INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

HERA: High-Efficiency Resource Allocation Scheme for Newly Joined Mobile Terminal in Heterogeneous Wireless Network

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OPEN ACCESS
Received: 06-04-2022
Accepted: 29-04-2022
Published: 11.07.2022

Citation: Nagaraja G, Rameshbabu HS, Gowrishankar (2022) HERA: High-Efficiency Resource Allocation Scheme for Newly Joined Mobile Terminal in Heterogeneous Wireless Network . Indian Journal of Science and Technology 15(25): 1244-1252. https://doi.org/10.17485/IJST/v15i25.713

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: To design an efficient resource allocation design for provisioning service of varied traffic classes to Multi-Mode Mobile Terminals (MMTs) in Heterogeneous Wireless Networks (HWNs). In HWNs, users prerequisite certain Quality of Service (QoS); thus, for meeting QoS, theMMTs are handoff to the new network. However, handoff MMTs might induce interference with the ongoing communication of existing MMTs. As resources are shared, resource allocation becomes a challenging task. **Methods:**This study presents a High-Efficiency Resource Allocation optimization model for HWNs. The HERA scheme first employs Channel State Information (CSI) estimation for mitigating interference and establishing channel availability. Second, using game theory optimal resource is allocated to MMTs and proves the existence of Nash equilibrium (NE) for spectrum resource allocation to MMTs in HWNs. Finally, a hybrid resource allocation algorithm combining contention-less and contention-based is designed to provide an improved resource allocation mechanism. **Findings:**The experiment outcome shows the HERA scheme allocates resources more efficiently in comparison with Access Fairness Resource Allocation (AFRA)(1), Joint Resource Allocation with Power Optimization (JRA-PO)(2), Resource Allocation and Node Placement (RANP)(3), and Existing Resource Allocation (ERA)(4). The HERA improves throughput by 19.07% and reduces collision by 42.96% in comparison with ERA(4) . **Novelty:** existing model predominantly focused on either addressing interference or maximizing throughput by leveraging either contention or contention-less resource allocation mechanism. However, in this study both contention-less and contention-based mechanisms are merged to maximize throughput and reduce collision.

Keywords: Interference; Quality of service; Resource allocation; Softcomputing; Spectrum utilization; Heterogeneous communication network

1 Introduction

HWNs have attained impetus growth in the research community and wireless industries. Spectrum allocation (SA) plays a verysignificant feature in providing tradeoffs between the user's QoS prerequisite and network performance under shared resources and non-shared environments(5). The adoption of shared resource aid in improving bandwidth efficiency of HWNs; however, at the cost of additional cross-tier interference(6). On the other side the non-shared environment cross-tier interference is not an issue; however, significantly impacts resource utilization(7,8). As the future wireless communication network is expected to coexist with different standard and multi-bands, the differentwireless access point (WAP) with different radio standards is expected to coexist and other operates in non-overlapping frequency(9); thus, shared and the non-shared standard is expected to coexist in future HWNs. As a result, spectrum allocation is very challenging in HWNs(10). For the general HWNs, as shown in Figure 1, it is necessary to study and analyze different spectrum allocation techniques and design an ideal spectrum allocation design for HWNs.

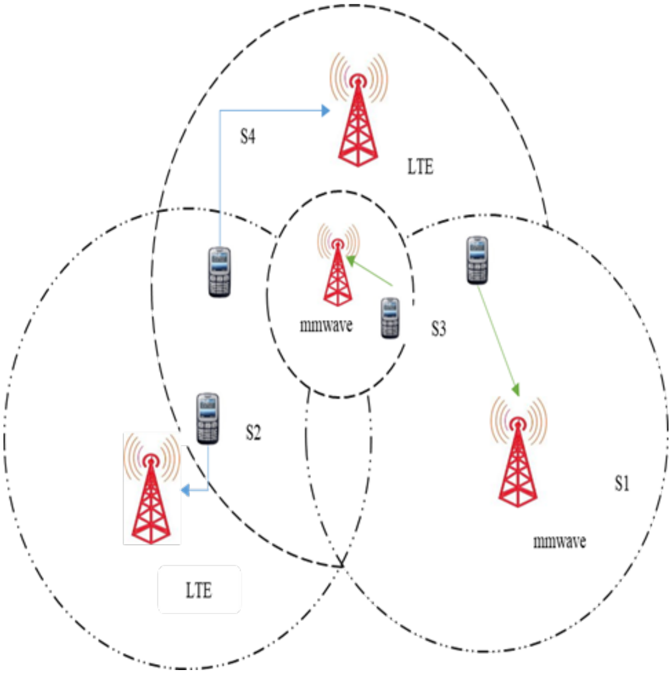

Fig 1. The architecture of General Heterogeneous cellular network.

