SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

An Optimization of RSRP on Wi-Fi and LTE-LAA Coexistence Networks

Nur Haidah Mohd Hanapiah[1,*], Azita Laily Yusof[1], Norsuzila Ya'acob[1]

[1] School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, 40450 Selangor, Malaysia

ARTICLE INFO

Article history:
Received 25 August 2024
Received in revised form 27 September 2024
Accepted 3 October 2024
Available online 30 October 2024

Keywords:
Wi-Fi; LTE-LAA; PSO; RSRP; energy detection

ABSTRACT

Over the last decade, mobile traffic has grown at an exponential rate, resulting in a scarcity and incompetent use of licensed spectrum by mobile network operators. Therefore, it is important to maintain effective communication to avoid disconnecting signals. The technique of regulating the power of a transmitter in order to improve the communication signal or entire quality of service is known as power control. It is mostly used to improve the performance of a communication device by controlling the transmission power. Power control, in most scenarios, allows the transmission or signal power to be scaled, leading to improved signal quality. On the other hand, power control methods are aimed at avoiding unnecessarily high-power transmission. Hence, particle swarm optimization (PSO) is a computational method for optimizing the reference signal received power (RSRP) by iteratively attempting to improve an unnecessarily high-power transmission solution in terms of a given quality measure. The objective of this research is to evaluate the optimum RSRP value and proposed ideal energy detection threshold for Wi-Fi and LTE-LAA in order to obtain fair coexistence between two networks. Thus, simulations for PSO are carried out using MATLAB software. Based on the results obtained, there are improvement in throughput for both networks after PSO implementation therefore, an ideal energy detection threshold is suitable to use in order to get fair coexistence between Wi-Fi and LTE-LAA networks. Consequently, all the results obtained will be used in following research work in order to evaluate user's handover in various scenarios.

1. Introduction

Wireless communications have seen tremendous growth in the number of mobile terminals as well as traffic demand for various multimedia applications. The vast disparity between current capabilities and forecast demand has expeditious academic and industrial communities to figure advanced technologies for increase in network capacity. Licensed-Assisted Access-Long Term Evolution (LAA-LTE) is evolving as a coming technology for telecommunication companies to operate in unlicensed spectrum for wireless data traffic offloading in order to sustain the potential growth in mobile services. Telecommunications companies have previously initiated unlicensed band technologies, such as Wi-Fi, that were integrated with their licensed wireless/wireline infrastructure

* *Corresponding author.*
E-mail address: nurhaidahmohdhanapiah96@gmail.com

https://doi.org/10.37934/aram.126.1.6070

for wireless traffic offloading. LAA-LTE is an extension of the 3G/4G/LTE-A network that offers unified mobility, authentication, security, and management. This allows for more efficient and seamless use of the unlicensed spectrum than the integration of Wi-Fi and LTE-A services. Furthermore, because they share the same core network and deployment strategy, LAA-LTE and Wi-Fi can coexist as good neighbours for mobile network users [1].

Nevertheless, in order to minimize or prevent performance degradation issues, the hidden node issue over shared medium access networks is a challenge that must be tackled. To minimize interference and ensure coexistence, LTE-LAA evolved node base station (eNB) attempt to choosing a channel not used by nearby Wi-Fi nodes or using a channel selection mechanism. In heavy traffic situations, the presence of high numbers of sensors in 5G networks would require the use of unlicensed bands when the restricted licensed band is unable to satisfy the demand for the service. The huge use of the free band for various operators would lead to an increase amount of interference from hidden nodes that Listen-before-Talk (LBT) mechanisms cannot prevent. Therefore, there is a need to have an optimum energy detection threshold for interference reduction by highlighting characteristic function of the energy detection decision variable in LTE-LAA and Wi-Fi coexistence networks [2]. The main objective in this research is to evaluate the optimum reference signal received power (RSRP) value and proposed ideal energy detection (ED) threshold for Wi-Fi and LTE-LAA in order to obtain fair coexistence between two networks. Calculation for optimum RSRP and energy detection threshold are used in this research. All simulation performance is performed using MATLAB. The rest of the paper is organized into three different sections. This section continues with further explain the related works on the Particle Swarm Optimization (PSO) and coexistence performance between LTE-LAA and Wi-Fi. The research methodology will be presented in Section 2. Simulation results and discussion are explained in Section 3 and finally, a conclusion is drawn in Section 4.

