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A Survey of Intersystem Handover Algorithms in Heterogeneous Wireless Networks

[1]Topside E. Mathonsi, [2]Okuthe P. Kogeda and [3]Thomas O. Olwal
[1]Department of Information Technology (Communication Networks),
[2]Department of Computer Science,
[3]Department of Electrical Engineering, Tshwane University of Technology,
Private Bag X680, 0001 Pretoria, South Africa

Abstract: This study surveys the literature in the field of intersystem handover algorithms as applied in Heterogeneous Wireless Networks (HWNs) over the previous years. Intersystem handover algorithms have been comprehensively studied and applied in HWNs, however, this is the first attempt to put in viewpoint the numerous efforts in form of a survey. In order to provide an inclusive survey of the existing literature. We examine current state of the art intersystem handover algorithms according to their common methodology applied in order to reduce intersystem handover delay while reducing packet loss during the handover process between RATs in HWNs. Additionally, we present a clear understanding of this active research area, by identifying a clear classification and guidelines used when intersystem handover algorithms are designed. Furthermore, we outline strength and weakness of existing solutions and highlight the key open research areas for further development. This comprehensive survey act as a basis starting point and a guide for everyone enthusiastic to explore into research on intersystem handover algorithms in HWNs. Finally, the study presents the conclusion.

Key words: Handover delay, heterogeneous wireless networks, intersystem/inter-radio access technology handover, intersystem handover delay, radio access technologies, packet loss

INTRODUCTION

One of the foremost challenges in Heterogeneous Wireless Networks (HWNs) is to uphold network connectivity when a mobile node switches between two different access networks such as Wireless Local Area Network (WLAN), Code Division Multiple Access (CDMA), Global System for Mobile Communication (GSM), High Speed Downlink/Uplink Packet Access (HSDPA/HSUPA), General Packet Radio Services (GPRS), Bluetooth-based Personal Area Network (PAN), IEEE 802.11 Wireless Local Area Network (WLAN), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX), Vehicular Ad-hoc Network (VANET), Universal Mobile Telecommunications System (UMTS), Satellite networks, Long Term Evolution/4th Generation (LTE/4G) network and 5th Generation (5G) network (Bernaschi *et al*., 2007; Wang *et al*., 2008; Nandanwar and Sahare, 2015; Saadi *et al*., 2016; Niyato *et al*., 2014; Mathonsi and Kogeda, 2016; Mathonsi, 2015; Thiripurasundari and Sumathy, 2016; Ali *et al*., 2016). These cellular networks often have overlapping coverage in the same service areas and can offer uninterrupted services based on user demands. The ultimate goal of HWNs is to provide continuous accesses to any type of the desired service at any time, independent of devices, locations and available network type (Nandanwar and Sahare, 2015; Saadi *et al*., 2016; Niyato *et al*., 2014; Lampropoulos *et al*., 2008; Eastwood *et al*., 2008; Rajule and Ambudkar, 2015; Mathonsi and Kogeda, 2016; Mathonsi, 2015; Thiripurasundari and Sumathy, 2016; Ali *et al*., 2016). Users are allowed to switch between different Radio Access Technologies (RATs) in HWNs through the intersystem handover process that takes place (Khan, 2013; Li *et al*., 2014;Mathonsi and Kogeda, 2016; Mathonsi, 2015; Thiripurasundari and Sumathy, 2016; Ali *et al*., 2016). Intersystem handover procedure is the migration of a mobile node from one access network to another.

However, supporting intersystem handover comes with the challenges of delay, total blackout, loss of signal, service degradation, handover decision making, inappropriate handover triggering and mobility management, etc. (Rajule and Ambudkar, 2015; Demydov *et al*., 2015; Mathonsi and Kogeda, 2016; Mathonsi, 2015; Thiripurasundari and Sumathy, 2016;

Corresponding Author: Topside E. Mathonsi, Department of Information Technology (Communication Networks), Tshwane University of Technology, Private Bag X680, 0001 Pretoria, South Africa

Ali *et al*., 2016). As a result, long intersystem handover delay and packet loss occur during the handover process in HWNs mainly because existing intersystem handover algorithm, vertical algorithm and horizontal algorithm separates parameters of authentication, authorization and handover procedures but running one procedure in each case and each operational cycle. Moreover, we have multiple authentication, authorization and handover procedures between RATs in HWNs during intersystem handover process. Therefore, as a result, achieving service continuity remains unsolved (Rajule and Ambudkar, 2015; Khan, 2013; Li and Xie, 2013; Polgar *et al*., 2015; Kim *et al*., 2014; Jin and Choi, 2014; Mathonsi and Kogeda, 2016; Mathonsi, 2015; Thiripurasundari and Sumathy, 2016; Ali *et al*., 2016).

As a result, a new/enhanced algorithm that reduces long intersystem handover delay and packet losses that are currently experienced with the classical/conventional solutions is needed. Hence, it is really significant to ensure that mobile nodes can function in an optimized manner without experiencing unreasonable intersystem handover delay and packet loss during the handover process in HWNs. Mainly, by providing seamless mobility and service continuousness, i.e., minimum service disruption during the handover process is vital to mobile node users. A survey on issues addressed in this study has not been published elsewhere to authors best knowledge.

MATERIALS AND METHODS

Typical architecture of the heterogeneous wireless networks: Endlessly growing development of cutting-edge communication technologies and user demands for the better service is the driving force for the evolution of Heterogeneous Wireless Network (HWN). A HWN is a wireless network type which consists of network devices using different underlying Radio Access Technology (RAT) (Abdoulaziz *et al*., 2012). HWN is typically made-up of base stations with varying power capacity, coverage areas, transmission solutions and numerous architectures. The purpose of developing HWNs is to improve user experience, reducing bottlenecks in RATs and core network (Chandavarkar and Reddy, 2012). Access technologies that make-up a HWNs includes: WLAN, WiMAX, GPRS, UMTS, HSPA, LTE/4G, etc., (Fig. 1) (Nandanwar and Sahare, 2015; Saadi *et al*., 2016; Kaleem, 2012; Sun *et al*., 2011).

HWNs typically have four main categories of BS/cells branded based on their operational range which includes microcells, macrocells, femtocells and picocells. A microcell is used in a mobile network with a covering

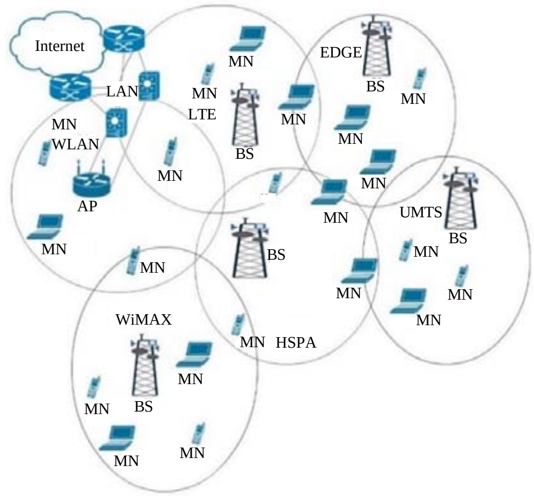

Fig. 1: Heterogeneous wireless networks architecture

range of fewer than 2 km wide provided by low power cellular base station (tower). Due to its covering range, this technology is usually used in limited areas such as a mall, a hotel or a transportation hub. Macrocell provides radio coverage served by a high-power cellular base station (tower) in a mobile network with varying distances depending on the frequency used. Macrocell provides the largest area of coverage within a mobile network, mainly because the antennas can be mounted on ground-based masts or rooftops where they can be less obstructed by terrains or buildings. A femtocell is a small, low-power cellular base station, classically intended for use in a home or small business wireless network. While picocells uses low-power cellular base station (tower) to provide mobile network reception indoors (Sun *et al*., 2011; Raoof *et al*., 2009).

