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Network selection in heterogeneous access networks simultaneously satisfying user profile and QoS

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Summary

Multimode capability empowers mobile devices to select the appropriate network to meet the requirements of user and applications. However, network selection is a challenging task owing to heterogeneous nature of network access links. At the same time, pervasiveness of mobile communication networks accompanied by the advances in wireless devices has raised the user expectations of persistent service and quality. Therefore, it is important for a mobile device to take situation-based and timely decisions while selecting an access network to ensure both user's and operator's demand. The existing standard, called IEEE 802.21 (media-independent handover), considers mobile device signal-strength parameter for network selection from a list of networks. This research has proposed a ranking algorithm to rank heterogeneous networks based on a set of parameters including user profile and QoS. It selects most suitable network owing to multiple handover scenarios. The simulation results have shown that the proposed scheme has successfully satisfied apparently the contradictory requirements related to user profiles and QoS simultaneously.

KEYWORDS

algorithms, design, MADM, network selection, NGN, performance optimization

1 | INTRODUCTION

Nowadays, because of the technological advancements, the mobile devices are multitasks and can performs high computational tasks to enrich user experience. With such a device in hand, the user's demand of guaranteed high-quality and on-the-move services have escalated from traditional voice calls and text messaging to multimedia streaming and video conferencing.[1-4] Consequently, service providers are trying hard to meet with the increasing demand of their clients, providing more resources to cope with the resulting network load. As a result, the operator's focus has shifted towards deployment of additional and more capable technologies, beside increasing capabilities of the existing infrastructure.[5,6] The strategy is to integrate these technologies for sharing the load and to allow the operators to implement their policies more effectively.[7]

Vertical handover (VHO) assist mobile phone users to roam across the network with graceful degradation in service. Media-independent handover (MIH)[8] provides the basis for the VHO. For VHO, network selection is a challenging task that leads to service degradation and affects mobile device battery lifetime if not properly handled. The existing network selection methods have considered network selection process either at mobile terminal or core network (CN). Moreover, the existing works such as MIH offer network selection at mobile terminal. However, MIH standard has only considered received signal strength to choose a network for handover (HO). It has overlooked user preferences (UPs) and QoS[9] attributes while selecting a network.

This study put forwards a solution to address the multi-attribute decision-making (MADM) problem[10] of network selection in heterogeneous access networks. The strategy takes into account vast range of QoS and non-QoS attributes in the decision-making process from user and operator's perspective. It proposes both ranking and selection services. The ranking process evaluates all important attributes of available networks, assigning priorities (rank list) to networks for each connection using a novel ranking algorithm. The selection process confirms the availability of the network from the operator's perspective, and the first available network in the prioritized list is chosen for the HO.

The network selection, in this paper, is based on the requirement of the traffic class of the application, in addition to the UPs. It also uses single-selection point using MIH command service to reduce the networking delays. The strategy was simulated on top of National Institute of Standard and Technology (NIST) MIH module using NS 2.29 (network simulator). Five different networks, with a UMTS, WiMAX, and 3 Wi-Fi interfaces, were used for the performance evaluation. The main contributions of this study includes the following:

a) Proposing a ranking algorithm that has opted multiobjective optimization to rank the heterogeneous access networks.
b) Proposing a network selection algorithm to choose the most suitable network while considering various HO scenarios.
c) Evaluating the proposed work for a set of parameters while considering various traffic classes.

The rest of this paper is organized as follows. Section 2 presents the related work. This is followed by 2 sections regarding our proposal, with Section 3 dealing with our algorithm on network selection and Section 4 handling the traffic classification. The simulation results are summarized in Section 5. Section 6 concludes the paper and puts forward the future research directions and challenges.

2 | RELATED WORK

There are numerous challenges (eg, meeting QoS, UPs, operator's preferences, and battery level) and technological advancement trends that affect overall performance when selecting an access network, dynamically.[10-14] Network selection opts to design a radio access technology selection while simultaneously enhancing overall network performance and end user's experience.[15] Another challenge is mobility management during HO process to optimize the network performance. Tamijetchelvy and Sivaradje[16] have proposed a study to analyze HO overhead[17] based on different mobility protocols by following IEEE 802.21 MIH standard. An important aspect for HO decision is estimating the bandwidth and packet delay for the target network, in addition to application performance.[18] Data off-loading is a mechanism to enhance battery lifetime of a mobile device. Whu et al[19] have proposed a mechanism to select network for data off-loading while considering 5G multiradio[20] heterogeneous networks. Niyato and Hossain[21] have investigated network selection process based on game theory concept using population evolution and reinforcement-learning algorithms. The scheme proposed by Malanchini et al[20] has modeled the interaction among end users based on a noncooperative congestion game theory approach. The objective of their approach was to minimize the network selection cost by provisioning a method where user selfishly selects the network.

The earlier wireless standards of IEEE 802.1x does not support the HO between different types of networks (VHO).[8,22] However, efforts are on to provide a platform for converged networks in the forthcoming IEEE 802.21 standard, also known as the MIH. The MIH framework has provided the basis for the VHO among heterogeneous access networks by providing common means of information exchange. It also defines commands and event services for triggering the HO in heterogeneous environment. In addition to these services, and the information that the MIH framework is offering, an optimal decision can be made in both horizontal handover (HHO) and VHO scenarios. The emerging standard will provide independence of media type to entities whenever an HO is deemed essential. The MIH function is used for the HO-related information. As the standard is designed to assist the future network communication trends, some amendments in existing standards are required. To incorporate HOs from different networks to WLANs, the IEEE 802.11 standard is amended in 802.11u. Similarly, the IEEE 802.16g amendment has an extension of service access points to support the MIH. The Internet Engineering Task Force working group is putting its efforts to overcome the problem related to information delivery in MIH.

