IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received February 11, 2017, accepted March 5, 2017, date of publication April 12, 2017, date of current version May 17, 2017.

*Digital Object Identifier 10.1109/ACCESS.2017.2689725*

# Context-Aware Radio Access Technology Selection in 5G Ultra Dense Networks

**ADIB HABBAL, (Senior Member, IEEE), SWETHA INDUDHAR GOUDAR, (Member, IEEE), AND SUHAIDI HASSAN, (Senior Member, IEEE)**
InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia, 06010 UUM Sintok, Malaysia

Corresponding author: Adib Habbal (adib@uum.edu.my)

This work was supported by the Ministry of Higher Education, Malaysia, through FRGS Research Grant 13257.

**ABSTRACT** Ultra dense network (UDN) is the extreme densification of heterogeneous radio access technologies (RATs) that are deployed closely in a coordinated or uncoordinated manner. The densification of RATs forms an overlapping zone of signal coverage, leading user equipment (UE) to frequent signal handovers among the available RATs. Consequently, this degrades the overall system performance. The traditional approach of RAT selection is network-centric and the decision is primarily focused on the signal aspect. However, the next generation of digital wave is a paradigm shift to being user-centric. In this paper, a context-aware multi-attribute RAT (CMRAT) selection approach is proposed to eliminate unnecessary handover of UE among RATs and determine the best RAT as the next point of attachment among the available ones in the UDN. CMRAT integrates the context-aware concept with multi-attribute decision making (MADM) theory in RAT selection. CMRAT is formed with two mechanisms, including, first, a context-aware analytical hierarchy process mechanism to prioritize the criteria for obtaining the weight. Then, a context-aware technique for order preference by similarity to an ideal solution mechanism is employed to choose the best RAT amongst the available RATs. The proposed CMRAT mechanism was implemented and validated using MATLAB. The obtained simulation findings demonstrate that the proposed CMRAT approach outperforms classic MADM methods, namely TOPSIS, SAW, and GRA with respect to the number of handovers and ranking abnormality metrics. Hence, this paper paves the way to choose RAT based on context information comprising network and user preference criteria information.

**INDEX TERMS** Context awareness, multi-attribute decision making, heterogeneous networks, 5G wireless technologies.

## I. INTRODUCTION

The recent societal development and explosion of smart phone usage with ubiquity support are leading to the avalanche of mobile and wireless traffic volume fore casted to intensify thousand fold over the next decade. According to the Cisco VNI survey, an avalanche of mobile and wireless traffic volume is forecasted to intensify thousand folds over the next decade [1]. The next generation of wireless communication beyond 2020 known to be the Fifth Generation (5G) technology. The main design objectives behind the 5G technology are the realization of the required massive capacity and connectivity, support for diversified set of services, applications, and consumer and network operator requirements to cater for the massive demand of services, while having efficient utilization of all available non-contiguous spectrum of resources; in short transforming from World Wide Web (WWW) to Wireless World Wide Web (WWWW) [2].

The increased demand for a plethora of existing and upcoming new applications has accelerated the evolution of wireless technology towards the 5G networks. The 5G networks are a kind of a revolution and evolution from previous generations. It is characteristically revolutionary, as it dynamically aids information access to various devices with different kinds of new upcoming applications with paradigm shift features. Meanwhile, it is also evolutionary, in the sense it extends the horizon like the previous generations in terms of signal strength, data rate, frequency bands, and other network resources to accommodate huge service demand [3].

The driving features of 5G networks are Ultra Dense Network (UDN), Multi-Radio Access Technology (RAT) environment, Device-to-Device communication (D2D), Ultra Reliable Communication (URC), Moving Network (MN), and Massive Machine Communication (MMC) [4]. In short, the 5G network is going to pole apart a newly evolved communication paradigm utilizing the available resources with the new mentioned features. The main focus in this article is on the UDN aspect.

Ultra Dense Network (UDN) is the close deployment of access points and base stations to increase the coverage and enable easy access for UE. The small cell architecture with densification of access nodes is employed. The 5G networks consist of heterogeneous multi-RATs to form a single global interface, and also, it supports UEs enabled with multi-interface. Due to this, the user has the liberty to move seamlessly across the RAT environment with the assurance of interconnection and interoperability between different access networks. However, due to the multi-RAT enabled architecture with overlapping network coverage, UE has a tendency of frequently switch among the RATs leading to system performance degradation. Hence, choosing the appropriate RAT between the available different RATs is a vital challenge. Therefore, an efficient mechanism needs to be incorporated at this decision point to avoid unnecessary handover among RATs.

The network-centric legacy approach of RAT selection should shift to the user-centric to keep up with the evolving digital wave. The RAT selection approach for future wireless networks beyond 2020 should be collaborative, considering both user and network preference in effective decision making of the target RAT. Apart from the collaborative criteria, the decision should be made with context-awareness [4] due to the involvement of densified heterogeneous networks. The wireless communication era is shifting from network-centric to user-centric. Although traditional approaches are able to manage the handover in choosing the RAT, they have yet to take into account the parameters typical to the 4G/5G mobile network. The specifications tailored for 4G/5G networks are stated in Release 10 and 12 [5].

Several research efforts in the literature focused on RAT selection issues based on different architectures and approaches adopted to resolve the RAT selection decision in heterogeneous wireless networks. An extensive investigation is available in the survey [6], [7] which elaborated different approaches for RAT selection. Most RAT selection processes are based on the link quality parameters like RSS, SINR, or bandwidth. However, this approach is inadequate for heterogeneous UDN [8].

The traditional approach is an imperative one, it primarily focuses on the signal aspect, handover is triggered either when the signal of the current serving RAT is weak or the UE finds a RAT with better signal than the current serving RAT. This approach is not effective in the UDN environment, where the selection should consider multiple criteria and not just the signal. The magnitude of the criteria to be evaluated for choosing a target RAT should possess both user and network factors. In order to have a collaborative RAT selection, the decision approach should be the one which harmonizes the preferences of the user and the network while harnessing the optimized usage of the network resources to foster the shift towards the user-centric paradigm.

The advancement in mobile access networks is forced to provide diverse services with user satisfaction. Mainly, the focus is towards multi-media applications like Voice over IP (VoIP), video conferencing, real-time streaming, online gaming, etc. while being always connected with mobility. Since many criteria are needed to be considered in accordance with the context of user and network preferences, Sgora *et al.* [9] recommended the Multiple Attribute Decision Making (MADM) perspective. The connotation of many criteria needs a mathematical operational research approach in analyzing and normalizing the heterogeneous criteria for consistency. MADM has been proven to be an appropriate strategy to study and model the RAT selection process [10]. The MADM prioritizes the multi-criteria aspect but the context of the UE and the network cannot be isolated in decision making. Consequently, there is a need for the context-aware decision making mechanism based on multi attributes in choosing appropriate RATs. This paper paves the way towards fulfilling the requirement in selecting the best RAT using context-aware multiple-attribute decision making for the UDN 5G networks.

The main aim of this paper is to design of Context-aware Multi-attribute RAT (CMRAT) selection approach that allows the multi-modal UE to choose a suitable RAT in the multi-RAT UDN environment.

Specifically, we make the following contributions:

- The System Model describes the network environment and the input criteria, user preferences, and certain considerations in designing and implementing the proposed approach (Section II).
- The MADM and context-awareness concept are integrated in the decision making to override the traditional imperative link-based approach of RAT selection (Section III).
- The operational research quantitative analysis of the proposed CMRAT approach two-layered mechanism is elaborated to evaluate the performance in contrast to the traditional approach (Section IV).
- The performance evaluation of the proposed CMRAT is done through the implementation in MATLAB (Section V). The findings revealed that the CMRAT was quantitatively better in comparison with the other MADM approaches.

## II. RELATED WORK

Traditional handover approach is primarily based on Radio Signal Strength (RSS) [11]. Handover is initiated imperatively, either when the UE senses the diminishing strength of the current RAT signal strength below the predefined threshold or if it detects a RAT with higher signal strength. Such, signal based schemes are not adequate in RAT selection for heterogeneous networks and future wireless technology. Hence, multi-criteria utility scheme for handover decision making is recommended [12], [13].

