CHAPTER 2

Integration of vertical networks is expected to become a significant aspect in the development of future generation wireless networks [36]. This will however lead to diversity in access technologies and network protocols. A common infrastructure to communicate with the networks of different access technology is necessary to accomplish the desires of mobile users under heterogeneous environment. The approach of future wireless system could provide better QoS with higher data transfer rates and achieve seamless mobility between the heterogeneous networks. The users would like to exploit vertical networks based on their preferences such as high bandwidth, availability, and real time for different applications. Seamless VHO is essential when connections are to be switched among heterogeneous networks for enhanced performance and high availability. The requirements such as network capability, network throughput, handover latency, monitoring cost, power consumption and user’s preferences etc., need to be considered as performance metric during VHO. Numerous challenging problems are to be resolved to offer uninterrupted services [24]. VHO management for discovering the best VHO decision making algorithm, and to meet the requirements of service providers and users, is one of the hot research area in wireless network [24]. Several methods are suggested in the literature survey, but even today there is no standard and proficient method to fulfill the network and user requirements offering enhanced QoS [24].

The VHO decision methods primarily emphasize on the following research issues [62]: (i) RSS plus network load, available BW etc. based HO decision method; (ii) Cost function such as available BW and network cost based HO decision method for evaluating the performance of all the available networks; (iii) Multi-attribute analysis based HO decision algorithms, such as gray correlation algorithm and level analysis algorithm; and (iv) Artificial intelligence technology based HO decision method.

VHO can be initiated in the following situations: (i) MT moves out from the present access network node to another network node; (ii) MN switches to another network node based on their preferences; (iii) HWN reallocates network load for system performance improvement.
VHO in heterogeneous networks can be originated for user appropriateness instead of just making a connection [24]. An algorithm designed for decision making gives enhanced performance when different dynamic and static parameters or combination of them are considered for decision making [63, 64]. Network Related Parameters, namely; available BW, handover latency, RSS, signal to interference ratio, cost, security, estimated time, power dissipation, average number of request made in unit time, number of networks under evaluation, average number of calls attended in unit time, threshold BW etc., node related parameters such as velocity, location information, power consumption, etc., user associated parameters such as user profile and preferences, service associated parameters such as service capabilities, quality of service etc., can be used for VHO decision making [24].

In literature, VHD algorithms considering network preference and user satisfaction are developed and are categorized based on handover decision making metrics [34, 65, and 66], such as, received signal strength (RSS) based algorithms, bandwidth (BW) based algorithms, cost function based algorithms, combinational algorithms, multiple attributes decision making based algorithms, authentication based algorithms etc. Also these VHD algorithms are evaluated and validated based on usage scenario metrics such as probability of call blocking, probability of handover blocking, Handover probability, call dropping probability, missing handover probability (MHP), unnecessary handover probability (UHP), wrong decision probability (WDP), duration of interruption, handover delay, number of handovers/Rate of handover, throughput etc. [55].

The key design aspects of VHD making algorithm are [36]:
- Reducing the number of unnecessary handovers to circumvent network overloading due to traffic signaling.
- Improving the utilization of underlay network.
- To fulfil the continuing application with the desired degree of QoS.
- Handover prioritization in the underlay network over the overlay network.
- Maintaining the high speed mobile user’s connectivity with overlay network.

2.1 RSS BASED VHD ALGORITHMS

In these algorithms, handover decision are initiated by comparing average RSS of existing network with that of the candidate network [37, 38, and 67]. Handover takes
place if the RSS of candidate network is higher than the RSS of present network ($RSS_{\text{new}} > RSS_{\text{cur}}$). In ref. [55] the RSS based handover decision approaches are classified as:

- Relative received signal strength.
- Relative received signal strength with hysteresis.
- Relative received signal strength with threshold.
- Relative received signal strength with threshold and hysteresis.
- Prediction techniques.

Due to the asymmetrical nature of VHO’s, the RSS’s are incomparable. However, they will be useful in determining the state and availability of different networks [36]. For measurement of the RSS these algorithms are simple in terms of required hardware. However in heterogeneous networks, VHO is more complex due to difference in access technology, having different threshold and hysteresis. Any VHD algorithm designed without considering RSS as one of the performance metric leads to greater probability of handover failure. RSS based VHD algorithms are widely available in literature [36, 37, 38, 68-72] and are briefly explained in the following sections.

### 2.1.1 Adaptive Lifetime Based VHD Algorithm

A handover algorithm to switch between third generation (3G) cellular wireless networks and WLANs is proposed by Zahran et al. [36]. In this work they combined the RSS with an assessed lifetime metric of mobile node connected to WLAN, and also combined the RSS with the available BW of the WLAN. In case of RSS and assessed lifetime metric combination, a handover to the third generation cellular network is initiated when mobile node moves away from WLAN. The handover occurs when average value of WLAN received signal strength falls below predefined threshold value and the predicted lifetime $\leq$ handover delay. The average value of RSS is calculated by the mobile node continuously, and is calculated as

$$\overline{RSS}[k] = \frac{1}{Wav} \sum_{i=0}^{Wav-1} RSS[k - i] \quad (2.1)$$

where, $\overline{RSS}[k]$ is the average RSS at time ‘k’, and $Wav$ is the window size of a slope estimator which is proportional to the velocity of the mobile terminal.
The lifetime metric $EL[k]$ of mobile terminal, within the WLAN is calculated as

$$EL[k] = \frac{\overline{RSS[k]} - ASST}{S[k]}$$  \hspace{1cm} (2.2)

where, $S[k]$ is RSS variation rate, and $ASST$ is the threshold value of signal strength.

The $S[k]$ is defined as

$$S[k] = \frac{M_1[k] - M_2[k]}{W_s T_s}$$  \hspace{1cm} (2.3)

where,

$$M_1[k] = 2 \frac{W_s}{W_s} \sum_{i=0}^{W_s/2} RSS[k - W_s + 1 + i]$$  \hspace{1cm} (2.4)

and

$$M_2[k] = 2 \frac{W_s}{W_s} \sum_{i=W_s/2}^{W_s-1} RSS[k - W_s + 1 + i]$$  \hspace{1cm} (2.5)

The $S[k]$ fluctuates with the slope estimator’s window size ‘$W_s$’ and the sampling interval of RSS ‘$T_s$’. $ASST$ value is estimated based on the BER of channel, error resilience of application and desired quality of service of application. The $ASST$ value is chosen to improve the overall performance of the system and satisfy the continuing application requirements.

In case of RSS and the available BW combination, the handover to the WLAN is triggered if the average value of RSS of the WLAN is > threshold value, and if the available BW of the WLAN meets the desired BW of the current application, while the mobile node is moving towards a WLAN cell.

In this work the number of UHO’s considerably got reduced as the lifetime metric algorithm get used to the requirements of application and the end user mobility. Also the average throughput is better due to the ability of mobile node being linked with the WLAN. However, as the mobile node moves towards the edge of the WLAN, the packet delays grows up with increase in the lifetime because of worsening of channel performance. For delay sensitive applications this problem may be serious and may worsen their performance. Authors recommend that this can be solved if $ASST$ is set based on numerous system parameters such as cost of handover signaling, penalties of packet delay, threshold value of delay, and velocities of mobile node.
2.1.2 Dynamic RSS Threshold Based VHD Algorithm

In these algorithms the handover is originated if RSS of candidate network is greater than that of RSS of present network and the RSS of the present network is less than certain threshold. However in practice this is not used alone, as its usefulness depends on preceding knowledge of the crossover signal strength between the present and candidate network [55].

Mohanty et al. [37], in their work proposed a handover decision technique, between wireless local area network (WLAN) and 3G cellular network. In this technique comparison is made between the existing RSS and a dynamic RSS threshold \((S_{d_{th}})\) with the mobile terminal attached to the access point of WLAN. where,

\[
S_{d_{th}}(dBm) = RSS_{min}(dBm) + 10\beta \log_{10}\left(\frac{d}{d - L_{BA}}\right)
\]  

(2.6)

To communicate with an access point, the lowest RSS value required for the mobile terminal is defined as \(RSS_{min}\), the path loss coefficient is defined as, the side length of WLAN cell is defined as \(d\) in meters, the least distance between the points at which handover is originated and the limit of WLAN coverage area is defined as \(L_{BA}\), and is calculated as

\[
L_{BA} = \left[\tau^2 v^2 + d^2 \left(p_f - 2 + 2 \sqrt{1 - p_f} \right)\right]^{\frac{1}{2}}
\]  

(2.7)

where, \(p_f\) is the probability of handover failure, \(\tau\) is the handover delay between WLAN and 3G network, and \(v\) is the mobile node velocity.

In [38] it is identified that the traveling time of mobile nodes, within a WLAN coverage area, is less than the delay in handover making. Authors conclude that this approach is not competent and handover may upshot the consumption of network resources in such cases.

2.1.3 Handover Traveling Time Estimation Based VHD Algorithm

Yan et al. [38] and Issaka Hassane Abdoulaziz et al. [73], developed VHD algorithms to reduce the handover failure rate and the unnecessary handovers between WLANs and cellular networks, by calculating the travelling time. The estimation includes calculation of threshold time for reducing the handover failures, and traveling time prediction for reducing the UHO’s. Handover to a WLAN is originated
when the predictable traveling time in the WLAN coverage area is greater than the threshold value, while the mobile node is within the coverage area of the WLAN.

The predictable traveling time \( t_{WLAN} \) [38] is calculated as

\[
t_{WLAN} = \frac{R^2 - l_{OS}^2 + v^2(t_s - t_{pl})^2}{v^2(t_s - t_{in})}
\]

(2.8)

where, the radius of the WLAN coverage area is defined as \( R \), \( l_{OS} \) is the distance from the access point to the place of mobile node at which the sample of RSS is collected and is predicted by using the RSS value and the path loss model log-distance, the mobile node velocity is defined as \( v \), \( t_s \) is the time at which sample of RSS is collected and \( t_{pl} \) is the time at which the mobile node reaches the WLAN cell coverage.

The threshold time \( T_{WLAN} \) [38] is calculated as

\[
T_1 = T_{WLAN} = \frac{2R}{v} \sin \left( \sin^{-1} \left( \frac{v \tau_i}{2R} \right) - \frac{\pi}{2} P_f \right)
\]

(2.9)

where, \( \tau_i \) is the delay in handover between the cellular network and the WLAN, and \( P_f \) is the probability of unnecessary handover or missing handover.

If the RSS of WLAN is declining continuously and if the mobile node approaches nearer to the edge of coverage area then a handover is originated to the to the cellular network.

In [73], another parameter \( T_2 \) \( (T_1 < T_2) \) is presented to reduce unnecessary handover probabilities.

The threshold time \( T_2 \) is calculated as

\[
T_2 = \frac{2R}{v} \sin \left( \sin^{-1} \left( \frac{v (\tau_i + \tau_o)}{2R} \right) - \frac{\pi}{2} P_M \right)
\]

(2.10)

where, \( T_1 \) and \( T_2 \) parameters are governed by the constants \( P_f \), \( P_M \) and are carefully chosen by system designers.

