Enabling Vertical Handover Decisions in Heterogeneous Wireless Networks: A State-of-the-Art and A Classification

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***Abstract*—Wireless networks are passing through a transition phase for the past few years now and this transition is giving a way towards the convergence of all IP-based networks to form the Next Generation Networks (NGNs). With the proliferation of these networks in daily life, users' needs are also increasing and service operators are offering different services to satisfy their customers for a better grade of service and an elevated quality of experience (QoE). However, a single operator cannot fulfill the huge demands of the users especially, if a user is nomadic. In nomadism, a user traverses number of available networks that might contain cellular or wireless data networks, usually known as heterogeneous wireless networks. These networks offer various services from email to live video streaming depending upon their capacity and nature. During this traversing procedure, a user switches among different networks to satisfy his/her needs in terms of quality of service. This process is commonly known as a vertical handover or handoff (VHO) due to the involvement of heterogeneous wireless networks in it. An extensive work has been carried out in this field in order to fulfill user demands for better QoS and QoE. In this paper, we give a detailed state-of-the-art of these existing vertical handover decision mechanisms that aim at providing ubiquitous connectivity to the mobile users. We have categorized these vertical handover measurement and decision schemes on the basis of their employed techniques and parameters. Also, we present a comprehensive summary of their advantages and drawbacks. This paper gives its readers an overview of the active research initiatives in the area of handover decision making process in heterogeneous wireless networks and identifies the challenges behind the seamless services provisioning during mobility.**

***Index Terms*—Vertical Handover Decision, Mobility Management, Quality of Service, Wireless Mobile Communication, Network Convergence.**

I. Introduction

DURING the past few decades, both telecommunication and the Internet technologies have been in a phase of remarkable development and experienced an evident paradigm shift. Till the beginning of the new century, the advances were mainly focusing the technology and the user needs were many times forgotten. Evolution of the current mobile Internet has taken several important measures in order to provide an enhanced quality of wireless data and network services to its users. In mobile networks, first three generations evolved to contribute in increasing data rates and enriched communication experiences, achieving its peak in the third generation (3G) cellular networks. The next evolutionary steps after the 3^{rd} generation aimed at providing extended mobility features with optimized and enhanced data rates and services. These systems are generally named as Beyond 3G (B3G) or Fourth Generation (4G) networks. They make heavy use of heterogeneous networking technologies in order to deliver mobile users more flexibility when using multi-service networks that provide diverse range of services [1] like seamless connection to the Internet by means of heterogeneous wireless networks, navigation services, location-aware services and IP-based real-time multimedia.

In order to attain network, service and application convergence, next generation of all-IP networks must be designed in a way, where all the related functions work independently of the used network technologies. This will help the service providers to deliver their network services in an efficient manner to users without worrying about the type of networks or the terminal capabilities. Continuity of service in heterogeneous networks is driven by all-IP based applications that set a continuously growing drive for more wireless services like increased bandwidth and throughput, and reduced packet loss. Mobility management with Quality of Service (QoS) support is an imperative issue in Next Generation Networks (NGNs) because it is desirable for users to be able to move between wireless data and cellular networks employing different technologies. This process is generally known as a handover [2]. This process is generally categorized as horizontal, vertical and diagonal handovers by the research community [3]–[6]. Usually, these types are recognized by the type of architecture or technology they use as expressed in Fig. 1.

1) ***Horizontal Handover:*** Generally, the handover process has been considered and studied among wireless networks using the same access technology. When a mobile node (MN) moves between two cells using the same technology, then this kind of handover process is defined as horizontal handover. It is also known as Intra-cell (Intra-domain) handover and sustaining the running services is done by masquerading the change of IP address like in Mobile IP or dynamically bringing

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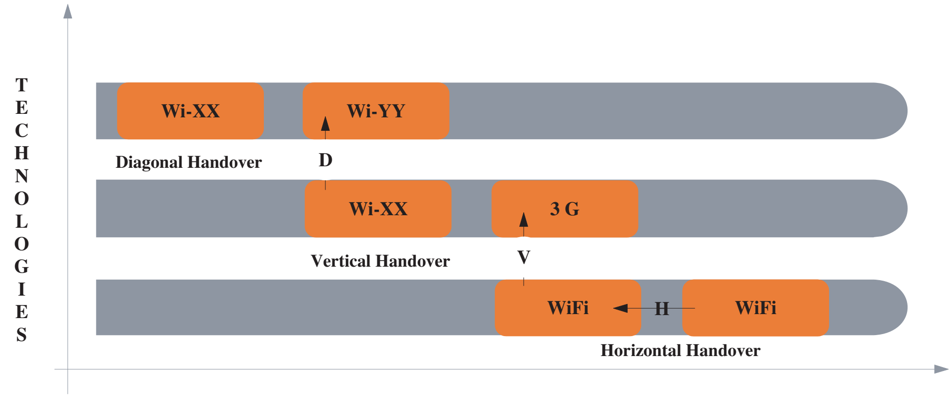

Fig. 1. An illustration of the handover types

up-to-date information of the altered IP address like in mobile Stream Control Transmission Protocol (mSCTP) [7].

2) ***Vertical Handover:*** A handover between two different access technologies is referred to as a vertical handover. It is also known as Inter-cell (Inter-domain, Inter-RAT[1]) handover as it occurs when the user moves into an adjacent cell and all of the terminals' connections must be transferred to a new base station (BS) [8]. The main concern of vertical handover is to uphold running services despite the alteration of IP addresses, but also the modification of network interfaces and QoS features of different networks accordingly.
3) ***Diagonal Handover:*** The Wi-Family is built around IEEE standards and quite a large number of committees are now working to set up wireless technologies linked between them by diagonal handovers. Diagonal handover is the combination of horizontal and vertical handovers. A handover is said to be diagonal when the mobile node traverses those cells that use a common underlying technology (like for example Ethernet) and it allows a user to continue its applications with the required QoS from Wi-XX to Wi-YY networks. In *IEEE 802.21* working group, this term is proposed for handover among IEEE networks and broadcast networks (i.e., downlink only networks) and it is usually needed in those cases where, heterogeneous networks share their allocated spectrum. It is also called as Media Independent Handover (MIH) [9].

Any of the above described handovers consists of mainly three main phases (Table I), which are crucial for deciding about the efficiency and applicability of the chosen handover mechanism.

Our main focus in this research is on the assessment of vertical handover decision making process in heterogeneous wireless networks as this is the heart of the handover process. Making a handover decision is one of the most important and crucial aspects of any handover mechanism. A vertical handover decision may be influenced by numerous issues that may be associated with the network to which an MN is at present connected and towards the one it will execute a handover in the future. For example, if an MN decides to execute a mobile-controlled handover then it may well be taken with the help of a vertical handover agent that is installed in the MN, based on the prerecorded policies such as available bandwidth, network load, network coverage area, monetary cost, network security, QoS, or/and user preferences. User preferences are important when performing vertical handovers. Let us assume, if the candidate network to which an MN intends to switch does not provide any security mechanism then the MN may possibly decide to stay connected to its old network. Similarly, if we consider network coverage, a mobile user may desire to utilize a secure and expensive connection for its email traffic flow (like a GPRS[2] link) but may still choose a low-cost connection for accessing web information (like a WLAN[3] link).

TABLE I
SUMMARY OF HANDOVER PROCEDURE [3] [10]

Handover Phase	Description
Handover Measurement & Initiation	Mobile Node (MN) or an Access Point (AP) makes the measurements for initiating a handover towards a new network or towards a new AP in the same network.
Handover Decision	Measurement results are compared with predefined values to decide whether to perform the handover or not.
Handover Execution	New base station is added, power of each channel is adjusted & active set is updated.

We have organized this paper as follows. Section II discusses the technical issues involved in vertical handovers along with some of the necessary parameters for making a vertical handover decision. Section III presents our proposed classification of the VHOs in heterogeneous networks. We discuss in detail handover decision making and present some of the existing techniques in this context that aim at providing mobility over a wide range of access technologies. We classify these approaches according to the handover decision criteria used to make a decision. Further, we elaborate in general the shortcomings and advantages of the quoted schemes in the shape of a short discussion by keeping in view their

[1]Inter-Radio Access Technology

[2]General Packet Radio Service
[3]Wireless Local Area Network

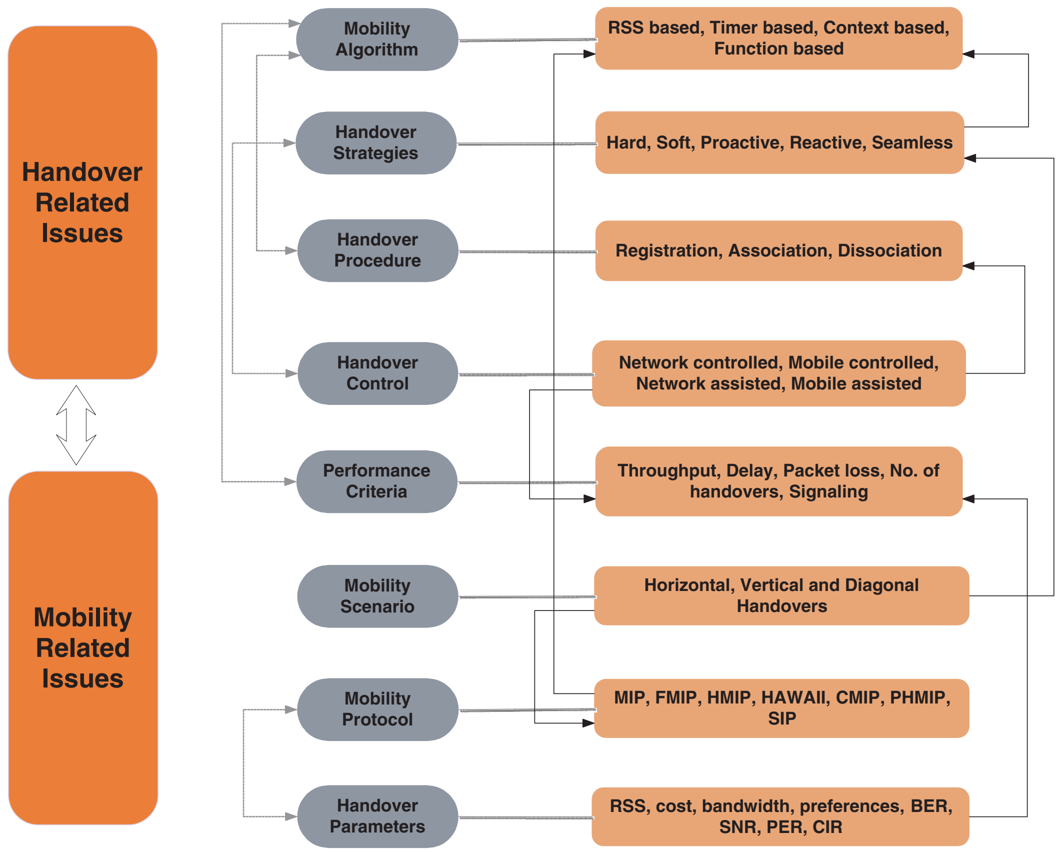

Fig. 2. Mobility Management and Handover Related Issues

operational methods in section IV. Section V encompasses the lessons learnt and some of the emerging trends by keeping in mind the existing handover methodology and future generation technologies and finally, we conclude this work.

II. Handover Characteristics and Handover Decision Metrics

In this section, we precisely discuss the main technical aspects of vertical handover function [11]–[13] followed by the handover criteria that is normally used to make a handover decision. Normally, an interdependency scenario exists between mobility and handover management. Discussion on all these aspects is a complicated task due to the enrichment and broadness of this topic. This is the reason that we have summarized this wide range of topics in Fig. 2.

We have logically divided mobility and handover related issues into several subgroups [14]–[16]. Mobility algorithms encompass different methods to design a handover decision scheme like some schemes are based on the value of RSS, timer and some are purely or partially context-aware schemes. Choosing an appropriate algorithm is a very important aspect as it directly influences the performance of that specific handover algorithm. Overall quality of service and experience entirely depends upon the design of the scheme. Handover strategies cover all the aspects that are related to the nature of a handover and they help in deciding whether a handover would be soft, hard or seamless. According to recent trends, a lot of research work is dedicated on providing seamless handover for uninterrupted service continuity.

Handover procedure includes the steps to be followed before/after or during a handover (as previously depicted in Table I as well). It is directly related with the mobility algorithms as every algorithm needs to follow the same sequence usually [17]. Handover control is concerned with the initialization of the handover procedure. This decides about the in-charge of making a handover request like, whether a handover will be network assisted or mobile controlled. As this control is decided, handover starts with the registration process. Handover control directly influences the performance of handover. Mobility scenario covers all the information related to handover types i.e., horizontal, vertical or diagonal handover. Once a handover initialization request is found from the terminal or the network, it is later decided about executing a soft, hard or seamless handover.

In existing literature, numerous mobility related protocols exist that support mobility. These protocols are applied in different mobility scenarios depending upon the need and feasibility of the environment. Choosing the handover parameters is a very important issue as it directly impacts the performance of handover decision. Selecting most relevant and appropriate parameters is still an open issue in handover decision making.

One of the key features of ubiquity is to facilitate mobile users with the opportunity to move freely and to provide them some means to communicate with the accessible applications using different intelligent and interactive equipment like mobile phones, PDAs[4] and digital TV sets. However, switching across different access networks is not an easy task and it needs a proper mechanism for accommodating user and application needs, especially in terms of QoS.

Handover decision making is the primary and key step in every handover procedure. It plays a vital role in accomplishing users' needs, harmonizing network resources and their utilization and makes best use of network performance. There are different triggers in handover algorithms that enable the activation of the handover decision procedure. It is a twofold process, where handover decision and target network selection takes place one after the other. To make a handover decision that comes across the particular handover needs, certain information from the candidate networks has to be extracted.

There are many criteria that can be used for handover decision. Usually, it makes sense to combine one or more criteria for handover decision making process. Based on the handover metrics, the decision will be made about how and when to switch the interface and to which network. Handover decision is a very active field of research in the current era and it involves many interesting issues to be dealt with like, What kind of handover decision procedure is used? How does the decision process exert in heterogeneous environments? What kind of vertical handover decision metric is applied? How are gathered the needed parameter values for a handover decision? Who is responsible for making the handover decision? What kind of performance optimizations can be achieved after the design of a handover policy? and so on. In order to keep users *Always Best Connected* [18], various QoS parameters are considered that affect the vertical handover decision. For making vertical handover decisions, some of the following QoS parameters are suggested [3], [19]–[21]:

- *Received Signal Strength Indicator (RSSI):* RSSI, also known as Received Signal Strength (RSS) and Relative Received Signal Strength (RRSS), is a traditional and unavoidable factor for making handover decisions. RSSI provides information about the power level being received by the antenna. It decreases when a user moves away from the currently accessed networks' access point (AP). The mobile user should handover to another available network before the connectivity is totally lost.
- *Network Load:* Background services (e.g., FTP and e-mail) or streaming services (e.g., real-time video) perform better if higher bandwidth is provided by the network.
- *Monetary Service Cost:* Every network provides certain services to its users which are usually charged against a cost. If two networks provide the same quality of service then the network with lower cost is usually preferred by service users.
- *Handover Delay/Latency:* Normally Layer-2 events occur to make a new association with the new network and this procedure might take larger delays (sometimes up to couple of seconds) also referred to as handover latency. Real-time services (e.g., video streaming, voice call) are usually accepted as delay sensitive and this degrades their overall performance. During handover, packets are usually buffered by the network till the next wireless station is prepared to accept them. This delay proliferates to higher layers and causes sudden upsurges in packet delays.
- *User preferences:* User preferences can be defined on the basis of preferred network from the available ones, in order to execute the applications. Preferences can also be defined on application priority executed by the user that can either be high or low (e.g., users usually prefer a connection with high bandwidth, low cost and reliable in terms of coverage).
- *Number of unnecessary handovers:* In the current wireless environments, decreasing the number of handovers is favored because recurrent handovers would cause extra consumption of network resources that might affect other functionalities of the network. A handover is considered as surplus when a handover back towards the actual access point is required within the certain point of time and number of this kind of handovers must be reduced. This kind of switching is also known as Ping-Pong Effect.
- *Handover failure probability:* It occurs when a handover is initialized by the network 'A' but the target network 'B' does not accommodate the handover request due to deficiency of resources. This shows that failure is directly linked to the availability of free channels in target network 'B'. Another possibility for handover failure might take place when the MN leaves the coverage area of target network 'B' before the handover process is completed. This usually happens because of the high speeds of the moving terminals.
- *Security Control:* It is one of the main issues that arise when networks are converged/ interconnected. This is because each network has its own security and privacy options and a mobile user must comply with them during the handover process. This needs harmonization of various security policies in heterogeneous wireless networks as networks and terminals have different security levels and security related characteristics. Handover process requires improved security and privacy from eavesdropping, registration hijacking, session tear-down and Denial of Service (DoS) attacks [22].
- *Throughput:* It refers to the data rate provided to the MNs in a network. Mobile users generally prefer a candidate network that provides higher throughput for their concurrent applications.
- *Bit error rate (BER):* BER is the number of received bits that have been altered due to noise and interference, divided by the total number of transferred bits during a time interval. BER of a network may be improved by choosing a network with stronger signal in order to improve the QoS.
- *Signal to Noise Ratio (SNR):* SNR is another very important parameter and it affects and reflects the QoS of a network.

