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Investigation of an Analytical Model Based on Resource Factor for Vertical Handoffs

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Abstract

In order to optimize the utilization of limited resources, the operators have already addressed to deploy their services in heterogeneous networks integrated different Radio Access Technologies (RAT), e.g. WLAN/WiMAX/WCDMA. Vertical handoffs (VHO) as a key problem should be overcome while mobile users are moving in heterogeneous networks. In existing works, resource assignment depends on the packet's size, which is usually defined a fix length. This paper proposes an analytical model for evaluating the VHO performance. In the model, resources are proportionally assigned to real-time services (RS) and to non real-time services (NRS) by a resource factor m, which can be defined as any value. The performances on blocking probability and on throughput are derived and evaluated with different values of m under the restriction of resources. For enhancing the effect of VHO, the Random Waypoint Model on the border (RWPB) is implemented in the simulation, which enforces the mobile users residing near the border of networks. Simulation results demonstrate that with a greater value of m, the blocking probability slightly increases while the total throughput is significantly improved.

Keywords: *resource factor; vertical handoff; real-time service; non real-time service; blocking probability; throughput; random waypoint model on the border*

1. Introduction

Investigating the performance of heterogeneous networks is being attracted by more and more researchers since various Radio Access Technologies (RAT), such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and 3G network can be integrated together to provide seamless coverage to mobile users. Vertical handoffs (VHO) may be occurred while mobile users move in heterogeneous networks. During a VHO process, a mobile user releases the resource assigned by the current network and requires the resource from the target network. It is possible that several types of service competing for the resources in the networks. Effective VHO algorithms can possibly maximize the resource utilization to provide the best quality of service (QoS) for different services, such as Voice over Internet Protocol (VoIP) and File Transfer Protocol (FTP) etc. Therefore, how to ensure the best QoS in heterogeneous networks has already become a great challenge for operators [1].

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2. Related Works

VHO allows mobile users to switch the wireless link from the current network to the target network in order to maintain the continuity for ongoing sessions [2]. Since each network has different characteristics in heterogeneous networks, *e.g.* bandwidth, access technology, inefficient VHO algorithms will degrade the QoS while VHO is occurring. Therefore, 3GPP has established a special workgroup that addresses the mobility enhancements in heterogeneous networks [3]. Recently, VHO based on different criteria was reported to be successfully achieved [4-6]. As a result, load balancing, Received Signal Strength Indicator (RSSI), and traffic priority are usually considered as VHO criteria. The solutions can be classified as balancing the load for each network in heterogeneous networks [4], RSSI policy in complicate networks [5], and assigning higher priority to VHO traffics [6], *etc.* In addition, fuzzy approach for VHO decision [7] and utility functions [8] are sometimes taken into account to solve VHO problems. However, the solutions mentioned above have limitations. Load Factor (LF) was taken as the triggering condition for VHO in [4], a negative LF indicated that there was lack of resource in the current network and thus, VHO should be solicited to avoid interrupting the ongoing session. Unfortunately, the cases of insufficient resources were not considered. An analytical framework for WLAN-cellular voice handover was proposed in [5], but the authors only analyzed the cases that there were only a single access point, a single mobile terminal, and Real-time Service (RS). They did not consider the resource competition between RS and non real-time service (NRS) in heterogeneous networks. In order to decrease the failure rate for new calls and Horizontal Handoff (HHO) while there is not enough resource in the networks, Zabanoot and Min proposed to directly switch new calls and HHO to WLAN in [6]. However, VHO from UMTS to WLAN was more complicated than HHO in UMTS. As a result, the complexity of algorithm for VHO appeared to be higher than that one for HHO. Singhrova and Prakash introduced the Fuzzy Vertical Handoff Decision Algorithm (FVHDA) [7], in which the performance of proposed algorithm was simulated. The total number of VHO during the same period, classical VHDA and existing fuzzy VHDA were compared and the results were 181, 307 and 211, respectively. Afterward, the performance of FVHDA on the End-point service accessibility (ESA) and the throughput were analyzed and calculated based on 181. However, the authors did not indicate how many successful VHO among 181 were successfully performed. Therefore, all analyses and derivations based on 181 probably were not correct. Yin et al. [8] examined the performance for heterogeneous networks by using the utility functions on the case that the user's number of each service was equal. However, it was not common that the user's number of each service was equal in the realistic networks. Furthermore, they did not investigate the Packet Loss Rate (PLR) and the Handoff Blocking Rate (HBR) with the proposed policy. Some proposals [9] investigated the case that vertical handoffs of multi-mode mobile terminals released the capacity needed for incoming calls from single-mode mobile terminals. Furuskar and Agusti demonstrated the importance of considering the different QoS requirements and RAT capabilities [10]. Besides, the existing solutions only considered the packet's size with fix length in the network while validating the VHO algorithms. They did not discuss the performance with variable size of packet. The policy of resource assignment was not flexible, which was not based on the realistic networks.

Comparing with existing researches, our proposed scheme is highlighted as follows:

①Resource factor *m* is applied to assign the resource to RS and NRS in proportion, which is more flexible than the existing policies of assignment resources.

②Since there is the problem of velocity distribution in Random Waypoint Model (RWP), Random Waypoint Model on the border (RWPB) implemented in [11-13] is applied as the mobility model. In RWPB, all Mobile Terminals (MT) are distributed near the border of cells in order to enhance the effect of VHO.

3. System Model and Performance Analysis

The proposed model is consisted of WLAN and 3G network as shown in Figure 1.

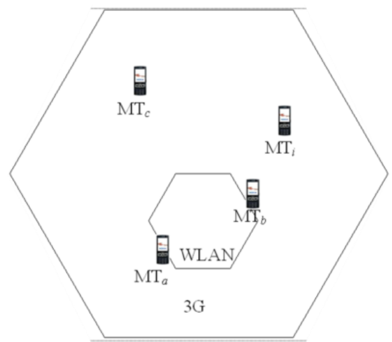

Figure 1. Illustration of Different Services in the Network

In Figure 1, MT$_a$ is with an ongoing RS session and MT$_b$ with an ongoing NRS session. They are performing VHO. VHO is distinguished as 3G→WLAN and WLAN→3G according to MT's trajectory.

3.1. Analysis of Blocking Probability

The continuous time Markov chain is applied to analyze the state transition of RS and NRS, as illustrated in Figure 2. The new arrival rates of RS and NRS according to Poisson distribution are denoted as λ_1 and λ_2, respectively. The service's duration according to negative exponential distribution are denoted as μ_1 and μ_2, respectively.

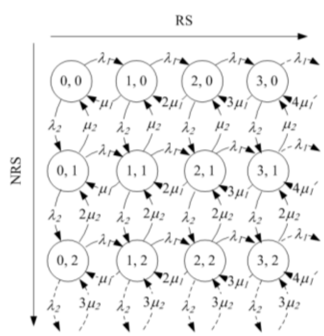

Figure 2. State Transition with Markov Chain

Denote that N=(n_1, n_2) represents the state of system at the moment T, where n_1 is denoted as the resource occupied by RS at T, and n_2 as the resource occupied by NRS at T.

For a reversible Markov process Q, stationary probability can be expressed as $\prod_i \in E$. While $E' \subset E$, the stationary probability of its reversible process Q' is equal to $\prod_i^{'} \in E'$. Thus, it can be described as:

$$\Pi_i' = \frac{\Pi_i}{\sum_{j \in E'} \Pi_j} \qquad (1)$$

For a queue with M/M/S/S, it can be obtained,

$$\forall n \in [0, S], \Pi_n = \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n \Pi_0$$

$$\Pi_n' = \frac{\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n \Pi_0}{\sum_{j \in [0, S]} \frac{1}{j!}\left(\frac{\lambda}{\mu}\right)^j \Pi_0} \qquad (2)$$

Let $\rho = \left(\frac{\lambda}{\mu}\right)\Pi_0$. After substituting ρ to the equation (2), it can be obtained,

$$\Pi_n' = \frac{\frac{\rho^n}{n!}}{\sum_{j \in [0, S]} \frac{\rho^j}{j!}} \qquad (3)$$

where S represents the total available resource in system, S_1 and S_2 represent the maximal resource occupied by RS and NRS at the moment T, respectively. Furthermore, S is respect to $S = \{(n_1, n_2), n_1 \le S_1, n_2 \le S_2\}$, where n_1 and n_2 are the actual resource assigned to RS and NRS, respectively.

Then, the stationary probability of RS and NRS can be described as

$$\prod(n_1) = \exp(-\rho_1)\frac{\rho_1^{n_1}}{n_1!} \qquad (4)$$

$$\prod(n_2) = \exp(-\rho_2)\frac{\rho_2^{n_2}}{n_2!} \qquad (5)$$

For system S=(S_1, S_2) where RS and NRS are coexisting, the stationary probability of S can be expressed as

$$\prod(n_1, n_2) = \frac{\rho_1^{n_1}}{n_1!}\frac{\rho_2^{n_2}}{n_2!}\exp(-(\rho_1 + \rho_2)) \qquad (6)$$

Substitute the equation (6) to the equation (2) and it can be obtained,

$$\Pi_s(n_1, n_2) = \frac{\frac{\rho_1^{n_1}}{n_1!}\frac{\rho_2^{n_2}}{n_2!}\exp(-(\rho_1 + \rho_2))}{\sum_{(k_1,k_2) \in S} \frac{\rho_1^{k_1}}{k_1!}\frac{\rho_2^{k_2}}{k_2!}\exp(-(\rho_1 + \rho_2))} = \frac{\frac{\rho_1^{n_1}}{n_1!}\frac{\rho_2^{n_2}}{n_2!}}{\sum_{(k_1,k_2) \in S} \frac{\rho_1^{k_1}}{k_1!}\frac{\rho_2^{k_2}}{k_2!}} \qquad (7)$$

While there are k types of service in the system, the equation (7) can be written as

$$\Pi_s(n_1,\cdots,n_k)=\frac{\prod_{i=1}^{k}\frac{\rho_i^{n_i}}{n_i!}}{\sum_{n\in S}\prod_{i=1}^{k}\frac{\rho_i^{n_i}}{n_i!}} \quad (8)$$

Suppose that the number of required resource to a single RS session is m times of that one to NRS. The number of resource assigned to a single NRS session is denoted as 1, and then the number of resource assigned to a single RS session is denoted as m. Therefore, the total available resource S in system is according to $m\cdot n_1+n_2\leq S$.

Thence, the probability of RS at the moment T can be expressed as

$$P_{B\_RS}=\sum_{\begin{cases}(mn_1+n_2)\leq S\\ m(n_1+1)+n_2>S\end{cases}}\Pi(n_1,n_2) \quad (9)$$

Similarly, the probability of NRS at the moment T can be expressed as

$$P_{B\_NRS}=\sum_{\begin{cases}(mn_1+n_2)\leq S\\ mn_1+(n_2+1)>S\end{cases}}\Pi(n_1,n_2) \quad (10)$$

Hence, the total probability in system at the moment T can be written as

$$\begin{aligned}P_B&=P_{B\_RS}+P_{B\_NRS}\\&=\sum_{\begin{cases}(mn_1+n_2)\leq S\\ m(n_1+1)+n_2>S\end{cases}}\Pi(n_1,n_2)+\sum_{\begin{cases}(mn_1+n_2)\leq S\\ mn_1+(n_2+1)>S\end{cases}}\Pi(n_1,n_2)\end{aligned} \quad (11)$$

3.2. Analysis of Throughput

The throughput during a given period of a MT can be calculated through the method introduced in [14]. Denote the throughputs are achieved by MT in WLAN and in 3G network denoted as Thr_{WLAN} and Thr_{3G}, respectively. The residing times of MT in WLAN and in 3G network are denoted as T_{WLAN} and T_{3G}, respectively. The data transmission rates in WLAN and in 3G network are denoted as R_{WLAN} and R_{3G}, respectively. The number of occurrence of VHO is denoted as N. The time spent for achieving one VHO from 3G network to WLAN and from WLAN to 3G can be denoted as $T_{VHO\text{-}WLAN}$ and $T_{VHO\text{-}3G}$, respectively.

VHO will be triggered while MT enters into WLAN or leaves from WLAN during an ongoing session. The wireless link will be broken during the VHO process. Therefore, the number of occurrence of VHO, N signifies the number of interruption of wireless link. Since there is no data transmission during the handoff process due to the interruption of wireless link, the values of $T_{VHO\text{-}WLAN}$ and $T_{VHO\text{-}3G}$ are identical to the period in which there is no data transmission during two successive VHO processes.

Suppose that all MTs are located in WLAN at the moment t_1. The moment when the first VHO is occurring is denoted as t_2, and the second one is denoted as t_3. Thus, the first residing period in heterogeneous networks for MT can be expressed as $T_{WLAN1}=(t_2-t_1)$. The second one can be expressed as $T_{3G1}=(t_3-t_2-T_{VHO\text{-}WLAN1})$, the third one can be expressed as $T_{WLAN2}=(t_4-t_3-T_{VHO\text{-}3G1})$and, so on, T_{WLAN} and T_{3G} can be given by

$$T_{WLAN}=\sum_{n=1}^{N/2}(t_{2n}-t_{2n-1})-\sum T_{VHO-3G} \quad (12)$$

$$T_{3G}=\sum_{n=1}^{N/2}(t_{2n+1}-t_{2n})-\sum T_{VHO-WLAN} \quad (13)$$

The diagram of VHO time sequence is shown as Figure 3

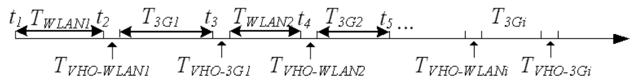

Figure 3. VHO Time Sequence in Proposed Scheme

Hence, the throughput achieved in WLAN can be expressed as,

$$Thr_{WLAN} = R_{WLAN} \times T_{WLAN} = R_{WLAN} \times \left[\sum_{n=1}^{N/2} (t_{2n} - t_{2n-1}) - \sum T_{VHO-3G} \right] \quad (14)$$

Similarly, the throughput achieved in 3G can be express as,

$$Thr_{3G} = R_{3G} \times T_{3G} = R_{3G} \times \left[\sum_{n=1}^{N/2} (t_{2n+1} - t_{2n}) - \sum T_{VHO-WLAN} \right] \quad (15)$$

Suppose the interrupted time of wireless link is identical in WLAN and in 3G, the total throughput Thr_{tot} can be obtained,

$$\begin{aligned} Thr_{tot} &= Thr_{WLAN} + Thr_{3G} \\ &= R_{WLAN} \times \left[\sum_{n=1}^{N/2} (t_{2n} - t_{2n-1}) - \sum T_{VHO-3G} \right] + R_{3G} \times \left[\sum_{n-1}^{N/2} (t_{2n+1} - t_{2n}) - \sum T_{VHO-WLAN} \right] \\ &= R_{WLAN} \times \left[\sum_{n=1}^{N/2} (t_{2n} - t_{2n-1}) - T_{VHO}/2 \right] + R_{3G} \times \left[\sum_{n-1}^{N/2} (t_{2n+1} - t_{2n}) - T_{VHO}/2 \right] \quad (16) \end{aligned}$$

where, T_{VHO} represents the total VHO latency, it can be estimated by cumulating the total interrupted time of wireless link.

4. Performance Evaluation and Analysis

To verify the effectiveness of the proposed scheme, the simulation framework as illustrated in Fig.1 is established. The simulation is performed by Matlab 7.0.4 R14.

The simulation steps are illustrated as follow:

① The total available resource in both WLAN and 3G network is denoted as S. As discussed in section 3.1, the proportion of assigned resource between RS and NRS can be expressed as $S_{RS}=m \times S_{NRS}$, where m is the resource factor.

② At the beginning, all MTs are distributed in WLAN, according to the RWPB model.

③ At the moment t_1, all MTs start to move and originate sessions, simultaneously. The probability of originating session rate for RS and NRS are expressed as P_{RS}, P_{NRS}, respectively. And, $P_{RS}+P_{NRS}=1$.

④ Once the sessions are established, the duration of session is denoted as μ.

⑤ During simulation, VHO is triggered while MT crosses the border of network. After VHO is terminated, MT will release the resource of the previous network, and occupy the resource of new network.

The main parameters of simulation are listed as shown in Table 1.

Table 1. Main Parameters of Simulation

λ (1/s)	180
Session duration μ (s)	Uniform [30, 90]
P_{RS}	0.5, 0.7
Radius of 3G network C_{3G} (m)	1000
Radius of WLAN C_{WLAN} (m)	100
Total MT number N_{tot}	100
Packet size of NRS S_{NRS} (B)	1024

S_{RS} resource factor m	m=2, 3, 5
Velocity of MT V_{ms} (m/s)	Uniform [1, 10]
Data transmission rate in WLAN R_{WLAN} (Mbps)	11
Data transmission rate in 3G network R_{3G} (Mbps)	2
Simulation duration (s)	600

4.1. Evaluation of Blocking Probability

Firstly, the performance on total blocking probability is evaluated with different value of m and P_{RS}. The value of m is set to 2, 3, and 5, respectively. The simulation results are shown as Figure 4.

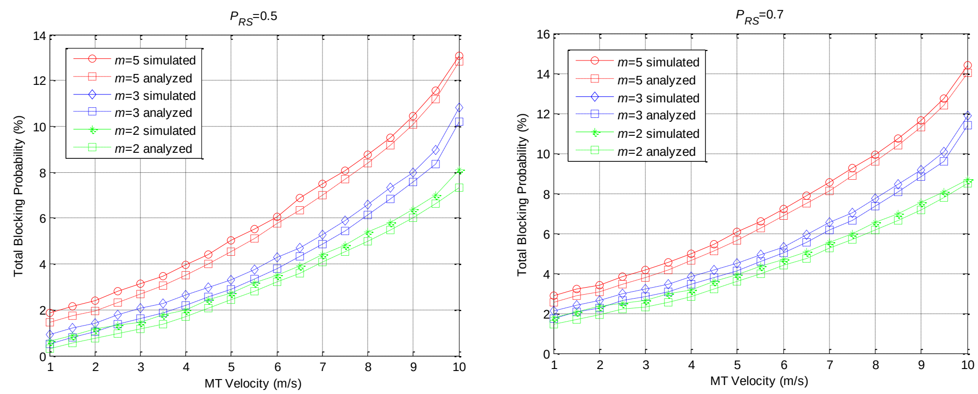

Figure 4. Total Blocking Probability

Figure 4 demonstrates that the analytical values obtained by using the proposed model are similar to the simulation results, and therefore, validate the utility of the proposed scheme in terms of total blocking probability.

As shown in Figure 4, some features can be summarized as follows:

① When P_{RS} = 0.5, the total blocking probability increased while the MT moved more rapidly. When P_{RS} = 0.7, a similar correlation between total blocking probability and MT velocity was obtained.

② With same P_{RS} and MT's velocity, the total blocking probability became greater while the resource factor m increased from m = 2 to m = 5. The highest one was approximately 13% while the value of m is equal to 5.

③ With same m and MT's velocity, the total blocking probability became higher while P_{RS} increased. For example, compared to the case that P_{RS} was set to 0.5, the highest one was 14% while P_{RS} was set to 0.7. The total blocking probability was degraded approximately 11.3%, 10.2%, 10.2% while the value of m was equal to 2, 3 and 5, respectively.

That's because:

① MT moves more rapidly, the probability of happening VHO becomes higher since MT has more chances to cross the border of networks.

② In the networks, the resource occupied by one single connection is inversely proportional to the number of available connections. With the same P_{RS}, there are less available connections due to a great value of m. Hence, there are more access collisions happening in the networks.

③ With same m and MT's velocity, a greater P_{RS} means that there are more resource assigned to the RS, which leads more access collisions for NRS due to lack of resource.

4.2. Evaluation of Throughput

Throughput is defined as the total transmitted data by all MTs in this article. The performance on throughput of the proposed scheme was evaluated with different value of *m* and P_{RS} in this section. The simulation results are illustrated as Fig. 5.

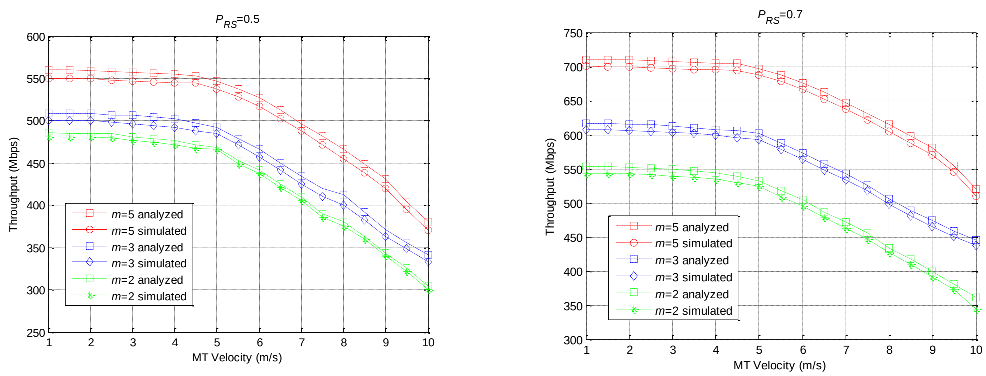

Figure 5. Throughput Illustration

As observed from Figure 5, the analytical values obtained by using the proposed model are very close to the simulation results, which validate the utility of the proposed scheme in terms of throughput.

The result analyses are listed as follow:

① With same P_{RS}, the throughput decreased while MT moved more rapidly.

② With same P_{RS} and MT's velocity, the throughput increased while the resource factor *m* increased. In the case that P_{RS} was set to 0.5, the best throughput is obtained while *m* is equal to 5, which was improved 14.5% and 10% compared to 2 and 3, respectively. In the case that P_{RS} was set to 0.7, the best throughput is obtained while *m* is equal to 5, which was improved 27.3% and 16.7% compared to 2 and 3, respectively.

③ With same *m* and MT's velocity, the obtained throughput increased while P_{RS} increased. Compared to the case that P_{RS} is set to 0.5, the obtained throughput is improved 13.7%, 25.3% and 31.5% while the value of *m* is equal to 2, 3, 5, respectively.

That is because:

① The probability of happening VHO became higher since MT moved more rapidly, thus the interruption of wireless link was more frequent. The throughput degraded since the available time spent to transmit data was shorter.

② As discussed in the section 4.1, the resource occupied by one single connection is inversely proportional to the number of available connections. With same MT's velocity and same P_{RS}, there were less available connections due to a great value of *m*. Less available connections led to more access collisions, but the probability of occurring VHO reduced, the available time spent to transmit data was more longer, thus a higher throughput could be obtained.

③ With same *m* and MT's velocity, the resource occupied by RS was greater due to a greater P_{RS}. Since one single RS takes more resource than one single NRS, the obtained throughput became greater.

5. Conclusion

The purpose of the next generation of wireless networks is to provide mobile users with the best coverage anywhere and anytime. For minimizing the investment, operators are trending to develop heterogeneous networks with various radio access technologies. The performance of heterogeneous networks depends on the effectiveness of VHO algorithm applied. An analytical model based on resource factor for VHO is proposed in this paper, which addresses to estimate the performance for VHO while there are different services in heterogeneous networks. Compared to the existing researches, a variable resource factor *m* is implemented in the model which allows proportionally assigning the network resource to different services. Furthermore, the performance of VHO is studied by applying different values of *m*. Simulation results demonstrate that while increasing the value of *m*, the total blocking probability slightly increases, but the benefice obtained on the throughput is more important in comparison with the degradation on total blocking probability.

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