International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 6, December 2022, pp. 6311~6319
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i6.pp6311-6319

Permutation based load balancing technique for long term evolution advanced heterogeneous networks

Mohammed Jaber Alam[1], Abdul Gafur[2], Syed Zahidur Rashid[2], Md. Golam Sadeque[3], Diponkor Kundu[3], Rosni Sayed[3]
[1]School of Engineering and Technology, Central Queensland University, Queensland, Australia
[2]Department of Electronic and Telecommunication Engineering, International Islamic University Chittagong, Chattogram, Bangladesh
[3]Faculty of Engineering, Pabna University of Science and Technology, Pabna, Bangladesh

Article Info

Article history:

Received Sep 27, 2021
Revised Jun 10, 2022
Accepted Jul 5, 2022

Keywords:

Cell range extension
Heterogeneous network
Interference mitigation
Load balancing
Long term evolution advanced

ABSTRACT

Traffic congestion has been one of the major performance limiting factors of heterogeneous networks (HetNets). There have been several load balancing schemes put up to solve this by balancing load among base stations (BSs), but they appear to be unfeasible due to the complexity required and other unsatisfactory performance aspects. Cell range extension (CRE) has been a promising technique to overcome this challenge. In this paper, a permutation based CRE technique is proposed to find the best possible formation of bias for BSs to achieve load balance among BSs. In comparison to the baseline scheme, results depict that the suggested method attains superior performance in terms of network load balancing and average throughput. The complexity of the suggested algorithm is considerably reduced in comparison to the proposed permutation based CRE method it is further modified from.

Corresponding Author:

Mohammed Jaber Alam
School of Engineering and Technology, CQ University
4721, Rockhampton, Australia
Email: alam.jaber42@gmail.com

1. INTRODUCTION

To meet the flooding traffic demands, cellular networks are evolving towards heterogeneous networks (HetNets) by deploying small base stations (SBSs), e.g., femto-cells and pico-cells, which are different from macro base stations (MBSs) usually in terms of physical size, transmit power, simplicity of arrangement and expense [1]. A HetNet generally contains an MBS and several small cells, which are costly to manage and keep up. The cell edge users of a macro cell still connect to the MBS despite the availability of small cells nearby the cell edges; because of the high transmit power of MBS, unlike SBS. Mobile users must be effectively offloaded onto the small cell, which will improve the data rate as small BSs can provide more resource blocks compared to the congested macro-cell. Thus, by transferring more users to the small BSs, the load of the macro-cell can be decreased, and the MBS can better serve its users. Moreover, the load of BSs becomes more uniformly balanced as the users are distributed fairly among the small BSs. Hence there will be less burden on the MBS whereas the SBSs can be effectively utilized to maximize the capacity [2], [3].

Annually, an average mobile user is projected to download around 1 terabyte (TB) of data. Supporting this huge and fast expansion in information use and network is an amazingly overwhelming undertaking in present 4G keen frameworks. Accordingly, for expanding limit the remote interchanges cannot resist the urge to confront, the new difficulties of high-recurrence data transmission [4]. 5G and 6G wireless communications envision smart systems with magnitudes of rise in bandwidth, wireless data rates, connectivity, and coverage together with energy consumption. There are several methodologies in the state of art to handle such challenges individually, but this project aims to deliver the multi-objective solution which is unique. Special attention will be given to minimize the cost of deployment of the network to make the research viable in practical application. The experimental study will develop a novel algorithm to achieve the 5G and 6G based smart systems [5]–[7].

In a two-stage femto-cell network, there are two sorts of disruptions: cross-tier and co-tier. Cross-tier interference occurs when femto-cells and macro-cells use a common channel. When the physical resource blocks (PRBs) of femto-cells and macro-cells are the same, there is interference. There has been a lack of attention paid to the potential for interference between the electrical network and the femto-electrical cell's system (FUEs). Co-tier interference, on the other hand, is interference between femto-cells [8]. Femto-cells spread uniformly within the macro-cell, and as a result there is space between each of these cells, resulting in an evenly spaced cover.

Using the same set of PRBs throughout a network of dispersed femto-cells can cause problems in both the uplink and the downlink. Direct links, backhaul links, and access links sharing the same set of PRBs can cause intracell interference. There is an inter-RN interruption when the same PRBs are used by two nearby nurseries. To describe the resulting interference as "intercellular disruption", in a macro-cell that shares PRBs with a neighboring macro-cell will use the term "nearby macro-cell user" [9].

