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Maximizing Network Utilization in IEEE 802.21 Assisted Vertical Handover over Wireless Heterogeneous Networks

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Abstract

In heterogeneous wireless networks supporting multi-access services, selecting the best network from among the possible heterogeneous connections and providing seamless service during handover for a higher Quality of Services (QoSs) is a big challenge. Thus, we need an intelligent vertical handover (VHO) decision using suitable network parameters. In the conventional VHOs, various network parameters (i.e., signal strength, bandwidth, dropping probability, monetary cost of service, and power consumption) have been used to measure network status and select the preferred network. Because of various parameter features defined in each wireless/mobile network, the parameter conversion between different networks is required for a handover decision. Therefore, the handover process is highly complex and the selection of parameters is always an issue. In this paper, we present how to maximize network utilization as more than one target network exists during VHO. Also, we show how network parameters can be imbedded into IEEE 802.21-based signaling procedures to provide seamless connectivity during a handover. The network simulation showed that QoS-effective target network selection could be achieved by choosing the suitable parameters from Layers 1 and 2 in each candidate network.

Keywords

Handover Decision, IEEE 802.21, Occupied Bandwidth, SINR, Vertical Handover

1. Introduction

Heterogeneous wireless networks still deserve a lot of research in order to fulfill users' Quality of Service (QoS) requirements during vertical handover (VHO). When a mobile user changes his location and is willing to link to a different network link, his current connection will be released due to the breakage of link [1,2]. In order to provide continuous service, we used the VHO that consists of handover information discovery, handover decision, and handover execution steps. Through these VHO steps, the best network supporting application service without any interruptions should be chosen from among the neighboring candidate networks. For the first step of VHO, several VHO frameworks have been introduced along with the selection of various network parameters.

One prime example would be as follows: media independent handover (MIH) creates a framework to support protocols for seamless service during VHO and optimizes the handover procedure between

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heterogeneous networks with the help of MIH function (MIHF) [3,4]. MIHF acts as an intermediate layer between the link layer and network layer [5]. It coordinates the information service and command service during a handover decision and executes the handover [6]. IEEE 802.21 defines MIHF and the events/commands required for the overall MIH framework operations, as shown in Fig. 1, but it leaves the implementation of the actual handover algorithms to the engineers designing the system. Therefore, it is essential to develop efficient VHO decision algorithms based on this framework.

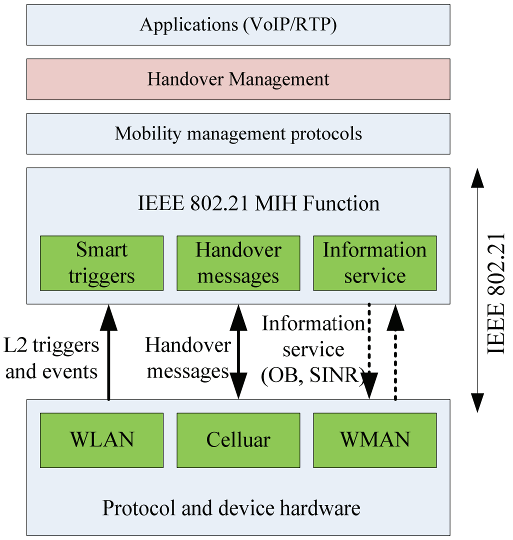

Fig. 1. MIHF structure in IEEE 802.21.

A number of methods for VHO have been proposed in the literature. [7-11] studied how the handover decision is operated by the mobile node (MN) with different metrics like received signal strength (RSS), QoS, network load, user preferences, signal-to-interference-and-noise-ratio (SINR), traffic load, and so on. Also, [12] classified the existing handover decision algorithms for the two-tier macrocell-femtocell network, depending on the similar primary HO decision criterions used. The various VHO metrics were also described for the best handover decision. As one of example of this, [13] facilitated the implementation of load balancing between Wi-Fi APs by using signal-to-noise-ratio (SNR) and the estimated transmission rates. All of these possible handover metrics provide a trade-off between them because of their computation and signaling overheads.

Basically, RSS is a popular parameter used for handover decision among the handover metrics. However, RSS-based handover sometimes unnecessarily occurs due to the resource misinterpretation of the target network [14]. This is because RSS possesses only signal power without valuable network information, such as noise level and network traffic load. The conventional handover decision algorithms based on RSS with no consideration of additional network parameters can be found in [15,16]. Another work, [17], shows that the VHO performance is affected by RSS, MN velocity, monetary cost, link capacity, and power consumption. However, this work uses a lot of metrics increasing signaling overhead and does not deal with seamless handover. Similarly, [18] describes a measurement-based network selection technique that mainly deals with a cost function approach that provides a filtering method to acquire more reliable QoS information and reduces unnecessary handovers. However, the selection of handover parameters and computation overhead of the cost function was not considered. Another work to reduce unnecessary handover is discussed in [9] with the prediction of the travelling distance based on the RSS measurements. However, the precision of RSS-based distance prediction is limited due to unreliable channel features of VHO channels. In [19], three different approaches for VHO decision are presented based on RSS, achievable data rate estimation, and their combined methods. Simulation results showed that the combined handover decision approach is better than the other two approaches. In this method, MN monitors RSS from neighboring networks for the network discovery, then compares with the VHO threshold and estimates the achievable data rate based on SINR. Generally, SINR is a parameter that can reflect noise and the interference properties of the networks. With this parameter, the target network can be selected, which results in better performance in terms of handover efficiency. That is, unnecessary handovers under interference and noisy environment can be reduced. Another SINR-based handover decision is shown in [20]. These SINR-based handover works require an inter-working unit (IWU) and SINR conversion between networks to recognize and compare them between different type of networks, which might increase the signaling overhead in a network. Also, this SINR-based approach is only effective where SINR clearly reflects the channel status of the target network. [21] shows that most of the handover schemes still rely on a traditional RSS-based approach and that seamless handover schemes are still a necessity for future networks. Thus, providing the required QoS is still the major issue due to the increase in mobility and a heterogeneous network environment. Specifically, most of these works on VHO decision approaches do not do a good job in presenting how to obtain channel information and exchange its handover decision signaling with target networks.