1.1 Related Works

Several researchers have been researched all over the world in order to fulfil the user’s requirement. In this research, an optimum RSRP was evaluated and new energy detection threshold value was proposed as an enhanced work to improvise the previous paper. In paper [3], the author creates a new framework for estimating Wi-Fi and LTE-LAA throughput in coexistence scenarios by modifying the well-known Bianchi model. As a byproduct, the impact of various network parameters such as the energy detection threshold on Wi-Fi and LTE-LAA coexistence is investigated and validated using a National Instrument (NI) experimental testbed. Paper [4], an adaptive Reference Signal Received Power Threshold ($RSRP_{th}$) was proposed in this paper to initiate the handover process using the user's speed and the handover signaling delay value. The probability of handover failure (pf) was calculated using the adaptive value of $RSRP_{th}$ and the proposed adaptive $RSRP_{th}$ value for handover initiation reduced the number of failed handovers. Particle swarm optimization (PSO) is a simple bio-inspired algorithm for searching for an optimal solution in the solution space. It differs from other optimization algorithms in that it requires only the objective function and is not affected by the gradient or any differential form of the objective [5]. Author [6], the PSO was the first to focus on simulating social behaviours as a stylized image of species movement or as a group [7] such as a bird flock or a fish school. The algorithm was simplified, and optimization was observed, as well as improved search performance [8].

The author's primary focus in this work will be the integration of these two domains: next-generation wireless networks (NGN) and swarm intelligence (SI) [9]. The author examines the applications of SI to resolve emerging issues in NGN, such as spectrum management and resource allocation, wireless caching and edge computing, network security, and a variety of other issues. In this paper [10], the authors conduct a thorough review of the existing literature on various issues concerning the operation of unlicensed radio access technologies (RATs) in the 6 GHz bands and they specifically discuss how key features in next-generation Wi-Fi are being designed to take advantage of these additional unlicensed bands. This paper also shed light on the potential challenges that unlicensed RAT designers may face in the near future. The authors investigated resource allocation issues in the 5G network using particle swarm optimization in this paper (PSO) [11]. The PSO algorithm is used to solve non-convex optimization problems and the simulation results show that their algorithm can reach convergence and outperforms the Genetic algorithm. This paper [12] has proposed a handover optimization technique based on signal strength, user speed, and data type. To optimize base station handovers, the author introduced a Particle Swarm Optimization (PSO) technique and a Particle Swarm Optimization with Passive Congregation (PSOPC) technique. The simulation results show that the proposed optimization technique precisely reduces handovers. Nonetheless, in this article [13], the author proposes a new strategy for resource allocation schemes that, through PSO-PFS hybridization, can assist users in a critical position (Particle Swarm Optimization). Furthermore, PFS (Proportional Fair Scheduling) takes into account the users' channel state conditions, and the PSO algorithm provides an optimal solution to the allocation problem and improves user performance based on their stat. The simulation results show that the PSO-PFS hybrid algorithm's resource allocation ensures the system's high throughput by ensuring user fairness. This paper [14] presents a repeatability study on raw RSRP measurements collected in a commercial LTE network in the 700 MHz frequency band. This process is aided by the common radio frequencies (RF) drive-test method, which employs a scanner-based tool as the measuring device. In the analysis phase, the main measurement statistical metrics are calculated after collecting all of the required data with the scanner. Thus, the repeatability of the RSRP measurements is investigated by comparing statistics from data collected along the same drive route on different days. Based on the limited data set collected, the LTE RSRP measurements have been confirmed to have good temporal repeatability and stability, allowing optimization to be based on a single LTE drive test. Authors in paper [15] evaluated the effect of asymmetry energy detection threshold between the Wi-Fi (-62 dBm) and LTE-LAA (-72 dBm) coexistence. The authors have developed a coexistence simulator in ns-3 and energy detection thresholds were varied for both Wi-Fi and LTE-LAA networks. The results demonstrated that performance of Wi-Fi and LTE-LAA were improved by lowering the Wi-Fi energy detection threshold from -62 dBm. It can be concluded that an overlapping Wi-Fi with LTE-LAA would improve coexistence performance compared to LTE-LAA are assumed by Wi-Fi as noise.

