# Proactive Policy Management for Heterogeneous Networks

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**Abstract—Context-awareness is a vital requirement of heterogeneous devices which allows them to predict future network conditions with sufficient accuracy. In this paper we present a proactive modelling-based approach for policy management which allows the mobile node to calculate Time Before Vertical Handover for open and closed environments. The paper explains how the knowledge of this component can improve the manner in which multi-class traffic streams are allocated to available network channels. Simulation results confirm the feasibility of the concept.**

***Keywords-policy management; QoS management; vertical handover;***

## I. INTRODUCTION

With the full fledged deployment of fourth generation (4G) networks just around the corner, the past few years have displayed a rapid growth in multi-interfaced devices which promise simultaneous connectivity to different networks like UMTS, WLAN, WiMAX and UWB. One of the main challenges faced in heterogeneous networking is the effective delivery of multi-class traffic across diverse channels offering different levels of Quality of Service (QoS). It must be done in a way which minimises the forced termination of ongoing connections during vertical handovers. This requirement has pushed forward demands for increased context and resource awareness among heterogeneous devices. Context gathering tasks are performed by policy management mechanisms which consist of a set of rules that evaluate the circumstances under which a handover should occur. With the rapid adaptation of the heterogeneity paradigm, policy management will play an increasingly important role in improving the stability of network connections.

Heterogeneous networking has also increased complexity of network components. Components of the 4G protocol stack will exhibit more complex functionality than components of the normal OSI protocol stack due to the additional tasks they will need to support in order to achieve seamless interoperability. In this paper, we briefly introduce our proposed architectural framework similar to the OSI framework which encapsulates the key challenges of heterogeneous networking. We then introduce a novel proactive policy management mechanism that calculates a sufficiently accurate estimate of the Time Before Vertical Handover (TBVH) for both indoor and outdoor environments. Our simulation results validate the feasibility of the concept and demonstrate the flexibility of the model which can be plugged into both simulations and real-time systems with ease.

The rest of the paper is organized as follows: Section 2 describes the heterogeneous framework, Section 3 discusses policy management, Section 4 introduces the TBVH mechanism, Section 5 discusses simulation results, Section 6 demonstrates the application of TBVH, and finally, Section 7 concludes the paper.

## II. THE HETEROGENEOUS FRAMEWORK

Due to the increase in the complexity and number of tasks in heterogeneous networking, successful implementation of seamless interoperability requires the introduction of a new level of intelligence to components at the network, device and application levels. Some of these new features include network component reconfigurability, policy management during vertical handovers and QoS management. There is also the pressing need for a reference model similar to the OSI model, which will clearly define the functions of all layers and provide a framework for the exchange of information between network components. We therefore propose the new heterogeneous framework [1] which consists of seven layers as follows:

- Hardware Platform Layer: This layer’s function is the definition of the hardware components and technologies required to support a wireless network. It defines characteristics like electromagnetic spectrum, modulation schemes and Media Access Control (MAC) algorithms.
- Network Abstraction Layer: This layer provides a common interface for supporting the different network technologies present at the lower layer. It is responsible for controlling and maintaining networks on the MN.

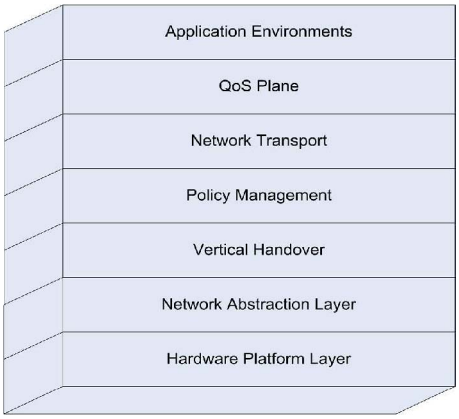


Figure 1. The heterogeneous framework

- Vertical Handover Layer: This layer is mainly responsible for the specification of mechanisms including state engines and triggers for vertical handovers. It supports both network-controlled and client-controlled handovers.

- Policy Management Layer: This layer evaluates the circumstances when a handover should occur. It consists of a set of rules which evaluate the relevant parameters and their values to make a decision about a handover.

- Network Transport Layer: This layer examines the addressing, routing and transport issues in peripheral networks.

- Quality-of-Service (QoS) Layer: This layer supports both upward and downward QoS. Its task is to ensure that the QoS offered to applications can be maintained at an acceptable level during the lifetime of a connection.