Currently, as stated elsewhere, the MIH standard does not provide a thorough strategy to select an optimum destination network.[23,24] Work is in progress in this direction by different researchers, and some fair solutions have been provided.[6,25-32] Studies like Dhar et al[27] and Mohammed and Aladdin[28] do not qualify for multiobjective optimization solutions. The proposals in Wang and Binet[29,30] are not feasible for automated seamless network selection and HO due to their manual weight selection policy for the required factors. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is more precise,[33] but the method experiences ranking abnormalities.[25]

RafoQ[26] is an algorithm that uses supervised aggregation of pair-wise ranking, for radio access networks technologies, in a heterogeneous environment. The algorithm involves comparisons of alternative networks AMOSA[34] for the evaluation of QoS factors of each network in order to find the optimal choice. RafoQ considers only the QoS parameters to rank available networks. It does not consider other influential factors such as UP, resource consumption, and operator's policies. Moreover, it merely ranks available networks on CN end assuming all available networks have common selection point. The work also needs performance evaluation for expected results.

The work of Kaloxylos et al[6] has proposed a mechanism where various factors are used for the network evaluation in heterogeneous environment. These include UPs, signal strength, battery level, network congestion, speed, and direction of the mobile node. They have proposed 2 decision points: a ranking algorithm at mobile terminal for ranking the alternative networks and a selection algorithm running in the CN for selection and resource allocation. The paper discusses a new infrastructure for information exchange between a mobile terminal and a network access point. It lacks the implementation details about the network selection strategy, however. Moreover, the communications between 2 decision points introduce an overhead in the network in the form of extra traffic and produces delays because of this communication between the decision points. The scheme has been tested using a test bed only for the Wi-Fi and WiMAX integration.

Dhar et al[27] have proposed a modified algorithm based on the TOPSIS.[35] They have considered cost and utilization of the network, along with other effective QoS factors, for ranking the alternatives. The said algorithm has been dealt with in a good detail for various scenarios. However, the scheme does not suggest any architecture for network selection. It also ignores operator's policies and mobile terminals conditions, like speed and battery power consumption. The work of Whang and Binet[29,30] provides a detailed analysis of MADM algorithms used by a number of researchers to cater for the problem of network selection in a heterogeneous environment. The study compares the MADM algorithms that use combined coefficients of total rank value and those that use pair-wise comparison of individual rank factor. TOPSIS,[35] simple additive weighting,[36] multiplicative exponent weighting, gray relational analysis,[37] and elimination and choice translating reality[38] have been analyzed, for QoS factors, for different use-case scenarios. The study has proposed a 4-step integrated strategy of MADM-based network selection to solve issues such as the need for efficient weighting method, the VHO properties usage, the trade-off for vertical handing-over, and moderate load balancing. Load balancing and hand-off overhead are the issues that they suggested to be worked on.

Mohammed and Aladdin[28] and Radhika and Reddy[32] have proposed a solution for the network selection problem using fuzzy logic. The study in Mohammed and Aladdin[28] compares the networks based on Code Division Multiple Access (CDMA) with those using Time Division Multiple Access (TDMA) and propose a Medium Access Control (MAC) layer strategy for the network selection. Two factors add complexity to the proposed strategy. First is the integral complexity of fuzzy logic based solution to the MADM problems. Second is the proposed strategy of a MAC layer solution, which is not flexible for the realm of next-generation networks where various technologies coexist and space must be provided for newly emerging technologies in order to absorb these in the integrated environment. Nguyen-Vuong et al[13] have modeled a framework to highlight the preferences of users for network selection. The proposed model is smart, as it has considered all the trade-offs among the quality offered by networks to select the best one among the available list.

TABLE 1 Comparison of network selection strategies

Methods	QoS factors	Selection of weights	Ranking observation	Factors considered	Selection point(s)
TOPSIS[25]	8	Multiobjective optimization	Ranking abnormalities	QoS, UP	MT+CN
Dhar et al[27]	8	Heuristic	Weight matrix analysis	QoS	…
Mohammed and Aladdin[28]	Limited	Single objective	Fuzzy analysis (single objective)	QoS, UP	MT
Wang and Binet[29,30]	Flexible	Manual	Pair-wise ranking	QoS	…
Kaloxylos et al[6]	Limited	Elimination	Step-wise elimination	QoS, UP, OP	MT+CN
RafoQ[26]	Flexible	Multiobjective optimization	Supervised pair-wise ranking	QoS	…
Hybrid (our scheme)	Flexible	Multiobjective optimization	Weight matrix analysis	QoS, UP, OP	MT using MIH IS

Abbreviations: CN, core network; MIH, media-independent handover; MT, mobile terminal; OP, operator's perspective; TOPSIS, Technique for Order Preference by Similarity to Ideal Solution; UP, user profile.

