for load balancing [10] is proposed in heterogeneous cellular networks, and it considers both user's achievable rate and load level of each BS by network-wide weighted utility maximization. The chunk-based resource allocation for multicast OFDMA systems [11] is introduced to maximize the total throughput with the bit error rate (BER) con-
a restraint. However, to our best knowledge, there is no research on load balancing for the multicast and unicast mixed services between MBSFN, especially considering PTM mode for multicast services in the LTE networks.

In order to minimize the demanded radio resources of the maximum load cell, a novel load balancing (LB) scheme with PTM mode is proposed for multicast services between MBSFN. With the two transmission modes of SFN and PTM, the SINR is analytically selected and the system model of the demanded radio resources in the maximum load cell is formulated. Then the simulated annealing (SA) algorithm selects the optimal transmission mode between SFN and PTM for multicast services.

The remainder of this paper is organized as follows: the system model is introduced in Section 2; the proposed LB is given in Section 3; Section 4 provides the simulation results; and Section 5 concludes with the paper.

2 SYSTEM MODEL

A multi-cell LTE network with the multicast and unicast mixed services is considered to be a MBSFN area. Let \( I \), \( K \) and \( J \) denote the number of cells, the number of users per cell and the number of multicast services in the MBSFN area, respectively. A set \( K_y \) is introduced to denote the users in cell \( i \) which need multicast service \( j \), and \( u_{ij} \) is defined for the demand relation between user \( k \) (\( 1 \leq k \leq K \)) in cell \( i \) (\( 1 \leq i \leq I \)) and multicast service \( j \) (\( 1 \leq j \leq J \)). And then \( u_{ij} \) is a binary variable as follows:

\[
u_{ij} = \begin{cases} 1 & k \in K_y \\ 0 & k \notin K_y \end{cases}
\]

Furthermore, a set \( I_j \) denotes the cells which need multicast service \( j \), and \( c_{ij} \) is defined for the demand relation between cell \( i \) (\( 1 \leq i \leq I \)) and multicast service \( j \) (\( 1 \leq j \leq J \)) as:

\[
c_{ij} = \begin{cases} 1 & i \in I_j \\ 0 & i \notin I_j \end{cases}
\]

i.e. \( c_{ij} \) can be also given by:

\[
c_{ij} = \begin{cases} 1 & \sum_{k=1}^{K} u_{ikj} \neq 0 \\ 0 & \sum_{k=1}^{K} u_{ikj} = 0 \end{cases}
\]

The multicast services are provided by SFN mode or PTM mode, while the unicast services are transmitted with PTP mode. A set \( \Omega \) represents the multicast services in the MBSFN area. Each multicast service can only select one mode between SFN and PTM. Let \( \Omega_{SFN} \) and \( \Omega_{PTM} \) be the set of multicast services in the set \( \Omega \) with the transmission mode of SFN and PTM respectively, where \( \Omega = \Omega_{SFN} + \Omega_{PTM} \).

For the multiple users in a cell, the demanded radio resources decide on the SINR of each user, especially the lowest SINR.

Taking \( N \) interfering cells into account in MBSFN, whose signals arrive to the receiver by \( R \) different paths, the average SINR expression of SFN mode at a given point \( o \) is expressed as [12]:

\[
SINR(o) = \frac{\sum_{i=0}^{N} \sum_{r=1}^{R} w(\tau(o) + \delta_r)P_r}{\sum_{i=1}^{N} \sum_{r=1}^{R} (1 - w(\tau(o) + \delta_r))P_r} + N_0
\]

For PTM mode, the average SINR expression at a given point \( o \) is also expressed as:

\[
SINR(o) = \frac{\sum_{i=1}^{N} \sum_{r=1}^{R} w(\delta_r)P_r}{\sum_{i=1}^{N} \sum_{r=1}^{R} P_r} + N_0
\]

Where, the weight function \( w(\tau) \) can be simplified by:

\[
w(\tau) = \begin{cases} 1 & 0 \leq \tau < T_{CP} \\ \frac{\tau - T_{CP}}{T_u} & T_{CP} \leq \tau < T_{CP} + T_u \\ 0 & \text{otherwise} \end{cases}
\]

Where, \( P_r \) is the average power associated with the \( r \) path, \( \tau(o) \) is the propagation delay from base station \( i \), \( \delta_r \) is the additional delay added by path \( r \), \( q_i(o) \) is the path loss from base station \( i \), \( T_{CP} \) is the length of the cyclic prefix and \( T_u \) is the length of the useful signal frame.