Orsino *et al.* [8] proposed a RAT selection approach for the UDN scenario for reducing frequent handovers and achieving better throughput and reduced delay. The approach focuses on the signal quality and strength, modulation technique employed, and SINR in making the decision. Though the approach employed MADM, all criteria are biased to the network while ignoring the user perspective. Therefore, this proposed CMRAT approach considers a collaborative criteria pertaining to both the user and network. The classic MADM methods were compared by Savitha and Chandrasekar [14] and conferred TOPSIS to be better in multi-criteria analysis. Also, Stevens-Navarro and Wong [15] compared many MADM methods and found GRA to be the better approach.

However, the GRA and TOPSIS approaches are comparatively better approaches than the traditional approach, but both still pose the ranking abnormality. Tawil *et al.* [16] presented a distributed SAW based VHO decision mechanism to choose RAT for a mobile terminal while reducing overall processing the overhead of the visiting network. Pink *et al.* [17] presented a distributed VHO decision making mechanism which coordinates the mobile terminal with RAT for optimal Quality of Service. However, all these approaches consider the multi-criteria but not related to the context, which is the basic requirement for upcoming applications of future wireless networks. The imperative approaches need to have a paradigm shift to implement context-aware decision making to meet the 1000X growth of the future digital wave. Therefore, CMRAT considers integration of MADM and context-awareness in RAT selection.

Kaloxylos *et al.* [18] stated the importance of efficient RAT selection in 5G networks, and proposed and implemented a multi-criteria based handover scheme for reducing unnecessary handovers, where the intelligence based mechanism with fuzzy logic was implemented to achieve better throughput. The fuzzification is based on predefined rules, so there is no dynamic decision making. The impact of RAT selection criteria on the performance in a heterogeneous environment with different multiple attributes was studied and inferred the importance of weight and scoring method in RAT selection [19].

A context-aware RAT selection based on fuzzy logic was proposed by Barmpounakis *et al.* [20] for 5G networks, but the fuzzy mechanism was governed by predetermined rules in a static form of decision making.

The RAT selection for future digital wave should comprise collaborative criteria pertaining to both the user and network. The decision should be MADM with contextual awareness. The context-aware conceptual model for RAT selection was proposed for 5G networks [21]. Realizing the potential of context-aware RAT selection, this paper proposed CMRAT mechanism combining the benefits of MADM with context-awareness in UDN environment for RAT selection. The decision is purely based on the collaborative (network and user preferences) context awareness in determining the best RAT to be associated with.

## III. SYSTEM MODEL

In this section, we precisely describe the system model defining the overall environment considered in the design of RAT selection in the UDN environment. Also, the system model describes the assumptions and considerations in formulating the analytical modelling and validation through the numerical analysis. A dense deployment of small cell architecture is proposed to satisfy seamless coverage in 5G networks. The small cell increases the throughput while reducing the power consumption [22]. The small cell in a dense heterogeneous network comprises of femtocell and macrocell. Femtocell is low power base stations confined to home or small business. Macrocell is the central network base station covering a larger area. The benefits of small cell are for both to the operator and the consumer. Femtocell enhances both coverage and capacity in indoors. Coverage by improving loss of signal through building and capacity of reducing the attempts to connect to the main network base station, while handling the services in offloaded manner [23].

The small cell scenario comprises the Home evolved base station (HeNB), which is the LTE femtocell. The macrocell is a high power network base station of LTE, and it is known as the evolved Node Base station (eNodeB). In this wireless network scenario, different types of small cells (femtocell and WiFi) are deployed in an unconditional manner with a macro coverage range, as shown in Figure 1. The main aim of this proposed network environment is ultra densification and sharing of the traffic load from central base station to HeNB or WiFi, depending on the contextual-awareness of user and network preferences. This research made the following assumptions to design the system model for implementing the proposed mechanism.

- The UDN heterogeneous RAT is formed with the RAT, such as, IEEE 802.11n, IEEE 802.11ac, HeNB, LTE (release 13) in the design and implementation of the proposed mechanism of this research.
- All classes of traffic are considered in triggering and decision making of the serving RAT, where the traffic classes and their requirements are described in Table 2.
- This study focused exclusively on vertical handover only in UDN environment. The vertical handover is the prominent scope of study due to the multi-RAT close deployment architecture.
- Table 1 outlines the common symbols employed across the article.

### A. SELECTION CRITERIA

Selection criteria plays a key role in RAT selection. The criteria should involve both the user and network criteria in determining the best RAT. The context is formed by harmonizing both user and network criteria in decision making. Hence, the broad classification of the criteria is made into network and user criteria and presented in this section further. The criteria available to choose are of wide range, choosing the right

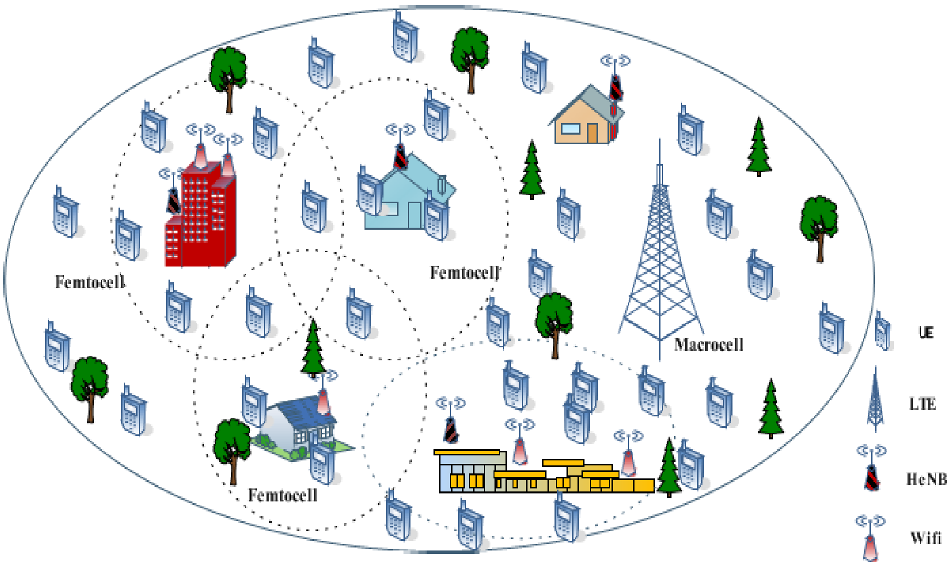


**FIGURE 1.** Macrocell and Femtocell scenario.

**TABLE 1.** Conventions of symbols throughout the article.

| Symbol | Description |
|---|---|
| $C_1....C_n$ | Criteria 1 to n |
| $W_1....W_n$ | Weights 1 to n |
| $A_1....A_n$ | Alternative 1 to n |
| $A_{norm}$ | Normal Matrix |
| CI | Consistency Index |
| RI | Random Index |
| CR | Coherence Ratio |
| $W_i$ | Weight |
| $S_j^+$ | Positive Similarity Distance |
| $S_j^-$ | Negative Similarity Distance |
| $C_j^*$ | Final Rank |

**TABLE 2.** Classes of traffic.

| Traffic Class | Description | Requirement |
|---|---|---|
| Background | One-dimensional transport. Example: User sending SMS or emails. | Packet Loss Rate (PLR) is a critical aspect. Delay, Jitter and Throughput are relatively less vital. |
| Conversational | Two-dimensional transport. Example: VoIP and video conferencing. | Delay and Jitter are very important. PLR and Throughput are relatively less critical. |
| Interactive | Two-dimensional transport based on request/response mechanism. Example: Chatting, online financial transaction. | Delay and PLR are very important. Jitter and Throughput are relatively less critical. |
| Streaming | One-dimensional transport. Example: Watching a video or live match on the web. | Delay is not important. Jitter and Throughput play a vital role. |

criteria and the right number is vital. The large magnitude of criteria may lead to system performance degradation and lesser may not yield good decision. Hence, a survey and review of the cardinality for the range of criteria are done, ranging from three [16], [17], [24] to ten [25], but from the literature review cardinality five [26], [27] is most frequently chosen magnitude.