Thus, authors from previous study [16] designed the MAC protocol for LTE-LAA for fair coexistence by optimized the transmission time for maximized the overall normalized channel rate contributed by both networks while protecting Wi-Fi. Paper [17] proposed Wi-Fi energy tracking algorithm to identify the duration a dynamic ED threshold and Wi-Fi frame. The author proposes a novel Markov chain-based analytic model in this paper [18] to deal with the variation of the LAA frame structure overhead. Hence, when the analysis and simulation results are compared, the difference is only 0.2% on average, demonstrating the accuracy of the proposed model. This paper [19] describes the design of the LTEPro network, which combines LTE-LAA and LTELWA. By designing an appropriate distance, density as a ratio, and bandwidth allocation between three technologies to find the best cell location for high throughput. The results show that the pico LTE-pro network was designed with a range D1 of 3:4 of the LAA radius and D2 of 4:5 of the LTE radius. The node ratio and bandwidth allocation of LTE: LAA: LWA are 2: 2: 10 and 2: 4: 4 respectively, which affect LTE-Pro network performance and will improve LTE-Pro network performance. This paper [20] proposed an emergency load shedding optimization model to solve the DC blocking fault of the multi direct current (DC) receiving-end power grid. The model uses each node's load shedding as an optimization variable and the minimum total load shedding as an optimization objective. Thus, improves the algorithm's efficiency through parallel computing and validates the algorithm's feasibility using the provincial power grid model in China.

Furthermore, an adaptive power control for cochannel femtocells is presented in this paper [21]. To avoid co-channel interference, femtocells must detect the presence of macro users in their surroundings. By using adaptive power control on the femtocell downlink, interference is avoided. Further to that, the femtocells have a reporting mechanism and are linked to a coordinator, allowing for direct connections between femtocells. The results show that the Block Error Rate (BLER) requirements are met, and interference can be reduced by implementing the adaptive power control and reporting scenarios proposed. The author proposed an effective approach called the Adaptive Smart Power Control Algorithm (ASPCA) in the paper [22], which can be used to cluster users in coverage gaps and to address cross-tier interference issues by determining an appropriate serving range for femtocells without requiring standard changes or complicated cell negotiation. As a result, the author shows that, when compared to the conventional method, the ASPCA improved significantly macrocell performance by about 51.32% in average user throughput while having a minor impact on femtocell performance by about 8.63% in average user throughput and causing a negligible 0.46% overall loss in average throughput. Thus, the ASPCA also established favourable conditions for frequency-reuse-based schemes of Inter-Cell Interference Coordination (ICIC), such as Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR), which can be combined to provide the greatest benefit to cellular networks. Next, the authors [23] explore the user throughput and spatial spectral efficiency (SSE) of multi-UC coexisting LTE-LAA and Wi-Fi networks versus network density using the Matern hard core process in this paper. Throughput and SSE are calculated as functions of downlink successful transmission probability (STP), for which analytical expressions are developed and validated using Monte Carlo simulations. The results show that there is an optimal LTE access point (LAP) density for maximising LTE-LAA user equipment (LUE) throughput, and their derived closed-form STP lower bound of LUE can be used to achieve a satisfactorily accurate prediction of the optimal LAP density.

2. Methodology

In this research, Particle Swarm Optimization (PSO) technique has been used in order to obtain the optimum value of RSRP with respect to certain parameters such as noise power and probability of detection. Therefore, the purpose of this research is to proposed optimum value of energy detection threshold that will be achieved against optimum RSRP value.

The PSO technique requires the algorithm to explore multiple regions of the search space in order to find an optimum value, hence this process is known as exploration. Exploitation is the ability to focus the search to a promising area for the purpose to refine a potential solution. The swarm's particles fly through hyperspace while exploring and exploiting, and they have two fundamental reasoning capabilities: memory of their own best position - local best (lb) - and knowledge of the global or their neighbourhood's best - global best (gb). The position of the particle is influenced by its velocity however, in this research, it was influenced by noise power.

Let $xi(t)$ indicate the particle's position in the search space at each time step as written in Eq. (1). The particle's position is altered by adding a power noise, $vi(t)$, to its current position as given by Eq. (2)

$$xi(t+1) = xi(t) + vi(t+1) \tag{1}$$

where

$$vi(t) = vi(t-1) + clrl\big(localbest(t) - xi(t-1)\big) + \ c2r2\big(globalbest(t) - xi(t-1)\big) \quad (2)$$

with $xi(0) \sim U(xmin, xmax)$, acceleration coefficient $c1$ and c, and random vector $r1$ and $r2$.

