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Review

Improved handoff stability using an enhanced vertical handoff decision algorithm

Onumanyi Adeiza* and E. N. Onwuka

Federal University of Technology, Minna, Nigeria.

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The next generation wireless networks generally called 4G networks will most likely be actualized by the integration of present day available heterogeneous wireless networks. Integration of these networks will largely depend on the process of Vertical Handoff (VHO). VHO occurs when an active communication session is transferred between different heterogeneous radio access technologies. Several algorithms have been proposed in literature to implement the decision phase of VHO, some of which are discussed in this paper. Most of these decision algorithms in literature were not tested or evaluated to show their effect on handoff stability. This paper clearly shows how an enhanced decision algorithm (EDA) that considers four different decision metrics provides better handoff stability than other decision algorithms that lay priority on available bandwidth to make handoff decision. This is because the available bandwidth may, sometimes, fluctuate rapidly thereby making the VHO algorithm unstable. Our EDA introduced a technique that tapers this effect.

Key words: Vertical Handoff, enhanced decision algorithm, algorithms, networks.

INTRODUCTION

Development in wireless communication has undoubtedly become the most significant responsible factor for the increase in the economic fortunes of most businesses and economies in the world. This is so because of the flexibility that wireless communication has provided. The ability to freely communicate and exchange information on the move has become the hallmark of wireless communication research and development. This further explains why the number of companies offering wireless communications services have grown steadily in recent years. For example, in 1988 about 500 companies offered cell phone services. By 2001, that number had grown to more than 2,500 companies serving about 120 million subscribers (Robert, 2007). By 2006, the mobile telecoms analysis company announced that there are now over 2.6 billion mobile users in the world (John, 2006) and it has been predicted that the number of mobile subscribers worldwide will rise to 3.96 billion by 2011 (Festprint, 2006). The unrelenting effort of researchers in this field, combined with the ever increasing demands from users and businesses intend to push the limits of wireless technology into a future age where anytime and anywhere communication will be possible at acceptable data rates and Quality of Service (QoS).

The vision of the future where users will move around the globe while communicating in an information-based internetwork at acceptable data rates serves as the impetus for the development of the popularly envisioned 4G network. The initial challenge therefore, was to provide a single network that will have both a ubiquitous coverage and very high data rate. This obviously seemed daunting and rather impossible due to the limitations present in radio technologies. On the other hand, present day 3G networks–particularly cellular networks – provide ubiquitous coverage area but suffer from limited data rates while 802.11 wireless standard networks offer high data rates but small coverage areas. The ability to take advantage of these complementary properties soon became the obvious solution to the provisioning of the next generation networks. The process that allows for the use of these integrated heterogeneous networks is called VHO. VHO occurs in the mobile terminal (MT) roams between different networks (Ahmed et al., 2006). This process occurs in inter-technology based network scenarios. In an intra-technology based network scenario, handoff is performed through a process called

*Corresponding author. Email: adeiza1@yahoo.com.

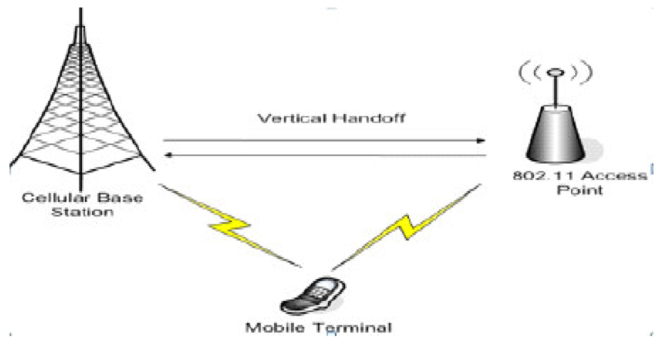

Figure 1. Vertical Handoff.

Horizontal Handoff (HHO). HHO is the process of transferring an MT from one base station (BS) or access point (AP) or channel to another (Nishith et al., 1998). The ability to roam in present day 3G networks while having the feel of a single ubiquitous network coverage area indicates that HHO is not much of a challenge anymore. The current research challenge is how to achieve seamless VHO with zero handoff delay and very low packet loss. Efforts to meet the challenge of VHO led to the establishment of the three stages in VHO implementation as thus explained.