This project aims to solve the critical challenges to achieve smart systems of 5G and 6G network standards. During the most recent few decades, the world has seen a continuous, yet consistent development of versatile remote correspondences towards 2G, 3G and 4G networks. Other than this, with the consistently expanding ubiquity of savvy gadgets, at present, all IP based long term evolution (LTE) networks have turned into a piece of regular daily existence. As a result, user-oriented multimedia applications such as video conferencing, high-definition video streaming, online education, e-healthcare, and online gaming are becoming increasingly popular. These new apps are not only meeting the needs of consumers, but they are also opening up new business opportunities for operators, allowing them to raise their revenue [10], [11].

Bias or offset values can be applied to SBSs to extend the cell range, such that the end-user will pick the Pico base stations (PBS) because of its cell association criterion being greater than the MBS after adding bias. However, because to the discrepancy in transmit power between MBSs and PBSs, UEs in the increased service area of PBSs might suffer from significant interference from the MBS [12], [13]. It is therefore vital to investigate how the bias for each SBS may be correctly established. Several research have been done on load balancing. The link between cell load and the signal-to-interference-and-noise ratio (SINR) was not taken into account in the research in [14]. Because each cell was merely estimated using the number of users in each cell, this may not be the most accurate way to measure the cell's real load. For instance, each user's traffic amount has a significant impact on cell load. If full queues are assumed at all base stations in a heterogeneous network with a CRE bias, outage and throughput of the entire network are negatively affected, according to [15]. However, as pointed out by [16]–[18], this assumption may not be accurate and has to be modified. In this research work, a permutation-based technique is proposed to determine the best bias formation for CRE to obtain load balance among BSs. Although this is a heuristic search, it can be used for all the BSs with consideration to find out the permutation that gives the improved network balance index (NBI) [19], [20].

2. SYSTEM MODEL

One MBS and several picocells at the macrocell edge servicing several customers are taken into account in the down-link of a 3 GPP LTE-A network, as depicted in Figure 1. The total network is simulated in accordance with TR 36.872 and assumes orthogonal frequency-division multiple access (OFDMA) with a frequency reuse factor of one (3 GPP, 2012 b) [21]–[23] with specifications shown in Table 1. S and U represent the sets of BSs (with s=0 denoting the MBS) and users, respectively. The available number of sub-channels in the heterogeneous network is represented by K and full physical resource block reuse is permitted in the heterogeneous network. b_{su} is stated as the association indicator where b_{su}=1 if user u associates with base station s, else b_{su}=0. The data rate or throughput of user u obtained on a sub-channel by base station s is modelled as Shannon's capacity:

$$R_{su} = B.\log(1 + \Upsilon_{su}) \tag{1}$$

where B is the bandwidth of a PRB and

$$\Upsilon_{su} = (P_s.G_{su})/(\sum_{i\in S|\{s\}} P_i G_{iu} + P_{AWGN}) \tag{2}$$

is the signal-to-interference-plus-noise-ratio (SINR) between base station *s* and user *u*. In (2), P_s is the transmission power of base station *s*, G_{su} is the gain of down-link channel between base station *s* and user *u*, P_{AWGN} is the additive white Gaussian noise power. P_i is the transmission power of the interfering cells other than the transmitting BS *s*, G_{iu} is their gain. It is expected that G_{su} has been averaged over all physical resource blocks in the whole channel spectrum, i.e., frequency-selective fading and rapid fading, due to the assumption that cell selection is carried out over an extended period of time. There are no significant differences in SINR between base station s and user u during the association time because G_{su} is constant regardless of dynamic channel fluctuations.

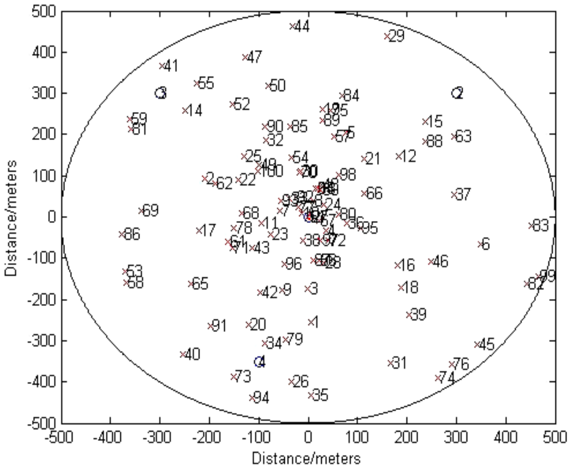

Figure 1. Layout of system model consisting 1 MBS, 3 PBSs and 100 users

Table 1. The performance of

Variable	Power (kW)
Macro cell radius	500 m
Small cell radius	50 m
Total number of sub-channels, k	100
Sub-channel bandwidth	180 kHz
Antenna gain	5 dB
SBS transmit power	30 dBm
MBS transmit power	43 dBm
Noise power spectral density	-174 dBm/Hz
User noise figure	9 dB
Shadowing standard deviation	10 dB
PBS path loss model	140.7+36.7*log10(d) dB (d [km])
MBS path loss model	128.1+36.7*log10(d) dB (d [km])
Channel	Rayleigh fading
Number of trials	1000