Initially, the particle velocity is supposed to be zero. At iteration i^th, two critical parameters for each particle j are obtained: the best value of $xj(i)$ (the coordinates of particle j at iteration i) and declare as $Pbest(j)$. $Gbest$ will select the smallest value function across all previous iterations for all particles $xj(i)$.

Eq. (2) is used to calculate the particle's position or coordinates at iteration i^th. Finally, PSO will determine whether the present solution is convergent. Convergence happens when all particle positions lead to a similar value. If the current outcome is convergent, the iteration will end and the most optimal value will be produced. In this case, the ultimate outcome of the PSO approach is the value of d and RSRP.

The pathloss calculation is given as Eq. (3)

$$PL(dB)_{opt} = 15.3 + 37.6\ \log_{10} 100 * d_{opt} \quad (3)$$

where $PL(dB)_{opt}$ is optimum pathloss in dB, d_{opt} is the optimum distance. Thus, received signal strength indicator $RSSI_{opt}$ is written as Eq. (4)

$$RSSI_{opt} = TxPower - PL(dB)_{opt} \quad (4)$$

where $TxPower$ is the power transmission. Hence, RSRP optimization is given as Eq. (5).

$$RSRP_{opt} = \ RSSI_{opt} - 12 * N \quad (5)$$

N is the number of Physical Resource Blocks (PRBs) and once the $RSRP_{opt}$ is calculated, the energy detection threshold will be executed to gain the optimum energy detection threshold.

Therefore, energy detection threshold optimization is written as Eq. (6)

$$\eta_{opt} = \left(\frac{2}{M}\left(RSRP_{opt} + \sigma_n^2\right)^2 \left(\frac{Pd}{Q}\right) + \sigma_n^2 - RSRP_{opt}\right) \quad (6)$$

where η_{opt} represent the optimum energy detection threshold, M is the length of received sample sequence for test statistics. For Wi-Fi DIFS duration of $34\mu s$, $M = 680$ and σ_n^2 is the noise power.

The throughput of Wi-Fi is calculated as written in Eq. (7)

$$Tput_\omega = \frac{P_{tr\omega} P_{s\omega}(1 - P_{trl}) Psize}{T_E} r_\omega \quad (7)$$

where $P_{tr\omega} P_{s\omega}(1 - P_{trl})$ represent the probability that Wi-Fi transmits a packet successfully in one Wi-Fi slot time, r_ω is Wi-Fi data rate. T_E is the average time of all possible events hence, $Psize$ as Wi-Fi data portion duration.

Next, LTE-LAA throughput is given as Eq. (8)

$$Tput_l = \frac{P_{trl} P_{sl}(1 - P_{tr\omega}) \frac{13}{14} T_D}{T_E} r_l \quad (8)$$

and $\frac{13}{14}T_D$ as fraction of the TXOP in which the data is transmitted, r_l is LTE-LAA date rate then, T_E is the average time of all possible events.

3. Results

The proposed performance in this research is simulated and evaluated through the simulation performed in MATLAB software. This part analyses the efficiency of the proposed network in term of throughput for LTE-LAA and Wi-Fi in order to obtain fair coexistence between two networks.

Figure 1 shows the fitness against the number of iterations for the optimization of the d value. The less the number of fitness values, the more accurate the target point for the d value. According to the figure above, as more iterations are performed, the chart approaches stabilization value, which means the value is approaching the lowest value of fitness for the target parameter.

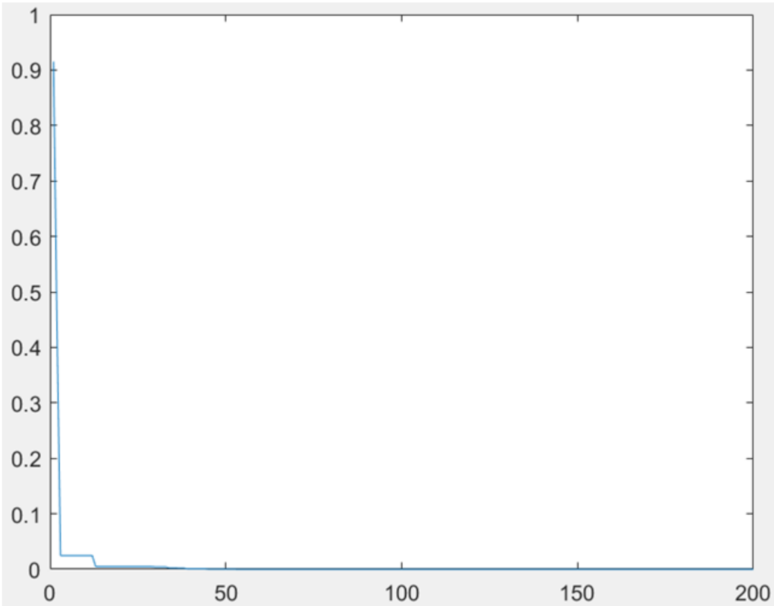

Fig. 1. Fitness result with 200 iterations of PSO technique

Figure 2 shows the relationship between RSRP and probability of detection. This simulation result shows that the higher the probability of detection, the higher the RSRP value for networks due to good quality and signal level.