The discovery phase

In this phase, the MT's Network interface cards (NICs) are powered on to scan for available candidate networks for connection.

The decision phase

Choice of best network for connection is made in this phase.

The execution phase

This phase conducts the actual handoff. Among these three phases, the decision phase is the most stringent because it determines how meaningful VHO will be to a user. This has made the decision phase a very important aspect of VHO. Researchers in literature have therefore, sort ways of discovering accurate and precise decision techniques for VHO. The use of decision policies or metrics soon became a popular technique in the VHO decision making process (Wang et al., 1999). In this paper, we discuss various decision making techniques in VHO with emphasis on the different policies employed. By policy, we mean the set of rules along with the metrics used in decision making. We lay emphasis also on the experimental results of these algorithms and examine what criteria against which these algorithms were tested. After showing very few algorithms that were tested for handoff stability, we introduce EDA (enhanced decision algorithm) and show in the result section how it provides better handoff stability than bandwidth alone techniques (BAT). By BAT, we refer to general techniques that rely solely on available bandwidth to make handoff decision. It was argued that though it is good to be always connected to the higher bandwidth network; consideration should also be given to handoff stability of the algorithm, especially in a situation where available bandwidth fluctuates rapidly.

The rest of this paper is organized as follows: In Section II, we discuss the general structure and implementation of VHO. Section III discusses certain selected works that exposed general techniques used in the decision making phase of VHO and the criteria against which the algorithms were tested. Section IV intro-duces EDA while Section V shows how it improved handoff stability through the use of an increased number of decision making metrics. Section VI concludes the paper.

IMPLEMENTATION STRUCTURE OF VHO

To implement VHO, an MT will be expected to have more than one NIC. Each NIC will be used to interface with their respective networks. The system discovery phase begins when an MT activates its NIC and starts scanning for available networks. Most likely, several networks will be available for connection; the best network to be chosen for connection will depend on the decision phase of VHO. The decision phase of VHO comprises the use of several metrics such as available bandwidth, battery power status, and financial cost, received signal strength etc. measured at the NICs of the MT or from a cross-layer architecture where information is obtained from several layers. Decision is made from these information as to which network to establish connection. Traditional handoff methods used only received signal strength as the decision metric. This is a constraint in VHO due to the asymmetric nature of these available networks. The final phase is the execution phase where actual handoff is performed. This can be implemented at different layers of the network model. Certain execution solutions exist in literature at different OSI layers. The Mobile IPv6 protocol, Hierarchical Mobile IPv6 and Intra-Domain Mobility Management Protocol (IDMP) exist as solutions at the IP layer (Chunming and Chi, 2004). At the transport layer, solutions like stream control transmission protocol (SCTP) (Ling-Jyh et al., 2004), mobile SCTP (MSCTP) and SCTP Dynamic Address Reconfiguration (DAR) extension (SCTP DAR) exist while Session Initiation Protocol (SIP) exists at the session layer.

The general idea of VHO is depicted in Figure 1. The integration of the various networks is either achieved through a loosely or tightly coupled architecture. In a loosely coupled architecture, the various heterogeneous networks are separately linked by an internetworking unit (ITU) that acts as a gateway between the networks (Ma et al., 2004).

In a tightly coupled architecture, networks are linked at different possible infrastructural points by incorporating the WLAN gateway into the UMTS network architecture so as to mimic the protocol stack of the 3G network and make WLAN network appear as another 3G network (Buddhikot et al., 2003). In a bid to standardize the VHO implementation, the 802.21 working group was formed with a charter to enhance users' experience by supporting VHO between heterogeneous networks (Stevens-Navarro and Wong, 2006). There are still several challenging issues on VHO support. These challenges majorly lie at the decision stage where multiple metrics must be used in decision making. Combining many metrics in a single decision process throws serious challenges. On-going research efforts are therefore geared towards finding solutions to these challenges.