Recent resource allocation designhas focused on addressing spectrum allocation issues considering static configuration with varied constraints and objective function(11,12), where they considered hexagonal macro cells overlapped by small cells.However, the traditional hexagonal network suffers when we try to increase network density and heterogeneity network(13,14). Thus, the new study is focused on modeling stochastic geometry(15), where the point process is used to capture the spatial information behavior of devices in HWNs. The geometry-based model is efficient in addressing the interference problem and satisfies the performance need of HWNs(16,17). In(18) addressed the interference problem of both single and multi-tier HWNs by considering signal interference with meta-distribution; the model reflects the idealistic model considering both LTE and ultra-dense 5G network deployments. However, the future network requires a high-speed and reliable resource allocation design for provisioning real-time safety applications considering dynamic user mobility(19). In meeting research issues existing methodologies have emphasized using Channel-State-Information (CSI) in resource allocation design. In(20) presented a Kernel-based machine learning model for effective modeling of channel-state-information. In(21)showed Game Theory (GT) model is very efficient in comparison with machine learning models(22) for obtaining optimal resource allocation in the heterogeneous wireless network. However, existing GT-based resource allocation model(23,24) fail to provide good access fairness(1)with high performance efficiency(2,3).

The main limitation of the existing method is the GT model is either designed for contention-based or contentionless-based resource allocation. In this working hypothesis, the problem of addressing interference and efficiency can be addressed by leveraging both contention-based or contentionless-based together for resource allocation in HWNs. In addressing the research issues this paper presents the High-Efficiency Resource Allocation (HERA) scheme for HWN. The HERA scheme is very efficient in mitigating interference issues and maintaining a high level of performance by using channel state information and employing both contentionless-based and contention-based resource allocation together for the selection of channels to carry out communication. HERA achieves high throughput with minimal collision using the game-theory model; thus, proving it is fair and efficient in allocating resources to newly joined MMTs.

The paper is arranged as follows. High-efficiency resource allocation scheme or newly joined mobile terminal in heterogeneous wireless networks is presented in section II. The resource allocation outcome achieved using High-efficiency resource allocation scheme and standard resource allocation scheme is discussed in section III. In the last section. The HERA model significance is discussed and future enhancement of the HERA model is discussed.

2 High-Efficiency Resource allocation Scheme for Newly Joined Mobile Terminal in Heterogeneous Wireless Network

This section presents a high-efficiency resource allocation (HERA) scheme for a newly joined mobile terminal in heterogeneous wireless networks. Here we present a model for channel state estimation using reinforcement learning through a continuous-time Markov chain. Then, present a contentionless-based resource allocation scheme and proves the existence of Nash equilibrium. Similarly, it presents a contention-based resource allocation scheme and proves the existence of Nash equilibrium. Finally, the HERA scheme combines both contentionless-based resource allocation and contention-based resource allocation scheme for providing a fair and high-efficiency resource allocation scheme for newly joined MMTs without affecting existing/primary MMTs.

2.1 Channel state estimation for modeling available channel

In HWNs every time the user is a handoff to a new network it may compete with another device for channel contention; poor channel allocation may result in high interference among neighboring devices which is mobile. Thus, it is important to measure the channel state for resource allocation. Using(4) the mean channel available $\omega_c$of channel $c$at any given time is obtained using the following equation

$$\omega_c = (1-\delta_c) + \delta_c \alpha_{I,c} = 1 - \delta_c \alpha_{B,c.} \tag{1}$$

whereδ_c defines the mean fraction area covered by the existing mobile terminal on channel c. The δ_c is obtained using the following equation

$$\delta_c = \frac{4T^2}{A_{l,i}^2} \tag{2}$$

$\alpha_{I,c}$ defines steady-state probabilities that primary MMTs is actively communicating in c and $\alpha_{B,c}$ defines the steady-state probabilities that primary MMTs is not communicating (i.e., inactive) in channel c. The state $M_{N,c}$determineswhether a MMTs have gone out the coverage area of primary MMTs; thus, the parameter $K_{N,c}$ is an exponential distribution of$\mu_{N,c}$ and is established using following equation

$$\mu_{N,c} = \mu_{b,c} + \frac{s'}{f\left(A_{l,c} - T_c\right)} \alpha_{b,c}. \tag{3}$$

