An Evaluation of Relative Importance of Dynamic Network Performance and the Predictability of End User Movement

Niall Maher, Shane Banks, Enda Fallon
Software Research Institute,
AIT Athlone Institute of Technology,
Dublin Road, Athlone, Co Westmeath.
Email: niallmaher@research.ait.ie, sbanks@ait.ie, efallon@ait.ie

***Abstract*—Many existing handover mechanisms trigger network selection based on dynamic performance characteristics such as Received Signal Strength (RSS), Delay, and Loss. These approaches do not take into account how the predictability of end user movement can be used to influence and optimize handover selection. Scenarios in which predictable movement can be observed include motorways, public service vehicles and student class schedules in educational institutions. This work investigates if the consideration of predictability of movement, with dynamic performance characteristics, could improve handover decision management. A range of relative weightings of dynamic performance and mobility predictability are evaluated. Results presented illustrate that taking predictable movement as an input metric has a significant beneficial effect on the handover decision process.**

***Keywords*- Network handover; Mobility; Probability; Predictable movement;**

I. INTRODUCTION

In principle, each mobile terminal (node) is at all times connected to a network and within range of at least one access point on that network [1]. For some time Wireless Local Area Networks (WLANs) have been used to establish network connectivity in hot spot areas. Using WLAN as a constituent component, heterogeneous networks enable access to a wider Internet Protocol (IP) infrastructure.

In a wireless IP environment, many network selection approaches use an evaluation of network performance to determine when handover should take place [2, 3, 4]. Traditional handover initiations are typically based on RSS, Delay and Loss [5, 6]. Such approaches have evolved by proactively predicting RSS values, though still making use of static handover triggering thresholds [7, 8]. Other criteria that are now taken into account in handover initiations include; bandwidth, latency, link quality and Quality of Service (QoS) [3]. With the number of mobile devices growing rapidly, the challenge of maintaining a sufficient QoS level when the user switches between networks is becoming a major problem [9]. Existing network selection approaches are limited as they do not consider how the predictable nature of mobility can be used to influence network selection. In [10] it was illustrated that 93% of human movement is predictable regardless of the distances people travel. The 93% predictability remains true both for those who travel far distances on a regular basis and for those who typically stay close to home. Recent research [11] has established that human movement can be predicted through mobile telecom services. Situations in which predictable movement can be established are vehicles on motorways and public service vehicles where they operate in preconfigured routes which are repeated at routine intervals. Other instances include students in educational institutions following class schedules.

This work investigates if the consideration of predictability of movement, with dynamic performance characteristics, could improve handover decision management. Dynamic performance characteristics are evaluated and a relative performance score is generated for each candidate Access Point (AP). Using an internal probability nodal tree candidate APs are also graded on the probability that a mobile user will travel towards or away from their coverage. This work evaluates a range of relative weightings of dynamic performance and mobility predictability scores. Results illustrate those configurations in which mobile user predictability out weighted dynamic performance had greater perceived end user performance.

This paper is organized as follows: Section 2 outlines related work in the area. Section 3 provides a brief overview of the technologies relevant to the work presented. Section 4 describes the experimental set-up used and presents results. Conclusions and future work is presented in Section 5.

II. RELATED WORK

The effect of performance metrics such as RSS, delay and Loss on the decision of network handover has been the subject of previous research. Traditionally, network handover was managed using static rules based systems, which utilize thresholds that were applied to different metrics such as Delay, Loss and RSS. These handover approaches have been upgraded and improved over years using different methods to implement and trigger handover decision process. Some solutions also consider metrics related to the content delivery quality as experienced by end users [12]. These approaches however are still performance limited as they take into account performance thresholds. Some related works have looked into different approaches in the area of improving network handover. These approaches are described in the following paragraph.

Reference [17] creates an algorithm that enables the optimal selection of candidate networks by the mobility protocol. It also takes into account Media Independent Handover (MIH) and heterogeneous networks environment. In paper [11], the researchers investigated human behaviour with the use of telecom's handoff in mobile networks in order to determine how accurate human movement is in a real world setting and how this information could be used to improve network efficiency. Work that considers end user movement patterns as an input metric is presented in [25], where the author used movement patterns alongside dynamic network conditions to optimize network performance. Previous work undertaken [13] illustrates that it is beneficial for the handover management algorithm to probe network performance and dynamically alter thresholds through synaptic weights. The results from the experiment in [5] which uses a RSS based indoor positioning algorithm with mobility predication, shows that the mobility prediction can ensure low and stable positioning with little error. Other methods look at how to avoid unnecessary handovers [27] by utilising the Movement Aware Virtual (MAV) handover algorithm, which adjusts the dwell time adaptively and predicts the residual time in the cell of target Base Station (BS). Consequently, the adaptive dwell timer of MAV handover algorithm allows a mobile station to stay connected to the best available connection for as long as possible.

