RAT Selection Algorithm for Multiservice Multimode Terminals in Next Generation Wireless Networks



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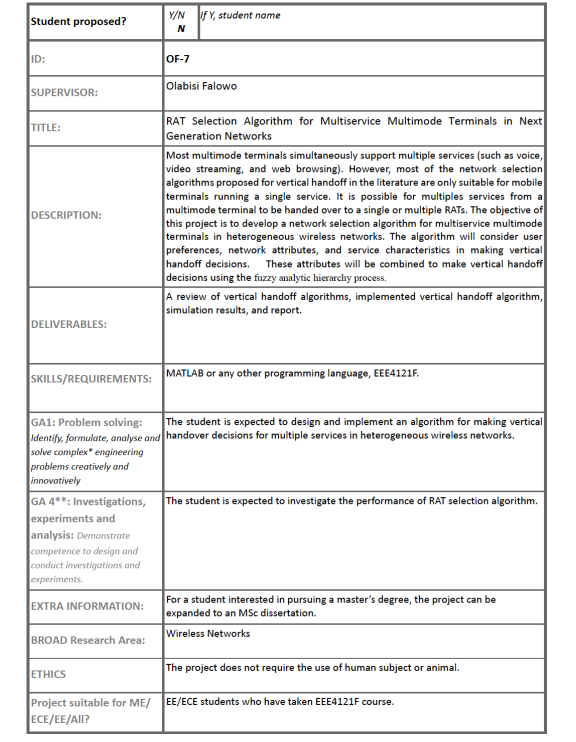
**Key Words:** Multimode, Multiservice, Heterogenous, RAT, Wireless Networks, 5G

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# Terms of Reference



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Abstract

This is a summary of your project. It should not be more than a page in length giving a brief background to the study, the main methodology, results and conclusions drawn.

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# Introduction

## Background to the study

Communication is a fundamental aspect of today's society as it is through communication that information is exchanged, relationships are built, and knowledge is shared. Over the past few years, there has been a global increase in the number of mobile device users (subscribers) [1]. This is no surprise as radio access technologies (RATs) continue to evolve to provide lower latencies, higher bandwidths, and throughputs. As a result, there is an increasing demand for appropriate network resource management algorithms to cater for the increasing load of mobile users on wireless networks. In doing so, mobile subscribers will be provided with the best quality of service (QoS) possible and have ubiquitous coverage. On the operator side, costs will be reduced as the network resources will be managed more efficiently for optimal operation.

## Objectives of this study

### Problems to be investigated

The study investigates vertical handoff algorithms for multimode multiservice mobile terminals in next-generation heterogeneous wireless networks for RAT selection. Currently in the literature, the existing RAT selection algorithms for vertical handoff are only suited to single-service multi-mode mobile terminals (mobile terminals running a single service). Therefore, there is a need to design and implement a RAT selection algorithm for mobile terminals running multiple services simultaneously.

### Purpose of the study

The purpose of the study is to ultimately design and implement a vertical handoff algorithm for RAT selection suitable for multiservice multimode mobile terminals. This is a relevant study to undertake because there needs to be a balance between meeting user preferences, operator service requirements and network characteristics to ensure users have the best possible quality of service (QoS) and coverage according to the always best-connected principle (ABC) and that network operators can manage and allocate network resources efficiently to have a stable network and maximize revenue.

## Scope and Limitations

The call admission decision aspect of joint call admission control (JCAC) algorithms, and other aspects of radio resource management such as bandwidth allocation strategies is not covered in the report as the focus is strictly on vertical handoff algorithms for RAT selection and load balancing. Also, older access technologies such as GSM (2G) will not be covered in the report as technological advancements in mobile communications have rendered them outdated. Likewise, 6G will not be covered as it is still being researched and is not yet commonplace.

Energy efficiency and power consumption of mobile terminals was not modelled in the simulation. Horizontal handoff algorithms, initiation, and methods for initiating horizontal handoff such as received signal strength is not in the scope of the project.

## Plan of development

Here you tell the reader how your final year project report has been organised and what is included in each chapter.

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The rest of this paper has been organized as follows section … talks about blah blah

# Literature Review

## Next-generation wireless networks

Next-generation wireless networks [2] are the evolution of heterogeneous wireless networks that incorporate multiple access networks on a common service platform. These networks provide users with seamless connectivity and the ability to access different services and modes of communication through a single terminal. The selection of the appropriate Radio Access Technology for multiservice multimode terminals in next-generation networks is crucial for ensuring optimal network performance and user experience. Some examples of current next-generation wireless networks are as follows.

Firstly 5G (fifth generation) is a next-generation wireless network that's an evolution of 4G (LTE and LTE advanced). Key features are significantly faster data rates (in Gbps), lower latency (1ms), network slicing using VN (SCVN), small cell densification, new air interface and multimode terminal connectivity. 5G networks use higher-frequency radio waves, known as millimetre waves(mmWave), which allow for higher bandwidth. 5G has many applications in industry such as massive IoT, mission-critical services and enhanced mobile broadband.

6G (sixth generation) is the next generation of wireless networks that will succeed 5G and is predicted for use in 2030. The key performance indicators of this network would be much lower latency than 5G(0.1ms) and much higher rates (1Tbps). It will provide sensing as an additional service to the services provided by 5G. 6G is envisioned to have very large coverage including space and air by integrating 5G with non-terrestrial network networks such as satellite communications.

## Multiservice and multimode terminals

Mobile terminals(mobile stations) are devices that are a combination of terminal equipment and subscriber data. The subscriber data is contained in the Subscriber identity module (SIM) card which contains info such as the ID number of the user and facilities for authentication [3].

Multiservice terminals refer to mobile terminals that can support multiple services and applications such as voice, video streaming and web browsing simultaneously.

Multi-mode terminals refer to mobile terminals that can connect to and operate on multiple generations of radio access technologies e.g., 3G to 5G.

As most modern-day mobile terminals are both multiservice and multimode, the RAT selection problem for an MMT is a GDM (Group decision-making) problem as a group of services simultaneously running on the MMT needs to be handed off to one or more appropriate RATs.

## Vertical handoff and Radio resource management

Handoff is the process of switching the channel associated with the current connection while a call is in progress. It is a means of achieving continuous service for a user moving across a network cell and is how mobility is realised in mobile and wireless cellular networks [4]. Vertical handoff refers to handing over calls of a mobile terminal between base stations/access points that support different network technologies e.g., between a 2G base station and 4G eNB access point. Whereas horizontal handoff is the handing over of calls of a mobile terminal between base stations that support the same network technology. It is typically conducted for homogenous networks to achieve continuous coverage.

For vertical handoff, many characteristics of the network are used to determine whether a handover should occur. Typical characteristics include Quality of Service (QoS), cost of service, security, power requirements and velocity[4]. Several criteria are derived from these characteristics and used in vertical handover algorithms to select the appropriate RAT.

Vertical Handover algorithms are handover algorithms that facilitate handoff between different types of wireless access technologies such as between different RATs in a heterogeneous wireless network [4]. This provides an uninterrupted connection(continuous service) for users that move between access points across cells. The algorithm identifies the best available access point or network based on one or more criteria such as cost, delay, jitter, available bandwidth and so on. There are several types of vertical handover algorithms, and each uses different criteria and methodology to make a handover decision. Some examples of vertical handover algorithms include Utility/Cost-based function algorithms, computational intelligence-based algorithms (using fuzzy logic), weighted summation algorithms and machine learning algorithms [5]. These will be discussed in detail below.

## A review of Vertical handoff algorithms

Traditional handover decision methods used in horizontal handover such as RSS(Received signal strength) are insufficient for making vertical handovers between RATs because they don’t take user preferences and the current context into account [6]. Some more complex considerations and trade-offs need to be considered when making vertical handover decisions because each RAT in a heterogeneous wireless network is designed for different services which each have different QoS requirements. Users in heterogeneous wireless networks have a broader and diverse range of QoS and application requirements.

There are 5 main categories of vertical handover algorithms that are used to achieve the always best-connected principle (ABC) for optimal network selection in heterogeneous wireless networks. However, it should be noted that most of the algorithms designed in the literature are combinations of 2 or more categories of vertical handover algorithms and some of the categories are derived from the other categories.

Firstly, there are cost function-based algorithms that choose the best network by using a mathematical function that involves the sum of weighted functions of network parameters according to policies (can be user-specified.)

Secondly, there are user-centric algorithms. These algorithms primarily take user preferences into account in terms of cost and QoS. These algorithms are designed for user satisfaction and are suitable for non-real-time applications.

