Chapter- 6

Performance Evaluation of Vertical Handoff
Chapter Overview

This chapter describes our unique approach towards the performance evaluation of vertical handoff. It provides brief introduction regarding vertical handoff criteria and policies. It also lightens up the concept of Cost Function Based Strategies (CFBS) and the results related to it [121].

6.1 Introduction

In the past decade, the telecommunications industry has witnessed an ever accelerated growth of the usage of the mobile communications. As a result, the mobile communications technology has evolved from the so-called second-generation (2G) technologies, GSM in Europe, IS-95(CDMA) and IS-136 (TDMA) in USA, to the third generation (3G) technologies. Along with the standards development for providing voice service to mobile users, a group of standards to deliver data to the mobile users have evolved from both SDOs (Standards Development Organizations) and industry. Systems and applications, such as Short Message Service (SMS) for sending and receiving short text messages for mobile phone users, have been built and continue to be developed.

The cellular approach requires a large number of base stations in a city of any size. A typical large city can have hundreds of towers. But because so many people are using cell phones, costs remain low per user. Each carrier in each city also runs one central office called the Mobile Telephone Switching Office (MTSO). This office handles the entire phone connections to the normal land-based phone system, and controls all of the base stations in the region. Groups of several cells are connected to a Mobile Switching Center (MSC) through which the calls are then routed to the telephone networks. The area serviced by a MSC is called a Registration Area (RA) or Location Area (LA). A group of RA’s composes a Service Area (SA). Each SA is serviced by a Home Location Register (HLR). A wireless network may include several SAs and thus several HLRs [122].

2G systems such as GSM, IS-95, and cdmaOne were designed to carry speech and low bit rate data. 3G systems were designed to provide higher data rate services. During
the evolution from 2G to 3G, a range of wireless systems, including GPRS, Bluetooth, WLAN and Hiper LAN have been developed. All these systems were designed independently, targeting different service types, data rates, and users. As these systems all have their own merits and shortcomings, there is no single system that is good enough to replace all the other technologies.

In cellular networks such as GSM, a call is seamlessly handed over from one cell to another using hard handoff without the loss of voice data. This is managed by networks based handoff control mechanisms that detect when a user is in a handoff zone between cells and redirect the voice data at the appropriate moment to the mobile node via the cell that the mobile node has just entered. In 4G networks a handoff between different networks is required [123]. A handoff between different networks is referred to as a **Vertical Handoff (VHO)**.

### 6.1.1 Handoff Management Process

Many literatures describe the handoff process in three phases.

1. **Handoff Information Gathering**: This phase is used to collect all the information required to identify the need for handoff and can subsequently initiate it. It can be called also handoff initiation phase or system discovery.

2. **Handoff Decision**: This process is used to determine whether and how to perform the handoff by selecting the most suitable access network (taking into account some criteria such as user preferences) and by giving instructions to the execution phase. It is also called network or system selection handoff.

3. **Handoff Execution**: This phase is used to change channels conforming to the details resolved during the decision phase.

The handoff procedure can be characterized in various types. On one hand, the handoff can be hard when the mobile terminal is connected to only one point of attachment at a time. It is referred to as a break before make handoff. On the other hand, it can be soft when the mobile terminal is connected to two points of attachment for a while and it is referred to make before break handoff. For achieving seamlessness aspect in mobility scenarios, the handoff has to be seamless. It means that the transition to the
new network point of attachment is transparent to the user (no perceptible service degradation). So, it is the one that performs a fast handoff (minimal handoff latency) and a smooth handoff (minimal packet loss).

Regardless of handoff types, the handoff process control or the handoff decision mechanism can be located in a network entity or in the mobile terminal itself. The handoff decision usually involves some sort of measurements and information about when and where to perform handoff and obtained from one entity or both. So, in Network-Controlled Handoff (NCHO), the network entity has the primary control over the handoff. In Mobile-Controlled Handoff (MCHO), the mobile terminal must take its own measurement and make the handoff decision on its own. When information and measurements from the mobile terminal are used by the network to decide, it is referred to a Mobile-Assisted Handoff (MAHO) like in GSM. When the network collects information that can be used by the mobile terminal in a handoff decision, it is a Network-Assisted Handoff (NAHO).

6.2 Classification of Vertical Handoff

The handoffs can be classified in many different ways. For VHO, there are two additional and useful classifications to understand why VHO mechanisms are different from traditional horizontal handoff (HHO) mechanisms such as signal strength-based.

The first classification is: upward and downward. An upward VHO occurs from a network with small coverage and high data rate to a network with wider coverage and lower data rate. On the other hand, a downward VHO occurs in the opposite direction [124]. As an example for this classification let’s consider the case of two of the most important current wireless technologies: 3G cellular networks and WLANs. The WLAN system can be considered as the small coverage network with high data rate while the 3G cellular system is the one with wider coverage and lower data rate. The trend in the literature has been to perform downward VHOs whenever possible [125].