3. METHOD

The introduced algorithm is presented in algorithm 1, serves to find the best bias of cell range extension individually for each of these Pico base stations (PBSs) to attain load balance across the network. The users are associated to the BSs by the best SINR received. It is assumed that the sub-channels are distributed to the users by round-robin scheduling, to minimize the complexity in the association part and also to study the effect of the proposed technique solely on the load balancing of the HetNets. The proposed method is a modified version of the permutation method with reduced complexity in terms of sorting a smaller number of formations. The bias range selected for the permutation method is from (0-20) dB following previous literatures [24], [25]. Permutation is a basic mathematical term which helps us to sort out all the possible formations of the variables present. Literature's depiction of permutation as an orderly arrangement is diverse [15].

3.1. k-permutations of *n*

In certain combinatorics textbooks, the term "permutation" is used as a synonym for "ordered arrangements where no detail occurs more than once, but without the necessity of using all the components from a given set. These are not variations except in exceptional circumstances; rather, they are natural features of the ordered association subject. Certainly, this utilizes frequently takes into account of thinking about preparations of hard and fast elements of k length taken from a given set of length *n*. The number of such *k* permutations of *n* is given by the product,

$$P(n,k) = n.(n-1)(n-2)\ldots(n-k+1) \tag{3}$$

which is zero when *k*>*n*, and otherwise is equal to (4).

$$P(n,k) = n!/(n-k)! \tag{4}$$

The time period combination is strongly linked to this use of the permutation word. A combination of *k*-element of an *n*-set *S* is a *k* detail subset of *S*, the factors that might not be structured. by taking all the *k* detail subsets of *S* and arranging every of them in all feasible methods we acquire all the *k*-diversification of *S*. The quantity of *k*-mixtures of an *n*-set, *C(n,k)*, is hence associated with the range of *k*-permutations of *n* by means of (5).

$$C(n,k) = \frac{P(n,k)}{p(k,k)} = \frac{n!}{(n-k)!*k!} \tag{5}$$

3.2. Permutations with repetition

Ordered preparations of the elements of a hard and fast *S* of length *n* in which repetition is authorized are referred to as *n*-tuples, however, have now and again been referred to as permutations with repetition even though these are no longer permutations in standard. These are also known as phrases over the alphabet *S* in a few contexts. If the set *S* has *k* elements, the variety of *n*-tuples over *S* is:

$$P(n,k) = k^n \tag{6}$$

K-tuples have no restrictions on the number of times an element or variable appears. If restrictions are placed on the frequency of an element or variable, this component ceases to be valid.

Here, the permutation possible for 3 PBSs is provided by (10), where *n* is the number of PBSs and *k* is the bias range. So, for 3 PBSs and (0-20) dB bias range, it becomes $21^3 = 9261$ possible formations. Figure 2 shows the NBI versus permutation index graph, where we can point out the best possible bias permutation index that provides the maximum NBI. For each of the situations, like different number of users or change of channel parameters, the permutation index needs to be found out. Due to the situation change, the bias also needs to change to obtain the maximum network balance. Therefore, it becomes a little bit complex and not feasible although it gives a satisfactory NBI.

‣ Algorithm 1: Proposed Algorithm

• Input: Initialize the network parameters
• Initialization of all variables to zeroes:

1. Each UE u measures the SINR based on the pilot signal from each BS s, and estimates R_{su} and N_{su} with (1) and (3) respectively.
2. Each UE u sends the information of R_{su} and N_{su} to each BS s.
3. for (b=0:1:x)
4. Bias, b is added to the SINR of the PBSs.
5. Users are associated by the best SINR received from the particular BS and NBI is calculated according to (11)
6. end
7. Choose the bias that gives he best NBI.

Figure 2. Proposed algorithm

As there are too many permutations to sort out for each instance, the range we need to search should be decreased. Because we need to also consider the time it consumes to enhance the network performance along with increasing the capacity. So, it is necessary to find an idea to decrease this number of possible formations yet achieve almost the same best possible outcome.