Thirdly and most used are Multiple Attribute/Multi-Criteria decision-making algorithms. The vertical handover problem is modelled as a MADM problem and involves selecting the optimal RAT from a limited number of candidate networks with respect to different attributes/criteria. A multi-criteria decision-making technique is a method used to choose the best option given a set of alternative options based on multiple criteria [7]. There are several MCDM techniques such as ELECTRE (The Elimination and Choice Expressing Reality), Technique for order preference by similarity to ideal solution(TOPSIS), computational intelligence methods (e.g., fuzzy logic, fuzzy neural), AHP (Analytic Hierarchy Process), Simple Additive Weighting (SAW) and multiplicative exponential weightings (MEW) [7] [8] [9]. MCDM techniques help make the best possible decision by providing a quantitative approach to critically evaluate the alternative options, thereby effectively taking into consideration factors which may impact network performance and user satisfaction. Table 1 [10] below summarises some popular MADM techniques.

Table 1: Summary of MADM techniques

|  |  |  |  |
| --- | --- | --- | --- |
| Technique | description | Advantages | Disadvantages |
| MEW | Uses multiplication to compute network parameter levels | The higher value of MEW implies the more preferred options are selected. | Not sensitive to parameters which change |
| TOPSIS | The selected network is near ideal network and far from the worst-case | The worst and best cases are computed using the best and worst values | Sensitive to user preference and parameter values |
| ELECTRE | Uses consistency and inconsistency to measure the satisfaction of decision-makers | Uses different methods for pairwise comparison under a standard | Outranked relations may be incomplete |
| AHP | Calculates relative weights of different parameters in the decision model | Computes the similarity to the best solution | Results may be inconsistent |

Fuzzy logic and neural network-based algorithms are another category of vertical handover algorithms. These algorithms are typically combined with the above MADM methods to develop more advanced algorithms for both real-time (e.g., video calls) and non-real-time (e.g., file transfer) applications. They are used to handle the imprecision and uncertainties that are found in decision criteria. For example, criteria such as network security level are described/specified in linguistic terms rather than numerically. This introduces imprecision because terms such as low, high, and medium don't have specific numbers attached to them. Therefore, Fuzzy logic is used to eliminate the uncertainty associated with the linguistic description of the criterion by converting the words to crisp values that can be used in the algorithm.

Neural network-based algorithms use machine learning and need to be configured using prior knowledge of the network environment and are usually responsible for choosing the time to handover whereas fuzzy logic is used to choose the most appropriate RAT according to user preferences.

Finally, context-aware algorithms are algorithms that use the contextual information from the mobile terminal and network to make intelligent network selections. The contextual information used includes the decision criteria linked to the mobile terminal such as its location and speed, and criteria linked to the network itself e.g., QoS and service type. These algorithms satisfy primary objectives based on the values of context parameters. However, it should be noted that these algorithms have increased overhead in radio links due to frequent communication between the MT and the network.

## Related Work

In the literature, there are very few works that address the RAT selection problem for a group of calls from an MMT. Most of the algorithms that have been developed in the literature are only suitable for vertical handoff of a single session from a mobile terminal. Below is a review of the most recent works that address RAT selection for both single and group calls from an MMT.

H. Yu, Y. Ma, and J. Yu in [11] proposed a RAT selection algorithm that considers user preferences, service characteristics and network attributes. Their work aimed at a RAT selection algorithm for a group of handoff sessions from a mobile terminal. They used Entropy and fuzzy AHP to calculate the objective weights of service characteristics and network attributes. User preferences and service priority were used to obtain the comprehensive weights of the network attributes. They used utility functions to calculate utility values of the network attributes implementing the SAW technique to synthesize utility values and comprehensive weights. Then TOPSIS and a threshold(used to determine whether the MMT maintains the current connection or handover to the optimal network) were used to select the most appropriate network.

MATLAB was used for their network model simulation and included services such as voice, video, and web browsing. The RATs used in their simulation included UMTS, LTE, WLAN and WiMAX. The network attribute parameters used were bandwidth, delay, jitter, loss rate and cost. They also used weight proportion parameter values set by the network operator according to policies to vary how much user preferences, service characteristics and network attributes contributed to the RAT selection algorithm. They conducted three types of simulation. Firstly, they simulated network selection at a time T, then simulated multiple network selections in different service priority scenes and finally compared their proposed algorithm with two existing MMT(Fuzzy MCDGM and utility GDM ) algorithms in a dynamic simulation environment.

Key findings from their experiments were that their proposed algorithm avoided making unnecessary network selections due to users having too subjective preferences (simulation 2). For the comparison between the other two MMT algorithms, the metrics used to compare the algorithm’s performances included candidate network selection probability, the gain of network selection, handoff numbers and unnecessary handoff probability. Results showed that their proposed algorithm, considered both the user's preferences and the service characteristics, but also considered the actual network environment and the services' QoS requirements. So, WLAN and UMTS had almost the same selection probability. Because the proposed algorithm considers both the user's preferences and the service characteristics the average bandwidth, cost, latency, and jitter obtained were between those of Fuzzy MCDGM(user preferences) and Utility-GDM(service characteristics).

In terms of the gain, the proposed algorithm wasn’t the best for a single attribute e.g., it had the highest average loss rate of the three algorithms, but the overall gain was higher than the other two MMT algorithms according to how they defined gain since it considers user preferences and service requirements. The proposed algorithm had the lowest number of handoffs and the lowest percentage of unnecessary handoffs because of the threshold used. It avoided frequent handover of MMTs due to the instantaneous changes of network parameters. They concluded that the proposed algorithm can effectively reduce the ping-pong effect, improve the end-user experience, and reduce the waste of resources. Their results also showed that the proposed algorithm was stable when new networks were added as the probability of unnecessary handoffs remained roughly the same.

The advantages of their algorithm were that it managed to consider user preferences, service characteristics and network attributes(conditions) for network selection resulting in an algorithm that isn't too objective or subjective thereby providing users and services with an adequate QoS. Also, despite having O(N3) time complexity the number of RATs and criteria considered by the algorithm are very small (usually less than 10) therefore the computational demands on the MT are kept minimal in addition to the MT already having strong computing power. Furthermore, the spatial complexity of the algorithm is also kept at a minimum because the allocation of weights and priorities for the network attributes are only done once, and these values are stored on the MT.

Their only drawback was that they used static weight proportion parameters for simulation. These parameters were not optimal. They also only considered network selection for a single MMT at a time. Thus, load balancing between multiple MMTs,power consumption and mobility (moving speed) were not factored into the simulation. Also, their algorithm only selected a single RAT for a group of calls from an MT and did not consider making independent call-by-call decisions to select multiple RATs which was addressed by [13].

In [12] Falowo and Chan proposed dynamic RAT selection for a group of calls from an MT using a modified TOPSIS-GDM algorithm. It was the first paper to address the problem of RAT selection for a group of calls from an MT. The algorithm considered user preferences according to call class by having users specify the weights of each criterion for each service. They treated the problem as an MCGDM problem where the alternatives were RATs, the criteria were network attributes, and the decision makers were the ongoing calls/services from an MT. It was made dynamic by varying the number of available RATs and calls with time. The algorithm was triggered when there was a change in the number of calls on the MT or there was a change in the availability of RATs.

To evaluate the performance of their algorithm, they measured the proportion of calls admitted into each RAT under different scenarios where the weights of the criteria and service priorities were varied. To reduce the frequency of vertical handoffs, they introduced a RAT preference margin where the preference margin is the value by which the newly preferred RAT must be greater than the current RAT before the newly preferred RAT can be selected for the calls from the MT. In general, the higher the preference margin was, the lower the frequency of vertical handovers. However, if this value was too high the newly preferred RAT would rarely be selected and the less preferred RAT would be selected most of the time. Results showed that the Probability of vertical handoff decreased as the number of existing calls on the MT increased.

The advantages of their approach were that it was simple to implement, and selecting a single RAT for the group of calls eliminated the issues of having to coordinate the handover if multiple RATs were selected for each call in the group(less overhead).

The disadvantages of their approach were that their algorithm only considered user preferences and did not account for service characteristics/requirements and network attributes, so it was too subjective. It also overlooked the level of agreement between the different calls in the group. This led to individual preferences for a single call being compromised in selecting a single RAT for the group i.e., what’s best for the group isn’t necessarily the best for the individuals in the group.

Taiwo and Falowo [13] proposed a network selection algorithm based on consensus level. Consensus-based MCGDM was used to reach a mutual agreement between decision-makers before a decision was made to enhance the quality of the decisions and remove conflict between decision-makers. The algorithm consisted of the consensus process(obtaining the maximum degree of agreement among the decision-makers) and the RAT selection process. They used a soft consensus model for their consensus process and then used MCGDM for the RAT selection process. For a single call, the algorithm selects a single RAT using the MCGDM technique. For a group of calls, the algorithm determines the consensus level among the handoff calls to be admitted into a RAT. If the consensus level is above a certain threshold, the best single RAT is selected for the group, otherwise, independent call RAT selection decisions are done. The threshold/consensus level was used to preserve the QoS of individual calls in the group so that their quality isn't compromised beyond acceptable levels in the group decision. Otherwise, it admitted them independently.