Wang et al[39] have proposed a scheme that have opted quantum-inspired immune clonal algorithm to select most suitable access network among a list pf networks. The proposed scheme is flexible, as it has considered several challenges related to (*a*) access networks and end users, (*b*) economic and noneconomic objectives, and (*c*) objective or subjective attributes. The authors have modeled the proposed work under always best connected environment based on the assumption that always best connected is a high priority for both mobile terminals and users. Another scheme proposed in Goyal et al[40] has considered fuzzy–analytic hierarchy process to select best network among Wi-Fi, WLAN, and cellular technologies. The proposed scheme has considered triangular fuzzy numbers for representation of the elements in comparison matrix. The proposed study has considered voice, video, and best effort applications for the evaluation. The work presented in Goyal et al[41] has considered real-time analysis approach for identifying the UPs to overcome the issues of prefixed static preference. The paper has proposed a mathematical formula to calculate and assign weights to the dynamic preferences. The evaluation is conducted to analyze the effect of dynamic preferences on the number of vertical hand-offs.

An analysis of the existing studies (closely related to our work) and its comparison with the proposed scheme (hybrid) are outlined in Table 1 to highlight the common and discrete features. As compared with aforementioned studies, the scheme proposed in this paper considers both QoS and non-QoS factors form user and operator's perspective. The scheme does not require pretraining and does not suffer form rank abnormalities problem. It also provides both ranking and selection services.

3 | PROPOSED NETWORK SELECTION SCHEME

The proposed scheme consists of 2 key modules, namely, network selection and ranking engine, as discussed below.

3.1 | The network selection process

To implement our strategies, we follow the specifications of IEEE 802.21 MIH to collect information regarding available access network alternatives. The IEEE 802.21 specification proposes to divide the process of HO into 3 phases: HO initiation, HO preparation, and HO execution,[43] as illustrated in Figure 1. New links are discovered during the HO initiation

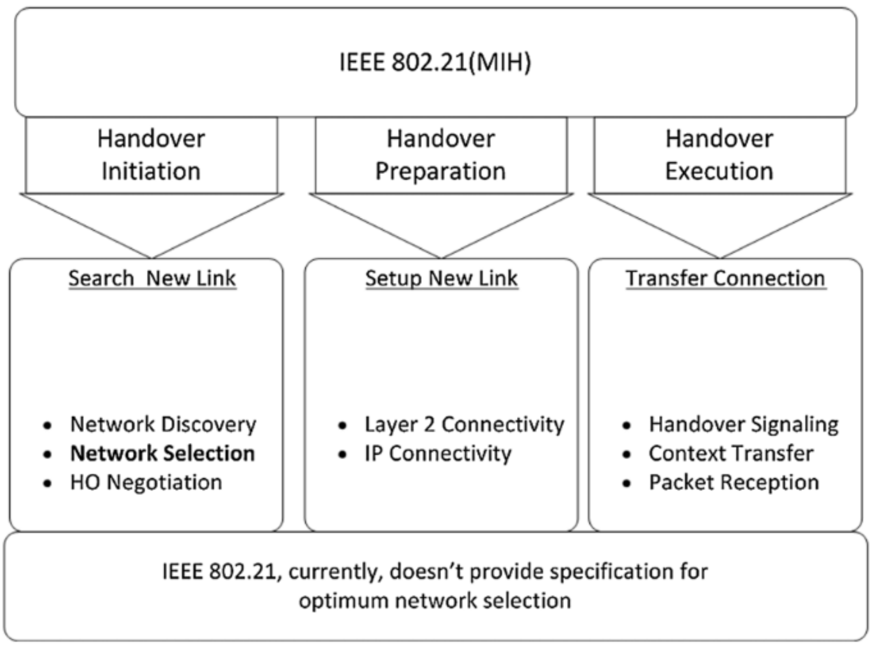


FIGURE 1 Media-independent handover process: adapted from Vivek[42]

TABLE 2 List of criteria for network selection

Type	Criteria	Description
Connection cost	Cost	Indication of cost for service or network usage.
Security	Network security	Security level of the link layer. Ranges from 0 to 10
QoS Subcriteria	Packet transfer delay	Average packet transfer delay in ms. (If class of service is in place, then the network needs to provide information of all the K classes.) Valid range for average packet transfer delay: [0-65535] ms
	Delay jitter	Packet transfer delay jitter for the class in ms. Valid range average packet transfer delay: [0-65535] ms
	Packet loss rate	Indicates the fraction of packets lost or detected as erroneous. A value equal to integer part of 100 times the log_{10} of the ratio between the number of error packets and the total number of the packets transmitted in the class population of interest
	Guaranteed (min) bit rate	The minimum information transfer rate in the class population of interest. It is measured in kbps
Speed	Speed of the mobile terminal	Average speed at which the mobile terminal moves. Measured in m/s
Battery consumption	Battery power consumption	Power requirement for the transmission and reception of data signals. Calculated in kJ. Transformed into level (ranges from 0 to 100)

phase followed by network selection phase. Handover negotiation governs the network being selected. After the HO initiation phase, a new network link is set up through layer 2 connectivity, referred as HO preparation phase. Finally, transfer of connection occurs in the last phase. The criteria for network selection is shown in Table 2.

The proposed approach divides the network selection process into 2 parts. The first part is the *ranking engine*, where values for all critical attributes of the available networks are calculated, normalized, and adjusted. A ranking algorithm is then applied to these values in order to produce a prioritized list of the available networks for each connection. The prioritized list is then forwarded to the second part of the selection process, the *selection engine*, where availability of the network is confirmed from the operator's perspective and the first available network in the prioritized list is chosen for the HO.