The experiments and papers mentioned above prove that performance on a network can be improved by taking other metrics or approaches into account, such as decreasing the importance of RSS, taking predictable movement patterns as a metric and using a MAV handover approach. Metrics such as delay and loss are also considered to be important metrics to monitor when considering network handovers. These finding are reflected in the results of the experiments presented in this paper.

III. Technology Overview

This section describes technologies relevant to the proposed approach Heterogeneous Networking (HetNet), handover triggering mechanisms, vertical handover approaches and general mobility approaches.

A. Heterogeneous Networking (HetNets)

HetNets is the use of multiple types of access nodes in a wireless networks. HetNets have been introduced in the LTE-Advanced standardization in order to provide available network for the increasing demand of mobile broadband requirements. HetNets will help to provide a significant network performance leap when other advanced technologies (carrier aggregation, multi input multi output, coordinated multipoint) are unable to achieve that, as they are reaching theoretical limits [14]. HetNets are made up of different components some of which are:

- *Wireless Transmission* - Small, powerful transmission link between base stations and the rest of the network.
- *Indoor Pico base station* - Takes over the connection when moving indoor 70% of traffic is generated indoors.
- *Micro base station* - A small base station with full features that can be used to cover indoors and outdoors in crowded areas.
- *Wi-Fi* - Used as a complement in small indoor or outdoor hotspots [15].

B. Handover Triggering Algorithms

Various studies have investigated algorithms to handover triggering mechanisms for HetNets. A handover triggering algorithm is an approach that utilises a set threshold to initialise a handover. Reference [16] proposed a mobility-based prediction algorithm with dynamic Link Going Down (LGD) triggering for vertical handover. The approach can advance the LGD trigger point dynamically to predictably prepare for the handover using the Possible Moving Area (PMA) to indicate the next target cell. Many of these mechanisms use RSS as the source performance metric on which threshold is applied as shown in Figure 1. The LGD will trigger a handover when the value crosses the RSS threshold. Such an event trigger mechanism is performance limited as neither the user's dynamic movement information nor the required time to prepare for handover are considered [17].

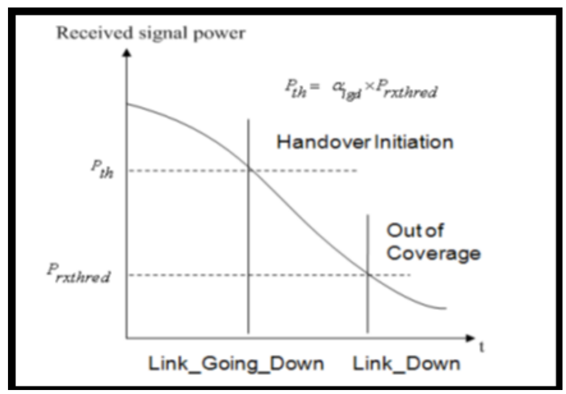

Figure 1. Shows pre-defined thresholds for LGD events.

C. Vertical Handover Approaches

Media Independent Handover (MIH) also known as IEEE 802.21 is a standard which has been developed to support seamless handover of IP sessions between homogenous and heterogeneous networks. The main function of MIH is to allow communication along different wireless layers and between them and the IP layer. MIH function relayed the messages between different layers in the protocol stack. Some of the protocols that MIH can communicate with include Session Initiation Protocol (SIP), Mobile IP, and IntServ etc. [18]. There are number of MIH based Vertical Handover (VHO) approaches proposed in the literature. Some of them are based on Mobile IP version 4 (MIPv4) [19, 20, 21] and some are on MIPv6 [22, 23, 24]. Most of the work in MIH for VHO decision utilise RSS as the most important factor in their handover decision making process. In [19], the research is based on the fading RSS.

IV. Proposed Approach

This work evaluates a range of relative weightings of dynamic performance and mobility predictability scores which result in eventual candidate network selection. It uses the Probability Based Handover Algorithm for Network Selection Using End User Predicted Movement (PHANS) algorithm [26] for handover management. The operation of the PHANS algorithm is described in this section.

A. The Dynamic Network Performance Evaluation

PHANS takes an input of dynamic network performance metrics; RSS, Delay and Loss. These metrics are parsed and normalised on a scale of 1 (poor performance) to 100 (excellent performance). Following performance normalisation, dynamic weight allocation provides a weight reflecting the relative importance of each metric. The dynamic weight is then multiplied by the normalised inputs and summed to indicate dynamic network performance.