To evaluate the performance of their algorithm they measured the number of calls admitted into each RAT for each type of call and the proportions that were based on group decisions and independent decisions. They compared results with a non-consensus-based algorithm. The consensus threshold and service priority levels were varied. As the value of the consensus threshold increased, the percentage of calls admitted based on group decisions decreased, with more calls admitted based on independent decisions(increased probability of call-by-call decisions). When the priority was varied the percentage of calls admitted based on group decisions was less than the corresponding percentage of calls admitted based on group decisions when all the calls had equal priority. They concluded that multiple calls could not easily reach a consensus on a single suitable RAT for them without compromising the users’ preferences for individual calls beyond acceptable limits. Also, different call priority levels significantly affect the distribution of calls in individual RATs.

The benefits of their approach were that the proposed consensus-based algorithm was able to combine the benefits of independent and group call RAT selection decisions. It was able to effectively find the compromise between making independent calls and group calls to meet individual QoS requirements.

The disadvantage of their approach was that it also only considered user preferences so was too subjective. The proposed scheme was also only suitable for MTs that had multihomed capability (able to support call-by-call network selection decisions) the algorithm wouldn’t be suitable for MTs that can only connect to a single RAT at a time. Also, there is increased signalling overhead, complexity and power consumption on the MT and network when selecting multiple RATs for each call in the group independently as opposed to [11] which only makes decisions for the group for a single RAT.

The authors in [14] proposed a Fuzzy MCGDM algorithm for multiple call handover. The algorithm used call priorities, user-specified weights for RAT selection criteria per call, and individual RAT characteristics for the RAT to select the most appropriate RAT for the group of calls from the MT. The algorithm first aggregates different call weights per criterion to obtain a group weight per criterion for all the RAT-selection criteria. It then aggregates the weights across all criteria to make a RAT selection decision for the group of calls.

To evaluate the performance of their algorithm they measured the number of calls admitted into each RAT under different scenarios where the priorities for each service were varied and the user-assigned weights were randomized. They concluded that RAT selection decisions for group calls in heterogeneous wireless networks varied extensively with individual call priorities.

The advantage of their approach was the use of fuzzy logic to eliminate uncertainties and imprecisions introduced in the algorithm by linguistic terms used to describe certain RAT selection criteria such as security and price resulting in a more well-defined selection decision for the group.

The disadvantage of their approach was that it only considered user preferences so was too subjective. They also only considered making group decisions and not making independent call decisions by taking the consensus level into account as done in [13].

In [15] Falowo and Taiwo conducted a comparative analysis of four GDM algorithms for RAT selection of group handoff calls from an MT. They compared four possible algorithms that could be modified for making MCGDM for multiple handoff calls from MTs in heterogeneous networks. The evaluation of the four algorithms was done by a sensitivity analysis of the criteria they chose for network selection. Criterion sensitivity was defined as a measure of how a particular criterion affects the choice of a RAT and load distribution for a group of multiple sessions in HWNs, due to user-specified preference weight levels assigned to the criterion.  The criteria that were assessed included service price, data rate, security level, battery power consumption and network delay.

The results showed that TOPSIS-GDM and DIA-GDM (Distance to Ideal Alternative) algorithms were less sensitive to the change of weights than SAW-GDM and MEW-GDM as they had more uniform distributions for multiple handoffs across RATs for the different criteria assessed. They therefore concluded that TOPSIS-GDM and DIA-GDM algorithms are better suited to RAT selection for a group of hand-off calls from a MT than SAW and MEW GDM algorithms since they better distribute the calls among the RATs thereby better utilizing resources and load balancing the network load.

The advantages of their approach were that the algorithms under consideration were simple to implement and flexible for modification to develop more robust algorithms. They also helped justify the use of TOPSIS-based GDM approaches for RAT selection for group calls. The popularity of TOPSIS for MCGDM algorithms for group calls from a MT is evident from its use in [11-15].

The drawbacks of their study were that all four algorithms under consideration only considered user preferences so was too subjective. They also did not consider the issue of individual calls in the group having different QoS requirements thereby compromising their individual QoS for the sake of the group decision. Since independent call decisions of calls in a group weren't evaluated for the algorithms.

The authors in [16] proposed an intuitionistic Fuzzy TOPSIS framework to select the best RAT for various users running multiple applications. Their framework also considered dynamic parameters in terms of network cost when selecting the optimal RAT. The proposed algorithm used IF-TOPSIS to model the uncertainties and ambiguities in heterogeneous wireless networks. Intuitionistic fuzzy logic which is an advanced form of fuzzy set theory was used to improve the precision of the network parameters such as delay, jitter, and throughput as these cannot be accurately measured in a dynamic network environment. The proposed algorithm also considered different classes of mobile subscribers by simulating users with different tariff plans (willingness to pay).

They compared the performance of the proposed scheme with TOPSIS and measured the number of calls admitted into each RAT for the different subscriber classes, the network price was varied to mimic time-dependent pricing by network operators. From their results, they concluded that the proposed scheme could eliminate the rank reversal problem and select the best RAT depending on the nature of the request made by the subscriber.

The advantages of their approach were the reduction of the rank reversal problem which affects algorithms such as TOPSIS. When the worst-performing RAT was removed the proposed algorithm remained stable in terms of network ranking as opposed to TOPSIS. Also, their model was made more realistic by considering different classes of users and willingness to pay. And their use of fuzzy logic resulted in more accurate dynamic parameters being used for their solution.

The disadvantage of their method was that they only considered user preferences which was too subjective.

In [17] Luo et al proposed a RAT selection algorithm that uses AHP, GDM and utility functions to obtain a weight vector for the network attributes per service, synthesize it and normalize the network attributes respectively. The synthesized weight vector and attribute utility are combined to select the most appropriate RAT for a group of calls on a MT. They compared the performance of their algorithm with TOPSIS by using Markov chains to simulate changes in the network attributes. Each network attribute was evaluated with respect to state transition probability. Each service was treated as a decision-maker when using the GDM algorithm and the network was selected according to the characteristics of the services running simultaneously on the MT.

They concluded that the proposed GDM-based algorithm can better meet the QoS requirements of the services in the network than TOPSIS.

The advantage of their approach is that they considered service characteristics to the extent that all services on the MT can meet their QoS requirements. However, the disadvantage of their approach was that the algorithm only considered service requirements and ignored user preferences resulting in poor user experience and a solution that was too objective.

Falowo and Obayiuwana [18] proposed a RAT selection algorithm for group calls with dynamic multi-criteria. The algorithm was termed MULTlplicative–form with Multi–Objective Optimization Ratio Analysis (MULTIMOORA) and the impact of dynamic criterion and the degree of importance of the class of call in group calls was investigated in their work. It was the first paper to investigate the impact of criterion dynamics on VHO decisions for group calls. The proposed algorithm integrated three ranking approaches (ratio system, reference point system and multiplicative form) and then used the theory of dominance to integrate the three independent ranking systems into a way of ranking the alternatives. The rank of an alternative was based on its dominance in the ratio, reference point and multiplication form systems.

The performance of the algorithm was evaluated by measuring the number of calls admitted into each RAT as dynamic criteria such as MT speed were varied. This was done to indicate the algorithm stability in selecting a RAT in high-speed regions. The MULTIMOORA algorithm was compared with TOPSIS for a range of mobile terminal speeds at various degrees of importance of triple calls occurring on the MT.

They concluded that the proposed algorithm had better stability than TOPSIS in high-speed regions. The advantage of their algorithm was that it considered dynamic criteria such as MT speed and traffic load variation in the RAT selection decisions for a group of calls from an MT. The disadvantages of their method were that it only considered user preferences so was too subjective and did not consider the individual QoS requirements of the calls in the group(service characteristics).

To conclude the related work undertaken for RAT selection algorithms for MMTs in heterogeneous wireless networks in the literature shows that they can reasonably select the optimal network for a group of calls on the MMT. However, their main shortcomings are that they either only take user preferences into account resulting in very subjective selection decisions [12-18] or they are too objective by only considering service characteristics such as [17]. There is a poor combination of the factors needed for network selection decisions (user preferences, service characteristics and network attributes) for group calls as discussed in [11]. Also, most of the works except [13] only consider group decisions in handing over the group of calls from the MT to a single RAT. They do not consider the QoS requirements of the individual services (level of agreement between the decision makers) sufficiently resulting in individual QoS requirements getting compromised for the sake of the group decision. I.e., the best RAT for the group isn't necessarily the best RAT for each service in the group since they do not consider selecting multiple RATs for independent call-by-call decisions for the services in the group as done by [13].