For multicast services, the SINR is selected according to the transmission modes. SFN mode selects the
3 LOAD BALANCING SCHEME WITH PTM MODE

3.1 Load Balancing Problem

To avoid the traffic congestion in the LTE networks with the multicast and unicast mixed services, the number of the demanded radio resources units for the maximum load cell is minimized by selecting the optimal mode between SFN and PTM for each multicast service in the set \( \Omega \). Since the unicast services are only provided with PTP mode, the corresponding demanded radio resources for the unicast services in the maximum load cell is constant. Furthermore, the multicast services can be transmitted with SFN mode or PTM mode.

When multicast service \( j \) is needed in each cell, it is provided by SFN mode with the minimum demanded radio resources for diversity gain. However, not all the cells require multicast service \( j \). SFN mode must allocate extra radio resources for the cell which does not need multicast service \( j \). For multicast service \( j \), PTM mode needs more resources than SFN mode because it has no diversity gain. But it only allocates the radio resources for those cells which need multicast service \( j \). Therefore, according to the current demand relation between cell \( i \) and multicast service \( j \), it is vital for multicast service \( j \) in the set \( \Omega \) to select the optimal transmission mode between SFN and PTM, so as to need less radio resources of the maximum load cell.

Then \( \Omega_{\text{SFN}} \) and \( \Omega_{\text{PTM}} \) are set according to the current demand relation between the users and the services. Let \( I^* \) be the maximum load cell in the MBSFN area, and then the set \( \Omega_{I^*} \) denotes the services in the cell \( I^* \) and \( L_{i^*} \) is the number of the demanded radio resources units for the services in \( \Omega_{I^*} \).

From the formula (8), \( L_{i^*} \) is given by:

\[
L_{i^*} = \sum_{j \in \Omega_{I^*}} B_j + U_{i^*}
\]

Each MBSFN area has its \( L_{i^*} \) and Let \( L_{\max} \) be the maximum \( L_{i^*} \) of all the MBSFN areas. For load balancing between the MBSFN areas, it minimizes \( L_{\max} \) by selecting the optimal mode between SFN and PTM. Therefore, the object function is formulated as:

\[
\min L_{\max}
\]
Note that $\Omega_{\text{SFN}}$ and $\Omega_{\text{PTM}}$ decide on the less $L_{\text{max}}$ where the conflict of selecting the optimal mode between SFN and PTM for the multicast service. When $L_{\text{max}}$ of SFN mode is equal to that of PTM mode, it selects SFN mode to deliver the multicast service.

According to the current demand relation between the users and the multicast and unicast mixed services, all kinds of the permutation and combination are performed between the multicast services and the set of $\Omega_{\text{SFN}}$ and $\Omega_{\text{PTM}}$. In each permutation and combination, $L_{\gamma}$ is calculated and the maximal $L_{\gamma}$ is selected as $L_{\gamma\ast}$ for each MBSFN area. And then $L_{\text{max}}$ is achieved for all the MBSFN areas. Among all kinds of the permutation and combination, the minimal $L_{\text{max}}$ with the corresponding $\Omega_{\text{SFN}}$ and $\Omega_{\text{PTM}}$ is the optimal solution to realize the object function of $\text{Min } L_{\text{max}}$. However, the comparative selection of the overall permutation and combination leads to high computation complexity. Therefore, the minimizing $L_{\text{max}}$ problem is solved by means of SA heuristics.