Considering balanced scenarios we have

$$\alpha_{X,c}\mu_{X,c} = \alpha_{N,c}\mu_{N,c}, \tag{4}$$

where$\alpha_{X,c}$ is obtained using following equation

$$\alpha_{X,c} = \omega_c \tag{5}$$

Similarly, $\alpha_{N,c}$ is obtained using following equation

$$\alpha_{N,c} = 1 - \omega_c \tag{6}$$

Thus, we can get $M_{X,c} \rightarrow M_{N,c}$ transition rate $\mu_{X,c}$ using following equation

$$\mu_{X,c} = \frac{\omega_c}{1-\omega_c}\mu_{N,c} = \frac{\delta_c \alpha_{b,c}}{1-\delta_c \alpha_{b,c}}\left(\mu_{b,c} + \frac{s^{'} \bullet \alpha_{b,c}}{f\left(A_{l,c} - T_c\right)}\right). \tag{7}$$

Therefore, $K_{X,c} \sim Exp\left(\mu_{X,c}\right)$. The feasible channel accessibility β of channel c as the mean time period in which channel c is accessible for sensor device to communicate is computed using following equation

$$\beta_c = \varphi_c \bullet K^{'}_{X,c} = \frac{\varphi_c}{\mu_{X,c}} \tag{8}$$

where $\varphi_c \in (0,1)$ defines interference threshold of primary MMTs. Setting an higher value of φ will aid in achieving higher channel availability at the cost of higher interference with primary MMTs.

In this work we assume the MMTs are aware of spatial distribution of primary MMTs and temporal channel usage behavior knowledge. The number channel available for primary MMTs are collected from HWNs. Using above assumption, the newly joined MMTs can obtain realistic channel availability, that is, $\beta_j,\ j \in A$, according to its mobile nature. Here the newly joined MMTs will sense and access the channel in distributed manner through game theory model and can maximize its utility function in a fair manner without affecting primary MMTs (i.e., existing MMTs). The existence of Nashequilibrium in HERA which composed of both contention and contentionless-based resource allocation is proved below sections.

2.2 Contentionless-based Resource Allocation Scheme:

In contentionless-based resource allocation scheme the channel is randomly allocated to MMTs with random backoff time (21,22). Channel is given to MMTs once backoff time is completed and if there exist anidle slot from respective channel. The MMTs can use the slots till the end of time slots, while other MMTs will be idle and wait till the backoff time is completed and establish the idle channels. In contentionless-based resource allocation scheme, the channel allocation function is defined using following equation

$$s\left(o\right) = \frac{1}{o} \tag{9}$$

and its utility function is obtained using following equation

$$V^{j}_{k(rnd\}} = \frac{\beta_j}{o_j}. \tag{10}$$

where $f_{rnd}\left(o\right) = 1$. Pure NE for contentionless-based resource allocation scheme is achieved through following assumption. Let us assume a resource access gameγ for contentionless-based resource allocation scheme, if a congestion vector $o = \left(o_1, o_2, o_3, \ldots, o_D\right)$result in NE-set (o), the constraint defined in Eq. (11) must be satisfied

$$\begin{cases} o_j = \left[\dfrac{\beta_j O - \sum_{a \neq j, a \in D} \beta_a}{\sum_{a \in D} \beta_a}\right| + X_0 j = 1,2,3,\ldots,D \\ \sum_{j=1}^{D} o_j = O \end{cases} \tag{11}$$

where$X_0 \in \left\{0,1,2,3,\ldots,\left(\beta_j\left(O\right| + \beta_j\left(\left(D\right| - 1\right)/\sum_{a \in D}\beta_a\right] - \left(\beta_j\left(O\right| - \sum_{a \neq j, a \in D}\beta_a/\sum_{a \in D}\beta_a\right] - 1\right\}$.