Therefore, the bias range has been reduced to minimize complexity. It is done by considering the traffic load of PBSs. By both theoretical calculation and simulation, it is concluded that the more the deviation of users associated with PBS away from 10% of total users, the NBI drops. As we can see from Figure 3, the permutation index has become 180 which was 9,261 in normal permutation that indicates a considerable complexity reduction. To study this, we need to see through:

$$NBI = 1 - \frac{|e-a|}{2*N} \tag{7}$$

where e is the expected associated number of users to the BSs. Actual user count is counted as a, and total user count as N. We assume e to be 70% for MBS and 10% of total number of users for each of the 3 PBSs. This is considered according to their transmission power disparity. We can observe that the closer the actual number of PBS users to 10%, NBI comes closer to 1. From experiments as shown in Figure 4, it is seen that a which refers to the actual number of users associated to BSs, the individual PBS's users are around 12-15% of total number when the NBI is maximum. At this point, the bias combination is observed to be 4-5 dB most of the time, for (20-100) users when there are 3 PBSs. For a greater number of BSs, the bias range drops because it needs a smaller number of users inside a further small area. This is because a greater number of PBSs means the area is further divided. So, for 3 PBSs in our system model, the extension observed is about 200 m for 5 dB bias (40 m per bias) where we can find (12-15)% of total users to achieve maximum NBI. So, we can conclude if 12-15% is under 250 m (50+200) of a PBS, we need to look for 5 dB as maximum bias for it. Similarly, if 12-15% of total users are under 210 m (50+160), 4 dB is considered as maximum bias and so on.

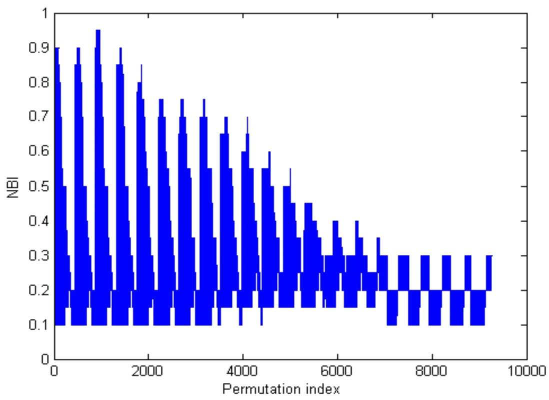

Figure 3. Network balance index for all the permutations of bias as regard to proposed method for 3 PBSs and 20 users

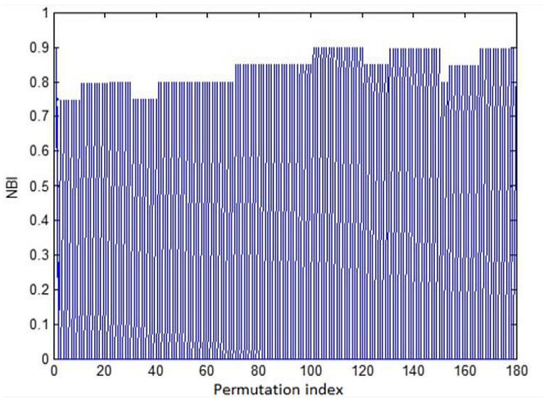

Figure 4. Network balance index for all the permutations of 0-20 dB for permutation method for 3 PBSs and 20 users

4. RESULTS AND DISCUSSION

The number of users linked simultaneously to the Pico base stations and macro base station has been depicted in Figure 5. It has been shown with regards to the different user number scenarios. The NBI versus the number of users graph is plotted for multiple users in Figure 6. 'No bias' depicts that the PBSs are not extended, and association is solely on best SINR among MBS and PBSs. For 'fixed bias', 12 dB has been used referred from recent literature. The best formation of bias for permutation method has been found out for (20-100) users and NBI is calculated. For permutation, bias range is set to 0-20 dB according to past literature. However, for the proposed method the bias range is managed to be decreased with respect to the traffic load. The range is 0-5 dB for proposed method. The result shows that NBI for proposed method is better than 'no bias' and 'fixed bias' and almost similar to the permutation method. The complexity is reduced a lot in the proposed method, which compromises for a slight drop at couple of instances.

In Figure 7, the average throughput is graphed against the number of users. At all instances, the permutation method exceeds the baseline schemes whereas the proposed technique also performs neck to neck with the permutation method. Again, considering the complexity of the permutation method, the outcome of the suggested technique seems acceptable considering its feasibility. The suggested scheme performs better than 'no bias' and 'fixed bias' in all instances. To prove that the algorithm is extendable to a larger number of base stations, a 5-PBS system has been modelled as shown in Figure 8. Here, the number of users, MBS and all other network parameters are kept like the original system model as used. The positions of the PBSs are chosen randomly but fixed for all the trials.