3.2 Simulated Annealing Algorithm

The method to find a feasible service set of $\Omega_{\text{SFN}}$ and $\Omega_{\text{PTM}}$ is realized by using the SA technique [13]. The algorithm aims to minimize $L_{\text{max}}$ while it searches for a feasible service set. It begins the search from an initial service set $S$ and an initial temperature value $T$, as illustrated in Figure 1:

1. Compute initial solution $S$ and temperature $T$
2. while thermal equilibrium or stopping criterion is not reached
3.     while max number of iterations or stopping criterion is not reached
4.         Obtain new solution $S'$;
5.         Compute $\delta = L_{\text{max}}(S') - L_{\text{max}}(S)$;
6.         if $\delta < 0$ then
7.             $S = S'$;
8.         else
9.             if random$(0,1) < \exp(-\delta/T)$ then
10.                $S = S'$;
11.            end_if
12.        end_if
13. Update number of iterations;
14. end_while
15. Decrease $T$ according to the annealing schedule;
16. end_while

Figure 1. Simulated annealing algorithm.

4 PERFORMANCE EVALUATION

To evaluate the $L_{\text{max}}$ performance of the proposed LB with PTM mode for multicast services between MBSFN, LB is compared with SFN and PTM in the different scenarios of $I$, $K$ and $J$. We consider $I$ cells to be a MBSFN area, each cell has $K$ users. There are $J$ multicast services which can be provided in the MBSFN area. Thus the topology of the multi-cell MBSFN area is scalable. LB minimizes $L_{\text{max}}$ by selecting the optimal mode between SFN and PTM for the multicast services. SFN and PTM only adopt SFN mode and PTM mode for all the multicast services in the MBSFN area, respectively. The greater the difference of $L_{\text{max}}$ between LB and the less one of SFN and PTM is, the higher the performance gain of the $L_{\text{max}}$ in LB is.

4.1 7 Cells in MBSFN Area

Figure 2. Impact of $K$ on $L_{\text{max}}$ of SFN, PTM and LB ($J = 50$).
To analyze the influence of $K$ on SFN, PTM and LB, the $L_{\text{max}}$ is compared via simulation with the different $K$ for the fixed $I = 7$ and $J = 50$. As indicated in Figure 2, SFN or PTM costs more $L_{\text{max}}$ than LB does because LB benefits from the selection of transmission mode between SFN and PTM for multicast services. When $K$ is smaller, SFN mode needs more radio resources for those unneeded multicast services and the $L_{\text{max}}$ of SFN mode is more than that of PTM mode. With the increasing $K$, PTM mode allocates multiple radio resources for more users and the $L_{\text{max}}$ of PTM mode is more than that of SFN mode. For multicast services, LB selects the optimal mode between SFN and PTM for multicast services. When $K$ is smaller, SFN mode needs more radio resources for those unneeded multicast services and the $L_{\text{max}}$ of SFN mode is more than that of PTM mode. With the increasing $K$, PTM mode allocates multiple radio resources for more users and the $L_{\text{max}}$ of PTM mode is more than that of SFN mode. For multicast services, LB selects the optimal mode between SFN and PTM for multicast services.

![Figure 3](image_url)

**Figure 3. Impact of $J$ on $L_{\text{max}}$ of SFN, PTM and LB ($I = 7$).**

To evaluate the impact of $J$ on SFN, PTM and LB, the $L_{\text{max}}$ performance of the different $J$ with the fixed $I = 7$ is depicted in Figure 3. For the same $I$, the $L_{\text{max}}$ of LB is the least whether the $L_{\text{max}}$ of SFN is more than that of PTM or not. From Figure 3(a), the $L_{\text{max}}$ of SFN is the most and that of LB is the least with $K = 40$. For $K = 50$ in Figure 3(b), the $L_{\text{max}}$ of PTM is the most and that of LB is the least. The larger $J$ is, the more $L_{\text{max}}$ are allocated to SFN, PTM and LB. But the difference of $L_{\text{max}}$ between LB and the less one of SFN and PTM becomes greater with the increasing $J$.