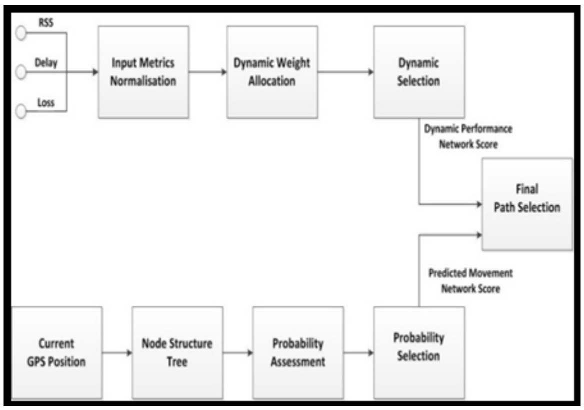

Figure 2. Illustrates the major components of the PHANS algorithm.

B. Probability of Movement Evaluation

In the PHANS approach a nodal structure is dynamically created representing the Access Points (AP) topology in a given area.

The topology is constructed based on previous mobility recorded by the GPS module on the device. Using historical data, PHANS overlays the probability of inter AP movement to the topology. The node with the highest score is suggested by the probability assessment module as the candidate AP.

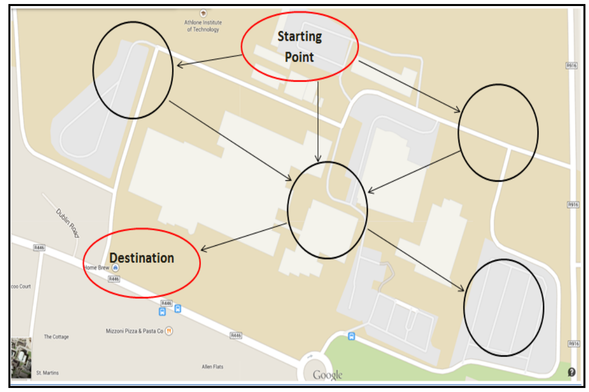

Figure 3. Proximity Nodes Structured Tree.

Figure 3 is an image of Athlone Institute of Technology (AIT) taken from Google maps. The image was then overlaid as an example of a nodal structure that would be created by PHANS [26] to represent the APs in the area that was used to run the simulations. It also shows the starting point and destination of the student group.

C. Candidate Path Selection

Within the PHANS algorithm, the path selection subcomponent takes two inputs: a candidate AP selection based on dynamic performance and a candidate AP selection based on predicted movement. If these selections conflict, the PHANS algorithm will weigh the previous performance of each selection when determining the current optimal paths election.

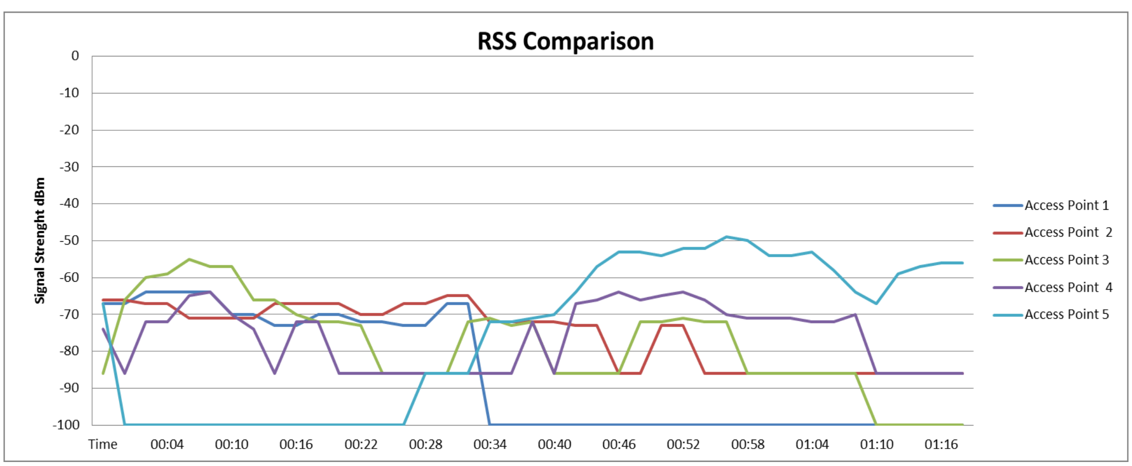

Figure 4. The recorded RSS for the 5 APs in the configuration.