2.3 Contention-based Resource Allocation Scheme:

Similarly with respect to contentionless-based resource allocation scheme, in contention-based resource allocation scheme, every MMTs access the channel with probability P and throughput/sum rate of each MMTs is obtained using following equation

$$pl\left(P\right) = P(1-P)^{o-1} \tag{12}$$

In order to maximize the throughput, let$pl^{'}\left(P\right) = 0$; then, $P = \frac{1}{o}$, and contention-based resource allocation function is obtained using following equation

$$f_{SMAC}\left(o\right) = \frac{1}{o}\left(1 - \frac{1}{o}\right)^{o-1} \tag{13}$$

It can be described, for contention-based resource allocation scheme, $f_{SMAC}(o) = (1-1/o)^{o-1}$, with $f'_{SMAC}(o) < 0$ and $f''_{SMAC}(o) > 0$. Besides, if o becomes infinite state, then total throughput of contention-based resource allocation becomes

$$\lim_{o\to\infty} fS_{MAC}(o) = \frac{1}{F} \tag{14}$$

The utility of MMTs k that chooses channel j utilizing contention-based resource allocation scheme is obtained through following equation

$$V^{j}_{k\{SMAC\}} = \beta_j \frac{1}{o_j}\left(1-\frac{1}{o_j}\right)^{o_j-1} \tag{15}$$

Different from a contentionless-based resource allocation scheme, it is extremely difficult to derive pure NE using a contention-based resource allocation scheme. Let's assume a resource access game considering MMTs size of O and channel size of D;each MMT in sequential order chooses an accessible channel one after the other. In every iteration, one MMT chooses Best Solution (BS) prior to perform channel access. Therefore, in each iteration, the best solution made by MMT is a pure NE.The following condition must be satisfied for achieving pure NE with adaptive resource allocation performance using a contentionless-based resource allocation scheme. If, in aniteration, the newly joined MMT have two BSnamely, BS_1 and BS_2, the following constraint must be satisfied. When BS_1agrees to empty resource (no MMT chooses it) and BS_2agrees to resource that has been chosen, BS_1 is perfect. When every resource is at least chosen by one MMT, the resource with larger realistic resource available is favored. In order to achieve fair and efficient resource allocation in next section high efficiency resource allocation scheme is presented.

2.4 High-Efficiency Resource Allocation Scheme:

In order to achieve pure NE with fair resource allocation performance in distributed environment here we combine both contention-based resource allocation scheme and contentionless-based resource allocation scheme together for designing HERA. The working of high efficiency resource allocation scheme is described in **Algorithm 1**.

```
Algorithm 1: High-efficiency resource allocation scheme
1. Obtain available resource/channel $D$ through sensing operation
2. Update and arrange available channel$(\beta_1, \beta_2, \beta_3, \ldots, \beta_D]$in decreasing order using Eq. (7) and (8) for respective time$u_t$.
3. Every MMT that looks for communication opportunity chosesarandom back-off time $u_c$from $(0, u_{c\uparrow})$& the backoff time is initialized.
4. While present time$\leq (u_t + u_{c\uparrow})$do
5.     if the backoff time of MMT $j$ finishesthen
6.         if contentionless-based resource allocation scheme then
7.             Select the BS with a free channel
8.         End if
9.         if contention-based resource allocation schemethen
10.            Select the resource with higher BS.
11.        End if
12.        The selected channel ID is broadcasted
13.    End if
14. End while
15. Every MMT optimize its radio according to ideal channel & initialize communication utilizing desired resource allocation schemes
16.return
```

In algorithm 1, every MMT randomly selects a backoff time and then backoff time is started. Once backoff period is finished, the MMT chooses a resource for communication using the best solution that is obtained previously with respective channel. Then, MMT broadcast its solution to other MMTs for establishing their solution. As the backoff time is randomly selected the HERA model aid in achieving fair resource allocation and good network performance in comparison with standard resource allocation scheme which is proved through simulation.

3 Result and Discussion

Here the performance achieved using high efficiency resource allocation scheme and existing resource allocation scheme (1–3) is evaluated. Experiment is conducted using NS3-based simulator namely, SIMITS simulator (4). Here the multi-mode terminal uses different kind of service classes such as Real-time polling service, non-real-time polling service, and best effort service and moves through a geographical area composed of heterogeneous network formed using UMTS, WiMAX, LTE, and WLAN. The MMT exhibit dynamic mobility that moves through high density environment with low speed such as city and less density environment with high speed such as expressway and highway. For modelling cellular network, the channel is composed of additive white Gaussian noise (AWGN). Then, multi path fading and log-normal shadowing model are used for modelling path loss model. Lastly, power control is ideal. Then, IEEE 802.11 is used for modelling WLAN, Rayleigh channel model are used, and bandwidth are set to 3-27 Mbps. The MMTs are distributed uniformly random across HWN environment. New mobile subscriber and HO subscribers will obey Poisson distribution. The throughput and collision are the performance metric used for validating HERA and ERA scheme.