RELATED WORKS

In this section, we sampled certain works in literature in the decision phase of VHO and examined what their algorithms were tested for and what number and type of metrics were employed. With this, we exposed how very few works have considered the effect of their algorithms on handoff stability. Pramod and Saxena (2008) proposed a decision algorithm which they called dynamic decision model. The 'Dynamic Decision Model' for VHO, adopts a three phase approach comprising Priority phase, Normal phase and Decision phase. The 'Priority phase' discovers all available networks, filters out ineligible networks based on Received Signal Strength (RSS) and velocity of the mobile and then assigns priorities to all eligible candidate networks using the difference between RSS and its threshold value, RSST. The network with the highest difference is assigned the priority. The 'Normal phase' records the system information and user preferences for offered bandwidth, power consumption, and network usage in terms of respective weight factors wb, wp, and wc where the higher the preference, the higher the value of weight factor. It then calculates a cost function for each candidate network. Finally, the 'Decision phase' calculates a Score function, by multiplying the priority from priority phase and cost function from normal phase, for each candidate network. It then selects a network having the highest value of score function as "Best" network to handoff to and all current transmissions are transferred to the selected network if it is different from the current network.

We observed that this decision model is quite simple and "seemingly" easy to deploy. However, the authors claim that it is dynamic because it considers the RSS and the velocity of the mobile terminal. It should be noted here that most decision algorithms do consider RSS and can also be considered to be dynamic to an extent; therefore, using RSS here does not really make it any more dynamic than others. This work also claims to consider the velocity of an MT in handoff decision; it however did not tells us how it intends to measure this metric. Furthermore, the authors compared their results against a standard decision model (SDM). They claim that SDMs' do not use RSS and Velocity in making decisions. It is however, not clear how the authors determined that SDMs do not use RSS and Velocity in making decisions, because so many techniques exists that do not use the velocity in particular as in SuKyoung et al. (2008), Stevens-Navarro and Wong, (2006) and Chuanxiong et al. (2004). No reference was made to any standard decision model in literature. It is necessary to know how a standard decision model was developed and what metrics are supported by it. The authors tested their algorithm for the number of handoffs performed against the selected weighted factors. They examined the handoff stability of their model as the user modifies the weighted factors. However, it remains unclear what the SDM technique actually meant.

In SuKyoung et al. (2008), the authors tried to highlight the metrics best suited for the VHO decision phase. They proposed a generalized VHO algorithm that optimizes a cost function. The cost function included the battery lifetime of an MT and the load balancing between access points and base stations. They further proposed an enhanced algorithm for the case when adhoc mode mobile nodes are included in the heterogeneous networks. They claim that the proposed algorithm performs much better than the conventional optimization based Strongest Signal First (SSF) method which is based on RSS alone. Metrics considered are; bandwidth (that is, data rate), financial cost, available battery power, power consumption of NIC and received signal strength (RSS). The authors in their conclusion drew attention to the fact that new metrics for handoff continue to emerge and the addition of new metrics to already measureable existing ones in literature makes the VHO decision process increasingly more complex. This further contributes to the challenges faced in the implementation of VHO. The authors mentioned certain metrics such as, "network latency, congestion, battery power and service type" that could be considered in future algorithms. It is then obvious that no algorithm could be said to be absolutely robust until every single minute metric for VHO has been considered. Metrics used in this paper were both dynamic and static in nature making the algorithm relatively good except for the high computational overhead involved in the cost function and load balancing process. The authors provided results on the effect of their algorithm on the average remaining battery life time, distributions of load across attachment points and the load status at APs and BS.