3.2 | The ranking engine

In the ranking engine, there are 5 well-known situations that can trigger ranking process. These are link discovery (*LD*), forced handover (*FH*), battery down threshold (*BD*), received signal strength (RSS) degrade (*RD*), and new call request (*NC*), culminating in an event invocation. This event e, in turn, triggers the process shown in Algorithm 1. In addition to e, the algorithm works with weight matrix $WM[4 \times N \times A]$ that contains weights of A attributes of N networks for 4 different classes of services; see Section 4. The output of the algorithm is a *Priority_List* and a *Request_type*. The *Priority_List* is a sorted list of N candidate networks from most favorable to least favorable, for C connections using *init* (initialization). The list is initialized with predefined static parameters of the networks such as the maximum bandwidth provided by the networks, monetary cost, and estimated battery consumption. The *Request_type* can either be urgent horizontal handover request (*UHHR*), urgent vertical handover request (*UVHR*), normal handover request (*NHR*), or a new call request (*NCR*). Algorithm 1 works as following.

The *BD* event is handled by prioritizing those networks that are currently providing low power consumption using *Prioritise*. Power consumption of each available network is calculated using linear model of power consumption within NS 2, and the corresponding entry in $WM[4 \times N \times A]$, represented by En_i, is updated. Other factors such as end-to-end delay, jitter, packet loss ratio (PLR) are given less weightage in such a scenario.

Against the *RD* event, the algorithm first tries for an urgent HHO, if possible. In that case, the target cell of the same network is selected, and MIH *HandoverInitiate* command is triggered along with next point of attachment (*TargetCell*). Otherwise, the algorithm goes for the VHO option. In case neither HHO nor VHO is possible, the mobile node will wait for RSS raise or call drop.

Algorithm 1 Ranking Engine

```
Input: event e and WM[4 × N × A]
Output: Priority_ List[C x N], Request_ type
begin
    init(Priority_ List)
    if e=BD then
        for n ← 1toN do
            En_i ← Power_Consumption(Network_i)
            Prioritise(Network_i, En_i)
        end
    else if e=RD then
        if HHOpossible then
            Request_type ← UHHR
            Target_Cell ← Get_New_Cell()
            Initiate_Handover(Target_Cell)
            Exit
        else if VHOpossible then
            Request_type ← UVHR
        else
            Wait
        end
    else
        if e=NC then
            Request_type ← NCR
        else
            Request_type ← NHR
        end
        for i ← 1 to N do
            rss_i ← Calc_RSS(Network_i)
        end
        Read(Batery_life)
        Modify(WM, Battery_Life)
    end
    Finalise(Priority_List)
    Send(Priority_List, Request_type)
    Exit
end
```

The rest of the events are considered as normal HO, and the algorithm takes all the static, as well as the dynamic parameters, of all available networks into account. Received signal strength value is calculated for each alternative $Network_i$, and its corresponding entry in *WM*, represented by rss_i in the algorithm, is updated. Battery life of the mobile node is observed, and new weight is assigned to battery power consumption criterion indicated by *Battery_life*. *WM* is modified through the weight elicitation process depicted in Table 5. After this revision of *WM* and selection of *Request_type*, in *Finalise* (see Algorithm 1), the links that are already used by the same node for other connections are preferred over new links, provided that they satisfy the QoS and UP requirement of the traffic class. After all the refinements, the *Priority_List* is sorted and filtered for networks that fulfill the minimum QoS criteria of the connection in focus. The list is finally sent to the selection engine, along with the *Request_type*, for further processing.

3.3 | The selection engine

Upon receiving the *Priority_List* and *Request_type* (Algorithm 1), the selection engine starts evaluating the alternatives from the operator's perspective. This part of the algorithm takes the final decision about the admittance of a new connection or HO of an existing one. The Algorithm 2 works in 3 different ways, based on request type, as under.

For the urgent VHO request, where delay may cause catastrophe, the algorithm only probes link status required against that particular connection. The link status is acquired using *Link_Status*, which in-turn uses *MIHGetStatus* command. *MIHGetStatus* is defined in the architecture of MIH.

For the new connection request, the algorithm calculates dynamic parameters and updates the attribute matrix for that specific class of service (CoS).

For normal HO requests, the dynamic parameters of all the alternatives are calculated, and attribute matrix is updated accordingly.

The status of each of the links is then probed, based on its priority against each connection request. As a result of the successful execution, the algorithm produces the decision matrix $DM[C \times N]$ for C connections and N alternatives. Media-independent handover *HandoverInitiate* command is executed according to the information stored in *DM*.

Algorithm 2 Selection Engine

Input: $Priority\_List[CxN], Request\_type.$
Output: $DM[C \times N]$

begin
  if $Request\_type = UVHR$ **then**
    $DM_{11} \leftarrow Link\_Status(Priority\_List_{11}$ **else**
      if $Request\_type = NCR$ **then**
        $C \leftarrow 1$
      end
    end
  end
  for $i = 1toN$ **do**
    $Calc\_Link\_Info(Network_i)$
    $Modify(AM, Network_i)$
  end
  for $i = 1toC$ **do**
    for $j = 1toN$ **do**
      $DM_{ij} \leftarrow Link\_Status(Priority\_List_{ij})$ **if** $DM_{ij} = True$ **then**
        Break
      end
    end
  end
  Send(DM)
  Exit
end

4 | TRAFFIC CLASSIFICATION

Different traffics have different characteristics, implying different demands on the QoS criteria. Thus, weights are elicited by the traffic type. We classify the traffic into 4 categories according to the CoSs (TS23.107) defined by 3GPP as summarized in Table 3.