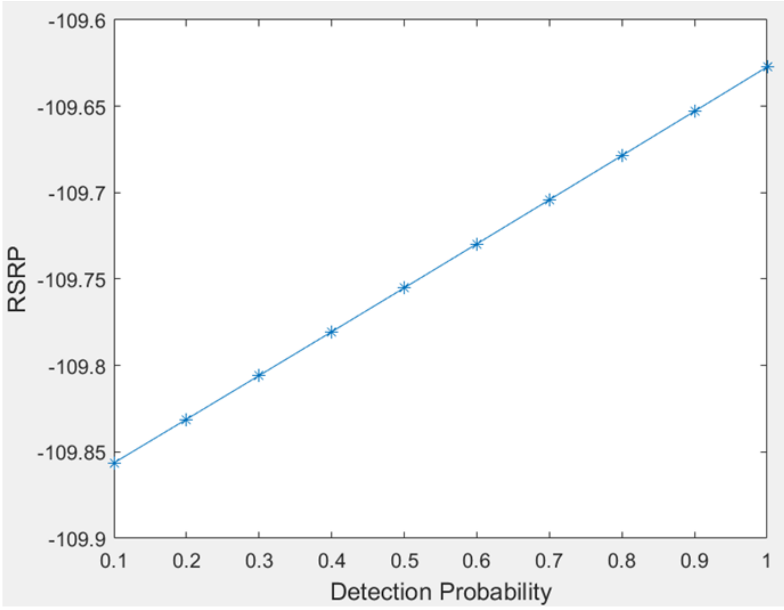

Fig. 2. RSRP result with probability of detection

Figure 3 demonstrates the simulation result of energy detection threshold and detection probability of Wi-Fi and LTE-LAA network. From Figure 3, the energy detection threshold approximately same for different value of detection probability hence, an ideal energy detection threshold was obtained. The energy detection threshold in a conventional Wi-Fi system is -62 dBm and in LTE-LAA, it is -72 dBm. However, in this research both Wi-Fi and LTE-LAA network have proposed same value of energy detection threshold which is -69 dBm.

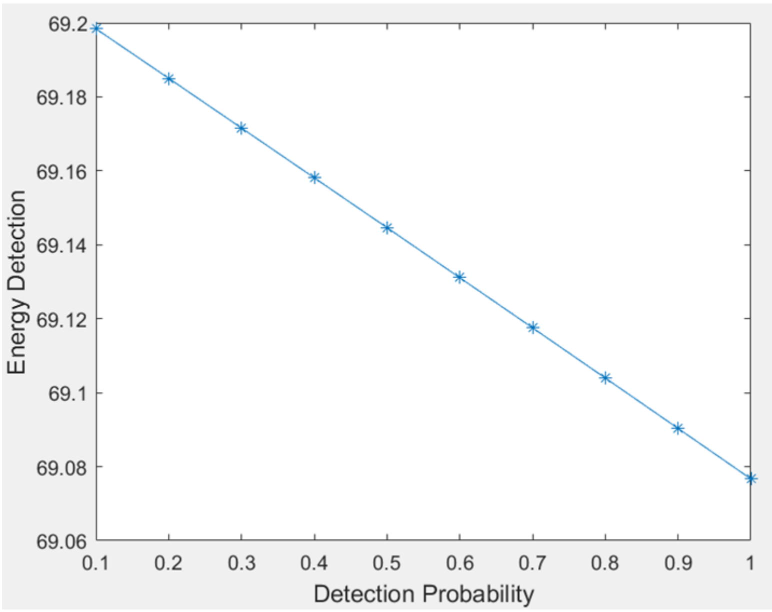

Fig. 3. Graph of energy detection threshold versus probability of detection

Figure 4 simulation results show the effect of reference paper [3] energy detection threshold value and our proposed energy detection threshold value on throughput of Wi-Fi in coexistence network. According to the graph of Wi-Fi coexistence throughput performance slightly increased than reference paper [3] throughput with respect to various number for user.

