A Survey on the Energy Efficiency of Vertical Handover Mechanisms

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Abstract. Recently, there is a growing demand for accessing information anywhere and any time due to the proliferation of wireless mobile devices. According to the availability of different overlapping wireless technologies such as 3G and WLAN, handover process between these wireless technologies is also available. Additionally, due of battery problems of mobile devices, energy efficiency is important and one of the hot subtopics of vertical handover process. There are several aspects for the energy efficient vertical handover process, such as battery level of mobile device, selection of the best wireless network technology among candidates, management of network interface cards of mobile device [1], deployment of proposed solutions within current infrastructure and media independent handover. In this paper, we review and evaluate energy efficient vertical handover algorithms proposed in the literature.

Keywords: Vertical handover, energy efficiency, battery, power consumption.

1 Introduction

In the last decade, demand for access to information anywhere and any time has been growing with the proliferation of mobile devices and availability of different wireless technologies. Therefore, connecting to a network is possible in different environments such as indoor and outdoor with wireless network technologies while mobile user is on the move. Vertical handover (VHO) is a technique that allows mobile user to stay connected to the Internet by switching to a different wireless network when it is necessary. In handoff process, mobile user is detached from one wireless network or access point (AP) and attached to another without connection loss. Overlap of these wireless technologies necessitates handover to provide better quality of service (QoS) and to satisfy user demands or application requirements. Although currently 3rd generation of mobile telecommunications technology (3G) and wireless local area network (WLAN) technologies are dominant, there are other wireless technologies such as UMTS (Universal Mobile Telecommunication System). Each of which has different advantages and disadvantages. Thus, VHO between these interfaces may be advantageous depending on the circumstances.

Connection can be transferred by horizontal or vertical handover methods as shown in Figure 1. In particular, horizontal handover process is executed for

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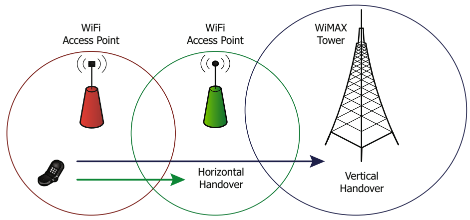

Fig. 1. Illustration of vertical handover types

transferring connection within the same wireless technology, such as WLAN to WLAN. In contrast, VHO process is done with two different wireless technologies such as WLAN and UMTS. It is also possible to make VHO between more than two different wireless technologies, if they are supported by the mobile device [10].

Vertical handover process has three main parts. In the first part, information collection process is handled for providing parameters to the next step. In the next step which is decision making, candidate wireless networks are evaluated according to selected metrics in order to choose the best one among them. Decision algorithms must be fast and energy efficient. Finally, seamless handover needs to be executed for sustaining communication between communicating nodes.

Making vertical handover is more complex than horizontal handover because of heterogeneous environment. Different wireless technologies are built on different infrastructures. While it is easy to make changes in some of them, modifying hardware or reimplementing software in others may be too costly in terms of performance, implementation (both for software and hardware) or affordability. The primary goal for making vertical handover is to sustain communication, in other words, to improve user satisfaction by providing service continuity. Each wireless technology has its own advantages and provides QoS at different levels. For example, Wi-Fi may provide more bandwidth with small coverage area with low mobility. In contrast to WLAN, 3G may cover wide area with high mobility and may provide lower bandwidth [7]. Nowadays, one of the major issues of mobile terminals is battery lifetime. It is possible to replace batteries with additional backup battery. Although it seems to be a very good feature, it may be costly and impractical in daily life. Therefore, methods that consume less energy and take battery level into consideration while making handover must be investigated.

The rest of the paper is organized as follows: In Section II, we outline the challenges in designing vertical handover by considering energy consumption. In Section III, we briefly discuss about decision making step by listing design challenges. We also make a comparison of the investigated proposals in Section IV and provide future directions for researchers with regard to open issues that have not yet been addressed. Finally, we conclude the survey in Section V. To the best of our knowledge, this is the first survey in the literature about energy efficient mechanisms in vertical handover.