RSS is usually employed as a prime factor for horizontal handovers, however, its implication in vertical handovers is also not ignorable. But there, it is normally combined with other factors to enhance user experience in terms of QoS

[4]Personal Digital Assistants

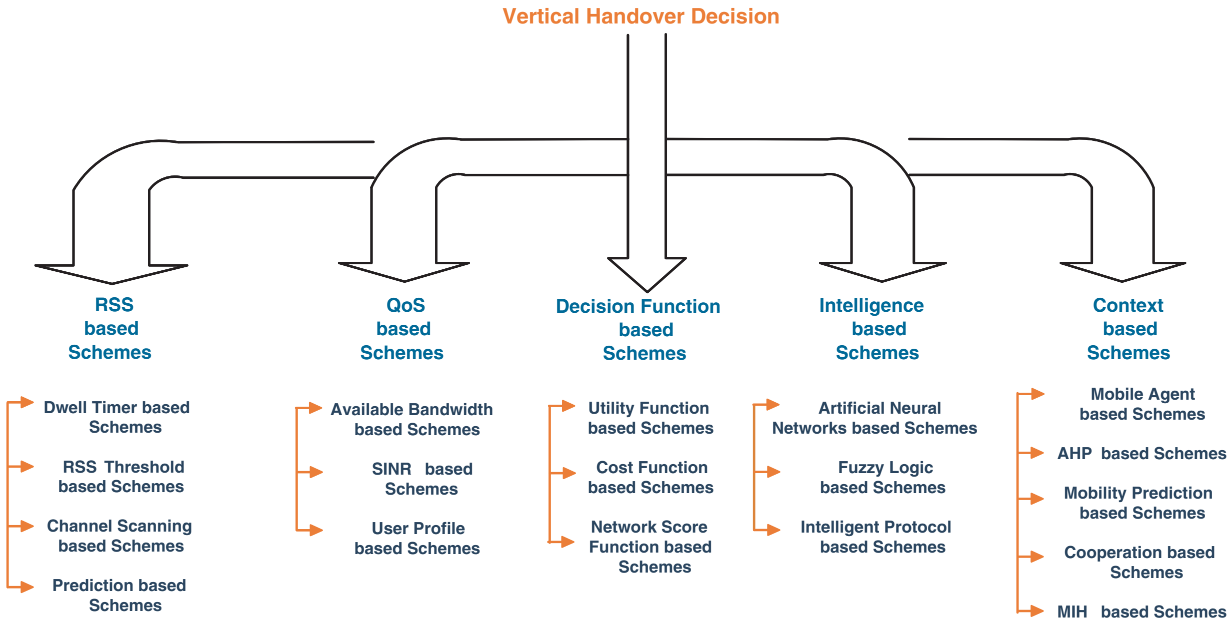

Fig. 3. Proposed Classification of Vertical Handover Decision Schemes

and QoE. In the next section, we present our proposed classification of the vertical handover decision mechanism in the context of heterogeneous wireless network environment.

III. Handover Decision Schemes

In this section, we present our proposed classification of the vertical handover decision schemes which is reflected in Fig. 3. In literature, various interesting classifications of handover decision schemes [3], [23]–[34] are presented. Most of these schemes have classified the handover on the basis of used parameters. Also, these approaches present recent trends and their respective underlying technologies to implement future next generation networks and depict some possible scenarios that might benefit NGNs. Authors in [3] proposed a fuzzy logic based framework for handover decision making and a classification of the available solutions. They mainly concentrated on the MADM based approaches. Authors in [24] mainly concentrate on the micro- and macro-mobility solutions along with the description of related protocols. This classification mostly concentrates on the handover related issues in general.

Works in [25] and [30] have mostly concentrated on resource management and provisioning issues involved in the context of vertical handovers. Their main focus is on providing a framework for proper resource management by keeping in mind network and operator preferences. Authors in [26] mainly highlighted the integration of cellular networks and WLANs and classified them on the basis of their practical feasibility. Authors in [27] and [31] focused on providing a taxonomy for context based approaches to provide autonomy to the handover decision mechanisms and their management. They provided different frameworks for unifying the process of handover in heterogeneous network environments which is more or less a holistic point of view. Another aspect that has been emphasized in these classifications is to choose the mobility algorithms that satisfy the QoS requirements of users to a varied range of applications while permitting seamless nomadism among different access technologies.

Compared to these existing classifications, we present an extensive research work that encompasses numerous solutions in the field to cover all the possible aspects of a vertical handover decision process. We believe that our proposed classification covers the research work to a greater extent and addresses many questions that were not discussed previously. Also, this work present many handover related concepts in an articulated way that contributes in simplifying the distinct positioning of the various handover decision schemes in this wide research area that also helps in identifying their advantages/disadvantages. In this work, we have chosen to divide vertical handover decision schemes into five classes based on the handover decision making criteria and the methodology employed to process the handover parameters.

1) RSS based Schemes
2) QoS based Schemes
3) Decision Function based Schemes
4) Network Intelligence based Schemes
5) Context based Schemes

Our proposed classification helps in regrouping different factors that are crucial for making a handover decision in heterogeneous wireless environments. The selected criteria for handover decision making can be static and dynamic in nature, depending upon the occurrence and causes of changes. Generally, static criteria are user profile and the monetary cost of the heterogeneous networks. On the other hand, the mobile nodes' velocity and RSS normally represent dynamic criteria. We would like to mention here that in our proposed classification, schemes are categorized according to the criterion that is responsible for triggering the handover decision. In the next section, we present the first candidate

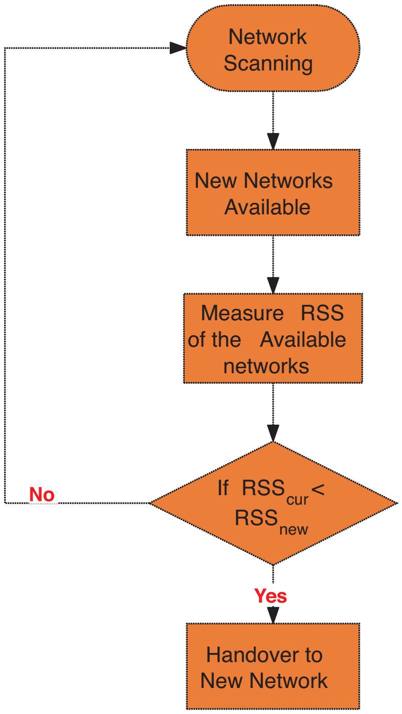

Fig. 4. Generalized Mechanism of RSS based Schemes

group i.e., RSS based handover decision making schemes for assisting vertical mobility in wireless networks.

A. RSS based Schemes

In RSS based decision algorithms, RSS of the current attachment point is compared with the RSS of the other available networks for making a handover decision. Because of the simplicity and availability of the hardware equipment required for RSS calculations, a fairly large number of studies has appeared in this area of research during the past years [10], [35]–[40]. In these schemes, criterion for making the handover decision is typically based on the RSS value. Other criteria might also be used but generally, they are for assisting the handover procedure and not directly involved in the handover decision making process. A generalized schema for RSS based vertical handovers is depicted in Fig. 4 where, at first initial network scanning is performed by the mobile node to check the availability of candidate wireless networks in the neighborhood. Then, their RSS levels are measured and compared either with the RSS of the current network or a predefined RSS threshold. If these measurements give a satisfactory result for RSS then a handover is performed otherwise, the process switches back to the network discovery phase. We have divided RSS based schemes into the following sub-categories.

1) Dwell timer based Schemes: Authors in [37] and [39] present an architecture that suggests to use location and cross-layer information to trigger vertical handovers. They compared two handover algorithms from the perspective of how the difference in the effective data rates, the terminal velocity and the amount of handover delay affects the mean throughput in a region, both in moving-in and moving-out scenarios. They analyzed the usage of a variable length dwell timer in entering and leaving a network, and compared its benefits and drawbacks against power-based algorithms. They have shown that the value for the dwell timer relies upon the difference between the available data rates in both networks i.e., current and target networks. A handover is triggered if RSS level of a network is consistently below a predefined threshold and smaller than the sum of the new RSS and a hysteresis. The proposed scheme seemed to be less sensitive to the increases of the handover delay but it may affect the performance of real time applications, which is a major drawback of this scheme.

Emmelmann *et al.* in [40] propose the design and a prototype of seamless handover mechanism for high speed vehicles using dynamic dwell timer. This scheme is designed for IEEE 802.11 networks and aims at reducing the handover delay for the provision of telemetry services. The proposed prototype consists of micro and macro cellular coverage areas that operate on same frequencies. According to authors, their proposed method circumvents all of the conventionally known handover phases to reduce overall handover latency. This is done by using a centralized Radio Control Unit (RCU) that tunes the dwell timer according to the coverage area and terminal speed and it also contains all the handover related information. As a mobile user enters a macro cell its handover needs are estimated by the RCU and transmitted to the neighboring RCUs. This helps in reducing packet loss due to advance packet buffering and also, reducing handover delay because of early binding.

In [41], authors propose a novel handover technique for reduction of handover failure probability and elimination of unnecessary handovers. In order to achieve these functions, they have fused together three different techniques: (1) *Signal Trend Detection* indicates the need of upward or downward vertical handover. For example, if a mobile node is entering in WLAN coverage area and RSS is raising then the handover is triggered to the nearest WLAN access point. (2) *Adaptive Threshold Fixing* is used as a trigger that adjusts to variations in MNs' velocity and channel parameters and it also estimates the possible handover delays and, (3) a *Dwell Timer* for fast moving terminals since at high velocities an MN must handover immediately as it enters or exits the coverage area of a specific network. This timer helps in fast handovers and reduces the waiting time. So, dwell timer interval is reduced for high speed MNs in the proposed mechanism. This scheme successfully reduces handover failure and ping-pong effect but some surplus amount of signalling is observed that eventually affects packet loss as well.

2) RSS threshold based Schemes: In order to improve the performance of handovers in WLANs in terms of handover delay, jitter and perceived throughput, a proactive mechanism is proposed in [42]. For performing these functions, channel scanning and triggering is executed in advance towards the candidate access point by using Received Signal-to-Noise Interference (RSNI)[5] [43] parameter for obtaining appropriate resources and reducing / avoiding the service discontinuity and handover latency. However, applicability of this parameter in

[5]RSNI is proved to be a better channel estimator/indicator and is more stable parameter than the RSSI [43].

terms of handover improvement is ambiguous in other access and cellular networks. Li *et al.* in [44] also addressed this issue and used a probing mechanism to adjust the network flows and control the data rates for appropriate service provision and QoS in heterogeneous networks.

Mohanty *et al.* in [45] proposed a handover decision algorithm from WLAN to 3G networks on the basis of comparison of current RSS level and a dynamic RSS threshold value in a scenario where, an MN is connected to a WLAN AP. Using a dynamic RSS threshold assists in decreasing the number of unnecessary handover and it also keeps the number of handover failures under a predefined limit. Authors have shown that handover failure probability increases in cases where, either velocity or handover signaling delay upsurges when a fixed value of RSS threshold is used. Nevertheless, in this scheme, handover failure probability from a 3G network to a WLAN is reflected as 0 because authors have considered the availability of 3G network as ubiquitous. This is the reason that in the proposed scheme a handover towards a WLAN is constantly essential each time the MN arrives the WLAN network coverage. However, this is not always favorable because such a handover might result in consumption of supplementary network resources because the overall efficiency of the proposed approach degrades if the traveling time of an MN in a WLAN is less than the handover latency.

Becvar *et al.* [46] propose a handover mechanism to maximize the handover prediction efficiency using the parameter of RSSI with hysteresis as in [39] and [45]. They have defined two thresholds for this parameter in order to exploit the best use of it. This scheme involves measurement of the mean value of the predetermined thresholds for handover initiation. For this purpose, a sufficient number of RSSI samples are calculated that help in estimating the number of handovers, which are most likely to happen between the actual and the target base stations. This procedure helps in evaluating the handover probabilities among the participating BSs. Authors also discussed the influence of RSSI fluctuations over handover prediction capacity. The proposed scheme does not need to take parametric input from the mobile users or any specific knowledge about target networks. But, authors need to discuss the issue of handover interruptions in the scenario of mobility prediction of VHOs.

3) Channel Scanning based Schemes: Authors in [47], [48] propose a handover scheme between third generation networks and WLANs. They combined the RSS measurements either with an estimated lifetime metric[6] or the available bandwidth of the candidate WLAN. They took into account two mobility scenarios. In the first one, the mobile node moves away from the WLAN coverage and enters into a 3G cell, a handover to the 3G network is initiated. A handover is performed if following two conditions are met at any point of time:

1) $\langle RSS \rangle < Threshold$ and;
2) Estimated Lifetime $\leq$ Handover Latency.

The mobile node continuously measures the average RSS using the moving average method as described in equations 3,4 and 5 of [47]. After this step, the life time metric is measured using the RSS change rate and another parameter known as Application Signal Strength Threshold (ASST)[7]. This parameter relies on the type of application and it usually denotes a combination of the channel BER and applications' QoS needs. Similarly, if we consider the second scenario, when an MN moves in the direction of WLAN, handover to the WLAN is initiated if WLAN provides higher RSS levels than a predetermined threshold and at the same time, it also complies with the applications' requirements of the available bandwidth. This depicts the adaptability of the proposed mechanism for users and applications both. If we summarize, the proposed scheme considerably decreases the number of unnecessary handovers because of the lifetime metric. Also, average perceived throughput of the mobile user is enhanced as the user stays connected to the WLAN for as long as possible. However, packet flow delay increases due to the utilization of increase in lifetime metric because of bad channel conditions. This is very critical for real time applications and it imperatively degrades their overall performance.

In order to tackle with these issues, Park *et al.* [49] proposed an application-aware scheme to uplift QoS of multimedia streaming services. They have done so by reducing the channel scanning time and the number of channels involved in each scanning. For obtaining an adaptive solution, they have modified the scanning method according to application type. For packet loss and delay sensitive applications like Voice over IP (VoIP), they have augmented the channel frequency and pre-scanning duration but, this also increases the consumption of battery power. Similarly, authors in [51] and [50] emphasize on the fact that by actively scanning the real-time information like speed and direction of mobile node, resources can be network reserved in advance and the amount of time involved in scanning can be intelligently adjusted. At the same time, if some intelligent reconfiguration mechanisms like self-(channel management, configuration, adaption) are put into network entities then, an optimal solution with end-to-end efficiency can be retrieved. This can also help in selecting the most appropriate network for performing a handover which fulfills users and applications QoS requirements.

4) Prediction based Schemes: For reducing the number of unnecessary handovers, authors in [38] described a handover decision scheme that considers the time a mobile node is likely to spend within a WLAN. This mechanism is highly dependent on the assessment of users' traveling time within a WLAN and the calculation of a time threshold. Handover towards a WLAN is initiated only if its coverage is present and if users' estimated traveling time in that specific network is larger than the predefined time threshold. If a handover towards any cellular network is intended then it needs to qualify for two conditions: (1) RSS of the WLAN is constantly degrading and (2) MN has reached the cell boundary due to its high velocity and a handover needs to be initiated. This scheme saves disconnections, reduces unnecessary handovers and also, decreases the probability of handover failures. However, higher handover delays are observed because authors utilize sampling and averaging of RSS which is a time consuming process.

[6]An expected time after which an MN may not be able to continue its connectivity with the WLAN

[7]ASST is the RSS level that is needed for the satisfactory performance of the active applications

TABLE II
RSS BASED VERTICAL HANDOVER DECISION SCHEMES

Category of Handover Decision Scheme	Candidate Handover Decision Scheme	Description of the Scheme	Advantages of the Scheme	Limitations of the Scheme
Dwell Timer based Schemes	[37] [39] [40] [41]	Dynamic Dwell Timer is employed for high mobility scenarios.	- Reduced handover failure - Reduced Ping-Pong effect - Reduced handover delay	- Increased Packet loss - Increased signalling - Unsuitable for real time applications
RSS Threshold based Schemes	[44] [42] [46] [45]	Dynamic RSS threshold is calculated & compared with the current RSS to determine the handover time for data & cellular networks.	- Reduced false handover initiation - Reduced handover failure	- Increased handover failures from data to cellular networks. - Wastage of network resources
Channel Scanning based Schemes	[47] [48] [49] [50] [51]	RSS is combined with an estimated lifetime scanning for deciding about the handover time.	- Adaptation to application and user mobility - Throughput Improvements	- Higher Handover delays - Extra Lookup Table
Prediction based Schemes	[38] [35] [36] [52]	Predictive RSS threshold is used for high speed nodes to attain continuity of service.	- Reduced connection breakdown - Unnecessary handover avoidance - Load balancing in target networks	- Ping-Pong Effect - High link utilization - Increased Handover Latency

Using a similar method in [35], [36], Chang *et al.* proposed a cross layer based polynomial regression predictive RSS scheme with the *Markov Decision Process (MDP)* based network selection for vertical handovers in heterogeneous wireless networks. The proposed scheme comprises of two phases i.e., (1) decision phase, where measurement of predictive RSS with a hysteresis value are carried out and (2) network selection phase, where an optimal target network, towards which a handover is intended, is determined. In the first phase, a polynomial regression based methodology is employed to forecast whether an MN moves closer to or away from a wireless network. Second phase determines the candidate access network with the lowest possible cost with the help of MDP for an optimal network selection for handover. The proposed approach achieves load balancing in the target networks and avoids unnecessary handovers while the wireless links are occupied for longer period that cause unnecessary handover delays and higher link utilization. Another predictive RSS based solution is presented in [52] that addresses the adjustment of QoS parameters according to dynamic network conditions in heterogeneous networks.

Table II summarizes the RSS based handover decision schemes presented in this section. Due to the emergence of the heterogeneous networking environments, complexity of the handover decision has increased to a great extent. RSS is an unavoidable factor when designing a decision scheme. However, it is observed in [53] that only RSS is not sufficient to make handover decisions in heterogeneous wireless environments because the RSS of heterogeneous wireless networks cannot be compared directly, and also, RSS cannot reflect the network conditions adequately. Optimal results cannot be obtained for vertical handovers when only considering RSS. It is very important to provide users a certain amount of quality of service as well. For this reason, a number of schemes are proposed in the literature that take into consideration the QoS aspect of the vertical handover. In the next section, we will present some of the handover decision algorithms based on different QoS parameters.

B. QoS Based Schemes

Next generation networks are envisioned as a convergence of diverse wireless access technologies providing the mobile users with enhanced connectivity in a ubiquitous manner to improve overall wireless resource consumption. In such converged systems, synchronicity of heterogeneous access technologies with fairly different features such as cost, bandwidth and coverage area fallouts in handover asymmetry that varies from the traditional horizontal handover. Thus, vertical handover must be QoS-aware. Our main focus in this category is on the schemes that tend to optimize the QoS using the parameters of available bandwidth, user preferences and Signal-to-Interference and Noise Ratio (SINR) for making an optimal handover decision. Usually RSS and SINR oriented schemes are considered similar but we would like to mention that RSS is more inclined towards providing connectivity to the users whereas, SINR also assists in improving the QoS of the network as it reflects and impacts the bandwidth of any available network. Fig. 5 presents the generalized mechanism of this category where the first three phases carry out network discovery and parameter collection as in RSS based schemes. However, the measurement criteria in decision making process is enriched to reach an optimal solution. Now, we will present a number of QoS-aware vertical handover decision strategies which we have subdivided into following categories.