The second classification is: imperative and alternative. An imperative VHO occurs due to low signal from the BS or AP. In other words, it can be considered as an HHO. The execution of an imperative VHO has to be fast in order to keep on-going
connections. On the other hand, a VHO initiated to provide the user with better performance (e.g., more bandwidth or lower access cost) is considered to be an alternative VHO. This VHO can occur when a user connected to a 3G cellular network goes inside the coverage of a WLAN, even if the signal of the connection to the 3G cellular networks does not lose any signal strength, the user may consider the connection to the WLAN a better option.

6.3 Vertical handoff in Heterogeneous Network

The deployment of various wireless technologies (2G, 3G, WLAN, WMAN, etc.) in combination with the evolution of Mobile Terminals (MTs) with multiple network interfaces and the development of IP-based applications (non-real-time or real-time) has allowed the user to have access to IP services anywhere at any time from any network.

One revolutionary step, driven by this universal wireless access, is the fourth Generation (4G) of wireless communications. This next-generation of wireless systems represents a heterogeneous environment with different access networks technologies that differ in bandwidth, latency or cost. In this kind of environment, mobility management is the essential issue that supports the roaming of users from one system to another. Handoff management, one of the mobility management components, controls the change of the MT’s point of attachment during active communication [126].

Handoff management issues include mobility scenarios, metrics, decision algorithms and procedures. Mobility scenarios can be classified into horizontal (between different cells of the same network) and vertical (between different types of networks). In homogeneous networks, horizontal handoffs are typically required when the serving access router becomes unavailable due to MT’s movement. In heterogeneous networks, the need for vertical handoffs can be initiated for convenience rather than connectivity reasons (e.g., according to user choice for a particular service).
Two of the major challenges in vertical handoff management are seamlessness and automation aspects in network switching. These particular requirements can refer to the Always Best Connected concept, of being connected in the best possible way in an environment of multiple access technologies, according to policies (expressed by rules based on parameters such as network conditions or user preferences). For that, a handoff management technique must choose the appropriate time to initiate the handoff and the most suitable access network for a specific service among those available, and must maintain service continuity. Figure 6.1 shows the generic vertical handoff in heterogeneous network. As mentioned in the previous section, we introduce a more general classification according to initiation reasons for a vertical handoff decision i) imperative or forced handoff: triggered by physical events regarding network interfaces availability and ii) Alternative or user handoff: triggered by user policies and preferences. Now it is necessary to device rules to fix how and when to trigger the handoff. These rules design a handoff decision policy and use policy parameters, called metrics or decision criteria (monetary cost, QoS, power requirements, etc.). Thus, a vertical handoff decision strategy should decide when to trigger the handoff procedure, select and switch seamlessly to the most optimal access network from those available.

6.3.1 Handoff Decision Criteria

Handoff criteria are the qualities that are measured to give an indication of whether or not a handoff is needed. We can regroup different criteria as follows:
1. Network-related: coverage, bandwidth, latency, link quality (RSS (Received Signal Strength), CIR (Carrier-to-Interferences Ratio), SIR (Signal-to-Interferences Ratio), BER (Bit Error Rate), etc.), monetary cost, security level, etc.
2. Terminal-related: velocity, battery power, location information, etc.
3. User-related: user profile and preferences
4. Service-related: service capabilities, QoS, etc.

These criteria can be classified into static and dynamic depending on the frequency and causes of changes. Typically static criteria are user profile and the cost of the different access networks, whereas the MT's velocity and RSS are typically dynamic criteria.

6.3.2 Handoff Decision Policy

Handoff decision criteria help to determine which access network should be chosen and the handoff decision policy represents the influence of the network on when and where the handoff occurs. The traditional handoff decision policy is based only on RSS:

1. RSS: choosing the new Base Station (BS) if \( RSS_{new} > RSS_{old} \).
2. RSS with Threshold \( T \): choosing the new BS if \( RSS_{new} > RSS_{old} \) and \( RSS_{old} < T \).
3. RSS with Hysteresis \( H \): choosing the new BS if \( RSS_{new} > RSS_{old} + H \).
4. RSS, Hysteresis and Threshold: choosing the new BS if \( RSS_{new} > RSS_{old} + H \) and \( RSS_{old} < T \).

In heterogeneous networks, vertical handoff decision policy must evaluate additional criteria such as monetary cost, offered services, network conditions, terminal capabilities and user preferences. More criteria are needed not only for the decision of the appropriate time to perform the handoff but also for user choice and intervention (user preferences among different access technologies).

It is obvious to mention that the combination of all these criteria and the dynamicity of some of them will increase significantly the complexity of the vertical handoff decision process. In general, this complex problem can be seen as: a user-centric (user satisfaction) problem, a context aware (user, network and terminal context)
problem, a network selection algorithm, or even a multi-criteria algorithm. Based on these different views of the handoff decision problem, we design different strategies.

### 6.4 Cost Function-Based Strategies (CFBS)

Vertical handoff decision cost function is a measurement of the benefit obtained by handing over to a particular network. It is evaluated for each network \( n \) that covers the service area of a user. It is a sum of weighted functions of specific parameters. The general form of the cost function \( f_n \) of wireless network \( n \) is

\[
f_n = \sum_{s} \sum_{i} w_{s,i} P_{s,i}^n
\]  

(6.1)

\( P_{s,i}^n \) is the cost in the \( i^{th} \) parameter to carry out service \( s \) on network \( n \); \( w_{s,i} \) : the weight (importance) assigned to using the \( i^{th} \) parameter to perform services (with \( \sum w_i = 1 \)). The parameters used are bandwidth \( B_n \) that network \( n \) can offer, power consumption \( P_n \) of using the network device for \( n \) and monetary cost \( C_n \) of \( n \). The cost of using a network \( n \) at a certain time, with \( N(i) \) as the normalization function of parameter \( i \) is defined as:

\[
f_n = w_b \cdot N(1/B_n) + w_p \cdot N(P_n) + w_c \cdot N(C_n)
\]  

(6.2)

The network that is consistently calculated to have the lowest cost is chosen as the target network. Therefore, this cost function-based policy model estimates dynamic network conditions and includes a stability period (a waiting period before handoffs) to ensure that a handoff is worthwhile for each mobile[143].

The proposed policy-enabled handoff system allows users to express policies on what is the best network and when to handoff. To achieve flexibility, the system separates the decision making scheme from the handoff mechanism (routing table manipulation and sending location updates). To achieve seamlessness, the system considers user involvement (for policy specification) with minimal user interaction (for automation). To improve system stability in the handoff mechanism, load balancing solution is proposed avoiding the handoff synchronization problem (simultaneous decision by many mobiles). For that, we have implemented a performance agent that collects the information on the current bandwidth usage at base stations, and periodically announces this information to its coverage.
Since, all data traffic goes through base station they have the most accurate information on current bandwidth usage and the available bandwidth in the network. They solve the problem through a randomized stability period. We use the utility function (higher utility = target network), to evaluate the reachable wireless networks discovered (bandwidth and movement speed as factors) and to quantify the QoS (Quality of Service) provided by the wireless network on the mobile terminal.

We introduce two adaptive handoff decision methods adjusting the stability period, according to the network resources and the running applications on the mobile terminal. In the proposed handoff scheme, the handoff decision method is preceded by a System Discovery Method (Algo-1). The latter is based on an adaptive interface activating method that adjusts the interface activating interval relying on the distance between the mobile terminal and the base station. For that, an ideal coverage concept (i.e., the real coverage in a wireless overlay network) is introduced in which mobile terminal’s position information and a Location Service Server can assist mobile terminal in deciding when to activate its interfaces (Algo-2). Thus, the system discovery method can balance the power consumption and system discovery time.

The proposed scheme discovers all the reachable networks and then selects the most suitable one as the handoff target through performance evaluation that relies on user preferences and service requirements. In order to guarantee the right decisions can be made timely with the minimum battery power consumption on interface activation, two algorithms of producing dynamic activating intervals are developed [127].

In the proposed handoff scheme, handoff decision method is preceded by two algorithms:

- **ALGORITHM 1: SYSTEM DISCOVERY METHOD.**

  Vertical handoff is the switching process between heterogeneous wireless networks. Discovering the reachable wireless networks is the first step for vertical handoff. After discovering the reachable candidate networks, the mobile terminal decides whether to perform handoff or not. We present an adaptive scheme for vertical handoff in wireless overlay networks. Our system discovery method effectively discovers the candidate networks for the mobile terminal. Moreover, we propose two adaptive evaluation
methods for the mobile terminal to determine the handoff time that relies on the candidates' resources and the running applications. The simulation results show that the proposed system discovery method can balance the power consumption and the system discovery time. Furthermore, the proposed handoff decision method can decide the appropriate time to perform handoff [128].

The coexistence of heterogeneous wireless networks providing service anywhere at any time is an inevitable trend in the development of next-generation wireless data networks. Vertical handoff is the switching of the mobile terminal (MT) among different types of wireless networks. How and when to carry out vertical handoff directly affects the performance and quality of network services. We propose a novel vertical handoff scheme in which the MT can request and initiate the handoff actively, contrary to other schemes where the MTs participate passively during the handoff process. Our active application oriented scheme provides an efficient interface management for multi-interface MTs to reduce the power consumption caused by unnecessary interface activation. By treating the application running in the MT as the main vertical handoff decision factor, the proposed scheme is able to switch the MT at the right time to the most suitable network to minimize the waste of network resources. Finally, simulation results are presented to show the improved performance over passive schemes [129].

**ALGORITHM 2 : LOCATION SERVICE SERVER**

Client-Server Approach to Mobile Location Services (MLS)

Wireless networks have utilized a client-server approach to the development of wireless network location services. The location services client is representative of location service applications that either reside within the wireless network (including MS) or may reside outside the wireless network. These clients are capable of requesting location information or network positioning assistance information from the wireless network. The location services server is a collection of wireless network and Mobile Station (MS) components that provide target MS location information to the location services client.
MLS Client

The mobile location services client is an entity that requests location information from the mobile location services server environment, for one or more target MS's within a specified set of interface parameters. The client may reside within the wireless network under the control of the wireless network operator, or outside the wireless network.

The client is expected to communicate and interface with the mobile location services server through a consistent set of parameters not limited to the following:

- Location request type (single, periodic update)
- Client Identity
- Target MS's (individual or list)
- Geographic location
- Quality of Service (accuracy, response time)
- Priority
- Timestamp
- Wireless network authorization of external clients

MLS Server

The mobile location services server is a collection of wireless network functions and bearer services responsible for responding to MLS Client requests for location information.

The MLS server makes use of a positioning function to obtain the location information and furnish the information to the MLS client. Positioning is the basic function that performs the actual positioning of a specific target MS. The input to this
function is a location request from a MLS client with a set of parameters such as Quality of Service (QoS) requirements. The end results of this function are the location information for the target MS provided back to the requesting MLS client.

The particular requirements and characteristics of the MLS client are supported in the MLS server environment via a MLS client profile. The MLS restrictions associated with each target MS are supported in the target MS subscription profile. The MLS server may respond to a location request from a properly authorized MLS client with location information for the target MS's.

The target MS is the object to be positioned by the MLS server environment. For network-based positioning methods no support is required in the MS. For mobile assisted and mobile-based positioning methods, the MS is actively involved in the procedures and support is required in the MS. For all positioning methods the ability to control privacy may be required by the MS user for each location request or through subscription to satisfy local regulatory requirements.

MLS Client-Server Interface

The MLS client and server communicate through a set of defined messages to exchange information. These messages contain a set of consistent parameters as described in the MLS client section above. In the case of MS-based positioning methods and the MLS client is in the MS, then an internal MLS client-server interface may be supported.

The MLS client performs a location service request to the MLS server within a specified set of QoS parameters to request location information for one or more target MS's. The location service request can ask for a single location estimate within a specific response time window (immediate) or can request periodic updates based on time duration or some event occurring in the wireless network (deferred). A location service response provides a result to the immediate request from the MLS server to the client. A location service request report provides the result of a deferred location service request from the server to the client.
Location Request Methods

There are two primary methods for MLS clients to request location information, the first being network-based, and the second is mobile-originated.

Network-based location requests include requests initiated by MLS clients within the wireless network based on wireless user events (digits dialed, mobility, etc) or network operator events to request positioning to occur. Network-based location requests also includes MLS clients external to the wireless network requesting location information for specified target MS's (e.g. Internet MLS client). External MLS clients must be authorized before positioning can occur.

Mobile-originated location requests allow the MS to obtain its own geographical location or have its location information transferred to another MLS client. There are two classes of mobile-originated requests.

1. Self Location - this is where the MS can determine its own location and needs to interact with the wireless network for each request.

2. Autonomous Self Location - this allows a MS to interact with the network once for multiple location positioning. One interaction with the network allows the MS to obtain multiple locations over a predetermined time period.

The proposed vertical handoff decision is based on a policy-based networking architecture (i.e., IETF framework). All the described decision strategies were evaluated on two types of networks: WLAN and WWAN such as GSM or GPRS.

In the simulations, the evaluated heterogeneous wireless networks consist of a single GSM network, 100 WLANs where WLANs are randomly deployed. The topology covers an area 3000 m in length and 3000 m in width with 10 base stations. The number of mobile nodes ranges from 10 to 70 in the area of 100×100 m, and the mobility of random way point is adopted for each mobile node with random direction and random velocity from 1 to 25 m/s. The transmission range of GSM covers the whole area, where
that of each WLAN is 100 m². The bandwidths of GSM, WLAN, are 384 kb/s, and 54 Mb/s respectively.

The simulation considers two classes of traffic, i.e., Constant Bit Rate (CBR) and Variable Bit Rate (VBR). The CBR traffic is assumed to arrive at the heterogeneous network to a Poisson distribution with arrival rate \( \lambda \). The average holding time of the CBR traffic is exponentially distributed (\( \mu \)), and its mean is normalized to unity. On the other hand, the VBR traffic is assumed to arrive based on a self similar model as suggested in chapter 4.

The RSS received by a mobile node is different when it uses different wireless networks. In WLAN, the RSS is computed based on indoor propagation model as suggested in chapter 4. Several useful parameters for the simulations are summarized in Table 6.1.

**Table 6.1: Simulation Parameters for Vertical Handoff Evaluation**

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of Coverage for Simulation</td>
<td>3000(m)×3000(m)</td>
</tr>
<tr>
<td>Number of WLAN Access Points</td>
<td>100</td>
</tr>
<tr>
<td>Number of Base Stations</td>
<td>10</td>
</tr>
<tr>
<td>Transmission Range of WLAN</td>
<td>100 m</td>
</tr>
<tr>
<td>Transmission Range of GSM</td>
<td>1000 m</td>
</tr>
<tr>
<td>Path Loss Exponent (WLAN)</td>
<td>4.5</td>
</tr>
<tr>
<td>Path Loss Exponent (GSM)</td>
<td>2.8</td>
</tr>
<tr>
<td>Arrival Rate CBR</td>
<td>Variable</td>
</tr>
<tr>
<td>Arrival Rate Self Similar Traffic</td>
<td>Variable</td>
</tr>
<tr>
<td>Data Rate : WLAN</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>Data Rate: GSM</td>
<td>384 Kbps</td>
</tr>
<tr>
<td>Mobility model (Random way Point)</td>
<td>Velocity (1-25 m/sec)</td>
</tr>
</tbody>
</table>
6.4.1 Results for CFBS Vertical Algorithms

In case of CFBS we have evaluated the performance in terms of number of handoffs, handoff delay and dropping probability. The blocking probability is not evaluated since this is a heterogeneous network, because it is assumed that two different networks have already accepted the call/request from the mobile terminal. The RSS based algorithms are derivatives of the conventional handoff algorithms in homogeneous networks. In case of heterogamous network we applied the same logic only difference is the propagation characteristics and the threshold is different for two networks.

Figure 6.2 shows the performance of vertical handoffs in discussion in terms of number of handoff requests generated. From the graphs we observe that for handoff algorithm based on RSS threshold performs similar to the handoff algorithm in homogeneous network. In this case also we observe the ‘ping-pong’ effect. To improve the performance we have tested the network for handoff algorithm based on RSS with hysteresis, the results of simulation indicate that number of handoff requests have reduced by a factor of 10 for traffic of 100 packets per second. For algorithm-1 the numbers of requests are 2 times less as compared to RSS with Threshold based algorithm. The simulation results indicate that the algorithm-2 improves the performance by a factor of 1.6 as compared to algorithm-1.
In case of heterogeneous networks it important to evaluate the handoff process in terms of time taken by the mobile terminal to change of its link from one type of network to another. We call this as ‘handoff delay’. Figure 6.3 shows the performance of the network under test for variable traffic (CBR). It is observed that handoff algorithm-2 strategy results in maximum delay for handoff execution; this is due to time taken by both the networks to evaluate handoff requirement and passing on the information of requirement and availability of resources and confirming the handoff request. Further it is observed that the variability of the delay is very high with respect to the traffic variations ($\sigma = 452$ with mean delay of 64 ms). The delay of handoff algorithm-1 is less as compared to algorithm-1 ($\sigma = 244$ with mean delay of 45 ms).
As it is well known the delay characteristics of RSS based handoff algorithms is less and variance is low. We observe the same effect in our experiment. The RSS with hysteresis executes handoff with mean delay of 22 ms and with variance of 31. For RSS with Threshold, the mean handoff delay is 11 ms and variance of 17.
In this research we are targeting the performance of the network to support uninterrupted service to the user hence we selected dropping probability as the prime performance metrics.

In our simulation experiment we computed the dropping probability for four vertical handoffs in discussion. Figure 6.4 shows the simulation results of CBR traffic. Since we have considered a high performance network, the resource capabilities are assumed to be sufficient to get best possible performance.

That is the underlay network (WLAN) has 100 access points in single overlay network with 10 base stations (GSM). The results indicated in figure 6.4 for RSS based algorithms show the dropping probability as low as $10^{-4}$ for RSS with hysteresis and $3\times10^{-3}$ for RSS with Threshold for traffic of $10^{-1}$ packets per second.
From Figure 6.4 we observe that algorithm-1 and algorithm-2 outperform the RSS based handoff algorithms. Algorithm-2 gives 100 times better performance than RSS based handoff algorithms and 10 time better performance than algorithm-1.

![Performance of Vertical Handoff for Self-similar Traffic](image)

**Figure 6.5**: Number of Handoffs versus Variable Traffic (Self-similar Traffic)

Present day networks have been demonstrating a shift in the traffic pattern, called ‘self-similar’ traffic. In chapter 4 we have discussed in detailed and evaluated the vertical handoff for such type of traffic. Figure 6.5 shows the simulation results of the network under consideration for number of handoff requests generated if the traffic is self-similar one.

From Figure 6.5 we observe that the vertical handoffs under consideration results into less number of handoff requests generated as compared to CBR traffic. Figure 6.6 shows the delay performance of the network under test for four vertical handoff
algorithms under self-similar traffic condition. It is observed that the delay characteristics are similar in nature as were observed in CBR traffic condition. The only difference is in the mean delay and variance values.

![Performance of Vertical Handoff for Self-similar Traffic](image)

Figure 6.6: Handoff Delay of Vertical Handoff for Variable Traffic (Self-similar Traffic)
Table 6.2 shows the comparison of delay statistics for CBR and Self-similar traffic.

**Table 6.2: Comparison of Delay Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>CBR Traffic</th>
<th>Self-similar Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Variance</td>
</tr>
<tr>
<td>RSS with Threshold</td>
<td>11.625</td>
<td>17.6964</td>
</tr>
<tr>
<td>RSS with Hysteresis</td>
<td>22.75</td>
<td>31.92</td>
</tr>
<tr>
<td>Algo-I</td>
<td>45</td>
<td>244.28</td>
</tr>
<tr>
<td>Algo-II</td>
<td>64</td>
<td>452.78</td>
</tr>
</tbody>
</table>

Figure 6.7: Dropping Probability of Vertical Handoff for Variable Traffic (Self-similar Traffic)
Figure 6.7 shows the performance of the network for self-similar traffic in terms of dropping probability. It is observed that the dropping probability is less as compared to the values observed for CBR traffic. Table 6.3 shows the comparison of the two at traffic = 5 packets per second.

<table>
<thead>
<tr>
<th>Table 6.3: Comparison of Dropping Probability (5 Packets per second)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CBR Traffic</strong></td>
</tr>
<tr>
<td>RSS with Threshold</td>
</tr>
<tr>
<td>RSS with Hysteresis</td>
</tr>
<tr>
<td>Algo-I</td>
</tr>
<tr>
<td>Algo-II</td>
</tr>
</tbody>
</table>

6.5 Design of Context Aware Vertical Handoff

This work strives for mobile nodes to execute handoff decisions in an optimal way depending on the context. This requires a dedicated procedure to efficiently collect and manage context information and an appropriate platform to use that information for a most favorable handoff decision.

6.5.1. Introduction to Context Aware Vertical Handoff

Context information may be classified as static or dynamic, depending on the frequency and reason of changes. It can be classified also based on where such information is maintained. Table 6.4 explains classification of context information. It is clearly just a summary, and mainly focuses on layer 3 and above. Novel kinds of context information may also appear. For instance, in future networks, new kinds of context information like the ‘groups a user belongs’ to may be relevant for handoff decisions. Some pieces of information, such as the user’s profile, appear twice, as the information is often spread over the user’s device, the operator’s network and possibly over several service providers. As an example, the user’s profile may include subscribed services and service preferences, e.g., which services have to be downgraded or dropped if available resources are not sufficient. The potential next AP, nearby APs, user history, and user
mobility can be used for location prediction and limit the options for selecting the next AP. It will help simplifying the selection of the best AP. The user’s settings for applications and the types of the ongoing applications indicate the preferable QoS level, etc.

Table 6.4: Classification of Context Information

| Static | User’s Setting and Profile Settings of Applications | User’s Profile and History Network Location(Location of Aps) Capacities and Services of the Network Charging Models Network Policies |
| Static within a Cell | Reachable Aps | Potential Next Ap, Nearby Aps |
| Dynamic | Type of ongoing Application Requirement of Application Status of Devices (Battery, Interface Status etc.) | Location Information and Location Prediction Status and Load of the Network |

However, context information is not available immediately to the entities involved in a handoff for several reasons. First, context information is distributed. For instance, some context information may be available in the user’s home network, some may be available in the network to be visited and some resides on the terminal. Second, dynamic context information may change frequently or lose accuracy over time. For instance, the mobile node is tempting to convey information about the load of the current AP, yet its relevance decreases quickly over time.

Third, the type of relevant context information and the methods to interpret it may evolve over time. Hence, algorithms for interpreting context data need to be adapted to the new requirements.
Therefore, we need a context management framework, which assures that the context information needed for handoff decisions is available in time (before the handoff decision needs to be made). Moreover, exchange of information between the network and the mobile nodes should be minimized to save wireless resources. Furthermore, a context-aware handoff requires an appropriate execution platform, which is flexible enough to adapt to the changing requirements of this service. It should be able to cope with dynamic context and automatically alter the handoff decision policy or the algorithm in use. It should support continuous exchange of context information between the nodes involved in the handoff service in an efficient way. It should also enable the mobility manager of the mobile node to take the right handoff decision.

![Figure 6.8: Basic Architecture of Context Aware Management Architecture](image)

6.5.2. Foundation of Context Management Architecture

Our approach integrates a context management framework, a programmable platform and a service deployment scheme to provide the functionality needed for context-aware handoff. The context management framework is in charge of collecting the relevant context information for different services and managing the context information. The programmable platform is used to download and install the suitable modules for context exchange and processing. The service deployment scheme is used to synchronize and manage the work of the involved active nodes [130].
In this architecture, as shown in Figure 6.8, context information is stored in context information repositories, such as the Location Information Server (LIS), Network Traffic Monitor (NTM) and the user's profile repository. The LIS is responsible to track the position of each mobile device in the provider's network and has the knowledge of nearby APs, while the user's profile repository stores user's profiles as seen by the network service providers. The NTM is used to monitor the available bandwidth of different APs. These are just examples of context information repositories, other types of these repositories can exist, as well. Moreover, we introduce a Handoff Manager (HM), which controls handoffs carried out in some part of an access network. The HM is responsible for filtering and processing handoff-related context information. At the same time, the HM acts as a Context-collection Point which collects the needed context information from various context repositories. Finally, a Service Deployment Server (SDS) is used to manage and install the service modules needed on the network nodes and mobile nodes.

6.5.3. Context Management Framework

In this research context management framework is in charge of context collection, compilation, exchange and evaluation. It defines the following main entities:

1. **Context-collection Point** on the network side, which collects and compiles the relevant context information from different sources. In this scenario, the context collection point is placed on the Handoff Manager.

2. **Handoff Decision Point** that decides which AP is to be selected for the handoff. In this design, the Handoff Decision Point is the mobile node. Of course, it is also possible to place it in the network. We use the mobile node because:
   
   (a) It is more scalable to have each mobile node maintain one Handoff Decision Point by itself.

   (b) In the current mobile systems, the signal strength based handoff decision mechanism is implemented in the mobile node. It is beneficial to be compatible with the existing handoff mechanism.

   (c) We can easily change the existing handoff decision procedure to our context-aware decision mechanism in the mobile node by extending it.
The Handoff Decision Point uses specific algorithms (e.g., rule-based logic) for interpreting the data delivered by the context management framework. It is the task of the service deployment to assure that both, the Handoff Decision Point, and the Context-collection Point are proactively supplied with the appropriate algorithms. It is difficult to have a generic algorithm for making handoff decisions based on any network topology, configuration, architecture, or type of mobile device. Even if we can build such an algorithm, it cannot be optimized for all the cases and might be quite complex. Therefore, we use flexible, programmable platform to install different algorithms for different cases without interrupting the proper working of the node. These algorithms need to be changed if there are structural changes in the context information, e.g., when the context format, user’s profile or context processing algorithm change. Notice that software updates can be applied in different ways. For instance, update the software each time when the user’s profile changes (e.g., when entering a car, new software modules that consider the changed context regarding higher speed and different applications are installed). The context information will be exchanged when needed using the context exchange protocol. This way, up-to-date context information is used for handoff decision. The detailed steps for context-aware handoff are the following:

1. Prepare the Handoff Decision Point and the Context-collection Point proactively with the suitable context processing and exchange protocol. Besides this, the Handoff Decision Point is updated proactively with the suitable handoff decision algorithm.

2. The Handoff Decision Point requests network context (Q) relevant to the Handoff Decision Point from the Context-Collection Point with some filtering parameters (e.g., ID, types of needed context information, etc.). The collection of related context information can be realized by some simple procedure such as a server-client based communication. However, such procedure is not elaborated here because of space limitation. The required software may be taken from a library of modules for specific situations.

3. The Context-collection Point gets the network context relevant to the Handoff Decision Point and compiles it as far as possible (i.e., integrates some static context).
4. The Context-Collection Point sends the compiled information to the Handoff Decision Point. The dynamic context from the network can be sent separately and be updated using the context exchange protocol when needed.

5. The handoff decision algorithm is parameterized with the information from the Context collection Point and with the static information from the mobile node.

6. The handoff decision algorithm is invoked at handoff time and completed with the dynamic context of the terminal (e.g., reachable access points, application requests and sessions) before the decision is made.

From these steps, we can see that some static context information is compiled before being sent out. In this way, the context information to be exchanged is minimized. Furthermore, this procedure ensures that the most up-to-date context information is used for handoff decision.

6.5.4. Context Aware Vertical Handoff Procedure

In this research we are designed the vertical handoff which takes into consideration the context generated in the network as defined in section 6.6.3. The realization of our context-aware handoff service can be divided into five phases, which are explained in the message sequence diagrams shown in Figure 6.9 and Figure 6.10. Phases A through C are referring to the service deployment mechanism.

![Sequence of Signaling for Service Deployment](image)

Figure 6.9: Sequence of Signaling for Service Deployment
During Phase D relevant context information is collected. In Phase E, the context information is evaluated and handoff decisions are made.

The service deployment phases include: fetching the right service components; installing them on the appropriate network node; and confirming the successful installation of all the components for that service. For example, to use a context-aware handoff service, we need to install a context exchange protocol, the *Handoff Support Module* (HSM), and a handoff decision mechanism, the *Handoff Decision Module* (HDM), on the related nodes. The HDM is installed on the mobile node, and the HSM is installed on both the mobile node and the HM. More specifically, here we need to install appropriate versions of both the HSM and HDM on the programmable platforms of the mobile node and HM. This is realized by the service deployment mechanism in Phase A, B and C.

We assume that the SDS will trigger the module installation in the HM using the concept of service broadcast, since the location and role of the HM are “fixed” comparing to the mobile node. On the other hand, the modules in the mobile node are very dependent on the terminal and the user. The terminal can move frequently from one network to another, or change its service. Therefore, it is better to have the mobile node initiating the module download with its requested service. Whenever the conditions

![Sequence of Signaling and Processing for Context-Aware Handoff.](image-url)

Figure 6.10: Sequence of Signaling and Processing for Context-Aware Handoff.
change in the mobile node, new requests will be sent to the SDS for new services. The
signaling used by the HDM to request the needed context information is detailed in Phase
D. Context information needed for handoff decision is requested using server-client based
mechanism. The HDM is the client of the HM, since the HM is the client of the Context
repositories. After the HDM makes the decision on the target AP based on the collected
context information, in Phase E the decision is sent to the Mobility Management
Component (MMC) of the mobile node to execute the handoff.

6.5.5. Performance Evaluation of Context aware Vertical Handoff

In this section, we evaluate the proposed architecture. The goal of this evaluation
is twofold: first, to exemplify the behavior of the proposed architecture, as a proof of
concept, by showing the feasibility of doing handoffs with the support of context
information. The second goal is to evaluate the impact that the proposed architecture has
on the network, namely, the signaling overhead, and to understand how much time is
required to deploy context-aware services and to collect customized handoff data. The
dynamic deployment of different type of handoff services will introduce additional
overhead (i.e., code transmission, signaling for service deployment, etc.) and latency (i.e.,
code retrieving, code installation, signal exchange, etc.). We need to prove that it does
not significantly affect the usage of context-aware handoff services. Moreover, the
context exchange and processing does not bring additional traffic and handoff latency in
the network. The simulation is carried out to evaluate the performance of context aware
handoff algorithm.
Figure 6.11: Flow Chart of Context Aware Vertical Handoff [131]
6.5.6. Results of Context Aware Handoff Algorithm

To keep the consistency in the comparison, we have simulated the context aware handoff algorithm to convey results in terms of number of handoff generated, delay and dropping probability.

Figure 6.12: Performance of Context Aware Handoff (CBR)

Figure 6.12 shows the performance of context aware handoff algorithm compared with CFBS handoff algorithms. In case of context aware handoff algorithm the number of vertical handoff generated are less, this is because the design is such that the network \textit{a priori} estimates the information pertaining to a call/data transfer.
Figure 6.13 shows the performance in terms of delay. The delay performance of context aware handoff algorithm is much enhanced as compared to CFBS handoff algorithms. For lower traffic it is higher than CFBS but for higher traffic it is less. Further it is observed that the performance of context aware handoff algorithm results very low variance in the delay for variable CBR traffic. (mean = 50.5 ms and $\sigma = 59.71$). This is the best feature of the designed algorithm.

In this research, the performance of network is evaluated in terms of dropping probability. In number of investigations, the performance is measured in terms of complexity of the handoff algorithm. The aim of selecting this metrics was to judge the performance which is directly related to the customer satisfaction. Figure 6.17 illustrate the outcome of the simulation carried out for context aware handoff algorithm and shows the comparison with CFBS algorithms. From Figure 6.17, it is observed that the context aware handoff algorithm outperforms the CFBS algorithms, but for low traffic its performance is equal to the algo-II (CFBS) for CBR traffic. For traffic of 100 packets per second algo-II gives a dropping probability of $5 \times 10^{-3}$ and the context aware algorithm
results into $5 \times 10^{-5}$. Further it is observed that the variation of the dropping probability for context aware handoff algorithm with respect to traffic is less, which suggests that the designed algorithm is better for large variations in the traffic pattern.

To demonstrate the applicability of the context aware handoff algorithm, the network for self-similar traffic was designed. Figure 6.14 shows the results for number of handoffs generated. It is observed that the performance of designed algorithm is the same as that of CBR.
Figure 6.15: Performance of Context Aware Handoff (Self-similar Traffic)

Figure 6.16: Comparison of Delay Performance. (Self-similar Traffic)
Figure 6.16 shows the performance of context aware handoff algorithm in terms of delay. Table 6.5 shows the comparison of delay characteristics for CBR and self-similar traffic. From figure 6.16 and Table 6.6, it is observed that algo-I gives minimum mean delay for CBR and self-similar traffic but the variance is not the minimum. Context aware handoff algorithm offers moderate mean delay and the variance is minimum of all the three algorithms in discussion.

**Table 6.5: Comparison of Delay Characteristics**

<table>
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<th></th>
<th>CBR Traffic</th>
<th>Self-similar Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Variance</td>
</tr>
<tr>
<td>Context-Aware HO</td>
<td>50.5</td>
<td>59.71</td>
</tr>
<tr>
<td>Algo-I</td>
<td>45</td>
<td>244.28</td>
</tr>
<tr>
<td>Algo-II</td>
<td>64.75</td>
<td>452.78</td>
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</tbody>
</table>
Figure 6.17: Dropping Probability Performance of Context Aware Handoff. (Self-similar Traffic)

Table 6.6: Comparison of Dropping Probability

<table>
<thead>
<tr>
<th></th>
<th>CBR Traffic</th>
<th>Self-similar Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context-Aware HO</td>
<td>0.0000025</td>
<td>0.0000025</td>
</tr>
<tr>
<td>Algo-II</td>
<td>0.00018</td>
<td>0.000006</td>
</tr>
<tr>
<td>Algo-I</td>
<td>0.00018</td>
<td>0.000006</td>
</tr>
</tbody>
</table>
6.6 Concluding Remarks

In this chapter, the concept of vertical handoff has been presented. To demonstrate the design of new context based handoff algorithm, the analysis and performance evaluation of CFBS vertical handoff, in which two variants have been designed and evaluated, has been presented first. Number of researchers dealt with the performance of vertical handoff for complexity, throughput, etc. In this research, the dropping probability and delay characteristics have been considered as the major performance metrics. To improve the performance of the network, a context aware handoff algorithm has been designed and shown that it out performs the adaptive vertical handoffs giving moderate rise in delay characteristics. Most importantly, the SIMILUTION work has been carried out to test the algorithms under considerations for CBR as well as self-similar traffic.