In this paper, we introduce an IEEE 802.21-based VHO signaling message exchange and show an example for a VHO decision with the selected handover metrics. The IEEE 802.21-based VHO signaling method can provide a better seamless handover between different overlapped networks, because of the earlier network detection based on MIH events/commands of IEEE 802.21 [3,4]. We assumed that a handover between the WLAN and a cellular network and give the higher handover priority to WLAN, since WLAN connectivity is generally much preferred due to its low cost, widely spread hot spots, and higher bandwidth. One of the experiments performed in cites in Korea showed that the average percentages having WLAN connectivity are 70% for all day and 63% for the daytime only when smartphone users move about in their daily life [22]. As we can see in this observation, WLAN is already widely spread and used. In order to prove that the IEEE 802.21-based VHO algorithm works, we implemented an IEEE 802.21-based signaling exchange and several channel measurements onto a network simulator-2 (NS-2) platform [23]. Then we performed a VHO simulation from a cellular network to one of the surrounding WLAN networks. As the first step in the simulation, MIH was combined with network parameters for candidate network discovery. Second, for the handover decision step, the selected network parameters (i.e., SINR and OB) related to network quality were measured to find out the real characteristics of the networks. Third, the selected target network was evaluated through a score value obtained from these network parameters if the handover was satisfied.

The rest of the paper is organized as follows: Section 2 introduces how to utilize and observe SINR and occupied bandwidth (OB) over a heterogeneous wireless network. Section 3 explains the classification of WLAN network status, which is preferred during a VHO decision. Sections 4 and 5 present the proposed vertical handover decisions and their simulation results, respectively. We conclude the paper in Section 6.

2. IEEE 802.21-Based Vertical Handover

IEEE 802.21 provides a framework that allows higher levels to interact with lower layers to provide session continuity without dealing with the specifics of each form of technology. The MIHF acts as an intermediate layer between the upper and lower layers whose main function is to coordinate the exchange of information and commands between the different devices involved in making handover decisions and executing handovers.

IEEE 802.21 defines three different types of communications with different associated semantics, the so-called MIH services:

- Event services (ES)
- Command services (CS)
- Information services (IS)

These services allow MIHF users to access handover-related information and deliver commands to the link layers or network. Events generated in link layers and transmitted to the MIHF or MIHF users are delivered asynchronously, while commands and information generated by a query/response mechanism are delivered synchronously.

For a detection of candidate network and seamless handover support, the following messages of MIH event are used (i.e., Link Detected, Link Up, Link Down, and Link Going Down). Fig. 2 shows the message diagram for a handover decision in the proposed VHO decision based on IEEE 802.21.

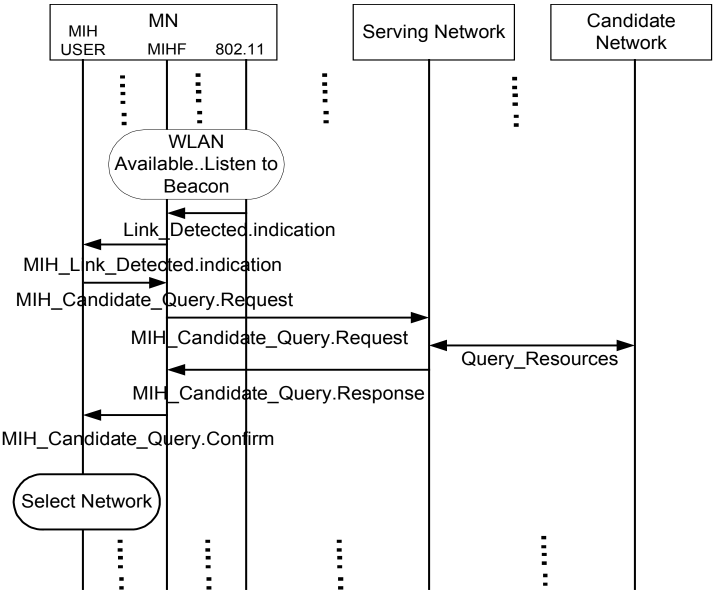

Fig. 2. Message diagram for handover decision based on MIH.

The primary step involves detecting the candidate networks by using a MIHF event (Link Detected) located on the MN itself [3]. The link detection notification is forwarded by the MIHF to the MIH users. The potential candidates discovered should be compared, and then the MIHF starts a query by asking the available resources (i.e., SINR, OB) through the serving network to target network. Finally, the reply to the query is sent back to MN with a form of a score value that we have defined as network quality (NQ). Now, MN has sufficient link status information about the target networks.

3. Observation of Network Parameters: RSS, SINR, and OB

Various wireless network services, including 3G/4G cellular networks, mobile WiMAX, and IEEE 802.11b/a/g/n WLAN, are currently used to meet different customers' needs. No single wireless network technology can provide low latency, high bandwidth, and wide area data service at the same time. We need VHO, which switches the MN amongst different types of wireless networks. VHO is divided into two categories: upward VHO is a handover to a wireless overlay with a larger cell size (and lower bandwidth per unit area), and downward VHO is a handover to a wireless overlay with a smaller cell size (and higher bandwidth per unit area) [24].