1) Available Bandwidth based Schemes: Cheng *et al.* [54] suggested a QoS based vertical handover decision scheme by considering available bandwidth and user preferences for deciding the handover direction from a WLAN to WWAN[8] and inverse. When an MN is connected to a WLAN, the proposed scheme is initiated by checking the state of the terminal and by comparing the RSS level with a predefined threshold. If the mobile node is found in the idle state then a handover is performed towards the preferred access network otherwise, application type is considered for making a handover decision. For delay-sensitive applications a handover takes place only if the current serving network is not suitable in terms of QoS to running applications. Similarly, if WWAN provides higher bandwidth as compared to WLAN then a handover is performed for delay-tolerant applications. The proposed methodology achieves higher throughput and lower handover latency due to the utilization of available bandwidth and application type as main handover decision criteria, respectively. However, measuring the bandwidth in

[8] Wireless Wide Area Network

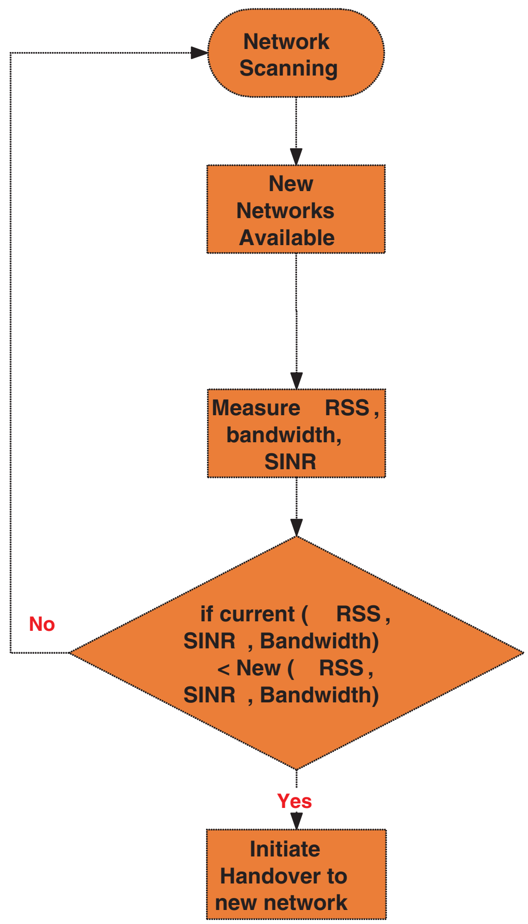

Fig. 5. Generalized Mechanism of QoS based Schemes

cellular networks is a complex task as stated by the authors themselves in [54]. Also, this scheme results in high blocking rate for new arriving applications due to performing handovers in idle state.

Bazzi in [55] proposes a new definition of the softer VHO in contrast to the existing one [56] along with an algorithm for heterogeneous wireless systems to support the discussion. This definition takes into consideration the network conditions like user mobility, available bandwidth and application type. The proposed definition mainly focuses on the best effort service in the UMTS networks using different mobility scenarios. An analytical model is also proposed that works for multi-mode terminals and uses some dynamic lists that measure the perceived throughput of the connected terminals for the best network selection. The proposed algorithm improves the overall throughput for a softer handover however, other aspects of the QoS like handover delay, packet loss, etc. seem to be totally ignored in all scenarios.

Authors in [57] propose integration of WLAN and cellular networks for connection and optimal resource management by considering coverage area, available bandwidth and RSS for achieving seamless handover. In the proposed mechanism, handover to cellular network is performed only if no other data network is found in the vicinity. This is done due to the limited capacity of handling heavy traffic loads by cellular networks. This scheme achieves proper load balancing and optimized battery life of the mobile terminals by restricting the off and on switching thus, reducing the Ping-Pong effect and number of unnecessary handovers.

2) SINR Based Schemes: Another important vertical handover decision parameter, SINR is considered in [58]. Authors have used SINR to assess the system performance in terms of dropping probabilities and throughput by using the equation 1:

$$R = B\log_2(1+\frac{\gamma}{N}) \tag{1}$$

where R is the maximum achievable data rate, B is the channel bandwidth, γ is the total received signal power over the bandwidth by the user, N is the total noise or interference power.

The relationship between the maximum achievable data rate and the received SINR from both WLAN and WCDMA[9] makes the SINR based vertical handover scheme applicable, in which the received SINR from WCDMA is being converted to the equivalent γ required to achieve the same data rate in WLAN, and compared with the actual receiving SINR from WLAN [58]. Handover is triggered when the user obtains higher levels of SINR from any other wireless network. This provides the vertical handover scheme the capability to take handover decisions by considering multimedia QoS constraints like the user maximum down-link throughput and minimum dropped user from the integrated network. The performance of SINR and RSS based vertical handover algorithms is assessed where the proposed SINR based scheme delivers improved system throughput and reasonably low handover dropping rates when compared to the existing RSS oriented method. Major drawback of this approach is that it is dependent on the velocity of the mobile users and performance of the scheme degrades with the increase in velocity. Also, this scheme provides high latency and a very high number of unnecessary handovers.

Using a very similar technique in [59], authors presented a bandwidth based handover decision scheme between WLAN and WCDMA. A handover is executed towards the network that exhibits larger SINR values. Usually, SINR oriented handovers provide users with higher overall throughput than the RSS based ones due to direct dependency of throughput over SINR. This is reason that the proposed scheme provides a load balancing across these two heterogeneous networks. However, this may also result in excessive handovers due to the variation of the SINR and causing Ping-Pong effect. Authors in [60] also present an SINR based approach by considering both available data-rate and the back-haul bandwidth for determining the handover decision time and optimizing the resource allocation in the networks. However, some latency is induced in their proposed scheme due to inappropriate network selection.

For enhancing the average throughput of the vertical handovers, Hu *et al.* [61], [62] proposed co-operated fast cell selection and softer handover based decision algorithms in 3GPP networks. They used SINR as a performance metric for VHO and proposed a new parameter called as *Interference-to-other-Interferences-plus-Noise Ratio* (IINR) and depicted

[9] Wideband Code Division Multiple Access

its feasibility in the course of handover. In their proposal, they delegate that by using IINR if only those mobile nodes get selected for handover whose cooperation costs are less than the cooperation gains then the average throughput of the complete handover procedure can be enhanced. However, this scheme works only in cooperative network environments. Libnik *et al.* propose a congestion-aware handover mechanism [63] that calculates the congestion status of the target point of attachment (PoA) in advance in order to perform a handover in heterogeneous environment. Authors take into account SNR as the decision making criteria using SIP protocol. The proposed mechanism reduces the handover delay however, other parameters need to be addressed for optimized handover decision making.

3) User Profile based Schemes: Calvagna *et al.* [64] proposed a vertical handover decision model which is based on the user preferences in order to satisfy users according to their specific needs i.e., QoS and monetary cost. Two handover decision strategies between GPRS and WLAN networks are presented: (a) the mobile node will never quit its GPRS connection until the occurrence of connection blackouts and (b) the proposed scheme searches for only WLAN APs with connection blackouts. The first strategy satisfies those users who are willing to pay for having their network connections as guaranteed as possible. The second strategy will content the users from the point of view of the cost but will disappoint their QoS expectation. On the basis of these two strategies, the simulation results have been shown by changing the handover decision strategy. The performance of some applications like FTP and HTTP that are running on the mobile node improves whereas for other applications it turns out to be not as good as expected. Authors have defined the following method for finding the optimal handover decision strategy as depicted in equation 2:

$$C = T_{wifi}.c_{wifi}(h) + T_{gprs}.c_{gprs} \tag{2}$$

where C is the monetary cost paid by the mobile user for a complete communication session, T_{wifi} and T_{gprs} are the amount of time spent by mobile user in the WiFi and GPRS network coverage, respectively and $c_{wifi}(h)$ and c_{gprs} are the fees per second that the service operators of the WiFi and GPRS wireless network charge from the mobile users, respectively.

This algorithm demonstrates that the readiness to pay a specific cost expressed by the user for a certain amount of QoS can be fulfilled when a suitable handover decision strategy is adopted. The proposed decision mechanism is incorporated in a network selection module, which is responsible for gathering coherent data from the network monitoring module periodically and obtaining the user preferences from the user profile management module as well. The proposed mechanism is implemented by integrating a Mobile IP-like mobility protocol to assist the roaming of nodes in WLAN and GPRS domains. However, the adoption of a policy that allows the user to save money does not give guarantees that the performance of the running application sessions will be preserved. For instance, a handover strategy might satisfy the user in terms of connection cost, but will dissatisfy his/her QoS expectations, depending on the application sessions currently going on. This is the case of an *http* session or a *telnet* session, whose performance does not benefit from such a policy [64]. To solve this, Roberto in [65] proposed a weighing vertical handover mechanism to achieve optimized QoS in terms of packet delay and available bandwidth utilization for Bluetooth and WLAN environments.

To achieve seamless mobility and end-to-end QoS guarantee for the users in a heterogeneous environment, Min *et al.* [67] proposed a mesh network based handover decision scheme. They have considered the user movements, RSS and user preferences as mobility decision parameters. Two scenarios have been elaborated by the authors for the movements between WLAN and WiMax networks i.e., moving out of the mesh overlay area and moving in the mesh overlay area. There are two domains which are administrated by WLAN and WiMax respectively in each mesh router. When the MN moves out of the overlay area, the RSS from the access point in the mobile node is used as the main metric to initiate the vertical handover. When the MN moves into the WLAN coverage area, the MN may keep the connection with the WiMax network or make a decision to trigger the handover to WLAN according to the user preference, the WLAN network condition, and the current traffic condition in the target network. This scheme reduces the handover delay and packet delivery delay but it may become resource consuming for networks as users switch between the two domains very often causing ping-pong effect.

Tamea *et al.* in [66] and [68] emphasize on the fact that using conventional QoS parameters does not perform the handover procedure optimally. Instead, it is important to monitor the influence of other technology specific techniques like power control, modulation and coding schemes and scheduling mechanisms. In their works, they have modeled the handover as a QoS issue and depicted its relation to the cost function mechanism. They have divided this problem into two strategies: (1) minimum power strategy that tries to attain a minimum level of QoS in terms of bit error rate, and (2) minimum handover strategy that reduces the Ping-Pong effect by limiting the number of handovers towards the target APs. Results show that the proposed mechanisms successfully achieve a minimum level of QoS by saving the precious wireless resources, save battery level and reduce the number of handovers by selecting an optimal network for handover.

Table III summarizes the QoS based handover decision schemes presented in this section. Above described QoS enabled techniques and criteria are mainly for user satisfaction and non-real-time applications. More criteria needs to be considered for the constraints associated with the real time applications. Real time applications are delay sensitive in nature thus, for deciding about the most suitable network that guarantees user satisfaction and network efficiency, more criteria to gather information from the heterogeneous wireless networks and additional state-of-the-art techniques need to be considered. Handover decision functions have been widely used for the past few years that combine various network and QoS parameters in order to select a network out of available ones. In the next section, we present some of the existing works which are dedicated to decision functions that incorporate both; real time and non-real time applications.

TABLE III
QoS BASED VERTICAL HANDOVER DECISION SCHEMES

Category of Handover Decision Scheme	Candidate Handover Decision Scheme	Description of the Scheme	Advantages of the Scheme	Limitations of the Scheme
Available Bandwidth based Schemes	[54] [55] [57]	Available Bandwidth is considered for achieving higher throughput in vertical handover.	- Low handover latency - Higher throughput - Proper Network Selection	- High packet loss - Inefficient bandwidth calculation
SINR based Schemes	[58] [59] [60] [62] [63]	Concerned with optimizing the resource allocation and reservation during a handover	- Higher throughput - Optimized resource allocation	- Increased handover latency - Not applicable for high speeds - Ping-Pong Effect
User Profile based Schemes	[64] [65] [66] [67]	Focuses on optimizing end-to-end QoS before & after a vertical handover.	- Assured QoS - Less Packet Loss - Reduced handover delay	- Higher resource consumption - Prone to session instability

C. Decision Function based Schemes

In heterogeneous networks with ubiquitous access facilities, the decision and selection processes become more complex because different access technologies usually provide different characteristics (QoS support, billing schemes, reliability, etc.). Handover decision and proper network selection becomes a multi-criteria decision making (MCDM) [69] problem that involves a number of parameters and complex trade-offs between conflicting criteria. A vertical handover decision function is a measurement of the advantages acquired by switching over towards a specific wireless network. It is evaluated for each network *i* that covers a specific service area of a mobile user. Generally, it is a weighted sum of specific network parameters as depicted in Fig. 6.

The first policy-enabled handover algorithm was proposed by Wang *et al.* in 1999 [70] in which they introduced a cost function in the handover decision making in order to select the best available network. Since then, they are widely used in case of multi-criteria decision making where multiple network parameters are summed together to select a specific network according to user or running applications needs. We are employing the term "Decision function" in order to generalize the cost, utility, score and policy based functions. Now, we will present a number of decision function based vertical handover decision strategies which we have subdivided into following categories.

1) Utility Function based Schemes: Utility refers to the level of usability of services in a specific network. In access network selection and decision management, it measures the users' satisfaction level corresponding to a set of characteristics of a wireless network, including the allocated resource parameters. Authors examine user satisfaction level by employing a utility function for non-real time applications (FTP[10] file transmission) in [71]. The network selection and handover decision relies upon consumer additional value i.e., the difference between the monetary value of the data transferred and the real price charged by the network operator, with forecasting the file transmission completion time in contrary to [72]–[74] where, they consider user preferences, mobility range, minimum required bandwidth and SINR along with a fixed cost to design their utility functions for load balancing schemes. These schemes perform better in terms of network load balancing and throughput as both of these criteria are

[10]File Transfer Protocol

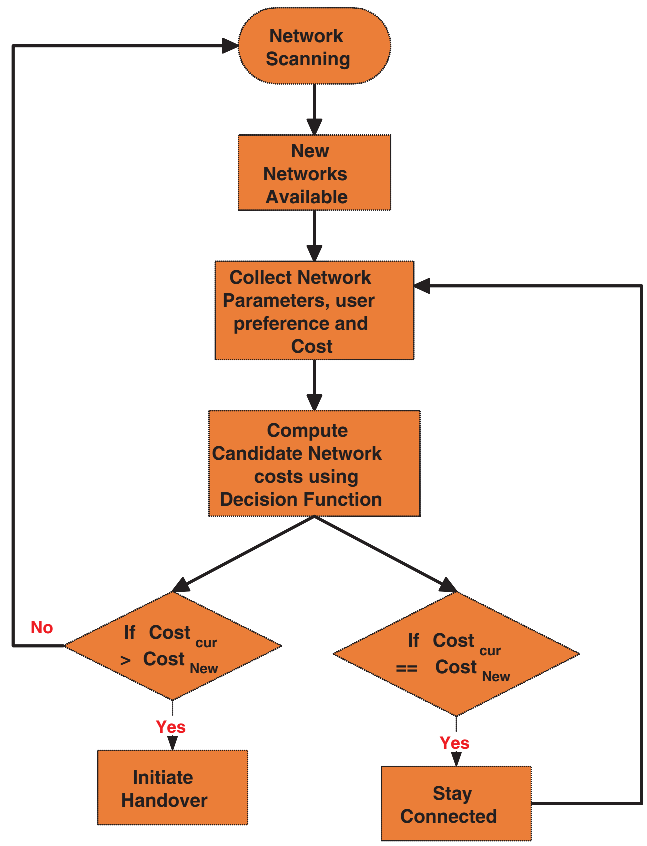

Fig. 6. Generalized Mechanism of Decision Function based Schemes

considered for proper network selection and other handover phases.

However, according to Ormand *et al.* [71], if the cost of a file transfer which is paid by a mobile user is less than that they are willing to pay then it becomes interesting for the mobile user to economize the overall cost of service. To select an appropriate utility function, the featured decision criteria are mobile users' risk behavior and are stated as follows:

- *Adverse user* prefers to be certain that he/she will pay less and hence, experience more delays;
- *Neutral user* prefers equally to pay less and to experience less communication delays and;
- *Seeking user* prefers to pay more for fewer delays.

The proposed model consists of a topology of a wired network which is linked to two WLAN APs with a multi-homed node integrating the consumer surplus based selection scheme. Results have revealed that the value of using a proper utility function for a given user preference is highly reliant on of the file size. For large file, the price difference may discourage low budget users from this choice. Also, it is not suitable for real time applications. The reason behind this is that negotiating the prices of the network just before the handover may cause very long delays and may also interrupt the user applications that is usually annoying to the users.

Following a similar pattern Quoc-Thinh *et al.* [75] proposed a user-centric scheme for vertical handovers in heterogeneous networks. They have explained the solutions for network selection and interface management and they have opted to use a terminal-controlled handover solution. They proposed to employ an aggregate utility method to best assess the candidate wireless networks for network selection which is calculated by the equation 3:

$$U(x_i) = \prod_{m=1}^{M} [u_m(x_m)]^{\alpha m} \tag{3}$$

where M is the number of considered criteria and x_m is the value of network parameter m, αm is the preference weight of network parameter m corresponding to the current user situation profile and current running application class and u_m is the elementary utility function of criterion m.

They have discussed and shown with the help of simulations the needs and the advantages of having user and application preference configurations. The network selection triggering conditions are specified to guarantee smooth vertical handovers and they are based on a predefined RSS threshold. Furthermore, they proposed the power-saving interface management strategy to improve the use of nodes' power for multi-mode radio devices and interfaces. It works as a complement to the network selection system by switching off inappropriate network interfaces according to the node velocity and the remaining battery lifetime. This solution assists in improving the power consumption to further extend the mobile users' communication time.