TABLE 3 Description of traffic classes

Service class	Description
Conversational traffic	Application: VoIP and video conferencing, etc User: live human (QoS requirements based on human perception) Characteristics: peers (or groups)
Streaming traffic	Application: real-time video/audio, etc User: human (receiver) Characteristics: 1-way transport
Interactive traffic	Application: web browsing, database retrieval, server access polling for measurement records, automatic database inquiries (tele-machines). User: human/machines
Background traffic	Application: background delivery of e-mails, SMS, downloads of databases, reception of measurement records.

4.1 | Ranking

Ranking networks for a particular traffic class is specified in this section. Assume m networks have complemented the requirements for noncompensatory criteria and have been added to the candidates list. The weighting vector of the 8 attributes (delay, delay jitter, PLR, guaranteed bit rate, security, cost, mobility, and power consumption) for conversation traffic is $W = W_1$. Here, W_1 represents weight matrix for conventional traffic.

1. Create the decision matrix from the original attributes of each network. The jth network, N_j, can be represented as a row vector, $\vec{D}_j =< \vec{d}_{i_j} >$, where each element $\vec{d}_i$ is the raw value with respect to certain attribute of the network. $D^- = [\vec{D}_j]$ is the original decision matrix before transformation.
2. Create the normalised decision matrix, R. Element r_{ij} of the normalized matrix is computed as below:

$$r_{ij} = \frac{\vec{d}_{ij}}{\sqrt{\sum_{k=1}^{4} (\vec{d}_{jk})^2}}. \tag{1}$$

   Thus, each attribute has the same unit length of vector.
3. Normalized attribute values receive tendency treatment to create the final decision matrix delay, delay jitter, PLR, cost, and power consumption are, in this context, constitute the cost criteria. It is transformed into benefit criteria, for uniform treatment of weights. Matrix $D = [d_{ij}]$ is constructed based on matrix R.

$$d_{ij} = \begin{matrix} 1 - r_{ij},\ if\ r_{ij} \in cost \\ r_{ij},\ if\ r_{ij} \in benefit \end{matrix} \tag{2}$$

4. Calculate the weighted normalized decision matrix V. Given weighting vector W_k for kth traffic class: $W_k = w_{i_k}$, where w_{i_k}represents weight of ith attribute with respect to kth traffic class; elements of matrix $V = [v_{ijk}]$ can be calculated as

$$v_{ijk} = r_{ij} \times w_{jk}. \tag{3}$$

5. Determine the absolute positive ideal and negative ideal solutions. This pair of absolute ideal solution can be simply set as

$$\check{A} = [\check{a}_{ij}], \check{a}_{ij} = \max_{1 \le k \le 4} v_{ik}, \tag{4}$$

$$\check{A} = [\check{a}_{ij}], \check{a}_{ij} = \min_{1 \le k \le 4} v_{ik}. \tag{5}$$

6. Calculate the separation measures. The separation from the absolute ideal solutions is calculated as indicated in Equation 6. Here, S_i^+ and S_i^- represent positive and negative separation, respectively, of node i.

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \frac{(\check{a}_{jk} - v_{ijk})^2}{\check{a}_{jk}}}, \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \frac{(\breve{a}_{jk} - v_{ijk})^2}{\breve{a}_{jk}}}. \tag{7}$$

7. Calculate the relative distance to the ideal solution. The relative closeness from attribute A_i to $\breve{A}$ is defined as

$$D_i = \frac{S_i^-}{S_i^+ + S_i^-}, \forall i \in 1, 2, 3, \cdots, m. \tag{8}$$

8. Rank the preference order. The larger the rank value of an alternative, the more it is preferred. Hence, the candidate network with the largest D_i will be chosen, if available, as the target network for HO. By the same token, we can rank the candidate networks for the other types of traffic.

5 | PERFORMANCE EVALUATION

The proposed strategy is compared with existing studies, and results are detailed in this section.

5.1 | Alternatives, attributes, and weights elicitation

We have considered 5 different networks providing different QoS and non-QoS attribute values for our simulation. Details of these networks are provided in Table 4. Two of the networks, ie, UMTS and WiMAX, provide QoS per CoS. WLAN networks offer the same quality for all CoS. Two different types of WLANs were selected for the simulation in order to find the frequency of HOs for specific CoS between 2 networks of the same nature but offering different quality. The fifth network is added as a test network to verify that our algorithm is immune to route abnormality.

We have assigned weights to attributes of each network based on their relative importance for each CoS. Largest eigenvalues have been used, and its corresponding eigenvector (weight vector) has been calculated for each CoS. These vectors

TABLE 4 Attribute values for selected networks[31]

Candidate networks		Delay, ms	Jitter, ms	PLR	GBW, Mbps	MBW, Mbps	Security, Level	Cost, per kB, % per kB	Battery Power	Mobility, m/s
Net. # 1: UMTS	Conversational	100	10	10-4	0.2	1	9	9	5	40
	Streaming	280	10	10-3	0.2	1	9			
	Interactive	800	70	10-6	0	2	9			
	Background	800	70	10-6	0	2	9			
Net. # 2: WiMAX	Conversational	60	15	10-3	0.1	20	6	6	3	10
	Streaming	350	20	10-3	0.1	20	6			
	Interactive	500	70	10-5	0	20	6			
	Background	1000	100	10-5	0	20	6			
WLAN. # 1: WLAN	No CoS	200	30	10-3	0	10	5	1.5	2	1
WLAN. # 2: WLAN	No CoS	400	80	10-3	0	3	5	1	2	1
WLAN. Test: Test	No CoS	1000	100	10-2	0	1	1	10	2	0

Abbreviation: CoS, class of service; PLR, packet loss ratio.