Hence, based on the rigorous study of previous literature following criteria related to user and network are chosen. The cardinality is five. Network-related criteria: These are the criteria related to the core network resources that help in providing the service according to the demand of the user, and these include: Received Signal Strength (RSS) and Data Rate (DR). RSS is the received power of the mobile terminal and it differs from RAT to RAT. It will be reduced when the terminal moves away from the access point expressed as network coverage. This metric determines the availability of the signal for the terminal. In the case of coexistence of two different networks with an acceptable signal the difference in bandwidth becomes the vital criteria. It is important for sensitive application delay to encounter the QoS requirements. DR is the maximum transfer rate maintained in between the two endpoints (transmitter and receiver). Throughput represents the data rate metric; networks support various ranges of throughput.

User-related criteria are the parameters which the user perceives in attaining better experience. It is directly related to the requirement of the user application. The applications broad classification is presented in Table 2. User preference specifies the kind of application requested by the UE. The applications are broadly classified into four categories. The four traffic classes defined by 3GPP [28] are considered, namely background, conversational, streaming and interactive. The background traffic or the simple data based traffic is one dimensional, like email, SMS, FTP, and etc. where the data is transferred from source to destination. For such applications the data should be received without any intermediate packet loss. The conversational class of traffic is the two-dimensional communication like VoIP, video conferencing, and etc. where both the ends are conversing live. In such applications, delay is not tolerated, and it is highly sensitive to delay and jitter. Interactive is the third class of traffic described in the table, where such applications follow a request-response pattern of communication. Example of interactive traffic applications are all online transactions related to booking, trading, or buying, and etc. The PLR and delay are very critical issues in such applications. Finally, the streaming class of traffic is also one-dimensional traffic involving broadcasting applications, such as live video streams, sports events, concerts, and etc. where such applications are not much delay sensitive but requires high throughput. The user preference is one important aspect to provide an input to the context-aware decision making. The preferred class will define criteria importance and the expected service quality to be achieved seamlessly. The criteria are in congruence with the application preference for RAT selection. The user related criteria include: Jitter (J), Packet Loss (L), and Delay (D). Jitter is a measure of the average delay variability within the access system. It can be measured in (milliseconds). While Packet Loss is a measure of the average packet loss rate within the access system over a considerable duration of time. It can be measured in packet losses per million packets. Delay is a measure of the average delay variability within the access system. It can be measured in milliseconds.

### B. CONTEXT-AWARENESS

Context is the concept that the system should be able to sense dynamically and react to the changes in the circumstance [29]. A recent definition of context is defined as any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object. Context-awareness or context-aware computing as the use of context to provide task-relevant information and/or services to a user, wherever they may require [30]. In the case of RAT selection, context information defines the relevant information that can be utilized in decision making based on the interaction of a user and network parameters to decide the next Point of Attachment (PoA). Context awareness is highly essential in order to optimize the initiation and decision process. Without context-awareness, the RAT selection does not yield an expected outcome as it is not aware of the external environment. However, implementing context-aware based RAT selection poses the following challenges [31].

- The heterogeneity of the wireless networks and technologies.
- The diversity of different applications which differs significantly in QoS requirements.
- The fact that the next generation of wireless is user-centric, thus user preferences are must in decision models.

RAT selection ensures the connectivity of each user to the best RAT to serve, depending on the context of user and network references. The procedure takes into consideration several criteria to evaluate the best RAT. The available RAT will be different from the current serving RAT, that means there is a vertical handover among the heterogeneous RAT. This selection needs to consider network resource availability along with efficient service to the user. To overcome these challenges, an understanding of context is must which aids in determining the behavior of the context in choosing the best RAT. Each preference of the user and network has its own QoS requirement and can impact the RAT selection decision.

### C. MULTIPLE ATTRIBUTE DECISION MAKING (MADM)

MADM is a quantitative computational technique incorporated in decision making over available alternatives usually conflicting and complex in nature to resolve. Several decision making schemes are proposed in the literature [32]. MADM is applicable to diverse problems, but all follow the common analyzing technique. The characteristics of MADM are: selecting the alternatives, multiple attributes are defined in different units of measurement and definition of a set of weights representing the relative priority among alternatives.

After the rigorous background study of several MADM mechanisms, this research of RAT selection mechanism for the UDN will integrate two MADM mechanisms, namely, the Analytical Hierarchy Process (AHP) mechanism [33] to ascertain weights of the criteria based on the priority of the UE and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) to determine the final RAT rank. The AHP method helps to review and relate the criteria at all levels of the hierarchy of the problem [34], while TOPSIS method provides a proportional linear transformation of weights resulting in the relative order of magnitude of the standardized scores to identify an alternative that will have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. Integrating the two MADM mechanisms gives a better ranking and choice while optimizing the criteria abnormalities encountered during a single MADM approach.

Hence, AHP gives the weights in between the multiple criteria, while TOPSIS draws the better choice of RAT among the available. Section III proposes the hybrid approach of combining Context-aware and enhanced MADM in RAT selection.

## IV. CONTEXT-AWARE MULTIPLE ATTRIBUTE RAT SELECTION (CMRAT) APPROACH

The proposed mechanism CMRAT hybridizes the context-aware and MADM concepts in the RAT selection of future

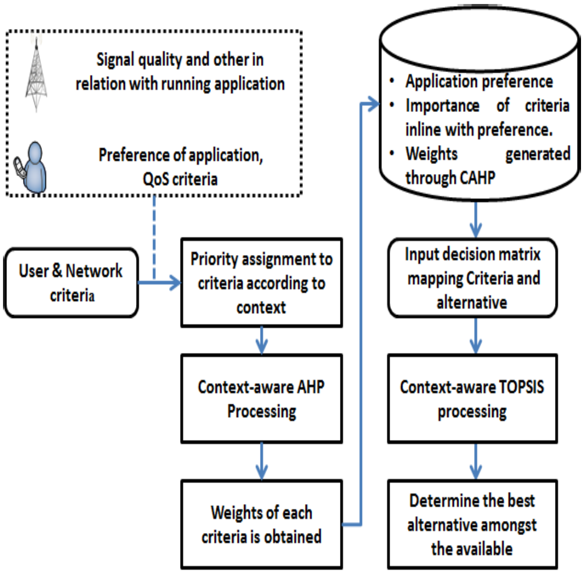


**FIGURE 2.** **CMRAT working with CAHP and CTOPSIS.**

UDN wireless network. The proposed mechanism is represented in Figure 2. The conceptual model comprises two parts, i.e., weighting of the criteria based on user application preference and network criteria. Additionally, decision making of RAT is based on criteria and available RATs coordination. The first part of the proposed system is weighting the importance of criteria based on user application requirement priority [35]. The input pair-wise matrix is constructed corresponding to criteria versus criteria mapping through a Context-aware AHP (CAHP) mechanism to obtain the weights. The detailed procedure of weighting is explained in subsection III-A. The ranking of RATs is done by mapping the alternative, i.e., available RATs versus the shortlisted criteria, forming a decision matrix and a further Context-aware TOPSIS (CTOPSIS) mechanism is applied to obtain the rank of the RATs. The ranking order specifies the best RAT when chosen in descending order. The complete procedure of ranking is briefed in sub-section IV-B. Also, the pseudo-code of CMRAT working is depicted in Algorithm 1.

This shows the comprehensive working of the CMRAT to select the best RAT and determined as the next target to serve for the demanded service. This is achieved by CTOPSIS, which is one of the classic MADM approach based on Euclidean Theory that confers the chosen outcome is sub-optimal solution while far from the negative ideal solution. The requirements of the user and network collaborate to form context-based information.

The priority of the criteria is assigned according to the user application demand. Furthermore, the priority of the weights is calculated through the CAHP mechanism. The weights determine the relative importance of the criteria in decision making of RAT selection with context-awareness factor. The CAHP contains the intra RAT analysis to trigger handover. The CTOPSIS mechanism determines the new target RAT

**Algorithm 1** CMRAT Selection

```
1:  Begin.
2:  Input the context-aware collaborative criteria.
3:  Construct pairwise matrix comparing criteria against criteria.
4:  Normalization of the pairwise matrix.
5:  Weight vector is computed by applying CAHP method.
6:  Compute the Consistency Ratio (CR), to check for the
    pairwise consistency to validate weight.
7:  if CR <0.1 then
8:      Go to Step 7.
9:  else
10:     Go to Step 3.
11: end if
12: Decision matrix is generated comparing the criteria
    against the available RAT.
13: harmonize the matrix undergoes the normalization process.
14: The CTOPSIS mechanism is applied on the normalized
    decision matrix to obtain the rank vector considering the
    weights from Step 5.
15: Positive and negative ideal solution is computed. Further,
    similarity distance and closeness index to the best solution
    is calculated forming a rank vector.
16: The RAT with highest rank in the rank vector is chosen
    to be the best RAT.
17: End.
```

**TABLE 3.** **Saatys scale of importance [36].**

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate values |

based on the inter assessment of the criteria and RATs available according to the requirements in the context repository.