V. Results

A. Experimental Evaluation of Characteristics

In order to calculate network performance using the PHANS algorithm with a weighted importance on the inputted metrics, a series of experimental tests were undertaken at the engineering building at AIT. With the aim of determine the probability of movement, students were tracked over a period of time. This enabled the profiling of student path selection between classes. Wireless broadband routers were placed at specific points along the route. The route that the majority of students took was then physically walked, passing into and out of the access point coverage areas recording delay, loss and RSS. This data was collected using network tools and the metrics extracted were then inputted into the Network Simulator (NS2) simulation models. The throughput of the simulations were collected and compared.

If the RSS in Figure 4 is examined at the two second mark it indicates that AP3 was the best available AP. A traditional handover decision mechanism, based on RSS, would connect to AP3. In contrast the PHANS algorithm would not connect to AP3 because at 2 seconds there was a 25% loss rate on AP3. The PHANS approach would avoid a potentially spurious handover to AP3. The RSS signature from Figure 4 indicates the end user is walking in the direction of AP2 and away from AP1 and AP3. Therefore using predicted movement to influence the decision of the handover and optimise the possible throughput as seen in Table 1.

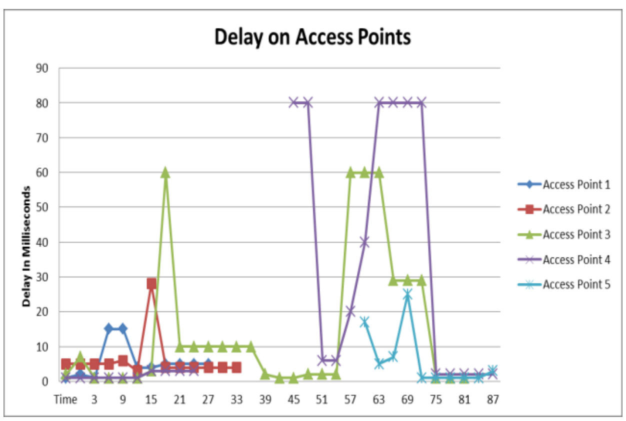

Figure 5. The recorded Delay for the 5 APs in the configuration.

Figure 5 illustrates the delay on each AP on a second by second basis over the course of the simulation. The recorded delay was normalised and allocated a weight configuration prior to its input in NS2.

Using the approach outlined in figure 2, dynamic performance characteristics are evaluated and a relative dynamic performance score is generated for each AP. Using an internal probability nodal tree, illustrated in Figure 3, candidate APs are also graded on the probability that a mobile user will travel towards or away from their coverage.

Table 1 illustrates a range of relative weightings of Dynamic Characteristics (DC) and Predictable Movement (PM) and the resulting throughput.

Table 1. Weight Categories/Relative Weights and Throughput.

Weights and Throughput results			
Weight Category:	***DC Weight***	***PM Weight***	***Throughput MB***
W1	0	0.25	30.53
W2	0	0.5	30.25
W3	0	0.75	202.24
W4	0	1	301.03
W5	0.25	0	30.25
W6	0.25	0.5	30.25
W7	0.25	0.75	470.71
W8	0.25	1	301.03
W9	0.5	0	133.55
W10	0.5	0.25	133.55
W11	0.5	0.5	133.55
W12	0.5	0.75	133.55
W13	0.5	1	466.64
W14	0.75	0	133.55
W15	0.75	0.25	133.55
W16	0.75	0.5	133.55
W17	0.75	0.75	133.55
W18	0.75	1	133.55
W19	1	0	133.55
W20	1	0.25	133.55
W21	1	0.5	133.55
W22	1	0.75	133.55
W23	1	1	133.55

Figures 6 and 7 provide a more detailed analysis of the weight configurations outlined in Table 1. In Figure 6 the weight configurations were sorted based on throughput from best to worst performing.

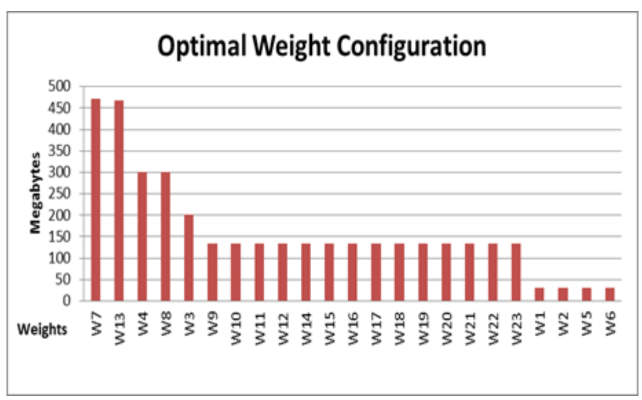

Figure 6. The best to worst performing weight configurations.