Similarly, Gozalvez *et al.* [76] solve the issue of appropriate resource distribution in heterogeneous environments by exploiting user configurations. They propose to use an average data rate using a utility function at first phase of the scheme for each candidate network and its available resources. Secondly a relationship between the resulting utility values and resources is established for mobile users to make a handover decision and a proper network selection. However, these schemes do not always guarantee a proper network selection because utility based scheme does not mirror the independence among the considered criteria. Thus, the recompensation between a very high utility network parameter and a very low utility network parameter in the aggregate utility approach leads to the improper network selection and decision.

2) Cost Function based Schemes: Zhu and McNair proposed several vertical handover decision algorithms that rely on a cost function that is used to calculate the cost of possible target networks from the available ones [10], [77], [78]. The proposed cost function lines up all the running applications and a cost for each candidate network is calculated using application preferences accordingly. The total cost of a candidate network is calculated using the sum of the cost of available QoS parameters like bandwidth, battery consumption and network delay. The mobile user is handed over to the network that offers the lowest cost for maximum services. The key advantage of using a cost function lies in handover initiation independency that eventually benefits users with request satisfaction and reduced call blocking probabilities. However, authors did not discuss in their proposed mechanism that how the QoS dynamics are controlled and normalized and, how weight assignment to those dynamics is carried out.

To solve these issues, Hasswa *et al.* in [79]–[81] propose a cost function for vertical handover decision making while roaming across heterogeneous wireless domains. The proposed cost function incorporates the parameters of cost, security, velocity and power consumption. A network quality factor is developed that normalizes these parameters and also, assigns weights to these dynamics in order to evaluate the performance of a candidate network as depicted in equation 4):

$$Q_i = w_c C_i + w_s S_i + w_p P_i + w_d D_i + w_f F_i \tag{4}$$

where w_c, w_s, w_p, w_d, w_f are the weights assigned to the parameters and Q_i represents the quality factor of i^{th} network, C_i is the cost of service, S_i is the security level, P_i is power consumption, D_i is the network conditions and F_i represents the network performance. Apart from this procedure, a handover necessity estimator is also described in their works that is used to avoid unnecessary handovers. The proposed scheme by Hasswa *et al.* receives overall high system throughput and user satisfaction. But, certain network parameters like security levels and signal interference levels are hard to approximate, and the authors have not provided any further information on how to compute these network dynamics.

Furthermore, a policy-enabled handover across a heterogeneous network environment is proposed using a cost function by authors in [82]. A cost function considering the parameters of RSS and bandwidth is used as a measurement of the benefit obtained by handing over to a particular network. The cost function presented in [82] is estimated for the available networks and later, used in the handover decision of a mobile node. Using a similar approach, a cost function based vertical handover decision algorithm for multi-services handover is proposed in [83] by Yifei *et al.* The available network with the lowest cost function value becomes the handover target. However, only the available bandwidth and the RSS of the available networks are considered in the handover decision performance comparisons in both solutions.

Authors in [84] concentrated on a network selection algorithm for seamless vertical handover among WiFi, HSPDA and Wi-Bro networks by taking into consideration the parameters of cost and user preferences. GPS and network maps are exploited for evaluating the current location of the mobile nodes and according to the results obtained via this calculation, a candidate network is prioritized. Once a priority list is available, mobile node is immediately switched to the new network. Authors do not describe the effect of their network selection method on perceived QoS. Also, authors have completely ignored to evaluate the parameter of RSS that may influence connectivity issues of the candidate networks.

Authors in [85] investigate the problem of guaranteeing the QoS in cellular relaying networks using the parameters of RSS, handover latency and signalling cost.They have defined a cost function that prioritizes the handover process upon receiving handover requests. In this way, all the handover requests are queued and the network with the lowest cost is chosen as a handover target. They have minimized the signalling cost by in-advance queueing mechanism. They also claim that QoS of the handover procedure is improved. However in our view, this scheme overburdens the channel capacity by keeping the handover requests that will consequently generate the handover latency.

Natasa *et al.* [86] address the scenario of very tight coupling in UMTS integrated environments for vertical handovers between IEEE 802.11, IEEE 802.16e and DVB-H networks [87] based on the pricing mechanisms for interface selection. However, authors do not provide the evaluation of the approach to depict the resulting performance of the vertical handovers. Similarly, authors in [88] propose three different mechanisms of imperative, alternative and power based vertical handovers across heterogeneous networks and claim to optimize the handover procedure. But, no evaluations of the algorithms are presented to justify their claims.

3) Network Score Function based Schemes: Multiple Attribute Decision Making (MADM) [89] is an algorithmic way of suitably realizing the network interface selection and handover decision using different alternatives and their respective attributes. A MADM scenario is usually represented in the following form: $A = A_i, i = 1,2,...,n$, which is the number of alternatives that signify the networks that any MN may support and $C = C_j, j = 1,2,...,m$ represents the set of network attributes/characteristics that might belong to the running applications or connected users like for example RSS, bandwidth, security, packet loss, etc. Finally, weight or score vector $W = w_1, w_2, ..., w_m$ denotes the significance of these characteristics. Simple Additive Weighting (SAW) [90], Weighted Product (WP) model[11] [92], Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) [93], Vlsekriterijumska optimizacija I KOmpromisno Resenje[12] (VIKOR) [94] and ELimination Et Choix Traduisant la REalite'[13] (ELECTRE) [95] are some of the methods that have been successfully employed in heterogeneous wireless network for making handover decisions.

In SAW, the total score of a network is calculated by the weighted sum of all the attribute values whereas, in WP, attribute values are multiplied to attain a network score [96]. In case of TOPSIS, a handover candidate network is the one that provides the closest scores to an ideal solution whereas, ELECTRE gives the concept of ranking the best available network using "outranking relations" by doing pairwise comparisons of alternatives and measuring each criteria separately. VIKOR, which is a compromise ranking method, is quite similar to TOPSIS. However, it facilitates the decision making using an aggregate score function that represents closeness to the ideal solution [97].

Following the above described pattern, a distributed vertical handover decision algorithm is proposed by Tawil *et al.* in [98], [99] that combines together the MADM and SAW methods. They treated the decision making process as an MADM problem using a score function. This score function is a consolidation of a set of performance parameters like network conditions, network bandwidth, monetary cost, power consumption, handover latency and network security and are expressed as indicated in the equation 5:

$$Q_i = (W_B \times B_i) + (W_{Dp} \times \frac{1}{D_{Pi}} + W_C \times \frac{1}{C_i}) \tag{5}$$

where, Q_i represents the quality of the i^{th} network, B_i is the bandwidth (depends on the network type) of the i^{th} network, D_{Pi} is the dropping probability of the i^{th} network and C_i is the cost of the service of the i^{th} network. W_B, W_{Dp}, W_C represent the weights of these parameters and where $W_B + W_{Dp} + W_C = 1$.

The candidate network with the highest quality is selected as the handover target. Authors emphasize on the fact that the handover decision time can be reduced if all the handover related calculations are carried out by the network because this will eventually conserve the critical resources of a mobile node. The proposed procedure helps in achieving reduced handover blocking, higher throughput and optimized handover decision delay. But, the proposed scheme needs some extra cooperation between the MNs and the attachment point of the visited network that tends to produce supplementary handover latency and excessive network load when a large number of mobile nodes are present. Also, the given solution does not address the complexity involved in the NGNs for applying such kind of solutions. Also, it is important to calculate the handover decision processing delay from the network.

Author in [100] uses fuzzy ELECTRE technique to cope up with the problem of complexity involved in a vertical handover in heterogeneous networks, respectively. They propose to use the parameters of MN speed, resource availability, RSS, service type, user preferred cost and security. In the first phase, they employ these parameters to a fuzzy system for initial ranking of networks and in the second phase, these criteria are computed by the ELECTRE method for total ranking of all the available networks. A pair-wise comparison of all the networks is done for separating the best and the worst available networks depending upon their network scores. Proposed scheme achieves better results in terms of handover rate and ping-pong effect when compared to the classical handover approaches. However, they have not discussed the impact and complexity of using a large number of parameters in the decision criteria. Also, how an optimum value of network scores is obtained for making a handover decision? seem to be an issue with the suggested mechanism as it may directly affect the scalability of the proposed solution. In another work, author proposes to use VIKOR for handover admission control [103]. Author aims to provide guaranteed QoS and to allocate uniform resources to all the users after a handover. However, it is not shown that how dissimilar information coming from heterogeneous sources is maintained or handled.

[11]This is also called as Multiplicative Exponent Weighting (MEW) [91].
[12]Serbian Term for Multi-criteria optimization and compromise solution
[13]French Term for ELimination and Choice Expressing REality

TABLE IV
DECISION FUNCTION BASED VERTICAL HANDOVER DECISION SCHEMES

Category of Handover Decision Scheme	**Candidate Handover Decision Scheme**	**Description of the Scheme**	**Advantages of the Scheme**	**Limitations of the Scheme**
Utility Function based Schemes	[71] [72] [74] [75] [73]	A utility function is designed that measures the users' satisfaction level according to network characteristics for balancing the allocated resource parameters.	- Cost effective - Conserves battery life - Guaranteed handover - Resource Balancing	- Longer communication delays - Unsuitable for real time applications - Inappropriate network selection
Cost Function based Schemes	[10] [79] [82] [84] [85] [86]	A function is designed based on the cost of possible target networks considering user/application preferences for an optimal handover decision and network selection	- Low handover blocking rate - High system throughput - Optimized handover decision delay	- Excessive load on the system - High handover latency - Difficult to estimate cost of some parameters
Network Score Function based Schemes	[96] [98] [99] [100] [101] [102]	An MADM based score function is defined that ranks the networks according to user needs for appropriate network selection	- Low handover blocking rate - Reduced Ping-Pong effect - Ranked network selection	- High Latency - Degrdaded QoS

Authors in [104] and [101] propose a network selection and handover decision method based on TOPSIS for ranking the networks in a wireless overlay environment. They take into consideration the handover history parameter as a prime factor for making a handover decision and proper network selection along with cost, security, bandwidth, jitter, packet loss and delay. They aim to make sure that an MN stays in currently connected access network for as long as possible. All the parameters are memorized by the TOPSIS decision engine which manipulates them accordingly for a suitable ranking according to user needs. Authors claim to reduce the number of handovers but, it seems that an MN is forced to stay in a network even if the QoS of that specific network drops below the user threshold. This shows the inappropriateness of such solutions in the heterogeneous radio access environments, which is also observed by [96] and [102], [105]. At the same time, they have observed that TOPSIS, SAW and VIKOR based handover decision making mechanisms are very effective in voice communication in 4G connections as they provide low values for jitter and packet loss whereas, MEW and ELECTRE based schemes usually provide higher throughput values for voice data [106]. If we summarize, it seems difficult to select between these schemes for an optimal solution for a vertical handover as ranking criteria is completely different among these and also, the influence of importance scoring in the evaluation of MADM schemes appears to be an open issue in NGNs, where a diversity of traffic type exists.

Table IV summarizes the decision function based vertical handover decision schemes presented in this section. Although these solutions are very interesting but most of them make the handover decisions on the basis of current system state only i.e., they consider only current QoS of the networks and current mobile nodes' conditions. Handover decisions should also consider the probabilistic outcomes of the future system states as a result of the current decision. Hence, some intelligence aspect and prediction technique needs to be integrated in the decision function. Some of the works like [98] have considered this aspect but not exploited to its fuller. Fuzzy logic and artificial neural network based techniques have played a very important role in providing an intelligent aspect to the decision mechanisms and they are widely used in decision making process. In the next section, we present some of the most interesting schemes for vertical handover decision making process.

D. Network Intelligence based Schemes

The access to multimedia applications in wireless networks is concerned with the performance of handover because of the irretrievable property of real time data delivery. In order to improve the performance of handover i.e., in terms of throughput, unnecessary handovers and handover latency, etc. it is very important to make the handover decision intelligently and timely. The concept of network intelligence comes when we want to tackle the issue of information visibility and consider the real-time network traffic. These solutions usually require some tools for correlating, analyzing and reporting the network using some source and input. This is the reason that we have chosen to put those solutions in this category that exhibit these properties to make an efficient handover decision and that help us unfolding the hidden network information for using in a handover decision. *Fuzzy Logic* (FL), *Artificial Neural Networks* (ANN) and intelligent IP-based protocols are applied for the past few years in order to choose when and over which network to handover among different available ones [107], [108] in an efficient and intelligent manner. Fig. 7 encompasses all these three categories and enlightens the generalized mechanism of network intelligence based schemes.

To the best of our knowledge, the works on fuzzy logic based handover appeared in 1998 by Edwards and Sankar [109]. They used fuzzy logic as a tool in order to reduce unnecessary handovers but no intelligent handover decision was involved in their approach due to the limitations of the field. With the advancements in the fields of fuzzy logic and neural networks, these are later combined with the multiple criteria concept to develop more advanced decision algorithms for both non-real time and real time applications [110].

It is revealed in the existing literature that classical MADM methods cannot efficiently handle a decision problem with imprecise data that decision criteria could contain [111], [112]. For that, the use of fuzzy logic is not only to deal with imprecise information but also to combine and evaluate multiple criteria simultaneously [113]. In this respect, fuzzy logic concept provides a robust mathematical framework where vertical handover decision can be formulated as a Fuzzy MADM.

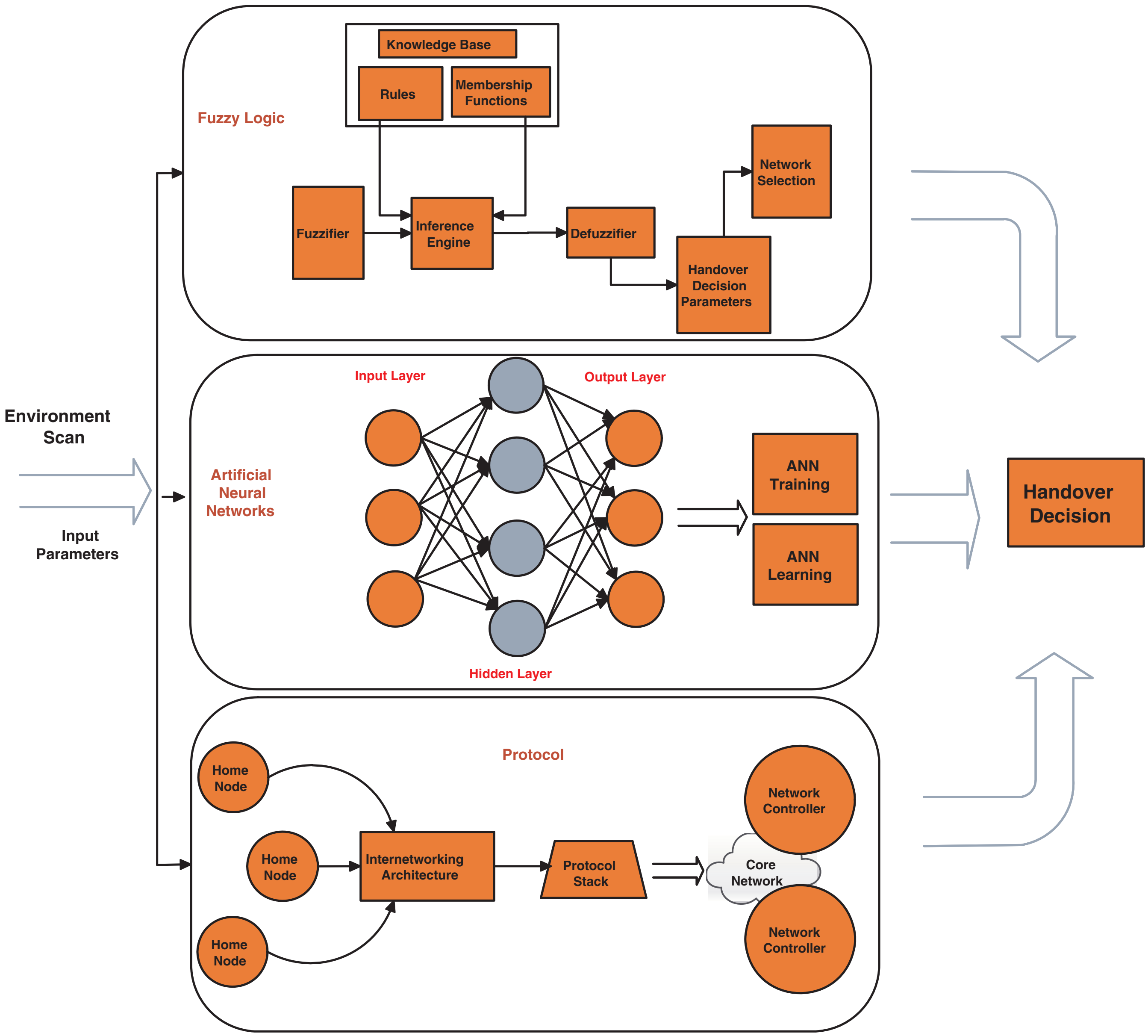

Fig. 7. Generalized Mechanism of Network Intelligence based Schemes

Similarly, the application of neural networks in handover related issues dates back to 2000 to our knowledge, where they were used for the estimation of the signal decay [114] and mobile users' profile prediction [115]. Neural networks have been successfully applied to solve complex problems by automatically learning the system behavior and generalizing it to situations that are not experienced before.

Furthermore, when we talk about intelligent protocol based approaches, IETF[14] proposed Mobile IPv4 (MIPv4) [116] which was altered with the evolution of IPv6 as MIPv6 [117] for dealing with the mobility and its related issues in IP-based networks. This protocol suffered a great deal of problems like maintenance and assignment of the home and care of addresses, latency and packet loss due to lack of network intelligence. Also, it failed completely in the high mobility and user congestion scenarios because immediate multiple binding requests are not entertained in MIP. This resulted in degradation of overall QoS. However, other mobility management protocols such as Hierarchical MIP (HMIP) [118], Proxy MIP (PMIP), Client MIP (CMIP) [119], Fast MIP (FMIP) [120], etc. were proposed by the research community to attain scalability and to make intelligent decisions in the course of high mobility in heterogeneous wireless environments. But these all versions are not without their shortcomings as discussed in [121] too. Now, we will present a number of network intelligence based vertical handover decision strategies which we have subdivided into following categories.