TABLE 5 Weight elicitation for conversational traffic

Criteria	QoS	Security	Cost	Mobility	Battery	Weights
QoS	1	4	7	8	8	0.562928
Security	1/4	1	3	7	7	0.244945
Cost	1/7	1/3	1	3	5	0.109541
Mobility	1/8	1/7	1/3	1	2	0.048219
Power	1/8	1/7	1/5	1/2	1	0.034368

are then applied to the normalized attribute values of each network per traffic class in order to find the final weight matrix. Table 5 shows the weight elicitation for conversational traffic. The experiments were performed on NS 2, and MIH module, which has been developed by NIST, was used for HO-related processes.

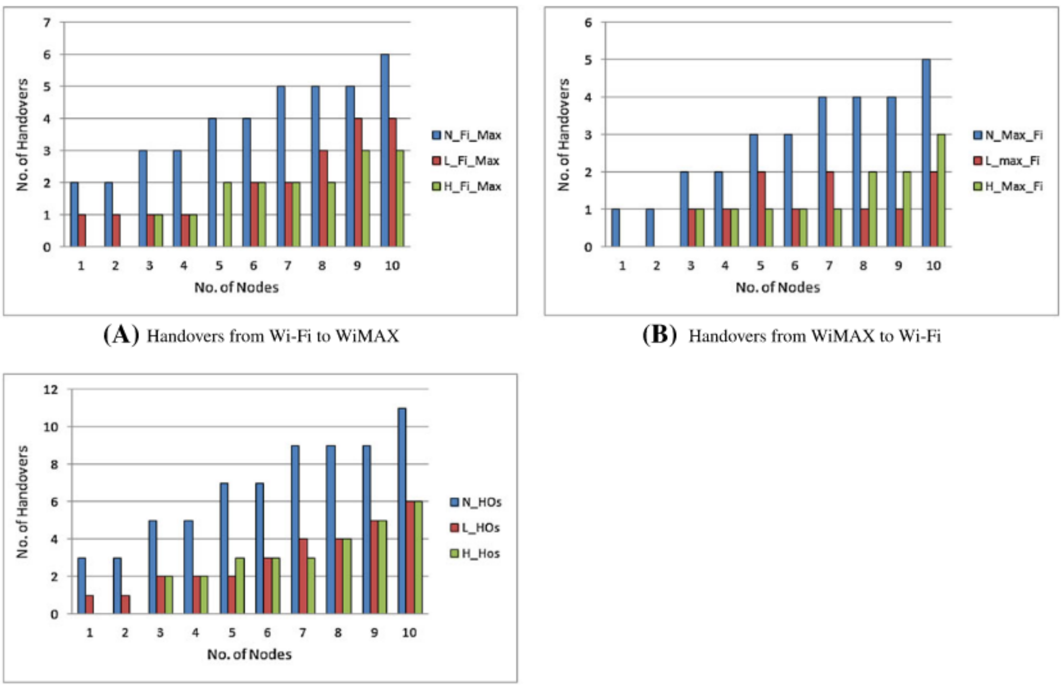
5.2 | Results and discussion

The proposed scheme is implemented in NS 2 simulation tool. We have used traffic classes as shown in Table 3 for our experimentation. Moreover, the attribute values that are used for implementation are shown in Table 4 for conventional traffic classes. The power consumption is estimated based on the power model of NS 2 that finds power values based on the amount of data transferred or received over the network link (linear model). We have considered average PLR, average end-to-end delay, and power consumption parameters to evaluate our proposed scheme. Finally, we compared our scheme with existing studies, and results are detailed in this section.

5.2.1 | HO frequency

The study has compared our proposed strategy with the strategy discussed by Liu[31] and that of NIST in order to examine the frequency of VHOs. We deliberately select the RSS-based network selection strategy of NIST in order to emphasize on the importance of optimized network selection. Two networks, Wi-Fi and WiMAX, were used in the comparison. Four channels[44] of WiMAX network were used to examine the behavior of the selection engine in case of nonavailability of a top-ranked access network. Comparisons were made based on the number of HOs that took place from Wi-Fi network to WiMAX network (Max_Fi) and Wi-Fi to WiMAX networks (Fi_Max). Aggregated number of the HOs, of all the 3 strategies, ie, H, our hybrid strategy; L, strategy of Liu[31]; and N, strategy of NIST, was also compared. These strategies were simulated in a scenario for number of nodes ranging from 1 to 10, in a quasi-random mobility with a speed of 10 m/s. The 2-dimensional random walk model of mobility was used initially, and the traces were stored for onward runs in order to provide the same simulation environment for the strategies under observation. Results of the comparison are shown in Figure 2.

The results show that strategy adopted by NIST suffer from frequent HO because of the fact that this strategy always prefers Wi-Fi over WiMAX network and the only selection criterion is RSS. The strategy adopted by Young Liu has fairly low HO frequency, but our strategy outperforms in reducing unnecessary HOs by considering speed of the mobile node



(A) Handovers from Wi-Fi to WiMAX

(B) Handovers from WiMAX to Wi-Fi

(C) Total Number of Handovers

FIGURE 2 Number of handovers between Wi-Fi and WiMAX and taking in and out movement of the node at the edge of the coverage. The frequency is further reduced by *finalise*() method of the ranking algorithm where old links are preferred over new links.