### 4.2 19 Cells in MBSFN Area

The impact of $K$ and $J$ on the $L_{\text{max}}$ of SFN, PTM and LB with the fixed $I = 19$ is depicted in Figure 4 and Figure 5, respectively. It can be seen that the $L_{\text{max}}$ performance of $I = 19$ is similar to that of $I = 7$. The $L_{\text{max}}$ of LB is less than that of both SFN and PTM. However, the equal $L_{\text{max}}$ for the two modes of SFN and PTM is the $K$ point from 40 to 50 and from 30 to 40 with the fixed $I = 7$ and $I = 19$, respectively. The $K$ of the equal $L_{\text{max}}$ for SFN and PTM is smaller with the increasing $I$. The larger $I$ is, the greater the diversity gain of SFN is achieved from more cells in the MBSFN area. Then the less $L_{\text{max}}$ are allocated to SFN and the same $L_{\text{max}}$ for PTM can be only allocated to smaller $K$ with multiple radio resources for less users. As can be seen from the figures, the $L_{\text{max}}$ of PTM is less than that of SFN when $K$ is smaller than the $K$ point of the equal $L_{\text{max}}$ for SFN and PTM; or vice versa. Therefore, the proposed LB selects the optimal mode between SFN and PTM for the multicast services and reduces the $L_{\text{max}}$ between MBSFN.

![Figure 4](image_url)

**Figure 4. Impact of $K$ on $L_{\text{max}}$ of SFN, PTM and LB ($I = 50$).**
5 CONCLUSION

In this paper, a novel LB with PTM mode is proposed for the LTE networks with the multicast and unicast mixed services. It formulates the system model based on the SINR of SFN mode and PTM mode and selects the optimal transmission mode by SA to minimize the demanded radio resources. The simulation results show that LB needs less demanded radio resources for the maximum load cell than SFN and PTM in the different number of cells in MBSFN area, users per cell and multicast services.

ACKNOWLEDGMENTS

This work is supported by Beijing Natural Science Foundation (4154072).

REFERENCES

[1] 3GPP TR 36.913. 2008. Requirements for further advancements for E-UTRAN (LTE-Advanced).
[2] A. Alexiou, C. Bouras, V. Kokkinos & G. Tsichritzis, 2010. Communication cost analysis of MBSFN in LTE. In Proc. PIMRC 2010, pp: 1366–1371.
[3] L. Du, J. Bigham & L. Cuthbert. 2003. Towards intelligent geographic load balancing for mobile cellular networks. *IEEE Trans. on Systems, Man, and Cybernetics*, 33(4): 480–491.
[4] S. Kyuho, C. Song, & G. Veciana. 2009. Dynamic association for load balancing and interference avoidance in multi-cell network. *IEEE Trans. on Wireless Communications*, 8(7): 3566–3576.
[5] Hongseok Kim, G. de Veciana, X.Y. Yang & M. Venkatachalam. 2012. Alpha-optimal user association and cell load balancing in wireless networks. *IEEE Trans. on Networking*, 20(1): 177-190.
[6] A.F. Al Rawi, B.S. Sharif & C.C. Tsimenidis. 2011. User priority aware scheduling and dynamic resource allocation in orthogonal frequency division multiple access. *IET Communications*, 5(7): 1006–1019.
[7] M. Sheng, C.G. Yang, Y. Zhang & J.D. Li. 2014. Zone-based load balancing in LTE self-optimizing networks: a game-theoretic approach. *IEEE Trans. on Vehicular Technology*, 63(6): 2916-2925.
[8] Q.Y. Ye, B.Y. Rong, Y.D. Chen, M. Al-Shalash, C. Caramanis, & J.G. Andrews. 2013. User association for load balancing in heterogeneous cellular networks. *IEEE Trans. on Wireless Communications*, 12(6): 2706-2716.
[9] Y. Bejerano & S. J. Han. 2009. Cell breathing techniques for load balancing in wireless LANs. *IEEE Trans. on Mobile Computing*, 8(6): 735–749.
[10] T.Q. Zhou, Y.M. Huang, L.X. Fan & L.X. Yang. 2015. Load-aware user association with quality of service support in heterogeneous cellular networks. *IET Communications*, 9(4): 494–500.
[11] V.D. Papoutsis & S.A. Kotsopoulos. 2011. Chunk-based resource allocation in multicast OFDMA systems with average BER constraint. *IEEE Communications Letter*, 15(5): 551–553.
[12] L. Rong, Q. Haddada & S. Elayoub. 2008. Analytical analysis of the coverage of a MBSFN OFDMA network. In Proc. GLOBECOM 2008, pp: 1-5.
[13] C.C. Ribeiro, S.L. Martins & I. Rosseti. 2007. Metaheuristics for Optimization Problems in Computer Communications. *Computer Networks*, 30(4): 656 – 669.