The rest of the works reviewed below are for the RAT selection of a single call from an MMT. These are the most recent works done in the literature so are reviewed for completeness.

A.Sgora et al, propose a network selection algorithm for 5G heterogeneous environments in [19]. They propose using a combination of MADM techniques for network selection in heterogeneous environments. They compared the performance of two MADM techniques for network selection (TOPSIS and VIKOR). For weight calculation, they combined the subjective weighting method AHP with two objective methods the Criteria Importance Through Intercriteria Correlation (CRITIC) method and the entropy weighting method. To compare the performance of the 2 algorithms they used the same approach as [20]. The RATs used in their simulation were 5G, WLAN,3G and LTE-A on the assumption that a mobile terminal connects to one RAT at a time with all the appropriate interfaces. The network attributes used for the simulation were the data rate (DR), the packet loss rate (PLR), the jitter (JIT), the price rate (PR) and the delay (DE). The traffic classes used to determine network selection were conversational, interactive, background and streaming classes.

AHP was used to identify the weights that represent the relative importance among network parameters for the different traffic classes. For the same traffic classes, CRITIC and entropy were used to calculate the objective weights of all criteria. For analysis, they used positive reciprocal matrices. The weights of the network decision parameters for each traffic (call) class were graphed after calculating using both AHP and AHP combined with Entropy and CRITIC. Then TOPSIS and VIKOR were used to Rank the networks(choose the best network for a particular class of call) after the weights calculation for the different network decision parameters of the different traffic classes. Then the performance of the new ranking methods was examined.

The conclusions they drew were that weight parameters affect network selection, especially for conversation and interactive classes. When only AHP was applied to the classes, all of them except the interactive class had identical rankings. Their limitation was that they had a limited number of scenarios for simulation. Therefore, they recommended evaluating the efficiency of the two network selection algorithms under more scenarios to examine how the weighting techniques, the number of criteria and the number of alternatives affect the decision process. Also, to compare the performance of the two algorithms with  ELECTRE and PROMETHEE.

In [21] a network selection algorithm called BGMNS (Bipartite Graph Matching Network Selection Algorithm) was proposed for multi-service edge users in 5G ultra-dense heterogeneous networks. The algorithm was designed to be adaptive and for multi-access. The problem of network selection for edge users requesting different services was modelled as a bipartite graph with the proposed BGMNS algorithm being based on a weighted bipartite graph matching for 5G UDHWN. The BGMNS algorithm combined AHP (to effectively obtain the weight preferences of each service for different network attributes since edge users requesting different types of services have different requirements for QoE, and the relative importance of each QoE attribute is different for these services) and GRA(Grey relational Analysis) to analyse the preferences of multiple services for different network attributes to obtain QoE (Quality of Experience) of edge users for each network. The importance of the requested services and the QoE of edge users was used to create a system fairness index to realize a fair allocation of network resources.

The RATs used for their network model simulation were 5G, LTE, WiMAX, UMTS, Wi-Fi 61 and Wi-Fi 62. The network attribute parameters used in the simulation were bandwidth, energy efficiency, delay, PLR(Packet loss rate), jitter, price, and convergence. The traffic classes requested by users included Virtual reality and augmented reality, Industrial machinery, office automation, background services and streaming where Office automation is an intelligent office that makes use of Artificial intelligence and Machine learning for services such as 4K video conferencing, intelligent security, and remote monitoring. Industrial machinery involves using 5G communication combined with industrial internet to achieve automation for real-time monitoring and remote control of machinery.

They evaluated the effectiveness of the BGMNS algorithm based on a bipartite graph, presented the service preference on each network attribute, and verified the performance of the BGMNS algorithm under the influence of network status fluctuation. In addition, compared BGMNS with existing networks.

The impact of network status fluctuation on QoE was assessed and when the network status fluctuates, the BGMNS algorithm enabled users to access the best network according to the importance of service. The algorithm ensured the fair allocation of network resources and was very robust in the dynamic network environment. The average QoE obtained by users was consistent with the importance of the services to users.

The impact of network status fluctuation on system fairness was also assessed by observing changes to the system fairness index of four algorithms (BGMNS, HUMANS, FTNS, and DVHD). According to their definition of fairness index, the system fairness index was expected to be as large as possible with a maximum value of 1. The system fairness index obtained by the BGMNS algorithm varied within a small range between 0.75 and 0.78, while the other three algorithms varied greatly. The result showed that the proposed BGMNS algorithm had good stability in ensuring system fairness when network status fluctuates.

The Impact of Network Status Fluctuation on Blocking Probability was also assessed when the network status fluctuates. The user blocking probability obtained by the proposed BGMNS algorithm changed steadily, remaining between 0.208 and 0.225 while the other 3 algorithms had greater fluctuation. The result showed that when the network status fluctuates, the user blocking probability obtained by BGMNS changes steadily.

The impact of the number of users on user access was also assessed by showing the ratio of edge users requesting different services using BGMNS. Results showed that UMTS can provide a good QoE for users who requested traditional services such as streaming service and background service. The user access ratio showed a downward trend. This is because as the number of users increased, the network bandwidth resources could not meet the bandwidth requirements of all the services requested and BGMNS accounted for this by adjusting users according to available resources.

System fairness was also compared between the above four algorithms by varying the number of users in the simulation. It was observed that there was a downward trend in system fairness for all algorithms as the number of users increased because the available bandwidth of networks decreased with some edge users unable to access their ideal networks and some getting blocked. However, the proposed BGMNS algorithm had the gentlest downward trend because it considered the fair allocation of network resources and the importance of services whereas the other algorithms only considered optimal network selection.

Comparison of blocking probability as the number of users increased was also compared between the different algorithms. The user blocking probability increased with the number of users due to the limited bandwidth in the system. When the number of users increased, the network couldn’t meet the access needs of all users resulting in increased blocking probability. The results showed that BGMNS had a lower probability than the others because the BGMNS algorithm reduced the risk of all users accessing the same network by effectively considering the service's importance. The BGMNS algorithm was able to reduce user blocking probability by at least 18%.

A comparison of average energy efficiency experienced by users between algorithms was made as the number of users increased. Results showed that for more than 60 users BGMNS was the most energy efficient due to its fair allocation of network resources among users requesting different services and taking personal requirements of different services into account. The BGMNS algorithm improved the average energy efficiency experienced by users by at least 11.82%.

Finally, a comparison was made on the packet loss rate between algorithms as the number of users increased, BGMNS had the lowest packet loss rate compared to the others because of its fair resource allocation for large numbers of users and low blocking probability. BGMNS reduced the total PLR experienced by users by at least 7.72%.

After conducting all these experiments, they concluded that the proposed BGMNS algorithm as shown by the results ensures stable access and user QoE when the network status fluctuates, it also effectively meets the requirements of services requested, significantly reduces the user blocking probability and total PLR, and improves the average energy efficiency due to its ability to fairly allocate network resources among users requesting different services and taking personal requirements of different services into account. Therefore, their algorithm would provide users with the best QoE.

S. Sridevi et al proposed a network selection algorithm for beyond 5G networks in [22]. The proposed algorithm was for the selection of an unmanned aerial vehicle (UAV) using an AHP (Analytic Hierarchy Process) based selection mechanism. The algorithm essentially captured the trade-off between power consumption and packet loss and secrecy throughput(Throughput not overhead by other mobile terminals) when associating a mobile terminal with a UAV.

The performance of their proposed algorithm was compared against the best downlink (BD) selection mechanism in terms of packet loss rate(packets lost per unit time), user throughput and secrecy throughput. The traffic load on user-perceived throughput was assessed with the AHP-based mechanism outperforming the BD mechanism. The AHP-based mechanism selected the lower altitude UAV due to its better throughput than high altitude UAVs which had higher power consumption.

The effect of user velocity on packet loss rate was assessed and the AHP-based mechanism outperformed the BD mechanism due to it selecting high-altitude UAVs which had lower packet loss rates, whereas BD always chose a UAV based on downlink condition irrespective of altitude. It resulted in lower handovers for increasing velocity.

The effect of traffic load on secrecy throughput was assessed and the AHP algorithm outperformed the BD algorithm by having a higher secrecy throughput. The BD algorithm always selected a UAV providing the maximum downlink  SINR (Signal interference to noise ratio) irrespective of altitude whereas the AHP mechanism prioritized the mobile terminal by accounting for trade-offs with altitude. However, throughput decreased with increased traffic load at any altitude, and it was observed that in extreme trafficloads (>400 mobile terminals)  the secrecy throughput of BD was roughly the same as AHP.