They are also influenced by the other parameters such as \( v, R, \tau_i \) and \( \tau_o \). Authors conclude that by considering network load, the parameter \( T_2 \) can be further dynamically adjusted to stimulate handovers to the WLAN.

2.1.4 Distance Threshold Based VHD Algorithm

Abhijit Bijwe et al. [74], have proposed an algorithm in which they introduced a distance threshold metric \( L \) while making a handover decision. Its value is calculated
using a spanning algorithm. The mobile node will trigger handover whenever the projected traveling distance \( d > L \). At high speed considering using the distance threshold metric the authors claim that a lower probability of handover failures and unnecessary is achieved.

### 2.1.5 RSS and Application Type Based VHD Algorithm

Elaheh Arabmakki et al. [67], proposed an algorithm which is divided into two parts. In the first case, the mobile node is in the WLAN and handover is originated to a cellular network depending upon the nature of application. If it is data application, then the mobile terminal tries to stay in the WLAN till RSS is greater than the predefined threshold. If RSS of the WLAN is less than the predefined threshold, then mobile node is handed over to the cellular network as it is more appropriate for data applications. If the type of application is voice then the mobile user wishes to handover to the cellular network due to its appropriateness for voice applications.

In the second case, the mobile node is considered to be in a cellular network, and in case RSS of WLAN is greater than the predefined threshold then handover is made to WLAN if the type of application is data, else stay in cellular network. Two mathematical models based on RSS and nature of application (data and voice) are proposed by authors. These models as described below are used to reduce the number of vertical handovers occurring between WLAN and Cellular network. Authors projected that this algorithm decreases the probability of handover occurrence.

- **Handover from WLAN to Cellular Network (Data Session)**

  In case the session is for data application, considering the mobile station is in the WLAN and wants to make a handover to cellular network, then the handover will be performed if \( \text{RSS} < \text{WLAN threshold} \).

  In time \( i \) the probability \( P_{c|w|i} \) of a mobile node being in WLAN and trying to perform a handover to a cellular network for data session is

  \[
  P_{c|w|i} = \int_{-\infty}^{t_w} Q \left( \frac{-t_{w} - \mu_{RSS_{i-1}} - \gamma (t - \mu_{RSS_{i-1}})}{\sigma_{RSS} (1 - \gamma^2)} \right) P_{RSS_{i}}(t) dt
  \]

  \[
  Q \left( \frac{-t_{w} - \mu_{RSS_{i-1}}}{\sigma_{RSS}} \right)
  \]

  where, \( Q \) is cumulative distribution function (cdf) of the standard normal distribution, \( t_{w} \) is the threshold of WLAN, \( \mu_{RSS_{i-1}} \) is the mean of RSS in time \( (i - 1) \), \( \sigma_{RSS} \) is the
variance of RSS, $\gamma$ is the correlation coefficient between $RSS_{i-1}$ and $RSS_i$, $RSS_{i-1}$ is the RSS in time $(i-1)$, $RSS_i$ is the RSS in time $i$, and $P_{RSS_i}(t)$ is the probability of expected RSS in time $i$.

- **Handover from WLAN to Cellular Network (Voice Session)**

  If the mobile node is in WLAN and wants to make a handover to cellular network, the handover will be executed if $(RSS) > \text{(Threshold of cellular network)}$ in case it receives a voice session.

  In time $i$ the probability ‘$P_{c|w[i]}$’ of a mobile node being in a WLAN and trying to perform a handover to cellular network for voice session is

  $$P_{c|w[i]} = Q \left( \frac{t_c - \mu_{RSS_i}}{\sigma_{RSS}} \right)$$

  (2.12)

  where, $Q$ is cumulative distribution function (cdf) of the standard normal distribution, $t_c$ is the threshold of cellular network, $\mu_{RSS_i}$ is the mean of RSS in time $i$ and $\sigma_{RSS}$ is the variance of RSS, $RSS_{i-1}$ is the RSS in time $(i-1)$, $RSS_i$ is the RSS in time $i$.

- **Handover from Cellular Network to WLAN (Data Session)**

  Probability of a mobile node being in a cellular network and trying to perform a handover to a WLAN for data session is

  $$P_{c|w[i]} = Q \left( \frac{t_w - \mu_{RSS_i}}{\sigma_{RSS}} \right)$$

  (2.13)

- **Handover from Cellular Network to WLAN (Voice Session)**

  The probability of a mobile node being in a cellular network trying to perform a handover to a WLAN when for voice session is given as

  $$P_{c|w[i]} = \frac{\int_{-\infty}^{t_c} Q \left( \frac{t - \gamma \mu_{RSS_{i-1}} - \mu_{RSS_i}}{\sigma_{RSS} (1 - \gamma^2)} \right) P_{RSS_i}(t) dt}{Q \left( \frac{-t_c \mu_{RSS_{i-1}}}{\sigma_{RSS}} \right)}$$

  (2.14)

  The probability of handover occurring is given as

  $$P_{ho}[i] = P_{w}[i-1]P_{c|w}[i] + P_{c}[i-1]P_{w|c}[i]$$

  (2.15)

  where,

  $P_{ho}[i] = \text{Probability that handover occurs between a WLAN and cellular network at time } i,$

  $P_{w}[i-1] = \text{Probability that the mobile node is in the WLAN at time } (i-1),$
\( P_{c|w}[i] \) = Probability that a mobile node performs handover from a WLAN to a cellular network at time \( i \).
\( P_c[i - 1] \) = Probability that the mobile node is in the cellular network at time \( (i - 1) \).
\( P_{w|c}[i] \) = Probability that the mobile node performs handover from cellular network to a WLAN at time \( i \).

### 2.1.6. Adaptive Hysteresis Margin Based VHD Algorithm

N. P. Singh et al. [75], proposed a VHD algorithm for an integrated cellular and wireless LAN considering the HO rate, probability of outage and probability of HO as performance metrics. The algorithm proposed is based on normalized power.

If the normalized signal power received by mobile node from WLAN ‘\( S_{W_n} \)’ surpasses the normalized signal power received by mobile node from UMTS ‘\( S_{U_n} \)’ then the mobile node is handed over to WLAN.

\[
S_{W_n} > S_{U_n} \tag{2.16}
\]

Similarly handover from UMTS to WLAN will take place if \( S_{U_n} \) surpasses \( S_{W_n} \) plus hysteresis margin.

\[
S_{U_n} > (S_{W_n} + \text{hys margin}) \tag{2.17}
\]

And ‘hys’ margin is calculated as

\[
\text{hys margin} = \max\left\{20 \left(1 - \left(\frac{X}{R}\right)^4\right), 0\right\} \tag{2.18}
\]

where, \( X \) is the distance of mobile node from WLAN access point and \( R \) is the radius of WLAN cell.

Though an adaptive handover margin reduces the number of unnecessary handovers, it increases the outage probability and handover delay with larger hysteresis. The comparison of RSS based VHD Algorithms is summarized in Table 2.1.
Table 2.1 RSS Based VHD Algorithms

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adaptive lifetime based</td>
<td>Zahran et al. [36]</td>
<td>Handover between 3G networks and WLANs. Combination of RSS with estimated lifetime and RSS with available BW is used for handover decision.</td>
<td>Improved Overall Throughput and reduced unnecessary handovers.</td>
<td>Relatively high probability of packet delay.</td>
</tr>
<tr>
<td>2</td>
<td>Dynamic RSS threshold Based</td>
<td>Mohanty and Akyildiz [37]</td>
<td>Handover between WLAN and 3G network. Dynamic RSS threshold is compared with the current RSS for making handover decision.</td>
<td>Reduction in probability of handover failure.</td>
<td>Wastage of network resources in case traveling time inside a WLAN cell is less than the handover delay.</td>
</tr>
<tr>
<td>3</td>
<td>Handover necessity estimation based</td>
<td>Yan et al. [38]</td>
<td>Handover takes place between cellular networks and WLAN’s based on estimation of necessity of handover. Dynamic time threshold is compared with the predicted travelling time for handover.</td>
<td>Reduced handover failures and unnecessary handovers.</td>
<td>Extra delay in RSS sampling (up to 2s)</td>
</tr>
<tr>
<td>4</td>
<td>Distance threshold based</td>
<td>Abhjit Bijwe et al. [74]</td>
<td>Handover takes place whenever the estimated traveling distance $d$, is greater than the distance threshold metric $L$.</td>
<td>Reduced unnecessary handover and low handover failure probability</td>
<td>Increased handover delay</td>
</tr>
<tr>
<td>5</td>
<td>RSS and application type based</td>
<td>Arabmakki et al. [67]</td>
<td>Handover takes place between WLAN and Cellular network based on RSS and type of application (data or voice).</td>
<td>Reduced handover probability</td>
<td>Proof of handoff probability, and simulation of algorithms is not provided.</td>
</tr>
<tr>
<td>6</td>
<td>Adaptive hysteresis margin based</td>
<td>N.P Singh et al. [75]</td>
<td>Handover is based on normalized power hysteresis margin between WLAN and UMTS networks.</td>
<td>Reduced unnecessary handover.</td>
<td>Increase in outage probability and delay in handover with larger hysteresis.</td>
</tr>
</tbody>
</table>

2.2 BANDWIDTH (BW) BASED VHD ALGORITHMS

BW available for a mobile node is the key criterion in this group [39, 41, and 42]. In few algorithms RSS is considered as a performance metric along with BW information for handover decision making [36, 43].

In case of VHD making algorithms using BW metric, the BW available for a
mobile node or the traffic demand is considered as the main criterion [39, 42, 76 and 77]. The BW based VHD algorithms are discussed in detail as follows.

2.2.1 QoS Based VHD Algorithm

Lee et al. [42], proposed a QoS based algorithm which performs HO between wireless local area network (WLAN) and wide area access network (WAAN) with residual BW and user service requirements as performance criteria.

In this algorithm the RSS of WLAN beacon is continuously observed and if the mobile node is attached to WLAN, it is compared with predefined threshold $RSS_T$. If the mobile node is attached with WLAN and if RSS received from beacon is less than $RRS_T$, it increments the value of the number of continuous RSS beacons i.e. $NRSS$ and checks for whether $NRSS$ is greater than predefined threshold $NRSS_T$ else it remains attached with WLAN. Now if $NRSS$ is greater than $NRSS_T$ and the mobile node (MN) is in idle state, a handover is initiated to the desired network. If mobile node is not in idle state it verifies for real time application & the measured BW and then compares it with minimum required BW. HO is initiated if WLAN BW is less than the required BW and also the WAAN’s BW is greater than minimum required BW, else it remains attached with WLAN. If the application is not real time and BW of WAAN is greater than WLAN a handover is initiated, else it remains attached with WLAN. A similar situation is performed if the mobile node is presently attached to WAAN. An estimated value of the minimum required BW (residual BW) of the WLAN is calculated as

$$Residual\ BW = T_h \times (1 - \alpha \times \text{Channel Utilization}) \times (1 - \text{Packet Loss Rate})$$

where, $T_h$ is the throughput of mobile nodes in the WLAN, Channel Utilization is the percentage of time the access point senses the medium as busy, $\alpha$ is IEEE 802.11 MAC overhead, and Packet Loss Rate is the part of transmitted medium access control protocol data units (MPDUs) that needs to be retransmitted/discarded.

