Proactive Policy Management using TBVH Mechanism in Heterogeneous Networks

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Abstract

In order to achieve seamless interoperability in heterogeneous networking, it is vital to improve the context-awareness of the mobile node (MN) so that it is able to predict future network conditions with sufficient accuracy. In this paper, we introduce a predictive mathematical model for calculating the estimated Time Before Vertical Handover (TBVH) component from available network parameters. The model is practically implemented in OPNET and our simulation results confirm the validity of the concept. We then demonstrate how the knowledge of TBVH along with other network parameters can be applied by downward Quality of Service management policies which bundle multi-class traffic streams on to available network channels based on application QoS, device mobility patterns and prevailing channel conditions.

1. Introduction

In 4G networks, the introduction of heterogeneity among existing wireless standards adds a new level of complexity to traffic and resource management issues, particularly during vertical handovers. Multi-interfaced heterogeneous clients supporting networks such as 3G, WLAN, WiMAX and UWB are expected to roam freely among these different networks without experiencing disruption to services, and benefit from the best available location-based network facilities. These devices are offered the choice of transmission on multiple but changing wireless channels exhibiting varying levels of QoS. The aim is to effectively deliver multi-class traffic across these diverse channels, by minimising the forced termination of ongoing connections during vertical handovers.

The advent of heterogeneous networking has increased the complexity of network components. In order to achieve seamless interoperability, 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 this paper, we briefly introduce our proposed architectural framework similar to the OSI model which encapsulates the key challenges of heterogeneous networking. The paper then proposes a proactive analytical model for calculating a sufficiently accurate estimate of the Time Before Vertical Handover (TBVH) for a roaming MN. Simulation results confirm 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. Next the paper demonstrates how TBVH is utilised by the proposed Stream Bundle Management Layer (SBM) which is an intelligent, client-based layer for downward QoS management. It consists of a set of policies that combine knowledge of TBVH along with the knowledge of networks' conditions for bundling multi-class traffic streams onto the most appropriate wireless channel.

The rest of the paper is organised as follows: Section 2 introduces the heterogeneous framework, Section 3 explains policy management and the TBVH model with simulation results. Section 4 introduces the SBM layer and demonstrates the application of TBVH; and finally the paper concludes with Section 5 with a brief discussion on future work.

2. Heterogeneous Networking Framework

The development of 4G heterogeneous networks introduced the attractive paradigm of "seamless QoS provisioning". However, it also brought along with it a plethora of new challenges at the network, device and application levels. What is needed is a new framework to encapsulate mechanisms that address these challenges in heterogeneous environments. Some of the key requirements of this framework include reconfigurability of network components, QoS management, and policy management for vertical handovers.

In order to address the issues mentioned above, we proposed the architectural framework for heterogeneous networking [2]. It acts as a reference model similar to the OSI model and clearly defines the functions of all layers and provides a framework for exchanging data between network applications. The seven layers of the framework are as follows:

- **Hardware Platform Layer:** This layer defines 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.

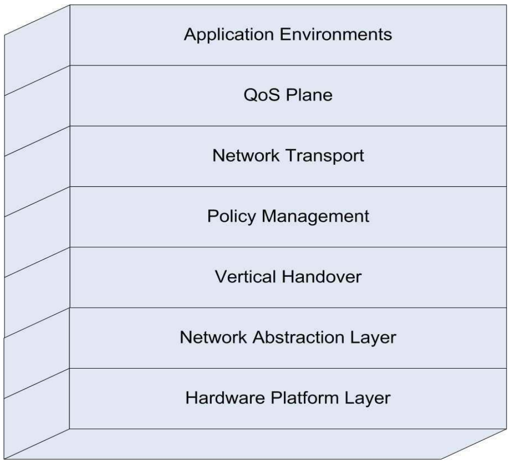

Figure 1. The heterogeneous framework

- **Network Abstraction Layer:** This layer provides a common interface for supporting the different network technologies. It is responsible for controlling and maintaining networks on the MN.