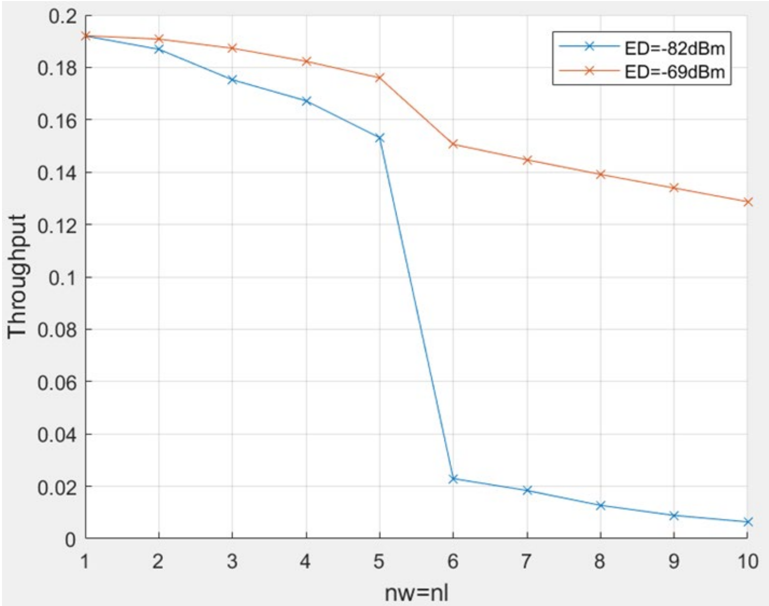

Fig. 4. Graph of Wi-Fi throughput performance

The performance of Wi-Fi throughput is summarized in Table 1. This table shows the comparison of Wi-Fi throughput between energy detection threshold -82dBm and -69dBm.

Table 1
The performance of Wi-Fi throughput

No of APs/eNB in coexistence	-69dBm	-82dBm
1	0.1921	0.1920
2	0.1908	0.1827
3	0.1873	0.1748
4	0.1823	0.1677
5	0.1760	0.1593
6	0.1506	0.1430
7	0.1447	0.1241
8	0.1391	0.01791
9	0.1339	0.01346
10	0.1287	0.01009

Figure 5 illustrates the simulation results of effect on reference paper [3] energy detection threshold value and our proposed energy detection threshold value on throughput of LTE-LAA in coexistence network. From Figure 5, it is shows that the graph of LTE-LAA coexistence throughput roughly improve compare to reference paper [3] throughput with respect to various number for user.

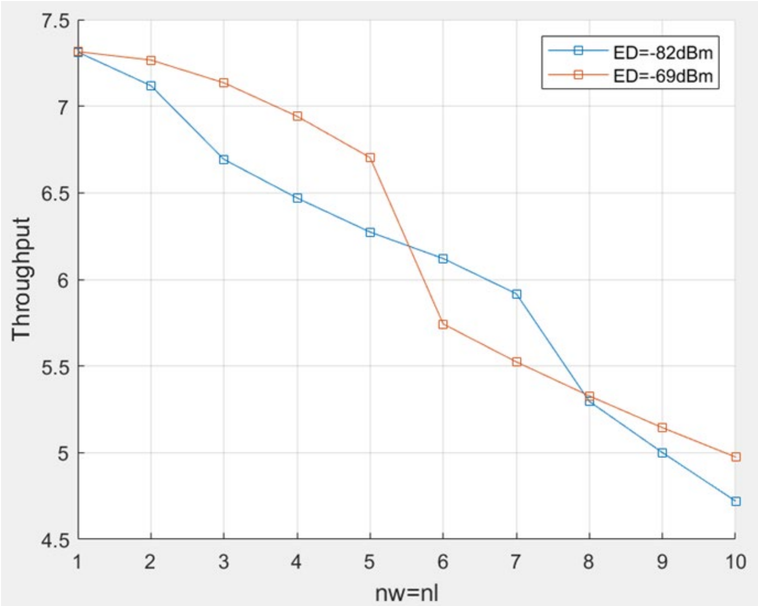

Fig. 5. Graph of LTE-LAA throughput performance

The performance of Wi-Fi throughput is summarized in Table 2. This table shows the comparison of LTE-LAA throughput between energy detection threshold -82dBm and -69dBm.