5.2.2 | Packet loss ratio

Figure 3 shows the overall PLR for 50 mobile nodes moving with the speed of 40 m/s, in an area covered by 2 Wi-Fi networks and a WiMAX network, for a conversational traffic. The proposed strategy has performed better than others because of the fact of low HO frequency. It can also be noted that, with the increase in node density, the difference in HO frequency increases which, in turn, increases the difference in PLR. Consequently, to increase the overall network performance, our strategy will perform better in highly dense scenario.

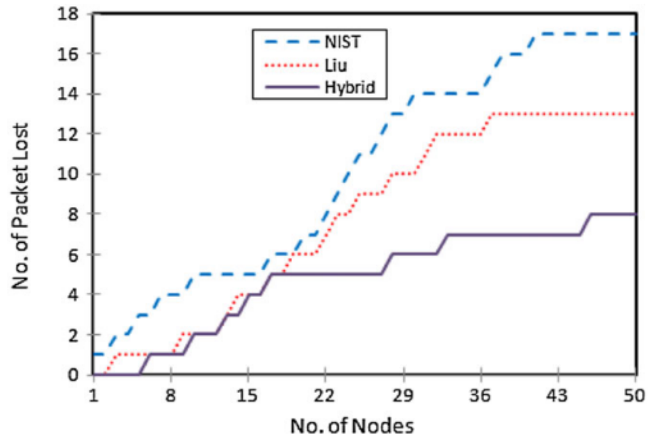
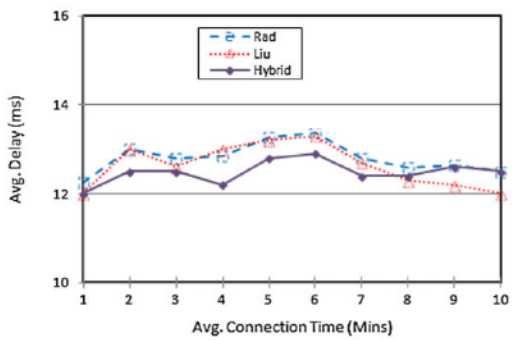
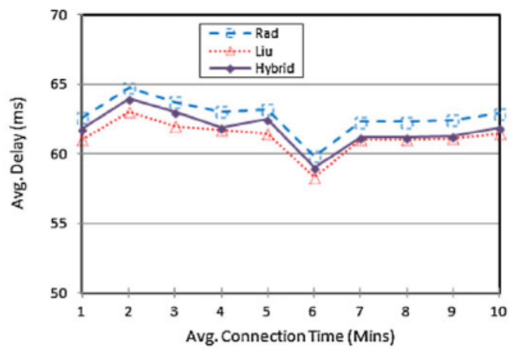


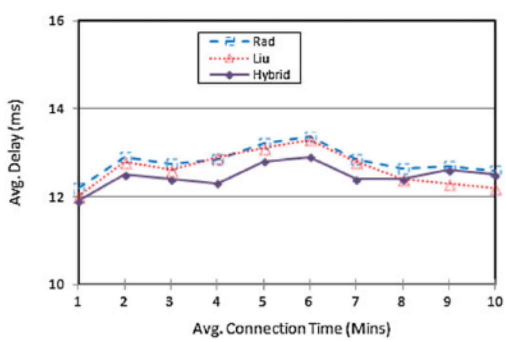
FIGURE 3 Packet loss ratio (conversational traffic). NIST, National Institute of Standard and Technology