In this paper, we assumed that a handover occurs between a cellular network and IEEE 802.11b/a/g/n-based WLAN and selects WLAN with the preference in the VHO decision policy due to its cost and larger bandwidth, if a WLAN network was available. In the upward VHO (network switching from WLAN to 3G/4G), MN connects with 3G/4G if there are no WLAN networks available around the MN. However, in the downward VHO (network switching from 3G/4G to WLAN), network parameters will be used to select the best-conditioned target network after the detection of candidate networks.

It is clear that wireless communication can be disrupted due to various reasons, such as obstacles, background noise, and the interference problem of simultaneous transmission. The widely used parameter, such as RSS, cannot reflect all network features, but SINR can possesses many features. Thus, SINR is one of the parameters that we used to measure the quality of the wireless connections, which can be represented as:

$$SINR = \frac{S}{N+I}, \tag{1}$$

where, S, N, and I represent the RSS, noise power, and interference caused by simultaneous transmissions, respectively. Noise power includes noises from the receiver and the surroundings. Noise derived from the receiver consists of thermal and platform noise. Thermal noise, like other forms of noise, is random in nature. The system with highly integrated high-speed digital circuits and multi-radio modules experiences performance degradation due to a complicated noisy environment platform. In addition to the noises, interference should be used to reflect the channel status during the VHO procedure.

For the performance evaluation of the proposed VHO method, we used NS-2, where the signal strength of a frame was calculated by using a propagation model, (i.e., Free Space, Two Ray Ground, and Shadowing models) and the distance between the transmitter and receiver. Also, thermal noise represented with a random process was observed in the simulation. Moreover, the platform noise was implemented by adapting the WLAN product feature. However, environmental noise was not simulated in this work, since all environments have different noise. We then considered the condition for packet reception. If more than one frame arrives simultaneously at the receiver, interference occurs.

When a frame arrives at the receiver, the receiver detects the frame if it is stronger than the carrier-sensing threshold (*CsThreshold*). Then, the frame is passed to the MAC layer if its signal is above the receiving threshold (*RxThreshold*), as shown in (2). If the signal power of the frame is weaker than the *RxThreshold*, the frame is considered to be corrupt by the MAC layer and is discarded. NS-2 has another threshold known as a collision threshold (*Cpthreshold*), which calculates the ratio of the strongest frame signal with the sum of the signal strength of all other simultaneously arrived frames. If the ratio is larger than the *CpThreshold*, as shown in (3), the frame is correctly received and other frames are ignored. In this simulation environment, the DCF of IEEE 802.11 was used and the hidden stations and terminals were ignored. Thus, the condition for successful packet reception from link *m* is as follows:

$$G_m P_m \geq RxThreshold, \tag{2}$$

$$\frac{G_m P_m}{\sum_{k=1}^{i} G_k P_k} \geq CpThreshold, (k \neq m) \tag{3}$$

where, G_m and P_m denote the channel gain and received power of link *m*, respectively. Here, we assumed that the packet coming from link *m* might interfere with *i* active links.

If the receiver only receives one frame, SINR is expressed as:

$$SINR[dB] = 10\log(\frac{Rx_{Power}}{N}) \tag{4}$$

where, Rx_{Power} is the signal strength of the received frame. If other frames arrive at the receiver when it is receiving one frame, the SINR of this receiving frame is:

$$SINR[dB] = 10\log(\frac{Rx_{Power}}{N + \sum_{k=1}^{i} Rx_{power}^{k}}), (k \neq m) \tag{5}$$

where, Rx_{Power}^{k} is the signal strength of other frame k observed at the receiver. This SINR can be normalized as:

$$SINR_{normalized} = \frac{SINR[dB]}{SINR_{\max}}, \tag{6}$$

where, $SINR_{max}$ is the maximum of SINR, which can be observed during VHO. $SINR_{normalized}$ represents the ratio of the current SINR to the largest SINR and stays between 0 and 1. By using $SINR_{normalized}$, the channel quality of a target network can be measured. The higher the $SINR_{normalized}$ is, the better the channel quality might be. This $SINR_{normalized}$ will be observed for each link and averaged at the AP.

In addition to Layer 1 parameters, like RSS and SINR, the MAC data rate in Layer 2 was considered. Available bandwidth is a good factor to determine if MN does the handover to the corresponding network. However, the available bandwidth is hard to observe and estimate. Thus, by observing the

SINR and OB in Layers 1 and 2 of the network, we approximated the available bandwidth, which is dependent on the total number of active MNs, RF channel status, and aggregated bit rates of all applications. On the other hand, OB in WLAN was estimated to be the successful MAC data transfer rate between the nodes and the AP. Hence, estimating OB delivered the approximate usage of the total bandwidth provided. If the maximum capacity of the link is L, the normalized OB is expressed as:

$$OB_{normalized} = \frac{\gamma}{L}, \tag{7}$$

where, γ is OB between the nodes and the AP. It can be obtained from:

$$\gamma = \sum_{x=1}^{n} \frac{T_x}{Observation\_duration}, \tag{8}$$

where, T_x is the number of bits transferred between nth MN and AP, and n denotes the number of active nodes involved with the network.

In the proposed VHO decision, the average $SINR_{normalized}$ is used solely and jointly with $OB_{normalized}$ as the network parameters in order to determine the network channel quality. The parameter combination depends on the data collection ability of the WLAN AP. After observing the normalized SINR and OB parameters, they were delivered from WLAN APs to MNs through the IEEE 802.21 MIHF.