- Application Environments Layer: This layer specifies mechanisms and routines that assist in building applications which can use all the layers of the framework.

This paper mainly explains the peripheral (client) side of the heterogeneous framework. Detailed information on the complete framework can be found in [1]. As the development of each layer involves extensive research, with each layer evolving into a separate study, the paper focuses mainly on the practical implementation of the Policy Management Layer.

## III. POLICY MANAGEMENT AND HETEROGENEOUS NETWORKS

As described earlier, the main function of the Policy Management layer is the evaluation of available context information like changes in signal strength, available channel resources and the state of active TCP connections to decide when to perform a vertical handover. This layer resides in the mobile node (MN) and contributes to the client-controlled vertical handover approach [4] which we have adopted in this study. In a client-controlled approach, the MN plays an active role in deciding when to perform a vertical handover. Being directly in touch with the different networks, the MN is more aware of the latest medium access, network and transport conditions that exist at each physical interface. Thus it is in a more superior position to decide when a vertical handover should take place.

Policy management mechanisms can be classified in to two categories:

- Reactive: In this category, the MN reacts according to explicit triggers received from lower layers which inform it of changes in network conditions.

- Proactive: The MN in this category attempts to predict existing and future conditions through the evaluation of measurable network parameters like the ones mentioned earlier. Proactive mechanisms can be further classified into knowledge-based and modelling-based approaches.

Several studies in literature have proposed different types of policy management schemes. Soh et al. in [5] proposed a scheme which relied on knowledge of road topology and MN position to predict future conditions. This approach was knowledge-based and mainly relied on large volumes of data on road maps stored in prediction databases inside every BS. Hence it was not possible to predict the path for an MN that strayed away from road topology. Cottingham et al. [7] applied the knowledge-based approach in the form of data coverage maps to predict the availability of network coverage in a particular location. This scheme however was mainly for outdoor environments and did not consider indoor coverage. Ebersman et al. [6] proposed calculating time before horizontal handovers based on the change in received signal strength (RSS). However, the study failed to capture the accuracy of the MN's movement and temporary fluctuations in RSS could falsely triggers handovers.

## IV. PROACTIVE POLICY MANAGEMENT USING TBVH

In this paper, we propose a novel modeling-based proactive policy management mechanism which aims to predict vertical handovers based on mathematical calculations. The mechanism targets both indoor and outdoor environments. Along with the usual parameters, our policy management mechanism depends largely on a new dynamically derived parameter call Time Before Vertical Handover (TBVH) which is derived from available information, namely, distance from BS, MN velocity, and its direction of motion.

### *A. TBVH – why is it important?*

A significant observation made in [8] was that TCP-connection adaptation latency after a vertical handover can actually be longer than the total handover latency. It is therefore crucial to broaden the scope and look beyond simply reducing delays and packet error rates during vertical handovers. The mere presence of another network offering increased network resources is no longer a sufficient reason for performing a vertical handover, it is vital to ensure that the new network coverage will be available long enough to allow the connection to recover from the handover and transmit for at least a certain minimum duration. Thus, in a heterogeneous environment, the knowledge of the duration for which a network channel may be available can significantly change the manner in which multi-class traffic streams are assigned to different available channels. This knowledge can also assist in minimising packet loss and latency due to handovers. For instance, consider a MN with several types of active multimedia connections. If this MN which is under the coverage of WLAN is aware that it may lose this coverage in the next minute, it can avoid allocating an interactive video stream to it. By choosing the next best available network, it can avoid the overhead associated with an upward vertical handover. Similarly, a user's PDA connected to UMTS may pick up the coverage of a WLAN for a short period when the user walks near a hotspot. The awareness that this coverage is only for a short period can help the MN in deciding not to perform a complete downward vertical handover to WLAN. Additionally, the knowledge that a high-bandwidth connection may be lost soon could actually allow the allocation of more resources to active data transfer connections and based on file size, allow the completion of transfer before the MN moves out of the current coverage. TBVH can therefore, play a crucial role in increasing the efficiency of channel allocation and resource reservation mechanisms for an MN and assist in the prevention of unnecessary vertical handovers.