1) Artificial Neural Network (ANN) based Schemes: Partha in [122] proposed a neural network based technique for fast and accurate handover decision making in heterogeneous networks. The network has three layers called as input layer, hidden layer and output layer. Author used a back-propagation neural network scheme that is an iterative method [123] using

[14] Internet Engineering Task Force

the parameters of RSS and traffic intensities in the current and target networks. This method starts with the last layer of the neural network and moves backward through the layers until the first layer is reached. Using this method, the outputs and the errors in outputs are calculated and the weights on the output units are altered. Then, the errors in the hidden nodes are calculated and the weights in the hidden nodes are altered. The back propagation algorithm changes the weights to minimize the errors. The back-propagation neural network is trained with supervised mode i.e., the actual output of a neural network is compared to the desired output. Author has shown from the results that the handover decisions are taken in appropriate positions, the number of fluctuations is low and numbers of handovers are also low. However, author does not give any information about the neural network learning/training process. Also, the delays caused by the learning procedure is an issue in the proposed scheme.

In [124], Nasser *et al.* propose a Vertical Handover Manager (VHM) middleware and explain the functions of its components. They used a neural networks-based approach to detect signal decay and to make handover decision. Authors aim to design an intelligent network selection system that has the ability to select the best available wireless network. It takes advantage of user preferences, device capabilities (e.g., power consumption), and wireless network features (e.g., cost and security) as network parameters in order to make a better handover decision and network selection. The proposed middleware has three main components named as (1) Network Handling Manager, (2) Feature Collector, and (3) Artificial Neural Networks Training/Selector as depicted in Fig. 8.

The mobile node gathers the information of available networks and directs them to this middleware through pre-established links. This network information, which usually includes network usage cost, security policies, network transmission range and network capacity, is used to assist the handover decisions. The neural network is employed for determining the best handover target wireless network available to the mobile node by making use of the user's preferences. It comprises of an input layer that contains five nodes representing various parameters of the candidate networks, a hidden layer that includes variable handover initiation functions and an output layer that is used to generate the network ID for candidate network. They have used the same cost function that was proposed in their earlier work in [80]. In order to train the neural network, they have generated few sets of user preferences by assigning random weights to the network parameters. Then, VHM is trained in order to select the best available network among all the available ones.

Nasser *et al.* stated in their work that if learning rate and acceptable error value rate are properly tuned then the proposed architecture is capable of finding the best available network optimally [124]. However, the proposed approach gives high latency during the handover execution due to the large data size of neural packages and their training. This could become an issue when implementing such a system in real time. In addition, the ability of the system configuration to adapt to current data being fed into VHM might become infeasible since, the proposed method defined the number of hidden nodes prior in the training mode.

Similarly, Horrich *et al.* [125] propose neural networks and fuzzy logic based technique for the handover decision. They propose to use a Fuzzy Logic Controller (FLC) handover decision making. FLC applies the predefined rules to the current system conditions. A neural network learns the FLC parameters from the resulting handover quality indicators. In their work, they proposed to use RSS, velocity and network load as the handover decision parameters. A preliminary selection of handover target networks is performed before initiating the vertical handover procedure. Target networks with signal level and network load above predefined thresholds are filtered and then, the target network with the best signal quality is chosen. This pre-selection reduces the FLC complexity and saves the processing time. However, this scheme faces the similar constraints as the one presented in [124]. Apart from those limitations, this scheme is applicable for the small environment variations and not adaptable to the new network conditions. For example, if the network load increases due to an increase in the number of mobile nodes, then the overall performance of the proposed scheme deteriorates. Neural network needs to learn at faster rate in order to tackle this problem.

Authors in [126] propose a link quality based handover mechanism by exploiting the benefits of ANN. They employed the parameter of Packet Success Rate (PSR) as a link estimator instead of RSS for making handover decision. This is because PSR helps in reducing handover delay. ANNs assist in learning the network behavior and the correlation function among PSR and network entities for their respective contexts like packet length, SNR, RSS and number of connected mobile users to a specific AP. During this learning phase, some measurement samples are collected and are later on, generalized for making a handover decision in any scenario. This helps in reducing the handover decision processing delay and overall handover latency. Also, packet loss is kept limited to a certain level by employing different ANN functions [127].

2) Fuzzy Logic based Schemes: In [128], Attaullah *et al.* proposed a fuzzy logic based vertical handover decision model in order to improve QoS in heterogeneous wireless networks. To keep the connection alive during handover they have applied a make-before-break handover strategy. Handover decision is based on triggers which are generated from different layers using fuzzy logic. They have proposed to use RSS, network load, available and required bandwidth and jitter as handover decision parameters. In their work, they have introduced an entity Event Collector that maintains the states of every interface variable for further processing and maintains final output selection that is returned from the fuzzy expert system. Then, fuzzy expert system collects input parameter values from event collector as crisp inputs and then evaluates them according to the predefined handover rules. The crisp input is then evaluated using rule base. The composed and aggregated output of rules evaluation is de-fuzzified and crisp output is obtained to make a handover decision. This scheme seems very simple and interesting but no justifications on the handover decision process are provided.

Another study has been conducted by Jun *et al.* [129] in this category. They proposed to use a Fuzzy Inference System in order to select an appropriate network and make

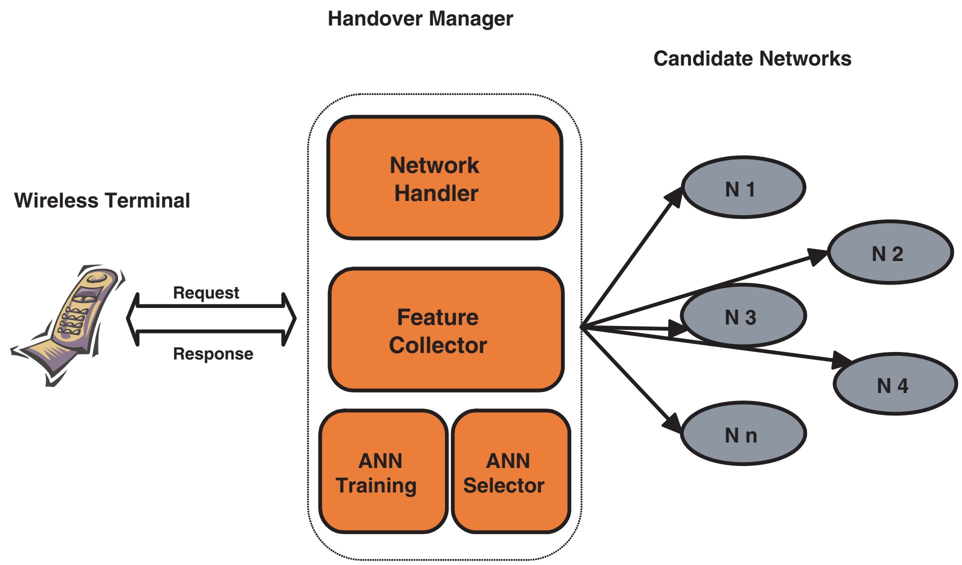

Fig. 8. VHM Middleware Architecture as proposed in [124]

a handover decision towards that. Following procedure was inducted by the authors using the input parameters of RSS, available bandwidth and the distance from the access point. Input parameters are fed into a fuzzifier that converts them into fuzzy sets by determining the degree to which they belong to each of the appropriate fuzzy sets via membership functions. Next, the fuzzy sets are sent to a fuzzy inference engine for the application of IF-THEN rules to attain fuzzy decision sets. The output fuzzy decision sets are accumulated into a single fuzzy set and delivered to the de-fuzzifier for conversion to an accurate quantity in final stage of the handover decision. For analyzing the performance of proposed scheme, a handover was performed between WLAN and WiMAX and, vice versa. The proposed scheme reduced handover delay and packet loss but somehow, the procedure seems to increase the decision processing delay because of fuzzification and de-fuzzification processes. Also, this scheme lacks the inputs from users about their priorities or specific needs.

Liu *et al.* [130] proposed a scheme to manage handovers between WLANs and UMTS networks. They introduced a pre-decision unit in their algorithm, which is responsible for service continuity between the two networks. According to the proposed scheme, if the mobile node is attached to the WLAN, and its velocity v is higher than a predefined threshold v_T, a handover towards the UMTS network is initialized in order to avoid a connection loss. In other situations, the pre-decision unit verifies whether the predicted RSS fulfills its requirements i.e., is it at a sufficient level for the mobile user? If the predicted RSS level from the WLAN PR_W is superior to its threshold Pr_W, or the predicted RSS from the UMTS PR_U is inferior to its threshold Pr_U, then a handover is not initiated. Afterwards, the fuzzy logic based normalized quantitative decision (FNQD) that consists of three processes i.e., fuzzification of the input parameters (current RSS, predicted RSS and bandwidth), normalization of parameters and quantitative decision making process is used to generate performance evaluation values (PEV). The handover decision is taken by comparing PEVs of the available networks. If an MN is connected to the UMTS and at the same time a WLAN connection is also accessible, then the pre-decision unit is employed to remove unnecessary handovers when the velocity of the MN is greater than the threshold v_T. A similar process is conducted for the vice versa condition. This handover scheme is able to attain better performance in terms of reduced number of unnecessary handovers and Ping-Pong effect avoidance. However, fixed weights are assigned to the three input parameters when PEVs are calculated which is not useful because the network conditions and user needs may vary in different network conditions. Additionally, some more performance assessment measures like handover latency need to be addressed.

In [107], authors present another fuzzy logic based handover decision algorithm. They consider the parameters of RSS, variation of the RSS (VRSS), bandwidth, traffic status and handover preference. The first fourth parameters i.e., RSS, VRSS, Bandwidth and Traffic status are used to initiate forced handovers, while the fifth one is used to trigger voluntary handovers. Authors have proposed a five step handover decision scheme:(1) handover initiation, (2) context preparation, (3) fuzzy conversion, (4) preliminary selection and (5) MADM. Handover initiation feeds the network parameters into a fuzzifier. The main role of the fuzzifier is to transform real time measurements into fuzzy sets and assign the values like *Weak*,*Medium* and *Strong*. Then Context preparation module defines for each service a list of weights that reflects its importance toward the considered criteria. In fact, during this process authors have assigned parameter thresholds for each service that refers to a particular networks' conditions in order to support mobile users' services. After the de-fuzzification phase, preliminary handover selection filters unsuitable candidate networks and performs the handover towards the chosen network. According to [107], the proposed decision strategy deals adequately with handover triggering by taking into account forced and voluntary handovers. However, authors did not explain that how unsuitable networks are eliminated and how a network is chosen for handover. In addition, they have not given any details about the experienced handover delay or packet loss in their scheme. A very similar approach that uses fuzzy sets is presented in [131] as well.

The approach presented by Haibo *et al.* in [132] is very similar to the one in [133] by Meriem *et al.* The only difference that can be seen is that, [133] focused on the decentralization aspects of VHO while [132] delegate the concept of fully terminal controlled VHO i.e., completely centralized VHO. A network discovery algorithm is presented which uses MCDM and fuzzy logic. Authors intend to reduce the power loss of the terminals and handover failure rate by controlling the states of their interfaces (i.e., ON & OFF). An MN contains different modules to assist the handover procedure. However, this approach tends to produce some overhead in terms of delay that may eventually degrades the performance of the scheme in our view point.

Kang *et al.* present a fuzzy logic based scheme for handover decision making in [134], [135] and [136]. They have used a large number of parameters as context information to design their autonomic oriented approach, like QoS, cost, user preferences, service type, battery level, etc. They have defined two metrics for assessing the capabilities of the future point of attachment: (1) AP acceptance value and (2) AP satisfaction value. These metrics help an MN to better select a future PoA. However, a regular feeding of the fuzzy rules is required to obtain this functionality, which is a cumbersome process due to the involvement of large number of parameters. Also, this approach provides the results that are very close to the conventional cost based schemes like [77] and [81]. The reason behind this is that the approach is not completely autonomic as authors have not shown that how they represent and store the contextual information. Also, the decision making process is not self-evaluating in a sense that it requires constant input of parameters from the mobile user. This scheme provides an elevated handover delay as well.

Authors in [137] propose an intelligent resource management technique for heterogeneous mobile networks. They have divided their approach into two folds: (1) fuzzy logic based network selector, and (2) genetic algorithm based bandwidth allocator. Fuzzy system is responsible for automatically determining the proximity of the availability of the new networks and new arriving calls, while genetic algorithms measures the amount of bandwidth utilized due to a call arrival, dropping and blockage. Generally speaking, the proposed mechanism optimizes call dropping and blocking however, extensive computation is involved in the decision making process that decreases the overall performance of the approach and, it also adds some overhead to the mechanism. Another fuzzy logic based scheme is presented by Ceken *et al.* [138], which takes into account data rate, RSSI, and terminal speed as inputs for handover decision making and proper network selection process. Apart from these parameters, an additional input i.e., interference rate is also introduced. A smart mobile terminal is designed that is responsible for performing the whole handover procedure from initialization to execution. This terminal is assumed to have intelligence for performing these tasks efficiently and it exhibits complete information about the environment, where it is serving.

A network selection and decision method is proposed by Ioannis *et al.* [139] using fuzzy TOPSIS in order to find the best balance between the network resources and to eliminate the conflictions in network selection process in heterogeneous wireless networks. Authors use various parameters in a utility function like network conditions, QoS, energy and user preferences for selecting an optimal network in terms of energy efficiency for real-time and non-real-time applications. This function also helps in normalizing the handover decision process by removing the existing inconsistency problem of ranking the networks, where multiple networks are present. However, authors do not provide any information that when a handover would be triggered? and how is the network scanning done? These questions are important to answer for seamlessness and Ping-Pong effect avoidance in our view.

3) Intelligent Protocol based Schemes: With the arrival of cooperative diversity and cooperative networks, users are changing their trend from QoS to QoE and in our stand point; this can only be achieved when the handover process could be made seamless and fast enough. In this regard, Partner-based HMIPv6 (PHMIPv6) [140] is proposed as one of the pioneer works for cooperative networks and that tries to accelerate the handover mechanism by resetting itself prior to the ingress of the MN into the overlapping area. An enhancement of the PHMIPv6 is introduced in [141] to reduce signaling overhead, integrate security especially, avoidance of Denial of Service (DoS) attacks and reducing the constancy of a mobile node on its partner nodes[15] while roaming. They have introduced a Link Expiration Timer (LET) that is utilized for setting up the pre-handover requests and localizing the MN by incorporating the doppler effect. For effective estimation of LET, data packets are sent at lower frequencies to avoid attenuations or other atmospheric effects. Partner node sends only those messages that it gets from its neighboring mobile host. This results in more pre-handover request failures and longer handover delays; this is the reason that the nodes perform handover using HMIPv6. However, in ad-hoc mode, PHMIP outperforms almost all other protocols in terms of handover success ratio, packet loss and delay because any node can communicate with the other nodes and receive the packet from them as well.

Vidal *et al.* [142] introduced a framework for proactive context transfer for P2P IPTV service in IMS networks. They considered inter-network handover scenarios in their approach by reducing the packet loss and enhancing users' quality of experience. For this purpose, they proposed to use buffers at the parent peers in IMS for reducing the handover delay at the user equipment. Packet loss is monitored by controlling the bit rate of the P2P streams. While, as the terminal initializes the handover process, all previous contexts in the MN are removed and a primary context for IMS signaling is established as the MN attaches to the target network. This is done via using some intra-domain controllers for context transfer in SIP protocol.

[15] A partner node is the one that performs different steps comprising the handover procedure on behalf of a Mobile Host and cooperation of the participating nodes in this case is not reciprocated.

This process helps in reducing handover delay at the user side. Context information in this approach consists of three main portions: (1) Configuration parameters of the user equipment, (2) QoS related information and its transfer parameters, and (3) user equipment's security configurations. This work was limited to the context transfer of the P2P streams. Authors extended their works in [143] and generalized their framework for multimedia applications. They introduced a handover manager and an address translator to increase the independency of the platform and to enhance the transparency of handover procedure for applications.

Authors in [144] addressed the issue of node authentication in networks, where trust relationship is not present, using the context of Mobile-Controlled Handovers (MCHO). For this, an authentication ticket is generated in the first phase which follows rapid authentication of the new arriving mobile nodes in that specific network. They took advantage of the AAA mechanism and defined a AAA proxy [145] that bridges the trust relation using a shared key across different networks. This shared key is normally sent to the candidate networks in advance. As a mobile node ascribes to a new network, it is directly authenticated using AAA proxy and does not involve home network for this purpose. This process helps in reducing packet loss as all the data is redirected to the new network in anticipation. Also, an MN is given the full control of keying information for rapid authentication which solves the issues of privacy and security like DoS and masquerading attacks to some extent as well.

Using Stream Control Transmission Protocol (SCTP) [149], Ma *et al.* discussed the issue of vertical handover at transport layer between UMTS and WLAN networks for efficient service provisioning and continuity by exploiting the multihoming features of the said protocol [150] [151]. They divided their proposed scheme into two scenarios based on the mapping and configuration of outgoing source and destination IP addresses in the routing table: (1) Single-Homing Fixed Server where, an IP address is added to the routing table, handover is triggered, and the IP address is deleted from the table and (2) Dual-Homing Fixed Server where Mobile user is given the priority for performing IP address management functions like adding, deleting and updating nodes from the routing table. Both these configurations are compared and dual-homing gives better results in contrast to single-homing in terms of throughput, latency and number of dropped packets. This is because, mobile user spent too much time in the handshake process that affects the arrival of packets into or out of the network. Also, address reconfiguration in single-homing scenario is a time consuming process.

To cope with these issues, Ezzouhairi *et al.* [152] contributed to the field and introduced MSCTP+ (Mobile SCTP+) that reduces the handover latency and packet loss due to dynamic address reconfigurations during a handover procedure. They also extended their works by introducing a hybrid interworking architecture for different protocols in [146]. This architecture incorporates diverse cellular and IP networks, which are considered as peers, around a single IP backbone that hides their respective heterogeneity from one another. Proposed architecture contains various entities like *Interworking Cooperation Server* that handles signaling the 3G networks and works in the control plane, and *Local Interworking Cooperation Server* that manages network data traffic for QoS assurance and seamless mobility. This hybrid architecture shows its scalability by treating the real time traffic and by reducing latency, packet loss and handover blocking.