### A. WEIGHTING OF CRITERIA WITH CONTEXT-AWARE DIFFERENTIATED AHP

The AHP method was introduced by Saaty and Vargas [36] with an aim to divide and conquer complicated problems in decision making by dividing the problem into sub-problems into a hierarchical model of goal, criteria and alternatives. The AHP primarily refers the integers from 1 to 9 from Saatys Table 3 to confer the criteria importance ranging from 1 to 9 in constructing the pairwise matrix. The AHP is integrated with context-awareness to form CAHP in assigning the weight. The context-awareness determines the dynamic importance of criteria in decision making. Assuming the consistency, weight ordering of the factors in each level is computed and then synthesize them into the overall weight ordering of all criteria towards the main goal [9]. The method consists

**TABLE 4. Value of random index.**

| Criteria | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

of following steps: Step 1: Determination of the objective and decision factor A pairwise matrix (n*n) is constructed comparing the criteria against each other based on the Saatys scale for pairwise comparisons. Table 3 defines the Saatys 1-9 scale of the pairwise comparison matrix [33], [36]. Let C= [Cj; j=1,2,. . . .,n] be the set of criteria. The resulting (n*n) pairwise matrix A in which every element $a_{ij}$ (i,j = 1,2,. . . .,n) is the quotient of the weight of the criteria. The priorities assigned are of different units, hence the values are normalized and converted to dimensional values. The elements of the constructing pairwise matrix are weighted against the each other based on the application preference. The weights obtained at the end of the CAHP process for each category of criteria is validated mathematically by computing the Coherence Ratio (CR) to check for consistency which can be derived from Equations 1 to 7. The eigenvector method used by CAHP can determine the weights [37]. The value 0.1 is the accepted upper limit for CR [33]. If the CR value > 0.1 the process need to be repeated for attaining consistency. The measured consistency can be used to evaluate the consistency of decision making. The pairwise matrix is expressed as,

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} where,\ a_{ii} = 1, a = \frac{1}{a_{ij}} \tag{1}$$

where $a_{ij}$ represents the importance of criterion versus another criterion in the constructed pairwise matrix A based on the intensity of importance drawn from Table 3. Determining the co-relation of the criteria against each other are known. In each level, the decision factors are compared in the pairwise matrix according to their level of influence w.r.t to the Table 2 & 3. Step 2: Normalization and calculation of the relative weights: The pairwise matrix comprises of different units of measurement, hence it needs to normalize for harmonizing the process. The normalized matrix $A_{norm}$ is constructed from Equation 1. In short, divide each element of the comparison matrix A by its respective column sum to obtain elements of the normalized matrix in Equation 2.

$$A = \begin{bmatrix} \frac{a_{11}}{\sum_{a_{i1}}} & \frac{a_{12}}{\sum_{a_{i2}}} & \dots & \frac{a_{1n}}{\sum_{a_{i1}}} \\ \frac{a_{21}}{\sum_{a_{i1}}} & \frac{a_{22}}{\sum_{a_{i2}}} & \dots & \frac{a_{2n}}{\sum_{a_{in}}} \\ \dots & \dots & \dots & \dots \\ \frac{a_{n1}}{\sum_{a_{i1}}} & \frac{a_{n1}}{\sum_{a_{i2}}} & \dots & \frac{a_{nn}}{\sum_{a_{in}}} \end{bmatrix} where, a_{ii} = 1, a = \frac{1}{a_{ij}} \tag{2}$$

Calculating the weight of the criteria, the decision factor, Wi is computed by,

$$W_i = \frac{\sum_{n}^{j=1} a_{ij}}{n}, \quad W = \begin{bmatrix} W_1 \\ W_2 \\ . \\ . \\ . \\ W_n \end{bmatrix}$$

$$Where,\ W_k = Avg(k^t hrowofA_{norm}) \tag{3}$$

where n is the number of comparable criteria. The column sum should yields 1 has in Equation 3, signifying the consistency in weight computing else needs to revise the pairwise matrix until the attainment of consistency. To check the consistency of the pairwise matrix Coherence Ratio (CR) is calculated. The values of Random Index (RI) are taken from Table 4 depending upon the number of input criteria the RI value is picked. In this proposed research magnitude of criteria is five. Hence the chosen RI value is 1.12 for the further computation of CR. CR is calculated as the ration of CI, which is the consistency Index to the RI which signifies based on the chosen magnitude of the criteria.

$$CR = \frac{CI}{RI} \tag{4}$$

where, Consistency Index (CI) and is the Random Index (RI) are determined by following steps,

$$\lambda = \frac{A * W}{W} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ . \\ . \\ . \\ \lambda_n \end{bmatrix} \tag{5}$$

$$\lambda_{max} = \frac{\lambda_1 + \lambda_2 + \ldots + \lambda_n}{n} \tag{6}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{7}$$

If the CR < 0.1, the pairwise comparison is acceptable. Thus, the relative weights are calculated by finding the right Eigen vector (W) corresponding to the largest Eigen vector $\lambda_{max}$.

### B. RANKING USING THE TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO AN IDEAL SOLUTION (TOPSIS)

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is a classic MADM approach based on Euclidian Theory, which confers the chosen outcome is near to the best ideal solution while far from the negative ideal solution. This TOPSIS is integrated with context-awareness concept and forms CTOPSIS. The decision matrix is formed with the mapping of alternative with the criteria represented by an element. CTOPSIS mechanism works well in obtaining the rank of the available RAT at the junction of decision making. The CTOPSIS gives the dynamics to the input criteria and also reflects in determining the best RAT. The context refers to the situation of decision making for the collaborative requirement of the user equipment.

The procedure to compute the rank of RAT through the TOPSIS method should adhere to the following steps: The decision matrix D is formed by the coordinated mapping of alternatives (RAT) to the shortlisted criteria of this proposed research. Each element is the intersection of the alternative (A) with the respective criteria (C) i.e $A_iC_j$ where i=1,…, 4 and j=1, …, 5.

$$D = \begin{bmatrix} A_1C_1 & \dots & \dots & A_1C_n \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ A_nC_1 & \dots & \dots & A_nC_n \end{bmatrix} \tag{8}$$

Normalizing the pairwise decision matrix: The decision matrix is normalized to apply the CTOPSIS mechanism. The normalization is done as in Equation 9.

$$R_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m}}}$$
$$where,\ i = 1, \dots m; j = 1, \dots, n \tag{9}$$

$d_{ij}$ corresponds to the value of action i for j in decision matrix. Generating the normalized matrix by multiplying the normalized decision criterion $R_{ij}$ with its assigned weight Wk. The weights obtained from CAHP mechanism in sub-section IV-A is the input to obtain $V_{ij}$ matrix. The $V_{ij}$ is the actual data formed with the integration of alternatives and criteria weights. Further, computation compute the ideal positive and negative solution for the formed data. The computations are done through the Equations from 10 to 17.

$$V_{ij} = R_{ij} * W_k$$
$$\text{where} \sum_{k=1}^{m} W_k = 1 \tag{10}$$

Determine the positive ideal solution $A^+$ and negative ideal solution $A^-$

$$A^+ = V_1^+, \dots, V_m^+$$
$$A^- = V_1^-, \dots, V_m^- \tag{11}$$

For desirable criteria,

$$V_1^+ = maxV_{ij}, j = 1, \dots, n \tag{12}$$
$$V_1^- = minV_{ij}, j = 1, \dots, n \tag{13}$$

For undesirable criteria,

$$V_1^+ = minV_{ij}, j = 1, \dots, n \tag{14}$$
$$V_1^- = maxV_{ij}, j = 1, \dots, n \tag{15}$$

Calculate similarity distance

$$S_j^+ = \sqrt{\sum_{j=1}^{n}(V_i^+ - V_{ij})^2}$$
$$where,\ j = 1, \dots, n \tag{16}$$

$$S_j^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_i^-)^2}$$
$$where,\ j = 1, \dots, n \tag{17}$$

Ranking: Once the positive and negative ideal solutions are obtained the final rank vector C is computed has in Equation 18. The rank vector determines the ranking order of the RATs among the available once. The best RAT from the vector is chosen in descending order of ranking. The one with highest rank is the best RAT.

$$C_j^* = \frac{S_j^-}{S_j^+ + S_j^-}$$
$$where,\ j = 1, \dots, n \tag{18}$$

For better understanding and clarity, the numerical analysis is presented for all the steps of CMRAT described.