One of the key requirements in the calculation of TBVH is knowledge of some aspects of network topology, in particular the knowledge of network boundaries. We propose some topological changes to networks by introducing additional specification to BSs at network boundaries, calling them Boundary Base Stations (BBS). These BBS inform the MN of imminent network boundaries. For example in outdoor scenarios, the BBS informs the MN of the vertical handover threshold and for indoor environments the dimensions of the enclosed space and the position of various exits. The BBS can also inform the MN of other networks that may be in its vicinity to which the MN is likely to perform a vertical handover but which it is yet to discover.

*B. TBVH for outdoor environments*

This scenario considers the case of an MN in an outdoor setting and under WLAN coverage, moving towards the boundary with velocity v (Figure 2). The networks considered are UMTS and WLAN, however, the model can be extended to other types of networks as well. For the sake of simplicity in explanation, we consider a circular coverage cell of radius R although a circular cell is not a requirement. In the above figure, the inner dotted circle of radius r represents the handover threshold where the MN is expected to perform the vertical handover. Angle x is the angle made by the MN's movement direction with the BBS and d is the distance of the MN from the BBS. All these parameters can be determined from the location coordinates of the various network components which in turn can be recorded using various available location prediction techniques. In this scenario we

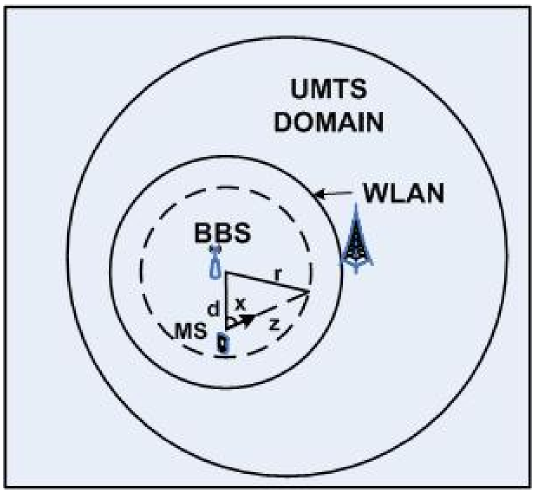


Figure 2. MN under BBS coverage

need to calculate z which is the point on the threshold circle where the MN is expected to vertically handover. As

$$r^2 = d^2 + z^2 - 2dzcosx \qquad (1)$$

Due to geometric considerations, we only consider one root of the quadratic equation as the formula below (2) will always give positive solution. So the value of $z$ is

$$z = (dcosx) + \sqrt{r^2 - d^2sin^2x} \quad (2)$$

Thus the estimated TBVH for this scenario is:

$$\frac{(dcosx) + \sqrt{r^2 - d^2sin^2x}}{v} \qquad (3)$$

Different cases in TBVH arise based on the movement of MN either towards or away from a network boundary. These have been discussed in detail in [2]. In all these cases, the formula for TBVH calculation remains essentially the same.

*C. TBVH for indoor environments*

This scenario considers movement of the MN under indoor WLAN coverage. TBVH can be predicted with greater accuracy for indoor environments due to the precise definition of coverage due to availability of accurate topological information. Indoor scenarios also facilitate ease in testing. During the connection setup phase the MN receives a beacon from the BBS which contains indoor topological information such as room dimensions and points of exit.

Unlike outdoor coverage, TBVH calculation here cannot depend only on handover threshold for several reasons. Firstly, an MN moving under a small coverage like WLAN is likely to exhibit frequent random movements, characteristic of pedestrian behaviour, causing frequent change in direction. For example the MN moving towards an exit may suddenly undergo a change in direction and move in the exact opposite direction. Secondly, as shown in