2 Overview and Issues of Vertical Handover Mechanism

In this section, evaluation criteria for energy efficient vertical handover are briefly explained for all steps of vertical handover process, which are information gathering, network selection (also named as decision making) and seamless handover.

2.1 Information Gathering

First step in VHO process is information gathering. This step is important because success of the following steps depends on this stage. Parameters can be collected by mobile user, which may not be energy efficient because candidate network parameters must be collected periodically or taken from a network element. Mixture of these two methods is also possible [7], [20]. There are many metrics such as received signal strength (RSS), distance, speed of mobile user, packet loss ratio, data rate, battery consumption and etc [12]. Moreover, parameters that will be selected depend on problems trying to be solved in studies such as data charging (or cost) [4]. For example, a study that aims to make vertical handover in free data charged networks, which are free to use without paying any money must choose parameters related to data charging. For energy-efficient vertical handover methods, studies may use battery-related parameters. Subsequently, parameters that are related to power consumption of network interface cards (NIC) can be used. One of the main problems at this stage is that collected data for selected metrics can be inaccurate because of mobility in wireless environment [8], [12]. Additionally, turning on other NICs periodically for surveying candidate networks also consumes energy. To avoid this situation, some parameters can be taken from network side.

2.2 Decision Making with Design Challenges

In this step, algorithms take parameters collected in the previous step, generate a set of values for each available wireless network and then assign scores to them. According to the designed decision algorithm, the highest [2], [7], [19], [20] or the lowest [5] scored network is selected and the last stage, handover execution, is initiated. There are several design challanges in this stage. First of all, number of selected parameters may be important. Execution time of algorithms that perform complex calculations with many parameters may be longer than algorithms that take less parameters. Besides, working with many parameters may result in more energy consumption while making complex computations. NIC management and power consumption in candidate wireless networks must be measured to make better decisions. NICs consume different power when they are in transmit, idle or sleep mode [13]. Another important aspect is that selected parameters in the previous stage may not adequately represent network conditions. Therefore, accuracy of choosing the best network technology for decision algorithms may be low. Necessity to perform vertical handover is less for algorithms that make better decisions in terms of QoS and battery lifetime. If selection is not made well, mobile user tends to make more frequent handover,

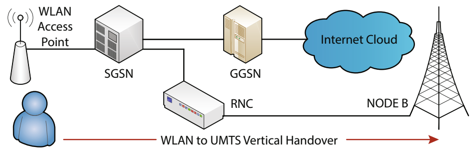

Fig. 2. Tightly coupled vertical handover network architecture

which in turn deteriorates the QoS. Because of mobile user's behaviour, moving within intersection area of networks sometimes cause ping-pong effect [6]. In ping-pong effect, mobile user makes too frequent handover between two different NICs. This situation must also be taken into account when designing a network decision algorithm. Speed of the mobile user must also be considered. High level of mobility necessitates frequent and mandatory handover. Therefore, algorithms must quickly decide which wireless technology is more suitable for the mobile user.

2.3 Execution of Handover

In the final step, mobile user tries to make a seamless handover between different wireless technologies, i.e., low delay, low packet loss and no connection loss. There are two main handover architectures: tightly-coupled and loosely coupled. Both have different advantages. In tightly coupled architectures, in order to implement the VHO mechanisms it may be necessary to modify infrastructure of a wireless technology both in hardware manner [3] and software manner [16]. This integration cost of modifying different technologies is high. Yet, speed of switching between two different wireless technologies is higher because of high level of integration. In contrast, loosely coupled architectures are easier to deploy over current architecture but migration from one network to another takes much more time. Inthis step, mobility management of mobile nodes is another issue. Mobile user has to inform server or client for new location. Otherwise, sender's packets are not received by mobile user and connection is lost. To prevent this situation, mobility can be handled in three layers of protocol stack. For application layer, mostly session initiation protocol (SIP) [9] is used and researchers make some modification on protocols if necessary. Some proposals are based on transport layer protocols such as stream control transmission protocol (SCTP) [11] with dynamic address reconfiguration (DAR). Variations of TCP and host identity protocol (HIP) [18] are also used. Finally, mobile IP (MIP) [15] is used for network layer mobility management. As in the decision making stage, speed of mobile user is also important in handover execution. Fast switching between interfaces is essential in this case. Otherwise connection will be lost.