## V. NUMERICAL ANALYSIS

This section elaborates the numerical analysis of the proposed mechanism CMRAT taking a case of background traffic; rest traffic types follow the same method. The following convention is assumed during the representation of the numerical results, Criteria [C1=RSS, C2=DR, C3=D, C4=J, C5=P]and Alternatives [A1=802.11n, A2=802.11ac, A3=HeNB, A4=LTE].

The pairwise matrix constructed based on Saatys table, as in Equation (1)

$$A = \begin{bmatrix} 1.000 & 2.000 & 3.000 & 3.000 & 4.000 \\ 0.500 & 1.000 & 2.000 & 2.000 & 3.000 \\ 0.330 & 0.500 & 1.000 & 1.000 & 2.000 \\ 0.330 & 0.500 & 1.000 & 1.000 & 2.000 \\ 0.250 & 0.330 & 0.500 & 0.500 & 1.000 \end{bmatrix}$$

The sum of the column is calculated to form the normalized matrix,

ColumnSum = [2.4104.3307.5007.50012.000]

$$A_{norm} = \begin{bmatrix} 0.415 & 0.461 & 0.400 & 0.400 & 0.333 \\ 0.207 & 0.231 & 0.267 & 0.267 & 0.250 \\ 0.137 & 0.115 & 0.133 & 0.133 & 0.167 \\ 0.137 & 0.115 & 0.133 & 0.133 & 0.167 \\ 0.104 & 0.076 & 0.067 & 0.067 & 0.083 \end{bmatrix}$$

The sum of the column is calculated to form the normalized matrix, Weight $W = [W_1, \dots, W_5]$ is calculated using the Equation 3, inferring the weight of each criteria $W = [0.4021|0.2443|0.1371|0.1371|0.0793]$ $\lambda_{max}$, is calculated as in Equation 6, $\lambda_{max} = 5.027$ Consistency Index (CI), is computed by applying the Equation 7, $CI = 0.007$ Finally,

**TABLE 5.** Network parameter with expected standard values for each RAT.

| Criteria Network | RSS (dBm) | Datarate (Mbps) | Delay (ms) | Jitter (ms) | Packet Loss (per $10^6$) |
|---|---|---|---|---|---|
| 802.11n | -72 to -92 | 7.2 - 72.2 | 100-150 | 1-30 | 10-20 |
| 802.11ac | -57 to -62 | 7.2 - 96.3 | 80-100 | 1-20 | 10-15 |
| HenB | -75 to -120 | 75 - 300 | 80-100 | 1-20 | 10-15 |
| LTE-eNodeB | -75 to -120 | 75 - 300 | 80-100 | 1-20 | 10-15 |

the Coherence Ratio (CR), is given by Equation 4 $CR = 0.006$

The CR value 0.006 is below the range of the upper limit acceptable for consistency. Hence, this has implicitly accredited the CAHP mechanism.

The values in the decision matrix D are generated from network parameter values, refer Table 5 and normalized matrix $R_{ij}$ is generated and varied at each iteration randomly. Similarly, values $V_{ij}$, and are computed using the Equation (10) to (16). Alternatives [A1= 802.11n, A2= 802.11ac, A3= HeNB, A4= LTE] and Criteria [C1=RSS, C2=Data rate, C3=delay, C4=Jitter and C5=Packet loss] are considered in forming the decision matrix D.

$$D = \begin{bmatrix} -91.4038 & 51.5282 & 102.1216 & 3.0719 & 15.2165 \\ -61.7582 & 80.0970 & 96.3509 & 14.7264 & 10.7493 \\ -105.1589 & 191.6839 & 99.4595 & 13.3308 & 14.0017 \\ -109.7896 & 172.2881 & 96.5063 & 2.5859 & 10.6659 \end{bmatrix}$$

$$R_{ij} = \begin{bmatrix} -0.4866 & 0.1875 & 0.5177 & 0.1516 & 0.5937 \\ -0.3288 & 0.2915 & 0.4884 & 0.7267 & 0.4194 \\ -0.5599 & 0.6976 & 0.5042 & 0.6578 & 0.5463 \\ -0.5845 & 0.6270 & 0.4892 & 0.1276 & 0.4161 \end{bmatrix}$$

$$V_{ij} = \begin{bmatrix} -0.0355 & 0.0306 & 0.1318 & 0.0386 & 0.1512 \\ -0.0815 & 0.0361 & 0.0985 & 0.1801 & 0.0749 \\ -0.0640 & 0.0848 & 0.1587 & 0.1924 & 0.0857 \\ -0.2051 & 0.1163 & 0.0907 & 0.0237 & 0.0386 \end{bmatrix}$$

$$C_j^* = \begin{bmatrix} 0.4610 \\ 0.3990 \\ 0.2447 \\ 0.7610 \end{bmatrix}$$

The final rank is given by C. According to the array C, alternate A4 is ranked highest. Hence, LTE is the chosen network for current generated context. For, a rank reversal the alternative to the lowest rank need to be evicted. In the current context A3, i.e. HeNB is removed. The number of RATs are only three (802.11n, 802.11ac and LTE). Further, employing CMRAT for new context and check for the rank. If the ranking order is still the same or affected by the removal of a RAT. If the ranking order is not the same it means there is abnormality in ranking. Section VI explains in details the evaluation in each context of traffic class the CMRAT approach of RAT selection.

## VI. PERFORMANCE EVALUATION

The performance of the proposed algorithm is evaluated by simulation using MATLAB. It incorporates 802.11n, 802.11ac, Home eNodeB (HeNB) and LTE (eNB) as the

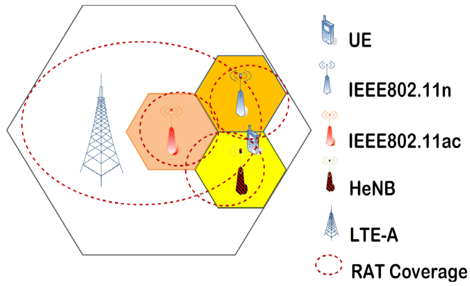


**FIGURE 3.** Illustrates RAT selection in Multi-RAT UDN.

RAT. The criteria considered are as mentioned in network parameter Table 5. The results are analyzed at thirty decision points and presented further in this section. For each iteration of simulation, the measure of each criterion for RAT is randomly varied according to the ranges in Table 5 during the course of experiment. According to Kassar *et al.* [38] and Tran and Boukhatem [39] all handover algorithms based on MADM still present two weaknesses, ranking abnormality and handover.

- Ranking Abnormality is the condition to investigate the ranking order of the access network due to the inclusion or exclusion of a RAT.
- Number of handover: unnecessary handoffs should be minimized as they waste network resources and rise processing overheads.

Hence, the CMRAT performance is evaluated with the contemporary classic MADM approaches namely TOPSIS, Simple Additive Weight (SAW) and Grey Relational Analysis (GRA) considering the ranking abnormality and number of handover metrics. The Figure 4 portrays the case to evaluate the CMRAT approach. The UE is currently connected to the LTE, which is shown by a black dotted line. The UE is in the range of HeNB also. The other RATs 802.11ac and 802.11n are not in the vicinty to the UE in the current context. The decision is triggered based on the CMRAT to switch to HeNB or to continue with the LTE. The same execution process is illustrated with the evaluation for mentioned two metrics in further sections of this article.

### A. NUMBER OF HANDOVERS

Handover is switching from one RAT to another, in this article, the RAT selection in UDN is mainly focusing on vertical handover in which RAT is heterogeneous. The handovers are tracked executing the simulation at thirty decision points and checked how many times the handover was hit in each of the MADM approaches. In general, the proposed CMRAT with CTOPSIS reduced handover compared to the classic TOPSIS, SAW and GRA.