In [147], authors propose Enhanced Mobile IP based handover scheme that uses layer 2 information for handover decision making like RSS, bandwidth and link indicator, etc. as this information is continuously available and can furnish the information about neighboring access networks. Conventional MIP message structure is modified for reducing handover latency and packet loss ratio in the proposed algorithm. A similar method is proposed in [153] using Proxy MIP (PMIP). However, this technique produces some extra signalling overhead and higher processing cost due to the implications of some application layer services involved in it. Following the same pattern, [154] propose to use inter-domain PMIP for reducing handover latency and packet loss in layer 3 handovers. This mechanism involves some extra messaging between the serving domains and as a result, succeeds to reduce handover latency and packet loss.

Munasinghe *et al.* [148] presented a tight-coupling interworking architecture of WLAN and UMTS employing IMS as a signal arbitrator. They analytically modeled the above scenario by using handover delay, packet loss, jitter and signaling cost; and created the relationships among these parameters too. Thus, if the value of one parameter is changed then it may change the whole set of results like for example, packet loss is directly proportional to the handover delay and its higher values may directly contribute to the behavior of packet loss. In the proposed architecture, which is an extension to their previous works [155], IMS is used for centralized terminal and session management via SIP that actually empowers the UMTS network to cope with the session mobility issues in heterogeneous wireless networks. The proposed approach reduces packet loss and handover latency to some extent. However, there is some extra signalling involved that produces overheads and affect the performance of the mechanism.

Table V summarizes the network intelligence based vertical handover decision schemes presented in this section. In the next section, we describe some of the candidate context based schemes for handover decision making process. Context transfer is a solution proposed by the Network Working Group (NWG) [156] in order to reduce the handover time by transferring the information related to the mobile node from the current access router to the next access router over the wired network for avoiding the extensive use of limited wireless bandwidth resources.

E. Context based Schemes

Context is formally defined as any information that is pertinent to the situation of an entity (person, place or object.) [157] [158]. However, keeping in mind computer networks in our view point, it is the delivery of correct and accurate information to the end users for making a decision and it allows the characterization of networks that need same content i.e., mobile users in similar circumstances must obtain

TABLE V
NETWORK INTELLIGENCE BASED VERTICAL HANDOVER DECISION SCHEMES

Category of Handover Decision Scheme	**Candidate Handover Decision Scheme**	**Description of the Scheme**	**Advantages of the Scheme**	**Limitations of the Scheme**
ANN based Schemes	[122] [125] [124] [126]	ANN is applied to tackle complex problems by automatically learning the network behavior & generalizing handover in dynamic situations.	- Successful Handovers - Better Network Selection - Lower handover processing delay	- High Latency - Slow training & learning - Supplementary resource consumption
Fuzzy Logic based Schemes	[128] [129] [130] [107] [132] [134] [137] [139] [138]	FL is used to carry out network assisted handover decision by prioritizing QoS dynamics according to user preferences	- Reduced handover delay - Reduced packet loss - Intelligent network selection - User satisfaction for QoS	- Increased Complexity - Higher decision processing delays
Intelligent Protocol based Schemes	[117] [120] [140] [141] [143] [144] [146] [147] [148]	Different mobility protocols are designed for providing seamlessness and proper network controlled handover mechanisms.	- Reduced packet loss - Terminal resource conservation - Successful handovers - Security provision	- Comparatively high latency - Centralized Control - High signalling overhead

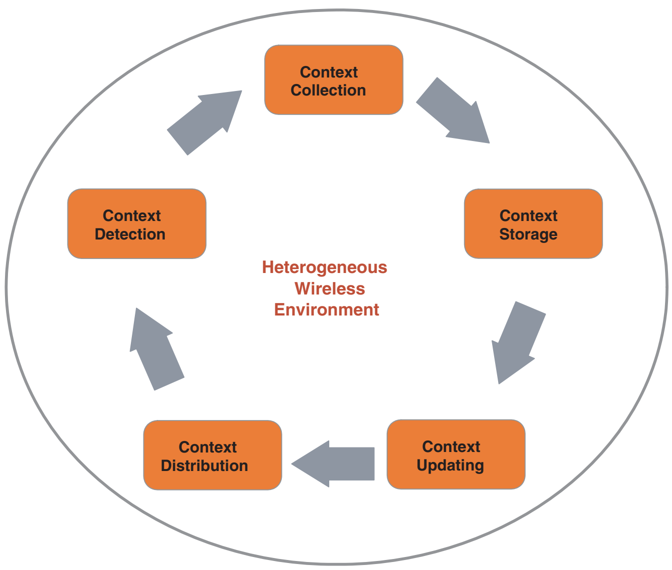

Fig. 9. Generalized Context-awareness Mechanism

the same information. We depict the generalized context-awareness mechanism in Fig. 9 where at first, contextual information is detected from different layers of the networks residing in the environment. Next, this information is stored in a knowledge-base for employing it in making handover decisions. Validity of information is very important in any context based system and for this purpose, information must be timely updated or matched with the user needs. This updated information is distributed all across the network or where it is needed to make optimal handover decisions.

Handover procedure necessitates the transmission of data packets towards a new wireless network for rerouting the MNs' connection path to the new access point. For doing so, it is necessary that the network transmits complete routing information pertaining to the nomadic user towards the new or target AP for appropriate packet forwarding. Since, heterogeneous networks function in an environment that consists of various standards and networks, packet transfer to a new wireless link likewise implicates transmission of additional contextual information. This is important so that the mobile nodes can roam freely across different networks while maintaining their packet flows active.

We define a context-aware handover procedure as *a handover in which a target access point is selected based not only on the signal quality or explicit advertisements sent by the access point(s), but also on the knowledge of the context information of the mobile nodes and the networks, in order to make better and intelligent decisions.* The desired goal of transmitting the context of an MN in anticipation to the target network is to reduce the delay which is caused in re-establishing the mobile nodes' traffic flows. However, if this delay is large, or in other words, large enough to upsurge the overall handover call dropping rate, then the advantages of context transfer are gone. A mechanism to support fast and seamless vertical handovers while avoiding a large amount of signaling message exchanges, is presently a crucial issue and an active area of research [159]–[165]. Now, we will present a number of context based vertical handover decision strategies which we have subdivided into following categories.

1) Mobile agent based Schemes: Mobile agents are programs, typically written in a script language, which may be dispatched from a client computer and transported to a remote server computer for execution [166]. In [167], Wei *et al.* propose a context based handover decision mechanism. It describes a mobile agent based decision mechanism in which, information is downloaded at the decision point and later, invoked at the time of handover. The proposed architecture consists of three main parts: (1) a context management framework, (2) a programmable platform and (3) a service deployment scheme to provide the functionality needed for context-aware handover. The context management framework is responsible for collecting and managing the context information of different network services. The programmable platform (i.e., mobile agent) is used to download and to install the suitable modules for contextual exchange. The service deployment scheme is used to synchronize and to manage the work of the mobile agents. It comprises of two main modules: (a) the context repository which collects, manages, and assesses the contextual information coming from various parts of the network and (b) the adaptability manager that decides about adaptation to contextual variations and handover execution. It is a rule based system which is responsible for taking the handover decisions that are invoked with the evaluation of mobile node's location changes and QoS of the current and available networks.

The QoS-aware network selection relies on Analytic Hierarchy Process (AHP) method that assists in applying user perceived QoS for an optimal handover performance. It has very important tasks to perform like maximizing application bandwidth, and minimizing jitter, delay, packet loss and bandwidth fluctuations. The proposed solution provides smart decision making mechanisms by integrating context gathering and handover decision processing in a mobile-assisted handover. Different types of wireless networks are used for testing the performance of prototype by considering different decision rules. It has revealed that smart decision strategies are essential for smooth adaptations to a diversity of context changes. Also, the throughput of the system is increased. This scheme minimizes the handover decision delay but a single point failure may crash the whole system as all the information is stored at a single point and there is no distribution of information. In addition, when a handover is needed then the responsible mobile agents need to be called, downloaded and installed from the service depository unit which increases the overall handover delay. Besides that, it needs a regular communication between the mobile nodes and the network that eventually results in an increased signaling overhead over the wireless links.

In [168], authors propose a Mobile agent-based Ubiquitous multimedia Middleware (MUM) with an aim to transparently avoid service interruptions during horizontal and vertical handovers in the heterogeneous environment. First, MUM monitors the signal quality from all the wireless network interfaces available at client and predicts possible handover. In order to predict a handover, RSS of different networks is compared and when a handover is predicted, it exploits its context to select an optimal network from the available ones that best satisfies user service requirements and preferences. Authors have implemented a simple decision function which assigns weight to different parameters like handover delay, bandwidth, and user specified preferred network. For context transfer and location awareness functionalities, they have used session initiation protocol (SIP). Proposed middleware is tested for non-real time applications and it attains a variable packet loss and optimizes the handover rebinding latency. However, a large number of agents are used, which is already a load over the network. Deployment of the proposed prototype is also an issue as it incorporates only application layer protocols for session management (e.g., RTP and SIP). Authors in [169] also proposed a similar context-aware middleware that collects the contextual information from fixed networks and mobile nodes for providing end-to-end QoS.

Zafeiris and Giakoumakis [170] proposed another interesting contribution to the context based handovers. They propose to use mobile agent based architecture for handover management by focusing on the handover initiation and decision phases. Authors have defined three agent types: (1) Multi-Access Provider (MAP), (2) Wireless provider agents and (3) Terminal device agents. Multi-Access Provider agent is responsible for supporting the activities of other agents residing in wireless networks and user terminals. MAP agents encapsulate services which are provided by the MAPs' core elements and send to other agents executing in wireless networks and user terminals. Wireless provider platform executes agents that comprise of:

- One Network Provider (NP) agent that represents the wireless network service provider and offers an interface for monitoring network management information including context transfer services, QoS and service cost;
- One Network Monitor (NM) agent that represents the MAP and is responsible of aggregating the overlapping coverage information by subscribing to its corresponding NP-agent;
- Several Access Facilitator (AF) agents that represent the nomadic users and are served by numerous NM agents. These agents are responsible for handover initialization and handover decision making.

Each mobile device employing the MAP services can run two agent types that represent the nomadic users: (a) Profile-agent that communicate the perceived QoS and application needs to AF-agent for assisting in making timely handover decisions and (b) Connection Manager-agent that is responsible for successful handover executions which is preceded by a process that controls the mobile nodes' capabilities of accessing the selected network. This scheme proposed a network-controlled handover in order to save the terminal resources. It seems that the user preferences will be ignored by the network as it is totally a network centric approach. Handover latency that is introduced because of the agent migration is about $100ms$ during the handover execution, which is quite high. Also, the proposed scheme produces very high signalling overhead due to the utilization of multiple agent platforms and their collaboration mechanisms.

2) Context-aware AHP based Schemes: For the provision of adequate services (anytime and anywhere) to the users, network applications and services must be aware of their contexts and should automatically adapt to their changing contexts. Ahmed *et al.* [171]–[173] proposed a context-aware handover decision architecture that deals with the session transfer of the multi-mode mobile devices. They employed the AHP [174] in their proposal, which is a recognized and proven mathematical procedure to find the most appropriate choice amongst multiple alternatives that are built on certain predefined objectives. They have considered both; network side (like delay, jitter and BER) and terminal side (like processor speed, memory size and battery life) contexts in their proposed scheme. By following the AHP method at first, they defined some primary objectives for decision algorithm that include interface priority, reduced cost, delay, BER and jitter, improved throughput. In the next step, scores[16] are assigned to the network parameters that range from $1-9$, where 1 represents the highest while 9 represents the lowest score value for a chosen parameter. These priorities are calculated using the following equation 6:

$$G = \frac{L_u - L_l}{N_p} \tag{6}$$

where G represents the numeric space-gap between the two scores, L_u and L_l are the highest and lowest possible scores, respectively, while N_p denotes the number of parameters.

[16] score = priority of a specific parameter

Then, capabilities of the reachable networks are compared with the pre-configured user preferences and suitable scores are assigned to each of the available networks. Later on, these networks are ranked according to their objective scores and the network with the highest rank is finally selected for performing a handover. A simulation software is developed that is user friendly. It is evaluated for one performance parameter i.e., time delay which is experienced at the decision making and the session transfer phases. The total average handover delay is about $50-65$ms [172]. However, it works only if the capabilities of the neighboring networks are being input by the user or are known in advance. This approach is applicable only if more than one network are present in the vicinity.

A very similar technique has been adopted by Kassar *et al.* for deciding about the proper time and selecting the most suitable wireless network to perform a handover in [175] and [133]. For handover initiation phase, they have used a fuzzy logic based system that collects the terminal and network information while for making a handover decision and a proper network selection, they have employed the AHP method proposed in [171]. They have presented a case study of mobile-controlled handover between UMTS and WLAN networks. Authors claim to provide the seamlessness, flexibility and efficiency to the handover decision procedure but the complexity associated with the AHP method and fuzzy logic is not discussed. Moreover, the proposed mechanism lacks evaluations in terms of performance for better understanding. A similar approach is proposed by Bchini *et al.* [176] for layer 2 and 3 handovers in WiMAX mobile networks. This approach uses fuzzy logic and presents a profound analysis of the QoS parameters using different protocols like MSCTP (Mobile Stream Control Transmission Protocol) [177], CMIP (Client Mobile IP) and PMIP (Proxy Mobile IP) [119]. The proposed methodology optimizes handover delay and packet loss and at the same time, provides higher throughput due to the rapidity of handover.

In [178], authors present a vertical handover decision method to enhance QoS and maximize the network revenue to facilitate mobile users with enhanced quality of experience. This scheme uses a merit function for evaluating network performance which relies on user preferences and selects the most suitable wireless network for mobile users. Furthermore, an adaptive QoS monitoring method is associated with merit function for reducing the power depletion upon nodes' interface activation. This scheme improves the performance of handover in terms of handover call dropping rate, power consumption and network revenue. In this work, authors aim at optimizing resource utilization and maximize network revenue without violating QoS administration policies by the network operators. For selecting a proper network from the candidate list, they have used a merit function with a time-adaptive QoS assessing scheme to assure that the performance of the chosen access network is consistently the best. General form of the proposed merit function is depicted below in the equation 7:

$$MF = E_n \sum_i w_i N(p_{n,i}) \tag{7}$$

where $p_{n,i}$ is the i^{th} QoS factor in network n, w_i is its corresponding weight, E_n is the elimination factor of network n and N represents the normalization function. The weights of the parameters are calculated by the AHP method according to different traffic classes and there is a possibility that the user can assign them directly when a call is initiated. A handover is executed if the handover call request is predicted to be accepted. The perceived QoS is observed after each handover. The information is used as the criteria for fine-tuning the weights of each QoS parameter for attaining improved perceived QoS in future network selections. In order to evaluate the proposed decision mechanism, GPRS, UMTS and WLANs were simulated for measuring network selection and handover decision. Network selection delay, handover dropping rate is reduced when compared to a user centric approach in [71]. Overall revenue and QoS is also improved, however, user-operator negotiation for the QoS over a wireless link is a resource consuming process and it might result in some handover latency.

Inspired from [168], [175], Mokhesi *et al.* address the vertical handover issue in the context of Bluetooth and WiFi networks and use Bayesian Belief framework to support QoS-aware mobility in [179]. Handover decision is based on MCDM process and it considers user and application preferences, MN parameters, cost and network flows to evaluate and enable the handover decision mechanism with the help of proxy agents. Furthermore, for modeling the network parameters a utility function is used which gives the possibility of creating different user profiles that can be used by network operators depending on the different interests and preferences of the users. This utility function is used for the evaluation of candidate networks on the basis of network cost, which is very similar to the one used in [71]. This method performs network selection on the basis of network service cost however, authors do not discourse the QoS aspect in this case like for example, a network operator may provide a low cost network but with poor QoS. Also, heaviness of the Bayesian framework may also influence/include some handover delay that may not accepted by real-time applications.

Authors in [180] propose a location-aware handover scheme for Body Sensor Networks (BSN) and discuss the issue of inter-BSN handover management via WLAN for reducing transmission delay. Sensors are attached to the human backbone and they communicate with the WLANs using portable BSN server. The proposed method works fine for a low constant velocity and a simple trajectory. However, for complex trajectories and higher velocities, it tends to produce ping-pong effect and higher call dropping rate. In [181], Joe *et al.* propose a network selection algorithm based on the battery level of the mobile users, in order to prevent unnecessary handovers when the battery level is very low. This algorithm uses AHP and Grey Relational Analysis (GRA) that can select the optimal network in a candidate network list based on user preferences.

Pervaiz *et al.* consider heterogeneous wireless networks containing WLAN and WiMAX for vertical handover using AHP and game theoretical approaches [182]. They take into account the parameters of pricing, bit rate, user preferences and mobility. The proposed mechanism is totally dependant on location of the mobile user and configuration of the network for calculating the payoff of the handover as in [183]. Using this measured payoff, network selection is performed in order to better satisfy the mobile users. The main focus of the proposed approach is on the decision making process and maximizing cooperation of the mobile nodes with the network for user contentment. Similarly, [184] showed the implications of reputation-based game theoretical model for appropriate network selection. This work mainly focuses on improving the cooperation between network device and also, on identifying the user behaviors based on their previous experiences for an appropriate network selection and handover decision making process.

Sgora *et al.* in [185] propose a network selection method based on multi-attribute decision making using AHP and TOPSIS mechanisms. They consider different service level agreements (SLAs) that contain cost and QoS needs of the nomadic users for optimizing the switching procedure in WLAN and WiMAX environments. These agreements are signed between the service providers and the end users in order to accommodate their service requirements according to the importance of service parameters. This process is executed via weight assignment to the SLAs using AHP and, TOPSIS is employed for ranking the available candidate networks. Results have shown that by applying different SLAs over time, an optimal network selection mechanism is achieved that satisfies user and application requirements and improves overall quality of service.

3) Context-aware Mobility Prediction based Schemes: Network availability prediction has emerged as a very important field in the next generation access networks. In this regard, [186] provide a Dynamic Bayesian Network (DBN) based solution to address the issue of handover while exploiting Semi-markov models and context variables. However, it is not probable to measure all the contextual information that impact future network availability. For example, user preferences may change at anytime due to their dynamic nature and user sensitivity and thus, they are unobservable. Similarly, user velocity is a highly variable context and the current devices are normally incapable of calculating a precise/exact value of it. Authors try to resolve these issues along with the problems of hidden context and computational complexity of managing these contexts in [187]. However, this procedure consumes a lot of network resources which seems unavoidable and delay tolerant applications may not support this.

Work presented in [188] provides a mobility prediction mechanism by means of estimating user behavior. Authors take into consideration time of the day, duration spent in a specific network, handover history, group and location as handover decision parameters. They try to obtain accuracy in mobility prediction by monitoring the mobile users and their movement directions in a particular cell. A handover decision is made on the basis of user's movement periodicity, instead of RSS or any other handover parameter, by keeping in mind the time of the day that he/she traversed a specific network. Once a mobility pattern is decided then handover decision making is done in advance as in [189]. However, if the mobile user changes its time of the day or route then the entire schema needs to be re-built which will cause longer handover delay and higher packet loss.

Authors in [190], [191] and [192] present a mobility pattern based mobile-assisted handover solution. They propose to store the historical data of users' mobility in a database and every time a nomadic user follows the same path using a constant velocity, MN handovers to the previously known networks. However in this scenario, if any traversed network is switched off or not available due to any reasons then mobile user may face serious connectivity issues. Furthermore, if velocity of the mobile users changes then it might also affect the blocking rate and throughput of the networks because the network selection process will not stay intact due to its static nature and un-adaptability. Using a similar pattern, applicability of WiMAX handovers is discussed in [193] and [194] where authors use speed and available bandwidth as performance metrics to measure the efficiency of handovers. [195] also proposed a network selection method to improve QoS and reduce Ping-Pong effect in heterogeneous networks.

Wang *et al.* in [196] propose handover decision making algorithms in radio systems to solve the issue of handover uncertainty and where the need of handover is due to signal deterioration. The first method is based on the conventional decision theory where different signal levels are monitored, while second methodology is based on the Markov model where mobility prediction plays an important role. They consider user preferences, device configurations, network conditions and a complex parameter of *environmental impact* on the performance of radio signals. Network scores are assigned and candidate networks are ranked on the basis of user preferences. As the network conditions change, mobile user is switched to a new network with better QoS. However, this solution may not work in the real-world as it is very hard to capture the environmental effects on the signal quality of a radio network.

Shi *et al.* [197] propose to use MN's location and mobility patterns in horizontal and vertical handover scenarios for mobility prediction across heterogeneous wireless networks. GPS is used to identify MN's location which saves this information in a buffer. This information assists in estimating the mobility pattern, direction and velocity of a mobile node. The proposed mechanism reduces packet loss and handover latency. But, the issue that needs to be discussed here is the validity of the stored information because according to the speed of the mobile user, stored information would be obsolete in a very short time interval and a handover decision made on such kind of information will not be proper. Also, if the MN changes its speed then the solution must be adaptable enough to cope with this issue otherwise, Ping-Pong rate would be very high.

4) Context-aware Cooperation based Schemes: A novel handover mechanism is proposed in [198] that combines spectrum awareness and MIH framework as a case study for mobility management in heterogeneous wireless networks. Authors employed the cognitive cycle [199] in their research to add cognizance, adaptability and to support seamlessness and to enhance user experience in heterogeneous networks. The proposed mechanism consists of several functional entities such as:

- **Context Acquisition Function (CAF)** encompasses collecting and detecting the contextual information related to radio resources;
- **Context Information Provider (CIP)** is responsible for

collecting the necessary contextual information regarding user location, sensors and end users to support mobility management;

- **Context Matching** is associated with combining the CAF and CIP contexts according to application/user preferences to achieve optimal QoS; and
- **Mobility Management** is responsible for seamless handovers.

These entities help the fast handover procedure and prepare a user to switch to a network with better QoS. The proposed mechanism tends to be scalable as it enhances user experiences due to an advanced resource allocation. A possible representation of this schemes is depicted in Fig. 10. In [200], Haldar *et al.* followed the same lines to present an architecture for dynamic spectrum access and proper network selection. Proposed mechanism succeeds to reduce the call blocking probability, waiting and response time. It also improves the spectrum utility and throughput perceived by the end user. However, in contrast to the existing approaches the proposed method receives higher number of handovers and Ping-Pong effect.

Liu *et al.* presented a game theory based loose-coupling interworking between WLAN and WiMAX for vertical handovers [201]. Formulation of the handover decision is a game process and it is done with the help of a bidding model that takes into account delay, bandwidth, jitter, packet loss and cost offered by a wireless network. Bidding strategy is based on three assumptions and each network is presented as a finite set or denoted as a bid. Against each bid a payoff function is defined that calculates the overall utility of the candidate network. Once this function is calculated, game process starts to play in different rounds. If any specific agreement is not finalized in the first round then the cooperating entities re-adjust their bids and next round of the game process is initiated. The proposed method achieves better load balancing in the networks as compared to other cooperative schemes such as TOPSIS, SAW and GRA schemes [98] [139] [202]. However, handover decision pertains to produce some handover delay due to the complexity of bidding adjustments.

Wang *et al.* [203] present an architecture to support mobility in ubiquitous environments. They propose a decentralized context management architecture that is designed to satisfy user needs like in [204]. This architecture contains a path planning module and a handover module. These modules are stored on the Ubiquitous gate or U-gate which is one of the key components of the proposed architecture and which works as a gateway among the networks and devices like, sensors and other smart equipment. This architecture works with a communication model which acts as a mediator between the U-gate and ubiquitous environment and all the contextual information is modeled and stored in it. A network discovery message is sent by the smart device for locating a U-gate for retrieving contexts and upon reception of the response the smart device could obtain local contextual information. If any additional context is required for making a handover decision then the same smart interface is used for it. Once all the context is collected, smart device can handover to the new network with better resources or according to its needs. However, security remains an open issue in this open environment as any device can interact with other device and privacy of the contributing peers could be threatened by this.

Ong *et al.* in [205] present cooperative radio resource management architecture for continuous and seamless service provision through network assisted vertical handovers in heterogeneous IP-based environments. The proposed mechanism enables the $MN \rightarrow network$ and $network \rightarrow MN$ cooperation as described in [206] [207] as well. A generic network selection algorithm is developed that helps the handover decision making process by incorporating the QoS and other contextual information which is generated as a result of cooperation between the network entities. Proposed architecture is a dual-stage process that at first involves cooperative information exchange of QoS among access nodes and at the second stage, selects an optimal candidate wireless network through the measurement-based network selection for better resource utilization. In our view point, heterogeneity of networks enhances the overall system capacity and perceived QoS of mobile users as they can take advantage of different services from a diverse range of networks for example, WLAN offers high bandwidth and UMTS presents a better coverage for longer connectivity sessions. The proposed architecture improves the overall system utilization and provides a QoS-balanced mechanism for assisting heterogeneity in IP-based systems.

A novel cross-layer adaptation architecture is introduced for seamless multimedia content transfer by keeping intact the integrity and quality of media in mobile networks [208]. Proposed architecture has the following functional blocks: (1) *Adaptation Decision Module* is a MCDM based process and it is liable of tuning different multimedia related parameters like encoding parameters, end-to-end rate and distortion in image quality; (2) *Adaptation Execution Module* is context-based and is responsible for different encoding and decoding layers of the multimedia streams and sending them over different communication routes; (3) *Content Storage Module* is responsible for caching different segments of a multimedia stream and it acts as a server for quality enhancement; (4) *Network Awareness Module* is liable of keeping the information about the network parameters like QoS, link type, coverage, number of connected users, bandwidth, etc.; and (5) *Terminal Awareness Module* is responsible for keeping the information about the nodes' physical characteristics such as battery, display and processing speed. The proposed architecture is evaluated on a P2P testbed and it is shown that the perceive QoS degrades only when the frames are lost due to network congestion or any other environmental reason during the handover process. Otherwise, the proposed architecture succeeds to comply with the multimedia content delivery requirements as stated in [209] and [210].

Another cooperative context-based scheme is proposed by Musa *et al.* in [211] that emphasizes on the service adaptation for user satisfaction while performing seamless handover. The proposed mechanism is based on reasoning theory where, certain inference rules are deployed and are fetched with the help of a network ontology. This ontology contains nomadic user, network environment and service profiles and it combines handover, location and QoS awareness in horizontal and vertical handover decision making procedure for supporting multimedia stream continuity. For analyzing the performance

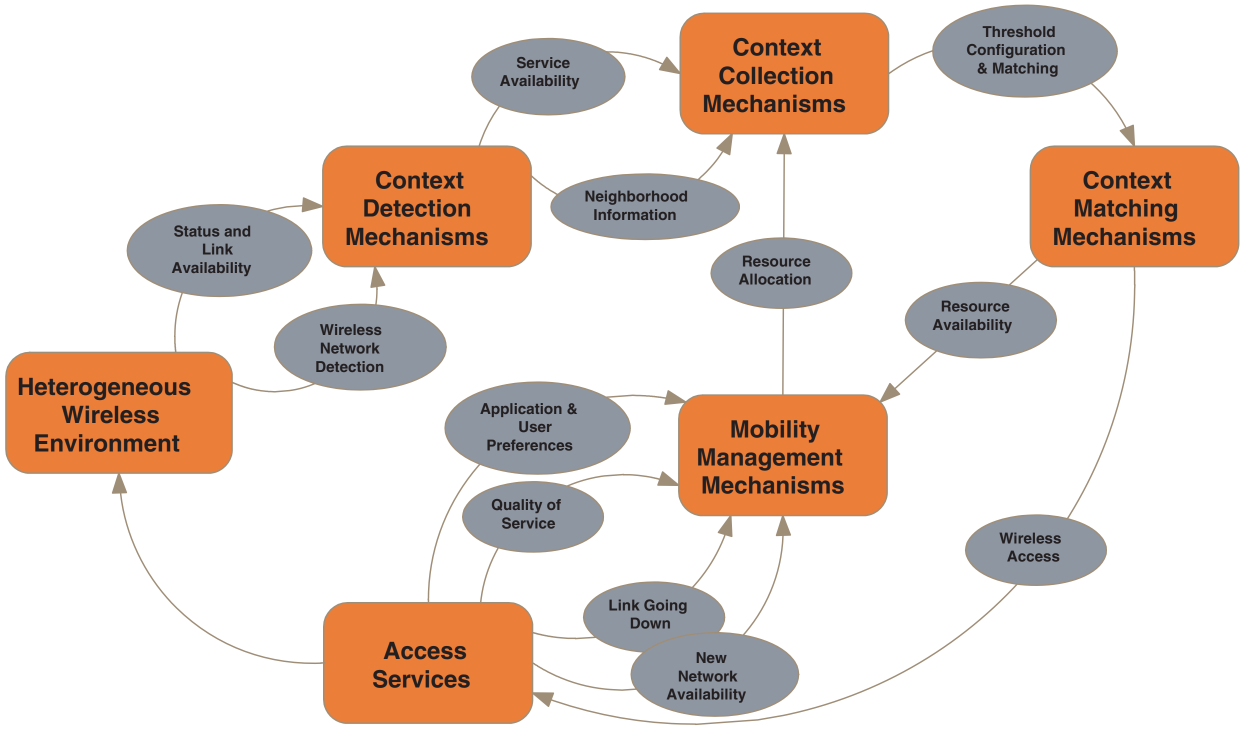

Fig. 10. Spectrum based Context-aware Handover Mechanism as in [198]

of the mechanism, a multi-layer demonstrator is developed, however, result are not provided for evaluations.

Sen *et al.* [212] propose a QoS and context-aware solution for end-to-end connectivity management using channel vertical handovers in heterogeneous wireless scenarios. Context information from different high and low level layers is integrated and coordinated for an optimal connectivity solution. For doing this, a policy based mechanism is designed that takes into consideration the parameters of QoS, application and user preferences and network connectivity. The proposed mechanism facilitates the end hosts however, the context of intermediate network entities like routers and base-stations is ignored as in [213]. This might arise some adaptability issues in the proposed scheme.

5) MIH based Context-aware Schemes: Media Independent Handover (MIH) [9], [214] scheme uses a mechanism that gathers and stores neighborhood information from both; network and client side to carry out a cooperative handover decision using link layer intelligence. MIH Function (MIHF) is a key component and provides different services to end users. Various interfaces (upper and lower layers) exist for the provision of different services to the users, some of which are as under (Fig. 11):

- Media Independent Event Service (MIES) senses and provides different triggers like link status and quality that correspond to the network dynamics;
- Media Independent Command Service (MICS) supports high level layers to manage the lower layers and network reconfigurations via a set of commands; and
- Media Independent Information Service (MIIS) is designed for network discovery using channel information, MAC address and collecting the neighborhood network information that might also include security information.

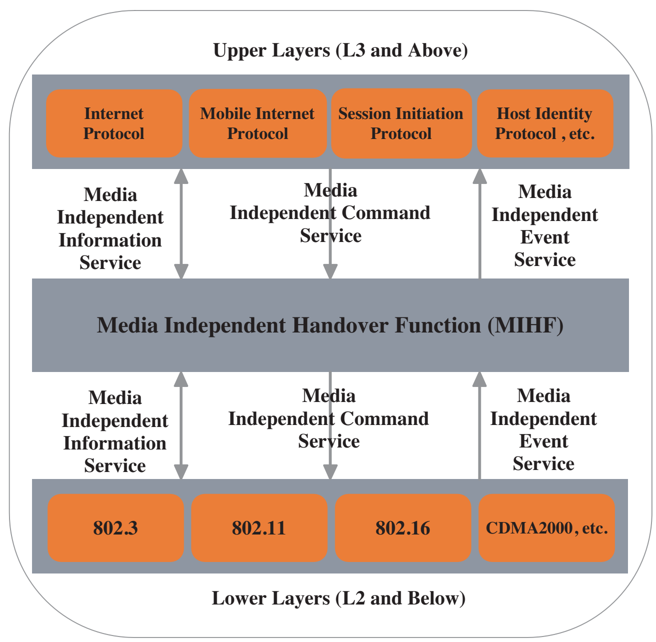

Fig. 11. Media Independent Handover and its related Services [9] [214]–[216]

To summarize this, it is important to consider that different services are used in IEEE 802.21 for an optimal handover decision, however, application layer and user related information are not usually employed for making the vertical handover decisions [217].

In [218], authors introduce Enhanced Information Server (EIS) architecture for MIH networks to speed up the vertical handover measures. EIS collects up-to-date information about certain parameters like location, timing and RSS level from the MNs and exploits it in a cooperative way to make the handover decision. Usually, this information is needed for triggering the handover towards the best available access point in the locality of a mobile node. By doing so, authors imply the possibility of skipping the channel scanning methods for reducing overall handover latency. EIS architecture is compared with the conventional vertical handover process where most of the times EIS outperforms that. However, the main issue that needs to be addressed like in other cooperative schemes is information collection in advance, which may result in some additional signalling overhead and may degrade the performance of the scheme.

Pedro *et al.* in [219] present a context-based approach for handover initialization and decision procedures. Authors propose to use an information server like [218], which is named as Context-aware Information Server (CIS). This server collects, manages and distributes real-time information in the network. This dynamic information is retrieved from both; network and terminal side, for example, MN capabilities, terminal services, user and network preferences, etc. This scheme considers the integration of WiFi, WiMAX and UMTS technologies within the framework of MIH. Information collected by the CIS helps in reducing handover initialization and execution times with some QoS. However, information distribution among different entities of the network through CIS seems to be an issue of this scheme.

Authors in [220] propose a generic virtual link layer (GVLL) and combine this layer with MIH platform for achieving QoS during a vertical handover between WLAN and WiMAX network. GVLL is designed for the best network selection and for MAC layer inter-operability. This is done by measuring and comparing the QoS of the available networks. MIH supports in QoS provisioning, triggering handovers and reducing handover latency. The proposed method provides low call blocking rate and higher throughput when GVLL module is enabled. This is made possible due to the inclusion of very limited number of mobile users which is normally not an applicable scenario in the real world. Also, this scheme lacks seamlessness as a mobile user is assigned with the complete process of network selection.

Corujo *et al.* in [217] address an important issue of managing complexity and diversity of technologies and services in ubiquitous environments. They employed MIH to couple their designed platform to cope with these concerns. The proposed framework is capable of providing a common abstract interface that combines together different network entities in the ubiquitous environment which communicate with both, network services and network devices. This enables cooperation among the devices for exchanging and retrieving the needed information for handover decision making. Average response time and signaling overhead of the proposed mechanism is significantly improved prior to handover execution. The proposed testbed is still in the process of evaluations that is the reason that further improvements or degradations in service provision cannot be identified for the moment.

A similar work towards ubiquity is discussed in [221] that emphasizes on improving the resource utilization and reducing packet loss by using MIH architecture. However, no evaluation of the results is shown in the research work. Authors in [222] propose a network selection and handover decision scheme. This scheme adjusts the handover initiation delays and optimizes the network selection process by selecting a network on the basis of remaining network bandwidth which also results in optimized call blocking rate.

Rouil *et al.* [215] discuss an integrated vertical mobility solution using MIH framework and SCTP protocol due to its abilities of optimal path selection, multi-homing and multi-streaming in diverse environments. They mainly emphasized on the reliability and timeliness of the message exchange among MNs and PoAs to avail an optimal solution in both; mobile and network initiated handovers via SCTP. They delegate that the protocol must be self-aware of the network congestion while context transferring and it must also self-adjust its transfer rate accordingly. Due to these hypothesis, they have achieved a lower packet loss and handover delay. Another integrated technique is presented in [223] for IP multimedia system handover using SIP, FMIP and MIH. This method reduced packet loss and service interruption time by exchanging the contextual information in anticipation by the MIH framework. But at the same time, some extra handover delay is caused due to different protocol exchange messages. Some other similar solutions also exist like [224] and [225] but they mainly focus on infrastructure-less/adhoc networks which is out of the scope of this study.

A cross-layer predictive vertical handover approach is presented in [226] that uses MIH protocol for supporting QoS and for managing connectivity issues in heterogeneous wireless networks. QoS mapping and classification is performed between UMTS and WiMAX networks that is very similar to the one presented in [227] and it employs velocity, distance, PLR, cost and power as handover decision parameters. Results have shown that the proposed mechanism reduces packet loss due to advance network prediction by monitoring the *Link Going Down* signal. Also, overall throughput of the mechanism remains consistent due to proper network selection which is good for QoS sensitive applications. [228] also discusses user adaptive MIH based solution for enhancing QoS in heterogeneous networks. This scheme optimizes user perceived throughput and reduces handover delay by picking up the most appropriate network instead of selecting the best one from the candidate network list as in [229].

Work presented in [230] focuses on the integration of link layer QoS parameters with MIH framework for determining network conditions and assisting handover decision making process. Integration process of WLAN and WiMAX is detailed with policy and threshold driven handovers that also take into consideration user preferences. A proper policy is enabled and a handover is executed as the perceived QoS degrades or user preferences change while roaming across different wireless networks. This mechanism effectively supports QoS enabled handovers according to application needs.

Tara *et al.* introduced a decentralized context-aware MIH based solution by integrating the concept of autonomic computing [231] in heterogeneous wireless environment. They

TABLE VI
CONTEXT BASED VERTICAL HANDOVER DECISION SCHEMES

Category of Handover Decision Scheme	**Candidate Handover Decision Schemes**	**Description of the Scheme**	**Advantages of the Scheme**	**Limitations of the Scheme**
Mobile Agent Based Schemes	[167] [168] [170] [169]	Mobile Agents are employed for a partially distributed handover decision solution where contextual info is gathered and distributed by agents.	- Intelligent context collection - Adaptable in different networks - Proper context storage - Optimized blocking rate	- Increased communication overhead - Large no. of agents - High handover latency - Deployment issues in the real world
AHP Based Schemes	[173] [133] [182] [185] [178] [179] [180]	Predefined objective based handover decision and network selection is carried out with the help of scoring mechanisms and merit functions.	- Optimized handover latency - Reduced packet loss - High throughput - Optimal network selection	- Resource consuming - Might compromise on QoS if a low cost network is available
Mobility Prediction Based Schemes	[187] [188] [197] [196] [192]	User's mobility patterns and historical data are collected as context for making a handover decision.	- Reduced ping-pong for low speeds - Suitable in uncertain network environments	- Instability for variable speeds - Longer handover delay - Higher packet loss
Cooperation Based Schemes	[198] [201] [203] [205] [211] [212] [208]	Completely distributed handover decisions are made, based on the cooperation of different network entities.	- Efficient decision making - Improved QoS - Fully distributed - Suitable for real-time streams - Improved system utilization	- High signalling cost - Higher packet loss - Security provision
MIH Based Schemes	[218] [219] [220] [217] [215] [230] [226] [231]	Distributed handover decision is made via certain predefined triggers that consider user/application contexts.	- Reduced packet loss - Optimal network selection - Embedded security - Reduced latency - Optimized throughput	- Supplementary signalling - Context distribution - Higher resource consumption

propose to use a knowledge plane and a piloting plane [19] in order to make the handover procedure between WLAN and WMAN more intelligent and self-governing. They used the parameters of network availability, MN's movement patterns, QoS and application/user preferences and this information is fed to the knowledge plane for handover decision making process. Piloting plane is responsible for handover execution phase. It is shown that by adding decentralization and autonomic concepts, overall handover performance is optimized due to better cooperation among MNs and APs. Knowledge is distributed in the network entities and it helps in better handover decision making with reduced packet loss, ping-pong effect and handover delay. For adding ubiquity to the interworking architectures, a location-aware interworking technique is presented in [232]. This methodology combines together 3G and wireless access network for better roaming across each other. This solution adds the security component for interworking solution using different protocols.

Table VI summarizes the context oriented approaches presented in this section. Next, we present a brief comparative analysis of the proposed classification and its respective handover decision algorithm.

IV. COMPARATIVE ANALYSIS OF THE PROPOSED CLASSIFICATION

In the previous section, we presented our classification for handover decision making schemes. We divided these schemes into five groups and detailed the candidate algorithms for handover decision making process. For extending and elaborating the problem scope, we present a brief comparison of these algorithms in this section. This comparison is based on their applicability, used parameters, complexity, network selection method and soundness of the approaches as expressed in Table VII.

A. Domain Applicability

RSS based handover decision schemes are generally designed to work in 3G and WLAN environments in order to take full benefits provided by WLANs i.e., high bandwidth and low cost for nomadic users. Rest of the schemes usually serve in heterogeneous wireless environments where, different network conditions are experienced by the mobile users. Previously, most of the mobile terminals had a single network interface available to communicate with other networks and terminals were usually confined to use a single path and this is where, RSS based schemes along with the QoS based played a vital role for providing continuity of service. However, with the emergence of multimode terminals where each mobile device can simultaneously connect to multiple networks; this scenario has completely changed by giving a way to multihoming. These multihomed entities as well as users are becoming more common. Every nomadic user has the possibility to connect to different networks or even different service providers in some cases. Basically, multihoming is employed to support resource sharing, balancing and allocation, fault tolerance and mobility engineering issues in the heterogeneous wireless environments [29]. This functionality is very well adapted by intelligence oriented and context based schemes where, the main purpose is to facilitate a mobile user in the best possible way in terms of QoS and QoE by choosing a network that best suites his/her preferences. Now, this can only be achieved if a terminal has more than one egress paths.

B. Complexity & Network Selection

RSS and QoS based schemes are the simplest ones as a handover decision is simply dependent on the values of RSS and bandwidth in order to assure the service continuity. However, various network parameters are adopted in decision function, network intelligence and context based schemes,

TABLE VII
COMPARATIVE ANALYSIS OF THE VERTICAL HANDOVER DECISION SCHEMES

Handover Decision Class	**Applied Domains**	**Network Dynamics Employed**	**Complexity**	**Parametric Evaluations**										
				Handover Latency	Packet Loss	Cost	Signalling Cost	Unnecessary Handovers	Ping-Pong Effect	Perceived Throughput	Handover Failure	Security	Adapt-ability	Reliability
RSS Based Schemes	Macro & Micro cellular networks	RSS with threshold, timer & hysteresis	Simple	High	High	Low	Low	High	High	Medium	Medium	Low	Low	Low
QoS Based Schemes	Usually WLAN & 3G networks	RSS, bandwidth, IINR & SINR	Usually Simple	High	Medium	Medium	Low	High	High	High	Medium	Low	Medium	Low
DF Based Schemes	Hetero-geneous networks	RSS, band-width, cost, BER, etc.	Somewhat Complex	Medium	Medium	Medium	Medium	Medium	High	Medium	High	Low	Low	Medium
Intelligence Based Schemes	Hetero-geneous networks	Variable parameters based on used technique	Complex	Medium	Medium	Low	Medium	Low	Medium	High	Low	Medium to High	Medium	High
Context Based Schemes	Hetero-geneous networks	Variable parameters based on used technique	Complex	Low	Low	Medium	High	Low	Low to Medium	High	Low	High	High	High

such as RSS, bandwidth, cost, user preferences, power consumption, bandwidth, security and application requirements. For network selection, the contender with the steadiest RSS level and the highest bandwidth is chosen as the handover target in RSS and QoS based schemes, respectively. On the contrary, decision function based, network intelligence based and context based approaches attempt to select the target network with the highest overall performance and end user satisfaction. This performance is measured on the basis of several network parameters.

Decision function based schemes lean to be somewhat complex as they need to gather and normalize different network parameters. In cost function based solutions, the major disadvantage is of their linearity of objectives and addition of different parameter in a simplex type function. As we mentioned earlier, a network is chosen on the basis of defined weights. However, using linear deployment and simplex-type mechanism for weight assignments will always select a candidate network for handover that has the highest weight value. There is no set of weights in cost functions that capitulate entirely user preferences for an optimal network selection. Similarly, score functions use ranking technique for candidate network selection where rank specifies the importance of different networks and their respective parameters. However, they fall back due to the introduction of different subsequent steps during the ranking process and pertain to possible handover latency. While network intelligence and context based schemes are more challenging ones due to their pre-training needs and context management issues, respectively.

C. Parametric Evaluations

1) Handover delay & Packet loss: RSS based schemes tend to produce high handover delays while it is emphasized in some of the schemes like [54], [59], [64] that their proposed mechanisms are able to uphold shorter handover latencies and higher throughput. According to our study and the information provided in the literature, we have observed that the decision function based or network intelligence based schemes suffer from the longest delays among all the categories due to the complexity of these schemes, as pre-training and/or learning mechanisms are involved. As far as context based schemes are concerned, a majority of the approaches obtains less handover delays due to the pre-selection of the handover target networks and usually anticipated handovers. In case of packet loss, RSS based schemes tend to achieve large packet loss as handover decision criteria contains only RSS and the main objective of the handover is to maintain connectivity only. For the decision function based algorithms, they tend to receive comparatively less packet loss as the decision is based on multiple criteria and the aim remains not only to provide connectivity but also satisfy users in terms of QoS as well. This situation is quite similar in network intelligence and context oriented schemes.

2) Cost: Also, authors emphasize on the successful handover rate and cost effectiveness of their schemes. If we consider from scratch, in our stand point, successful handover rate of the decision function based schemes will be higher than the RSS and QoS based solutions because a handover decision is based on the user satisfaction and more complex parameter calculation which makes them reliable in terms of handover decision as well. In terms of cost effectiveness, context based solutions tend to produce some extra overhead because of extra signalling between the network entities in order to make an optimal handover decision. Anyhow, the rest of the categories in the given classification may be cost effective in terms of overhead. For throughput, QoS based, network intelligence based and context based schemes are capable of attaining higher throughput levels than the RSS and decision function based schemes. However, fuzzy logic and neural network based approaches receive improved throughput but they face the problem of scale and cannot be applied in a larger environment due to their heaviness. As far as context based approaches are concerned, they are designed to provide the user satisfaction and optimized quality of experience along with scalability.

3) No. of handovers: In terms of number of handovers, the RSS based schemes lead to produce a high number of handovers because every time if a network with better RSS is present in the vicinity then it is chosen for executing a handover. This behavior is quite similar in QoS based schemes as well and there, it is due to the sudden variation of SINR levels of the different available networks. In decision function based schemes, this property lean to be at a consistent level due to the involvement of various network parameters and a handover decision is based on the optimal cost of a network. Thus, every available network in these schemes is a candidate network which is evaluated for its given parameters but only the one with the best cost is selected for a handover, resulting in comparatively lower number of handovers. Network intelligence and context based proposals are capable of keeping the unnecessary handovers at a low level by reducing the ping-pong effect.

4) Handover failure probability & Reliability: It can always be kept under control for RSS and QoS based schemes, while this probability is observed quite high for decision function based approaches in [67], [130] without the inclusion of RSS. The authors delegate that a handover failure is more unlikely to happen by adapting to the network conditions. Network Intelligence and context based schemes are able to attain low handover failure rate due to their distributed handover decision making methodologies. As mentioned above, context based schemes like for example [170] tend to have less handover failure probability as their main emphasis is on user satisfaction and handover success rate. This is because a handover decision is made by considering user preferences and an optimal network in terms of QoS is chosen out of those available ones that best satisfies user and/or application needs.

In terms of reliability, variations of RSS level decrease the reliability of RSS based schemes, and the difficulty in measuring available bandwidth lessens the reliability of QoS based approaches. In decision function based proposals, certain factors like security level are difficult to quantify, because of this, their reliability is also degraded as compared to other two approaches. Reliability of Fuzzy logic, Neural network and context based schemes is on the higher levels as the systems are trained beforehand and users are satisfied according to their preferences. As the authors of every scheme provide diverse performance parameters in their works, a compromising comparison is very hard to find.

If we summarize, RSS and QoS based mechanisms are generally simple, but they only reflect only one or two handover decision making criteria (like bandwidth) as inputs and other critical parameters for example, service cost, user/application preferences, BER or power consumption of the wireless networks are totally neglected. Also, they are typically used to only two particular network technologies (macro-cellular and micro-cellular). Decision function based, network intelligence based and context based algorithms are considered as more complex ones, and they consider a variety of network parameters in contrast to other schemes. Nevertheless, they are mostly in the theoretic stage or still too complicated to be operational in the real world.

V. Lessons Learnt and Emerging Trends

Vertical handover decision and network selection algorithms reviewed in the above sections are based on a general assumption that the precise values of the entire decision making parameters are obtained before a vertical handover decision and candidate network selection. However, this hypothesis does not seem to work for many real world scenarios because some of the decision parameters like available bandwidth, handover delay, etc. cannot be estimated or their estimated values turn out to be error prone and they might affect the overall handover decision procedure and also, make it difficult to choose an optimal network for handover. This raises two important research issues that need to be addressed (a) how to make a handover decision with the availability of incomplete or partial network information? (b) how a chosen network can be made more robust based on the partial network information?

Apart from this, existing communication systems whether wireless or wired types of scenarios suffer from a great deal of limitations in terms of spectrum allocation, bandwidth and so on. This restricts a user's access to various services, greatly affects its security and its mobility. Various networks and services have now converged into a single network due to the digitalization of content and provision of high speed networks which ultimately facilitates the delivery of conventional services over IP based networks in the form of converged services. In this scenario, one of the prime objectives is to develop and implement distributed multimedia applications and at the same time, support flexible network configurations as well in order to accommodate distinct service classes with end-to-end QoS guarantees. Different QoS management mechanisms must be implemented in each of the environments to support the continuity of service. The emergence of future Internet (also called as Post-IP [233]), which is supposed to be a service layer and an optimized network layer solution for the provisioning of ubiquitous services and communications among billions of machine and human users with the provision of guaranteed quality of service, consistency and robustness to the communication and services, make it imperative to revisit the mobility scenarios and mechanisms in a new architecture of the Internet.

Current vertical or diagonal handover solutions are not designed to deal with the complexity of the future Internet with new service and management requirements. It is possible that some conflicts may arise between new and existing network services though it is said that some features of the current Internet will be kept intact or merged with the future generation of the Internet. Network configurability, services personalization and content adaptation in heterogeneous wireless networks require injecting a reactive and dynamic spatio-temporal nature within the networks and system properties. The implications of this development for resource management and transverse properties of systems and networks i.e., QoS, mobility, inter-operability and security, cause additional complexity that requires revising network models and architectures, services, traffic flow types, network behavior and management. Handover solutions must be developed in such a manner that permit its end users and service providers to easily grasp the existing Internet and the upcoming service and management solutions, which should not restrict their extent of freedom that they have in the existing Internet or mobile world scenarios.

Some of the open research issues could be depicted here as follows. Providing the quality of service in such ambient and ubiquitous environments along with the location management information will be a prime factor for seamless and well-timed service delivery. Future terminals that are supposed to be exhibiting the capability of operating in heterogeneous wireless environments in an autonomous way will also challenge the existing network selection mechanism. In order to make use of various services, they will utilize the neighboring information like negotiations with the location servers and other cross layered devices. With mobility, it is necessary to revise the ergonomics of devices with new and adaptive multimode interfaces using virtual and augmented reality. Customization of interfaces and applications should facilitate mobile use. Technologies that help in ameliorating the interaction between users, mobile terminals and communication services over networks (by integrating multimode techniques) must be analyzed in the light of new applications and services available in our mobile world. Cooperative handover management schemes along with cognitive radio might facilitate theses terminals but they have to tune their control planes in order to satisfy the terminal needs in terms of dense user services and also embed situation, feeling, context and location awareness mechanisms.

It is believed that the real world will turn into our interface for communication in the future generations of the Internet and communication among distributed devices and human users will be based on senses using smart mechanisms. This new communication paradigm might take its roots from a combination of technologies and fields like chaotic networks, content based networks, autonomous peer-to-peer systems, cognitive radio and other interdisciplinary fields like quantum physics, teleportation and biology. Multimedia transmission will not only include voice, data and video but also, feelings and positions. This kind of environment where the communications networks would be based on IP and Post-IP access techniques, design of a proficient handover scheme will play a very significant role in optimal service provisioning.

In addition to these issues, provision of the refined service delivery schemes (network- or application- layer based), cross layered optimizations [234], fault tolerance, intelligent routing, vertical protocol integration procedures are some of the issues that need to be addressed in the context of mobility management in future wireless environments.

VI. Conclusion

In the transition to next generation networks, convergence of IP-based core networks with heterogeneous wireless networks is inevitable. Thanks to the rapid progressions in network technologies, the consumers are becoming more dominant in their routine choice. Mobile users in this service oriented heterogeneous wireless network environment will be at liberty to select the available access network that can best fulfill their requirements and objectives in the existing connectivity conditions.

In this work, we presented a detailed state-of-the-art in the field of vertical handover decision management. We divided the proposed schemes into five groups and compared them in terms of reliability, input parameters, their complexity and network selection methodology. It has been a matter of research for over a long time now, and it is used in several commodities and field tests. Nevertheless, the reputation of seamless services has not occupied its place in the daily life of users in the similar way that talking to a cellular phone or using the Internet from a home PC. Convergence of IP based networks with the existing heterogeneous networks is unavoidable in the shift towards NGNs or Post-IP networks. In this convergence, users are looking forward to the simultaneous handling of various traffic types like voice, data and multimedia streams. Therefore, NGNs should be built such that all the service associated functions are provisioned in an independent way from the core transport technologies. At the same time, the service providers in this novel architecture should also enable the service delivery seamlessly to the nomadic users regardless of the underlying access network or terminal characteristics.

Unluckily, presently suggested decision schemes either lack an ample reflection of various network parameters or the studies reporting these schemes fall short of sufficient detail for implementations in the real world. Research in vertical handover decision mechanisms in heterogeneous wireless networks is still a challenging area and an open issue. The main difficulty is the formulation of a scheme which is truly beneficial in a wide variety of network conditions and user/application preferences. Furthermore, empowering better nomadic applications via plug-and-play connectivity and 'always best connected' paradigms in an autonomous manner is a new dimension for mobility management and related research areas. We believe that as the Internet becomes increasingly pervasive, more and more applications need to learn more about network conditions to work correctly and efficiently besides service connectivity. Therefore, we need a common infrastructure to provide such network with knowledge and mechanisms at low cost for applications, and hence, it does not contradict the end-to-end arguments.

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