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

- **Policy Management Layer:** The function of this layer is to evaluate the circumstances when a handover should occur. It is implemented through the definition of a set of rules with regard to all the relevant parameters and their values which are evaluated with respect to handover.

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

- **Quality-of-Service (QoS) Layer:** This layer is designed to support both upward and downward QoS in a heterogeneous device. It ensures that the QoS offered to applications can be maintained at an acceptable level during the lifetime of a connection.

- **Application Environments Layer:** The function of this layer is to specify mechanisms and routines that assist in building applications which can use all the layers of the framework.

3. Policy Management and TBVH

A successful implementation of the heterogeneous framework involves a lot of intensive research, and each layer's functioning could evolve into a separate research study. In this paper we focus on the Policy management and QoS layers and propose mechanisms for their practical implementation.

3.1. Client-controlled approach for vertical handovers

Vertical handovers can be classified into two main categories - network-controlled and client-controlled. Before the advent of heterogeneous networking handover management was mainly network-controlled where the base station (BS) maintained up-to-date context information for the MN and decided when and how it should perform a handover. However, this approach is not scalable in heterogeneous networking where a MN is simultaneously connected to several different BSs. Furthermore, in a loosely coupled heterogeneous scenario where networks may belong to different service providers, a network-controlled approach will require the detailed sharing of network and customer information, something service providers may be unwilling to share.

In a client-controlled approach, the MN is assigned a more active role in handover management. As the MN is directly connected to different networks, it possesses up-to-date knowledge of the medium access, network and transport conditions for each active network interface. It is thus in a superior position to decide when a vertical handover should take place. In this study we adopt the client-based approach as explored in the Cambridge wireless test bed [3] and the IEEE 802.21 working group [4].

3.2. Time Before Vertical Handover (TBVH)

As described earlier in the reference model, the main function of the Policy Management layer is to decide when to execute a vertical handover based on several key parameters like changes in signal strength, available network bandwidth, state of active transport connections on the MN and the time the MN has before it performs a vertical handover. While most of these parameters can be sensed directly from network interfaces, TBVH is derived from other available information, namely, distance from BS, MN velocity, and its direction of motion.

A few attempts were made earlier for determining the time before handover. The study in [5] proposed a history-based mobility prediction technique based on positioning knowledge and road topology. However, the approach mainly relied on large volumes of data on road maps stored in prediction databases inside every BS so it was not possible to predict the path for an MN that strayed away from road topology. Ebersman et al. [6] proposed calculating time before horizontal handovers based on the change in received signal strength (RSS). However, by relying only on change in RSS, the study failed to capture the accuracy of the MN's movement and temporary fluctuations in RSS could falsely triggers handovers.

In a heterogeneous environment, the knowledge of the time for which an MN will have access to a particular network channel offers it the opportunity to minimise packet loss and latency due to handover mechanisms. For instance, an MN that is aware that it may loose WLAN coverage in the next minute will avoid allocating an interactive video stream to it. By choosing the next best available network, it avoids 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. TBVH therefore, plays a key role in increasing the efficiency of channel allocation and resource reservation mechanisms for an MN and assists in the prevention of unnecessary vertical handovers.

A key requirement in the calculation of TBVH is the knowledge of some aspects of network topology, in particular the knowledge of network boundaries. To address this issue we proposed some topological changes to networks by introducing additional specification to BSs at network boundaries, calling them Boundary Base Stations (BBS). An MN approaching a BBS becomes aware of the fact that it may have to perform a vertical handover. The main function of the BBS is to inform the MN of its location parameters and other information it may need for the vertical handover, e.g. a record 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.