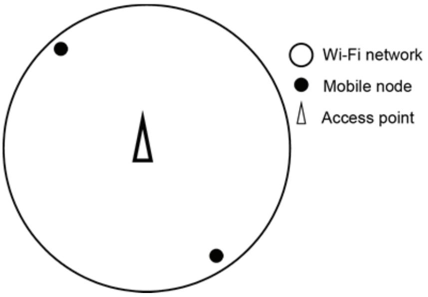

Fig. 3. Network type 1: small number of nodes are located sparsely far away from AP.

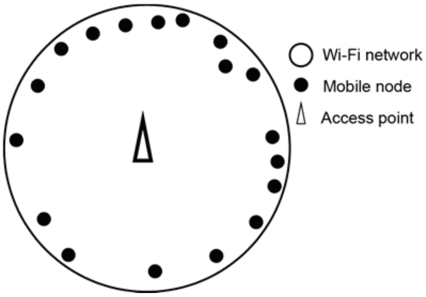

Fig. 4. Network type 2: large number of nodes are located densely faraway from AP.

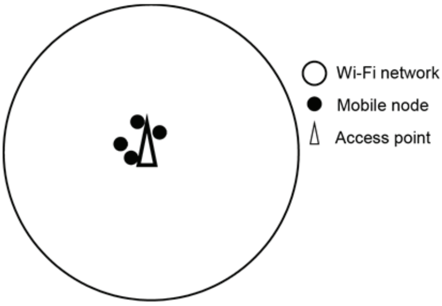

Fig. 5. Network type 3: small number of nodes are located sparsely close to AP.

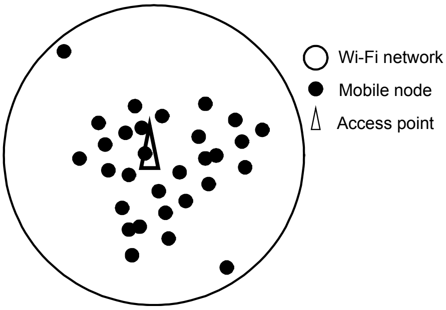

Fig. 6. Network type 4: large number of nodes are located densely close to AP.

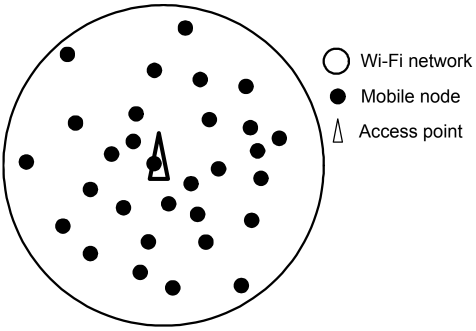

Fig. 7. Network type 5: nodes are uniformly distributed around AP.

4. Classification of WLAN Networks for a Handover Decision

WLAN network status can be classified into five categories, as shown in Figs. 3 to 7, according to MN position and the amount of traffic involved. In this classification, Fig. 7 shows a uniform distribution of nodes, which is regarded as being common in wireless scenarios. Figs. 3 and 4 are, respectively, the first and second types of network statuses showing nodes located far away from the AP, whereas Figs. 5 and 6 are the third and fourth types of network statuses showing nodes located close to the AP. $OB_{normalized}$ and/or $SINR_{normalized}$ can be observed at the AP and asked through MIHF query request message to deliver to MN deciding a handover. We assumed that all MNs communicate with the AP at similar data rates for this type of classification.

Under the first type of network status, shown in Fig. 3, we expected $OB_{normalized}$ to be low due to the small number of active MNs. The average $SINR_{normalized}$ of all of the links was also low due to the weak signal strengths from MNs. MN is able to determine that this WLAN target network has a good channel status to join by using $OB_{normalized}$, since low OB can imply for a large available bandwidth. If only an average $SINR_{normalized}$ is observed at the AP and delivered to MN, the MN has to decide the VHO according to the received SINR. The VHO decision will be negative in regards to joining this network due to the low SINR, which causes to misunderstand the channel status. In the second type of network status, which is shown in Fig. 4, VHO is not recommended since a low SINR and large OB was obtained. That is, a network with a high density of nodes (shown in Fig. 4) should be recommended and not selected during the handover procedure due to high interferences and large OB usages. Here, both SINR and OB parameters can be useful to verify WLAN network status. On the other hand, the third type of network status (Fig. 5) is preferred as the target network because of the strong signal strength and low OB usages. Both SINR and OB parameters can be effective by providing useful channel quality information. In fourth type of network (Fig. 6), a large number of nodes are placed close to the AP. SINR can be variable according to the strong signal powers and the interference caused by a large number of MNs. If only $SINR_{normalized}$ is obtained from the network, the VHO decision will be difficult in regards to determining the network status. However, $OB_{normalized}$ is high due to the large number of MNs and will be a valuable parameter to decide if this WLAN can become a target network. That is, the suitable selection of network parameters and their combination will enormously affect the decision of the VHO.

5. Proposed Vertical Handover Decision

Generally, a mobile device will do a handover to a neighboring available network when it cannot receive a pre-established minimum receiving power from the current serving network. The signal strength is useful in the VHO decision, but an unwanted or premature handover can frequently occur as it cannot reflect the actual properties of the network [14]. The proposed VHO was designed for a handover between a cellular network and WLAN networks, based on IEEE 802.21 MIHF. In order to perform an effective QoS handover at the time of downward VHO, two algorithms using different parameter combinations are introduced in this work. First, there is the SINR aware handover decision (SAHD), which is comprised of SINR with IEEE 802.21. Second, there is the traffic aware handover decision (TAHD), which improves handover decisions by merging SINR and OB.