They concluded that the proposed AHP algorithm selects the best UAV based on the application class since it outperforms the existing best downlink (BD) based approach in terms of user throughput, secrecy throughput and packet loss rate. Therefore, it has potential use in next-generation heterogeneous networks such as beyond 5G which make use of non-terrestrial access points such as the UAVs.

The authors in [23] proposed an intelligent network selection mechanism for hybrid classical-quantum systems.  The selection mechanism was based on the Fuzzy Analytic Hierarchy Process (FAHP) and TOPSIS and was designed to adapt classical network selection algorithms to handle hybrid communication scenarios involving classical and quantum communication systems. This paper contributed to literature addressing the problem of network selection in the context of quantum communication systems or hybrid communication systems. This was aimed at addressing the issues when generalizing classical network selection algorithms to hybrid systems. E.g., the bit error rate which is a classical attribute is described differently in a quantum channel therefore generalization isn’t straightforward.

Their simulation was a modified version of the approach they studied in [X] as they introduced energy awareness into the system by adding a power consumption module so that QoS requirements are met for various application classes. The RATs used for the simulation were UMTS and 5G-NR. A simulation was dynamically done using Python, with the attribute values varied between the standard min and max for 1000-time steps and tracking attribute values of the selected network for each application class. The network attributes used for simulation were Bandwidth, Qubit transfer rate, Average fidelity, Bit Error Rate (BER), packet loss, delay, and price. The traffic classes simulated were conversational, streaming, interactive, background, entanglement distribution and quantum key distribution which are quantum classes. The dynamic performance of the FAHP-TOPSIS algorithm was evaluated for both classical and hybrid communication systems by tracking the values of each network parameter over time and plotting these values for all traffic classes per graph. The dynamic system used Quantum Key distribution and entanglement distribution. A power consumption analysis was also done for each selected network by tracking the power consumption of each traffic class individually.

Simulation results showed that the proposed algorithm approximately achieved 25% power savings. The selected network was able to keep a standard level of the attribute values for each application class while at the same time minimizing power consumption for the selected networks. They concluded that the proposed algorithm provides a reasonable level of performance while also maintaining energy awareness at the same time.

The limitations of their study, however, were that there was a lack of datasets related to quantum communication systems as the field is still new( since 2022). An increased amount of parameter tuning is needed to obtain optimal operation due to the large number of free parameters(triangular fuzzy numbers). They therefore recommended using the proposed model as a template for further optimization using machine learning and due to the lack of datasets, reinforcement learning based on agent-environment models was opted for as a more feasible option.

In [24] González et al proposed a Dynamic radio Access selection and Slice Allocation (DASA) algorithm for differentiated traffic management on future mobile networks. The algorithm combined the network slicing paradigm with software-defined networking and network function virtualization to provide flexible traffic management for future wireless networks. The radio access selection was based on multi-attribute decision-making (MADM) and analytical hierarchy process (AHP). The proposed algorithm was said to differentiate between novel services such as virtual reality, cloud gaming and IoT(Internet of things) in terms of throughput, delay, jitter, packet loss ratio and energy consumption. The DASA algorithm was evaluated through network-level simulations, with a focus on flexibility and the efficient utilization of network resources during network selection and load-balancing mechanisms.

The network was simulated using  OMNeT++ with Simu5G and Python tools. Python was used to implement the DASA algorithm and evaluate its performance. The RATs used for simulation were 5G-NR and WLAN(802.11ac). The simulation also modelled pedestrians being stationary or moving linearly in the cells. The network attributes used for their simulation were bandwidth, data rate and transmission power. Two scenarios were conducted by simulation with the first scenario evaluating the network selection process by having background users in the area move around the base stations, requesting up to 4 services simultaneously. A new user was introduced and changed their request at fixed times to test the algorithm’s performance under different conditions. The second scenario was similar to the first but had increased users to evaluate the network selection and load-balancing mechanisms in terms of ADR(Aggregated data rate), throughput satisfaction, and satisfaction degree.

The results from the first scenario simulation showed that the DASA algorithm always selected the best combination of access network/Network slices, considering the user priority, network conditions, and the Network slices' access. The results of the second scenario demonstrated the advantages of applying two phases of game theory among base stations and network slices.

They concluded that since the proposed DASA algorithm was able to consider users with different tariff plans, device resolutions, and service preferencesand was also able to consider users requesting multiple services simultaneously, it was guaranteed to choose the most resourceful combination of access networks and network slices to satisfy the user requirements. In addition, the algorithm could face overload situations by using a collaborative game theory-based approach which allows on-demand network slice reallocation and adequate service perception.

Dai et al [25] proposed a multi-objective intelligent handover scheme (MIHO) for network selection in satellite-terrestrial integrated networks (STIN). The scheme uses a handover algorithm based on discrete particle swarm optimization (ffiPSO-HO) which is designed by jointly considering the achievable rate and load balance. The study aimed to address the problem of continuous communication/coverage for low earth orbit satellites (LEO) which experience high delays and time-varying network topology due to their fast periodic motion.

The MIHO scheme was implemented using the IBPSO-based handover algorithm (IBPSO-HO) to maximize throughput and balance load under the constraint of handover delay. The network model used for simulation consisted of Low Earth Orbit satellites and terrestrial base stations. Handover delay was modelled to guarantee QoS requirements. Randomly distributed users were represented as a mathematical set. The height, minimum elevation, transmit power channel model and coverage radius for the satellites and base stations were simulated. The network simulation could service multiple users simultaneously but only one user selected the network at a time.

The performance of the proposed algorithm (IBPSO-HO) was compared with the received signal strength-based handover scheme (RSS-HO) and Neuro-Fuzzy and particle swarm optimization combined handover scheme (NFPSO-HO). The throughput performance of the proposed algorithm was lower than RSS-HO because it accounted for the trade-off between throughput and load balancing whereas RSS-HO only considered throughput. The variance of the number of users served by each network for IBPSO-HO, was smaller than that of the other two algorithms because it considered load balancing. In terms of average handover delay, the MIHO scheme had the lowest average handover delay of the three.

Based on the obtained results they concluded that the IBPSO-HO algorithm obtained optimal solutions and had smaller computational complexity than other algorithms. They recommended that future studies should consider resource allocation after handover and include machine learning techniques. Their only limitation was that they had insufficient time to produce more results.

In [26] a multi-attribute access selection algorithm was proposed for heterogenous wireless networks. The algorithm was based on fuzzy network attributes where the subjective weights of network attribute values were calculated by the analytic hierarchy process and the objective weights of network attribute values were calculated by the entropy method. The integrated weights were obtained by the method based on the longest geometric distance to the negative ideal solution. The scores of the candidate networks were determined by grey relational analysis based on the intuitionistic fuzzy decision matrix. The paper aimed to address the issue of the uncertainty of network attribute values.

MATLAB was used to test and compare the algorithms under investigation. The network model used bandwidth, delay, jitter, loss, and error(Bit error rate) as the network attributes. These were dynamically changed to simulate user movement. The RATs used for simulation included UMTS, LTE, WLAN and WiMAX. The application classes/services used were voice video and data. The simulation first tested the performance of the algorithm, under various services and selections of candidate networks. Then the second part involved comparing the performance of the three algorithms in terms of the number of selections of candidate networks, the number of handoffs between networks and unnecessary handoffs under different applications. The weights of network attribute values of all algorithms were the same in the experiments for fairness.

The results showed that the proposed algorithm chose the appropriate network according to network attribute values that were desired for that service i.e., high bandwidth was a priority for data, so most users chose WLAN which had the highest bandwidth and so on. Under different applications/service classes, the handoffs of the algorithm proposed by the authors of the paper were less than the other algorithms. The algorithm proposed by this paper can reduce unnecessary handoffs more effectively since it has both a lower number of handoffs and unnecessary handoffs than the other algorithms for each application.

They concluded that the simulation shows that this algorithm can select the most suitable network under the environment and reduce unnecessary handoffs with inaccurate network attribute values. The algorithm is suitable for access selection in the scenario of network attribute value uncertainty. They recommended that future studies of the behaviour of the algorithm should be conducted in scenarios such as user movement, wireless interference, and network state fluctuations.

Xu et al [27] proposed two online RAT selection heuristic algorithms for a 5G multi-RAT network. The proposed algorithms did not require knowledge of the statistics of system dynamics and had low computational and storage complexity. Network simulator 3 (ns-3) was used for simulation based on 5G-NR setup using the 5G stack for mmWave with customizable PHY and MAC layers. The performance of the proposed algorithms was compared with traditional RAT selection schemes under many practical scenarios which included user mobility. Performance was assessed in terms of blocking probability of high-priority users, offloading probability of low-priority users and throughput. They also compared the performances of the proposed algorithms with the association scheme adopted in the existing network and compared the performances of the proposed algorithms with on-the-spot offloading in the face of user mobility. They used a centralized 5G controller and WIFI controller to handle the RAT selection functionalities as a logical unit and assumed users to be stationary.