3.3. Determination of TBVH

Here we explain the mathematical derivation of TBVH and the different scenarios that arise based on the MN's location in the network and its direction of motion. For the sake of simplicity, only the UMTS-WLAN network combination is considered, although the model can be easily applied to other network combinations. The explanation here is restricted to upward vertical handovers, although the concept can also be applied in a similar manner to avoid downward vertical handovers. TBVH does not need to be calculated when an MN moves among normal BSs. The two scenarios for TBVH calculation are as follows:

Case I: Outward movement of MN in BBS towards boundary

This scenario considers the case of an MN that is roaming under the coverage of a BBS and is moving towards the boundary with velocity v (Fig. 2). Here we consider a circular cell of radius R. The inner dotted concentric circle represents the handover threshold of radius r which is the distance from the BSS where a MN is expected to perform a handover. Angle x is the angle

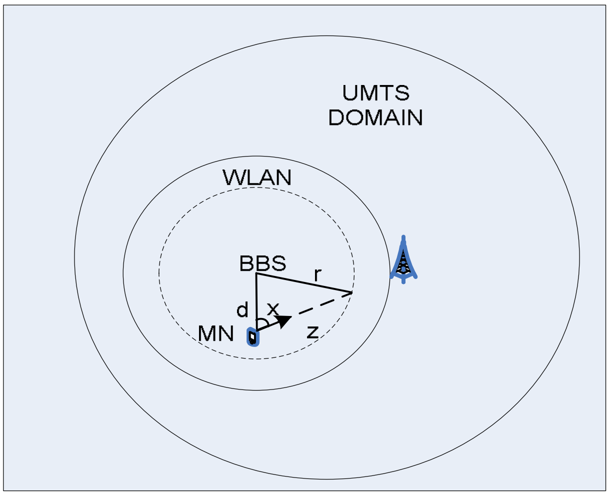

Figure 2. Movement of MN in BBS

made by the line joining the BBS and the direction of MN movement, and d is the distance of the MN from the BBS which can be determined either from the received signal strength (RSS) or from the location co-ordinates of the MN and BBS. In order to determine the TBVH in this scenario we need to calculate the distance z which is the point on the threshold circle where the MN is expected to vertically handover. As

$$r^2 = d^2 + z^2 - 2dz\cos x \qquad (1)$$

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

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

Thus the estimated TBVH for this scenario is:

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

As WLANs may have specific points of exits such as doors in a building, the prediction accuracy of TBVH can be improved if the co-ordinates of these exit points are stored in the BBS and passed on the MN when required.

CASE II: Movement of MN from normal BS to BBS

In this scenario (Fig. 3), a MN (point C) is under the coverage of a normal BS (NBS) (point A), but is moving towards a BBS (point B) with velocity v, as displayed in fig. . The goal here is to improve the prediction capability of the model by making it able to predict the TBVH of MN while it still moves in the coverage of A. In this case, the concept of threshold distance TD [8] is used in the normal BS. This is a distance smaller than the cell's radius and defines a smaller concentric circle