The values of channel utilization and packet loss rate are as defined in IEEE 802.11e [78]. This method is able to achieve high system throughput, and lower handover latency for delay-sensitive applications. However, when the mobile terminal is remaining in the selected network for only a short duration of time, the movement can result in high blocking rate for new applications.
2.2.2 BW and RSSI Based VHD Algorithm

Nie et al. [76], proposed an algorithm based on bandwidth (BW) and received signal strength index (RSSI) as performance metric to make handover. Authors considered handover between IEEE 802.16a and IEEE 802.11 high BW networks. A decision to handover is made by comparing the average values of the sampled RSSI obtained from access point of the network with the threshold of RSSI. As both BW and RSSI are considered the unnecessary handover probability (UHP) and access delay are reduced so as to make appropriate handover decision.

2.2.3 Signal to Interference + Noise Ratio (SINR) Based VHD Algorithm

Sudipta Patowary et al. [79], proposed BW based algorithm considering the received signal to interference plus noise ratio (SINR) as performance metric to make handover between GPRS and Wi-Fi networks. The SINR of the GPRS signal is converted to an equivalent SINR as given below.

\[
g_{gs} = \frac{I_{gs}}{1 + \frac{W_{wf}}{W_{gs}}} - 1
\]  

(2.19)

where, \(g_{gs}\) and \(g_{wf}\) are the SINR at the mobile terminal when associated with GPRS and Wi-Fi respectively. \(I\) is the gap in dB between the un-coded Quadrature Amplitude Modulation (QAM) and channel capacity minus the coding gain, and \(I_{gs}\) is 3dB for GPRS and \(I_{wf}\) is 3dB for WLAN. \(W_{gs}\) and \(W_{wf}\) are the carrier BW of GPRS and Wi-Fi links.

The SINR from Wi-Fi can be converted to the equivalent SINR of GPRS using the above equation by knowing the data rate from both the networks. Handover decision can now be made by comparing the SINR of GPRS and Wi-Fi. The mobile node will handover itself to the Wi-Fi network as soon as the equivalent SINR received from the GPRS network falls below the SINR of the Wi-Fi network. As the available throughput is directly reliant on the SINR, such handovers can provide users with higher overall throughput than RSS based handovers. Also such algorithm outcomes with a balanced load between the GPRS and the Wi-Fi networks and may introduce excess handovers with the variation of the SINR making the node to hand over back and forth between the two networks referred as ping-pong effect [55].
2.2.4 WDP and HP Based Evaluation of VHD Algorithm

Chi et al. [41], proposed an analytical model for Wrong Decision Probability (WDP) and Handover Probability (HP) to understand the performance of QoS metric based handover algorithms under different network conditions and end user requirements. In [41] WDP is given as summation of UHP and the MHP.

\[ WDP = UHP + MHP \]  

and WDP is calculated as

\[ WDP = \sum_{i=1}^{N} \sum_{j=1}^{N} P_r \{ \gamma_{n_j/n_i} \} + \sum_{i=1}^{N} P_r \{ \theta_{n_i} \} \]  

where, \( \gamma_{n_j/n_i} \) represents Unnecessary Handover (UHO) when mobile terminal tends to move from network \( j \) to \( i \), \( \theta_{n_i} \) represents Missing Handover (MHO) at network \( n_i \), and \( i \neq j \).

HP is calculated as

\[ HP = P_{n_i} P_{n_j/n_i} + P_{n_j} P_{n_i/n_j} \]  

where, \( P_{n_i} \) and \( P_{n_j} \) are the probabilities that a mobile node stays at \( n_i \) and \( n_j \).

They are expressed as

\[ P_{n_i} = \frac{P_{n_i/n_j}}{P_{n_i/n_j} + P_{n_j/n_i}} \]  

\[ P_{n_j} = \frac{P_{n_j/n_i}}{P_{n_i/n_j} + P_{n_j/n_i}} \]  

\( P_{n_i/n_j} \) is the probability of mobile node moving from node \( n_j \) to \( n_i \)

\( P_{n_j/n_i} \) is the probability of mobile node moving from node \( n_i \) to \( n_j \)

2.2.4.1 Analysis of BW Based Two Node Network Model

In [41] expressions for WDP and HP parameters are studied via a general BW based HO algorithm considering two node network model. In [41] two overlying coverage area networks \( i \) and \( j \) having BW \( B_i \) and \( B_j \) are considered. UHO occurs when \( B_j \) is less than \( B_i \) and the MN in network \( i \) decides to HO to \( j \). MHO occurs when MN decides to stay in network \( I \) though \( B_j \) is greater than \( B_i \). HO from network \( i \) to \( j \) takes place if \( (P_r < \rho \times l_o) \) or \( (B_j - B_i \leq L_B) \), where \( P_r \) is the UHP, \( \rho \) is traffic load of the network \( i \), \( l_o = 0.001 \), and \( L_B \) is a BW threshold.
It is concluded by the authors that this algorithm reduces the WDP and balances the traffic load. In this algorithm however the authors did not consider RSS and in such a case it is not desirable to handover to a target network with high BW and weak RSS, else the ongoing connection may be lost. Also the authors considered only two networks for the purpose of handover analysis, but in practice there may be more number of overlaid heterogeneous networks. Further additional QoS performance parameters required as per user preference namely; power consumption, handover delay, throughput rate, speed etc., are not considered for the purpose of analyzing the handover algorithms.

2.2.4.2 Analysis of BW Based Two Node Network Model for Different Decision Times and Large BW Channels

S. Akhila and Suthikshn Kumar [80], in their work used wrong decision probability (WDP) models to predict the probabilities of missing handovers (MHO’s) and unnecessary handovers (UHO’s) for different decision times and large BW channels. The probability equations are derived based on a two networks model. It is concluded by the authors that higher the decision time, more is the probability of making wrong decision. Also higher the probability of change in the available BW in both networks, higher will be the probability of making wrong decision.

2.2.4.3 Analysis of BW Based Three Node Network Model for Different Decision Times and Large BW Channels

S. Akhila and Suthikshn Kumar [81], in their work used WDP model to predict the probabilities of MHO’s and UHO’s for different decision times and large BW channels in three network model. It is concluded by the authors that there is a substantial reduction of wrong decision making when two network models is replaced by a three network model and also the ping-pong effect caused due to UHO is reduced. Also there is increase in the throughput in three network model compared to two network model.

2.2.4.4 Analysis of BW and RSS Based Three Node Network Model for Different Decision Times and Large BW Channels

Akhila. S et al. [82], used WDP model to evaluate the performance of a BW, RSS and BW plus RSS based VHO algorithms using three node network model. It is concluded by authors that making a handover decision with BW plus RSS criteria will
reduce WDP and improve the throughput compared with BW alone. Comparison of the BW based VHD algorithms is summarized in Table 2.2.

**Table 2.2. Bandwidth Based VHD Algorithms**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QoS based</td>
<td>Lee et al. [42]</td>
<td>Handover takes place between WLAN and WWAN considering RSS, residual BW and user service requirements.</td>
<td>High system throughput, and lower handover latency for delay-sensitive applications.</td>
<td>High blocking rate for new applications.</td>
</tr>
<tr>
<td>2</td>
<td>BW and RSSI based</td>
<td>Nie et al. [76]</td>
<td>Handover takes place between two high BW networks namely IEEE 802.16a and IEEE 802.11 considering BW and RSSI as criteria.</td>
<td>Reduced UHP and access delay.</td>
<td>Only two heterogeneous networks WMAN and WLAN are considered.</td>
</tr>
<tr>
<td>3</td>
<td>SINR based</td>
<td>Sudipta Patowary et al. [79]</td>
<td>Bandwidth based handover is initiated between GPRS and Wi-Fi networks using SINR.</td>
<td>High overall throughput. Balanced load between GPRS and Wi-Fi networks.</td>
<td>Leads to Ping-Pong effect.</td>
</tr>
<tr>
<td>4</td>
<td>Wrong Decision Probability (WDP) and Handover Probability (HP) based</td>
<td>Chi et al. [41]</td>
<td>Analytical model of WDP and HP is used for analysis of two network model using BW criteria.</td>
<td>Reduced WDP and balanced traffic load.</td>
<td>RSS is not considered, and analysis is carried out considering only two networks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. Akhila and Suthikshn Kumar [80]</td>
<td>Analytical model for WDP and HP is used for analysis of two network model using large BW criteria, for different decision time.</td>
<td>Reduced WDP and balanced traffic load.</td>
<td>Increase in WDP with higher decision time and with higher probability of changes in the available BW. Only BW is considered.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S. Akhila and Suthikshn Kumar [81]</td>
<td>Analytical model for WDP and HP is considered for analysis of three network model using large BW criteria, for different decision time.</td>
<td>Reduced WDP with increase in No. of networks. Reduced ping-pong, improved Throughput.</td>
<td>High cost and more delay in handover decision making.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Akhila. S et al. [82]</td>
<td>Analytical model for WDP and HP is considered for analysis of three network model using RSS and large BW criteria for different decision time.</td>
<td>Increased Throughput and reduced WDP.</td>
<td>Cost is high and more delay in handover decision making.</td>
</tr>
</tbody>
</table>

### 2.3 MOBILE NODE MISBEHAVIOR BASED EVALUATION OF VHD ALGORITHMS

Analysis of node misbehavior involves many challenges such as multiple failures caused by selfishness, mobility, and potential Denial of Service (DOS) attacks. Mobile node may change its performance while considering four states in which a
mobile node can reside (i.e., cooperative, selfish, malicious and failed state) according to an embedded Markov chain [83].

Fei Xing and Wenye Wang [83], proposed a model to illustrate the node misconducts based on a semi-Markov process. They analyzed the influence of node misconduct on network connectivity in a mobile ad hoc network stochastically. Based on the stochastic properties of the model, authors analyzed the problem of node inaccessibility due to misbehaving neighbor nodes and obtained the probability of an ad-hoc network being connected in the presence of disobedient nodes. In this model, mobile nodes change their performance according to the transition probability matrix and transition time distribution matrix. They obtained the limiting probability of presence of a node in each state and then analyzed the node inaccessibility problem resulting from misbehaving neighbor nodes providing the condition under which mobile nodes can be connected with a mobile ad-hoc network. Authors conclude that besides mobility-induced failures, node misconducts can cause node inaccessibility problem as well, which influences the network connectivity significantly.

Matthias Hollick et al. in [84] discussed the effects of node misconduct in ad-hoc networks. They derived well-defined modules such as general and spontaneous misconduct, appropriate for analytical study. An analytical model covering the different types of misconduct is presented in their work. Authors concluded that sedentary nodes harm less to ad-hoc networks whereas selfish nodes will influence the routing process.

2.3.1 Analysis of BW Based Four State Two Node Network Model

Patil Shweta and B.N. Manjunatha Reddy [85], in their work, proposed probability models to determine the probabilities of UHO’s, MHO’s and wrong decisions for different decision times and for two different models considering BW as performance criteria. The probabilities of four different states of the mobile node are also modeled namely, cooperative, selfish, failed and malicious states. Semi Markov models are used to represent the actual scenario and the probabilities are calculated to evaluate the performance of the two node network model.

The probability that the mobile node stays in network node 1 is given as

\[ P_{c2c-1} = \frac{P_{n_1/n_2}}{P_{n_1/n_2} + P_{n_2/n_1}} \]  

(2.25)
The probability that a mobile node continues to stay in the cooperative network node 1 is

$$P_{n_1} = P_{c2c-1} + P_{f2c-1} + P_{s2c-1} - P_{c2s-1} - P_{c2m-1} - P_{c2f-1}$$ (2.26)

The probability that mobile node stays in network node 2 is given as

$$P_{c2c-2} = \frac{P_{n_2/n_1}}{P_{n_1/n_2} + P_{n_2/n_1}}$$ (2.27)

The probability that a mobile node continues to stay in the cooperative network node 2 is

$$P_{n_2} = P_{c2c-2} + P_{f2c-2} + P_{s2c-2} - P_{c2s-2} - P_{c2m-2} - P_{c2f-2}$$ (2.28)

The Probability of a mobile node $n$ moving from failed state to cooperative state is

$$P_{f2c} = \frac{1}{T_{Recover}}$$ (2.29)

Similarly, Probability of a mobile node $n$ moving from selfish state to cooperative state can be represented as

$$P_{s2c} = \frac{TC_{Thr}}{TC_{Max}}$$ (2.30)

Malicious state is a dead state of the mobile node, where in it does not respond to network signals. Hence the probability of a mobile node moving from malicious state to cooperative state is zero. Also the probabilities of the mobile node moving from the cooperative state to the failed state, selfish state or malicious state are as follows.

The probability of a MN $n$ moving from cooperative state to selfish state is

$$P_{c2s} = \frac{1}{T_{Selfish}}$$ (2.31)

The Probability of a MN $n$ moving from cooperative to malicious state is

$$P_{c2m} = q_a \frac{k_a}{N} \frac{1}{T_{attack}}$$ (2.32)

The Probability of a MN $n$ moving from cooperative state to failed state is

$$\max \left[ \frac{1}{T_{Life}}, \frac{1}{T_{Residence}} \right]$$ (2.33)

These probabilities are used to determine the HO probability which is given as

$$HP = P_{n_1} P_{n_2/n_1} + P_{n_2} P_{n_1/n_2}$$ (2.34)

Authors conclude that WDP’s are anticipated much accurately by at least 60% higher than the baseline model proposed in reference [41]. Performance declines for
certain values of the decision time and for the factors used in this model. Hence for essential probabilities of user interest one should choose proper values of the factors. These models can further include performance metrics such as RSS, movement of the mobile node, access delays etc. for optimum handover. The mobile node misconduct based VHD algorithm is summarized in Table 2.3.

Table 2.3 Mobile Node Misbehavior Based VHD Algorithms

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Probability Models of Four States of Mobile Node Based</td>
<td>Patil Shweta and B.N. Manjunatha Reddy [85]</td>
<td>Probabilities of four different states of the mobile node are modeled namely, cooperative, selfish, failed and malicious states. Semi Markov models are used to represent the actual scenario and the probabilities are considered to evaluate the performance of the two node network model.</td>
<td>WDP’s are predicted much accurately by at least 60% higher than the baseline model proposed in reference [41].</td>
<td>Only BW is considered as criteria for handover decision making. Performance deteriorates for certain values of decision time and for the factors used in this model.</td>
</tr>
</tbody>
</table>

2.4 COST FUNCTION BASED VHD ALGORITHMS

VHD Algorithms based on cost function selects a combination of network factors such as RSS, network covering area, service monetary cost, available BW, reliability, battery power, security and mobility model, etc., and define a cost function to assess the performance of target networks and take the handover decision.

Depending on the user preferences and network situations, different weights are assigned to various input metrics in order to calculate the cost function. Many researchers have worked in this area [25, 46, 44, 45, 63, 86-93]. As these algorithms collect and normalize multiple network parameters, they incline to be more complex. For wireless networks the general form of cost function defined in [94] is given as

\[
f_n = \sum_s \sum_i W_s \cdot i \cdot P_s^n \cdot l
\]  

(2.35)

where, \( P_s^n \cdot l \) is the cost in the \( i^{th} \) parameter to achieve services of network \( n \), \( W_s \cdot i \) is the weight allotted by the user for using the \( i^{th} \) parameter to achieve services.
2.4.1 Multi-service Based VHD Algorithm

Multi-service Based VHD algorithm proposed by Zhu and McNairs [46] is based on the cost function in which cost of all probable target networks is calculated. All the on the go applications are prioritized in this algorithm, and to offer services with highest priority the cost of each possible target network is calculated as

\[ C_s^n = \sum W_{s,j}^n Q_{s,j}^n E_{s,j}^n \neq 0, \]

where \( C_s^n \) is the service cost of network \( n \), \( W_{s,j}^n \) is the weight provided to the user or the network based on QoS, \( Q_{s,j}^n \) is the normalized QoS provided by network \( n \) for parameter \( j \) and service \( s \), and \( E_{s,j}^n \) is the network elimination factor which indicates whether the minimum requirement of parameter \( j \) can be met by network \( n \).

The total cost is the sum of the cost of each QoS parameter, including the battery power, BW, and delay. Using cost function the percentage of user satisfied requests is increased and there is substantial reduction in HO blocking probability.

2.4.2 Normalization and Weight Distribution Based VHD Algorithm

Hasswa et al. [44], proposed a cost function based VHD algorithm using normalization and distribution of weights. A network quality factor is used to assess the performance of a handover, and is defined as

\[ Q_l = w_c C_l + w_s S_l + w_p P_l + w_d D_l + w_f F_l \]

where, \( Q_l \) is the quality factor of network \( I \); \( C_l, S_l, P_l, D_l, \) and \( F_l \) are the cost of service, security, power consumption, network condition and network performance; \( w_c, w_s, w_p, w_d, \) and \( w_f \) are the weights of these network parameters.

The network parameters have different unit hence a normalization procedure is used. The normalized quality factor for network \( n \) is calculated as

\[ Q_l = \frac{w_c \left( \frac{1}{C_l} \right)}{\max \left( \frac{1}{C_1}, \ldots, \frac{1}{C_n} \right)} + \frac{w_s S_l}{\max (S_1, \ldots, S_n)} + \frac{w_p \left( \frac{1}{P_l} \right)}{\max \left( \frac{1}{P_1}, \ldots, \frac{1}{P_n} \right)} \]

\[ + \frac{w_d D_l}{\max (D_1, \ldots, D_n)} + \frac{w_f F_l}{\max (F_1, \ldots, F_n)} \]

To avoid UHO’s a handover necessity estimator is introduced. High system throughput and user’s satisfaction can be accomplished, but parameters like security and interference levels are hard to estimate, and the information required to follow the
procedure of measuring these parameters is not explained.

2.4.3 Weighted Function Based VHD Algorithm

Weighted function based VHD algorithm proposed by Tawil et al. [45] is used to calculate the weighted function of candidate network for HO decision and is given as:

\[ Q_i = W_B B_i + W_{DP} \frac{1}{D_{P_i}} + W_C \frac{1}{C_i} \]  \hspace{2cm} (2.39)

where, \( Q_i \) is the quality of network \( i \), \( B_i \), \( D_{P_i} \) and \( C_i \) are BW, dropping probability, monetary cost of service, and \( W_B \), \( W_{DP} \) and \( W_C \) are their weights, such that

\[ W_B + W_{DP} + W_C = 1 \]  \hspace{2cm} (2.40)

The candidate network with the highest \( Q_i \) is selected as the target for HO. The resource of the MT can be saved by assigning the calculation to the network visited and due to this the system is able to attain small HO decision delay, low HO blocking rate and high throughput. However, there is added latency and excess load on the network when there are enormous number of MT’s. This is due to extra cooperation required between the MT & the point of attachment of the network visited.

2.4.4 Ad-hoc Technique Based VHD Algorithm

Lee et al. in [91] proposed a cost based VHD algorithm considering load balancing and battery performance metric. In the preliminary stage they developed an algorithm to improve the cost function considering battery life time of the mobile node and load balancing over access points. At the later stage they considered mobile node to form an ad-hoc VANET or MANET. These ad-hoc network provide connectivity to the nearest access points or base stations for the mobile nodes in ad-hoc mode. This is to share transit loads and for balancing their battery power consumption. This algorithm is realized in multiple VHD controllers (VHDC) located in the access networks. It also provides the HO decision function for a region covering one or more access points and/or base stations. VHDC improves the overall performance of the integrated system of access network, particularly in terms of battery lifetime and load balancing. This algorithm saves substantial amount of battery power but it still needs to be improved to fulfill the needs of mobile node if the access point has enough signal strength.

2.4.5 Integrated Network Based VHD Algorithm

Hong et al. [95], proposed a VHD algorithm based on cost function for
performing a HO when mobile node is traveling from WWAN area to an area covered by both WWAN and WLAN. As per user preference, weights are allocated to the performance metrics such as power consumption, data throughput, and monetary cost to calculate the cost function for making HO decision. When a MN enters the overlaid area, the serving general packet radio service support node (SGSN) collects information such as cost per bit, power consumption and data rate for calculating the cost given as

\[ C(l) = \mu_t f_t(l) + \mu_p f_p(l) + \mu_m f_m(l) \quad \text{for } l \in \{ \text{wlan, wwan} \} \]  

(2.41)

where, \( f_t(l) \), \( f_p(l) \) and \( f_m(l) \) are the normalized variables for data rate, power consumption and monetary cost of network \( l \).

The mobile nodes will HO from WWAN to WLAN in case the cost for WLAN is less than the cost of WWAN.

2.4.6 User Satisfaction Based Algorithm

Nikhil Patel et al. [96], proposed several VHD optimization schemes for implementation of VHD algorithm. User preference (UP), security (S), monetary cost of service (C), power consumption (P) and network conditions (N) parameters are used to optimize the VHD. A VHD function is calculated based on these parameters.

The network quality is a function of these parameters and is given as

\[ Q_i = f \left( \frac{1}{C_i}, S_i, \frac{1}{P_i}, B_i \right) \]  

(2.42)

Depending on the extent of its effect on the VHD, the parameters are weighted ranging from 0 to 1 and the weights are allocated as

\[ Q_i = f \left( wc \frac{1}{C_i}, ws S_i, wp \frac{1}{P_i}, wb B_i \right) \]  

(2.43)

As each network parameter has diverse units, the normalization of these parameters is done with respect to the cost function. Further HO to the network with maximum \( Q_i \) is performed. Also the user’s satisfaction parameter is calculated by adding all the network parameters and their corresponding weights.

\[
\text{User Satisfaction} = \frac{\text{Preferred BW} - \text{Actual BW}}{\text{Actual BW}} \cdot wb + \frac{\text{Preferred Cost} - \text{Actual Cost}}{\text{Actual Cost}} \cdot wc \\
+ \frac{\text{Preferred Security} - \text{Actual Security}}{\text{Actual Security}} \cdot ws
\]  

(2.44)
Comparison of cost function based VHD algorithms is summarized in Table 2.4.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multi-service based</td>
<td>Zhu and McNair’s [46]</td>
<td>Cost of all possible target networks is calculated and all the active applications are prioritized to provide service with highest priority.</td>
<td>Increased user satisfaction and reduced handover blocking probability.</td>
<td>Normalization of QoS factors is not specified.</td>
</tr>
<tr>
<td>2</td>
<td>Normalization and Weight Distribution Based</td>
<td>Hasswa et al. [44]</td>
<td>Normalized QoS is calculated and weights of network parameters are used to calculate the cost function. Handover necessity estimator is introduced to avoid unnecessary handovers.</td>
<td>High system throughput and better user’s satisfaction.</td>
<td>Security parameters and interference levels are difficult to estimate and procedure to measure these parameters is not specified.</td>
</tr>
<tr>
<td>3</td>
<td>Weighted Function Based</td>
<td>Tawil et al. [45]</td>
<td>Candidate network with highest $Q_i$ is selected as the target for handover. BW, dropping probability, monetary cost are used for handover.</td>
<td>Short handover decision delay, low handover blocking rate and high throughput.</td>
<td>Additional latency and excessive load to the network with large number of mobile nodes.</td>
</tr>
<tr>
<td>4</td>
<td>Ad-hoc Technique Based</td>
<td>Lee et al. [91]</td>
<td>VHDC optimizes the cost function considering battery life time of mobile node and load balancing over access points and mobile node to form an ad-hoc VANET/MANET.</td>
<td>Saves significant amount of battery power.</td>
<td>It still needs to be enhanced to fulfill the needs of mobile node, in case the access point has sufficient signal strength.</td>
</tr>
<tr>
<td>5</td>
<td>Integrated network Based</td>
<td>Hong et al. [95]</td>
<td>Weighted metrics such as power consumption, data throughput, and monetary cost are used to calculate the cost function for making handover.</td>
<td>User preferences for cost factors are used to select a network with least service cost.</td>
<td>Capacity of network is not specified.</td>
</tr>
<tr>
<td>6</td>
<td>User Satisfaction Based</td>
<td>Nikhil Patel et al. [96]</td>
<td>Combination of weight distribution and cost factor is used make handover between WLAN and UMTS.</td>
<td>Improved user satisfaction.</td>
<td>RSS as indicator for QoS level need to be used fulfill user’s satisfaction optimally.</td>
</tr>
</tbody>
</table>
2.5 MOBILITY BASED VHD ALGORITHMS

In order to take optimum HO decision for user satisfaction the MT location and velocity are well-thought-out in algorithms based on mobility management. To increase the system capacity and to reduce the UHO’s in overlay networks an umbrella cell approach is used in which slow moving nodes are consigned to micro-cell and pico-cell and fast moving nodes are consigned to macro cells. In literature there are various types of mobility models available, and are categorized based on the type of traffic such as pedestrian or vehicle user, the purpose like radio resource or location or propagation management, level of microscopic and macroscopic description, and degree of randomness in user behavior like statistical or analytical.

2.5.1 Location Based VHD Algorithm

In [97] a VHD algorithm is proposed by Zhang et al. which is dynamically programmed based on the location information of mobile terminal. They considered Broadband wireless network (BWN) and Cellular networks for the purpose of analysis. A network assisted handover decision scheme is used to take full advantage of the user utility as expected.

Considering $d_{up}$ and $d_{down}$ as service poverty caused by upward (BWN to cellular network) or downward handover (cellular to BWN network), the utility factor for the cellular and broadband network ($U_{cellular}$ and $U_{BWN}$) indicating the user satisfaction at $i^{th}$ unit time is calculated as

$$U_i = \begin{cases} 
U_{cellular}, & \text{if connected with cellular network, no handover is initiated at } t = i \\
U_{cellular} - d_{up}, & \text{if handover from BWN to cellular network at } t = i \\
U_{BWN}, & \text{if connected with BWN, no handover is initiated at } t = i \\
U_{BWN} - d_{down}, & \text{if handover from cellular network to BWN at } t = i 
\end{cases}$$

(2.45)

The location of the mobile terminal is always tracked by the algorithm in order to provide improved user satisfaction and reduced UHO. However a predefined consciousness of the coverage area of the BWN and mobility pattern of the mobile terminal is required for making a balanced decision. Based on the mobility information and acceptable utilities of both the networks, the location service serve (LSS) initiates handover decision, and can be pre calculated and stored in the LSS when mobile terminal moves from cellular network to broadband network.
2.5.2 Mobility Prediction Based VHD Algorithm

Joe et al. [98], proposed a VHD algorithm based on mobility prediction in heterogeneous wireless networks that calculates the dwell time of mobile node in the network, and compares it with the handover delay to make handover decision. Four different types of users are considered viz., metro speed, ultra-speed, pedestrians, communication cutoff speed & highway speed users. The dwell time ‘T’ of mobile node for different users is calculated as

\[ T_{\text{pedestrian}} = \frac{4R}{v\pi} \]  
\[ T_{\text{metro}} = \frac{16R}{v\pi^2} \]  
\[ T_{\text{highway}} = \frac{1.767R}{v} \]  
\[ T_{\text{ultra}} = \frac{2R}{v} \]

where, \( v \) refers to the velocity of mobile node, and \( R \) is the range of network.

The dwell time are compared with HO delay and then decision for HO is made if dwell time is larger than the HO delay time, else the MN remains in the present network. The UHO’s are reduced because of prediction of the mobility and the list of candidate network helping for elimination of the unsuitable networks while making HO decision. Increase in number of HO’s due to zoning and sectoring of the networks and consumption of more battery power are the main drawbacks of such algorithm.

2.5.3 Network Ranking Based VHD Algorithm

Lusheng Wang et al. [99], categorized heterogeneous networks into two groups’ namely ubiquitous networks and hotspot networks. The ubiquitous networks comprises of UMTS and WiMAX whereas the hotspot network comprises of WLAN and Bluetooth. Such a combination is made considering that identical group typically have similar values on various criteria, such as monetary cost, security level, power consumption, mobility support capabilities, etc. In order to easily differentiate networks of dissimilar groups more particularly when the dissimilarities between different groups increases, and to make utilities of the networks in the same group more similar, a sigmoid form utility function has been used to form the groups of the networks.
In this work the requirements like operator policies, customer preferences, terminal properties, and application QoS levels are used to assign the weights and to build four groups on terminal side and two groups on network side. These groups consists of either static or dynamic criteria’s, attuned by either fuzzy logic normalization or utility theory and are combined by multi-criteria decision making (MCDM) network ranking algorithm. VHO properties does not match with the properties of some of the networks hence the mobility related measures cannot be covered by any of the two criteria’s of the groups. The probability of a random MN moving from one of the hotspots and inflowing another one in a mobility based network selection model equals precisely to the percentage of the earlier hotspot limits covered by others. Considering the unplanned nature of hotspot’s distribution, the transiting-out probability ‘P’ of the hotspot network when MN moves out of a hotspot is given as

\[ P = 1 - Q_{k-1} \approx 1 - Q_a \]  \hspace{1cm} (2.50)

where, \( Q_a \) is the percentage coverage on the square area covered by the \( k \) hotspots and \( Q_{k-1} \) is the coverage probability of \( (k-1) \) hotspots, and is roughly equal to \( Q_a \) with large value of \( k \).

Monte Carlo simulation is used by authors to verify this model. The rate of HO for four different cases are calculated as listed in table 2.5. Rate of HO is computed to select the best suitable network for mobile node having different mobility features.

\((1 - P)\) is the probability of the mobile node moving to another hotspot, \( r \) is the radius of hotspot, and \( R \) is the equivalent radius of the area that can be considered as the cell radius of certain ubiquitous network. \( a \) and \( d \) are the states that the mobile node is covered and uncovered by this network. \( U_a \) is the transiting rate from a hotspot and \( 1/U_a \) is the mean residence time within a hotspot.

Considering HO rate as performance metric and if the ubiquitous networks are better than the hotspot networks, then ubiquitous networks will indicate that the cost of HO will be among the cells of ubiquitous networks. If the hotspot networks are superior to ubiquitous networks than one of the conditions as listed in table 2.5 is considered for making HO. The network is then weighted and ranked to select the appropriate network for making HO. The advantage such algorithm is that it is simple to distinguish networks of different groups due to the categorization. Such an
algorithm is more appropriate for urban areas as hotspots are considered to have personal areas that are covered by Bluetooth, WLAN’s, etc.

Table 2.5 Rate of Handover between Ubiquitous and Hotspot Networks

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Handover</th>
<th>Rate of Handover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two ubiquitous networks</td>
<td>( U_a \frac{R}{R} )</td>
</tr>
<tr>
<td>2</td>
<td>Two hotspots</td>
<td>( U_a(1 - P)Q_a )</td>
</tr>
<tr>
<td>3</td>
<td>Between a hotspot and an ubiquitous network</td>
<td>( U_aPQ_a )</td>
</tr>
<tr>
<td>4</td>
<td>Between an ubiquitous network and a hotspot</td>
<td>( U_a(1 - Q_a) )</td>
</tr>
</tbody>
</table>

2.5.4 Gain Function Based VHD Algorithm

Agalya and Seethalakshmi [3] used performance criteria’s such as cost, power consumption, velocity, BW, RSS, position of MN and velocity to calculate the gain function and to make HO at proper time. The gain function \( G_i \) is given as

\[
G_i = w_b f_{b,i} + w_p f_{p,i} + w_c f_{c,i}
\]  

(2.51)

where, \( w_b, w_p, \) and \( w_c \) are the weight factors for offered BW, power consumption and usage cost of the network respectively, \( f_{b,i}, f_{p,i}, \) and \( f_{c,i} \) are the normalized values of the network \( i \) of BW, power consumption and cost.

Depending on the importance of the service required the weights are assigned to these parameters. Further handover is originated based on the position threshold which is determined from the position of mobile node measured, and is calculated as

\[
r = a - \nu \xi
\]  

(2.52)

where, \( \nu \) is the velocity of mobile node and \( \xi \) is the estimated HO signaling delay.

In order to assign priority for each network the position difference is calculated as difference between position threshold and position of the MN. Higher level of difference in position threshold, greater will be the priority level \( p_i \) and nearer will be the MN to the access point. Thus there is no need of HO and position of MN helps in minimizing the UHO. A network with larger overall gain function is chosen as the finest available network for HO. The overall gain function is calculated as

\[
OG = G * p_i
\]  

(2.53)
2.5.5 Constrained Markov Decision Process Based VHD Algorithm

Chi et al. in [100], proposed an algorithm based on constrained markov decision process (CMDP) in order to find a criteria under which VHO can be performed. Epochs, actions, states, rewards, cost, and transition probabilities are few of the elements used to characterize a CMDP model. A network at each decision epoch is selected by the mobile node depending on the current system parameters such as velocity, QoS and location of the mobile node. According to the transition probability function the system then shifts to a new state and lasts in this state for a period of time until the next decision epoch appears. Further the mobile node takes a new decision for selecting a network. There is a value and a cost associated with the mobile node for any action the mobile node selects at each state. This supports in increasing the anticipated total reward which can be obtained during the connection with a limitation of increase in expected total access cost.

In this work authors used a policy iteration and Q-learning algorithms to regulate the optimal VHD making policy. The optimal VHD making policy is a threshold policy in delay, velocity and BW available. To evaluate the quality of the connection a benefit function is used, and to model the signaling experienced and call dropping, a penalty function is used. Following features are considered for proper HO decision.

- User’s preference.
- User’s monetary budget.
- The present condition of the system as well as its future probable evolutions.
- The information of the wireless access networks such as delay, available BW, switching cost, and access cost of the overlaying networks.
- The information of the user and MN such as user’s velocity and location information.

To control the cost of accessing a particular network an access cost function has been used for each connection and the optimal VHD policy is determined based on the use of policy iteration and Q-learning algorithm. In policy iteration algorithm the authors used Lagrangian technique to transform the CMDP problem to an unconfined MDP problem so as to control the monetary budget of the user. The authors concluded that the CMDP based VHD algorithm developed for extensive range of conditions such as user's velocity, deviation in connection duration, traffic type, and
user’s budget, monetary access cost, and signaling cost is more advantageous for VHD making at the cost of increased complexity of the algorithm.

2.5.6 Prediction of Wrong Decisions with Mobility Pattern Based VHD Algorithm

Akhila. S and V. Sambasiva Rao [101], in their work considered the mobility pattern of the vehicle supported MT to study wrong decisions. An algorithm is proposed by authors to reduce the wrong decisions made at the junction points near the boundary of the network. The wrong decisions are independent of location and depend on the time period, velocity of the MT and/or distance of the mobile terminal from the base station. In their simulation work, two cases are considered namely;

**Case A:** Mobile terminal moving normal to the boundary i.e. radial movement.

**Case B:** Mobile terminal moving parallel to the boundary i.e. Peripheral movement.

Analysis is done considering the junction point to have eight roads connected to it, which are 45° relative to each other. When the Mobile node is moving normal to the peripheral of the coverage area, the UHP and MHP is calculated as

\[
UHP = P\left(\frac{\pi}{2}\right) + P\left(\frac{3\pi}{4}\right) + P(\pi) + P\left(\frac{5\pi}{4}\right) + P\left(\frac{3\pi}{2}\right) \quad (2.54)
\]

\[
MHP = P\left(\frac{7\pi}{4}\right) + P(0) + P\left(\frac{\pi}{4}\right) \quad (2.55)
\]

Similarly, when the Mobile Terminal is moving alongside the periphery of the coverage area, the UHP increases. This happens due to increase in propensity of making a handover. This in turn upturns the ping pong effect, and can be overcome by considering the speed and/or distance of the mobile terminal from the base station. The UHP and MHP for the case of the mobile terminal moving alongside the periphery of the coverage area is calculated as

\[
UHP = P(0) + P\left(\frac{\pi}{4}\right) + P\left(\frac{\pi}{2}\right) + P\left(\frac{3\pi}{4}\right) + P(\pi) \quad (2.56)
\]

\[
MHP = P\left(\frac{7\pi}{4}\right) + P\left(\frac{3\pi}{2}\right) + P\left(\frac{5\pi}{4}\right) \quad (2.57)
\]

The MT is considered to take either a U-turn, right turn, left turn or continue to move in the same direction or in the cross roads. The resultant probability function for any direction change is written as \(P(180^\circ), P(90^\circ), P(-90^\circ), P(0^\circ)\) and \(P(n*45^\circ)\) respectively. Thus they sum up to be \(P(180^\circ) + P(90^\circ) + P(-90^\circ) + P(0^\circ) + P\)
\((n \times 45^\circ) = 1\), where \(n = \pm 1, 2\) and \(\sigma_{\text{p}}\) is the standard deviation of all four directions, and is assumed to be equal for all the four distributions. The analysis is made considering five scenarios, and the probabilities are of only illustrative values at the junctions of a metropolitan city. Authors while calculating the WDP have only considered mobility as performance metric. The VHD algorithms based on Mobility are summarized in Table 2.6.

**Table 2.6. Mobility Based Algorithms**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Ref.]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location Based</td>
<td>Zhang et al. [97]</td>
<td>Broadband and Cellular networks are used for analysis. Time, distance and speed are quantized into discrete units. Utility function is used to evaluate user satisfaction.</td>
<td>Reduced unnecessary handover and increased user satisfaction.</td>
<td>Position of MN needs to be monitored continuously. LSS should be aware of movement and location topology of MN.</td>
</tr>
<tr>
<td>2</td>
<td>Mobility Prediction Based</td>
<td>Joe et al. [98]</td>
<td>Calculates the dwell time of mobile node and compares it with the handover delay to make handover decision.</td>
<td>Reduced unnecessary handovers.</td>
<td>Increase in number of handovers. More consumption of battery power.</td>
</tr>
<tr>
<td>3</td>
<td>Network Ranking Based</td>
<td>Lusheng Wang et al. [99]</td>
<td>Operator policies, customer preferences, terminal properties, and application QoS levels are used for weighting and ranking to select the optimum network for handover.</td>
<td>Distinguishing networks of different groups and selecting the optimum network for handover is easy.</td>
<td>Only suitable for urban areas</td>
</tr>
<tr>
<td>4</td>
<td>Gain Function Based</td>
<td>Agalya and Seethalaks hmi in [3]</td>
<td>Cost function metric is used to calculate the gain function and to make handover to network with highest gain at proper time. Handover is initiated based on the position threshold.</td>
<td>Improved throughput, Reduced unnecessary handover. Considers static as well as dynamic parameters.</td>
<td>Estimation of position of mobile node is not specified.</td>
</tr>
<tr>
<td>5</td>
<td>Constrained Markov Decision Process Based</td>
<td>Chi et al. [100]</td>
<td>Policy iteration and Q-learning algorithms are used to determine the optimal VHD policy. To assess the quality of the connection a benefit function is used and to model the signaling and call dropping, a penalty function is used.</td>
<td>CDMDP based VHD algorithm for wide range of conditions is used for handover.</td>
<td>Increased complexity of the algorithm</td>
</tr>
<tr>
<td>6</td>
<td>Prediction of Wrong Decisions with Mobility Pattern</td>
<td>S. Akhila and V. Sambasiva Rao [101]</td>
<td>Mobility pattern of the vehicle-borne mobile node is used to study wrong decisions.</td>
<td>Reduced WDP</td>
<td>Only mobility is Considered as performance metric.</td>
</tr>
</tbody>
</table>
2.6 COMBINATION BASED VHD ALGORITHMS

These algorithms are based on either fuzzy logic or artificial neural networks, which makes the handover decision considering combination of various parameters such as RSS, network covering area, service monetary cost, available BW, reliability, battery power, security and mobility model, etc. In order to solve multiple attribute decision making (MADM) problems, fuzzy logic and artificial neural networks (ANN’s) are best suitable and are currently the hot research topics. In literature many combination based algorithms have been proposed [50, 51, 102-107].

2.6.1 Two Neural Networks Based VHD Algorithm

A VHD method based on two neural network is proposed by Pahlavan et al. [107]. Authors used an ANN for VHO between WLAN and General Packet Radio Service (GPRS). In this method RSS are measured periodically by the mobile node and five current RSS samples of the access point are fed into the ANN. ANN is trained with the multiple samples obtained from the access points using pattern recognition technique. This is done for selecting the best network among the available candidate networks with reduced ping pong effect and handover delay. HO decision from WLAN to GPRS is made if the output of ANN is binary 1 else the MN remains connected to the WLAN.

In this method authors have not specified the details of training provided to ANN and the purpose of selecting the specific parameters. Also there is more intricacy in the training process and the algorithm proposed.

2.6.2 Control Theory Based VHD Algorithm

Hongwei Liao et al. [106], proposed a VHD algorithm based on fuzzy control theory. Performance metrics such as cost, power level, and BW are considered for handover decision making in this algorithm. Initially, by using the performance metrics as input parameters a membership function is established and then the membership degrees of corresponding parameters are obtained. These are then processed by the weight vector to determine the fuzzy vertical handoff decision (FVHD) value of each network. FVHD vector is derived from these values and then the handover decision is made. The membership function of power level $\mu_1$ is calculated as
\[ \mu_1 = \begin{cases} 0 & 0 \leq p(x) \leq p_{TH} \\ \frac{p(x) - p_{TH}}{p_{max} - p_{TH}} & p(x) > p_{TH} \end{cases} \]  

(2.58)

where, \( p(x) \) is the actual power level that is received from the candidate network from location \( x \), \( p_{TH} \) is the threshold power level and \( p_{max} \) is the maximum power level that can be received from a candidate network.

\( \mu_2 \) is calculated as

\[ \mu_2 = \begin{cases} 1 - \frac{c(x)}{c_{TH}} & 0 \leq c(x) \leq c_{TH} \\ 0 & c(x) > c_{TH} \end{cases} \]  

(2.59)

where, \( c(x) \) is the actual cost of the candidate network and \( c_{TH} \) defines the threshold cost.

When \( (x) > c_{TH} \) the user identifies the need for handover as the current network is too expensive to be continued with.

Also \( \mu_3 \) is calculated as

\[ \mu_3 = \begin{cases} \frac{B(x)}{B_{max}} & 0 \leq B(x) \leq B_{max} \\ 0 & B(x) > B_{max} \end{cases} \]  

(2.60)

where, \( B_{max} \) is the maximum amount of BW a candidate can offer and \( B(x) \) is the amount of BW currently available in the candidate network.

The membership degrees for each of these parameters and for each candidate network is then calculated. Further the weights for three input parameters of each network, in order to arrive at the FVHD value is calculated as

\[ w_i = \frac{\sigma_i}{\sum_{i=1}^{2} \sigma_i} \]  

(2.61)

where, \( \sigma_i \) is the standard deviation of \( \mu_{1,n}(x) \).

The base station with the highest FVHD value and acceptable FVHD margin limit will be chosen for handover.

### 2.6.3 Multilayer Feed Forward Artificial Neural Network Based VHD Algorithm

VHD algorithm based on artificial neural networks (ANN) is proposed by Nasser et al. [50]. It shows that the features of accessible wireless networks can be collected by mobile device for making handover decisions. It comprises of network usage cost, network security, network transmission range, and network capacity. Through the current link the mobile device sends these features to VHO manager which is a
middleware consisting of network handling manager and feature collector. Further it provides ANN training. As per the user’s preferences the preferred network is carefully chosen by using a multilayer feedforward ANN. Series of user preference sets with random weights are generated from the cost function for ANN training, as in reference [44]. Subsequently the best network is selected by training the system. To find the finest network among all the available candidate networks, the authors propose that the learning rate and the acceptable error value should be properly selected by the system at the cost of long delay during the training process.

### 2.6.4 Fuzzy Logic Based VHD Algorithm

Dealing with the expanded set of input parameters for making VHO decision using fuzzy logic [51, 105 and 106] is one of the methodology, similar to ANN approach. Xia et al. [51] proposed one such method to make handovers between WLANs and UMTS. A pre-decision unit is used in this method. In this algorithm, if the mobile terminal is connected to the WLAN, and if the velocity of the mobile terminal \((v)\) is greater than a predefined threshold value of velocity \((v_T)\), a handover to the UMTS is originated so as to avoid a connection breakdown. Also the pre-decision unit checks whether the predicted RSS satisfies its requirements. If the predicted RSS from the WLAN \((P_{RW})\) is larger than predefined threshold value of RSS \((P_{rW})\), or the predicted RSS from the UMTS \((P_{RU})\) is smaller than predefined threshold value of RSS \((P_{rU})\) then handover is not originated. After the pre-decision making the fuzzy logic based normalized quantitative decision (FNQD) is applied. The FNQD undergoes three steps namely; fuzzification, normalization and quantitative decision. The three inputs, present RSS, and the anticipated Fuzzy logic is applied to RSS and BW. Further they are normalized to generate performance evaluation values (PEV). VHD is made after comparing PEVs of the candidate networks. If the mobile terminal is connected to the UMTS and if the WLAN connectivity is available, the pre-decision unit is used to eliminate UHO’s when the velocity of the mobile terminal is greater than the threshold \((v_T)\). A similar process is run as the one described for handover from UMTS to WLAN.

Authors concluded that the performance is improved due to reduction in the number of UHO’s and thus avoid the ping-pong effect. Such a technique is not applicable in practice as the network condition and user requirements may vary in
different situations. In addition, additional performance evaluation criteria such as handover delay and system load need to be addressed. Comparison of combination based VHD algorithms is summarized in Table 2.7.

**Table 2.7 Combination based VHD algorithms**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two Neural Networks based</td>
<td>Pahlavan et al. [107]</td>
<td>ANN is used for vertical handover between WLAN and GPRS. RSS samples of the access point are fed into the ANN and the system is trained for making handover decisions.</td>
<td>Reduced Wrong decision probability of handover.</td>
<td>Complexity in training. Details of ANN training and the purpose of selecting the particular parameters are not specified.</td>
</tr>
<tr>
<td>2</td>
<td>Control Theory Based</td>
<td>Hongwei Liao et al. [106]</td>
<td>Cost, power level, and bandwidth are considered for handover decision making. FVHD value and vector of each network is obtained from weight vector for making handover decision.</td>
<td>Dynamic evaluation and analysis of input parameters is obtained for optimum HO decision making.</td>
<td>Handover delay is not addressed.</td>
</tr>
<tr>
<td>3</td>
<td>Multilayer Feed Forward Artificial Neural Network Based</td>
<td>Nasser et al. [50]</td>
<td>ANN is used to train the parameters such as network usage cost, network security, network transmission range and network capacity for handover.</td>
<td>High success rate of optimum network selection.</td>
<td>Long delay during the training process.</td>
</tr>
<tr>
<td>4</td>
<td>Fuzzy Logic Based</td>
<td>Xia et al.’s [51]</td>
<td>Handover between WLANs and UMTS. Fuzzy logic is applied to RSS, predicted RSS and BW, and then they are normalized to generate PEV. VHD is made by comparing PEVs of the candidate network.</td>
<td>Reduced unnecessary handovers and the ping-pong effect.</td>
<td>Not practical as the network conditions and user requirements vary. Handover delay and system load need to be addressed.</td>
</tr>
</tbody>
</table>
2.7 MULTIPLE ATTRIBUTES DECISION BASED VHD ALGORITHMS

Algorithms based on multiple attributes decision making (MADM) [52, 111-128], makes the final decision for handover only after calculating the quantitative value of each normalized attribute and evaluating the target systems through the weighted function of the quantitative values.

In literature there are many VHD making algorithms based on multi attributes decision making (MADM) and are proposed to deal with the problems of VHD algorithms. MADM methods include simple additive weighting (SAW), analytic hierarchy process (AHP), grey relational analysis (GRA), multiplicative exponential weighting (MEW), and technique for order preference by similarity to ideal solution (TOPSIS) and the distance to the ideal alternative (DIA).

It is possible to meet the QoS of different users and improve the performance of the complete network using simple additive weighting (SAW) based MADM, in which different weights are assigned to different factors and can be vigorously adjusted according to network state and several user services [108]. To assign weights to different metrics there are several methods used, such as analytic hierarchy process (AHP) method, fuzzy analytic hierarchy process (FAHP), analytic network process (ANP), fuzzy analytic network process (FANP) and random weighting. In the process of decision making for the selection of network, determining the optimum weights for different metrics, and for each traffic classes is one of the key problem.

To determine the degree of association of different factors an analytical technique known as gray relation analysis based algorithm (GRAA) is used. These factors are categorized by grey relational coefficient (GRC). GRC is applied to calculate the association of each candidate network with users existing network. Then the candidate network with highest correlation of current network is selected as target network for handover. To advance the performance of VHD algorithm, GRA can be combined with other methods such as AHP and fuzzy logic. GRAA is able to analyze different system factors with few data available and the trend of system development can be measured quantitatively. Thus GRAA is very appropriate for dynamic network analysis, however, the computation difficulty is high enough and hence limits the practical applications.

TOPSIS algorithms is a perfect solution for performance comparison and is
considered as the best alternative approach, and is closer to the ideal solution [109]. MWE uses the weighted product of all the features to improve the performance, and works similarly to SAW algorithms. As this does not have an upper-bound it is most suitable algorithm for comparing the score.

K. Savitha and C. Chandrasekar in [110] proposed a decision maker TOPSIS to select the finest network from the visitor network for VHD making. Authors in [110] conclude that TOPSIS is the best decision maker than SAW to select the optimum network for handover.

The network selection algorithm in [114-117] is based on AHP and GRA methods. The weights for each criterion are determined by AHP method, and GRA method is used to rank the alternatives. AHP and TOPSIS methods are combined in [118-120], for network selection. The weights of the criteria are determined by the AHP method and the ranking of access network is determined by TOPSIS method.

In [121], the authors present DIA method which selects an alternative that is the shortest Euclidean distance instead of positive ideal alternative (PIA). The authors in [122] proposed a method considering MADM techniques and Mahalanobis distance, which considers the association between the metrics for selecting the appropriate network, and to reduce the number of handovers.

Escobar et al. [123], proposed an evaluation model to assess the performance of five MADM methods namely SAW, MEW, TOPSIS, ELECTRE, and VIKOR. The performance of available BW, jitter, cost per byte, packet loss, and delay is analyzed. The major drawback of this model is the lack of a weighting algorithm which can be used to assign a relative weight to each handover metric by considering each traffic classes.

In [124], a fuzzy logic based multiple attribute decision making algorithm is proposed. In this algorithm the RSS, QoS parameters and mobile velocity attributes are used as performance metrics and AHP is used as a weighting scheme. Finally TOPSIS ranking algorithm is used to select the target network. This algorithm cannot perform properly due to quickly changing RF conditions in outdoor environment.

An algorithm based on the dwell timer for eliminating ping pong effect is achieved by reducing the shadow fading effect in reference [125]. Usage of dwell
timer based on the user’s need is not practically feasible. A fuzzy based multiple attribute decision making algorithm is used for deciding when and to which network it has to handover. An optimal network selection algorithm based on analytic network process and grey relational analysis is proposed in [126]. A novel context aware VHO algorithm based on multiple attribute decision making is proposed in [127, 128]. The results in this work show that algorithm avoids UHO’s, but the fuzziness of the attributes used for handover decision in this algorithm cannot be handled by network process.

Few MADM based algorithms among the above listed algorithms are explained in the following section

2.7.1 MDP_SAW and MDP_TOPSIS Based VHD Algorithm

Sharma et al. [113], proposed an algorithm in which handover decision is based on QoS parameters namely delay and available BW. In this work value iteration algorithm (VIA) is designed by integrating analytic hierarchy process (AHP) and markov decision process (MDP). The process is made using simple additive weighting (SAW) and technique for order preference by similar to ideal solution (TOPSIS) to select the best available network as per user’s choice.

For all the accessible candidate networks the link reward functions $f_{SAW}(s, a)$ and $f_{TOPSIS}(s, a)$ of SAW and TOPSIS, in each of the system state ‘$s$’, and a set of all possible actions ‘$a$’ is calculated based on the reward function of QoS parameter defined for SAW and TOPSIS.

The link reward functions $f_{SAW}(s, a)$ and $f_{TOPSIS}(s, a)$ are calculated as

$$f_{SAW}(s, a) = \omega_{b} f_{dSAW}(s, a) + \omega_{d} f_{dSAW}(s, a)$$

$$f_{TOPSIS}(s, a) = \frac{I^{-}(s, a)}{I^{-}(s, a)} + I^{+}(s, a)$$

To obtain the optimal network, reward functions of MDP_SAW and MDP_TOPSIS are calculated using these link rewards. After determining the optimal network the anticipated total BW and delay is calculated to determine the finest network for handover. This algorithm reduces UHO’s, offers improved BW, and supports the mobile node for selecting the best candidate network for user satisfaction. This is accomplished at the cost of additional delay in making the decision, which is not addressed by the authors.
2.7.2 AHP-MADM Based VHD Algorithm

Mohamed Lahby et al. [111], proposed an algorithm which combines MADM methods. An AHP method is used in this model to find optimum weight of each performance metric which need to be used in a particular traffic class. The procedure includes identification of the assessment parameters which are represented as indicators. These parameters influence the performance of VHO algorithm and allows for comparison. The assessment parameters used are ranking abnormality of candidate network and number of handovers. The assessment matrix is generated representing the evaluation of each VHO algorithm with respect to the assessment parameter. The assessment matrix is expressed as:

\[ EM = \begin{bmatrix} v_{11} & \cdots & v_{1m} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & v_{nm} \end{bmatrix} \] (2.64)

where, \( v_{ij} \) is the measured value of the VHO algorithm with respect to the assessment parameters.

Normalized assessment matrix is calculated in order to govern the magnitude of assessment parameters and to prevent domination of some of the assessment parameters over others.

For benefit attribute, the normalized value of \( d_{ij} \) is calculated as

\[ d_{ij} = \frac{v_{ij}}{v_{ij}^{\text{max}}} \] (2.65)

For cost attribute, the normalized value of \( d_{ij} \) is calculated as

\[ d_{ij} = \frac{v_{ij}^{\text{max}}}{v_{ij}} \] (2.66)

and criticality matrix \( c_{ij} \) is calculated as

\[ c_{ij} = k \] (2.67)

where, \( k \) is acquired from table 2.8, according to the value of \( d_{ij} \).