They concluded that their proposed algorithms did not suffer from high storage complexity and slow convergence issues which are present in learning-based schemes.

# Methodology

The methodology used for RAT selection for a group of calls from a MMT was a modified version of the algorithm implementation used in [11]. In addition to the limitations discussed in section 1.3 above, the following assumptions were made concerning the network model ,algorithm and simulation setup.

Note add justifications for everything using literature, talk about shortcomings in conclusions

## Assumptions

A user/MMT can connect to any RAT in the network i.e., all RATs in the network can support the services on the MMT.

A user/MMT only connects to (selects) one RAT at a time i.e., algorithm only considers group decisions and not independent call decisions done in [13] for vertical handoff of a group of calls from the MMTs as the MMT power consumption and coordination between RATs for multiple simultaneous independent call handovers hasn’t been simulated for simplicity.

It is assumed one or more services can simultaneously run on the MMTs in the network being simulated.

It is assumed the MMT has the intelligence for the VHO i.e., algorithm is executed by the MMT.

It is assumed the handoff is a hybrid form of mobile controlled handoff but using information provided by the network.

It is assumed the algorithm has already been triggered initially (At time 0) (For now) i.e., the events triggering the algorithm are assumed to have already occurred when the simulation begins.

It is assumed the MMTs are within coverage of all RATs in the network and all MMTs are stationary (MMT speed/mobility was outside project scope)

## Problem Definition

Let R={r1 ,r2…, r|R|} , |R| 2 be the set of RATs present in the network. Let S={ s1 ,s2 ,… s|S|} , |S| 1 be the set of supported services in the network. The set of network attributes/RAT selection criteria used for the RAT selection by the MMT is denoted by C ={ c1 ,c2…cN } , N 2. Let St = { st1,…, stg , … stY } , stg S, Ybe the set representing the group of services running simultaneously on an MMT(let t represent an MMT). Where |X| is the cardinality (no of members) in a set , N is the number of criteria/network attributes and Y is the number of services.

The goal of the algorithm is to select the best RAT ri R to admit the set of services St on the mobile terminal.

## Network Model

The network environment modelled for the designed RAT selection algorithm is shown in figure 1 below. Clip art obtained from [28].

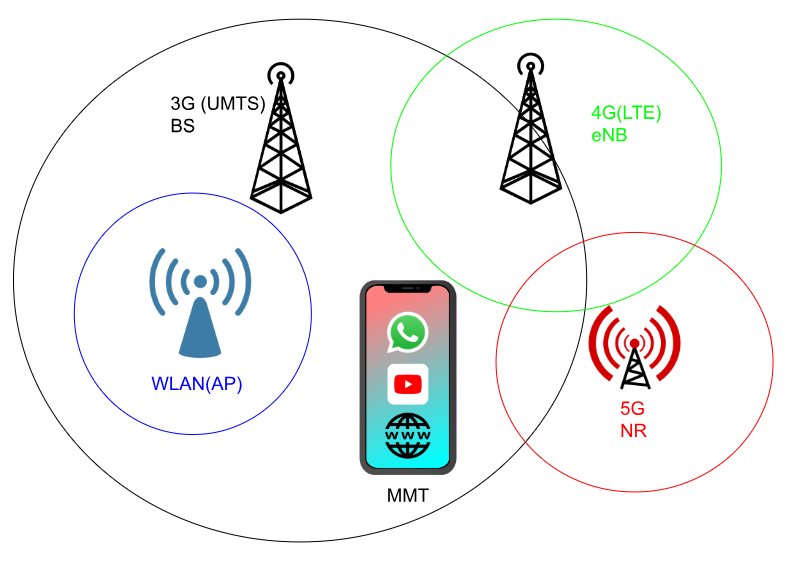


Figure 1: Network Model

The RATs used for the algorithm were 5G(nR), 4G(LTE), 3G (UMTS) and WLAN (IEEE 802.11.ax). The set of services running simultaneously on the MMT were voice (st1), video streaming (st2) and web browsing (st3). The network attributes/RAT selection criteria used for the model were bandwidth(c1) and security level(c2) (benefit criteria) and delay(c3) and packet loss rate(c4) (cost criteria) as shown in Table 2 below. The table shows the range of values that the RATs typically have for such criteria(performance ratings). The values were obtained from the literature [11],[19],[29] for the 5G values and [30] for the security values for all RATs (where was 1=very low and 5=very high). It should be noted that the bandwidth of 5G is around 1000Mbps so is converted to kbps.

Table 2: Network attribute values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RAT | Bandwidth (kbps) | Security level | Delay (ms) | Packet loss rate (%) |
| 3G (UMTS) | 700-2000 | High | 10-50 | 2-10 |
| 4G (LTE) | 800-4000 | Very high | 40-80 | 6-20 |
| WLAN | 1000-8000 | Very low | 70-90 | 4-15 |
| 5G | >1000000 | medium | 1-25 | 0.1-8 |

The choice of RATs was due to them being the latest and most common access technologies used around the world. Likewise, the services used were chosen because they are some of the most common applications that MMTs run, and the choice of the above RAT selection criteria was due to them being the most used throughout the literature on RAT selection algorithms [7].

## Algorithm Design

Figure 2 below shows the submodules that the algorithm is composed of. Each submodule will be explained in detail below. Numeric examples will be used to illustrate each step.

A diagram of a weighting and utility

Description automatically generated

Figure 2: Block diagram of algorithm submodules

### Network Attributes

The inputs to this submodule were the performance ratings of the RAT selection criteria/network attributes and the output was a normalized matrix of these network attribute values. The performance ratings/network attribute values for each RAT in the network were detected/measured by the MMT. For the simulation below assume the values are obtained from Table 2.

For demonstration purposes let Table 3 below represent the actual network attributes at time t, this table will be used for all the numerical examples in this section

Table 3: detected Network attribute values at time t

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RAT | Bandwidth (kbps) | Security level | Delay (ms) | Packet loss rate (%) |
| 3G (UMTS) | 1350 | 0.8 | 30 | 6 |
| 4G (LTE) | 2400 | 0.9 | 60 | 13 |
| WLAN | 4500 | 0.0333 | 80 | 10 |
| 5G | 1000000 | 0.5 | 13 | 4 |

The linguistic terms for the security criterion were converted to crisp numbers using a fuzzy conversion scale such as the one in Table 1 of [18]

Step 1: Create and populate a network attribute matrix Mt using specific values from Table 2 as shown by (1).

where mij is an element of the matrix which is the MMT detected value of criterion cj for RAT ri (performance rating)and ( i=1, …, M and j=1, … , N) M is the number of RATs in the network and N is the number of RAT selection criteria/network attributes.

Example matrix using Table 3 values

Step 2: Normalize the matrix Mt using (2) below to create the normalized network attribute matrix

I.e., the normalized value is the current value divided by the sum of the column it is in.

Example matrix

(i.e., the normalized element is the current element divided by the sum of elements in the current column)

### Weighting

The inputs to this submodule were the normalized network attribute matrix () obtained from section 3.4.1, the user specified attribute weights and priority per service, service characteristics and service determined priority for each service. The output of this submodule is the comprehensive weight vector which is a weighted combination of the user specified subjective weights, service determined weights and objective weights of the network attributes.

#### Objective weight vector calculation

Let be the objective weight vector of the network attributes. The elements of the vector are calculated using ENTROPY as shown below.

Step 1: Calculate the entropy value of each criterion/attribute using (3) as shown below.

Where EJ is the entropy value of criterion cj, M=number of rows of = number of RATs and is the normalized criterion from and j=1, … , N(number of attributes). i.e., the entropy value for criterion cj is found by multiplying the constant with the sum of products of the element with its natural logarithm for a fixed column.

Example calculation

For instance, to calculate the entropy of c1 = bandwidth, M=4

Then repeat the same for the other criteria.

Step 2: calculate the objective weight of criterion cj using (4) below.

Example calculation

To find objective weight of c1 (bandwidth)

Step 3: Populate using the values obtained from step 2 to get objective weight vector of the network attributes.