Table 2
The performance of LTE-LAA throughput

No of APs/eNB in coexistence	-69dBm	-82dBm
1	7.3147	7.3128
2	7.2664	6.9593
3	7.1348	6.6667
4	6.9420	6.4328
5	6.7033	6.2328
6	5.7428	6.0368
7	5.5241	5.8434
8	5.3274	4.2043
9	5.1441	4.8873
10	4.9750	4.6022

4. Conclusions

Our thorough simulation study's key finding is that Wi-Fi and LTE-LAA performance can be enhanced when the energy detection threshold employed by Wi-Fi in the presence of LTE is optimum. Thus, this finding suggests a coexistence scenario in which Wi-Fi employs the same energy detection threshold to defend against both Wi-Fi and LTE-LAA. Wi-Fi would need to integrate LTE detection, which can be done quickly by detecting the LTE synchronization signals, in order to discriminate between LTE-LAA and other signals. Future work will extend to user handover, using combinations of Wi-Fi and LTE-LAA in various deployment scenarios.

Acknowledgement
This paper is part of research work that supported by FRGS Grant file no.: FRGS/1/2019/TK04/UITM/02/26 and School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA Shah Alam.

References

[1] Jian, Yubing, Chao-Fang Shih, Bhuvana Krishnaswamy, and Raghupathy Sivakumar. "Coexistence of Wi-Fi and LAA-LTE: Experimental evaluation, analysis and insights." In *2015 IEEE international conference on communication workshop (ICCW)*, pp. 2325-2331. IEEE, 2015. https://doi.org/10.1109/iccw.2015.7247528

[2] Yusof, Azita Laily, Nur Haidah Mohd Hanapiah, and Norsuzila Ya'acob. "Performance Evaluation of Changing Energy Detection Threshold on Wi-Fi and LTE-LAA Coexistence Networks." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 34, no. 2 (2023): 342-351. https://doi.org/10.37934/araset.34.2.342351

[3] Mehrnoush, Morteza, Vanlin Sathya, Sumit Roy, and Monisha Ghosh. "Analytical modeling of Wi-Fi and LTE-LAA coexistence: Throughput and impact of energy detection threshold." *IEEE/ACM Transactions on Networking* 26, no. 4 (2018): 1990-2003. https://doi.org/10.1109/tnet.2018.2856901

[4] Azita Laily Yusof, Muhammad Aiman Zainali, Ainnur Eiza Azhar, Norsuzila Ya'acob. 2020. "An Adaptive Handover Initiation Threshold for Seamless Mobility based Wireless Networks using Particle Swarm Optimization (PSO) Algorithm."

[5] Rini, Dian Palupi, Siti Mariyam Shamsuddin, and Siti Sophiyati Yuhaniz. "Particle swarm optimization: technique, system and challenges." *International journal of computer applications* 14, no. 1 (2011): 19-26. https://doi.org/10.5120/ijais-3651

[6] Akande, Olukunle Akinyinka, Onyebuchi Chikezie Nosiri, Agubor Cosmas Kemdirim, and Okpara Chinedu Reginald. "Implementation of Particle Swarm Optimization Technique for Enhanced Outdoor Network Coverage in Long Term Evolution Network in Port Harcourt, Nigeria." *European Journal of Engineering and Technology Research* 2, no. 5 (2017): 36-43. https://doi.org/10.24018/ejers.2017.2.5.346

[7] Sedighizadeh, Davoud, and Ellips Masehian. "Particle swarm optimization methods, taxonomy and applications." *International journal of computer theory and engineering* 1, no. 5 (2009): 486-502. https://doi.org/10.7763/ijcte.2009.v1.80

[8] Zemzami, Maria, Aicha Koulou, Norelislam Elhami, Mhamed Itmi, and Nabil Hmina. "Interoperability optimization using a modified PSO algorithm." *International Journal of Advanced Trends in Computer Science and Engineering* 8, no. 2 (2019): 101-107. https://doi.org/10.30534/ijatcse/2019/01822019

[9] Pham, Quoc-Viet, Dinh C. Nguyen, Seyedali Mirjalili, Dinh Thai Hoang, Diep N. Nguyen, Pubudu N. Pathirana, and Won-Joo Hwang. "Swarm intelligence for next-generation networks: Recent advances and applications." *Journal of Network and Computer Applications* 191 (2021): 103141. https://doi.org/10.1016/j.jnca.2021.103141