A number of handovers is the quantification of the number of times the user equipment moves from one RAT to another. In the proposed mechanism, one of the objectives is to reduce the number of unnecessary handovers. Hence the multiple case illustration made in this section graphically illustrates the number of handovers in each of the mechanisms, e.g., TOPSIS, SAW and GRA in comparison with the proposed CMRAT.

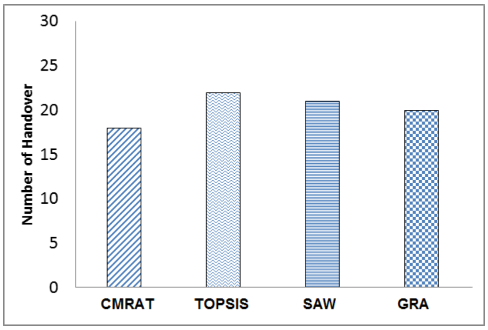


**FIGURE 4.** Number of handover for background traffic.

Figure 4 showcases that the number of handovers is comparatively less in CMRAT compared to TOPSIS, SAW, and GRA mechanisms. The user priority here is background traffic, meaning the data connection is for email, FTP, transfers, and etc. The applications are more toward reliability of transferring rather than the delay. The handover is tested in the context of differentiating the class of application requested by the user. Figure 4 is the interpretation of different approaches employed to background traffic at thirty decision points. CMRAT outperforms by reducing the number of handovers. The handover was reduced by 22.22%, 16.66%, and 11.11% when comparing the number of handovers in the classic TOPSIS, SAW, and GRA respectively with proposed CMRAT. The CMRAT decision is based purely on the contextual information for the differentiated traffic. The priority of traffic is on packet loss rather than other criteria.

Figure 5 showcases that the number of handovers with the conversational flow in CMRAT as compared to TOPSIS, SAW, and GRA mechanisms. When the user preference is conversational, delay and jitter are very crucial for such applications, and packet loss and throughput take the back seat. So, the context of the criteria should be considered during the weight computation and when determining the ranking. With the CMRAT, the number of handovers for a conversational class of traffic is reduced by 58.33% when compared against TOPSIS and SAW, and for GRA by 41.66%. The application is delay sensitive, so the contextual decision is implied in congruence to the RAT with all the criteria and higher priority to the delay criteria, than just the signal alone. The contextual decision priorities the criteria preference for the requested

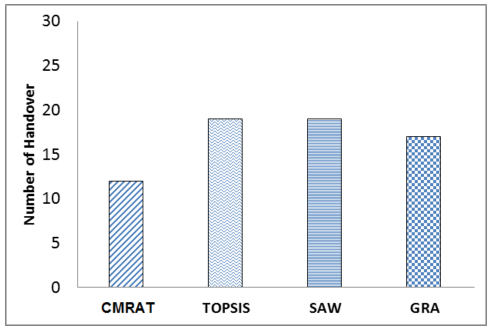


**FIGURE 5.** Number of handover for conversational traffic.

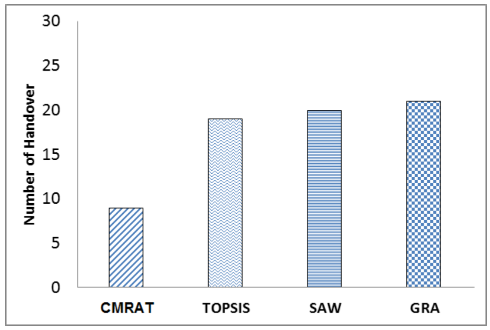


**FIGURE 6.** Number of handover for streaming traffic.

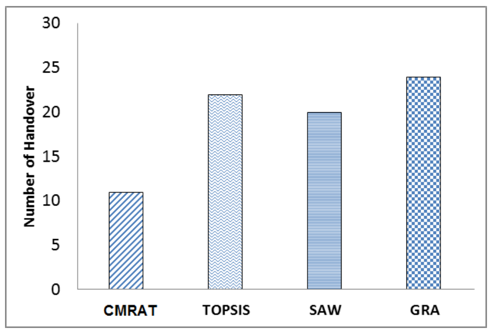


**FIGURE 7.** Number of handover for interactive traffic.

application. However, it does not isolate other criteria, rather the decision is harmonizing all the shortlisted criteria with the priority to the application sensitivity in determining the RAT.

Similarly, Figures 6 and 7 showcase that the number of handovers with streaming and interactive traffic respectively in CMRAT, TOPSIS, SAW, and GRA mechanisms. For streaming traffic, the handovers are reduced by CMRAT in comparison with other three by 50%, 45%, and 54% respectively, followed by an interactive type of application with 57%, 55% and 52%, when compared to TOPSIS, SAW, and GRA. In general, the context based design is more efficient compared to the imperative approach.

The decision in the case of streaming data prefers the high data rate in congruence with the other criteria along with the available RAT, whereas for the interactive class applications, the mechanism prioritizes delay and packet loss with the other

**TABLE 6.** Ranking order of RAT with data connection.

| RAT | Cj* | Ranking Order |
|---|---|---|
| 802.11n | 0.407 | 4 |
| 802.11ac | 0.645 | 2 |
| HenB | 0.589 | 3 |
| LTE-eNodeB | 0.733 | 1 |

| RAT | Cj* | Ranking Order |
|---|---|---|
| 802.11ac | 0.603 | 2 |
| HenB | 0.287 | 3 |
| LTE-eNodeB | 0.755 | 1 |

criteria. Hence, the decision is made with the preference of collaborative criteria, but mainly prioritizing the differentiated class of applications.

Hence, from the multiple case illustration and experimental results, it can be ascertained that the context-aware mechanism of ranking reduces the number of handovers quantitatively, because the decision is not imperative or based on a single criteria, but rather based on collaborative with context-awareness. The handover is triggered exclusively based on context-awareness of user and network.

### B. RANKING ABNORMALITY

As stated earlier, the rank reversal is the state of RAT ranking order when one of the RAT is removed. The ranking of the remaining available RATs should be unchanged. If the removal of RAT affects the ranking order, it can be concluded that there is a rank reversal issue. The proposed CMRAT mechanism reduces the rank reversal problem quantitatively in comparison to other MADM mechanisms, in order to determine the validation multiple case with varying context, which is illustrated in this section. In the experiment design of this proposed mechanism, the RAT with the lowest is evicted and the experiment is run to check for rank reversal. The illustration of this is presented in Table 6, where the lowest ranked RAT, i.e., 802.11n (A1) is removed. The A2, A3 and A4 alternatives are only three RATs (802.11ac, HeNB, and LTE) remaining for the next round of execution to test the rank reversal by employing CMRAT for new context and checking for the ranking order. If the ranking order is still the same or not affected by the removal of a RAT, then there is no abnormality, but if the ranking order is not the same, it means that there is abnormality in ranking. However, in the experiment carried out to check rank reversal for data connection, as illustrated in Table 6, the ranking order remained the same after removing the lowest ranked RAT from the first run. The results presented in the table show no ranking abnormality for the background traffic context tested using CTOPSIS.

The eviction of the RAT should not make any difference in the ranking order of RAT selection. If the operation is affected and rank order changes, it means that there is a ranking abnormality. This metric is measured in the current research and the proposed CMRAT approach is evaluated

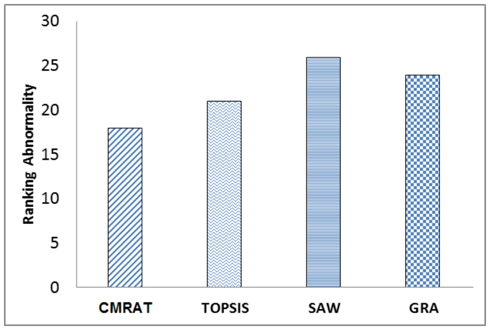


**FIGURE 8.** Ranking abnormality for background traffic.

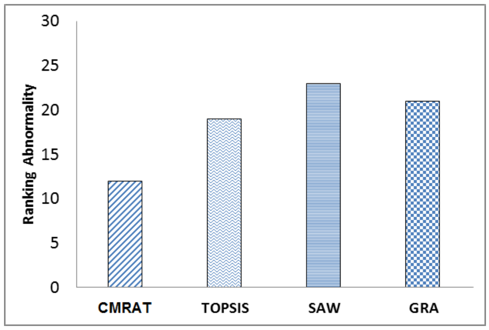


**FIGURE 9.** Ranking abnormality for conversational traffic.

with the other classic MADM approaches, namely TOPSIS, SAW and GRA. The ranking abnormality for background flow is outlined in Figure 8.