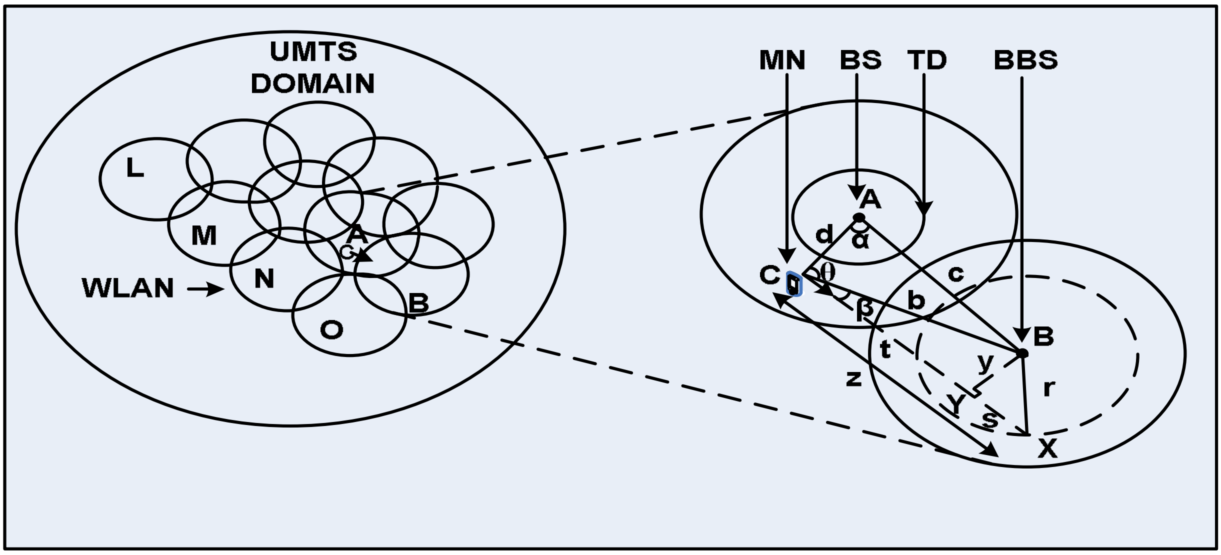

Figure 3. Movement of MN towards BBS

located within the cell. A MN moving inside the TD circle is more likely to change direction, however on moving out of this circle, it is less likely to undergo a sudden change in its direction, thus enabling a correct prediction of the next cell the MN is moving towards. As the MN is too far from the BBS to get a reasonably accurate value of b, it is necessary first to find this distance and the angle β in order to calculate distance z. In Fig. 3,

$$c^2 = d^2 + b^2 - 2db\cos\theta \qquad (4)$$

Therefore,

$$\theta = \cos^{-1}\left(\left(b^2 + d^2 - c^2\right)/ 2db\right) \qquad (5)$$

Depending on which side of line AB point X lies,

$$\text{angle}\, \beta = |x - \theta| \qquad (6)$$

Considering triangle BYC, we have

$$t = b\cos\beta \qquad (7)$$

$$y = b\sin\beta \qquad (8)$$

Therefore, in triangle BYX,

$$s = \sqrt{r^2 - b^2\sin^2\beta} \qquad (9)$$

As

$$z = t + s\,,$$

From (7), (8) and (9) we have

$$z = b\cos\beta + \sqrt{r^2 - b^2\sin^2\beta} \qquad (10)$$

Thus the TBVH component for this scenario is,

$$TBVH = \frac{b\cos\beta + \sqrt{r^2 - b^2\sin^2\beta}}{v} \qquad (11)$$

This is similar to the equation obtained in (3).

It is important to note that while TBVH may vary due to random movements of the MN, the calculated TBVH when considered in the weighted resource allocation mechanism (discussed in next section) along with other parameters will greatly assist in improving the context-awareness of the MN during an imminent vertical handover.

3.4. TBVH Simulation and Results

Based on the ideas proposed earlier in the paper, the proactive TBVH simulation model was developed in OPNET Modeler. The TBVH module's block diagram is shown below.

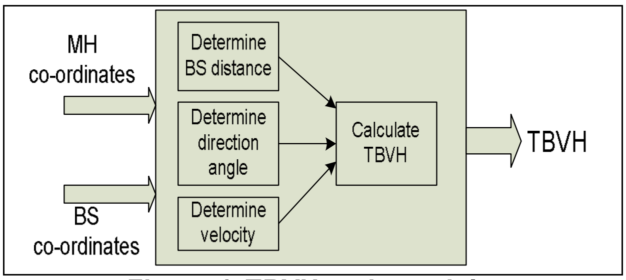

Figure 4. TBVH node module

Input parameters employed in TBVH calculation were mainly the location co-ordinates for the MN and BBS available using GPS or network-based positioning techniques. These input parameters were used to calculate the MN-BBS distance, angle of direction and MN velocity.

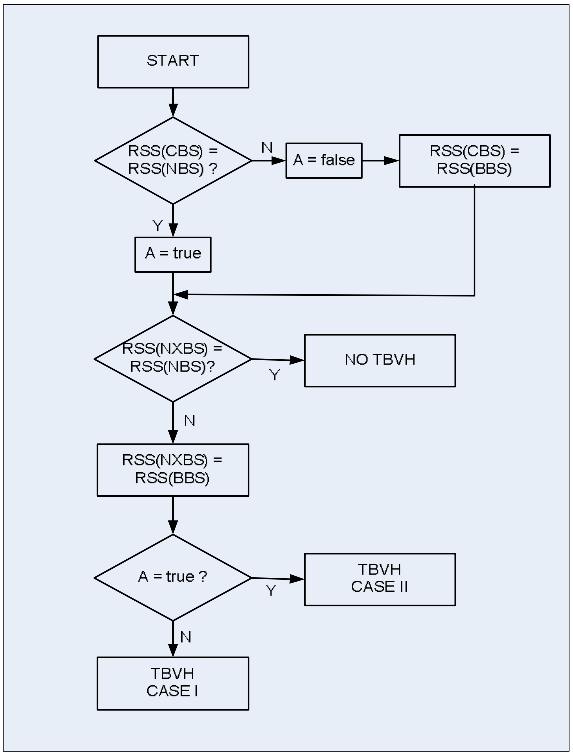

Figure 5. TBVH choice flow chart

The TBVH module was embedded in the node model of a wireless LAN workstation. The scenario simulated (Fig. 6) was a WLAN of cell radius 300m with a handoff threshold of 290m. Positioning delay was set to 3 seconds and positioning interval to 5 seconds. The mobile node was assigned a random trajectory and a speed of 2 m/s, equivalent to the speed of a walking person. Based on the values of changing RSS for current BS (CBS) and next BS (NXBS), the different cases for TBVH calculation were applied as shown in Fig. 5.

Fig. 7 depicts the simulated results for TBVH calculated for the moving mobile node. The horizontal axis represented the simulated time in minutes while the vertical axis represented TBVH in seconds. 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 the network boundary, TBVH represented time before handover to next WLAN cell instead of a vertical handover. For example points 6 and 7 in table 1 showed the time before handover to the next WLAN cell. This was decided based on the change in RSS values of current BS and neighbouring BSs.

4. Application of TBVH for Downward QoS Management

After explaining how TBVH can be calculated at the policy management level, we demonstrate how it can be applied to support downward QoS in heterogeneous devices using the Stream Bundle Management (SBM)

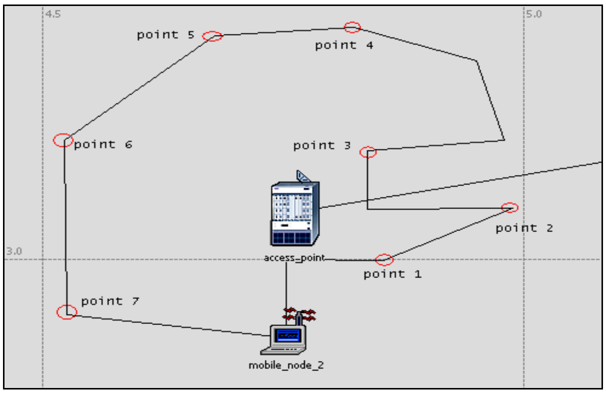

Figure 6. Simulated path of MN in WLAN BBS

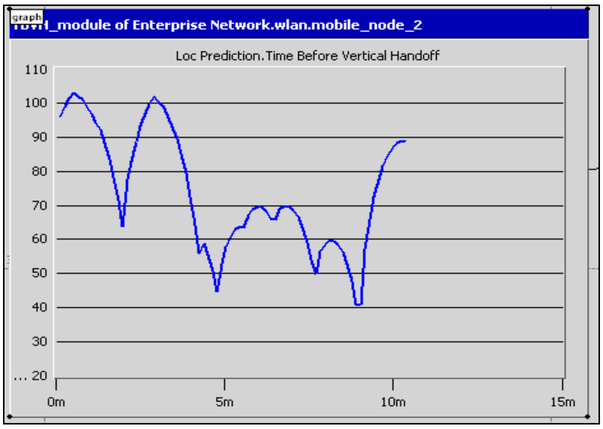

Figure 7. Generated TBVH for MN

Table 1. TBVH in MN trajectory

POINT	TBVH (SECONDS)
Point 1	96.026
Point 2	65.81
Point 3	95.61
Point 4	63.74
Point 5	65.81
Point 6	51.32
Point 7	40.97

Layer. This section mainly highlights the role of TBVH in multi-class traffic management. Readers can refer to [1] for a detailed explanation on the SBM layer.

The presence of multiple network channels at the MN in heterogeneous networks, offering different levels of QoS increases the complexity of multi-class traffic management issues such as resource management, traffic scheduling and flow control. Downward QoS management at the MN requires answers to several key issues including:

- The QoS requirements of the 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.

Thus it is crucial for the MN to improve its knowledge of available networks' contexts before bundling traffic streams over them.

The SBM layer is a specialised proactive layer residing in the QoS Plane in a heterogeneous MN and is responsible for handling downward QoS. It consists of a set of intelligent policies for allocation and scheduling of multi-class traffic streams onto different available channels based on application priority and behavioural patterns, device mobility patterns as well as network and transport conditions of available wireless channels. Network context information for each network interface is stored in the two-dimensional matrix called the Network Descriptor Matrix (NDM). 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.

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

Traffic streams considered are interactive video, one-way streaming video, audio and data. The layer maintains a prioritised list of compatible networks for each traffic type. In the absence of a suitable channel the application is assigned to a dynamic priority waiting queue. The application leaves the queue when a channel becomes available or when its waiting timer expires. In order to avoid starvation of low priority traffic, application streams are assigned an urgency value which increases the longer the application request remains in the waiting queue.

The SBM layer's Resource Allocation and Traffic Scheduling mechanism (RATS) continuously monitors the amount of resources allocated to a traffic stream. Here, the TBVH parameter plays an important role in deciding the choice of a network and amount of resources allocated to the traffic stream. Fig. 8 demonstrates the choice of network for video/ file transfer traffic. Possible high resource requirements for these types of traffic make WLAN the first network choice. 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 urgency value is incremented.

The amount of resources (available bandwidth) allocated to a stream is decided with the help of the Weighted Resource Allocation (WRA) equation.

$$(TBVH \times W1) + (UV \times W2) + (V \times W3)$$

where UV is the urgency value for the stream, V the velocity of MN and (W1+ W2 + W3 = 1). For example for a file transfer stream, the WRA mechanism can allocate more bandwidth to the flow and allow it to complete transfer before the MN performs the upward vertical handover. The concept of WRA is similar to the reservation ordering scheme in [7]. However, instead of assigning a single priority to all streams on a MN, our WRA mechanism adapts a more refined approach and bandwidth allocation is considered on a per-flow basis.

5. Conclusion and Future Work

QoS management in heterogeneous networking requires the development of improved mechanisms capable of adapting to continuous changes in network conditions. In this paper we proposed the predictive mathematical model for calculating the estimated TBVH. Different cases in TBVH calculation that could arise based on the MN's trajectory were discussed. The model was practically implemented in OPNET and simulation results demonstrated the validity of the concept. We then addressed the problem of QoS management and introduced the Stream Bundle Management Layer which consisted of a set of policies that applied knowledge of TBVH along with other channel conditions for bundling multi-class traffic onto different available channels. Future work in this area will include the performance study of the TBVH model and SBM layer after their implementation in a proposed extended test-bed.

6. Acknowledgements

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7. References

[1] F. Shaikh, A. Lasebae and G. Mapp, "Client-based SBM Layer for predictive management of traffic flows in heterogeneous networks." *Proc. IEEE ICTTA'06*, April 2006.

[2] G. Mapp, D. Cottingham, F. Shaikh, P. Vidales, L. Patanapongpibul, J. Baliosian and J. Crowcroft, "An Architectural Framework for Heterogeneous Networking." *Proc. WINSYS'06*. August 2006, pp. 5-10.

[3] P.Vidales, L. Patanapongpibul, G. Mapp, A. Hopper, "Experiences with Heterogeneous Wireless Networks, Unveiling the Challenges", *Proc. HET-NET'04*, July 2004, pp. WP10/1-WP10/8.

[4] A.Dutta, S.Das, D. Famolari, Y.Ohba, K.Taniuchi, T.Kodama and H.Schulzrinne, "Seamless Handover across

Heterogeneous Networks – An IEEE 802.21 Centric Approach", *Proc. IEEE WPMC*, Sept 2005.

[5] W-S Soh and H.S. Kim, "Dynamic Bandwidth Reservation in Cellular Networks Using Road Topology Based Mobility Predictions", *Proc. IEEE INFOCOM'23*, Honkong, March 2004.

[6] H.G. Ebersman, O.K. Tonguz, "Handoff ordering using signal prediction priority queuing in personal communication systems," IEEE Trans. Veh. Techno., Vol. 48. No. 1 1999, pp. 22-35.

[7] F. Hu and N.K. Sharma, "Multimedia Call Admission Control in Mobile Networks: A Dynamic Pool Reservation Approach," *Computer Networks*, vol. 43, pp. 263-288, 2003.

[8] M-H Chiu, M. Bassiouni, "Predictive Schemes for Handoff Prioritization in Cellular Networks Based on Mobile Positioning", *IEEE J. Select Areas Commun.*, vol. 18, no. 3, Mar. 2000, pp. 510-522.

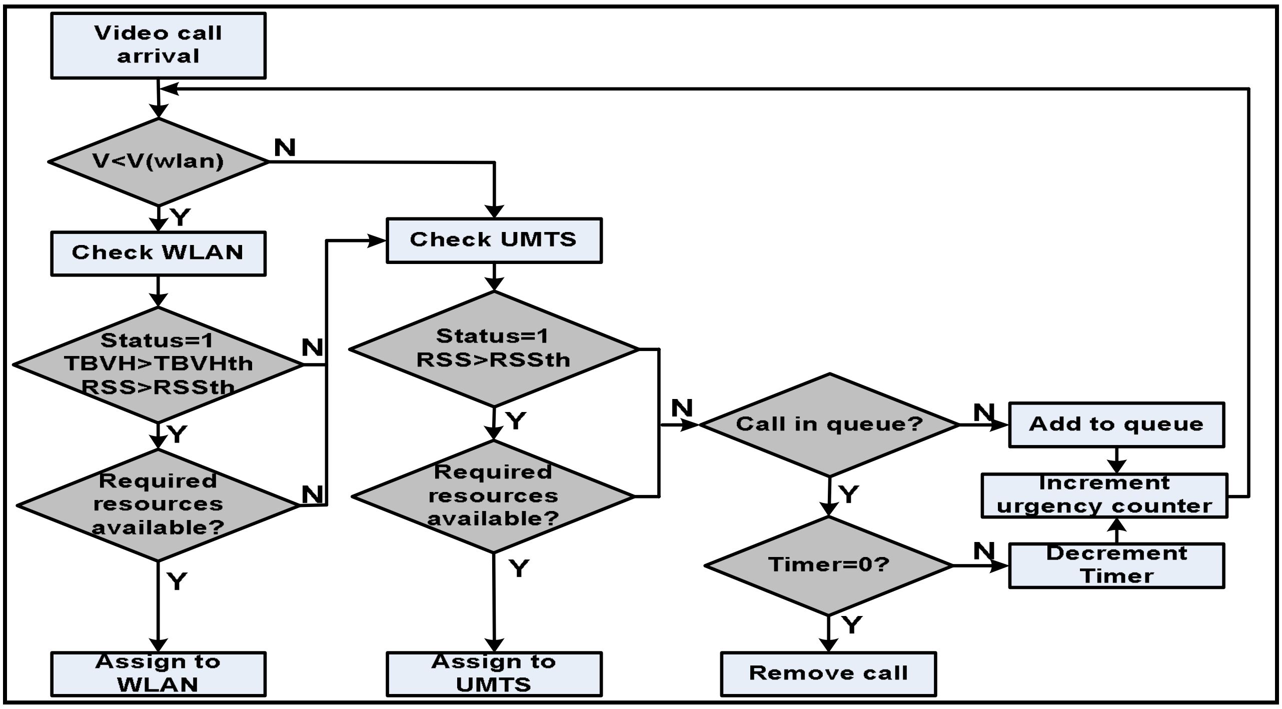

Figure 8. Network choice for video/data calls