Stevens-Navarro and Wong (2006) presented a platform for the analysis and comparison of the four most

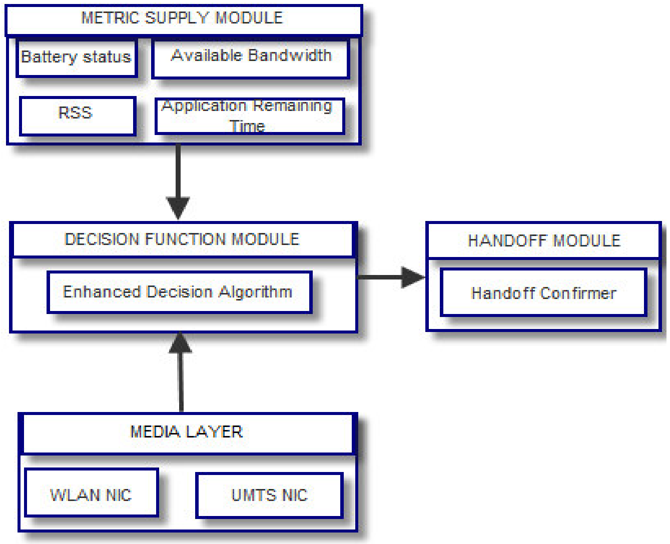

Figure 2. Block diagram of the EDA design.

prominent decision algorithms in literature, that is, Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Multiplicative Exponent Weighting (MEW) and the Grey Relational Analysis (GRA). Due to the ability of all algorithms to accept different attributes, the authors selected parameters such as bandwidth, delay, jitter, and Bit error rate (BER) to conduct their comparisons. The results showed that MEW, SAW and TOPSIS provide similar performance to all four traffic classes while GRA provides a slightly higher bandwidth and lower delay for interactive and background traffic classes. This work is a commendable effort owing to the absence of standard performance comparison platforms in literature but we identified the inability to determine the handoff stability effect of these algorithms. The authors showed that different algorithms can be simulated, analyzed and their performances compared. It will be beneficial if further studies of this nature are carried out to accommodate for more decision making parameters.

Ezil and Srivatsa (2008) used a cross layer approach to decision making and employed the following metrics: Connection status, RSS, speed of mobile terminal and Quality of Service (QoS) requirement of certain applications. They estimated their work against the offered throughput and handoff delay experienced by each application. Chuanxiong et al. (2004) employed available bandwidth and delay as decision metrics in their work and measured its performance against throughput and unnecessary handoff rate experienced during handoff. Wei and Qing-An (2006) considered traffic load, RSS and variation of RSS. They made use of a cost function that normalized these metrics to enable comparison. The normalized RSS value in their cost function was only added to traffic load. This indicated the inability of their cost function to include other metrics like power consumption, financial cost as obtained in other popular cost functions. Their results were measured against the average blocking probability the algorithm offered. The popular work of Wang et al. (1999) also employed the use of a cost function that involved offered bandwidth, power consumption of Network Interface Cards and financial cost. Their work was evaluated with respect to the handoff latency experienced. It is essential to mention that all algorithms that employ cost functions require manual inputs by the user especially for each weight factor. This can become a bottle neck for both experienced and inexperienced users and result in poor handoff in the event of any input mistake. It is necessary that algorithms should be more independent and require less interaction with the user.

Having examined these techniques in literature, we have been able to identify that very few algorithms were tested to analyse their handoff stability effect on a VHO system except for a few in Pramod and Saxena (2008) and Chuanxiong et al. (2004). Also, we determined the number and types of metrics used by these algorithms and revealed that though an average number were used in most works, some metrics might not be easily measurable. We therefore introduce EDA, an algorithm that employs four different metrics namely: Available bandwidth, battery power status, RSS and the application remaining time (ART). The number of metrics used by EDA is relatively adequate and above all, they are readily measurable. EDA is a unique VHO algorithm as it introduces a new metric ART and employs it in a unique way to make handoff decisions. The results reveal EDA's improved handoff stability effect as compared to BAT.

ENHANCED DECISION ALGORITHM

This section presents the design of EDA. Our design employs a cross layer approach where information representing each metric is obtained from different layers of the OSI model. The MT consists of the Metric Supply Module, Physical Layer Module and the Decision Function Module implemented just above the link layer to serve as a switch between the different link layer models. The design model is as shown in Figure 2.

The decision algorithm employed in the Decision Function Module is as shown in Figure 3.