Example

Applying (4) to all criteria

#### Subjective user preference weight vector calculation

Let be the set of user specified weights (superscript U refers to user) where each element is the weight of criterion cj for service stg. In a similar manner let be the set of service determined weights (superscript S refers to service) where each element is the weight of criterion cj for service stg .Let represent the set of user specified priority for each service in St and let be the set of service determined priority for each service in St . Where g=1 ,…, Y and j=1 ,…, N .For all subsequent calculations assume

Priority values indicate how important the service in the group is to the user. The priority values ranged from 1(Very low) to 5(Very High). The user specified weights were based on a 10-point scale [0,9] where 0=criterion not important to user and 9=criterion very important to the user. The allocation of weights and service priority are done once and are always used to select the RAT, but these can be modified based on user preferences.

Step 4: Allocate the user specified weights for each criterion into the weight vectors for each service stg  where g = 1, … , Y

Example of a single user’s preferences for each service.

Voice

Video streaming

Web browsing

these weights were chosen at random, but values typically reflect what a user for a specific service may deem more important to them.

Step 5: Normalize the weight vectors for each service using (5) as shown below.

i.e., the normalized weight is the current weight divided by the sum of weights in the vector. This results in the normalized weight vectors for each service.

Example

Voice

Video streaming

Web browsing

Step 6: Allocate the user specified priorities for each service into the user specified service priority vector

Example

Step 7: Normalize using (6) below to obtain the normalized user specified service priority vector

Example

Where is an element of and is the normalized priority of service stg.

Let be the user specified weight vector of network attributes for the group of services on the MMT.

Step 8: To obtain WU , synthesize(aggregate) and by using (7) below.

Example

NB: the 3 weight vectors for each service are combined into a matrix (each row represents a different service) so that they can be used in step 8.

Repeat the same for all criteria then

Where Y= number of services simultaneously running on the MMT and is the weight of criterion cj for a group of services specified by the user. i.e., each element in is found by calculating the sum of products of each normalized service priority with each normalized weight of a criterion j for all services.

#### Service determined weight vector calculation.

The same definitions for and defined above are used here and it is assumed . Fuzzy analytic hierarchy process (FAHP) is used to determine the service determined weight vector of network attributes defined as . FAHP eliminates the ambiguity associated with decision criteria by use of fuzzy numbers. It differs from AHP in the sense that the consistency of the pairwise comparison matrices is already guaranteed when they are formed so doesn’t need to be judged [31]. Fuzzification is the process used to convert linguistic descriptions into crisp values using a conversion scale such as in [18].

It is a very common approach used to determine subjective weights for network parameters in the literature as seen by [11], [31] and [32]. The decision-making process is placed into different hierarchies and the comparison of criteria for each layer are the fuzzy numbers. Similar to AHP, comparison matrices are formed to compare each attribute with respect to the goal.

The methodology used in this report differs from [11] as the FAHP approach used for service determined weight vector calculation was adapted from [31] due its simplicity (less computational complexity) as it doesn’t use triangular fuzzy numbers so the dimension of the calculation is reduced from 3 to 1.

Step 9: Determine the normalized service determined priority vector . Since

Then . So just use the same vectors calculated in step 6 and 7 above.

Example

Step 10: create the hierarchy of the RAT selection problem to be used by FAHP as shown in figure 3 below for example.

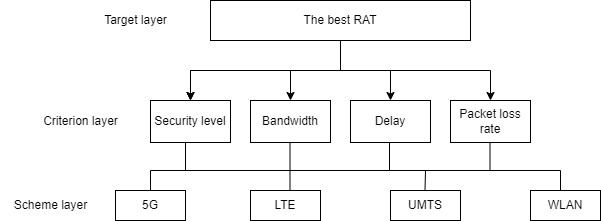


Figure 3: FAHP hierarchical structure

Step 11: Construct a pairwise comparison matrix Ag for each service as shown in (8) below.

Where is an element of the comparison matrix, (g=1 ,…, Y) which represents the relative importance of criterion ci compared to cj  for service stg as defined in table 1 of [31] repeated in table 4 below. For the case of this network model the matrices are constructed below using information from tables 2-5 in [31] where conversational class=voice, Interactive class=web browsing and Streaming=video streaming. The relative importance of security to the other criteria was based on tables 3,20 and 25 in [22] for the same classes.

Table 4: Scale for elements of fuzzy comparison

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Compare ci and cj | Equally important | Moderately important | Obviously important | Strongly important | Especially important | Extremely  Important |
|  | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |

Where (0.55, 0.65, 0.75 and 0.85) are the intermediate values. If then ci is less important than cj. where i else (equal importance for diagonal entries)

Example

Table 5: Fuzzy consistent matrix (voice)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Voice | Bandwidth | Security level | Delay | Packet loss rate |
| Bandwidth | 0.5 | 0.3 | 0.1 | 0.4 |
| Security level | 0.7 | 0.5 | 0.4 | 0.6 |
| Delay | 0.9 | 0.6 | 0.5 | 0.7 |
| Packet loss rate | 0.6 | 0.4 | 0.3 | 0.5 |

Table 6: Fuzzy consistent matrix (video)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Video | Bandwidth | Security level | Delay | Packet loss rate |
| Bandwidth | 0.5 | 0.6 | 0.3 | 0.75 |
| Security level | 0.4 | 0.5 | 0.3 | 0.65 |
| Delay | 0.7 | 0.7 | 0.5 | 0.95 |
| Packet loss rate | 0.25 | 0.35 | 0.05 | 0.5 |

Table 7: Fuzzy consistent matrix (Web browsing)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Web browsing | Bandwidth | Security level | Delay | Packet loss rate |
| Bandwidth | 0.5 | 0.4 | 0.75 | 0.4 |
| Security level | 0.6 | 0.5 | 0.85 | 0.5 |
| Delay | 0.25 | 0.15 | 0.5 | 0.15 |
| Packet loss rate | 0.6 | 0.5 | 0.85 | 0.5 |

Step 12: Using tables(matrices) 5 to 7 and (9) below, calculate the weight of each criterion cj for each service stg.

Where n=N= no of criteria and k is a constant, let k=2 for this report.

Example

For voice(s1) using (9) and table 5 to calculate the weight for bandwidth (c1) we get

Repeat the above for the other criteria and the other services.

Step 13: Place the calculated weights for the criteria in step 12 into weight vectors for each service.

Example

Step 14: (NB: This is an optional step) If all weights are already between 0 and 1 then there is no need to normalize so skip to step 15. Else, normalize the initial weights calculated in step 14 using (10) below to obtain .

Step 15: To obtain WS , synthesize(aggregate) and using (11) below (same procedure as step 8)

Example

Repeat the same for all criteria then

#### Comprehensive weight vector calculation

Let and be defined as the weight proportion parameters which represent the contributions of user preferences, network attributes, and service characteristics to the final comprehensive weight vector W of the network attributes.

Step 17: determine W by combining WO, WU, and WS with the weight proportion parameters using (12) below. Let , as this combination resulted in the maximum gain in [11].

Example

[0.4792,0.2285,0.2699,0.1485]

### Utility

The inputs to this submodule are the performance ratings of the RAT selection criteria detected by the MMT (and the normalized determined priority vector for each service ( The output of this submodule is the comprehensive utility value matrix of the network attributes

Utility is defined as the ability of a good or service to satisfy a consumer need [11]. A utility function refers to the utility derived from using a good or service by the consumer. Utility functions are used to normalize the criteria/network attributes so that the QoS requirements of the different services can be considered. In this method Sigmoid utility function is used for criteria that have both upper and lower threshold limits for their QoS requirements while linear utility function and inverse proportional function are used for criteria that have only 1 QoS requirement threshold.

The sigmoid (13-14) and linear utility functions (15-16) for benefit and cost criteria are defined using the following equations below.

where a, b, and g are constants, and x is the value of the network attribute/criterion of a particular RAT.

Step 1: calculate the utility value of the network attribute/criterion **for each service** by substituting the appropriate performance rating ( from Mt that was created in (1) in section 3.4.1 into one of the above equations (13-16) according to the QoS requirements of that criterion for that service using Table 3 in [11]. Use the appropriate constants (a,b or g) according to the table.

Table 3 in [11] did not include information for security level, there isn’t a universal standard utility function used for network security because utility derived from security levels depends on the network, threats involved and the operator’s priorities. However, a sigmoidal or linear utility function can be applied to security level according to table 3 in [33] because it is a benefit criterion, QoS related and has an upper and lower threshold for its QoS requirements such as integrity, and confidentiality [34]. Also, it is intuitively expected to derive more utility from increasing security levels in a network because better security would imply better safety and more resistance cyber-attacks. Therefore, it will be assumed that security uses the same utility function and QoS requirements as bandwidth in [11].

Example

For voice for example using Table 3 in [11] , (13) and substituting the appropriate values we get:

Step 2: Create the network attribute utility value matrix for each service stg using the calculated utility values of the network attributes/performance ratings from step 1 using (19) below.