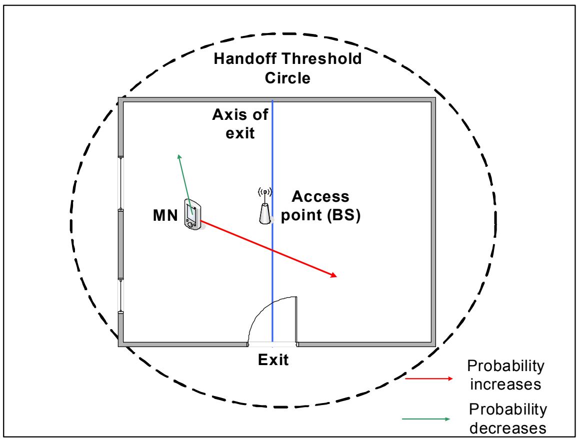


Figure 3. MN in indoor environment

Figure 3, the MN may appear to move closer to the threshold circle but in the direction of a wall instead of an exit. In this case TBVH value alone is not a sufficient indicator of handover because although the value reduces as the MN approaches the boundary, in reality it cannot leave the WLAN coverage as it will be stopped by the wall. It is thus important to develop a mechanism that will take into consideration these random movements of the MN. To address this issue we propose assigning a weight W1 to TBVH. W1 is the cosine of the MN direction calculated with respect to a particular point of exit. The higher the value of W1, the more likely it is to pass through the exit. TBVH mechanism for indoor environments must also accommodate the presence of multiple exits points. In this case, TBVH and W1are calculated separately for each point of exit. Thus for indoor scenarios, the final probability of when the MN will perform a vertical handover is indicated by both TBVH and W1. Once the MN moves out of the enclosed area, TBVH is calculated as per equation (3). The next section demonstrates the simulations of TBVH mechanisms for both indoor and outdoor environments.

## V. SIMULATION AND RESULTS

Based on the ideas proposed earlier in the paper, the experimental proactive TBVH simulation model was developed in OPNET Modeler. The TBVH module's block diagram is shown below. Input parameters employed in TBVH calculation were mainly the location co-ordinates for for the MN and BBS. Figure 5 represents the scenario where the MN moves in open space. Figure 6 displays the graphed results for TBVH calculated for the moving mobile node.

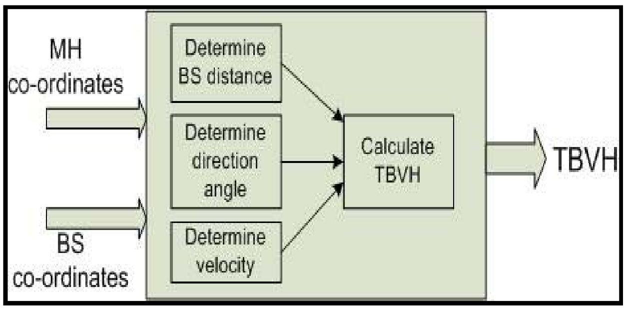


Figure 4. TBVH node module

TABLE I. TBVH POINTS IN THE MN TRAJECTORY

| MN location | TBVH before direction change | TBVH after direction change |
|---|---|---|
| Point 1 | 35.42 | 176.50 |
| Point 2 | 37.10 | 166.97 |
| Point 3 | 77.10 | 158.97 |
| Point 4 | 97.85 | 150.24 |
| Point 5 | 63.40 | 193.13 |
| Point 6 | 88.07 | 185.66 |
| Point 7 | 122.30 | |

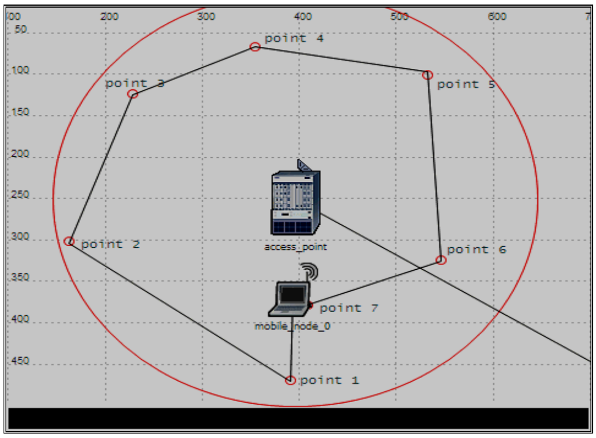


Figure 5. MN movement in open environment

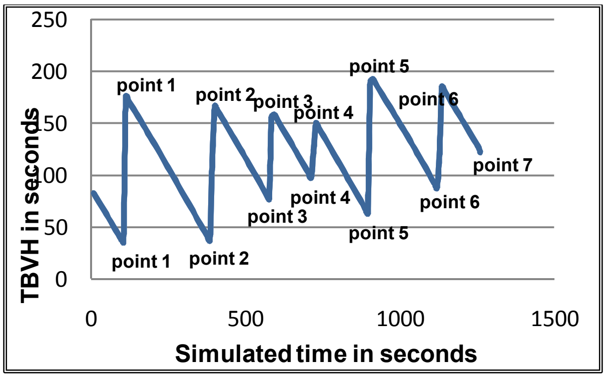


Figure 6. TBVH graph for open environment

Results agreed with intuition and instantaneous TBVH values closely coincided with the location and behaviour of the MN along its trajectory as shown in table 1. When the MN moved towards another BS in the WLAN cell but not