The physical layer module describes the existence of the two NICs belonging to both the Wireless Local Area Network (WLAN) and Universal Mobile Telecommunication Service (UMTS) network. The NICs are configured to continuously scan for the presence of available networks. This scanning technique was chosen in preference to the periodic activation method (PAM) that activates NICs only when needed because the continuously-on technique assures high sensing reliability than PAM. On the other hand, it might perform poorer in power management scenarios than PAM. The RSS measured for any WLAN network is weighed against a

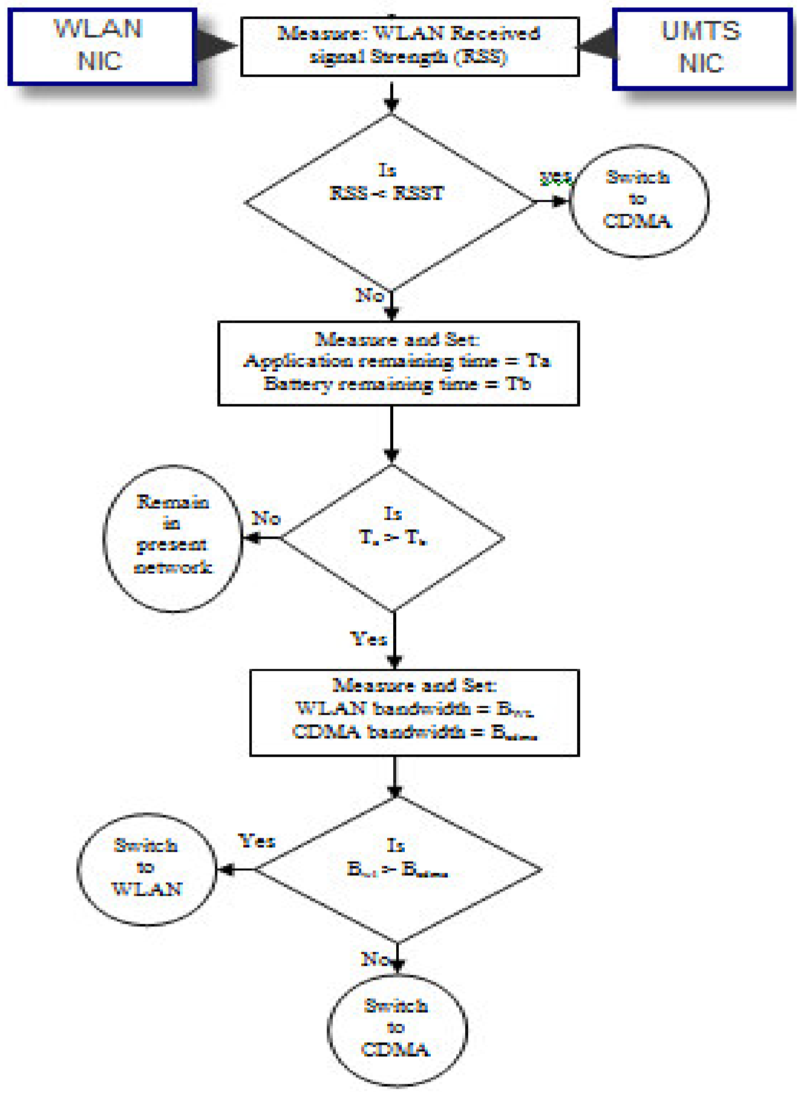

Figure 3. Enhanced decision algorithm.

predefined threshold value. In the absence of WLAN signals, the algorithm employs the ubiquitous coverage of the UMTS network. If the measured RSS is greater than the threshold value, the algorithm switches to the WLAN. The above sequence endeavours to keep the MT always connected while in motion. The algorithm initiates in the WLAN network following the argument that the available bandwidth on the WLAN is 'always' better than the UMTS. Many works in literature have held strongly to this notion and tailored their designs along this argument. In contrast, our design constantly measures the available WLAN and UMTS bandwidth. This is necessary because available bandwidth varies with load on the network. It therefore, could happen that UMTS may have larger available bandwidth than WLAN at some points in time due to traffic load on WLAN. The algorithm also begins to measure the battery power status with regards to its remaining time and the ART. Whenever the ART becomes greater than the battery remaining time, it signals for handoff to the network with better available bandwidth. This novel technique in making decision to handoff comes with an inherent advantage. It ensures better load balancing across the networks. Other designs in literature that use BAT algorithms simply indicate handoff to network with better bandwidth, but our work further argues that handoff due to available bandwidth should only be done if there is an ultimate constraint by the MT's battery. Any other reason for handoff is made available to the user through a manual command prompt. This keeps the supposed better bandwidth network available for another user who is constrained by impending battery expiration to finish his/her work before battery time is out. EDA requires little or no input from the user thereby avoiding the possibility of errors or the need to be only employed by experienced users. We made use of available and measurable metrics making the design