3.1 Throughput outcome achieved using HERA and ERA scheme

Here throughput performance of HERA scheme and ERA scheme is evaluated by varying network density, speed and slot size. In case 1, throughput is measured by varying the MMTs size with fixed speed of 5 m/s. Here the MMTs size is varied from 50, 100, &200 and throughput outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 2. An average throughput enhancement of 19.52% is achieved using HERA scheme in comparison with ERA scheme for varied multi-mode mobile terminals density. In case 2, throughput is measured by varying MMTs speed with fixed MTTs size of 100. Here the MMTs speed is varied from 3m/s, 6m/s, & 9m/s and throughput outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 3. An average throughput enhancement of 13.12% is achieved using HERA scheme in comparison with ERA scheme for varied multi-mode mobile terminals speed. In case 3, throughput is measured by varying time slot size with fixed MMTs size of 100 and fixed MMTs speed of 6m/s. Here the time slot size is varied from 5μs, 6μs, & 9μs and throughput outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 4. An average throughput enhancement of 24.57% is achieved using HERA scheme in comparison with ERA scheme for varied time slots size.

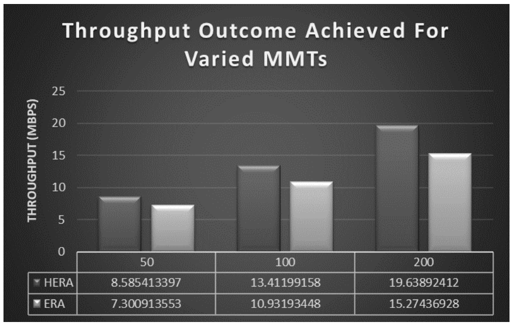

Fig 2. Throughput outcomeachieved for varied Multi-mode mobile terminals density

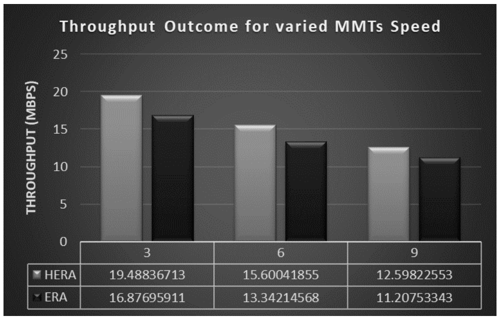

Fig 3. Throughput outcome achieved for varied Multi-mode mobile terminals speed

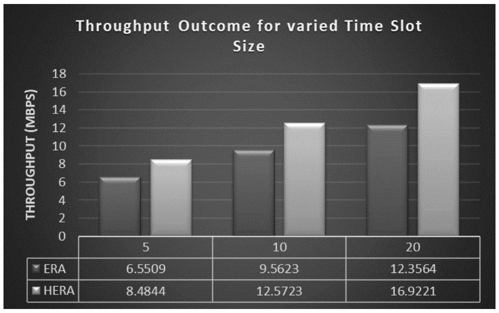

Fig 4. Throughput outcome achieved for varied time slot size

3.2 Collision outcome achieved using HERA and ERA scheme

Here collision performance of HERA scheme and ERA scheme is evaluated by varying network density, speed and slot size. In case 1, collision is measured by varying the MMTs size with fixed speed of 5 m/s. Here the MMTs size is varied from 50, 100, & 200 and collision outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 5. An average collision reduction of 24.5% is achieved using HERA scheme in comparison with ERA schemefor varied multi-mode mobile terminals density. In case 2, collision is measured by varying MMTs speed with fixed MTTs size of 100. Here the MMTs speed is varied from 3m/s, 6m/s, & 9m/s and collision outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 6. An average collision reduction of 28.27% is achieved using HERA scheme in comparison with ERA scheme for varied multi-mode mobile terminals speed. In case 3, collision is measured by varying time slot size with fixed MMTs size of 100 and fixed MMTs speed of 6m/s. Here the time slot size is varied from 5μs, 6μs, & 9μs and collision outcome achieved using HERA scheme and ERA scheme is graphically shown in Fig. 7. An average collision reduction of 76.12% is achieved using HERA scheme in comparison with ERA scheme for varied time slots size.