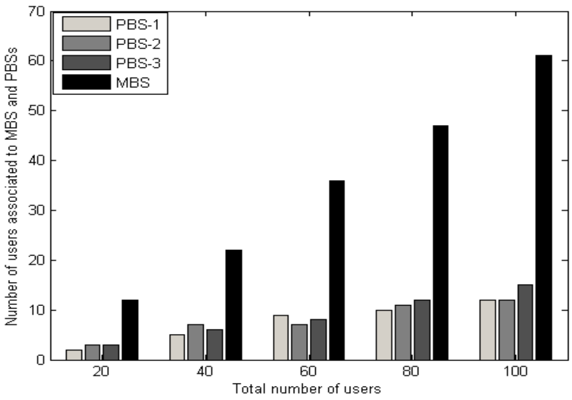

Figure 5. Comparison of number of users connected to PBS and MBS

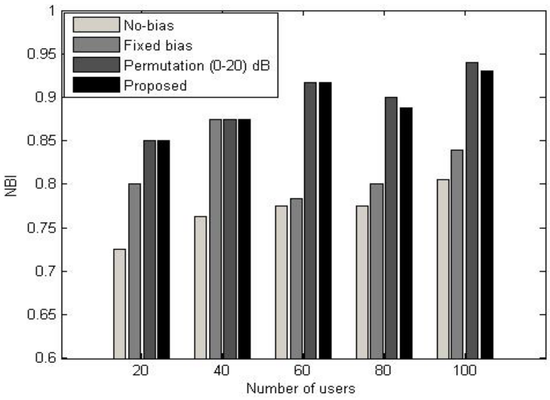

Figure 6. NBI comparison for multiple number of users

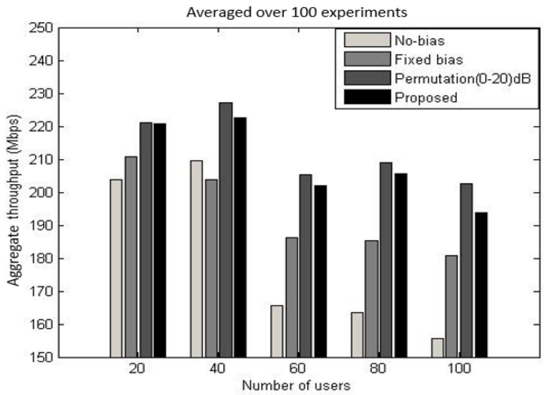

Figure 7. Average throughput performance for multiple number of users

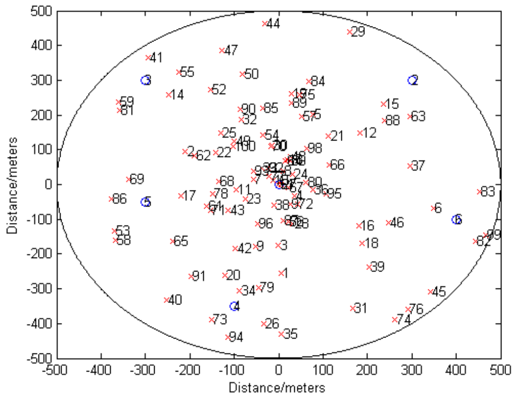

Figure 8. Layout for 1 MBS and 5 PBSs with multi-users

The NBI for the 5-PBS model is similarly measured and compared to the same schemes as shown in Figure 9. The performance of the permutation method is the best, but the proposed method also performs better in some instances. In Figure 10, the average throughput performance is observed to have a similar pattern for the permutation and proposed method. Thus, these two performs much better than the ‘no bias’ and ‘fixed bias’ method. The complexity of the proposed method is in fact much lesser than the permutation method. From above we can observe that as we increase the number of PBSs in the same MBS area, the maximum bias required to be searched for becomes less.