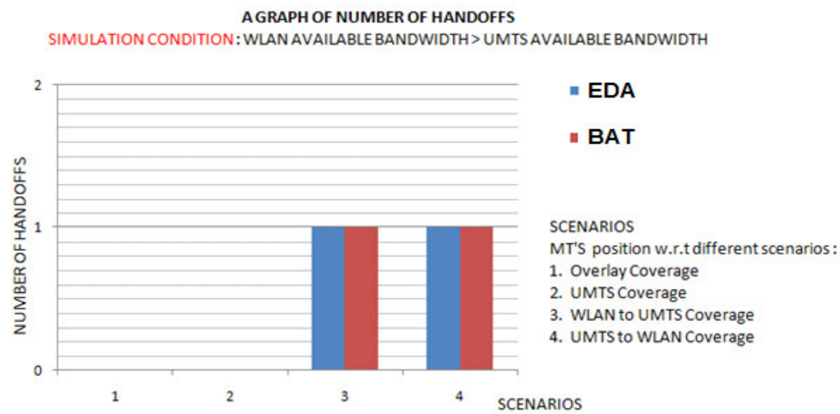

Figure 4. Number of Handoff when WLAN bandwidth is constantly greater than UMTS bandwidth.

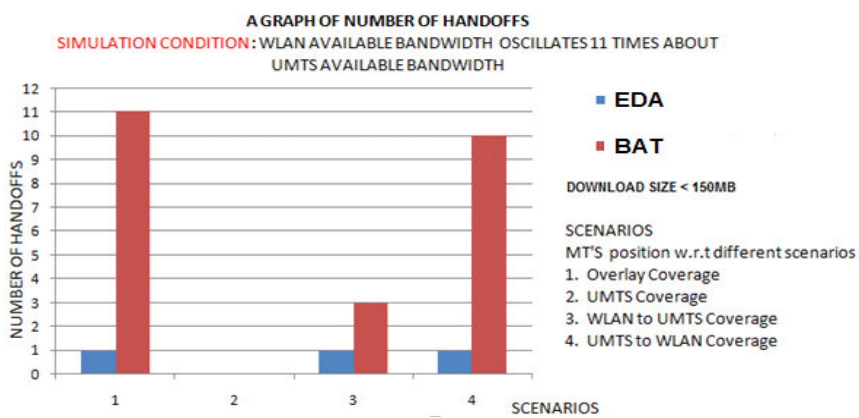

Figure 5. Number of handoff when download size is greater than 150MB and availble WLAN bandwidth fluactuates rapidly.

simple, logical and adaptable to existing infrastructure.

