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# Performance Analysis and Evaluation of an Analytical Model for Vertical Handoffs in Heterogeneous Networks

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## *Abstract*

*Heterogeneous networks are consisted of the networks with different Radio Access Technologies (RAT). Vertical handoffs would be triggered while mobile users moving across two cells implemented different RATs during the session. Thus, some serious problems will be caused due to characteristics of different RATs. Numerous solutions have been proposed to solve these problems. However, most of existing solutions only take into account single traffic, e.g. vertical handoffs (VHO). In this paper, an analytical model is proposed, with which VHO is taken into account, but also new services (NS). Simulation results illustrate that the performance could be significantly improved with the algorithms in the proposed model. Compared with existing strategies, i.e. Signal to Interference and Noise (SINR) and Vertical Handoff Management (VHOM), for NS, the blocking probability could be improved by 33% and 40%, respectively; for VHO, the blocking probability could be improved by 17% and 19%, respectively; and the resource utilization could be improved by approximately 8% and 11%, respectively.*

**Keywords:** *heterogeneous networks, vertical handoff, quality of experience, traffic blocking probability, resource utilization*

## 1. Introduction

The future wireless networks tend to integrate different Radio Access Technologies (RAT) in order for offering users the best quality of experience (QoE). Such networks are well-known as heterogeneous networks. It is expected that mobile stations (MS) will increasingly have multiple heterogeneous interfaces to obtain services from different networks simultaneously. Actually, the components in heterogeneous networks usually are considered as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and Universal Mobile Telecommunications System (UMTS). These networks have different characteristics, but complementary. WLAN which provides a small coverage has become the most popular wireless technology due to the low cost and high data transmission rate, however, it only supports low mobility. WiMAX could cover a city with its high bandwidth over long-range transmission and Quality of Service (QoS), while its mobility is limited. UMTS could support high mobility due to the infrastructures provided by the operators, but with less data transmission bandwidth.

From the view of network, there are two kinds of handoff: horizontal handoff (HHO) and vertical handoff (VHO). A HHO happens between different cells controlled by different Base Stations (BS) with the same RAT. A VHO is a handoff occurring between different cells

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controlled by different BS with the different RAT. During a handoff process, the network will provide users another dedicated channel [1], and the communication will be interrupted if the switching procedure of channel is too long. Therefore, an acceptable unsuccessful handoff rate is an important factor for engaging Quality of Experience (QoE) for users.

## 2. Related Works

Actually, most existing researches have focused on the heterogeneous networks, which are integrated with WLAN and WiMAX, or integrated with WLAN and 3G networks. Ma *et al.*, [2] proposed a framework of heterogeneous network consisted of WLAN and WiMAX. In such a framework, a Vertical Handoff Management scheme (VHOM) was studied. Two algorithms predicting the bandwidth are designed to ensure the QoS for real-time traffics, which allow that MS could always connect with the suitable network. Chen, *et al.*, [3] introduced that a Vertical Handoff Translation Center Architecture (VHTC) was to improve the transmission QoS guarantees in WLAN/WiMAX heterogeneous network. The proposed architecture combined Packet Translation, QoS mapping, Bandwidth Borrowing Management and Vertical Handoff Protocol. The authors performed the simulations on throughput, delay, jitter and packet loss rate in an NS2 simulation system. The simulation results illustrated that great performance could be achieved by VHTC. In literature, a general analytical model was proposed for load sharing [4]. There were the problems of load sharing for the integrated UMTS/WLAN networks, and thus, three load sharing schemes, *i.e.*, Block Balancing, Full Sharing, and Reserved Sharing, were proposed [4]. These solutions are based on four dimensional Markov chain on considering the requirements of QoS and the load of traffic in the network. Song, *et al.*, [5] proposed a new load sharing scheme for voice and flexible data services in a cellular/WLAN integrated network, with a load sharing policy considering the service's characteristics in order to balance the load between voice service and data service. A great QoS and the multiplexing gain could be achieved in the network through the effective admission control mechanism and dynamic vertical handoff. Kim, *et al.*, [6] proposed vertical handoff algorithm based-service history information for heterogeneous network, which could reduce unnecessary handoffs and call blocking probability. The simulation results show that the proposed VHO algorithm could achieve outstanding performance. Lee, *et al.*, [7] proposed a centralized algorithm for vertical handoff in order to reduce the rate of handoff failure and balance the load in heterogeneous network. Researchers [8-9] analyzed and compared different algorithms for vertical handoff decisions, and validated the algorithms with different criteria. Wang, *et al.*, [10] introduced a vertical handoff scheme which considered both received signal to noise ratio and loopback bandwidth and it was able to achieve the better throughput. Zeki, *et al.*, [11] designed an intelligent vertical handoff algorithm on context aware. The user preferences and type of services required were taken as network selection criteria. A radio resource management policy for vertical handoff between WiMAX and UMTS networks was introduced recently [12], which focused on balancing load with a load factor relevant to the voice quality.

However, the solutions mentioned above only considered the resource requirements of vertical handoff traffics. Since the actual networks are complicated, containing vertical handoff traffics and other traffics, these studies did not investigate the effects while new traffics and vertical handoff traffics competing the network resources at the same time.

In this work, an Analytical Model for Vertical Handoff (AMVH) is proposed. We analyze and derive the effect while New Sessions (NS) and Vertical Handoff sessions (VHO) require the resources at the same time in heterogeneous network in detail. Furthermore, the performance of AMVH is compared with some existing solutions.

## 3. AMVH Model

The heterogeneous network is consisted of one single WLAN cell and one single WiMAX cell in the AMVH model. There are two kinds of services implementing in the proposed model, NS and VHO. As shown in Figure 1 a VHO is triggered while MS with an ongoing session enters or leaves the current cell, where $\lambda_{NS}$ and $\lambda_{VHO}$ refer to the arrival rates of NS and VHO, respectively.

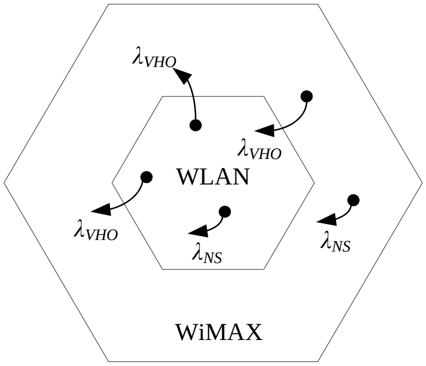

**Figure 1. Illustration of Different Services in the Network**

It is defined:

① $1/\mu$ represents the average service time for MS; $1/\alpha$ represents the resident time in the current cell for MS, indicating that MS will change its current cell after $1/\alpha$;

② $T$ means the total service time for one session, and $S$ means the total resident time in the current cell for MS. For a time variable $x$, the probability of $T$ being equal to and longer than $x$ can be written as

$$P[T \geq x] = e^{-\mu x}$$

③ The probability for MS during the total resident time in the current cell not less than $x$ can be written as

$$P[S \geq x] = e^{-\alpha x}$$

Therefore, from the view of network, the probability of duration for one session not less than $x$ is

$$P[\min(S,T) \geq x] = e^{-(\alpha+\mu)x} \qquad (1)$$

For the network, the duration of one session is denoted as

$$T_{NET} = \frac{1}{\alpha + \mu} \qquad (2)$$

The probability of MS in an ongoing session which MS leaves its current cell is defined as $\gamma$, *i.e.*, the probability of occurring VHO.

$$\gamma = P(S \leq T) = \frac{\alpha}{\alpha + \mu} \qquad (3)$$

Therefore, the probability for MS terminating the session is

$$P(T \le S) = \frac{\mu}{\alpha + \mu} = 1 - \gamma \qquad (4)$$

The number of VHO occurring in the network can be expressed as

$$N_{VHO} = \sum_{i=0}^{+\infty} i \times \gamma^{i} (1 - \gamma) \qquad (5)$$

where *i* represents any cell in the network.
Since

$$\sum_{i=0}^{+\infty} i \times \gamma^{i} = \gamma \times \frac{1}{(1-\gamma)^{2}} \qquad (6)$$

Substitute the equation (6) to the equation (5),

$$N_{VHO} = \frac{\gamma}{1 - \gamma} \qquad (7)$$

For any cell, the arrival rate of VHO can be written as

$$\lambda_{VHO} = (\lambda_{NS} + \lambda_{VHO}) \bullet \gamma = \frac{\lambda_{NS} \bullet \gamma}{1 - \gamma} \qquad (8)$$

The load per unit time in the network produced by one session can be calculated by

$$\begin{aligned} \rho &= (\lambda_{NS} + \lambda_{VHO}) \frac{1}{\mu + \alpha} = \lambda_{NS} \left(1 + \frac{\gamma}{1 - \gamma}\right) \frac{1}{\mu + \alpha} \\ &= \lambda_{NS} \left(\frac{1}{1 - \gamma}\right) \frac{1}{\mu + \alpha} = \frac{\lambda_{NS}}{\mu} \qquad (9) \end{aligned}$$

The available resource and the threshold of resource in the network are denoted as *N* and $N_{th}$, respectively.

The rules for resource assignment are defined as follow:

If $0 \le n < N_{th}$, NS and VHO will be accepted.
If $N_{th} \le n < N$, NT will be rejected and VHO will be accepted.
If $n = N$, all services will be rejected.

where *n* is the resource assigned to MS in the network.

The new arrival services, NS and VHO, will be accepted while the available resources in the network are greater than $N_{th}$. If the assigned resource reaches to $N_{th}$, only VHO will be accepted, but NS will be rejected.

The state transition of different services associated with Markov chain is shown in Figure 2.

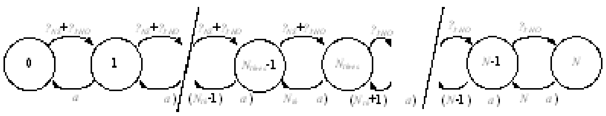

Figure 2. State Transition with Markov Chain

From Figure 2, it can be obtained

$$A = \begin{pmatrix} A_1 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & A_2 & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & A_3 \end{pmatrix} \qquad (10)$$

$$A_1 = \begin{pmatrix} -(\lambda_{NS}+\lambda_{VHO}) & \lambda_{NS}+\lambda_{VHO} & 0 \\ \mu+\alpha & -(\lambda_{NS}+\lambda_{VHO}+\mu+\alpha) & \lambda_{NS}+\lambda_{VHO} \\ 0 & 2(\mu+\alpha) & -(\lambda_{NS}+\lambda_{VHO}+2(\mu+\alpha)) \end{pmatrix} (11)$$

$$A_2 = \begin{pmatrix} -(\lambda_{NT}+\lambda_{VHO}+(N_{th}-1)(\mu+\alpha)) & \lambda_{NT}+\lambda_{VHO} & 0 \\ N_{th}(\mu+\alpha) & -(\lambda_{VHO}+N_{th}(\mu+\alpha) & \lambda_{VHO} \\ 0 & (N_{th}+1)(\mu+\alpha) & -(\lambda_{VHO}+(N_{th}+1)(\mu+\alpha)) \end{pmatrix} (12)$$

$$A_3 = \begin{pmatrix} -(\lambda_{VHO}+(N_{th}-2)(\mu+\alpha)) & \lambda_{VHO} & 0 \\ (N_{th}-1)(\mu+\alpha) & -(\lambda_{VHO}+(N_{th}-1)(\mu+\alpha) & \lambda_{VHO} \\ 0 & N_{th}(\mu+\alpha) & -N_{th}(\mu+\alpha) \end{pmatrix} \qquad (13)$$

Therefore, the blocking probability for NS and VHO can be calculated as follows

$$\begin{cases} \Pi^{(N_{th})} A = 0 \\ \sum \Pi_i^{(N_{th})} = 1 \end{cases} \qquad (14)$$

$$\forall n \in \;\; 0, N_{th} \;\; ,$$

$$\Pi_n = \frac{1}{n!}\left(\frac{\lambda_{NS}+\lambda_{VHO}}{\mu+\alpha}\right)^n \Pi_0 = \frac{1}{n!}(\rho_{NS}+\rho_{VHO})^n \Pi_0 \qquad (15)$$

$$\forall n \in \;\; N_{th}+1, N \;\; ,$$

$$\Pi_n = \frac{1}{n!}\left(\frac{(\lambda_{NS}+\lambda_{VHO})^{N_{th}} \times \lambda_{VHO}^{(n-N_{th})}}{(\mu+\alpha)^n}\right)\Pi_0$$

$$= \frac{1}{n!}\left((\rho_{NS}+\rho_{VHO})^{N_{th}} \times \rho_{VHO}^{n-N_{th}}\right)\Pi_0 \qquad (16)$$

The probability **Π** can be normalized by Equation (14)

$$\Pi_0 = \frac{1}{\sum_{n=0}^{N_{th}} \frac{1}{n!}(\rho_{NS}+\rho_{VHO})^n + \sum_{n=N_{th}+1}^{N} \frac{1}{n!}\left((\rho_{NS}+\rho_{VHO})^{N_{th}} \times \rho_{VHO}^{n-N_{th}}\right)} \qquad (17)$$

Based on Equation (17), the blocking probability of NS and VHO can be obtained

$$\begin{cases} P_{VHO\_BLO} = \Pi_N \\ P_{NS\_BLO} = \sum_{n=N_{th}}^{N} \Pi_n \end{cases} \qquad (18)$$

## 4. Performance Evaluation

The simulations are achieved in the framework as shown in Fig.1. There are 50 MSs that are distributed according to the uniform distribution in WLAN and WiMAX. The MS in WLAN are denoted as $MS_{WLAN}$, and the MS in WiMAX are denoted as $MS_{WiMAX}$. At the beginning, all MSs can only receive the System Information (SI) broadcasted in the networks. The cell where MS is locating is considered as its current cell.

Simulations are performed as follows:

① At the moment $T$, MSs start to move, and generate NS successively. The movement trajectory of MS is according to Random Waypoint model (RWP), and the pause time is set to 30s. At the end of $1/\alpha$, MSs with an ongoing session are considered leaving their current cell, and a VHO will be triggered.

② At the moment $T$, MSs are randomly added in WLAN and WiMAX after the MSs begin to move. Five MSs are added each time until there are 100 MSs in the network. Additional MSs Follow the identical rule to that of the first 50 MSs.

③ The threshold of resource $N_{th}$ is set to 70% of $N$.

The main simulation parameters are illustrated in Table I.

**Table 1. Main Simulation Parameters**

| | |
|---|---|
| $\lambda_{NT}$ (1/s) | 30 |
| $1/\mu$ (s) | Uniform [30, 90] |
| $1/\alpha$ (s) | Uniform [30, 180] |
| Data rate in WLAN (Mbps) | 11 |
| Size of packet in WLAN (B) | 1024 |
| PHY specification in WiMAX | OFDMA |
| FFT size in WiMAX | 2048 |
| Frame duration in WiMAX (ms) | 10 |
| Mobility model | Random WayPoint |
| Pause time in RWP $T_{pause}$ (s) | 30 |
| Initial number of MS $N_{ini}$ | 50 |
| Total of MS $N_{tot}$ | 100 |
| Velocity of MS $V_{ms}$ (m/s) | Uniform [1, 5] |
| Channel bandwidth in WiMAX (MHz) | 20 |
| Threshold of network resource $N_{th}$ | $0.7N$ |
| Simulation time (s) | 6000 |

The simulation is performed with Matlab 7.0.4 R14. The performance of the proposed model is compared with the VHOM [2] and the SINR [13]. The blocking probability of NS with different number of MS is investigated. The simulation results are shown as Figure 3.

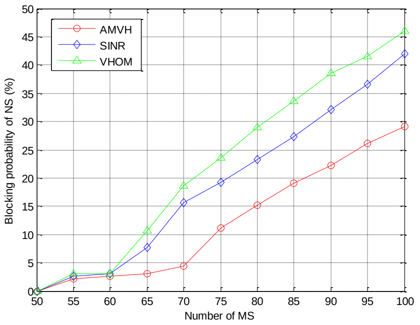

Figure 3. Blocking Probability of NS vs. Number of MS

The relationship between the blocking probability and the number of MSa has been shown in Figure 3. As can be observed, the blocking probability of NS increases more rapidly after the number of MS reaches to 60 for VHOM and SINR. However, the blocking probability of NS with AMVH increases more rapidly after the number of MS reaches to 70, and it is improved approximately 40% and 33%, respectively, compared to VHOM and SINR.

The results of a comparison of the blocking probability of VHO with different number of MS are illustrated in Figure 4.

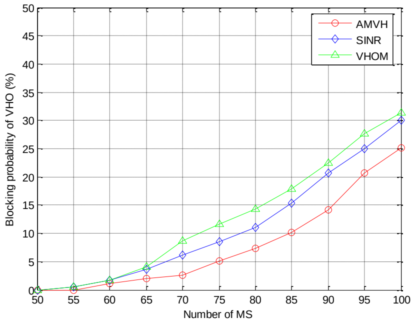

Figure 4. Blocking Probability of VHO vs. Number of MS

As can be seen in Figure 4, the performance of AMVH is the best among the three. The blocking probability of VHO with AMVH increases more rapidly after the number of MS reaches to 70, the others increase more rapid after the number of MS reaches to 65. The performance is improved approximately 17% and 19%, respectively, compared to SINR and VHOM.

This is because VHOM and SINR only take into account the VHO service, while they ignore the resource competitions between NS and VHO in the heterogeneous network. However, the proposed model takes into account the competition by design.

We compare the resource utilization $\eta$ for VHO, SINR and AMVH,

$$\eta = \frac{n_{WLAN} + n_{WiMAX}}{N_{WLAN} + N_{WiMAX}} \qquad (19)$$

where $n_{WLAN}$ and $n_{WiMAX}$ are denoted as the assigned resources in WLAN and WiMAX, respectively, and $N_{WLAN}$ and $N_{WiMAX}$ as the available resources in WLAN and WiMAX, respectively.

The simulation result is shown in Figure 5.

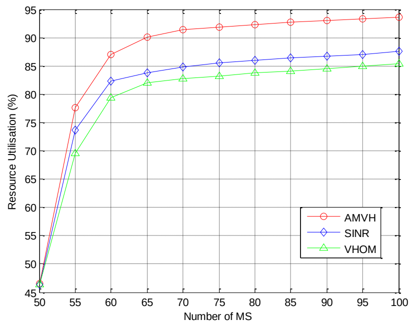

**Figure 5. Comparison of the Resource Utilization**

As shown in Figure 5, compared to SINR and VHOM, the resource utilization with AMVH can be improved approximately 8% and 11%, respectively.

## 5. Conclusion

Since heterogeneous networks have been considered as the candidature of next generation wireless communication, the vertical handoff algorithms have already been considered as one important issue to overcome the problems caused by different RATs. For this purpose, an analytical model for vertical handoff is proposed in this paper. The model takes into account the resource competitions between NS and VHO, and focuses on providing users the better QoE in terms of blocking probability. The resource utilization also has been considered. By the simulation experiments, the feasibility and effectiveness of this proposed AMVH have been examined in heterogeneous network consisted of WiMAX and WLAN. Simulation results illustrate that an outstanding performance can be achieved with the proposed model. Finally, since nothing needs to be modified in the model, it can be used to analyze the performance of any heterogeneous networks by simply changing the parameters.

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