2.4 Media Independent Handover Services (IEEE 802.21)

Assume that there are N types of different wireless technologies, each of which supports VHO with other N-1 wireless technologies. Therefore, there have to be

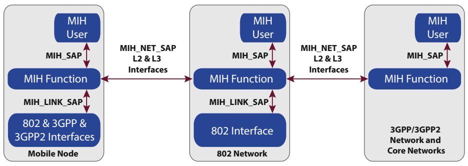

Fig. 3. Illustration of 802.21 architecture

N(N-1)/2 number of specific methods to make handover available between these technologies and scalability problem occurs. IEEE published a new standard (802.21) named Media Independent Handover Services (MIH)[14] to solve this problem in 2008. This standard allows to switching seamlessly between the IEEE 802 and non IEEE 802 technologies without session interruption [17]. Only one extension for each technology will be enough to support VHO. The standard defines exchange of information, events and commands but not actual execution method due to the support of mobility management in different layers. The word "media" indicates communication type such as cable or radio. There are several abstract elements in this standard such as MIH function (MIHF), service access points (SAPs) and MIH users (MIHU). Figure 3 illustrates MIH architecture.

MIHF resides in layer 2.5 and contains 3 entities. The media independent event service (MIES) detects changes in the link layer and reports events occured in the lower layers such as physical layer and link layer. MIHF informs MIHUs about changes. The media independent command service (MICS) is used to control lower layer by upper layers in the protocol stack or a remote entity such as MIHF of network controller. The media independent information service (MIIS) acquires information related to neighbor networks in the surrounding area. The information such as location and properties of candidate networks can be used by local or remote entity as in the MICS. Information is formed by Information Elements (IEs) and query/response mechanism is used for communication. SAPs, which define both media dependent and independent interfaces, are used to provide MIHF services to MIHUs. There are three types of SAPs. MIH_SAP stays between MIHF and MIHUs. Communication between these entities are provided by MIH_SAP. MIH_LINK_SAP stays between lower layers and MIHF. MIH_LINK_SAP interfaces are dependent to specific wireless access technologies such as 802.11x, 802.16 and 3GPP. Finally, MIH_NET_SAP is used to provide information exchange between remote MIHFs.

3 Proposed Energy Efficient VHO Mechanisms

In this section, we briefly describe proposed energy efficient decision making algorithms. Additionally, we discuss the advantages and disadvantages of solutions primarily based on the aforementioned criteria.

3.1 Speed Sensitive-Energy Aware Adaptive Fuzzy Logic Based Vertical Handoff Decision Algorithm

Authors in [2] propose an adaptive fuzzy logic based algorithm. Their algorithm simply takes 5 parameters, which are RSS, data rate (DR), monetary cost, speed of mobile, and battery level of mobile terminal. Each metric has its own membership function and map to different values. DR can change dynamically according to the application's requirements. If application is bandwidth intensive, membership values are higher. RSSI acts in the same way as DR. Fuzzier takes only 4 of these parameters except battery status and generates an output value called APCV (Access Point Candidacy Value). This value varies between 0 and 10. AP with the highest value indicates that it is the best among candidates. Battery status value is not evaluated in fuzzier but it affects handoff initialization process. SMT (Smart Mobile Terminal) calculates remaining battery value and output is given to AP selection function. Therefore, the current AP's APCV value is compared with the highest scored AP. If the difference between these two values is greater than or equal to the APCV value of the current AP, handover is initiated and new AP serves to the mobile user.

Advantages: Algorithm has the ability to change DR value based on different wireless technologies because each wireless technology provides different DR. Thus, considering provided services for each technology improves system's accuracy of decision. Moreover, speed of mobile user is also considered as a metric in decision phase. This metric also improves the accuracy of the decision. Both of these properties enable less frequent handover and improves the mobile device uptime.

Disadvantages: Handover is initiated even if the APCV of the current AP is equal to APCV of the best AP. Equality means it is not really necessary to switch between networks. Assume that after making handover, APCV of the new network is equal to APCV of old network. Therefore, another handover will be made. This situation causes redundant vertical handover. If user stays the same for a while, then ping-pong effect occurs. In addition, if battery level of SMT is above the specific threshold (40%), handoff process is triggered irrespective of whether it is necessary or not. In contrast, if battery level is below the threshold and it is not vital to make handoff, handover process is not triggered. Note that algorithm allows mobile user to make unnecessary handover when battery level is above the threshold. In spite of this situation, handover frequency will be decreased starting from the beginning in order to make battery lifetime longer. Furthermore, power consumption in candidate networks is not taken into account and there is no NIC management in this study. Finally, 802.21 standard is not used in this work.

3.2 Energy Efficient Handoff Decision Algorithms for CSH-MU Mobility Solution

Authors in [19] propose one simple decision making algorithm without considering energy consumption of the user and two different energy aware decision

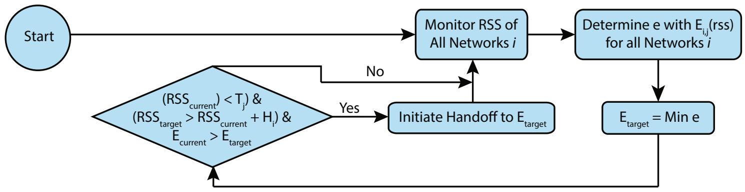

Fig. 4. E-RSS based Vertical Handover Decision Algorithm

algorithms in order to compare both of the advanced algorithms with the simple one. The two advanced algorithms are developed using the simple algorithm. The simple algorithm, Fuzzy VHDA (Vertical Handover Decision Making Algorithm), initiates handover if RSS value of the current network is lower than a certain threshold value T_i, which depends on the network type i such as GSM, and UMTS, and a value H, which prevents ping-pong effect.

Basically there are three steps. In the first step, collected parameters, in this case RSS, throughput and CPU load, are normalized before using them in algorithms. This normalization is necessary because collected data that belong to different wireless technologies such as UMTS or Wi-Fi may be noisy. In the second step, membership evaluation process is executed. Each metric is mapped to 3 fuzzy variables (low, medium and high) by using a membership function. Finally, Performance Evaluation Value (PEV) is generated for each candidate network. After these computations, the highest PEV is compared with the PEV of the current network plus PEV-H value, which ensures stable handoff decisions.

In enhanced fuzzy (E-Fuzzy) model, energy consumption metric is added to other metrics. The energy function $E_{i,j}(rss)$, where i represents the network types (i.e., UMTS or Wi-Fi) and j stands for applications, uses TCP or UDP and return an energy value e based on the RSS value. Subsequently, energy value e is also normalized based on maximum and minimum energy value e as others. Afterwards energy membership function takes energy value e as an input and generates a membership value based on predefined energy model. This model contains only Wi-Fi and UMTS wireless technologies. The rest is the same as simple VHDA. In enhanced RSS (E-RSS) model, RSS value of all networks are scanned periodically. As in E-Fuzzy, power consumption value is determined but the rest of the algorithm is different than two other fuzzy based algorithms. Network with lowest e value is set as E_{target} and if $RSS_{current} < T_i$, $RSS_{target} > RSS_{current} + H_i$ and $E_{target} < E_{current}$, then handoff is initiated.

Advantages: Network selection is made by provisioning energy consumption in the target networks. Since client side‘s power consumption in candidate networks is taken into account while making decision, system’s energy function is designed well. Energy model is pre-installed to mobile device and mobile device has all the necessary parameters. Therefore, this proposed method can be applied to mobile devices directly without using additional hardware for measurements. Besides, no modification is necessary to deploy system on the current infrastructure by modifying the protocol stack. Finally, ping-pong effect is avoided by adding H_i to the currently connected network.

Disadvantages: Energy functions of proposed methods support only two transport layer protocols, mostly TCP and UDP. In the near future, there may be other transport layer protocols such as Stream Control Transport Protocol (SCTP) to support vertical handover. Therefore, in terms of generality, the fact that only TCP and UDP are supported is disadvantageous. Moreover, network selection is made between UMTS and Wi-Fi wireless technologies and vice versa. There are other emerging wireless technologies like 4G. Although energy model can be extended to support emerging technologies, further investigation has to be made. Either speed of mobile user is not considered as a parameter or no precautionary action is taken to support this case. Furthermore, NIC cards are turned on periodically to discover candidate wireless technologies. This method causes mobile device to consume more power while trying to save energy. Finally, MIH standard is not used in this work.

3.3 Energy Savings for Wireless Terminals through Smart Vertical Handover

Authors in [5] propose an optimized handover decision between WLAN and WiMAX (Worldwide Interoperability for Microwave Access) technologies. In this work, two energy models are generated for each wireless technology. It is assumed that networks are optimized in terms of power consumption and data rate. Consequently, minimum power is consumed for desired data rate. The proposed algorithm decides when to perform VHO and do network scanning by taking channel coherence time into account. The term "coherence time" is a duration that communication channel is expected to last.

Due to the trade off between coherence time and channel scanning period there are two situations. In the first situation, channel coherence time can be greater than scanning period. Whenever a scanning is performed at predetermined frequency, E_{total}, which is expected energy consumption for transmitting a given amount of data, is computed for all available networks as well as currently connected network by taking handover cost, which is the energy consumption when moving to other NIC and retransmission cost caused by handover. The algorithm takes application rate, potential number of packets remaining in the queue and available throughput into account. If power consumption in a different network is less than current network, handover is initiated. When the scanning period is greater than coherence time, decision may not be valid although there is a chance that communication channel remains stable. As in the previous situation, power consumption of networks are calculated based on channel coherence time (E_{Step1}). Then, as a second part, power consumption during uncorrelated state is computed based on average power consumption (E_{Step2}). These two values are passed to decision algorithm.

Advantages: The algorithm considers almost all future costs like expected energy consumption for a network to send data and the cost of moving to another network including handover cost. Therefore, more accurate decisions are made at the expense of increasing system complexity. Besides, algorithm prevents ping-pong effect by considering T_{Switch}, which is time of switching from current

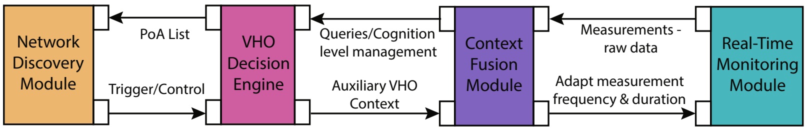

Fig. 5. Illustration of proposed framework

network to the other network where data is not transmitted and $E_{Handover}$, which is the cost of handover.

Disadvantages: Due to considering all situations, there are many calculations. Power consumption may increase when there are many available networks in the surrounding area although these calculations are simple. Furthermore, the system works for only WLAN and WiMAX wireless technologies. However, there are many other available technologies in use such as 3G and 4G. Moreover, network scaninning by activating other NICs for network discovery will consume more power while trying to save energy. Besides, speed of mobile user is not taken into account. Finally, 802.21 standard is not used in this work.

3.4 A Context-Aware Vertical Handover Framework towards Energy-Efficiency

Authors in [20] propose an integrated framework on mobile device. The framework contains 3 helper modules and a main module residing in the device as shown in Figure 5.

The first module, Real-Time Monitoring Module (RTMM), monitors and collects necessary energy related data which are related to mobile device and information about the AP. For the mobile device, some of the collected data are QoS class, jitter, delay tolerance, rate, quality of experience (QoE), energy consumption, power consumption and the remaining life time. Signal interference to noise ratio (SINR), RF level, capacity, load, location and a few additional parameters are taken into account for each AP. To provide this capability, cross-layer mechanism where physical and network layers are used is applied.

The second module, called Context Fusion Module (CFM), uses pre-collected values and derives a context that contains energy consumption values per interface of the mobile device, energy profile of point of attachment (PoA) for different service types, delay, throughput and energy overhead observed in previous handover execution procedures. The main module, called vertical handover decision engine (VDE), can be enabled for auto adjustment of context-awareness. Therefore, number of parameters to be collected dynamically changes. VDE also takes network dynamics, network operation environment such as rural, urban or suburban as well as battery level and QoS requirements into consideration.

The third auxiliary module, called Network Discovery Module (NDM), provides a list of available PoAs to VDE. This list can be obtained by two ways. It can be sensed by a mobile terminal as the first option or it may be incorporated with Access Network Discovery and Selection Function (ANDSF) module in LTE architecture. If battery level drops under a specific rate or SINR value decreases under a specific ratio, handover process is initiated. It is stated that these thresholds can be set dynamically by machine learning methods and it is unclear whether these methods are implemented.

The main module VDE make use of both the NDM and CFM module because it uses context offered by these two auxiliary modules. VDE has two functions. The first function is management of network discovery. VDE manages network discovery by triggering NDM if high battery drain rate is reached, signal strength decreases under a threshold or QoS deterioration occurs in the currently connected network. The second function of VDE is the evaluation of the candidate PoAs with the context gathered from CFM including the currently connected network characteristics such as energy profile, QoS characteristics, service residual time and serving PoA characteristics sucah as channel state, distance, energy consumption per interface state, VHO delay, and overheads. User preferences such as security and data charging policy are also evaluated. For making decision, first, VDE evaluates each PoA alternative and decides if it supports QoS requirements. After that, energy consumption of the candidate PoA is evaluated by considering service residual utilization time, energy profile and the expected energy consumption of the interface. Finally, penalties introduced by VHO are taken into account in the final decision. If all these three conditions are satisfied, candidate PoA is added to a list. After processing all candidates in NDM list, VDE picks the most energy-efficient PoA within the list. After all these operations, VDE configures the cognition level of CFM for the next VHO in order to adjust duration and frequecy of real-time monitoring.

Advantages: Proposed context-aware framework adaptively selects and evaluates network parameters by respectively modifying RTMM and CFM in order to make accurate decisions. Ping-Pong effect is prevented by considering QoS deterioration. Moreover, VHO overheads (swithing NICs and signalling cost) are also evaluated by the proposed framework.

Disadvantages: Monitoring many real-time raw-data may introduce energy consumption although it provides better decisions and some parameters are gathered from APs. Working with many parameters also may take time to make a decision. Furthermore, it may increase energy consumption of the mobile device because some machine learning (ML) methods, which makes many complex computations are used. Media independent handover standard is not used and speed of the mobile user problem is not addressed in the proposed framework.

3.5 Energy-Efficient Media Independent Handover Mechanism

3G Network interface card (NIC) consumes approximately two times more power than WLAN NIC in transmit mode. However, it consumes less power in receive and idle modes [13]. Therefore, it is better to be in 3G NIC if there is no data to send. To this end, authors in [7] propose an energy efficient handover mechanism consisting of two parts. Application classification is made in the first part, whereas handover decision is made in the second part.

Mobile devices run wide variety of applications like phone calls, video calls, emails, remote connection applications and online games. Some of them are bandwidth intensive and some them are not. Therefore, applications are divided into two categories: real-time and best effort. It is assumed that these parameters are either taken from applications or operators. Information about APs is gathered by broadcast messages called location service server (LSS). LSS messages contain AP conditions such as coverage area. This way, no communication is required with candidate APs to learn their condition by turning on other NIC of mobile device.

In handover decision model, a fuzzy logic based algorithm is used. Multiple parameters about NIC, application and device are used in the decision step. Only data rate is dynamically changed based on application requirements. Algorithm also evaluates Handover Decision (HD) value which indicates handover cost taken from AP to prevent ping-pong effect. Collected values are mapped to fuzzy variables and finally, APSV (AP Suitability Value) is calculated for each AP. APSV value can be between 0 and 100. Each APSV value is stored in a handover decision table (HDT). After all calculations are made, algorithm starts in 3G NIC and if 3G NIC satisfies requirements, a second condition check is made. Otherwise no handover is necessary. In the second control, algorithm checks if switching to the other NIC is better. If it is, then handover is initiated.

Advantages: Energy efficiency is provided in two ways. First, other NIC is not turned on to get information about candidate networks. This information is taken by periodically broadcasting LSS messages. Secondly, battery saving is achieved by switching to 3G NIC if there is no data to transmit. In this study, speed of mobile user is also considered. If mobile user‘s speed is above the threshold, which is 10km/h, algorithm automatically prefers only 3G networks. Additionally, ping-pong effect is avoided due to the usage of HD value. Finally, media independent handover services are used in this work.

Disadvantages: Proposed method is built on tightly-coupled network architecture. Therefore, cost of modifying current network infrastructure may be high. Moreover, decision algorithm always starts with 3G NIC card. In some cases, for instance, when bandwidth intensive applications are running on mobile device, the algorithm executes handover to the most suitable WLAN network. Therefore, VHO is performed everytime initially from a 3G network to a WLAN network. Besides, 3G NIC consumes power twice as WLAN NIC consumes. Finally, proposal considers only 2 network technologies which are used in common.

4 Open Issues

Table 1 gives a comparison of the vertical handover decision making algorithms investigated in Section III, which address various issues of the specific research challenges of the network selection aforementioned in Section II. Each algorithm explained is marked as either (+), indicating that the corresponding research issue is addressed or (−), indicating that the issue is not addressed.

Speed of Mobile User Problem: Proposals [2] and [7] solve this problem by considering speed of mobile user while making decision compared to the other energy efficient decision algorithms. Remaining algorithms fail when mobile user moves with high speed such as by car because they do not consider this issue.

Table 1. Comparison of energy aware decision making algorithms

ISSUES					
	N<: More than number N +: Addressed -: Not Addressed				
	Adaptive Fuzzy [1]	E-Fuzzy E-RSS [2]	Smart System [3]	Context Aware [4]	EMIH [5]
Number of Params.	5	4	3	5<	5<
Selected Params.	RSS, monetary cost, speed of mobile user, data rate, battery level	RSS, throughput, energy consumption on network, CPU load	App. rate, throughput, packets remaining in the queue	Unspecified	Unspecified
Ping-Pong Effect	-	-	-	+	+
Speed of User	+	-	-	Unspecified	+
Handover Cost	-	-	-	+	+
Supported Techs.	GSM, GPRS, Wi-Fi WiMAX, UMTS,	UMTS, Wi-Fi	WiMAX, Wi-Fi	3G, WLAN	3G, WLAN
802.21 Support	-	-	-	-	+
NIC Management	-	-	-	-	+

Ping-Pong Effect Problem: [5], [7] and [20] evaluate cost of VHO to avoid ping-pong effect in order to reduce redundant handover, therefore, energy consumption.

Energy Metric: Battery level of mobile device is taken into account only in [2] and [7] while making handover decision. Other works do not consider this.

Deployment Problem: Studies in [2], [5] and [19] are based on software solutions. No extra hardware is required to make network selection. However, in others, currently deployed infrastructure has to be modified.

Supported Technologies: Adaptive Fuzzy algorithm [2] works for almost all wireless technologies currently available today. The rest of the algorithms work for specific pairs.

Media Independent Handover Services Support: Although there is standard for media independent vertical handover, only one [7] study uses this standard. Moreover, even [7] uses 802.21 standard, it is not works for all available wireless technologies. Therefore, also this study is not fully media independent. Although there are few works that support media independent VHO, further investigation can be made to support all of the wireless technologies without turning on other NICs for network discovery. Moreover, packet loss rate (PLR) can be used for eliminating candidate networks in order to avoid retransmissions, therefore, power consumption. Since a network with more PLR will cause more retransmissions of lost packets compared to networks with less PLR. More transmission means that NIC will be used longer before switching to idle or sleep mode. Hybrid system can be used for reducing power consumption by concurrent interface usage based on running applications on mobile device. For instance, data could send by using two NICs in a short period of time in return for sending by only one NIC in a long period of time.

5 Conclusion

To put it in a nutshell, energy efficient vertical handover methods inherit vertical handover problems such as speed of mobile user or ping-pong effect and must overcome energy consumption problem by considering battery level, excepted energy consumption, NIC management or by making better decisions to prevent making redundant vertical handovers. Major issues are to make better decisions by considering less parameters with less power consumption in calculations, to consider the speed of mobile user, to prevent ping-pong effect in order to reduce unnecessary handover execution and managing NICs. Currently, there is only one study [7] that satisfies these criteria in the literature. Therefore, decision algorithms that propose solutions to given problems are crucial to realize energy efficient decision making for vertical handover.

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