Performance Improvement of Vertical Handoff Algorithms for QoS Support over Heterogeneous Wireless Networks

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Abstract

During the vertical handoff procedure, handoff decision is the most important step that affects the normal working of communication. An incorrect handoff decision or selection of a non-optimal network can result in undesirable effects such as higher costs, poor service experience, degrade the quality of service and even break off current communication. The objective of this paper is to determine the conditions under which vertical handoff should be performed in heterogeneous wireless networks. In this paper, we present a comprehensive analysis of different vertical handoff decision algorithms. To evaluate tradeoffs between their performance and efficiency, we propose two improved vertical handoff decision algorithm based on Markov Decision Process which are referred to as MDP_SAW and MDP_TOPSIS. The proposed mechanism assists the terminal in selecting the top candidate network and offer better available bandwidth so that user satisfaction is effectively maximized. In addition, our proposed method avoids unbeneﬁcial handoffs in the wireless overlay networks.

Keywords: Heterogeneous Wireless Networks; Markov Decision Processes; Vertical Handoff.

1 Introduction

Nowadays many different types of networks communicate among themselves to form heterogeneous networks. Due to different network access technologies, topologies, and implementations, one network might not be able to provide continuous coverage and required QoS parameters to a mobile user during an entire session. That is why handing over between different wireless networks appears as one of the fundamental solutions in today’s heterogeneous wireless systems. Traditionally in a homogeneous network, handoff decision strategy is relatively simple based on received signal strength and network coverage. In heterogeneous networks, the problem is far complicated since handoff decision depends on various network quality-of-service (QoS) parameters (McNair and Zhu 2004). These new kind of handoff processes, used to rank and select among networks using different access technologies, are categorically termed as vertical handoff (Stemm and Katz 1998).

Several interworking mechanisms have been proposed in recent literature to combine WLANs and cellular data networks into integrated wireless data environments. As mentioned by Zhang, the vertical handoff decision is formulated as a fuzzy MADM (Multiple Attribute Decision Making) problem. Two classical MADM methods are proposed: SAW (Simple Additive Weighting) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Zhang 2004). Tawil, Pujolle, and Salazar have introduced a novel Distributed Vertical Handoff Decision scheme (Tawil, Pujolle, and Salazar 2008). It places the calculation of the network quality at the candidate networks side instead of the mobile terminal side. Xia, Ling-ge, Chen, and Hong-wei mainly deal with a novel vertical handoff decision algorithm based on fuzzy logic with the aid of grey theory and dynamic weights adaptation (Xia, Ling-ge, Chen, and Hong-wei 2008). As mentioned by Stevens-Navarro, Lin, and Wong, the algorithm is based on the Markov Decision Process formulation with the objective of maximizing the expected total reward of a connection (Stevens-Navarro, Lin, and Wong 2008). Sun, Stevens-Navarro, and Wong also have proposed a vertical handoff decision algorithm for 4G wireless networks. The problem is formulated as a Constrained MDP (Sun, Stevens-Navarro, and Wong, 2008). As mentioned by Song and Jamalipour, the network selected is based on the Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) (Song and Jamalipour 2005). The AHP and GRA are also used for network selection in another work, where a mobile controlled three-step vertical handoff prediction algorithm is proposed (Kibria, Jamalipour, and Mirchandani 2005). Yang, Gondal, and Qi have proposed a Multi-dimensional Adaptive SINR based Vertical Handoff algorithm, which uses the combined effects of SINR, user required bandwidth, user traffic cost and utilization from participating access networks to make handoff decisions for multi-attribute QoS consideration (Yang, Gondal, and Qi 2008). Ormond, Murphy, and Muntean have proposed a utility-based strategy for network selection (Ormond, Murphy, and Muntean 2006). Liu, Li, Guo, and Dutkiewicz have discussed a hysteresis based and a dwelling-timer based algorithm (Liu, Li, Guo, and Dutkiewicz 2008). Shen and Zeng have proposed a cost-function-based network selection strategy in an integrated wireless and mobile network (Shen and Zeng 2008).

Although there have been various vertical handoff algorithms proposed in the literature, our goal is to introduce an efficient vertical handoff decision algorithm...
by considering appropriate weights of each of the QoS parameters of candidate networks so that user satisfaction is effectively maximized. In order to assure required QoS for various applications and meanwhile avoid frequent handoffs in the heterogeneous systems, we integrate the analytic hierarchy process (AHP) (Alexander and Saaty 1989) and the Markov decision process (MDP) (Puterman 1994) on the network selection algorithms based on SAW (Simple Additive Weighting), and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to decide the best network for mobile users. We refer to these algorithms as MDP_SAW and MDP_TOPSIS. We have used both analytical and simulation tools ns-2.29 (The Network Simulator ns-2) to evaluate and compare expected total QoS offerings and the expected number of vertical handoff in the mean duration of a service under different states, discount factor and network switching costs. Numerical results show good performance improvement of our proposed scheme over SAW, TOPSIS, and MDP based algorithms.

The remainder of this paper is structured as follows. Section 2 provides the proposed model of vertical handoff decision algorithm. Section 3 shows simulation setup. The performance evaluation between different vertical handoff algorithms are presented in section 4. This paper is concluded in section 5.

2 Model Formulation

Assume that a heterogeneous wireless network comprises a single 3G network and a WLAN. We consider two QoS parameters, such as available bandwidth and delay for vertical handoff decision. Traditional SAW and TOPSIS use only the link reward function for network selection. Chosen network by SAW (Zhang 2004) and TOPSIS (Zhang 2004) for vertical handoff is the one which has the largest link reward function. In this paper we integrate the Analytic Hierarchy Process (AHP) (Alexander and Saaty 1989) and the Markov Decision Process (MDP) (Puterman 1994) on the traditional SAW, and TOPSIS to decide the best network for mobile users. We refer to these algorithms as MDP_SAW and MDP_TOPSIS.

In MDP_SAW and MDP_TOPSIS, the optimal network is selected by using Value Iteration Algorithm (VIA) (Puterman 1994).

Value Iteration Algorithm

1) Set $U^0(s) = 0$ for each state $s$. Specify $\varepsilon > 0$, and set $k = 0$.
2) For each state $s$, compute $U^{k+1}(s)$ by $U^{k+1}(s) = \max_{a \in A} [R(s,a) + \sum_{s' \in S} \lambda Pr[s'|s,a]U^k(s')]$ \hspace{1cm} (1)
3) If $\|U^{k+1} - U^k\| < \varepsilon (1 - \lambda)/2\lambda$, go to step 4. Otherwise, increase $k$ by 1 and return to step 2.
4) For each $s \in S$, compute the stationary optimal policy $\pi(s)$.

$$\pi(s) = \arg \max_{a \in A} \left[ R(s,a) + \sum_{s' \in S} \lambda Pr[s'|s,a]U^{k+1}(s') \right]$$

and stop.

Chosen network by MDP_SAW and MDP_TOPSIS for vertical handoff is the one which has the optimal policy. The definitions of notations used in VIA followed by (Stevens-Navarro, Lin, and Wong 2008) are summarized below.

System states $S$ are represented as a multi-dimensional vector. The state space $S$ is defined as:

$$S = N \times B_1 \times D_1 \times B_2 \times D_2 \times \cdots \times B_N \times D_N$$

where $B$ and $D$ denotes the available bandwidth and delay. To reduce the number elements in the state space, we have considered large unit values so that each parameter space is divided into 15 discrete levels.

$A = \{a_1, a_2, \ldots, a_n\}$ represents the all possible action set where $N$ denotes the total number of collocated networks in the coverage area of interest. $U(s)$ stands for expected total reward. The reward function $R(s,a)$ of MDP_SAW and MDP_TOPSIS can be augmented to consider the effect of switching cost as

$$R(s,a) = f(s,a) - K(s,a) \hspace{1cm} (2)$$

where $K(s,a)$ is the signalling cost function,

$$K(s,a) = \begin{cases} K_i, & i \neq a \\ 0, & i = a \end{cases} \hspace{1cm} (3)$$

and, link reward function $f(s,a)$ is equal to $f_{SAW}(s,a)$ and $f_{TOPSIS}(s,a)$ given by (4) and (5), respectively for MDP_SAW and MDP_TOPSIS using current state $s$ and the chosen action $a$. 

$$f_{SAW}(s,a) = \omega_b f_{b,SAW}(s,a) + \omega_d f_{d,SAW}(s,a) \hspace{1cm} (4)$$

$$f_{TOPSIS}(s,a) = I^{-}(s,a)/I^{-}(s,a) + I^{+}(s,a) \hspace{1cm} (5)$$

where $\omega_b$ and $\omega_d$ are the weight of bandwidth and delay, respectively. In (4) $f_{b,SAW}(s,a)$ and $f_{d,SAW}(s,a)$ are the bandwidth and delay reward function for MDP_SAW and are defined as follows:

$$f_{b,SAW}(s,a) = \frac{b_a}{b_{\text{max}}} \hspace{1cm} (6)$$

$$f_{d,SAW}(s,a) = \frac{d_a}{d_{\text{min}}} \hspace{1cm} (7)$$

where $b_a$ and $d_a$ are the bandwidth and delay, respectively of the network selected by the action $a$, and $b_{\text{max}}$ and $d_{\text{min}}$ are the maximum bandwidth and the minimum delay, respectively, among all the networks.

In (5) $I^{+}(s,a)$ and $I^{-}(s,a)$ are close to ideal solution and far from ideal solution, respectively and are calculated using the formula given below.

$$I^{+}(s,a) = \sqrt{(f_b,\text{TOPSIS} - f_{b,\text{TOPSIS}}_{\text{max}})^2 + (f_d,\text{TOPSIS} - f_{d,\text{TOPSIS}}_{\text{min}})^2}$$
Cellular Network

WLAN

Choosing a network for data application

Bandwidth

Delay

We also integrate Analytic Hierarchy Process (AHP) (Alexander and Saaty 1989) in the proposed scheme to derive the weights of each QoS parameters based on user’s preference. The AHP is based on the structuring a problem in a hierarchical form. The hierarchy is structured on different levels. The overall goal is the first level of the hierarchy. The decision factors are presented in the intermediate level. The solution alternatives are located at the lowest level. For instance, a mobile unit is trying to make a selection among two networks cellular network and WLAN. The preferences are bandwidth and delay. The hierarchy on "choosing a network" is established as shown in Fig. 1. In second step the objectives are compared with each other in order to determine their relative importance by using fundamental 1 to 9 scales. The numbers from 1 to 9 are used to respectively present equally, weakly moderately, moderately, moderately plus, strongly, strongly plus, very strongly, very strongly, and extremely important to the objective. In the last step, the overall weights of the factors are achieved by computing the values of AHP matrix. For example, we fixed BW to 1 and vary delay from 1 to 9. i.e. 1_1 denote bandwidth and delay is equally important to the objective and 1_2 denote bandwidth and delay is weakly moderately important to the objective and so on. Hence 1_1 to 1_9 scale denote different weight level.

3 Simulation Setup

We consider a scenario of collocated networks (i.e., n=2) as shown in fig. 2 which is composed of a WLAN and a cellular system. WLAN is considered as network 1 and cellular network is 2. The application is assumed to be voice (i.e., conversational). To evaluate the state transition probability function of the WLAN, a typical IEEE 802.11b WLAN is simulated using ns-2(2.29) (The Network Simulator ns-2); where users arrive and depart from the network according to an exponential distribution with an average inter arrival time 1.6 s. The basic rate and date rate of the WLAN are 1 Mbps and 11 Mbps, respectively. The counting of transitions among states is performed to estimate the state transition probabilities. For the state transition probability function of the wireless cellular system, the values of bandwidth and delay are assumed to be guaranteed for the duration of the connection (Stevens-Navarro, Lin, and Wong 2008). Thus

$$Pr [s'|s, a] = \begin{cases} \prod_{n=1}^{N} Pr[b_n', d_n'|b_n, d_n], & j = a \\ 0, & j \neq a \end{cases}$$

where $b_n$ and $d_n$ are the weight of bandwidth and delay, respectively and $b_n'$ and $d_n'$ are the bandwidth and delay, respectively of the action selected by the move action $a$.

$$f_{b, \text{TOPSIS}}(s,a) = \frac{b_a}{\sqrt{\sum b^2}} \times \omega_b$$

$$f_{d, \text{TOPSIS}}(s,a) = \frac{d_a}{\sqrt{\sum d^2}} \times \omega_d$$
network which provides highest link reward. For MDP_SAW and MDP_TOPSIS a switching cost is included with link reward function of SAW and TOPSIS, respectively to derive reward function of MDP_SAW and MDP_TOPSIS. MDP also include switching cost function with their own link reward function (Stevens-Navarro, Lin, and Wong 2008).

Finally candidate network for MDP_SAW, and MDP_TOPSIS is the one, which gives highest total whereas MDP_SAW and MDP_TOPSIS use VIA for obtaining optimal network. Based on network selection our further step is to determine expected total bandwidth and expected number of vertical handoff for each algorithms using VIA by solving equations (10) and (11), respectively.

\[ B(s) = \{ b + \sum_{s' \in S} \lambda Pr[s'|s, a]B(s') \} \]  \hspace{1cm} (10)

\[ V(s) = \{ v + \sum_{s' \in S} \lambda Pr[s'|s, a]V(s') \} \]  \hspace{1cm} (11)

where \( b \) and \( v \) are the bandwidth unit (1 to 15) and number of vertical handoff (0 or 1), respectively of the corresponding optimal network. For solving (10), we replace (10) with (1) and \( B(s) \) with \( U(s) \) and follow steps 1 to 3 in VIA (section 2). Thus we get expected total bandwidth \( B(s) \) after final iteration. Same steps are followed for (11) to solve it.

The parameters of the experiment used in the numerical results are summarized in Table 1. Our proposed method MDP_SAW and MDP_TOPSIS is tested against individual SAW, TOPSIS, and MDP and tested with different aspects. At first the performance matrices are investigated with respect to discount factor, \( \lambda \). Next we took into account the influence of switching cost, \( K \) on the expected total bandwidth and expected number of vertical handoff. We do not consider expected total reward because it does not translate to optimal QoS offerings at different user perception levels which have been presented in our previous works (Sharma and Murshed 2010). Furthermore we provide the result of performance metrics with different weight factor. The weight factor considers here is the scale of AHP from 1.1 to 1.9. Finally we see the variation of expected number of vertical handoff on state space.

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<th>Table 1: Simulation Parameters.</th>
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<tr>
<td><strong>Simulation Parameters</strong></td>
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<tr>
<td>Average time between successive decision epochs</td>
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<td>Discount Factor, ( \lambda )</td>
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<td>Switching cost from network 1 to network 2, ( K_{1,2} )</td>
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<td>Switching cost from network 2 to network 1, ( K_{2,1} )</td>
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<td>Maximum available bandwidth</td>
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<td>Relative importance between bandwidth and delay</td>
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<td>Weight factor for Bandwidth using AHP</td>
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<td>Weight factor for Delay using AHP</td>
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4 Experiment Result

With the discount factor increasing from 0.94 to 0.98 MDP_SAW and MDP_TOPSIS provide more expected total bandwidth then SAW, TOPSIS, and MDP as shown in fig. 3. The initial state vector at the beginning of connection is assumed to be \( \{2, 5, 5, 7, 8\} \). When \( \lambda \) is varied from 0.94 to 0.98, it corresponds to the variation of the average connection duration from to 4 to 12.5 min. We also observed that when \( \lambda \) increases expected total bandwidth is also increases and MDP_SAW provides highest values for all values of \( \lambda \).

Fig. 4 shows the variation of \( \lambda \) versus expected number of vertical handoff where MDP_SAW shows significant improvement because it provides far lower values of vertical handoff then SAW, TOPSIS, and MDP. Fewer handoffs indicate better handoff algorithm because it can avoid ping-pong effect.

Fig. 5 and fig. 6 show the expected total bandwidth and expected number of vertical handoff versus switching cost. The discount factor is 0.96. MDP_SAW gives better result in both cases. That means higher expected total bandwidth and lower expected number of vertical handoff.

In fig. 5 MDP perform better then MDP_TOPSIS but there is sudden degradation of performance at switching cost 1. On the other hand SAW and TOPSIS choose the candidate network based on QoS parameter and do not consider switching cost. Thus expected values are constant for those algorithms.

Fig. 7 and fig. 8 show the variation versus different weight level. Here weight 1.1 denote bandwidth and delay is equally important to the objective and 1.2 denote bandwidth and delay is weakly moderately important to the objective and so on. In both cases MDP_SAW provide far better results than all other algorithms.

Fig. 9 shows the expected number of vertical handoff varies in state space. Here state vector \( \{2, 14, 2, 7, 8\} \) to \( \{2, 15, 15, 7, 8\} \) has been consider for space limitation. Thus their corresponding integer values are 421 to 449. Expected number of vertical handoff is varied in different state space. This is because different state has different optimal policy for vertical handoff. Beyond them MDP_SAW gives lowest values then all other algorithms.
Figure 3: Effect of expected total bandwidth under different discount factor, \( \lambda \) in state \( \{2, 5, 5, 7, 8\} \).

Figure 4: Effect of expected number of vertical handoff under different discount factor, \( \lambda \) in state \( \{2, 5, 5, 7, 8\} \).

Figure 5: Effect of expected total bandwidth under different switching cost, \( K \) in state \( \{2, 5, 5, 7, 8\} \).
Figure 6: Effect of expected number of vertical handoff under different switching cost, $K$ in state $\{2, 5, 7, 8\}$.

Figure 7: Effect of expected total bandwidth under different weight factor in state $\{2, 5, 7, 8\}$.

Figure 8: Effect of expected number of vertical handoff under different weight factor in state $\{2, 5, 7, 8\}$. 
5 Conclusion

We have presented a novel algorithm for vertical handover which integrate the Markov decision process (MDP) on traditional algorithms SAW and TOPSIS. Although we propose both MDP_SAW and MDP_TOPSIS, MDP_SAW outperforms all other algorithms. Numerical results show that our proposed MDP_SAW gives a higher expected total bandwidth. In addition from our experiment, it is observed that policy from MDP_SAW gives the lower expected number of vertical handoff per connection. The ping-pong effect occurs when a mobile node moves around the overlay area between two networks, causing unnecessary handoffs and increasing the handoff overhead. Fewer handoffs indicate a better handoff algorithm. Numerical results also revealed interesting behavioural patterns for the expected number of vertical handoff as it varied at different states of mobile user. This means that it not only depend on the current network but also the QoS offered by the candidate network, which can be changed at each decision epoch. This model could be successfully used for designing, evaluating and optimizing cost effective handoff mechanisms in wireless overlay networking environments.

6 References


Figure 9: Effect of expected number of vertical handoff under states \(\{2, 14, 2, 7, 8\}\) to \(\{2, 15, 15, 7, 8\}\).
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