The background traffic was considered and evaluated, Figure 8 outlines the evaluation of ranking abnormality in CMRAT to the TOPSIS, SAW, and GRA. The data flow is not stringent to any criteria like other classes of traffic. The CMRAT is less prone to ranking abnormality in comparison to other mechanisms. CMRAT is less prone to RA 14%, 30%, and 25% than TOPSIS, SAW and GRA, respectively.

Simulation analyses the data connection or the conversational flow, in order to compare the performance of the proposed CMRAT mechanism with the other three mechanisms (TOPSIS, SAW and GRA). From Figure 9, while considering the conversational traffic, such as VoIP application which is delay sensitive. The determining RAT should be very critical and CMRAT outperforms in this context also by 36%, 47%, and 42% compared to TOPSIS, SAW, and GRA, respectively. The context-awareness with integration of MADM approaches aids in efficient decision making in RAT selection.

In the context of streaming, the application priority is jitter and throughput, indexing this preference into the criteria during the computation of weights through CAHP. Later, the weights of CAHP are induced in CTOPSIS for RAT selection. The integration of these to MADM approaches with context-awareness not only makes an efficient decision, it also performs better in terms of RA by 13%, 20%, and 29% as compared to TOPSIS, SAW, and GRA respectively.

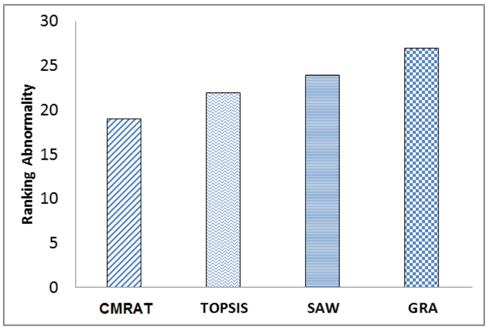


**FIGURE 10. Ranking abnormality for streaming traffic.**

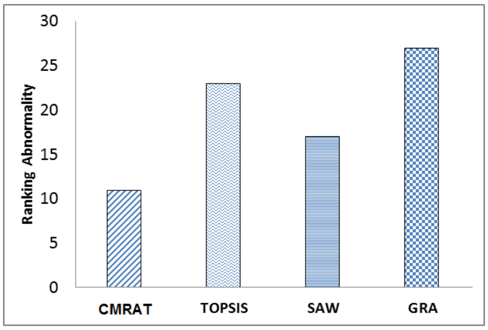


**FIGURE 11. Ranking abnormality for interactive traffic.**

Figure 10 presents the ranking abnormality in the context of streaming type of traffic. Finally, Figure 11 considers the interactive traffic, which is delay sensitive, and packet loss rate should be low. The mechanism takes care in the process of assigning the weight and determining the RAT according to the requirements and the availability at the context during the decision making. Furthermore, based on this theory, the CMRAT performs better 52%, 35%, and 59% than TOPSIS, SAW, and GRA, respectively.

From the case illustration, it can be ascertained that the ranking abnormality is comparatively reduced in case of CMRAT. However, there is a scope to improve toward zero. The CMRAT is less prone to abnormality issue. From the above evaluation, it can be deliberated that CMRAT is performing better and less prone to ranking abnormality compared to other approaches irrespective of the traffic classes. The reduced ranking abnormality is due to the integration of MADM mechanisms while harnessing the benefits of the mechanism. Also, the decision is not just multi-attribute based, but rather it is context-aware.

## VII. CONCLUSION

The UDN is one of the driving features of the future wireless heterogeneous networks. The densified multi-RAT heterogeneous environment with imperative approach of RAT selection leads to frequent unnecessary handover while degrading system performance. Hence, there is a need for an efficient RAT selection mechanism which enhances the quality of experience of the user while utilizing the network resources optimally. This paper proposed a novel approach of RAT selection comprising two mechanisms, namely the Context-aware Analytical Hierarchy Process (CAHP) and Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS). The CAHP mechanism measures the need to switch from the current RAT, while CTOPSIS aids in decision making to choose the best target RAT. CMRAT approach was able to choose the best RAT with less number of handovers and it is less susceptible to ranking abnormality. The evaluation was done by comparing with the other classic MADM approaches, namely TOPSIS, SAW, and GRA approaches. Future work, CMRAT will be incorporated into a network simulator environment to obtain more realistic results.

## REFERENCES

[1] Cisco. (Feb. 2015.). *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update*. [Online]. Available: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html
[2] A. Gohil, H. Modi, and S. K. Patel, "5G technology of mobile communication: A survey," in *Proc. Int. Conf. Intell. Syst. Signal Process. (ISSP)*, Mar. 2013, pp. 288–292.
[3] O. Fagbohun, "Comparative studies on 3G, 4G and 5G wireless technology," *IOSR J. Electron. Commun. Eng.*, vol. 9, no. 3, pp. 88–94, 2014.
[4] A. Osseiran *et al.*, "Scenarios for 5G mobile and wireless communications: The vision of the METIS project," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 26–35, May 2014.
[5] D. Astely, E. Dahlman, G. Fodor, S. Parkvall, and J. Sachs, "LTE release 12 and beyond [accepted from open call]," *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 154–160, Jul. 2013.
[6] X. Yan, Y. A. Şekercioğlu, and S. Narayanan, "A survey of vertical handover decision algorithms in fourth generation heterogeneous wireless networks," *Comput. Netw.*, vol. 54, no. 11, pp. 1848–1863, 2010.
[7] G. Mahardhika, M. Ismail, and R. Nordin, "Multi-criteria vertical handover decision algorithm in heterogeneous wireless network," *J. Theor. Appl. Inf. Technol.*, vol. 53, no. 2, pp. 339–345, 2013.
[8] A. Orsino, G. Araniti, A. Molinaro, and A. Iera, "Effective RAT selection approach for 5G dense wireless networks," in *Proc. IEEE 81st Veh. Technol. Conf. (VTC Spring)*, May 2015, pp. 1–5.
[9] A. Sgora, D. D. Vergados, and P. Chatzimisios, "An access network selection algorithm for heterogeneous wireless environments," in *Proc. IEEE Symp. Comput. Commun. (ISCC)*, Jun. 2010, pp. 890–892.
[10] Q. Song and A. Jamalipour, "A network selection mechanism for next generation networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, vol. 2. May 2005, pp. 1418–1422.
[11] M. N. Halgamuge, H. L. Vu, K. Rarnamohanarao, and M. Zukerman, "Signal-based evaluation of handoff algorithms," *IEEE Commun. Lett.*, vol. 9, no. 9, pp. 790–792, Sep. 2005.
[12] S. Maaloul, M. Afif, and S. Tabbane, "A new vertical handover decision based context awareness for ubiquitous access," in *Proc. Int. Conf. Commun. Inf. Technol. (ICCIT)*, Jun. 2012, pp. 231–236.
[13] S. Maaloul, M. Afif, and S. Tabbane, "A vertical handover decision based context awareness guaranteeing the user perceived quality of service," in *Proc. 10th ACM Int. Symp. Mobility Manage. Wireless Access*, 2012, pp. 149–152.
[14] K. Savitha and C. Chandrasekar. (Jul. 2011). "Trusted network selection using saw and topsis algorithms for heterogeneous wireless networks." [Online]. Available: https://arxiv.org/abs/1108.0141
[15] E. Stevens-Navarro and V. W. S. Wong, "Comparison between vertical handoff decision algorithms for heterogeneous wireless networks," in *Proc. IEEE 63rd Veh. Technol. Conf. (VTC)*, vol. 2. May 2006, pp. 947–951.
[16] R. Tawil, G. Pujolle, and O. Salazar, "A vertical handoff decision scheme in heterogeneous wireless systems," in *Proc. IEEE Veh. Technol. Conf. (VTC)*, May 2008, pp. 2626–2630.
[17] M. Pink, M. Sprejz, and H. Koenig, "A coordinated group decision for vertical handovers in heterogeneous wireless networks," in *Proc. Int. Conf. MOBILe Wireless MiddleWARE, Oper. Syst. Appl. (Mobilware)*, Nov. 2013, pp. 130–137.

[18] A. Kaloxylos, S. Barmpounakis, P. Spapis, and N. Alonistioti, "An efficient RAT selection mechanism for 5G cellular networks," in *Proc. Int. Conf. Wireless Commun. Mobile Comput. (IWCMC)*, Aug. 2014, pp. 942–947.
[19] S. M. Matinkhah, S. Khorsandi, and S. Yarahmadian, "A new handoff management system for heterogeneous wireless access networks," *Int. J. Commun. Syst.*, vol. 27, no. 7, pp. 1020–1033, 2014.
[20] S. Barmpounakis, A. Kaloxylos, P. Spapis, and N. Alonistioti, "COmpAsS: A context-aware, user-oriented RAT selection mechanism in heterogeneous wireless networks," in *Proc. Int. Conf. Adv. Commun. Comput. (INFOCOMP)*, Paris, France, 2014, pp. 1–7.
[21] S. I. Goudar, A. Habbal, and S. Hassan, "Context-aware multi-attribute radio access technology selection for 5G networks," in *Proc. 4th Int. Conf. Internet Appl., Protocols Services (NETAPPS)*, 2015, pp. 81–86.
[22] S. F. Yunas, M. Valkama, and J. Niemelä, "Spectral and energy efficiency of ultra-dense networks under different deployment strategies," *IEEE Commun. Mag.*, vol. 53, no. 1, pp. 90–100, Jan. 2015.
[23] S. I. Goudar, S. C. Chit, B. Mounira, M. Radia, and S. Hassan, "Implementation of an offloading strategy in heterogeneous environment," in *Proc. 4th Int. Conf. Internet Appl., Protocols Services (NETAPPS)*, 2015, pp. 105–109.
[24] S.-M. Liu, S. Pan, Z.-K. Mi, Q.-M. Meng, and M.-H. Xu, "A simple additive weighting vertical handoff algorithm based on SINR and AHP for heterogeneous wireless networks," in *Proc. Int. Conf. Intell. Comput. Technol. Autom. (ICICTA)*, vol. 1. May 2010, pp. 347–350.
[25] V. Sasirekha and M. Ilanzkumaran, "Heterogeneous wireless network selection using FAHP integrated with TOPSIS and VIKOR," in *Proc. Int. Conf. Pattern Recognit., Informat. Mobile Eng. (PRIME)*, Feb. 2013, pp. 399–407.
[26] O. Markaki, D. Charilas, and D. Nikitopoulos, "Enhancing quality of experience in next generation networks through network selection mechanisms," in *Proc. IEEE 18th Int. Symp. Pers., Indoor Mobile Radio Commun.*, Sep. 2007, pp. 1–5.
[27] D. Zhang, Y. Zhang, N. Lv, and Y. He, "An access selection algorithm based on GRA integrated with FAHP and entropy weight in hybrid wireless environment," in *Proc. 7th Int. Conf. Appl. Inf. Commun. Technol. (AICT)*, Oct. 2013, pp. 1–5.
[28] *QoS Concepts and Architecture*, document TS22.107, 3GPP, 2005.
[29] S. Balasubramaniam and J. Indulska, "Vertical handover supporting pervasive computing in future wireless networks," *Comput. Commun.*, vol. 27, no. 8, pp. 708–719, May 2004.
[30] G. D. Abowd, A. K. Dey, P. J. Brown, N. Davies, M. Smith, and P. Steggles, "Towards a better understanding of context and context-awareness," in *Handheld Ubiquitous Computing*. Berlin, Germany: Springer, 1999, pp. 304–307.
[31] B. Schilit, N. Adams, and R. Want, "Context-aware computing applications," in *Proc. 1st Workshop Mobile Comput. Syst. Appl. (WMCSA)*, Dec. 1994, pp. 85–90.
[32] M. Zekri, J. Pokhrel, B. Jouaber, and D. Zeghlache, "Reputation for vertical handover decision making," in *Proc. 17th Asia–Pacific Conf. Commun. (APCC)*, Oct. 2011, pp. 318–323.
[33] T. L. Saaty, "How to make a decision: The analytic hierarchy process," *Eur. J. Oper. Res.*, vol. 48, no. 1, pp. 9–26, Sep. 1990.
[34] L. Ekiz *et al.*, "Potential of cooperative information for vertical handover decision algorithms," in *Proc. 16th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, Oct. 2013, pp. 455–460.
[35] J. F. Kurose, *Computer Networking: A Top-Down Approach Featuring the Internet*, 3rd ed. Upper Saddle River, NJ, USA: Pearson Education, 2005.
[36] T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, vol. 175. New York, NY, USA: Springer, 2012.
[37] C.-L. Hwang and K. Yoon, *Multiple Attribute Decision Making: Methods and Applications a State-of-the-Art Survey*, vol. 186. Berlin, Germany: Springer, 2012.
[38] M. Kassar, B. Kervella, and G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Comput. Commun.*, vol. 31, no. 10, pp. 2607–2620, 2008.
[39] P. N. Tran and N. Boukhatem, "Comparison of MADM decision algorithms for interface selection in heterogeneous wireless networks," in *Proc. 16th Int. Conf. Softw., Telecommun. Comput. Netw., SoftCOM*, Sep. 2008, pp. 119–124.


**ADIB HABBAL** (SM'15) received the Ph.D. degree in computer science (specializing in networked computing) from Universiti Utara Malaysia. He has more than ten years of experience in teaching and university lecturing. He is currently the Head of InterNetWorks Research Platform, School of Computing, Universiti Utara Malaysia (UUM). His current area of research focuses on future internet and 5G mobile networks. He serves as an IEEE UUM Student Branch Counselor and an Executive Council Member of the Internet Society Malaysia Chapter. He is actively involved in IEEE Communications Society. He is also the Internet Society (ISOC) Fellow alumni to the Internet Engineering Task Force. In 2013, he was selected as an Asia–Pacific Advanced Network Fellow to the APAN 35th and Techs in Paradise (TIP2013) held at the University of Hawaii. In addition to being a Speaker at a number of renowned research conferences and technical meetings, he also participates in various international fora, such as IEEE meetings, ACM SIGCOMM meeting, the IETF, internet2 meeting, APNIC, and APAN.

**SWETHA INDUDHAR GOUDAR** (M'16) received the B.C.A. degree from Karnataka University, India, in 2005, and the M.C.A. degree from Visvesvaraya Technological University, India, in 2008. She is currently working towards the Ph.D. degree in computer science with the InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia. She has carried out many industrial and academic projects in computer applications. Her current research activities include current area of research focuses on Future Internet and 5G mobile networks. She was a Fellow for SANOG XXIV, held at Greater Noida, India, in 2014. She is actively involved in IEEE activities, and also was an Executive Member of the Student Chapter for two consecutive terms. Also, she was a Student Delegate of the Japan-Asia Exchange Program in Science administered by Japan Science and Technology, held at the Shibuara Institute of Technology, Tokyo, Japan, 2016.

**SUHAIDI HASSAN** (SM'08) received the B.S. degree in computer science from Binghamton University, NY, USA, the M.S. degree in information science (with concentration in telecommunications and networks) from the University of Pittsburgh, PA, USA, and the Ph.D. degree in computing (specializing in networks performance engineering) from the University of Leeds, U.K. He is currently the Professor of Computing Networks and the Founding Chair of the InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia (UUM). He is actively involved in both the IEEE Communications Society and IEEE Computer Society. He is also an Internet Society Fellow Alumni to the Internet Engineering Task Force. In 2006, he was nominated as a WKD Foundation's (Switzerland) Young Scientist Fellow at the World Knowledge Dialogue, Crans-Montana, Switzerland. In 2006, he led a task force for the establishment of the International Telecommunication Union (ITU)-UUM Asia Pacific Centre of Excellence (ASP CoE) for Rural ICT Development, a human resource development initiative of ITU, which serves as the focal point for all rural ICT development initiatives across the Asia Pacific region. He has authored or co-authored more than 200 refereed technical publications, successfully supervised 18 Ph.D. scholars in the area of computer and communication networks, served as reviewer and referee for journals and conferences on computing networks as well as the examiner for more than 80 Ph.D. and master's scholars in his research areas.