[10] Naik, Gaurang, Jung-Min Park, Jonathan Ashdown, and William Lehr. "Next generation Wi-Fi and 5G NR-U in the 6 GHz bands: Opportunities and challenges." *IEEE Access* 8 (2020): 153027-153056. https://doi.org/10.1109/access.2020.3016036

[11] Waleed, Syed, Inam Ullah, Wali Ullah Khan, Ateeq Ur Rehman, Taj Rahman, and Shanbin Li. "Resource allocation of 5G network by exploiting particle swarm optimization." *Iran Journal of Computer Science* 4, no. 3 (2021): 211-219. https://doi.org/10.1007/s42044-021-00091-5

[12] Kumari, Savita. "Optimization of Handovers in Small Cell Networks Using Soft Computing." (2022). https://doi.org/10.21203/rs.3.rs-1536518/v1

[13] Sylia, Zenadji, Cédric Gueguen, Brikh Lamine, Talbi Larbi, and Abdelkrim Khireddine. "New strategy for resource allocation using PSO-PFS hybrid." *International Journal of Wireless and Mobile Computing* 18, no. 2 (2020): 175-182. https://doi.org/10.1504/IJWMC.2020.105711

[14] Khzaali, Hayder, Josko Zec, and Ivica Kostanic. "Repeatability of Reference Signal Received Power Measurements in LTE Networks." In *2018 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, pp. 1-6. IEEE, 2018. https://doi.org/10.1109/wispnet.2018.8538631

[15] Iqbal, Muhammad, Cholilur Rochman, Vanlin Sathya, and Monisha Ghosh. "Impact of changing energy detection thresholds on fair coexistence of Wi-Fi and LTE in the unlicensed spectrum." In *2017 wireless telecommunications symposium (WTS)*, pp. 1-9. IEEE, 2017. https://doi.org/10.1109/WTS.2017.7943527

[16] Han, Shiying, Ying-Chang Liang, Qian Chen, and Boon-Hee Soong. "Licensed-assisted access for LTE in unlicensed spectrum: A MAC protocol design." *IEEE Journal on Selected Areas in Communications* 34, no. 10 (2016): 2550-2561. https://doi.org/10.1109/icc.2016.7511104

[17] Hong, Sung-Tae, Harim Lee, Hyoil Kim, and Hyun Jong Yang. "Lightweight Wi-Fi frame detection for licensed assisted access LTE." *IEEE Access* 7 (2019): 77618-77628. https://doi.org/10.1109/access.2019.2921724

[18] Jaehong Yi, Weiping Sun, Seungkeun Park, and Sunghyun Choi. 2018. "Performance Analysis of LTE-LAA Network."

[19] Chanita Phangphan, Narongchon A-mapat, and Phichet Moungnoul. 2020. "Network Design for LTE-Pro," July. https://doi.org/10.1109/iceast50382.2020.9165529

[20] Liu, Meng, Taoyanz Xu, Fangfang Shi, Yue Wu, Jianjun Su, Guohui Zhang, Kuan Li, and Changgang Li. "Optimization of emergency load shedding following HVDC blocking of receiving-end power systems based on PSO." In *2018 2nd*

IEEE Conference on Energy Internet and Energy System Integration (EI2), pp. 1-6. IEEE, 2018. https://doi.org/10.1109/ei2.2018.8582595

[21] Khwandah, Sinan A., John P. Cosmas, Zaharias D. Zaharis, Pavlos I. Lazaridis, Ian A. Glover, and Shadi M. Saleh. "Interference management scheme for co-channel femtocells." In *2018 24th International Conference on Automation and Computing (ICAC)*, pp. 1-4. IEEE, 2018. https://doi.org/10.23919/iconac.2018.8749067

[22] Kuo, Yen-Wei, Li-Der Chou, and Yi-Ming Chen. "Adaptive Smart Power Control Algorithm for LTE downlink cross-tier interference avoidance." In *2015 11th International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness (QSHINE)*, pp. 24-30. IEEE, 2015. https://doi.org/10.4108/eai.19-8-2015.2261142

[23] Hu, Haonan, Yuan Gao, Jiliang Zhang, Xiaoli Chu, Qianbin Chen, and Jie Zhang. "Density analysis of LTE-LAA networks coexisting with WiFi sharing multiple unlicensed channels." *IEEE Access* 7 (2019): 148004-148018. https://doi.org/10.1109/ACCESS.2019.2946604