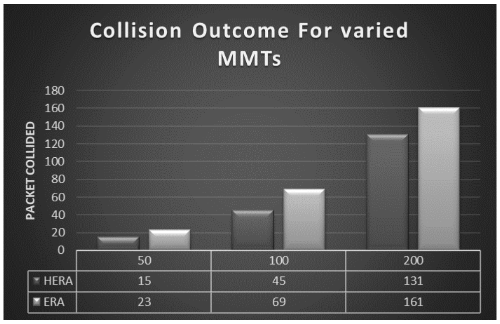

Fig 5. Collision outcome achieved for varied Multi-mode mobile terminals density

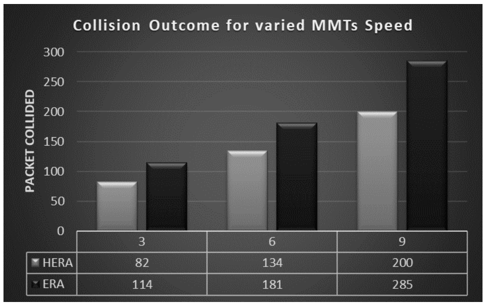

Fig 6. Collision outcome achieved for varied Multi-mode mobile terminals speed

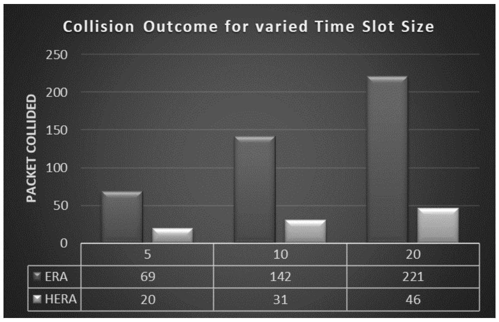

Fig 7. Collision outcome achieved for varied time slot size

3.3 Comparative study

The Table 1 describes comparatives analysis of HERA with respect to other resource allocation models such as Access Fairness Resource Allocation (AFRA)(1), Joint Resource Allocation with Power Optimization (JRA-PO)(2), Resource Allocation and Node Placement(RANP)(3), and Existing Resource Allocation (ERA)(4). The AFRA model is designed provide fairness with maximum throughput for 3G and LTE network. The MAC is designed as contention-less MAC to mitigate collision using cognitive learning. Similarly, the JRA-PO model is adopting a contention-less through mixed integer programing for LTE and 5G network. The model optimizes fairness and load for resource allocation. On the other side, the RANP uses contention-based MAC for LTE and 5G network; the spectrum reuse decision is optimized as non-convex problem. Similarly, the RRA adopt a contention-based MAC for LTE and mm-wave network; using machine learning algorithm the slot selection optimization is done.the AFRA and JRA-PO are good in achieving improved throughput; however, spectrum is not utilized well. On the other side, the RANP and ERA aid in aching higher throughput but induces higher collision because of interference. However, the proposed model leverage both contention and contention-less MAC where optimization is done through game theory aiding in improving throughput and reducing collision in network.

Table 1. Comparative analysis of proposed EC-WSC with various other existing WSC models

	AFRA (1), 2019	**JRA-PO (2), 2020**	**RANP (3), 2020**	**ERA (4), 2021**	**HERA**
Heterogeneous Wireless network	Yes	Yes	Yes	Yes	Yes
Hybrid resource allocation design	No	No	No	No	Yes
Network used	3G and LTE	LTE and 5G	LTE and 5G	LTE and mm-wave	UMTS, WiMAX, LTE, and WLAN
MAC type	Contention-less	Contention-less	Contention	Contention	Hybrid (i.e., both Contention-less & Contention
QoS Metrics	Fairness and throughput	Fairness & load adjustment	Spectrum reuse	throughput	Fairness, interference & throughput
Performance metrics	Throughput and satisfaction	Energy, spectral& throughput efficiency	Spectrum efficiency	Throughput and energy overhead	Throughput and collision
Optimization strategy	Cognitive learning	mixed integer programming	Non-convex optimization	Machine Learning	Game-theory

4 Conclusion

This study presented high efficiency resource allocation scheme for heterogeneous network. The HERA scheme uses channel state information through continuous chain Markov chain model for establishing channel availability for different instance of time. The HERA employs both contentionless-based and contention-based resource allocation scheme for providing high throughput and minimal collision. Game-theory is applied for obtaining optimal resource allocation for newly-joined users without affecting the current ongoing communication of existing MMT's. Here for providing fair resource allocation back-off window is selected in random manner. Experiment is conducted for validating HERA over ERA scheme. The HERA scheme achieves much higher throughput with less number collision in comparison with ERA considering varied network density, speed, and time slots size. Thus, HERA scheme is robust and can allocate resource to MMT's in fair and efficient manner.

Future work would consider using software defined network for dynamically optimizing contention window back-off time parameter and also study the impact of different radio propagation parameter with presence of obstacle in line-of-sight and non-line of sight.

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