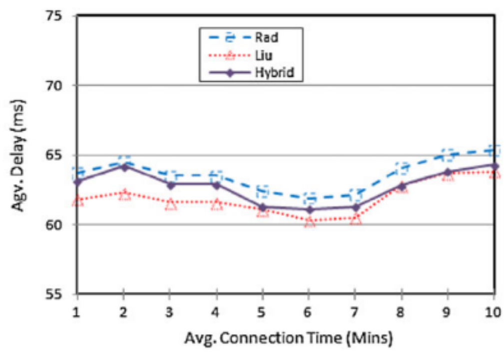
(A) Conversations Traffic



(B) Streaming Traffic



(C) Interactive Traffic



(D) Background Traffic

FIGURE 4 Average end-to-end delay among different traffic classes

5.2.3 | Average end-to-end delay

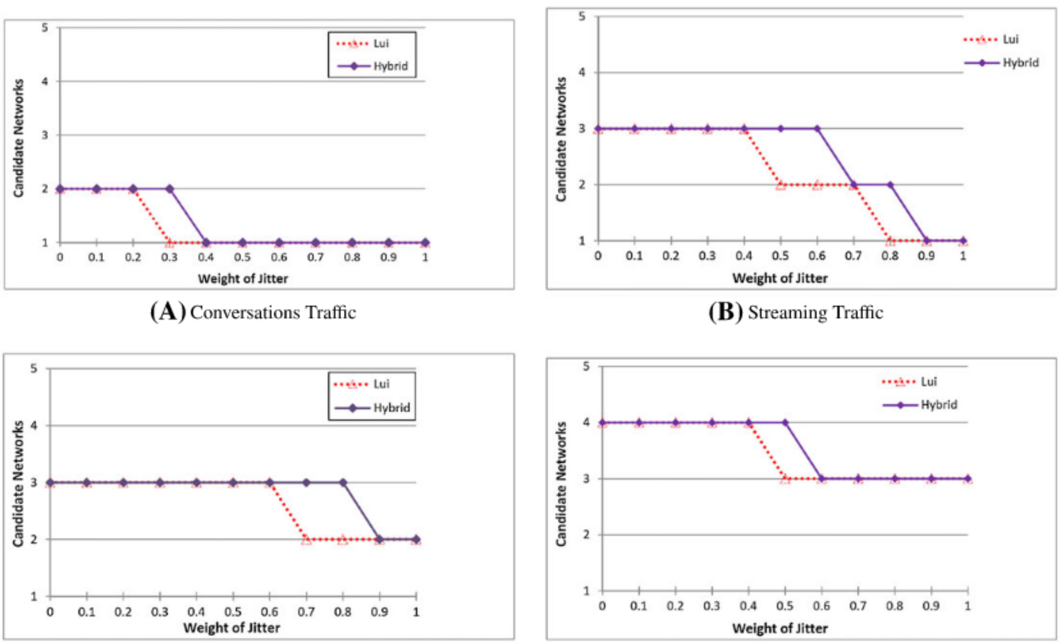
We have compared our proposed strategy with that discussed in Liu[31] and Radhika and Reddy[32] for the end-to-end delay. A fuzzy logic–based approach[32] was selected, for the comparison, in order to evaluate the effect of hidden complexity of fuzzy logic–based solutions on the end-to-end delay. Two nodes, under observations, were covered by 5 networks (see Table 4 for details) that were simulated for all the 4 traffic classes. The ensued results are shown in Figure 4. End-to-end delay aberration is subject to the network selection decision of the mobile node on the move. Nonetheless, for the delay sensitive communications, ie, conversational and interactive traffic, our strategy stood fairly low in delay compared with that of Liu.[31] As the time increases, non-QoS factors like power consumption slightly affect the overall delay. For a delay tolerant communication, our strategy supersedes that of Liu,[31] in the context of end-to-end delay. Nonetheless, the delay is still well inside the commonly acceptable range for each class of traffic.[45] The results also show that both the strategies performed better than that of Radhika and Reddy[32] for all the 4 CoS.

5.2.4 | Sensitivity analysis

We have also conducted a sensitivity analysis of the key factors for a specific CoSs, and the technique of Lui[31] was considered for comparison on the basis of the fact that it provides CoS-based network selection and is suitable for such analysis. Figure 5 shows the effect of weight, given to jitter, on the network selection of both the strategies. The candidate networks (shown on the y-axis) presented in Table 4 were considered in these analysis. As the weight (shown on x-axis) of jitter increases, both the strategies opt for a network with decreased jitter. The wobbly nature of the jitter may cause more sensitive strategies to suffer from unnecessary HOs, particularly for outdoor coverage with high interference. Our robust weight elicitation strategy reduces the effect of jitter on the network selection in order to avoid extraneous HOs.

5.2.5 | Power consumption

To analyze the power consumption, we simulated the mobile node in poor battery conditions. In such a condition, factor related to power are assigned high weights. Power consumed per unit of data transferred was calculated at the node under observation. For the same amount of data transfer, our solution performed way better than the other two, because of the fact that the other 2 strategies did not consider any such condition. Figure 6 shows the results. The intermittent bursts during data transfer were observed as shown at time 2 to 3, 3 to 4, and 9 to 10. These bursts are a common characteristic of streaming traffic. If multiple inputs multiple outputs–based connections are used, these bursts intuitively be exploited for further increase in performance for certain criteria of Table 5.



(A) Conversations Traffic

(B) Streaming Traffic

(C) Interactive Traffic

(D) Background Traffic

FIGURE 5 Effect of W_j on network selection

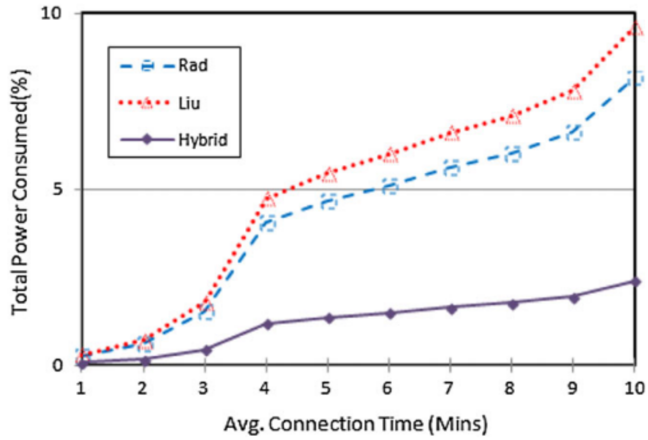


FIGURE 6 Battery power consumption (conversational traffic)

6 | CONCLUSIONS AND FUTURE WORK

The dynamic selection of the best access network, for a multimodal device whenever a HO is imminent, is extremely important. In this paper, a solution to the intrinsic problem of network selection is being proposed that relies on both the user profiles and QoS factors.

The simulation results show the fact that UPs slightly affect the service quality, but this effect is still well inside the commonly accepted range of QoS requirements for all classes. On the other hand, the scheme performs well in scenarios where non-QoS factors are critical, such as poor battery conditions. Despite the promising results, improvements can be brought to the proposed strategy by applying more accurate and recently developed mobility and power models. For the simulation-based studies, movement patterns of mobile users are important for the performance analyses of wireless devices and communication networks. Currently, we have used linear model for the power consumption, available in the simulator. In mobile wireless networks, affected by the wireless environment, power consumption is nonlinear. Therefore, nonlinear models may produce more realistic results. Similarly, predictability of human mobility may further improve the accuracy in network selection process.

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