5.1 SINR Aware Handover Decision (SAHD)

The proposed SAHD is comprised of the acquisition of the current SINR and its comparison with other WLAN networks. The SINR is delivered from the candidate AP and is used to select a better network for a vertical handover. In this proposed SAHD, SINR can be effective for handover even though the RSS of a link is high but has traffic congestion or interferences with other flows. The network quality factor *NQ* for SAHD is introduced as:

$$NQ = SINR_{normalized}. \tag{9}$$

We expected for SAHD to be able to provide a more valuable choice than an RSS-based method for a target network decision as it considers channel interference and noisy conditions even though signal strength in a current network is greater than a certain handover threshold. However, there is still a limitation in regards to not reflecting the traffic resources of Layer 2, which were discussed in Section 3.

5.2 Traffic Aware Handover Decision (TAHD)

SINR can be considered to be a good parameter for the verification of link quality in a handover decision procedure. However, the verification can still be improved by adopting a bandwidth metric. For example, if the network is highly occupied with data traffic, the network slows down or suffers from packet loss. As shown in Fig. 6, SINR alone cannot clearly verify the network status. With the combination of SINR and OB in TAHD, a more preferable handover decision can be derived. This can result in higher throughput, lower handover latency, and a reduced number of handovers at the expense of computation overhead on the AP.

Fig. 8 demonstrates the handover decision procedure of TAHD. When a multi-interface enabled MN detects a new WLAN network, NQ, which consists of SINR and OB, in (10) is estimated. A network with greater NQ is preferred for handover among the available WLAN networks. In order to apply this to various circumstances, there is a clear necessity to allocate weight to each factor for the vertical handover decision. The weight allocation is introduced as follows:

$$NQ = \alpha \times SINR_{normalized} + (1-\alpha)(1-OB_{normalized}), \tag{10}$$

where, α is the weighting parameter affecting the SINR and estimated bandwidth. To evaluate the *NQ*, the value of the weighting factor is varied in the simulation as follows: 0.25, 0.5, and 0.75. Balancing between OB and SINR will increase the confidence level to select the best network. As shown in Fig. 3, networks with low traffic might not be selected in SAHD due to the low SINR in terms of channel quality. Similarly, the SINR of a certain network might be high even though the network is highly populated with incoming traffic, as shown in Fig. 6. Hence, the combination of SINR and OB in TAHD seems to be effective for the precise handover decision. The selection of the downward VHO method between SAHD and TAHD depends on the data collection ability of the WLAN AP. In order to utilize TAHD, the AP should be able to collect information regarding how much the channel is occupied with incoming traffic, which increases the computation overhead on the AP. If OB can be observed in AP, TAHD is preferable due to the expectation of a higher channel diagnosis.

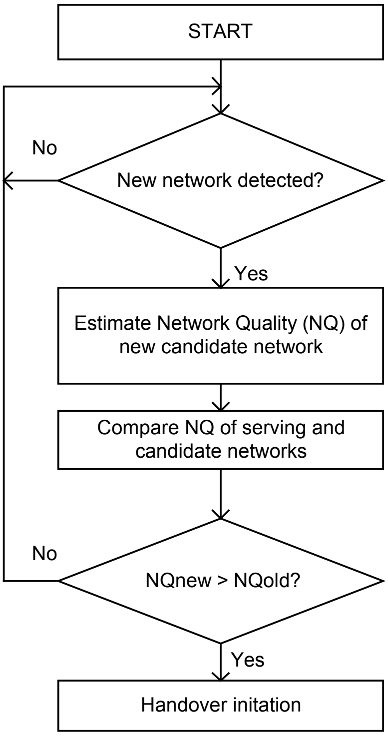

Fig. 8. Handover decision procedure in TAHD.

6. Performance Evaluation and Results

The performance evaluation of VHO algorithms combined with IEEE 802.21 is demonstrated in this section. That is, the TAHD was compared with SAHD and simple MIH-based VHO using RSS. Reception of the IEEE 802.11 beacon initiates the simulation, which generates the link-detected indication. IEEE 802.21 defines the primitives within the link layer, which indicate the detection of a new link. In TAHD, SINR and OB are chosen as the handover decision parameters in order to select a suitable WLAN network and maximize its resource usage.

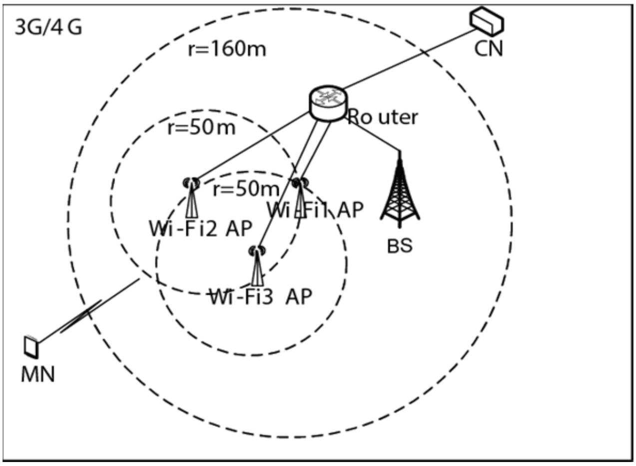

Fig. 9. Simulation network topology for the evaluation of SAHD and TAHD.