Weighted criticality matrix is created by applying the AHP method to weigh each assessment parameter, and the weighted criticality matrix \( t_{ij} \) is calculated as

\[ t_{ij} = w_i \times c_{ij} \] (2.68)

where,

\[ \sum_{i=1}^{m} w_i = 1 \] (2.69)
and the criticality index of each VHO algorithm is calculated as

\[ CI_i = \frac{100 \times \left( \sum_{l=1}^{m} t_{il} \right)}{n} \]  

(2.70)

where \( i = 1, \ldots, n \) and \( n \) is the maximum estimation level of all parameters.

The authors in this work conclude that the GRA method has the uppermost criticality index for all traffic classes namely: background, conversational, interactive and streaming.

### Table 2.8 Attribute Values for the Candidate Networks

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k=1 )</td>
<td>( k=3 )</td>
<td>( k=5 )</td>
<td>( k=7 )</td>
<td>( k=9 )</td>
</tr>
<tr>
<td></td>
<td>( d_{ij} &gt; 80% ) of the max value</td>
<td>( d_{ij} &gt; 60% ) of the max value</td>
<td>( d_{ij} &gt; 40% ) of the max value</td>
<td>( d_{ij} &gt; 20% ) of the max value</td>
</tr>
</tbody>
</table>

#### 2.7.3 FMADM with Context Aware Strategy Based VHD Algorithm

Anantha Narayanan et al. [112], in their work combined fuzzy logic system with multiple attributes decision making (FMADM) to handle various attributes and their fuzziness through fuzzy logic system. FMADM uses the context aware approach to make the decision engine further intelligent, by taking the existing status of the target network and requirements of the application resource into consideration. To reduce the packet loss during the handover it finally applies “make before break handover”.

The metrics such as RSSI, network coverage, mobile velocity, data rate, service cost, battery power, and network latency of mobile device are used in the algorithm. To make context based HO decision it uses context aware pattern by collecting present network characteristics such as RSSI, QoS parameters, battery status and velocity of the mobile. These metrics are weighted and then delivered to fuzzy based multiple attribute decision making scheme. The fuzzy based system converts them into membership functions, and are fed to the fuzzy extrapolation engine. To obtain fuzzy decision sets, a set of fuzzy IF-THEN rules are applied which includes linguistic values like ‘strongly yes,’ ‘yes,’ ‘uncertain,’ ‘no,’ and ‘strongly No’.
These decision sets are combined into a single fuzzy set and are transformed into handover decision metric value using defuzzifier. Handover decision is made based on this value. Make before break handover is made once the optimum network is selected and authenticated, and thereafter registration of mobile IP is done. Further the decision algorithm seamlessly routes the traffic to the selected interface with minimum packet loss.

To decrease the UHO’s the proposed decision algorithm [112] attain intelligence by combining fuzzy logic system to handle imprecise data, multiple attribute decision making to handle multiple attributes for decision making and context aware heuristic. Before making the handover it recognizes the best network, authenticate, and does mobile IP registration, which in turn reduces the packet loss to ensure high QoS. To increase battery lifetime and to maintain load balancing it need to forward data packets to suitable attachment point. The authors have shown that the proposed algorithm efficiently uses the network resources by switching between 3G and Wi-Fi, under the different RF environmental conditions so as to offer best connectivity with negligible service cost to the users. 30-40ms is the average handover delay, and the integration of cellular network with WLAN reduces the call dropping rate (<0.006) and call blocking probability (<0.00607) as well as UHO in the heterogeneous networks.

The performance analysis shows that the effectiveness of proposed algorithm in terms of negligible packet loss (<1%), running time (2ms.), handover delay (<150ms.), large BW and efficient resource utilization are based on the application requirements. This performance result shows that the proposed approach fulfills QoS requirements of audio, video and data in terms of packet loss and handover delay during the handover, as recommended by Cisco Systems. This decision algorithm efficiently uses the network resources by switching between 3G and Wi-Fi under the different RF environmental conditions to offer best connectivity with negligible service cost to the users. The application resource requirements are classified into real time and non-real time in this algorithm. But if they are classified based on the requirement using software agents then the algorithm would perform better. Summary of the multiple attribute decision making based VHD algorithms is shown in Table 2.9.
### Table 2.9. Multiple Attribute Decision Based VHD Algorithms

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MDP_SAW and MDP_TOPSIS Based</td>
<td>Sharna et al. [113]</td>
<td>Handover decision is based on QoS parameters namely delay and available bandwidth. SAW and TOPSIS are used to select the best available network as per user preference.</td>
<td>Reduces unnecessary handovers, offers better bandwidth, and selection of optimum network as per user need.</td>
<td>Excess delay in making the decision.</td>
</tr>
<tr>
<td>2</td>
<td>AHP-MADM Based</td>
<td>Mohamed Lahby et al. [111]</td>
<td>An AHP method is used in this model to find optimum weight of each performance metric. Evaluation parameters such as ranking abnormality and number of handovers are used for handover.</td>
<td>GRA method has the highest criticality index for all traffic classes namely: background, conversational, interactive and streaming. Reduced procession delay.</td>
<td>Handover dropping rate is high.</td>
</tr>
<tr>
<td>3</td>
<td>FMADM with Context Aware Strategy Based</td>
<td>Anantha Narayanan et al. [112]</td>
<td>Handover between 3G and Wi-Fi. Combine fuzzy logic system with FMADM to handle multiple attributes. Metric such as RSSI, network coverage, mobile velocity, data rate, service cost, battery power requirements and network latency are used for handover.</td>
<td>Reduced packet loss and handover delay with minimal service cost. Reduced call dropping rate, call blocking probability, and unnecessary handover.</td>
<td>Load on the decision engine is high.</td>
</tr>
</tbody>
</table>

### 2.8 AUTHENTICATION BASED VHD ALGORITHMS

Authentication is one of the main challenge in the process of handover. In order to get access to other networks, multi-pass authentication procedures are to be executed by the user. This causes overhead on the authentication, authorization, and accounting (AAA) server, and delay in authenticating the user is increased because of
unnecessary and repeated procedures and protocols. The authentication based VHD algorithm takes care of authentication process and proactive handover. It maintains the QoS and reduces the handover delay. In next generation networks the most stimulating problem introduced by mobile networking is security. With user mobility the risk of illegal user's is increased. Ultimately it is essential to provide security as well as authentication scheme for the handover process and reduce authentication delay during the handover process. There are many authentication based VHD algorithms and few among them are explained in the next section.

2.8.1 Extensible Authentication Protocol Based Algorithm

András Bohák et al. [53], proposed an authentication scheme for fast handover between Wi-Fi access points. Authors used EAP (Extensible Authentication Protocol-RFC3748) - SIM (Subscriber Identity Module) in there algorithm. Pre-authorization is used in this technique to eliminate the need of communication to be made with the remote server when the handover actually takes place. This method decreases the authentication delay and eliminate the linear dependency of the round trip delay (RTT) between the authentication server and AP is also eliminated.

2.8.2 Fast Authentication Based VHD Algorithm

Ganti et al. [54], proposed a fast authentication scheme in the handover process for next generation networks. To optimize QoS parameters in the process of handover, authors used a method that eliminates the frequent authentication steps without affecting the security level. At the time of registration of mobile node with AAA server, a proper certificate is issued. This certification is an agreement among all the service providers which will be unique and in force for each network. Because of reduction in frequent repetitions there is significant amount of saving in BW, time, cost, handover latency, and packet loss. The fast authentication based VHD algorithms are summarized in the Table 2.10.
Table 2.10. Authentication Based VHD Algorithms

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VHD Algorithms</th>
<th>Authors [Reference]</th>
<th>Features</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extensible Authentication Protocol Based</td>
<td>András Bohák et al. [53]</td>
<td>Authentication scheme for fast handover between Wi-Fi access points is used. EAP-SIM protocol and Pre-authorization issued to eliminate the need for communication with the remote server at the time of handover.</td>
<td>Reduced authentication delay and elimination of linear dependency on the round trip delay (RTT) between the authentication server and AP.</td>
<td>This method is proposed only for Wi-Fi access points.</td>
</tr>
<tr>
<td>2</td>
<td>Fast Authentication Based</td>
<td>Ganti et al. [54]</td>
<td>Valid certificate issued to reduce the handover delay. eliminates the repeated authentication steps without affecting the security level</td>
<td>Saving in bandwidth, time and cost and reduction in handover latency, packet loss and cost.</td>
<td></td>
</tr>
</tbody>
</table>

2.9 CONCLUSION

A broad survey of VHD algorithms is presented in this chapter. The overall performance of different network parameters based VHD algorithms is summarized. It is observed that the RSS and BW based VHD algorithms are used for selection of optimum network with the most stable RSS and highest BW as handover performance metrics. Also it is addressed that the algorithms based on cost function, combination, MADMA and authentication select the target candidate network having highest overall performance. Normally algorithms based on RSS are the simplest one, followed by the BW based algorithms. Cost function based VHD algorithms need to collect and normalize several network parameters and hence are more complex. Combination, MADMA and authentication based algorithms are the most challenging ones because of their pre-training requirements.

As far as reliability is concerned it differs among the algorithms. The RSS based VHD algorithms are less reliable because of variations in RSS, and the reliability of BW based VHD algorithms is reduced because of difficulty in measurement of available BW. Security level parameters are hard to measure and thus reliability of algorithms based on the cost function is reduced. As far as combination and MADMA
algorithms are considered they are utmost reliable because they are trained beforehand. Security level is better in authentication based algorithms in addition they provide lesser delay, packet loss and cost. Higher throughput is achieved in BW and cost function based algorithms as compared with RSS based algorithm. The throughput of combination, MADMA and authentication based algorithms is not much addressed by the authors.

In short, VHD algorithms based on RSS and BW are much simple as they are analyzed considering not more than two input HO criteria while ignoring other input parameters such as monetary cost, power consumption etc. Also, they involved not more than two different access technology networks. On the other hand algorithms based on cost function, combination, MADMA and authentication are more complex, and larger range of network parameters are consider as compared to others, but are much complicated to implement and still are in the theoretical analysis phase yet.

Due to the varying performance metrics used for handover and various types of VHD algorithms, the decision process of selecting the best network is still a complex issue. VHD algorithms need to be analyzed before making the handover decision for seamlessly selecting the suitable network as per user contentment and for reducing the complexity issues in VHD making. The computational power of mobile node should be enhanced such that multiple VHD algorithms can be included in a mobile device. Also adaptive techniques need to be implemented such that mobile device selects a VHD algorithm intelligently based on the situation and user preferences.

In the research literature published, the VHD algorithms for optimum selection of network as per user need, fail to broadly consider various network parameters, user mobility and user preferences, particularly when the number of heterogeneous networks are more in numbers. Also there is lacuna in the analysis of VHD algorithms in terms of probability of making wrong decision for the handover decision when the number of heterogeneous network nodes are more in number. To resolve these issues an analysis of VHD algorithms based on wrong decision probability for five node networks and to provide an integrated solution to the optimization of the VHD process is the main focus of this research project.

Analysis of probabilistic based formulation of single and four state, five node network model is presented in the next section.