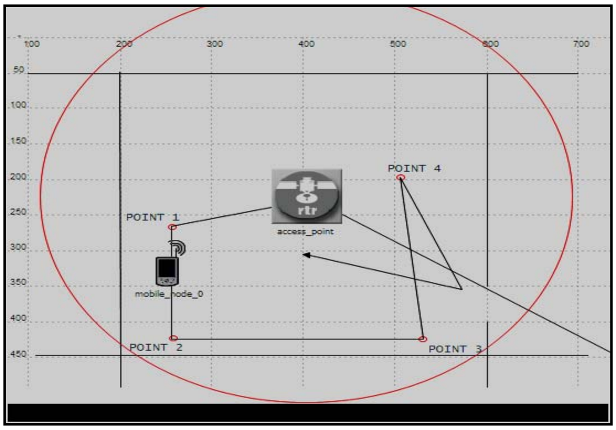


Figure 7. MN movement in a closed enviornment

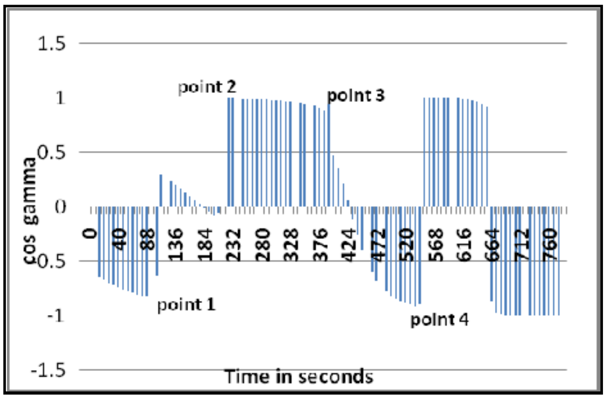


Figure 8. TBVH weight correstponding to MN direction

the network boundary, TBVH represented time before handover to next WLAN cell instead of a vertical handover. In the TBVH graph, each physical point is represented twice. This corresponds to the value of TBVH before and after the MN changes its direction at a particular position. For example, point1 lower down in the graph represents the TBVH value when the MN's direction is downward while the point 1 higher up represents TBVH calculated at the same position but when the MN changes direction and moves upwards. Figures 7 and 8 represent the network model and TBVH weight graph for indoor scenario respectively. We now have the graph for TBVH weight which is mainly the cosine of the direction angle made by the MN's direction with respect to the point of exit. This graph of cosine values captures closely the MN's direction, displaying values greater than 0 each time the MN approaches towards the exit. For instance, considering the movement between points 3 and 4, it can be observed that the weight value begins to decrease as the MN moves away from the exit but it remains above zero while the MN roams in the vicinity of the exit and goes negative only when the MN moves further away, approaching minus 1 eventually at point 4. A similar behaviour can be observed between points 1 and 2. Thus experimental results clearly demonstrate the successful implementation of our proposed mechanim for calculating the time before vertical handover for an MN.

## VI. TBVH FOR DOWNWARD QOS MANAGEMENT

In this section, we briefly demonstrate how TBVH can be applied for the management of downward QoS. More detailed explanation is found in [3]. For a multi-interfaced MN, the simultaneous presence of different network channels offering different levels of QoS causes an increase in the complexity of multi-class traffic management issues such as resources management, traffic scheduling and flow control. Downward QoS management can be defined as the task of mapping application stream requirements down to the appropriate available network channel. Downward QoS at the MN requires answers to several key issues including:

- The QoS requirements of application streams.
- Most suitable networks among currently available ones for allocating a particular call.
- The current and likely future conditions of these networks.
- How long are these networks likely to remain available.