Figure 6 shows that the weight configurations can be grouped in 4 general categories; very good performance W=7 and W=13, good performance W=4,8,3, fair performance W =9-12, 14-23 and poor performance W=1,2,5 and 6.

Figure 7 compares DC against PM weight configurations from best to worst performing.

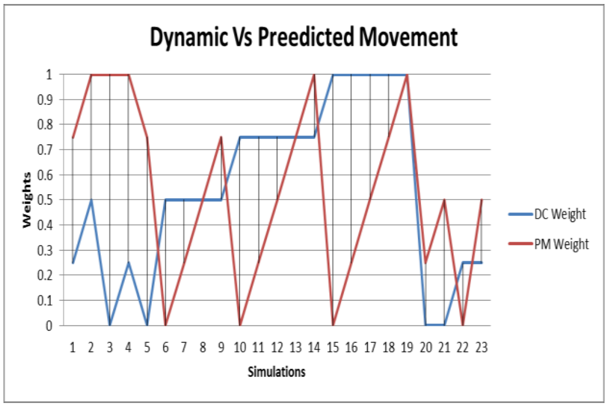

Figure 7. Dynamic and Predicted movement weights.

Very good performing configurations W=7 and W=13, and good performing W=4, 8, 3 have a higher weight on predicted movement than the dynamic performance. In the configurations with fair performance W=9 - 23 throughput falls as the relative weighting of the dynamic characteristics increases. In the weight configuration W9, DC has a .5 relative weighting while PM has a 0 weighting, effectively removing the predictability of movement as a consideration.

Finally, for the worst performing configurations W=1, 2, 5 and 6 the configurations did not exceed the threshold need to migrate from the backup LTE network.

Table 2. Very good simulation performance weights.

Very good simulation performance weights			
Weight Category:	***DC Weight***	***PM Weight***	***Throughput MB***
W7	0.25	0.75	470.71
W13	0.5	1	466.64

Table 2 illustrates the performance of the very good weight configurations. In this configuration the average DC weighting was 0.375 while the average PM weighting was 0.875. Table 2 illustrates that very good weights are heavily dependent on a high predicted movement.

Table 3. Good simulation performance weights.

Good simulation performance weights			
Weight Category:	***DC Weight***	***PM Weight***	***Throughput MB***
W4	0	1	301.03
W8	0.25	1	301.03
W3	0	0.75	202.24

Table 3 illustrates the good performing weights over the course of the simulation. In this configuration the average DC weighting was 0.083 while the average PM weighting was 0.916.

Table 3 illustrates a heavy weighting on predicted movement without little or any weight on the dynamic performance which will achieve a good network performance.

Table 4. Fair simulation performance weights.

Fair simulation performance weights			
Weight Category:	***DC Weight***	***PM Weight***	***Throughput MB***
W11	0.5	0.5	133.55
W12	0.5	0.75	133.55
W14	0.75	0	133.55

Table 4 illustrates some of the weight configurations that led to a fair network performance throughout over the course of the simulation. In this configuration the average DC weighting was 0.583 while the average PM weighting was 0.416. Table 4 illustrates an equal weighting on PM and DC will achieve a fair network performance.

Table 5. Poor simulation performance weights.

Poor simulation performance weights			
Weight Category:	***DC Weight***	***PM Weight***	***Throughput MB***
W2	0	0.5	30.25
W5	0.25	0	30.25

The weights in Table 5 are the worst possible combination of weight configurations. In this configuration the average DC weighting was 0.125 while the average PM weighting was 0.25. These weights never overcame the threshold to allow handover from the LTE network to the wireless network. Therefore, the connection to the LTE network was maintained for the entire simulation, which is why the throughput for these simulations is so low.

VI. CONCLUSION AND FUTURE WORK

This work investigated if the consideration of predictability of movement, with dynamic performance characteristics could improve handover decision management. Dynamic performance characteristics were evaluated and a relative performance score was generated for each candidate AP. Using an internal probability nodal tree candidate APs were also graded on the probability that a mobile user will travel towards or away from their coverage. Results illustrate that very good or good performing configurations have a higher weight on predicted movement than the dynamic performance. In the configurations with fair performance throughput falls as the relative weighting of the dynamic characteristics increases. For the worst performing configurations the configurations did not exceed the threshold needed to migrate from the backup LTE network.

Future work will focus on the enhancement of the existing movement predictability model.

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