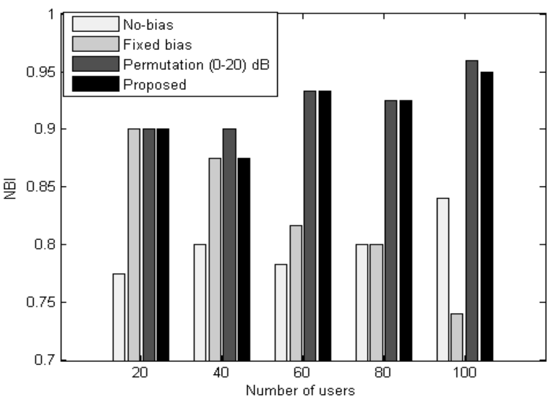

Figure 9. NBI for different number of users

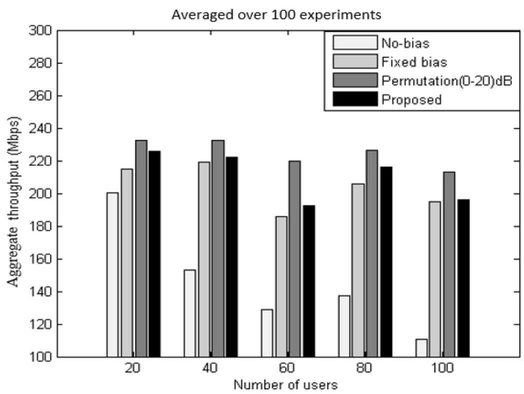

Figure 10. Average throughput performance for multiple number of users

As a result, the complexity will also be lower because a smaller number of formations needs to be searched whereas if the maximum bias would have been more than it would be actually not feasible. For example, if the maximum bias needed to be searched for in 5-PBS model is 6 in place of 3, the total formations would become 7^5 than 4^5 This trend is shown in Figure 11. Also, each of the PBS will have a less percentage of associated users individually to achieve the load balance.

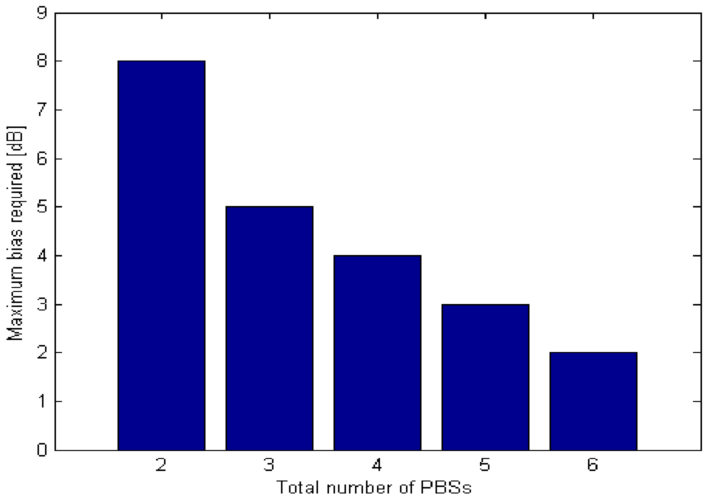

Figure 11. Trend of required maximum bias versus increasing number of PBSs

5. CONCLUSION

In this work, a permutation-based heuristic user association algorithm is suggested to locate the best bias formation based on the cell range extension (CRE) method for heterogeneous networks. Compared to the baseline techniques, the suggested solution outperforms them hands down, except for the initially proposed permutation method. The modified version of the permutation method has a considerably lower complexity, compared to initially proposed one. The proposed method is shown to be feasible, compatible, and extendable for load balancing in HetNets.

ACKNOWLEDGEMENTS

The author wants to acknowledge the support provided by the ICT department of Bangladesh for this work.

REFERENCES

[1] B.-J. Chang and S.-H. Liou, "Adaptive cooperative communication for maximizing reliability and reward in ultra-dense small cells LTE-A toward 5G cellular networking," *Computer Networks*, vol. 115, pp. 16–28, Mar. 2017, doi: 10.1016/j.comnet.2017.01.014.
[2] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 3, pp. 1617–1655, 2016, doi: 10.1109/COMST.2016.2532458.
[3] M. J. Alam, A. A. El-Saleh, C. K. Tan, I. Ku, Y. L. Lee, and T. C. Chuah, "Improved joint cell association and interference mitigation for LTE-a heterogeneous networks," in *2018 IEEE 4th International Symposium on Telecommunication Technologies (ISTT)*, Nov. 2018, pp. 1–4., doi: 10.1109/ISTT.2018.8701715.
[4] Y. Chen, J. Li, Z. Lin, G. Mao, and B. Vucetic, "User association with unequal user priorities in heterogeneous cellular networks," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 9, pp. 7374–7388, 2016, doi: 10.1109/TVT.2015.2488039.
[5] J. G. Andrews, S. Singh, Q. Ye, X. Lin, and H. S. Dhillon, "An overview of load balancing in hetnets: old myths and open problems," *IEEE Wireless Communications*, vol. 21, no. 2, pp. 18–25, Apr. 2014, doi: 10.1109/MWC.2014.6812287.
[6] H. Elshaer, M. N. Kulkarni, F. Boccardi, J. G. Andrews, and M. Dohler, "Downlink and uplink cell association with traditional macrocells and millimeter wave small cells," *IEEE Transactions on Wireless Communications*, vol. 15, no. 9, pp. 6244–6258, Sep. 2016, doi: 10.1109/TWC.2016.2582152.
[7] Y. Huang, S. Durrani, P. Dmochowski, and X. Zhou, "A proposed network balance index for heterogeneous networks," *IEEE Wireless Communications Letters*, p. 1, 2016, doi: 10.1109/LWC.2016.2633996.
[8] H.-S. Jo, Y. J. Sang, P. Xia, and J. G. Andrews, "Heterogeneous cellular networks with flexible cell association: a comprehensive downlink SINR analysis," *IEEE Transactions on Wireless Communications*, vol. 11, no. 10, pp. 3484–3495, Oct. 2012, doi: 10.1109/TWC.2012.081612.111361.
[9] M. Kamel, W. Hamouda, and A. Youssef, "Ultra-dense networks: a survey," *IEEE Communications Surveys and Tutorials*,