Where is the normalized utility value of criterion cj , RAT ri  for service stg. i=1, …, M and j=1, …, N

Example

Repeating the calculation for all network attributes the following are obtained.

Step 3: To obtain the comprehensive utility value matrix for a group of services , synthesize (aggregate) (normalized determined priority vector for each service) with (network attribute utility value matrix) using (20) below.

Example

### Network Ranking and Selection

The inputs to this submodule are the comprehensive utility value matrix for multiservice U and the comprehensive weight vector of network attributes W. Both are calculated in section 3.4.2 and 3.4.3 respectively. The output of this module is a single RAT (ri R) that represents the best network for vertical handover of the group of services St on the MMT.

To score and rank the candidate RATs (all RATs are candidate RATs in this algorithm) TOPSIS was chosen as the MADM technique to determine the scores of the RATs. This is because TOPSIS is a common approach taken to select RATs for group call handoff in the literature (refer to the discussion about [15] in section 2)

With TOPSIS the Euclidean distance between the candidate solution and the PIS(Positive Ideal Solution) and NIS(Negative Ideal Solution) is calculated. The best option/candidate is the one with the shortest distance to the PIS and longest distance from the NIS. To select the best RAT for Vertical handover of a group of calls the following steps are taken.

Step 1: Create the normalized decision matrix. In this case it is the same as the comprehensive utility value matrix U

Example

Step 2: Create the weighted normalized decision matrix by multiplying each row of U (the normalized decision matrix) with the comprehensive weight vector W of the network attributes.

Where i=1, …, M and j=1, …, N (22)

is the comprehensive weight and is the comprehensive utility value of criterion cj. For RAT ri

Example

Step 3: calculate the PIS(D+) and the NIS(D-) using (23) below.

Where indicates the ideal value, indicates the worst value of criterion cj among all RATs.

Example

Step 4: calculate the Euclidean distances and of each candidate RAT ri  to and using (24)

i= 1,…, M

Example

Step 5: Calculate the score sci of RAT ri using (25) below.

Example

Step 6: Store the scores of each RAT in a vector SC=

Example

Step 7: Select the RAT with the highest score.

Example

The selected RAT is the one with the highest score i.e. RAT=max(SC). To reduce the ping-pong effect (minimize the number of unnecessary vertical handoffs) a threshold is introduced to implement this.

If there is no RAT connected to the MMT initially (at time 0) the RAT with the highest score is selected else if the currently connected RAT rj has score scj and there is a RAT ri with the highest score sci and . Then the following condition is tested (NB: )

If the above condition is true the MMT switches to RAT ri otherwise it maintains its current connection.

Example

The flowchart in figure def below shows a summary of the algorithm designed for RAT selection discussed above.

A diagram of a flowchart

Description automatically generated

## Simulation and Experiments

PC details, SW details for csc report. Several subsections talking about setup, what experiments were done and how performance was evaluated, what was measured or tested what was used to test what language. Etc refer to appendix to find code. Scenarios etc

# Results

Present your results in a suitable format using tables and graphs where necessary. Remember to refer to them in text and caption them properly.

# Discussion

Discuss the relevance of your results and how they fit into the theoretical work you described in your literature review.

# Conclusions

Draw suitable and intelligent conclusions from your results and subsequent discussion.

# Recommendations

Make sensible recommendations for further work.

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# Appendices

Add any information here that you would like to have in your project but is not necessary in the main text. Remember to refer to it in the main text. Separate your appendices based on what they are for example. Equation derivations in Appendix A and code in Appendix B etc.

# EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer ([Zulpha.Geyer@uct.ac.za](mailto:Zulpha.Geyer@uct.ac.za); Chem Eng Building, Ph 021 650 4791).Students must include a copy of the completed form with the final year project when it is submitted for examination.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name of Principal Researcher/Student:** | | Bina Mukuyamba | | **Department:** | ELECTRICAL ENGINEERING |
| **If a Student:** | YES | **Degree:** | ECE | **Supervisor:** | Olabisi Falowo |
| **If a Research Contract indicate source of funding/sponsorship:** | | | | N/A | |
| **Research Project Title:** | | RAT Selection Algorithm for Multiservice Multimode Terminals in Next Generation Wireless Networks | | | |

Overview of ethics issues in your research project:

|  |  |  |
| --- | --- | --- |
| **Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?** | YES | NO |
| **Question 2: Is your research making use of human subjects as sources of data?**  If your answer is YES, please complete Addendum 2. | YES | NO |
| **Question 3: Does your research involve the participation of or provision of services to communities?**  If your answer is YES, please complete Addendum 3. | YES | NO |
| **Question 4: If your research is sponsored, is there any potential for conflicts of interest?**  If your answer is YES, please complete Addendum 4. | YES | NO |

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

* there is no apparent legal objection to the nature or the method of research; and
* the research will not compromise staff or students or the other responsibilities of the University;
* the stated objective will be achieved, and the findings will have a high degree of validity;
* limitations and alternative interpretations will be considered;
* the findings could be subject to peer review and publicly available; and
* I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

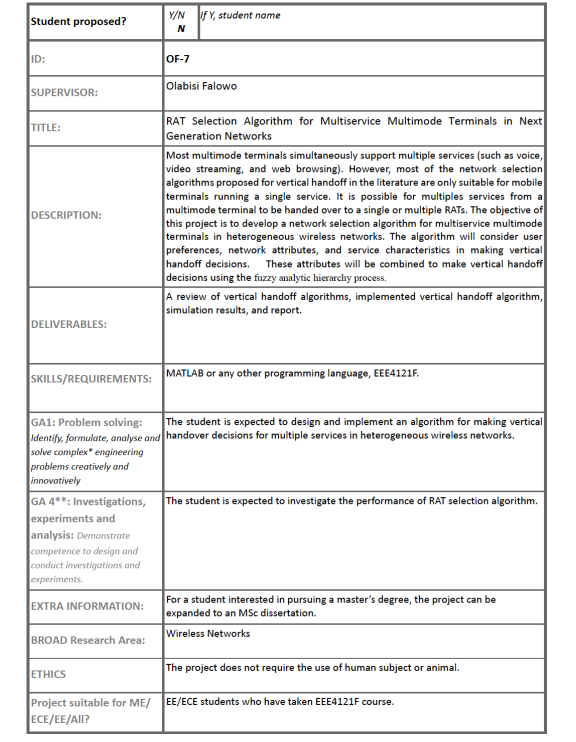
|  |  |  |
| --- | --- | --- |
|  | **Full name and signature** | **Date** |
| **Principal Researcher/Student:** | **Bina Eric Mukuyamba** | 03 October 2023 |

This application is approved by:

|  |  |  |
| --- | --- | --- |
| **Supervisor (if applicable):** | **Olabisi Falowo** | 03 October 2023 |
| **HOD (or delegated nominee):**  Final authority for all assessments with NO to all questions and for all undergraduate research. | **Janine Buxey** | 03 October 2023 |
| **Chair : Faculty EIR Committee**  For applicants other than undergraduate students who have answered YES to any of the above questions. |  |  |

**ADDENDUM 1:**

Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:



**ADDENDUM 2:** To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at <http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf>) in order to be able to answer the questions in this addendum.

|  |  |  |
| --- | --- | --- |
| 2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification? | YES | NO |
| 2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups? | YES | NO |
| 2.3 Will you not be able to secure the informed consent of all participants in the research?  (In the case of children, will you not be able to obtain the consent of their guardians or parents?) | YES | NO |
| 2.4 Will any confidential data be collected or will identifiable records of individuals be kept? | YES | NO |
| 2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous? | YES | NO |
| 2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research? | YES | NO |
| 2.7 Does the research include making payments or giving gifts to any participants? | YES | NO |

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

**ADDENDUM 3:** To be completed if you answered YES to Question 3:

|  |  |  |
| --- | --- | --- |
| 3.1 Is the community expected to make decisions for, during or based on the research? | YES | NO |
| 3.2 At the end of the research will any economic or social process be terminated or left unsupported, or equipment or facilities used in the research be recovered from the participants or community? | YES | NO |
| 3.3 Will any service be provided at a level below the generally accepted standards? | YES | NO |

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

**ADDENDUM 4:** To be completed if you answered YES to Question 4

|  |  |  |
| --- | --- | --- |
| 4.1 Is there any existing or potential conflict of interest between a research sponsor, academic supervisor, other researchers or participants? | YES | NO |
| 4.2 Will information that reveals the identity of participants be supplied to a research sponsor, other than with the permission of the individuals? | YES | NO |
| 4.3 Does the proposed research potentially conflict with the research of any other individual or group within the University? | YES | NO |

If you have answered YES to any of these questions, please describe below how you plan to address these issues: