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User-Driven Network Selection during Vertical Handover in 4G Networks

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Abstract — The importance of network selection for wireless networks, is to facilitate users with various personal wireless devices to access their desired services via a range of available radio access networks. The inability of these networks to provide broadband data service applications to users poses a serious challenge in the wireless environment. Network Optimization has therefore become necessary, so as to accommodate the increasing number of users' service application demands while maintaining the required quality of services. To achieve that, the need to incorporate intelligent and fast mechanism as a solution to select the best value network for the user arises. This paper provides an intelligent network selection strategy based on the user- and network-valued metrics to suit their preferences when communicating in multi-access environment. A user-driven network selection strategy that employs Multi-Access Service Selection Vertical Handover Decision Algorithm (MASS-VHDA) via three interfaces; Wi-Fi, WiMAX and LTE-A is proposed, numerically evaluated and simulated. The results from the performance analysis demonstrate some improvement in the QoS and network blocking probability to satisfy user application requests for multiple simultaneous services.

Index Terms— *Network Selection, Handover, LTE-A, Algorithm, MADM.*

I. INTRODUCTION

The unprecedented boost of data traffic across broadband wireless networks has been as a result of the continued increase of mobile applications and the emergence of multitude mobile devices. Nowadays, the resources of the existing cellular networks are continuously being overstretched leading to its shortage due to bandwidth-intensive application services such as video streaming that are constantly being demanded by smartphones. The desire to access multimedia services has been the driving force that brought technological revolution towards the integration of diverse wireless access technologies. As a result, the Radio communications Sector of the International Telecommunications Union (ITU-R) in 2006 initiated the move to improve the existing technologies for smooth transition to the fourth generation networks, also called LTE-Advanced networks [1]. The technologies of LTE-A and IEEE802.16m, having being ratified in 2010 by the International Telecommunication Union (ITU) as initially satisfying the requirements of the IMT-Advanced (Fourth Generation - 4G) technology [2], has the objective of meeting numerous threats posed by the ever increasing use of "smart" wireless devices that require high spectral resources than the conventional cellular phones.

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Today, however, no single wireless or mobile network technology can provide all the diverse types of service requests from users (wide-area coverage and high data rates). Consequently, different types of networks are integrated to constitute a large heterogeneous access network of different characteristics (bandwidth, delay, communication range, speed support, power consumption, security, end-user cost) and several other aspects. It is the convergence of these wireless networks that provides the mobile user equipment (UE) variety of choices to select the best Network Access Technology (NAT), which surely differ from one another in terms of Quality of Service (QoS) and radio characteristics. Fig. 1 shows the convergence of different wireless technologies that inform the level of research being conducted to achieve seamlessness in mobility of the UE.

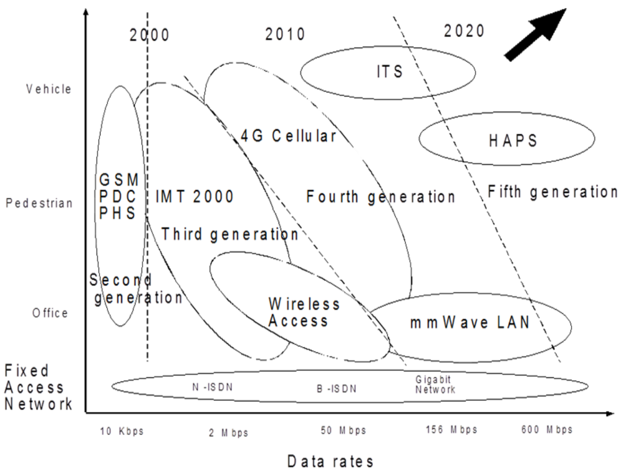

Fig.1 . Convergence of Wireless Network Technologies towards 2020.

From the perspective of service requirements a balance has to be established for ensuring good QoS with data security on one hand and guarantee efficient resource allocation while considering the capabilities and capacities of both the devices and networks on the other hand. In order to collect information about different users in the network selection process, efficient context discovery mechanism should be put in place. For instance, a user profile should be established to define his preferred networks and networks' parameters should be collected to find the appropriate radio access technology a mobile user should connect to, according to his running class of service and to his preferences. The context discovery may be realized either on the terminal side or on the network side, or on both of them. A good and efficient interworking architecture is therefore required at this stage to take the advantage of integrating all heterogeneous technologies and avoid their standalone weakness.

II. Literature Review

The main focus of this paper is to select the best network during vertical handover decision making process in heterogeneous wireless networks, considered as the heartbeat of the handover process. A vertical handover decision may be influenced by numerous issues associated with the network to which mobile user equipment (UE) is connected and towards the one a handover execution is intended for. The decision of a UE to execute handover may well be taken with the help of a vertical handover agent based on the pre-recorded policies such as available bandwidth, network load, network coverage area, monetary cost, network security, QoS, and user preferences.

One of the key features of ubiquity is to facilitate free movement of mobile users and to communicate with the accessible applications using different intelligent and interactive equipment. However, switching across different access networks requires a proper mechanism to accommodate user and application needs, especially in terms of QoS. It plays a vital role in accomplishing users' needs, harmonizing network resources and their utilization and makes best use of network performance.

Decision Function based Schemes

Decision making and network selection processes are becoming more complex in heterogeneous networks because of the varying nature (QoS support, billing schemes, reliability, etc.) of the access technologies. Handover decision and proper network selection become a multi-criteria decision making (MCDM) problem that involves a number of parameters and complex trade-offs between conflicting criteria as a weighted sum of specific network parameters [xx]. The first policy-enabled handover algorithm was introduced as a cost function in the handover decision making in order to select the best available network. Since then, they are widely used in case of multi-criteria decision making where multiple network parameters are summed together to select a specific network according to user or running application needs.

Utility Function based Schemes:

In the access network selection and decision management, the level of user satisfaction is measured by the characteristics of the preferred network and allocated resource parameters. In [3] and [4], the authors adopted load balancing schemes to design utility functions for network selection and handover decision. They argued that these schemes perform better in terms of throughput when they are considered for network selection and handover decision.

To resolve these problems, [6] proposed a cost function for vertical handover decision making. The proposal incorporates the parameters of cost, velocity, security and power consumption. The performance of the candidate network was evaluated by developing a network quality factor to normalize these parameters and assigns to them weights. Also developed was a handover necessity estimator used to avoid unnecessary handovers. Consequently, certain network parameters like security levels and signal interference levels could not be approximated and the authors fall short in providing solution on how these network dynamics could be computed.

Reference [8] proposes a network selection and handover decision method based on TOPSIS for ranking the networks in a wireless overlay environment. They take into consideration the handover history parameter as a prime factor in making a handover decision and proper network selection, along with cost, security, bandwidth, jitter, packet loss and delay. The parameters were memorized by the TOPSIS decision engine to manipulate these decision machines accordingly for a suitable ranking suitable to user needs. The authors claim to reduce the number of handovers but, it seems that UE is forced to stay in a network, even if the QoS of that specific network drops below the user threshold. This shows the inappropriateness of such solutions in the heterogeneous radio access environments. Some authors like [9] and [10] observed that TOPSIS, SAW and VIKOR based handover decision making mechanisms are very effective for voice communication in 4G connections as they provide low values of jitter and packet loss, whereas, [11] stated that MEW and ELECTRE based schemes usually provide higher throughput values for voice data. It becomes difficult after summarizing all to make any meaningful choice between these schemes for an optimal solution to vertical handover. This is so, as ranking criteria among these schemes are completely different and the influence of scoring appears to be important in the evaluation of MADM schemes where diversity of traffic type exists.

Network Intelligence based Schemes

The access to multimedia applications in wireless networks is concerned with the performance of handover because of the irretrievable property of real time data delivery. In order to improve the performance of handover in terms of throughput, unnecessary handovers and handover latency, it is very important to make the handover decision intelligent and timely. Neural networks have been successfully applied to solve complex problems by automatically learning the system behaviour and generalizing it to situations that are not experienced before. Similarly, [12] propose neural networks and fuzzy logic based technique for the handover decision making. A neural network learns the FLC parameters by applying the predefined rules to the current system conditions from the resulting handover quality indicators. In their work, they proposed to use RSS, velocity and network load as the handover decision parameters. A preliminary selection of handover target networks was performed before initiating the vertical handover procedure. Target networks with signal level and network load above predefined thresholds were filtered and the target network with the best signal quality chosen. This pre-selection reduces the FLC complexity and saves the processing time. However, this scheme faces the similar constraints as the one presented by [13]. Apart from those limitations, this scheme is applicable for small environmental variations and not adaptable to the new network conditions [14], [15] [16], [17].

QoS based Schemes:

It has been revealed in the existing literature that classical MADM methods cannot efficiently handle a decision problem with imprecise data that decision criteria could contain as demonstrated in [18]. For that reason, the use of fuzzy logic is not only to deal with imprecise information, but to simultaneously combine and evaluate multiple criteria [19]. A network selection and decision method is proposed by [20].

The QoS-aware network selection relies on Analytic Hierarchy Process (AHP) method that assists in applying user perceived QoS for an optimal handover performance. The proposed solution provides smart decision making mechanisms by integrating context gathering and handover decision processing in a mobile-assisted handover. In order to predict a handover, RSS of different networks are compared and when a handover is predicted, it exploits its context to select an optimal network from the available ones that best satisfies user service requirements and preferences. Utility function is used for the evaluation of candidate networks on the basis of network cost, which is very similar to the one used by [21]. This method performs network selection on the basis of network service cost, however, the authors did not discourse the QoS aspect in this case.

A very similar technique was equally adopted by [22].

Authors in [23] considered heterogeneous wireless networks containing WLAN and WiMAX for vertical handover using AHP and game theoretical approaches. They take into account the parameters of pricing, bit rate, user preferences and mobility. The proposed mechanism suggested total dependence on location of mobile user and network configuration to calculate the payoff of the handover as indicated in [23]. Similarly, [24] [25]. Haldar et al., [26] followed the same lines to present architecture for dynamic spectrum access and proper network selection. The proposed mechanism succeeded in reducing the call blocking probability, waiting and response time. It also improves the spectrum utility and throughput perceived by the end user. However, in contrast to the existing approaches the proposed method receives a higher number of handovers and Ping-Pong effect.

After carefully analyzing all the different methods of handover decisions for network selection, a generic network selection algorithm is developed that helps the handover decision making process by incorporating the QoS and other contextual information which is generated as a result of cooperation between the network entities. In this respect, a fuzzy logic concept that provides a framework to decide the selection of the best network is formulated as Fuzzy MADM.

III. SYSTEM MODEL

The proposed model depicted in Fig. 2 as an overlayed network of three interfaces (WiMAX, Wi-Fi & LTE-A). Active user that happens to be in the overlayed region of all the three networks must decide the time and the candidate network to select or choose to trigger a vertical handover request. However, the serving network assigns certain amount of bandwidth as soon as the requested service is accepted. On the other hand, denial of such request by any one network, re-directs request to another network, once there is availability of resources. The service(s) requested can get blocked easily and quickly by the system as more UE tend to re-direct their requests to such network.

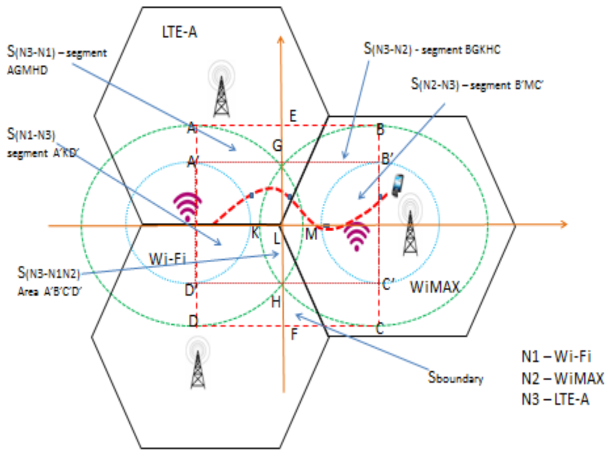

Fig.2. System Model of the Proposed MASS-VHDA.

3.1 Blocking Probability

Though the blocking probabilities of the various radio access networks considered independent input parameters, the approach here is that a Performance Evaluation Process Algebra (PEPA) model [28] is proposed to derive the blocking probabilities. The model monitors the mobility and traffic characteristics of UE in the networks with acceptable behaviour of the UE that finds itself in another network selection. One of the key characteristic of trunked system that dedicates the quality of the service offered to users, concerns how the system handles blocked calls. Two basic strategies are used; i) call requests that does not find any available channels are blocked and cleared, ii) blocked calls are held in a queue and served as soon as a channel becomes available. In this work, the focus is on the first strategy (blocked calls) as this type of system is more often found in practice. An $M/M/1/N_n$ queue system of modelling by [29] was adopted to model each of the three networks represented in Fig. 2 and are expressed in Equation 1. The value CH_n is the number of available channels in Network ***n*** and calculated as:

$$CH_n = \frac{BW_n}{D_{av}} \tag{1}$$

Where BW_n is the whole bit rate (bandwidth) of the network ***and***, D_{av} is the mean data rate of every user.

Poisson distributions were used to model the traffic load in the overlay cells and expressed as $\rho = \frac{\lambda}{\mu}$, where λ and μ are the arrival rate of service requests and departure rate respectively. High priority is given to handover calls rather than new requests and for ease; a buffer-less handover algorithm is used.

Under these conditions, a call is blocked, denoted as P_b and called Erlang B probability formula. It is the probability expressed by population of users that generates the traffic A offered to a trunked system with C channels as presented in Equation 2 [30].

$$\mathbf{P}_b = \frac{A^C / C!}{\sum_{k=0}^{C} \frac{A^k}{k!}} \tag{2}$$

The blocking probability P_{bn}, adopted by the queuing theory $M/M/1/N_n$ of N_n users as expressed in [29] is computed using Equation 3:

$$P_{bn} = \frac{\rho_n^{Nn}}{1-\rho_n^{Nn+1}}(1-\rho_n) \tag{3}$$

ρ_n - Network load of ***n*** network:

$$\rho_n = r_n \times \rho \tag{4}$$

The average requested service(s) (ARS) to the satisfaction of user(s) as measured in percentage in the overlay network is thus estimated by Equation 5:

$$\Psi[\Gamma_{Ri}] = \sum_i A_{Ri} \times P(R_i) \tag{5}$$

where A_{Ri} is the ARS for Region ***i*** and Γ_{Ri} is thus calculated from the expression in Equation (6):

$$\Gamma_{Ri} = \sum_j t_{i,j} \times P(N_{i,j}) \tag{6}$$

With $t_{i,j}$ as maximum throughput of network $N_{i,j}$ in region ***i*** , and $P(N_{i,j})$ in Equation (6) chosen by user as the probability that network $N_{i,j}$ is accessible as the serving network. The value of $P(R_i)$ is indicating the probable situation that a user might be located in Region ***i*** , and is calculated in terms of the geometrical proportion of Region ***i*** to the entire boundary region given in Equation (7) as:

$$P(R_i) = \frac{A_i}{A_{Bound}} \tag{7}$$

The assumption is that mobile users are distributed uniformly. This has been verified by a comparison of theoretical results based on the uniform distribution and simulation results using the improved random way point (RWP) model.

IV. NETWORK SELECTION ALGORITHM

The proposed network selection algorithm helps the handover decision making process by incorporating the quality of service (QoS) and other contextual information generated as a result of cooperation between the network entities. The architecture of the algorithm is a dual stage process that involves cooperative information exchange of QoS among access nodes and then selects the optimum candidate wireless network through the measurement-based network selection for better resource utilization as depicted in Fig. 3. The aim here is to design an intelligent network selection system that has the ability to select the best available wireless network. It takes advantage of user preferences, device capabilities (power consumption), and wireless network features (cost and context-aware) as network parameters in order to make a better handover decision and network selection.

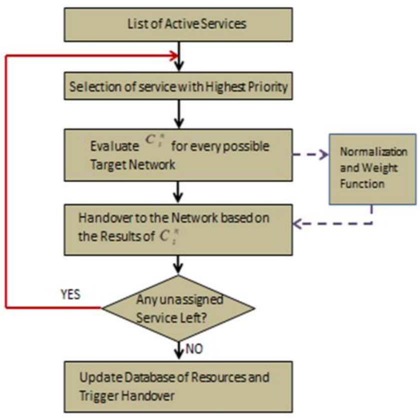

Fig. 3. Flow Diagram of Prioritized End-User Session.

The approach to select a network consists of two stages: vertical handover with predictive power level sensitivity (PRSS) which determines, on one hand the optimal network to hand over. On the other hand, the scheme adopts polynomial regression to achieve the prediction with hysteresis to monitor the closeness of UE to candidate network. However, the other stage, makes use of Markov Decision Process (MDP) to determine handover cost and the network with the least cost eventually becoming the optimal target network to be selected. It is to mitigate significantly the number of handovers, improve network utilization and grade of service (GoS).

The conceptual model proposed for network selection algorithm considers the aspect of the monetary cost of the network, application requirements, user mobility and network conditions in terms of average throughput as illustrated by the functional block diagram of the proposed mechanism in Fig. 4.

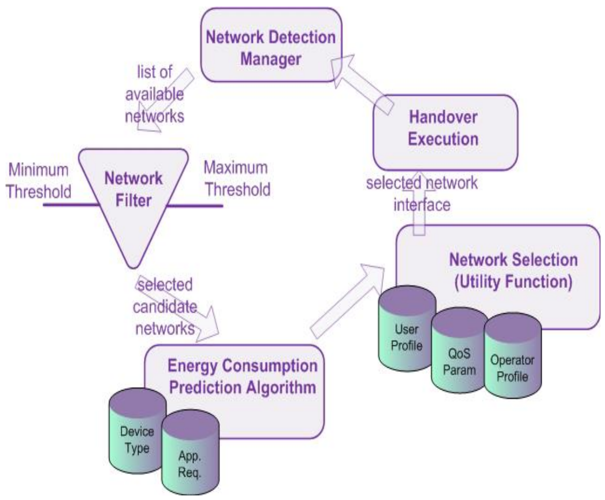

Fig. 4. Functional Blocks of the Network Selection Mechanisms.

The Network Detection Manager is responsible for scanning and providing a checklist of all available networks within the surrounding location to the Network Filter. Elimination of networks that fail to meet the required minimum criteria is executed by the Network Filter module. A threshold (minimum/maximum) is set for every type of application with defined criteria. Only networks that pass the set thresholds can escape elimination and be considered as candidate access networks for the network selection algorithm, which consequently minimise, to an extent, the time needed for making decision. The received signal strength (RSS) for the running application is then predicted for each of the selected candidate networks which eventually will be used to evaluate the network selection utility cost function. Any of the networks found to have the highest score is then selected as the candidate network. With the candidate network known, the handover mechanism is then triggered by the Handover Execution module and the mobile user is served by the new network.

Performance Measures

By using Continuous Markov Chain (CMC), an investigation is launched into the performance of UE in steady condition where the reward structure of CMC used is measured as given in [31]:

$$R = \sum_{s_i \varepsilon S} \rho_i * \pi(s_i) \qquad (8)$$

where S_i is the set of all feasible system states of the performance evaluation model, while ρ_i stands for any useful value.

Three performance measures are to be investigated, namely handover rate, average throughput and blocking probability.

i) Handover Rate: This is the average number of executed session attempts by UE per unit time.

ii) Average throughput: This is the expected mean data rate achievable by UE while communicating. Obtaining the dwelling time of the UE confirms the first move to derive this measure with divergent interfaces being used for different sessions. Four groups of engaging times emerge and defined thus:

The optimum wireless access network selection problem must satisfy the mathematical expression:

$$f_i(u) = f(A_i, 1/C_i, D_i, E_i, 1/L_i, 1/P_i, R_i, S_i, V_i)$$
$$= \sum_{i=1}^{6} w_X \times N_f(X_i) + \sum_{i=1}^{3} w_y \times N_f\left(1/Y_i\right), \qquad (9)$$

where $N_f(X)$ - normalization function of X parameter while w_X - weight that indicates how important the parameter X is, $X_i = A_i, D_i, E_i, R_i, S_i, V_i$, and $Y_i = C_i, L_i, P_i$. The reason for the normalization is to ensure the meaningfulness of the total/sum of values in different units. The weights are proportionally significant to the associated parameter of the decision maker in the VHDA. The more important a parameter is to the user, the larger the weight of that specific parameter and vice versa. The values of these weights range from 0 to 1 and add up to 1.

The normalization $N_f(X)$ is expressed as:

$$f_i(x) = \sum_{i=1}^{6} w_X \times \left(X_i / X_{max}\right) + \sum_{i=1}^{3} w_Y \times \left(Y_{min} / Y_i\right) \qquad (10)$$

Normalized parameter values lies between 0 and 1. If the network selection is considering selecting a network with high parameter X value; then single membership function will thus be defined to suit the condition; $\mu C_j(0) = 0$ and $\mu C_j(1) = 1$. However, if on the other hand is to select network with low parameter X value, then must fulfil the condition; $\mu C_j(0) = 1$ and $\mu C_j(1) = 0$.

The FMADM Algorithm

Fuzzy Multiple Attribute Decision Making (FMADM) is a Multi Attribute Decision Making technique, the concept of which is based on making use of fuzzy logic to solve the imprecise and obscured information contained in the decision attributes and to evaluate multiple attributes. The technique of fuzzy multiple attributes decision making (FMADM) method therefore offer an appropriate solution with proven mathematical tool that guarantees sequence of solution preference.

This method (Fuzzy MADM) has the capability of not only recognising the different QoS goals, but also cope with imprecise and contradictory attributes of candidate networks. It first decomposes the network selection problem into a system of hierarchies of several sub-problems, and then elucidates pairwise judgments of criteria and assigns a weight value for each sub-problem.

The second step is to establish the priorities among the elements at the same level of the hierarchy. The user judges the relative importance between the elements by making a series of pairwise comparisons. The judgements are converted into numerical values on a scale of 1 to 9 based on the contribution intensity of the elements to the objective as the fundamental scale of importance in decision making.

Table 1 Scale of Importance in Decision Making

Intensity of Importance	**Definition**
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2, 4, 6, 8	Intermediate Values

The third step is to synthesize the comparison results and calculate the weights of each decision factor. For example, the weight of decision factor Cost (W_{Cost}) with respect to the decision goal can be calculated as:

$$W_{Cost} = \frac{1}{3}\left(\frac{m_{11}}{\sum_{i=1}^{3} m_{i1}} + \frac{m_{12}}{\sum_{i=1}^{3} m_{i2}} + \frac{m_{13}}{\sum_{i=1}^{3} m_{i3}}\right) \quad (11)$$

For example, the value of matrix element m_{12} is 3, which means that, comparing cost to coverage area, the user considers cost slightly more important than coverage Area when choosing a network. Correspondingly, the matrix element m_{21} represents the judgement of the importance of coverage area to cost. The matrixes m_{21} and m_{12} are correlated and the value of m_{21} can be derived as $m_{21} = 1/m_{12}$. The diagonal elements of the matrix present the results of decision factors of self-comparisons and their values are 1. Based on equation 11, the weights of decision factors for coverage area (W_{CA}) and voice quality (W_{VQ}) can also be obtained.

The last step of AHP is to calculate the synthesised weights for each solution alternative. Given the weights for Network A with respect to Cost, Coverage Area, Voice Quality and the synthesised weight for network A, can be calculated as:

$$W^{NA} = W_{Cost} \times W_{Cost}^{NA} + W_{CA} \times W_{CA}^{NA} + W_{VQ} \times W_{VQ}^{NA} \quad (12)$$

Finally, the network which produces the greatest synthesised weight will be selected. There have been a number of research efforts concerning seamless mobility and seamless vertical handover as reviewed earlier. Consequently, limitations in the on-going research efforts are still prominent. First, there is no efficient way to deal with imprecise information that the decision attributes could contain. Secondly, it is difficult to provide user personalization for optimal network access selection. Thirdly, the few literatures that used cost or objective functions did not employ optimization algorithms.

The pseudo-code of the decision making process of MADM is described in the MASS network selection algorithm. The computational efficiency is an important concern when dealing with network selection algorithms. The algorithm starts by elimination process and from the list of available wireless networks, only networks with required thresholds are processed further as candidate networks. The networks having the overall maximum score from the computed function (cost, mobility, quality and so forth) are chosen as the target network. This process is repeated every time the serving network fails to fulfill the user requirements or a better network is available. The algorithm of network selection is given:

Algorithm: MASS Network Selection Algorithm

INPUT:
w_e; - *energy weight*
w_q; - *quality weight*
w_c; - *cost weight*
w_m; - *mobility weight*
(user preferences)
Th_{min}; - *application requirements – the minimum acceptable throughput*
C_{max}; - *user's budget – the maximum cost the user is willing to pay for the services*
Throughput$_i$; - *the available throughput of RAN i*
Monetary_Cost$_i$; - *the monetary cost of RAN i*

PROCEDURE:
i = 0;
ELIMINATION PHASE
Input:
List of Available Networks;
Procedure:

for i = 0 **to** number of available networks **do**
if Throughputi ≤ Th_{min} or $C_i > C_{max}$ **then**
eliminate Network$_i$
end if
end for
Output:
List of Candidate Networks;

SCORE GENERATION PHASE
Input:
List of Candidate Networks;
Procedure:
for i = 0 **to** number of candidate networks **do**
compute utilities: u_{ei}, u_{qi}, $_{ci}$, u_{mi};
compute score $U_i = \cdot \; u_{ei}^{we} \cdot \; u_{qi}^{wq} \cdot \; u_{ci}^{wc} \cdot \; u_{mi}^{wm}$
end for
Output:
Ranked List of Candidate Networks;

OUTPUT:
Ranked List of Candidate Networks;
With the **Target** first choice **Network** – the network with the highest score (U_i)

V. DISCUSSION OF RESULTS

A close examination of the RSS performance provides the basis for comparison with the results obtained from MASS-VHDA. Fig. 5 displays the Mean User Service Request (MUSR) of RSS-based handover algorithm when the network load increases. At the initial stage, the average requests (in percentage) by users for service availability indicates the status of each network with Wi-Fi network spearheading as the network with more resources. By steadily increasing the network load, the resources of the Wi-Fi network start getting saturated and begin to decrease as users start to search less congested networks (WiMAX and LTE-A). Gradually the two networks take over from Wi-Fi network as they continue to receive more mobile users until a peak is reached where they cannot accommodate beyond their capabilities and then drops to a measurable level.

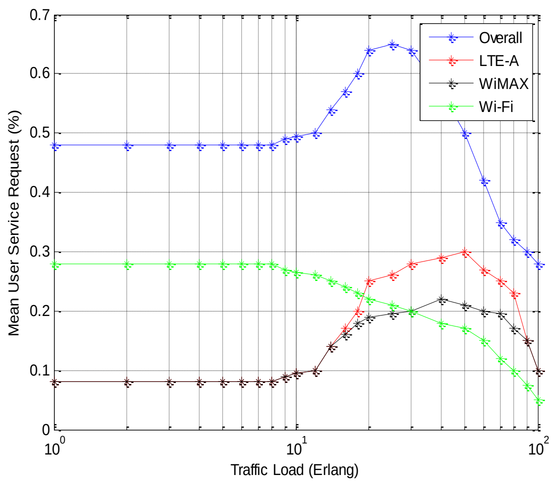

Fig.5. MUSR provided by RSS-based Algorithm.

However, because of the difference in mobile distribution and that of the bandwidth among the WLANs, significant variations (10%) of the MUSR exist in these networks. The general notion is that there is a fairly proportional distribution of the number of mobile users in the selection of target network. This could be seen as the resulting overall combination of the networks in Figure 5.

The plots in Figure 6 demonstrate the analogous blocking probability of every individual network in question. The early increase in the blocking probability of Wi-Fi and WiMAX networks is observed to indicate that LTE-A network was chosen often by mobile users as the target network to hand over to and leads to an early blocking, while Wi-Fi and WiMAX networks take the advantage of the relatively large bandwidth availability to each user, thereby making them (Wi-Fi and WiMAX) as favourite networks.

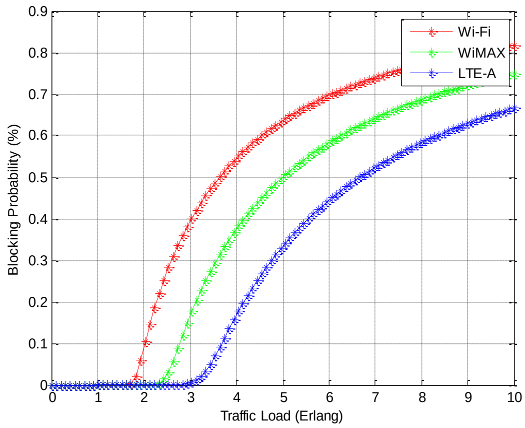

Fig. 6. Blocking Probabilities of three networks in MASS-VHDA.

Since Wi-Fi and WiMAX networks provide comparatively large data rates than LTE-A network, they eventually become the default service providers for the mobile users, depending of course on their locations. Hence, with low network load, Wi-Fi and WiMAX networks try to fulfill the larger part of the whole request from mobile users. As the build-up of the network load start to progress, the resources of the other two networks (Wi-Fi and WiMAX network) eventually get used up faster than the resources of LTE-A network. These makes the mobile users to turn back and begin to seek connection with LTE-A network more often than when the network load is low. Fig. 7 shows the results of MASS-VHDA for the MUSR provided by each of the three (LTE-A, Wi-Fi and WiMAX) networks and the overall achievable MUSR implementing the overall handover algorithm.

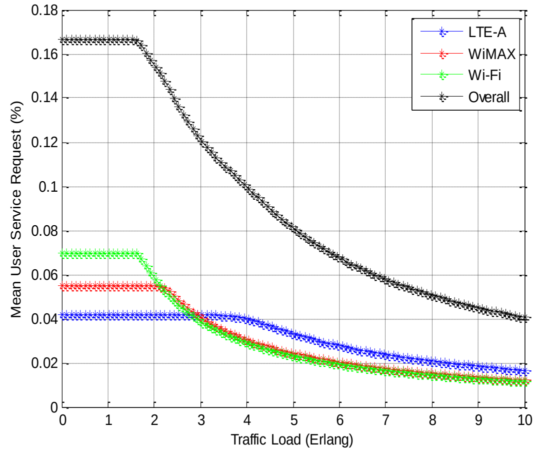

Fig. 7. Mean User Service Requests as Performance of MASS-VHDA.

Since either Wi-Fi or WiMAX networks provide relatively larger data rate than LTE-A network, they become the default service provider for the mobile users, depending on their location. Thus, at the low load range, the two WLANs (Wi-Fi and WiMAX) satisfy the most portion of the total request. With the network load on the increase, the resources of the WLAN networks start to decrease earlier than that of LTE-A network. Then mobile users start to select LTE-A more frequently than in low-load range when the coverage area of the WLANs shrinks while the traffic load is becoming larger. The portion of requests satisfied by LTE-A network thus starts to increase when the portion satisfied by Wi-Fi and WiMAX networks decreases.

Three techniques was used to plot Figure 8 that compares RSS-only with that of the mobility-level which as a metric, can easily combine with RSS-based algorithm for the improvement of the overall system performance. This happens with fast moving users (v > vthreshold) capable of receiving service(s) from the larger network, while medium and slow speed mobile clients (v < vthreshold) receives service(s) from the smaller networks.

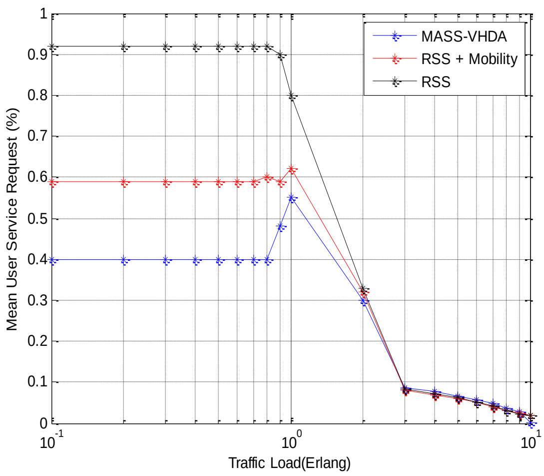

Fig. 8: Comparison of MUSR to Traffic Load using different Techniques.

The algorithm exhibits an improved performance for the MUSR. However, the achieved MUSR shows very low value than that of MASS-VHDA, which in essence indicates that load-balancing issue still, remains unresolved as a result of the rise in service requests from network users.

A plot of MUSR and blocking probability vs. user requests is shown in Fig. 8 for the three different handover algorithms. In this case, LTE-A is eliminated in the RSS-based and the overall MASS-VHD handover algorithms, due to its limited bit rate per user. Thus, users will only have to choose between Wi-Fi and WiMAX networks. This correspondingly increases the MUSR in the RSS-based algorithm to a status of light traffic (ρ<1 in Fig. 9), since users no longer join the LTE-A network. However, the MUSR in in the overall MASS-VHD decreases, since Wi-Fi and WiMAX networks cannot cover the whole area. On the other hand, all the three (3) networks can be used in prioritized MASS-VHDA, where user's two sessions can spread into multiple networks.

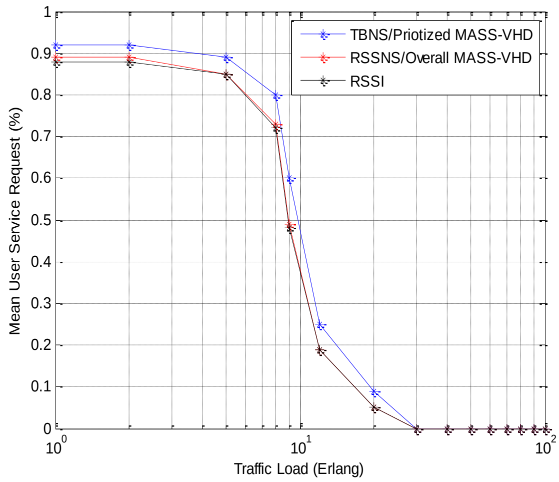

Fig. 8: Comparison of three Different Algorithms (RSS-based, overall and Prioritized MASS-VHD).

If the bandwidth for one session cannot be satisfied, only one session will be blocked. This results in a higher MUSR and a lower blocking probability than the other two handover schemes. Moreover, since users moving out of the limited coverage of Wi-Fi and WiMAX networks cannot be served in RSS-based handover algorithm and overall MASS-VHDA, a non-zero blocking probability can be observed all the time. As a result of its flexibility, the performance of the prioritized MASS-VHDA becomes similar to the performance in Fig. 9.

VI. CONCLUSION

In order to assess the effectiveness of the network selection strategies (NSSs) on the performance of both the mobile UE and radio access networks, a performance evaluation for MASS-VHDA was conducted. A utility function strategy that is based on two scenarios, namely RSSNS/overall and TBNS/prioritised network selection strategies under multi-network handovers was evaluated.

The types of performance measures discussed in this work are meaningful from the perspectives of both the user and the network operator as the effect of the average throughput and that of the handover rate affects the quality of service (QoS) perceived by the user. While the average throughput reflects the efficiency of the communication, especially for non-real time sessions, the handover rate deals with the volume of signalling load and the frequency of the service blockade during a session. On the other hand, the network administrators may be more concerned about resource utilization of the RANs and the RAN blocking probability that might reflect on the traffic loads of other RANs.

Since, the WLAN (Wi-Fi and WiMAX) has the lowest blocking probability at the expense of having the highest WRAN (LTE-A) blocking probability, the strategy of the prioritised scenario prefer to accommodate users in the WLAN networks whenever they are available as high average throughput at long session durations are set to be achieved. More so, since users moving out of the limited coverage of the WRAN (Wi-Fi and WiMAX networks) cannot be served in RSS-based handover algorithm and the overall MASS-VHD, a non-zero blocking probability are observed at all times. As a result of the strategy being aware of the type of the session (RT or NRT), its performance becomes very sensitive to the traffic pattern of the mobile UE. The nondeterministic strategy, such as the relative RSS strategies introduces randomness in network selection and therefore the user will experience uncertainty during the handover. As visible from the results, they have a more balanced performance measures than the deterministic strategies.

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