vol. 18, no. 4, pp. 2522–2545, 2016, doi: 10.1109/COMST.2016.2571730.

[10] D. Liu *et al.*, "User association in 5G networks: a survey and an outlook," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 2, pp. 1018–1044, 2016, doi: 10.1109/COMST.2016.2516538.

[11] S. Moon *et al.*, "Cell selection and resource allocation for interference management in a macro-picocell heterogeneous network," *Wireless Personal Communications*, vol. 83, no. 3, pp. 1887–1901, Aug. 2015, doi: 10.1007/s11277-015-2489-9.

[12] E. Rakotomanana and F. Gagnon, "Optimum biasing for cell load balancing under QoS and interference management in HetNets," *IEEE Access*, vol. 4, pp. 5196–5208, 2016, doi: 10.1109/ACCESS.2016.2607702.

[13] J. Roessler, "LTE-Advanced (3GPP Rel. 12) technology introduction white paper," White paper, Munchen: Application Note=1MA252-Rhode and Swarz International, pp. 1–58, 2015.

[14] Y. Qi and H. Wang, "Interference-aware user association under cell sleeping for heterogeneous cloud cellular networks," *IEEE Wireless Communications Letters*, vol. 6, no. 2, pp. 242–245, Apr. 2017, doi: 10.1109/LWC.2017.2665556.

[15] R. Sedgewick, "Permutation generation methods," *ACM Computing Surveys*, vol. 9, no. 2, pp. 137–164, Jun. 1977, doi: 10.1145/356689.356692.

[16] A. De Domenico, L.-F. Diez, R. Aguero, D. Ktenas, and V. Savin, "EMF-aware cell selection in heterogeneous cellular networks," *IEEE Communications Letters*, vol. 19, no. 2, pp. 271–274, Feb. 2015, doi: 10.1109/LCOMM.2014.2385094.

[17] J. Liu, R. Xie, and F. R. Yu, "Resource allocation and user association for HTTP adaptive streaming in heterogeneous cellular networks with small cells," *China Communications*, vol. 13, no. 9, pp. 1–11, Sep. 2016, doi: 10.1109/CC.2016.7582291.

[18] K. Sheikhidris, M. Y. Alias, M. Roslee, and M. J. Alam, "Throughput maximization based on user association in heterogeneous networks," in *2018 6th International Conference on Information and Communication Technology (ICoICT)*, May 2018, pp. 34–37., doi: 10.1109/ICoICT.2018.8528793.

[19] M. A. Lema, E. Pardo, O. Galinina, S. Andreev, and M. Dohler, "Flexible dual-connectivity spectrum aggregation for decoupled uplink and downlink access in 5G heterogeneous systems," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 11, pp. 2851–2865, Nov. 2016, doi: 10.1109/JSAC.2016.2615185.

[20] Y. L. Lee, J. Loo, T. C. Chuah, and A. A. El-Saleh, "Multi-objective resource allocation for LTE/LTE-A femtocell/HeNB networks using ant colony optimization," *Wireless Personal Communications*, vol. 92, no. 2, pp. 565–586, Jan. 2017, doi: 10.1007/s11277-016-3557-5.

[21] Y. L. Lee, J. Loo, T. C. Chuah, and A. A. El-Saleh, "Fair resource allocation with interference mitigation and resource reuse for LTE/LTE-A femtocell networks," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 10, pp. 8203–8217, Oct. 2016, doi: 10.1109/TVT.2016.2514535.

[22] M. D. M. Hasan and S. Kwon, "Cluster-based load balancing algorithm for ultra-dense heterogeneous networks," *IEEE Access*, vol. 8, pp. 2153–2162, 2020, doi: 10.1109/ACCESS.2019.2961949.

[23] M. A. Gadam, M. A. Ahmed, C. K. Ng, N. K. Nordin, A. Sali, and F. Hashim, "Review of adaptive cell selection techniques in LTE-Advanced heterogeneous networks," *Journal of Computer Networks and Communications*, vol. 2016, pp. 1–12, 2016, doi: 10.1155/2016/7394136.

[24] M. Eguizábal and Á. Hernández, "Joint dynamic resource allocation and load balancing-cell selection in LTE-A HetNet scenarios based on Type 1 inband relay deployments," *Computer Networks*, vol. 100, pp. 90–109, May 2016, doi: 10.1016/j.comnet.2016.02.018.

[25] A. Alhammadi *et al.*, "An intelligent spectrum handoff scheme based on multiple attribute decision making for LTE-A network," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 6, pp. 5330–5339, Dec. 2019, doi: 10.11591/ijece.v9i6.pp5330-5339.

BIOGRAPHIES OF AUTHORS

Mohammed Jaber Alam has been pursuing his PhD degree from CQ University, Australia. He is a research fellow at the School of Engineering and Technology, CQ University. He has completed his Master of Engineering Science by research from Multimedia University, Malaysia in 2019. He has been a Research Scholar in the same institution for couple of years. Previously in 2016, he has completed his Bachelor of Engineering Science degree with distinction achieving the best CGPA among the departments from IIUC, Bangladesh. He has authored and co-authored several publications in the field of engineering. His research interests include wireless communication, antenna systems, electrical systems, and semiconductor electronics fields. He can be contacted at email: alam.jaber42@gmail.com.

Abdul Gafur received the M.Sc. degree in Electrical Engineering (Telecommunication) from Blekinge Institute of Technology, Sweden. He is currently working as an Associate Professor in the department of Electronic and Telecommunication Engineering (ETE) under the Faculty of Science and Engineering (FSE) of International Islamic University Chittagong (IIUC), Bangladesh. He has contributed more than 23 technical articles in different international journals and conferences as an author and co-author. His main research interests include coherent optical transmission systems, free space optic and optical wireless communication systems. He can be contacted at email:engr.abdul.gafur@gmail.com.

Syed Zahidur Rashid received the M.Sc. degree in Computer Science and Engineering from Daffodil International University, Bangladesh. Previously he received the B.Sc. degree in Computer and Communication Engineering from International Islamic University Chittagong, Bangladesh. He is currently working as the Chairman of the Department of Electronics and Telecommunication Engineering, Faculty of Science and Engineering, International Islamic University Chittagong, Bangladesh. He has contributed to numerous research articles in various international refereed journals and conferences. His main research interests include free-space optical communications, wireless communications, enabling technologies for IoT, and machine learning. He can be contacted at email: szrashidcce@yahoo.com.

Md. Golam Sadeque has received B. Sc. Eng. degree in Electrical and Electronics Engineering (EEE) from Rajshahi University of Engineering and Technology (RUET) in 2011. He is pursuing a master of engineering science (M. Eng. Sc.) degree under the faculty of engineering at Multimedia University. He is also working as an assistant professor since 23 June 2015 in the department of EEE at Pabna University of Science and Technology (PUST), Pabna-6600, Bangladesh. His research interest includes the design of Radiofrequency power amplifier (RFPA) and Biomedical engineering. He can be contacted at email: msadeque.eee@pust.ac.bd.

Diponkar Kundu received the Master of Engineering Science (M.Eng.Sc.) degree from the department of Electrical Engineering of University of Malaya, Malaysia on 2015 and the B.Sc. Engineering degree from the department of Electrical and Electronic Engineering of Khulna University of Engineering and Technology, Khulna, Bangladesh on 2009. He joined as a Lecturer in the department of Electrical and Electronic Engineering (EEE) of Pabna University of Science and Technology (PUST), Bangladesh on 1 April 2009 and now he is serving as an Associate Professor, Department of EEE, PUST. He has published several publications in the field of Electrical and Electronic engineering. His current research interests are in antenna design, electronics and communication engineering. He can be contacted at email: d.kundu.eee@gmail.com.

Rosni Sayed has completed her B.Sc. and M.Sc. Engineering Degrees from Rajshahi University of Engineering and Technology, Bangladesh in 2012 and 2017, respectively. She has been working as a lecturer of Pabna University of Science and Technology (PUST), Pabna-6600, Bangladesh since 25th November, 2014. Currently she is an Assistant Professor. She has authored and co-authored several publications in the field of Electrical and Electronic Engineering. Her research interests include wireless communication, Bio-medical Engineering and Control System. She can be contacted at email: rosnisayed@gmail.com.