In a multi-interfaced client, the context parameters for each physical interface are stored in a two-dimensional matrix called the Network Descriptor Matrix (NDM).

$$\begin{array}{cccccc}
NWid_1 & status_1 & avbw_1 & RSS_1 & TBVH_1 & RTT_1 \\
NWid_2 & status_2 & avbw_2 & RSS_2 & TBVH_2 & RTT_2 \\
NWid_3 & status_3 & avbw_3 & RSS_3 & TBVH_3 & RTT_3 \\
NWid_4 & status_4 & avbw_4 & RSS_4 & TBVH_4 & RTT_4 \\
NWid_5 & status_5 & avbw_5 & RSS_5 & TBVH_5 & RTT_5
\end{array}$$

Parameters of each row in the NDM represent network ID (NWid), network status (status) with on/off values, available bandwidth (avbw), received signal strength (RSS), time before vertical handover (TBVH), and round trip time (RTT) between BS and MN respectively.

Application traffic streams can be of largely varying behavioural characteristics e.g. interactive video, streaming video, audio and data. Improved context awareness of available networks is necessary for an MN before it can bundle these traffic streams more efficiently over them. In such situations, the TBVH parameter can play an important role in deciding the choice of a network and the amount of resources allocated to a particular traffic stream. Figure 9 shows the choice of a network for video/ftp traffic based on conditions mentioned above. As these applications are more likely have high resource requirements, WLAN is designated as the first network choice for these types of applications. The algorithm checks if the MN speed is less than a specific threshold required for WLAN and then checks for other network parameter conditions. If both conditions are satisfied, the stream is allocated to WLAN else resource availability is checked for UMTS. If both resource availability checks fail, the stream request is queued and an urgency value is incremented. The urgency value is assigned

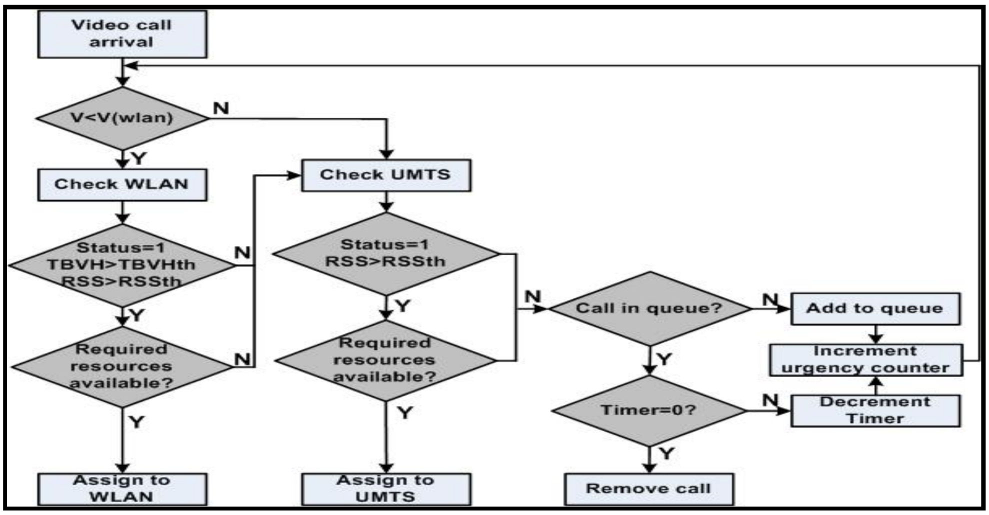


Figure 9. Application of TBVH in choice of networks

in order to avoid the starvation of low priority traffic. This value increases the longer the application request remains in the queue. In future, the application leaves the queue when a channel becomes available or when its waiting timer expires. The amount of resources e.g. available bandwidth allocated to a stream is decided with the help of the Weighted Resource Allocation (WRA) equation

$$(TBVH \, x \, W1) \, (UV \, x \, W2) \, (V \, x \, W3) \qquad (4)$$

where UV is the urgency value for the stream, V the velocity of MN and (W1+ W2 + W3 = 1).

## VII. CONCLUSION AND FUTURE WORK

In this paper we dealt with one of the main concerns with heterogeneous networking – QoS issues in multi-class traffic management. We highlighted the importance of policy management mechanisms in improving the context awareness of mobile nodes and proposed a client-based proactive policy management scheme for the prediction of the time before vertical handovers in mobile nodes. This scheme was developed for both open and closed environments and successfully captured the random movement behaviour of devices. The proposed mechanism was practically implemented in OPNET Modeler and results demostrated that the scheme worked correctly for both environments. The The paper also explained how the knowledge of TBVH helped to improve the management of multi-class traffic streams in a heterogeneous client. Future work in this area will include the performance study of the TBVH model after its real-lfe implementation in a proposed extended test-bed [9].

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