PERFORMANCE EVALUATION AND RESULTS

For performance evaluation, simulations were run with the OPNET modeller version 14. VHO simulation was run between WLAN and UMTS networks. The results compare EDA with BAT algorithms. We measured their performances with respect to their handoff stability effect. This gives an indication about the ability of a decision algorithm to ensure a stable VHO system while avoiding unnecessary handoffs (ping-pong effect). The results in Figures 4, 5 and 6, show that EDA performed less number of handoffs in different mobility scenarios as compared to BAT. In Figure 4, EDA and BAT were tested in four different scenarios represented by the values on the x-axis. Scenario 1 represents MT within overlay coverage of both WLAN and UMTS signal. Scenario 2 represents MT in UMTS coverage alone. Scenario 3 describes the movement of MT from WLAN to UMTS coverage while scenario 4 simulates movement of MT from UMTS to WLAN coverage. In scenario 1 of Figure 4, it was observed that both EDA and BAT performed no handoff. This is as a result of the constant better available bandwidth of WLAN over the UMTS. In scenarios 3 and 4 of Figure 4, it was observed that EDA and BAT perform same number of handoffs for same reasons just mentioned. In Figure 5, we simulated both techniques in different scenarios where the available bandwidth of WLAN oscillates about the UMTS value and the MT performing a download from the Internet for a file size greater than 150MB. We observe that in these conditions and scenarios, EDA performed less handoff as compared to BAT in all possible four scenarios. This is because EDA does not base handoff decision only on available bandwidth. However, BAT by design, makes handoff decision only on available bandwidth. Therefore, in situation where available bandwidth fluctuates, this algorithm will have to make several handoffs resulting in system instability. This indicates better system stability with EDA than BAT. This

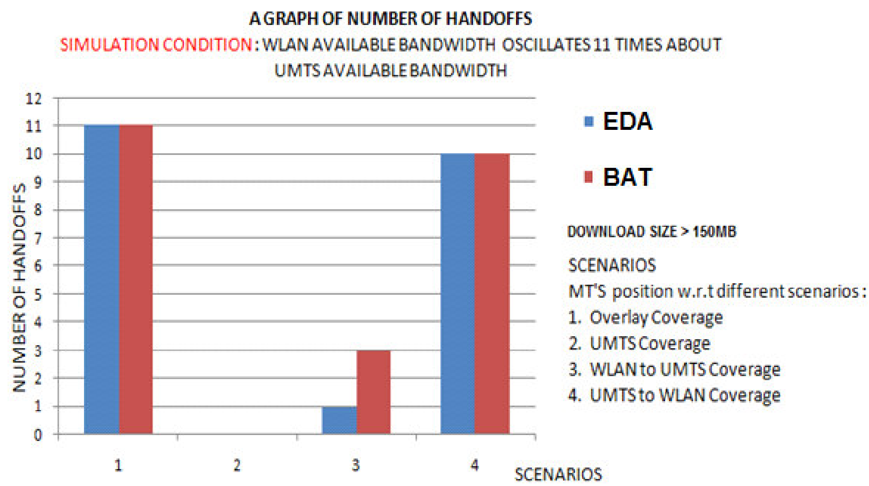

Figure 6. Number of handoff when download size is less than 150MB.

is obviously as a result of the four different metrics employed by EDA and the technique used to make handoff decisions. Finally, in Figure 6, the MT was set to make a download of less than 150MB. EDA and BAT performed same number of handoffs except in scenario 3 where EDA made less number of handoffs because VHO system was not constrained by the battery power. Once again, EDA performs better than BAT. It can be noticed in scenario 2 of all figures that no handoffs were performed by either algorithm. This is as a result of the presence of only UMTS signal for connection.

We have been able to show how EDA was thoroughly tested in four different mobility scenarios as obtainable in real life and revealed its better handoff stability than BAT algorithms. We can therefore, say that alongside other interesting features of EDA as reported in Onumanyi and Onwuka (2009), EDA still improves on the handoff stability of a VHO system than BAT algorithms.

CONCLUSION

VHO is an essential component of the next generation networks. Efficient VHO algorithms can greatly enhance system capacity and improve service quality cost effectively. In this paper, we examined certain works in literature focusing on the decision phase of VHO. We revealed the number and types of metrics used by these algorithms and showed how very few measured the handoff stability effect of their algorithms. We then introduced EDA by summarizing its design features. In Section V, we described the handoff stability tests that EDA was subjected to and compared the results with that of BAT algorithms. We showed that EDA either performed same number of handoffs as BAT or less in certain mobility scenarios. This indicates that EDA provides a better handoff system stability than BAT algorithms. The future of the wireless communication world tends towards the ability of users to roam amongst today's available networks with a single terminal rather than the designing of a new single network. VHO remains an essential function in the future wireless communication and a stable decision phase will definitely be responsible for the performance of the whole process.

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