Table 1. Network condition for VHO network simulation

Parameter	Value
Simulation area	1000 m × 1000 m
Traffic source	CBR
Packet size	500 bytes
Packet interval	0.01 seconds
Routing protocol	DSDV
Simulation time	1,000 seconds
Network type	3G/4G and 802.11
WLAN coverage	160 m, 50 m, 50 m
Node speed	5, 10, 15, 20 m/s

Table 2. The number of nodes allocated to WLAN networks for the network simulation

Network	Case 1	Case 2	Case 3
WLAN 1	15 nodes	20 nodes	5 nodes
WLAN 2	5 nodes	15 nodes	20 nodes
WLAN 3	20 nodes	5 nodes	15 nodes

Table 3. Different number of nodes allocated to WLAN for the network simulation

MN speed	Case 1		Case 2		Case 3	
	SAHD	TAHD	SAHD	TAHD	SAHD	TAHD
5 m/s	17%	21%	5%	15%	15%	16%
10 m/s	15%	22%	6%	10%	13%	16%

The these two processes in terms of throughput, number of handovers, network quality, and handover latency were tested for usefulness and verification in all methods.

Fig. 9 shows the network topology in NS-2, which was comprised of three WLAN networks with different ranges and 3G/4G as the backend. The simulation area was set to 1,000 m × 1,000 m, where 3G/4G is available everywhere. The corresponding node (CN) located in 3G/4G cellular network generated and transmitted the constant bit rate (CBR) traffic to the MN. Furthermore, IEEE 802.21 was built on MN, AP, and base stations (BSs). A modification on the MAC and PHY layer of IEEE 802.11 was done in NS-2 to obtain SINR and OB from each connection. Also, modifications to IEEE 802.21 were carried out in order to adopt the decision procedure. Node locations and moving direction were considered to be random in the simulation. The simulation conditions, such as data rate, coverage, simulation time, and node speed, are listed in Table 1. The wireless communication range of AP 1 was set to 160m to ensure a strong channel link, where others were set to 50 m for general channel links. In the absence of WLAN links, a new connection was directly handed to 3G/4G for upward VHO. Three simulations were conducted in different environments at varying speeds and a different number of MNs, as listed in Table 2. The main purpose of performing the simulation in a different environment was to test the proposed TAHD in different types of network scenarios. This provided the details and precise analysis of the SINR and OB operation in a vertical handover.

6.1 Network Quality (NQ) Score

The performance of TAHD depends on network conditions, which are shown in Figs. 3–6. From the observations presented in Section 3, it is seen that SAHD might be lacking in regards to verifying the real condition of the network. However, with TAHD, it was expected to obtain a precise NQ in the simulation. This is because the combination of OB and SINR mirror the available capacity of the target network better than SINR alone.

In our simulations, we placed the nodes in three different locations of *Random*, *Far*, and *Close* to verify the performance of TAHD, as shown in Figs. 10 to 12. *Random* refers to the placement of nodes in a random order. *Far* depicts the placement of nodes distant from the AP and *Close* refers to the placement of nodes close to the AP. The weighting factor (α) was given less, equal, and more preference to SINR and tested. From the experiment, the result was obtained that the NQ of the network with low traffic was constantly high in TAHD compared to SAHD. Similarly, the NQ of the network with high traffic was comparatively lower in TAHD than in SAHD. The results in the Figs. 10 to 12 describe the slope of the NQ depending on α. Thus, α should be carefully selected to verify the status of a target network. In this work, we used 0.25 for α in the simulation in order to give higher priority to OB than SINR, which helped to maximize WLAN network resource usage.

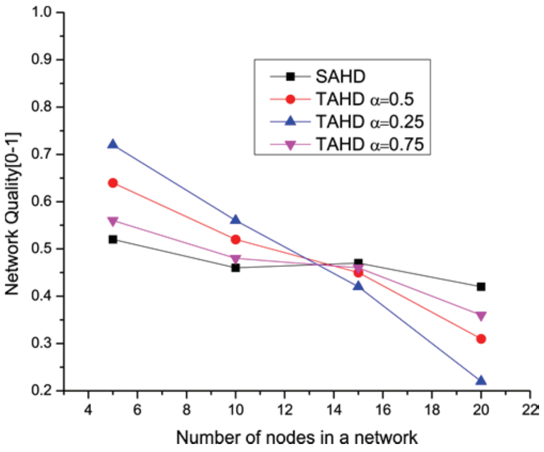

Fig. 10. Network quality with random node position (*Random*).

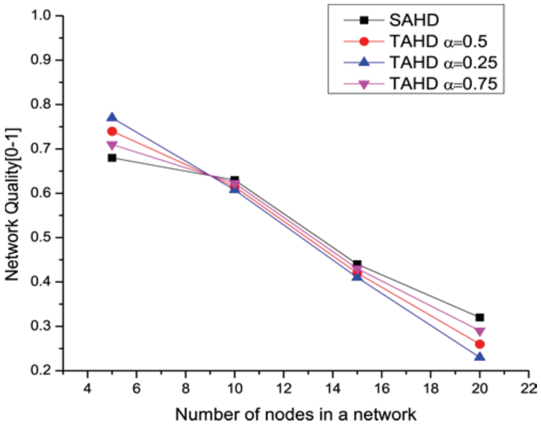

Fig. 11. Network quality with node position close to AP (*Close*).

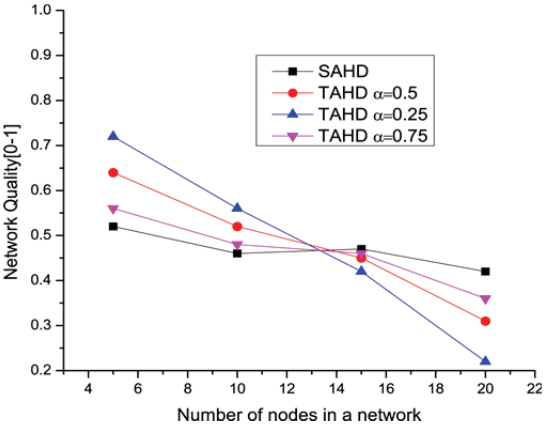

Fig. 12. Network quality with node position far from AP (*Far*).