The coverage areas of different access technologies that forms HWNs often overlap which provides more possibilities of handover between RATs in HWNs (Nandanwar and Sahare, 2015; Saadi *et al*., 2016; Roos *et al*., 2003). Handover refers to the process of transferring an active call or data session from one BS/cell in a cellular network to another or from one traffic channel in a BS/cell to another (Fig. 2) (Sindal and Tokekar, 2008). A handover process in HWNs is made up of the following 3 phases (Kaleem, 2012; Sindal and Tokekar, 2008; Akyildiz and Wang, 2002; Gupta and Rohil, 2013; Ahmed *et al*., 2014; Pink *et al*., 2013; Boussen *et al*., 2014; Khattab and Alani, 2014; Kumaran and Shaji, 2014).

Network discovery: A mobile node can discover numerous wireless networks using multiple active interfaces based on the signal strength provided by these wireless networks.

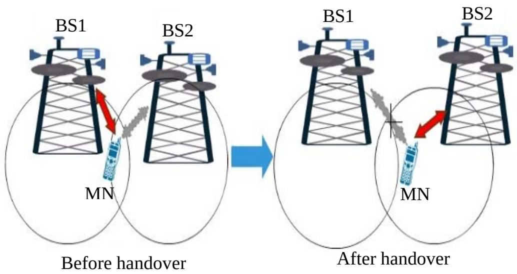

Fig. 2: Handover phases (Kaleem, 2012; Sindal and Tokekar, 2008; Akyildiz and Wang, 2002)

Handover triggering and decision: The decision regarding when to perform handover is made in this phase after the mobile node has compared the signal strength provided by other wireless networks it desires to roam to.

Handover execution: In this phase, the actual transfer of the current session from a BS/cell to the new BS/cell takes place.

Due to HWNs architecture features, there exist several intersystem handover challenges discussed in the next section.

Overview of intersystem handover challenges in heterogeneous wireless networks: Handover/handoff types have been classified based on the following criteria: network type involved, frequencies used, number of connections involved, administrative domain involved, necessity of handoff and user control allowance. Classification of handover types in HWNs are exhibited using Fig. 3 (Ahmed *et al*., 2014; Nasser *et al*., 2006).

Challenges with intersystem handover schemes: Intersystem handover schemes have different challenges as discussed below.

Intersystem/Inter-RAT handover: Is handover that occurs between different RATs in HWNs (Brunner *et al*., 2006). In intersystem/inter-RAT handover, the challenge posed lies in complexity in non-homogeneity of the processes that must be overcome before a successful handover takes place (Frei *et al*., 2011).

Intra-frequency handover: in this type of handover the mobile nodes remain on the same traffic channel as it merely moves to another cell on the same frequency (Altradt and Muhaidat, 2012). The challenge in intra-frequency handover is that the scheme can only be used in a network where the handoff is handled by same Mobile Telephone Switching Office (MTSO) (Altradt and Muhaidat, 2012).

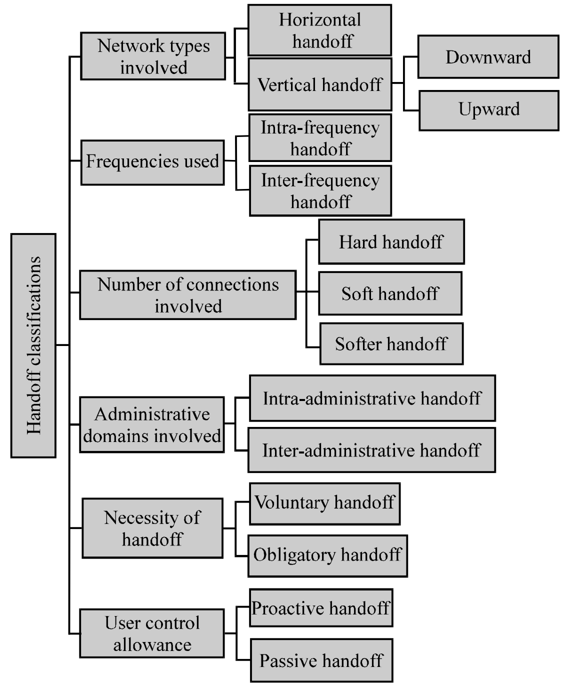

Fig. 3: Handover classification tree (Kaleem, 2012; Ahmed *et al*., 2014)

Inter-frequency handover: In this type of handover the mobile nodes moves to a different traffic channel; an operator may have multiple traffic channels in the same area in order to serve high traffic demands (Altradt and Muhaidat, 2012). However, when the mobile node moves to the traffic channel of another BS, the radio link to the old BS is eventually disconnected before a radio link to the new BS has been established to continue accessing network servers and applications (Altradt and Muhaidat, 2012; Zhao and Xie, 2012).

Horizontal handover: Occurs when a mobile node switches between different Base Stations (BSs) or Access Point (AP) of the same access network, i.e., when a mobile node changes traffic channels between BSs that support LTE (Fig. 4). However, this scheme waste network resources by providing extra lookup table before the handover process can take place (Syuhada *et al*., 2008).

Vertical handover: Occurs when a mobile node switches between different BS or cells of different wireless access networks or technologies, i.e., when a mobile node changes traffic channel from BS that support UMTS to a BS that support LTE (Fig. 4) (Syuhada *et al*., 2008). A challenge with this scheme is that there is total blackout when a mobile node when wants to move from BS to

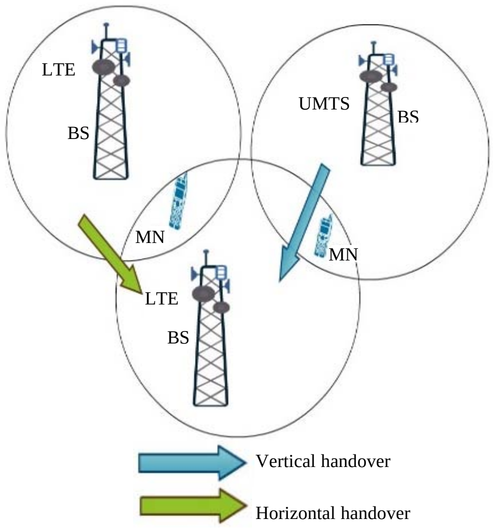

Fig. 4: Horizontal and vertical handover architecture

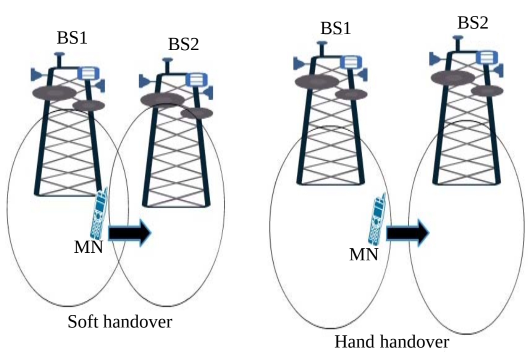

Fig. 5: Soft and hard handover architecture

another BS due to dissimilar operational parameters and characteristics of the BSs used just like in intersystem handover (Syuhada *et al*., 2008).

Soft handover: Involves multiple BSs and APs. In this type of handover a mobile node can communicate and connect with more than one access network during the handover process (Fig. 5) (Sindal and Tokekar, 2008; Mao *et al*., 2009). However, this can only happen if the frequenciesof the BSs/APs overlap between each other (Syuhada *et al*., 2008).

Hard handover: Involves only one BS or AP at a time. In this type of a handover, the mobile node must break its connection from the current access network before it can connect to a new one (Fig. 5) (Dixit *et al*., 2008). The challenge with this handover type is that the handover process starts only when mobile node has completely lost its current BS/AP signal (Syuhada *et al*., 2008).

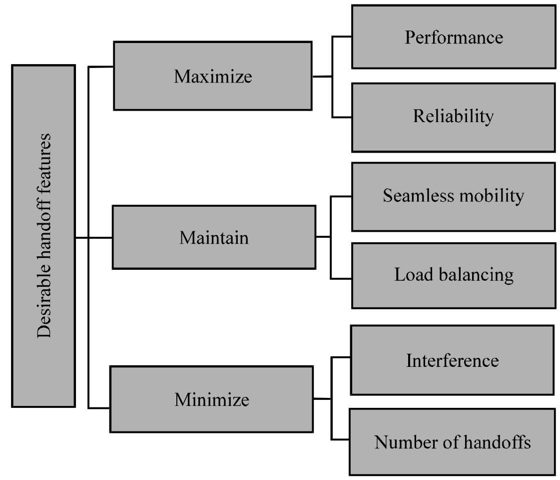

Fig. 6: Desirable handover features (Kaleem, 2012)

Passive handover: In this type of a handover a client does not have control over when handover will be executed (Chen *et al*., 2009). Mainly because, only the MTSO determines when should the handover occur.

Active handover: In this type of a handover a MTSO sends a message to the client asking if they will like to be handed over to other BS for better QoS. As a result, a client have control over when handover will be executed in this handover type (Chen *et al*., 2009).

Desirable features of handover: Numerous desirable features of handover have been categorized based on their criteria (Fig. 6) and are described underneath (Gupta and Rohil, 2013; Ahmed *et al*., 2014; Pink *et al*., 2013; Boussen *et al*., 2014; Nasser *et al*., 2006; Dias *et al*., 2012; Tamijetchelvy and Sivaradje, 2012).

Number of handovers: The number of handovers must be diminished, mainly because unnecessary number of handovers results to poor QoS in HWNs.

Reliability: A handover procedure should be reliable enough such that the mobile node will be able to uphold the obligatory QoS after handover has occurred.

Available resources: Free channels and the available resources, i.e., bandwidth must always be available at all times in the secondary network in order to make the handover process successful for a mobile node.

Speed: A handover process should be fast in order to evade service and application interruption and degradation for the mobile node (Fig. 6).

Performance metrics are used to determine the best intersystem handover algorithm that can be used in HWNs. However, these performance metrics have challenges as discussed in this segment (Kaleem, 2012; Gupta and Rohil, 2013; Ahmed *et al.*, 2014; Pink *et al.*, 2013; Boussen *et al.*, 2014; Dias *et al.*, 2012; Tamijetchelvy and Sivaradje, 2012).

Handover delay: This is the metric that is used to signify the time used between the handover initiation and completion phases. During the handover process mobile node user's desires for a smallest possible value of handover delay for real-time, delay-sensitive servers and applications.

Number of handovers: For a network to produce better QoS, unneeded handovers should be curtailed as they increase processing overheads and waste network resources, i.e., available bandwidth.

Number of handover failures: When a handover fails, the QoS of an ongoing session gets affected. A handover failure happens when a moving mobile node goes out of the coverage area of primary network or secondary network before the conclusion of the handover process or the network that a mobile node wishes to be handed over to fails to allow adequate resources for the handover process to be completed.

Intersystem handover metrics: In this study, we present intersystem handover metrics (Kaleem, 2012; Ahmed *et al.*, 2014; Pink *et al.*, 2013; Boussen *et al.*, 2014; Nasser *et al.*, 2006; Stevens-Navarro and Wong, 2006).

Handover latency: It is defined as the elapsed time that takes for a packet to be transmitted from the old access network to the new access network after a successful handover in HWNs.

Received Signal Strength (RSS): This handover metric is used to measure or compare signal strength received from different BS/cell in an HWNs before choosing a cellular network a mobile device can be handed over to. This handover metric is also used in order to avoid unnecessary handovers in HWNs.

Security: This handover metric is used for authenticating and authorizing mobile nodes during the handover process between different RATs in HWNs.

RESULTS AND DISCUSSION

State-of-the art intersystem handover algorithms in heterogeneous wireless networks: There have been many improvements in handover algorithm for fast handover in wireless networks technologies including Wi-Fi, WiMAX and cellular networking in the past years (Kim *et al.*, 2014; Zhao and Xie, 2012). Detailed solutions according to vertical handover, solutions according to horizontal handover, solutions according to joint vertical and horizontal handover are provided in this section according to their common goals or objectives or common methodology applied.

Vertical handover based solutions: A Quality of Experience (QoE) fuzzy mechanism for handover in heterogeneous mobile wireless multimedia networks was proposed by Zineb *et al.* (2016). The aim was to maximize the user's perception, optimize QoS and the usage of wireless network resources in a competitive system. Performances evaluation were carried out using Network Simulator 3 (NS-3) to setup a heterogeneous environment and a MATLAB multimedia tool to control the video quality. Their objective was to analyze the impact and benefits of the QoE handover architecture for heterogeneous mobile wireless multimedia networks 3G, 4G, WLAN and WWAN networks, compared to a system without QoE control mechanism. Obtained results showed the good performances of their QoE mechanism. In fact, it maximized the user's perception, optimized QoS and the usage of wireless network resources by controlling throughput before, during and after handover event. In addition, their QoE mechanism reduced packet loss ratio and packet delay variation parameters during the handover process. However, their QoE mechanism only allowed a mobile node to use single mobile IP address during the handover process which increased the handover delay.

A multi-criteria group decision making scheme name Multimoora was proposed by Obayiuwana and Falowo (2016) to check the mobile node speed and network traffic load before the handover process can take place. They further integrated three ranking approaches namely: ratio system, reference point system and multiplicative form. The performance of multimoora was validated by comparing it with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for various classes of degree of importance triple calls across the speed range of 0-100 km/h. The of performance of TOPSIS was seen to be unstable at high speed region, unlike multimoora. However, multimoora scheme separates the parameters of authentication, authorization and handover procedure during the handover process between WLAN, UMTS and LTE.

A vertical handover mechanism that selected a new network based on the provided QoS and the perceived QoS was proposed by Maaloul *et al.* (2016). Their algorithm was divided into two phase. In the first phase of their approach they introduced a threshold value of sensitive context criteria which had a great impact on the processing delay which was closely linked to the quality of service offered by a given network. In their second phase before switching to the chosen network there was a necessity to check the performance of the selected network in identifying the best solution. This stage specified the QoS perceived by the end users (QoE). Network Simulator 2 (NS-2) simulation results showed that their method avoids the processing delay caused by unnecessary computation over available radio access technologies which do not ensure connection performance. So with such pre-selection, they avoid multiple triggered handover decisions generating a ping pong effect caused by the inefficient network choice according to end user required transmission performance. However, they algorithm does not introduce the use of two mobile IP addresses by a mobile node during the handover process, as a result, long handover delay remained the problem with their solution.

Radial Basis Function Neural Network (RBFNN) was used for decision making process in vertical handover based on received signal strength, mobile speed and monetary cost metrics (Kunarak, 2016). In their vertical handover algorithm, they used RBFNN to reduce the number of vertical handovers and number of dropping calls. MATLAB simulation results showed that the number of vertical handovers and number of dropping calls have been reduced when RBFNN was applied during vertical handover process. However, their algorithm separates the parameters of authentication, authorization and handover procedure during the handover process.

A vertical handover algorithm that used fuzzy logic controllers to estimate the necessity of handover and to determine the user satisfaction degree based on the critical parameters such as mobile terminal speed, network load and service cost was proposed by Chinnappan and Balasubramanian (2016). In their algorithm, fuzzy analytic hierarchy process was used to calculate the weights of each attribute according to the traffic. Furthermore, it handed the uncertainty and vagueness in mapping the user preference to the priority scales, so that the consistency level of network selection can be improved. Quality of service factor was calculated for each network by processing the weighted decision matrix using principal component analysis. MATLAB simulation results showed that their scheme reduced the computational cost but also improved the consistency of network selection by reducing the number of unnecessary handovers in comparison with fuzzy logic-based approaches. While their algorithm reduced computational cost and selected the best network using fuzzy logic, however, their algorithm separates the parameters of authentication, authorization and handover procedure during the handover process.

A self-configured vertical handover algorithm which used Time-To-Trigger (TTT) to reduce the impact of fast fading on vertical handover algorithm performance and eliminates unnecessary handovers was proposed by Ranjan *et al*. (2015). Their algorithm, handover from LTE to WLAN was executed only when the Signal-to-Interference-plus-Noise Ratio (SINR) threshold criteria for handover is met consistently during the TTT/dwell timer time period. In their algorithm, handover was performed if the dwell timer the condition is true and if it continues to be true until the TTT expires. Extensive simulations in Network Simulator 3 (NS-3), showed that unnecessary handovers were reduced between LTE and WLAN interworking as per the 3rd Generation Partnership Project (3GPP) standard. However, their algorithm only uses TTT and SINR determine which RATs can be selected by a mobile node during the handover process. Their algorithm does not check RSS and RAT link quality and those parameters are very important during the handover process as they can increase the handover delay while increasing the number of packet loss.

A Prediction Vertical Handover Algorithm (PVHO) that used interruption durations, message sizes and access delays as critical metrics to make a handover decision between visible light communication and LTE was proposed by Liang *et al*. (2015). In their algorithm, a mobile terminal records both total number and total duration of the interruptions and then figured out the average interruption duration as an estimate of the next interruption interval. Total number of the performed handovers and total access delay were also recorded. The expectation of the access delays was calculated afterwards and acted as the prediction of the value of the next access delay. Analysis of the numeric results gave an indication that the performance of PVHO was superior under various circumstances. However, their algorithm can only operate over LTE technologies.

An Adaptive Neuro-Fuzzy Inference System (ANFIS) which was used for predicting the user video perception and for managed decisions that can be achieved by a specific radio configuration (e.g., data rate, handover) was proposed by Zineb *et al*. (2015). Their ANFIS model with Quality of Services/Quality of Experience (QoS/QoE) mapping was used to estimate Mean Opinion Score (MOS) values related to user's perception level by sensing network environment using learning mechanisms, to assist the cognitive radios in deciding for their operating radio configuration. They implemented their ANFIS model under MATLAB/Simulink and the simulation results showed users received better QoS. However, if the learning phase takes long to be completed, the handover delay increases during the handover process.

Mahardhika *et al*. (2015) proposed an improved vertical handover decision using multi-criteria metrics in the environment of heterogeneous network consisting of three network interfaces: WLAN, WCDMA and WiMAX. In their vertical handover decision, four metrics were considered: RSS, mobile speed, traffic class and network occupancy. They further integrated the following three parameters in their vertical handover decision algorithm: equal priority, mobile priority and network priority. MATLAB simulation results showed that equal priority multi-criteria handover algorithm improved the number of handoffs by 46.60 while mobile priority multi-criteria algorithm improved the number of handoffs by 90.41% and improved the balance index by 0.09%. Network priority multi-criteria method improved the number of handoffs by 84.60%, balance index by 18.03% and average blocking probability by 20.23%. However, the algorithm has not yet been tested in LTE network, therefore algorithm does not operate over any data link layer technologies.

A Vertical Hand Over (VHO) decision algorithm for heterogeneous network architectures which uses an open coupling to reduce handover delay was proposed by Polgar *et al*. (2015). The cellular-WLAN and WLAN VHO decision algorithm was only designed to work in 3G and 4G cellular networks. After several computer simulations were performed in complex scenarios, the simulation results showed that their cellular-WLAN and WLAN VHO decision algorithm ensures better performance compared to "classical" VHO decision algorithms. However, their cellular-Wireless Local Area Network (WLAN) and WLAN VHO decision algorithm is not versatile which means it does not operate over any RATs that can be used in HWNs.

A Seamless and Optimized Vertical Handover algorithm that uses fuzzy logic for the normalization of handover parameters. Their algorithm was modeled to calculate the Performance Evaluation Value (PEV) of the available networks and consider the type of application in progress for the handover process to take place (Rajule and Ambudkar, 2015). Then handover decision was based on the highest PEV available. The simulation results showed that their algorithm improved QoS when handover occurs between LTE and WiMAX (Rajule and Ambudkar, 2015). However, the algorithm only operates over LTE and WiMAX data-link layer technology.

Demydov *et al*. (2015) proposed an intellectual vertical handover b ased on cloud technology and fuzzy logic to reduced packet loss during the handover process in heterogeneous wireless network. Their algorithm selects the best network based on QoS parameters using the theory of fuzzy sets. In order to ensure that users are always connected to the best BS in a network (Demydov *et al*., 2015). Simulation results showed better QoS for cloud computing platform and core network for services such as video conferencing. Their algorithm only operates over cloud computing platform.

A multi-criteria based Vertical Handover Management (VHM) scheme was proposed by Khan *et al*. (2015) to solve challenges such as inappropriate handover triggering and network selection in HWNs when mobile node needs to change traffic channels in order to continue accessing network services and applications. The handover triggering process was based on the data rate required by the number of applications running on a mobile node's device. Grey Relational Analysis (GRA) decision scheme was used for network selection based on delay, jitter, bandwidth, communication cost and network load. Their scheme has been tested on a number of mobility scenarios with three different networks Wi-Fi, WiMAX and LTE cellular networks. The simulation results showed that their scheme outperforms other schemes used for a similar purpose. However, mobile nodes can only use one IP address during the handover process when their algorithm is applied which results to high packet loss rate.

A Quality of Experience (QoE) driven Vertical Handover Algorithm (VHO) based on Media Independent Handover (MIH) framework to maintain multimedia service with acceptable QoE and avoid unnecessary handover in HWNs was proposed by Winston and Kkuzhaloli (2014). The performance assessment was carried out to compare QoE-driven VHO algorithm with default MIH bandwidth-based VHO algorithm on video service over UMTS and WI-FI networks in Network Simulator 2 (NS2). The simulation results showed that their QoE-driven VHO algorithm could maintain better QoE of multimedia service than the bandwidth-based VHO algorithm by considering video content and initiated VHO immediately when the QoE of multimedia service became unacceptable. Furthermore, acceptable QoE policy helps to avoid unnecessary handover in HWNs.

An adaptive vertical handover algorithm based on the Analytic Hierarchy Process (AHP) was proposed by Guo and Li (2015) to reduce the handover delay and improve user experience. Their algorithm uses parameters that includes: cost, security, power consumption, received signal strength and signal delay to selection an access technology that it can use to continue accessing network servers and applications in HWNs. Through simulation, comparisons of the AHP algorithm with the previous algorithm using another adaptive method are done. The results show that the AHP algorithm can avoid unnecessary handover, reduce the handover delay effectively and embody user-experience at the same time. However, their AHP algorithm separates the parameters of authentication, authorization and handover procedure during the handover process between RATs in HWNs.

A packet-loss based vertical handover triggering algorithm for voice over WLAN/cellular media was proposed by Ali and Saquib (2014) to reduce packet loss rate. In order to analyze packet-loss based algorithm, they employed both a simple packet loss, block-wise packet loss pattern and Gilbert packet loss pattern. Simulation results showed that the packet-loss based vertical handover triggering algorithm minimized packet loss during the handover process. However, their packet-loss based vertical handover triggering algorithm separates the parameters of authentication, authorization and handover procedure between RATs in HWNs.

An adaptive weight vertical handover algorithm which can select the most suitable network as target handover network, according to the type of working application and the adaptive calculating weight vector to user's preference was proposed by Feng *et al*. (2014). The simulation results showed that their algorithm cannot automatically select access points that suit mobile users best. As a result, unnecessary handovers are created and network resources are wasted during the unnecessary handovers that occurs between RATs in HWNs.

A vertical handover method that uses Session Initiation Protocol (SIP) and bicasting to improve SIP handover delay was proposed by Hemmati and Moghadam (2014). Their algorithm uses make before break technique to allow mobile nodes to get a new IP address while it is still using the old IP address to access network services and applications. While the bi-casting media streams to both access networks of the session's device to ensure a seamless session handover between two different wireless networks. OPNET simulation results demonstrate that using this method can improve SIP handover. But since the start and end time of bicasting highly influence limited resources of network such as network bandwidth backhaul and network buffers, providing a method to determine the most optimal time for beginning and ending the bicasting remained as a problem for this scheme.

Imperative alternative media independent handover for VHO (I AM 4 VHO) to provide low connection failure (probability of session rejection) for enhancing VHO between RATs in HWNs environment was proposed by Khattab and Alani (2014). I AM 4 VHO algorithm is based on MIH framework and using fuzzy logic to achieve low VHO connection failure as a result of identifying the optimum RATs (list of priority). RATs priority list is based on Radio Signal Strength (RSS), whereby the RATs with best RSS becomes first on the priority list. Simulation results showed that the probability of minimizing VHO connection failure is minimized. However, their algorithm separates parameters of authentication, authorization and handover procedure between different RATs during the handover process. Whereas, the proposed algorithm proposes to incorporate parameters of authentication, authorization and handover procedure by merging similar parameters in order to reduce packet loss during the handover process in HWNs.

IEEE 802.21 Media Independent Handover (MIH) algorithm that uses two different mobility protocol of Mobile IP (MIP) and Session Initiation Protocol (SIP) to reduce handover delay in HWNs was proposed by Navitha *et al*. (2014). Their algorithm was modelled and implemented using a network simulator. The simulation results showed that IEEE 802.21 Media Independent Handover (MIH) algorithm reduced handover delay in UMTS and WLAN architectures. However, IEEE 802.21 Media Independent Handover (MIH) algorithm only operates in UMTS and WLAN architectures.

Vertical handover algorithm that uses Stream Control Transmission Protocol (SCTP) to reduce handover delay in UMTS and WLAN integrated networks was proposed by Dhivya *et al*.. Their scheme relies on bandwidth estimation and congestion control to reduce data loss over error prone wireless link. The reduction of transmission rate is due to the channel error in wireless links. Their algorithm was modelled and implemented using OPNET modeler. The OPNET modeler simulations result showed that this algorithm diminished handover delay between UMTS and WLAN integrated networks. However, this algorithm only operates in UMTS and WLAN integrated networks.

A decentralized algorithm for network selection which is based on the congestion game to resolve the problem of network congestion between WIMAX and HSDPA was proposed by Walid *et al*. (2014). Their algorithm was modelled and implemented using a network simulator. The network simulator validated their algorithm and showed its robustness when number of mobile nodes increases in the network. However, their algorithm only allows mobile nodes to use one mobile IP address. While the proposed EIH algorithm introduces the use of least two mobile IP addresses by mobile nodes during the handover process in HWNs.

A new vertical handover decision algorithm named Handover Necessity Estimation (HNE) was proposed to minimize the number of handover failure in HWNs by Abdoulaziz *et al.* (2012). Their algorithm was designed based on two parts: traveling time estimation and time threshold calculation. Their algorithm was compared with other two methods: the fixed Received Signal Strength (RSS) threshold based method in which handovers between the cellular network and the WLAN are initiated when the RSS reaches a fixed threshold and the hysteresis based method in which a hysteresis is introduced to prevent the ping-pong effect. Simulation results show that HNE algorithm abridged the number of handover failures to 80%. However, high packet loss remained as a problem for HNE algorithm during the unnecessary handovers that occurred between RATs. This is mainly because the HNE algorithm separates the parameters of authentication, authorization and handover procedure between RATs in a HWNs.

The integrated model for Universal Mobile Telecommunications System (UMTS) and Wireless LAN based on loose coupling architecture and tight coupling architecture was proposed by Kumar *et al.* (2011). Their model was designed to achieve unified mobile for cellular and broadband wireless access coverage. OPNET 14.5 was used to implement their algorithm and the simulation results showed that loose coupling architecture is better than the tight coupling architecture scheme when it comes to reducing intersystem handover delay. This is because the loose coupling architecture scheme supports Mobile-assisted and Mobile-controlled handovers. However, this loose coupling architecture scheme does not support Network-controlled handover which increases packet loss during the handover process in a HWNs. Predominantly because a HWNs is made-up of different RATs that support different cellular networks.

Vertical Hand Over (VHO) decision algorithm was designed to enable a wireless access network to not only decrease handover delay but also balance the overall load among all attachment points (e.g., Base Stations (BS) and Access Points (APs) but also maximize the collective battery lifetime of all Mobile Nodes (MNs) was proposed by Nankani. The VHO algorithm was modelled and implemented using a network simulator. The simulation results showed that their VHO decision algorithm lessened handover delay much better than the conventional optimization models. This is mainly because the VHO decision algorithm is based on the Strongest-Signal First (SSF) method to select the BS that a mobile node can use during the handover process.

An adaptive scheme for vertical handover in wireless overlay networks was proposed by Chen *et al.* (2009) for system discovery and handover decision methods. Their adaptive scheme reduced the complexity to establish or maintain the location-service server by adjusting the interface activating interval relying on the distance between the mobile node and the base station. The simulation results showed that adaptive scheme avoided performing handover while the utility ratio is decreasing and shorten the stability period before performing handover while the utility ratio is increasing. However, their adaptive scheme does not measure the RSS provided by the BS/APs that a mobile node can use to continue accessing network services in HWNs.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Grey Relational Analysis (GRA) algorithms were proposed by Akyildiz and Wang (2002), Stevens-Navarro and Wong (2006), respectively to choose the best network from the available Visitor Networks (VNs) for the continuous connection by the mobile node. The network simulator was used to implement their algorithm. The simulation results showed that their TOPSIS and GRA algorithms minimized the processing delays between access technologies in HWNs. However, their TOPSIS and GRA algorithms separates the parameters of authentication, authorization and handover procedure between RATs in a HWNs and they are not applicable to any data-link layer technologies.

A Signal to Interference plus Noise Ratio (SINR) and Analytic Hierarchy Process (AHP) based simple additive weighting vertical handover algorithm which uses the combined effects of SINR, user required bandwidth, user traffic cost and available bandwidth of the participating access networks to make handover decisions was proposed by Nasser *et al.* (2006). According to the analysis of simulation results, it is shown that their algorithm can achieve the excellent performance against the characteristics and requirement of the traffic and the user. However, their algorithm does not allow a mobile node to use the Broadcast Channel (BC) to search for an Aps/BS/cell that provides best RSS so that the Aps/BS/cell is selected based on the best RSS.

A new architectural design, ImeX was proposed to facilitate inter-gateway handover management in internet-based infrastructure Wireless Mesh Networks (WMNs) by Zhao and Xie (2012). IMeX was designed to facilitate parallel executions of handovers from multilayers, in conjunction with a data caching mechanism which guarantees minimum packet loss during handovers. Their handoff scheme was depending on router advertisement messages to trigger a handoff and allowing a mobile node to use two mobile IP addresses. OPNET simulator was used to test their solution. OPNET simulation results demonstrated that their IMeX architecture with both the parallel handover execution and data caching mechanism, outperforms the conventional WMN handover schemes in terms of reducing handover delays caused in multilayers and improving end-to-end performance of applications in WMNs. However, their algorithm cannot operate over any data-link layer technology.

A Gateway Scheduling-based (GaS) handover scheme was proposed to improve the handover performance in multi-hop WMNs by Li and Xie. GaS handover scheme can realize single-hop handover signaling packet transmissions and eliminate the channel contentions between data and signaling packets. As result, data and signaling packet transmissions were scheduled in different periods, so the channel contentions between them was completely eliminated. In addition, their scheme was designed to use media access control techniques to provide fast handoff support whereby the directional signaling transmissions and data transmissions were executed simultaneously on different channels. This was done by using single-hop in order to reduce the multi-hop transmission of signaling packets. They used OPNET simulator to test the performance of their solution. OPNET simulation results showed that the total handover delay is improved significantly using the GaS handover scheme under various scenarios. However, their GaS handover scheme separates the parameters of authentication, authorization and handover procedures during the handover process.

Horizontal handover based solutions: A Call Admission Control (CAC) based horizontal handover decision in LTE networks using their femtocells was proposed by Khan *et al*. (2016) to assign enough network resources, i.e., bandwidth based on user's service demands. This was done by allowing new call or handover requests if there are sufficient network resources available to fulfill the call or handover needs in terms of QoS without compromising the QoS needs of the already running applications or calls. In their wireless environments, there was always a mutual agreement across user perceived QoS and limited network resources and this is where CAC come act to help with bandwidth allocation. The performance of their approach was evaluated using MATLAB, LTE system toolbox and the simulation results showed that their algorithm can improve bandwidth allocation during horizontal handover process. However, in dense environments their mechanism produced some undesirable amount of signaling overhead and link delay.

The use of Particle Swarm Optimization (PSO) algorithm and Greedy algorithm was proposed by Fiona *et al*. (2014) to provide better QoS in a wireless network. Greedy algorithm was used to retrieve the distance of a particular network coverage area. Thereafter, PSO algorithm was used to develop the top network on the source of its signal strength over a given particular distance. Their solution was implemented and results gained on dot net plat form with C# as a code behind language showed that their solution provided better QoS during horizontal handover process. However, their solution can only operate between RATs that supports the same network type.

Received Signal Strength (RSS) based algorithm was proposed by Sindal and Tokekar (2008) to provide seamless handover in wireless networks by measuring the signal strength received from a BS/cell that a mobile node can use to continue accessing network services. Furthermore, finite queue model was for determining the threshold parameters of a BS on the queue capacity and finally on blocking and forced termination probabilities. The simulation results showed the significant improvement on decision delay as well as on the number of handovers when their RSS based algorithm is used in a Wireless Local Area Network (WLAN). However, unnecessary handovers are created due to signal fluctuations and multipath fading during the handover process.

Media Independent Information Service (MIIS) algorithm that reduces scanning delay in order to reduce handover delay in 802.11 was proposed by Niteshkumar *et al*. (2012). Their MIIS algorithm stores the channel numbers on which APs are connected to and the coordinates at where APs are placed. Mobile node acquires this information from MIIS algorithm then mobile node calculates its own coordinates. Based on these coordinates the mobile node decides which AP to use next after the handover process. In their algorithm, mobile node may scan only one channel which reduced scanning delay greatly. However, their MIIS algorithm separates the parameters of authentication, authorization and handover procedures between RATs in 802.11.

A channel-assignment algorithm to maximize Signal-to-Interference Ratio (SIR) at the user level in WLAN was proposed by Syuhada *et al*. (2008). MATLAB simulations were carried out with service areas consisting of 4, 6, 9 and 12 APs, and 20, 30, 40 and 50 users, respectively forming a WLAN. This was done to test the performance of their solution. The simulation results showed that their channel-assignment algorithm improved network performance by reducing the number of packets lost during the handover process. However, handover is only initiated if the SIR of the current BS or AP is lower than the threshold as compared to the SIR of the target network.

Strongest-Signal First (SSF) algorithm was proposed by Mao *et al*. (2009) to allow MNs to select an AP with the strongest signal during handover. In their SSF if an AP has poor signal, MNs searches for another AP. Then it chooses an AP which gives it maximum RSS. Network simulator was used to implement their algorithm. The simulation results showed that their SSF improved the QoS that the network provide by minimizing the handover delay and packet loss during the handover process. However, SSF algorithm separates the parameters of authentication, authorization and handover procedure.

A novel and feasible 802.11 handover scheme for the 802.11 Wireless Local Area Networks (WLANs) was proposed by Jin and Choi (2014). In their handover scheme, the 802.11 Access Points (APs) have multiple radios. One of the multiple radios is exclusively reserved for scanning purpose. Moreover, the reserved exclusive channel is available for data frame exchanges. It certainly helps the 802.11 mobile stations easily search neighboring APs. The performance evaluations were done in a real life network and the analytical results showed that their novel and feasible 802.11 handover scheme significantly reduces the packet losses. However, the algorithm only supports handover for 802.11 devices.

Proof tokens algorithm was proposed by Kbar to authenticate mobile user's access request in wireless networks. The token-based model includes token certificate selection mechanisms for authentication in HWNs. The model extends the use of tokens instead of certificates in the Extensible Authentication Protocol-Transport Layer Security (EAP-TLS) authentication method. When the token-based model is used in 802.11 WLAN, inter-domain authentication takes place in the foreign wireless network when a user handover to another network. However, the authenticator in the foreign network requests the identity of the user which is presented as a user at domain hence the foreign network must have a roaming agreement, i.e., direct trust relationship with the user's home network. The simulation results showed that their token-certification-based model reduced handover delay and packet loss during the handover process in wireless networks. However, a detailed description of how to build and update a trust relationship between wireless networks is needed as it is the key for fast inter-domain authentication.

Kim *et al*. (2014) proposed the use of Global Positioning System (GPS) capacity based handover algorithm to transmit the location information of AP to all users in the network. As a result, the expected capacity based handover improved bandwidth by about 35.48% more than that of the IEEE 802.11 handover.

Joint vertical and horizontal handover based solutions: A Packet Data Network Gate Way (PDN-GW) based algorithm was proposed by Tomici *et al*. (2015) to reduce unnecessary intersystem handover delay between the LTE and WLAN (Wi-Fi) air interfaces. An application protocol named S1a-AP was used for the communication between the two networks. Their S1a-AP utilizes the general packet radio service tunneling protocol version 2 to control and convey handover related messages such as handover request. This was done in order to reduce handover delay between the two networks. Simulation results showed that their algorithm reduced intersystem handover delay between the LTE and Wi-Fi access technologies. However, their algorithm separates the parameters of authentication, authorization and handover procedure between LTE and Wi-Fi access technologies.

An Inter-System Handover (ISHO) algorithm that uses context data from a connectivity map to reduce intersystem handover delay in HWNs was proposed by Pogel and Wolf (2013, 2015). In their algorithm, vehicles which go around can be exploited to collect data on the current network properties. Afterwards they are transferred to a central server where predictions of the future connectivity can be estimated. The newly gained knowledge can be made available to the vehicles for optimizing the handover times. However, their algorithm has not yet been tested in networks such as LTE. Furthermore, the algorithm does not solve the issue of signal properties that can be used for handover trigger decision to reduce the additional waiting time (Pogel and Wolf, 2013).

The integration of Access Network Discovery and Selection Function (ANDSF) algorithm with Media Independent Handover (MIH) algorithm was proposed by Frei *et al*. (2011) and Kwon *et al*. (2013). The two algorithms were integrated with the aim of minimizing intersystem handover delay and packet loss between RATs in HWNs. The integration of the two algorithms was done in order to eliminate packet loss, triggering the resource release in the source network right after the handover is finished and to improve the handover decision making process with additional operator's policies information from the ANDSF. The simulation results showed that a co-operation of these two optimization mechanisms minimized handover delay and packet loss during the handover process in HWNs. Especially if the operator policies from the ANDSF are taken into account and used with MIH algorithm. However, the integration of these two algorithms didn't solve the separation of authentication, authorization and handover procedure between different RATs during the handover process in HWNs.

A scheme that enhances the performance of the ANDSF server in real time was proposed by Orimolade and Ventura (2015) to reduce intersystem handover delays. Their scheme uses TOPSIS-based for network selection in HWNs. The simulation results showed that the network discovery and selection process was improved when this algorithm is employed in a HWNs. Mainly because their algorithm uses the real time parameters of the network and user's assigned weight as input. However, their algorithm only allows mobile nodes to use one mobile IP address during the intersystem handover which increases the number of packet loss.

Media-independent Pre-Authentication (MPA) mechanism was proposed by Dutta *et al.* (2008) which is a pre-authentication and pre-configuration model. MPA was designed to allow a user to select a network it wishes to connect to before the actual handoff takes place. Network Simulation Testbed (NEST) was used to implement and test MPA scheme. The simulation results showed that due to the separation of authentication, authorization and handover procedures but running one procedure in each case and each operational cycle, this increases the number of packet loss during the handover process (Dutta *et al.*, 2008).

Trust-based fast authentication algorithm was proposed by Hassan *et al.* (2008) to exploit the trust between the owners of neighboring APs for reducing the authentication delay during the handover process in HWNs. In their authentication scheme, neighboring APs that trust each other share the security key for the visiting node to avoid lengthy authentication routines each time the visiting node switches APs during the handover process in HWNs. The simulation results showed that the average number of full authentications needed for a roaming mobile was reduced linearly as the likelihood of two neighboring APs trusting each other increases. As a result, the handover delay was minimized. However, their Trust-based fast authentication algorithm separates the parameters of authentication, authorization and handover procedures but running one procedure in each case and each operational cycle.

Media Independent Handover (MIH) framework was proposed by Taniuchi *et al.* (2009) to achieve mobility of end user devices by enabling the handover of Internet Protocol (IP) sessions from one layer access technology to another. The MIH framework was integrated with a SIP client for obtaining interface-changed information when running on a multi-interface device. The MIH provided notifications of events and trigger the SIP client to issue re-invite messages to preserve session continuity during mobility. The SIP client were registered to all interfaces for MIH link-up and MIH link-down events. After a notification was received and a SIP session exists, the SIP client can utilize the re-INVITE message to ensure continuity. To further improve handover performance, the SIP client used additional link state information provided by the MIH-Link-Param-Report event. NEST simulation results showed that Media Independent Handover framework is limited only to the initiation and the preparation phases of the handover process. As a result, there is a separation of authentication, authorization and handover procedures.

Extensible Authentication Protocol (EAP) authentication framework was proposed by Harkins and Zorn. In their algorithm, the peer and server used the identity exchange to discover each other's identities and to agree upon a ciphersuite to use in the subsequent exchanges. In addition, the EAP server used the EAP-pwd-ID/request message to inform the client of any password pre-processing that may be required. Thereafter, the peer and server exchanged information to generate a shared key. This was done in order to reduce handover delay and packet loss during the handover. The simulation results showed that the EAP framework shortened the handover delay during the handover process. However, their EAP framework separates the parameters of authentication, authorization and handover procedure between RATs in HWNs as their framework only focuses on negotiating for a common authentication method server and client.

Media Independent Handover message Security (MIHSec) algorithm was proposed by Li *et al.* (2010). Their algorithm used MSK (Master Session Key) to maintain key hierarchy in order to reduce handover delay during the handover process. Their algorithm was modeled to eliminate IKE/DTLS authentication procedures, confidentiality and message integrity in order to diminish handover delay. The simulation results showed that the handover delay was lessened. However, their MIHSec algorithm separates the parameters of authentication, authorization and handover procedure as the algorithm only focus on providing a MSK for a mobile node and eliminating IKE/DTLS.

A channel splitting strategy was proposed to diminish channel access delay of handoff signaling packets over multihop wireless links in Wireless Mesh Networks (WMNs) by Li *et al.* (2012). In their scheme, network-layer handoff signaling packets and signaling messages were used for obtaining a new IP address, finding a new route to the new gateway and updating the new IP address for mobile client in WMNs. The signaling packet and messages were transmitted over the multihop wireless mesh backbone with data packets on the same backhaul channel in order to improve channel utilization in WMNs. They used OPNET simulator to test the performance of their solution. OPNET simulation results indicated that when their channel splitting strategy is implemented in WMNs, the average channel utilization improved. However, their channel splitting strategy scheme failed to reduce handover delay and packet loss mostly because signaling packets compete with data packets for the same wireless resources. Therefore, the more data packets are generated in the mesh backbone, the more possible collisions may occur between the two types of packets which results in long handoff delay and packet lose during sthe handover process in WMNs.

In 2013, the use of Multimedia Independent Handover (MIH) to assist mobility across HWNs was proposed by Khan (2013). Their model was designed to allow a user to get authenticated from both service providers using authentication, authorization and accounting protocol. However, their MIH model only focuses on providing reliable security and as a result, handover delay increases delays which lead to performance degradation.

As the literature review has shown, other researchers have tried to optimize intersystem handover in order to lessen intersystem handover delay and packet loss in HWNs. However, there is a need for a new/enhanced algorithm that reduces long intersystem handover delay and packet losses that is currently experienced with the classical/conventional solutions.

Open research issues: Literature surveys has indicated that few research papers have focused on reducing intersystem handover delay and packet loss during the handover process between RATs in HWNs. However, more research is still required in this area, primarily because existing intersystem handover algorithms result in unfavorable situations such as unnecessary delays, long communication disruptions, loss of signal, service degradation, poor handover decision making, inappropriate handover triggering and mobility management.

This occurs mainly because existing intersystem handover algorithms separate the parameters of authentication, authorization and handover procedures between RATs during the handover process in HWNs but run one procedure in each case and each operational cycle.

Additional, existing intersystem handover algorithms do not operate over any data-link layer technology. As a result, we end up with multiple authentication authorization and handover procedures between these data-link layer technologies (RATs) during the handover process in HWNs which increases the handover delay. Moreover, multiple existing intersystem handover algorithms used a single network selection decision marking technique (metric/criteria), i.e., mobile node speed/RSS/monetary cost/network traffic load (link/channel quality indicator) during the handover process which increases the handover delay while maximizing the number of packet loss during the handover

Table 1: Limitations of intersystem handover algorithms (Ahmed *et al*., 2014)

Category of handover decision schemes	Limitations of the schemes
Fuzzy logic based schemes	Increased complexity Higher decision processing delays
ANN based schemes	High latency Slow training and learning Supplementary resource
consumption	
Intelligent protocol based schemes	Comparatively high latency Centralized control High signaling overhead
Utility function based schemes	Longer communication delays Unsuitable for real time applications Inappropriate network selection
Cost function based schemes	Excessive load on the system High handover latency Difficult to estimate cost of some parameters
Network score function based schemes	High latency Degraded QoS
Available bandwidth based schemes	High packet loss Inefficient bandwidth Calculation
SINR based schemes	Increased handover latency Not applicable for high speeds Ping-Pong effect
User profile based schemes	Higher resource consumption Prone to session instability
Dwell timer based schemes	Increased packet loss Increased signaling Unsuitable for real time applications
RSS threshold based schemes	Increased handover failures from data to cellular networks Wastage of network resources
Channel scanning based schemes	Higher handover delays Extra lookup table
Prediction based schemes	Ping-Pong effect High link utilization Increased handover latency
Mobile agent based schemes	Increased communication overhead Large number of agents High handover latency Deployment issues in the real world
AHP based schemes	Resource consuming Might compromise on QoS if a low cost network is available
Mobility prediction based schemes	Instability for variable speeds Longer handover delay Higher packet loss
Cooperation based schemes	High signaling cost Higher packet loss Security provision
MIH based schemes	Supplementary signaling Context distribution Higher resource consumption

process between RATs in HWNs. Additionally, existing works used combination methods and used many parameters at the same time (e.g. neural network, fuzzy logic, etc.) however, those algorithms neglected the wireless surrounding which increases handover delay while increasing number of packet loss. Furthermore, existing intersystem handover algorithms only allow a mobile node to use one mobile IP address during the handover process. In future, it is desired to design and implement an intersystem handover algorithm that solves the identified open research issues. It is also desirable to produce simulation results to show that the developed intersystem handover algorithm has solved identified open research issues. A summary of limitations of intersystem handover schemes is presented in Table 1.

CONCLUSION

In this study, we presented an insight into the evolution of HWNs by stating the access technologies that forms a HWNs which includes: WLAN, WiMAX, GPRS, UMTS, HSPA and LTE/4G. Moreover, we discussed handover phases and handover performance metrics in HWNs. Additionally, we provided intersystem handover challenges in HWNs and current state of art intersystem handover algorithms according to their common methodology applied.

Thereafter, we highlighted a number of open research issues on intersystem handover algorithms in HWNs. We hope that this inclusive survey act as a starting point for new research in intersystem handover algorithms in HWNs and act as an indicator to the unanswered problems for future networks.

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