6.2 Average Throughput

This section explains the average throughput observed at the different environments and speeds. For our throughput experiment, we carried out four simulations. Simulations were done at two different MN speeds of 5 m/s and 10 m/s under the random node distribution. The results showed that TAHD and SAHD in all three cases, shown in Table 2, outperformed the IEEE 802.21 (MIH) using only RSS with respect to average throughput, as shown in Figs. 13–15. The probability of selecting the best network was the highest with the TAHD method, since TAHD uses two parameters that clearly reflect the network status, as discussed in Section 3. Table 3 shows the percentage of increased throughput when TAHD and SAHD are compared to IEEE 802.21 alone. We observed that TAHD had an average increased throughput of 5% and 4.7% more than SAHD at 5 m/s and 10 m/s, respectively.

The obtained throughput at different node speeds is presented in Figs. 16–18. The throughput was reduced on the MN with a higher speed. This is because associations with the network can be easily lost as the MN moved quickly and reestablishing the path after every re-association was frequently carried out. Even at this high MN speed, TAHD and SAHD showed higher throughput by selecting the network that was in the lower interference environment. However, SAHD might not be able to do as well as TAHD at selecting the best network since SAHD only uses channel features, such as signal powers and interferences related to Layer 1. Thus, we could confirm that TAHD, using the parameters of Layers 1 and 2, provides consistently maximum throughput to the end user by selecting the network with higher QoS. In addition to the increased throughput, we needed to verify if the proposed methods could also provide seamless service by observing the total number of handovers and handover latencies during VHO.

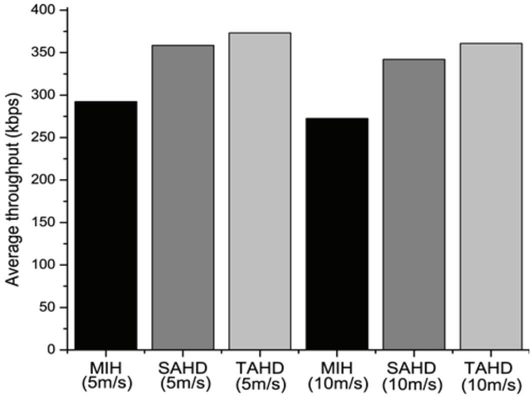

Fig. 13. Average throughput observed: Case 1.

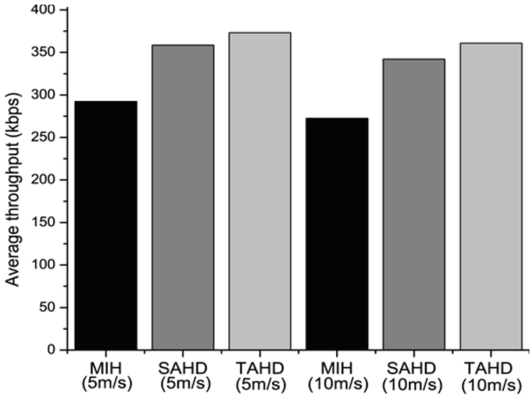

Fig. 14. Average throughput observed: Case 2.

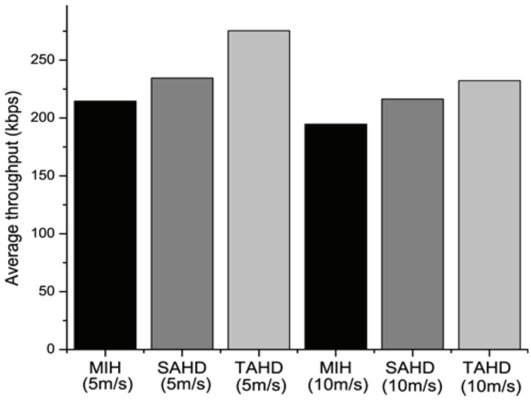

Fig. 15. Average throughput observed: Case 3.

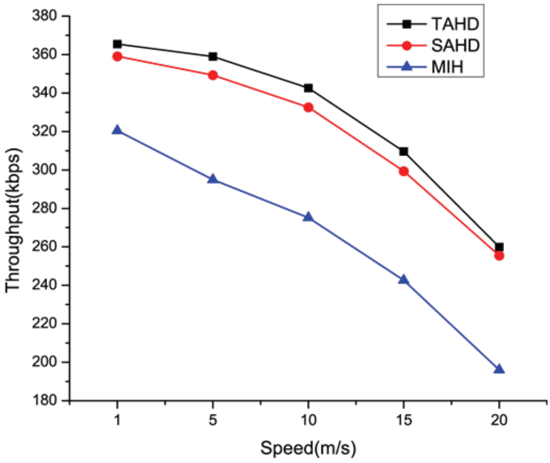

Fig. 16. Average throughput vs. speed: Case 1.

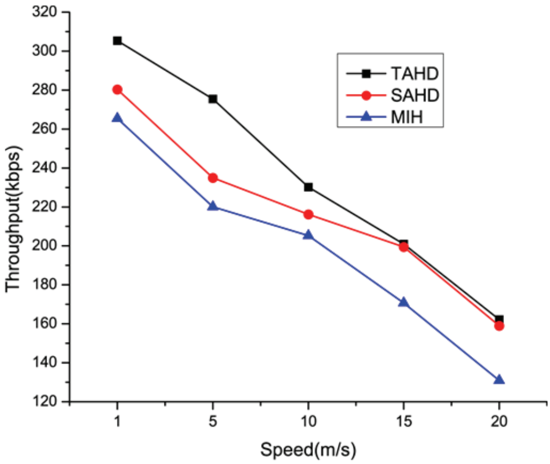

Fig. 17. Average throughput vs. speed: Case 2.

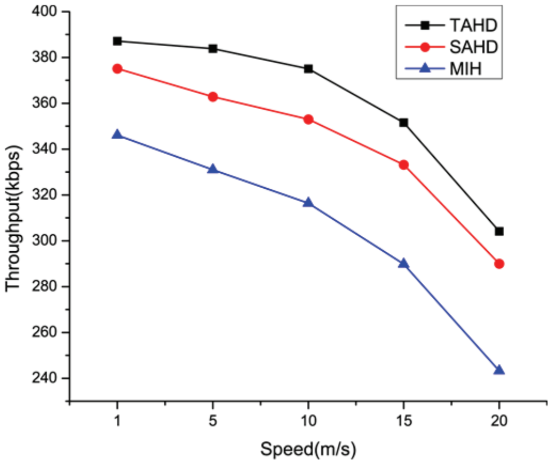

Fig. 18. Average throughput vs. speed: Case 3.

6.3 Number of Handovers

A heterogeneous wireless network contains many different types of networks. The unnecessary handovers between networks needs to be reduced, which will improve the entire performance of the network. Fig. 19 shows that unnecessary handovers were reduced in the TAHD and SAHD schemes as compared to IEEE 802.21. MIH indicated a 100% meaning for a reference compared with our proposed methods in terms of the probability of handover occurrence. SAHD had a 8%, 4%, and 30% reduction in the frequency of handovers observed in Cases 1, 2, and 3, respectively, as shown in Fig. 19. Similarly, TAHD had a 30%, 12%, and 60% reduction of handovers, respectively. This is because the MN in TAHD stayed on the selected network for the longer time and reduced the number of handovers. The handover result of TAHD had the highest performance in Case 3 because the network with a greater range WLAN 1 had a low traffic load and MN stayed on the same network for longer time.

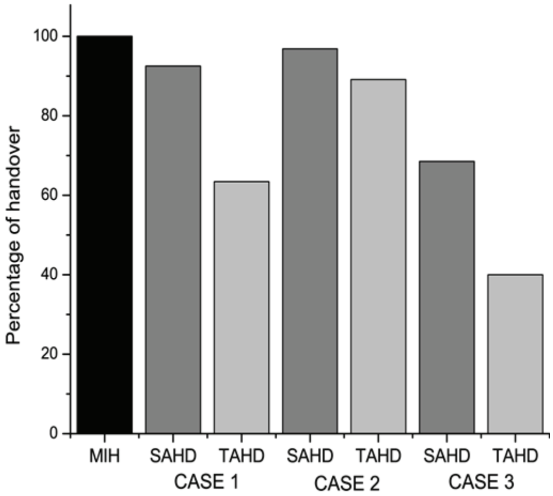

Fig. 19. Percentage of handover occurred in each VHO method.

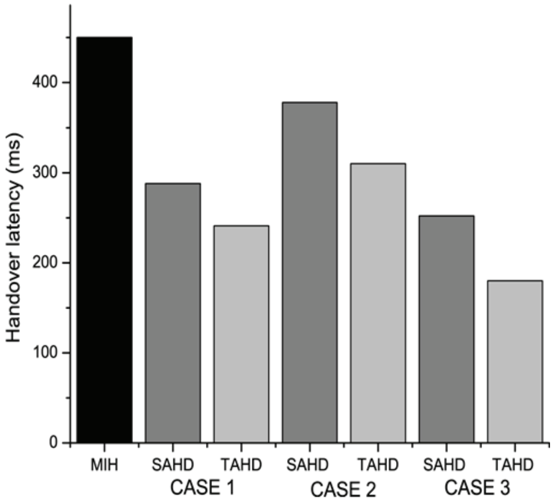

Fig. 20. Handover latency observed in each VHO method.

6.4 Handover Latency

Handover latency is the time of service interrupted during VHO on the wireless overlay networks. The variation in handover latency was measured in three different cases and the results are presented in Fig. 20. Total handover latency in TAHD and SAHD was significantly less than for a pure IEEE 802.21 because the unnecessary association with different networks was reduced. In our simulations, the reduction of latency in TAHD was approximately 50% in all cases; whereas, SAHD reduced up to 32%. This verifies that TAHD performs best in all cases.

7. Conclusion

In a heterogeneous wireless network, the VHO operation is required to provide the preferred low cost and large bandwidth network. For the VHO decision, handover information discovery related to network metrics has been discussed a lot in the literature so far. In this paper, we focused more on how to combine a standard VHO framework, such as IEEE 802.21, with network metrics selected for a VHO decision. Also, the simulation method on NS-2 was described for an IEEE 802.21-based VHO. The selected network metrics (i.e., RSS, SINR, and OB) were compared to find the best target network from among the neighboring candidate WLAN networks. We used and evaluated two metrics (SINR and OB), both jointly and solely, for the downward VHO decision. Through our simulations, we figured out that the proposed IEEE 802.21 schemes using SAHD and TAHD provide high throughput, unwanted handover reduction, and low handover latency as compared to the MIH handover method that is based on RSS. This is due to the fact that the signal strength does not provide enough information about the status of the candidate network links. Specifically, TAHD, using both SINR and OB, works better at maximizing network resource usages than SAHD using SINR. This achievement was obtained in TAHD by using information about the amount of bandwidth used and physical channel quality. These selected parameters can be also combined with other parameters, such as packet loss ratio, power consumption, and monetary cost of service, to find the best quality WLAN channel and provide a QoS effective VHO.

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