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"A Bandwidth Based Adaptive Fuzzy Logic Handoff in IEEE 802.16 and IEEE 802.11 Hybrid Networks"
by Jing Nie, Liaoyuan Zeng, Jiangchuan Wen
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A Bandwidth based Adaptive Fuzzy Logic Handoff in IEEE 802.16 and IEEE 802.11 Hybrid Networks

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Abstract

The future wireless Internet is expected to consist of different types of wireless networks with different coverage range. The hybrid network of WLAN and WMAN can take advantage of them to offer high quality service. In this paper, we propose a scheme to make handoff in IEEE 802.16 and IEEE 802.11 hybrid networks. The metric is the bandwidth of network level. The proposed algorithm is a bandwidth based adaptive fuzzy logic algorithm that can adapt itself with the dynamic conditions of the hybrid networks. It uses mobile host's speed and traffic in the WLAN as input fuzzy variables. This algorithm is designed to meet special requirements of hybrid networks. The scheme can reduce the unnecessary handoff probability because of the signal strength temporary dropping down or the high speed of mobile host. This handoff algorithm has much better performance than conventional algorithms and can be extended to other heterogeneous networks.

1. Introduction

Based on IEEE 802.11 standard, the companies and families can connect to the Internet in a limited range only with an access point (AP), which has accelerated the network deployment. Similar to IEEE standard 802.11, IEEE 802.16 [1] [2] includes a serial of standards. At the lower ranges, the signals can penetrate barriers and thus do not require a line of sight between transceiver and antenna. This enables more flexible in WMAN implementations while maintaining the technology's data rate and transmission range.

The limited coverage range of WLAN makes it difficult to fulfill the future networks' character of connecting to the network anywhere and anytime. IEEE 802.16 can provide high speed internet access in wide area. A natural trend is the combination of IEEE 802.16 and IEEE 802.11 to create a complete wireless solution for delivering high speed Internet access to businesses, homes and hot spots. The system is to utilize high bandwidth provided by IEEE 802.11 networks and the wide coverage range of IEEE 802.16 networks. Figure 1 shows the relation between the two heterogeneous networks.

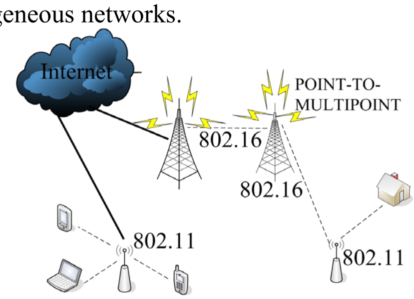

Figure 1. The model of hybrid network consisting of IEEE 802.11 networks and IEEE 802.16 networks

In WMANs, when a mobile host (MH) moves away from a base station the signal level degrades and there is a need to switch to another base station. Handoff is the mechanism by which an ongoing connection between MH and its correspondent host is transferred from one point of access to the fixed network to another. In WMANs, such points of attachment are referred to as base stations (BSs) and in WLANs they are called access points (APs).

There are two types of handoff in networks: horizontal handoff and vertical handoff. Normally, the switch between base stations or access points in the homogeneous wireless system is named as horizontal handoff. Correspondently, the switch between heterogeneous networks is named as vertical handoff. For example, the handoff inside the WLAN is horizontal handoff and the handoff from WLAN to WMAN is vertical handoff.

At present, there are some works on vertical handoff. In [4], a mobile-IP-based architecture and a mobility gateway/proxy-based architecture were proposed. However, there is no detailed handoff decision algorithm in this paper. In [5], Inayat et al. proposed a seamless handoff for dual-interfaced mobile devices in WLAN and GPRS hybrid wireless access networks, which utilizes the signal-to-interference ratio of physical level to decide the handoff. In [6, 7], a seamless and proactive end-to-end mobility

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management system was presented, which can maintain the connections based on the end-to-end principle by incorporating an intelligent network status detection mechanism. But all the solutions have not shown the handoffs between two high bandwidth networks.

The rest paper is organized as follows. Section 2 introduces four types of handoff in hybrid networks consisting of WLAN and WMAN. Some challenges of the vertical handoff between heterogeneous networks are analyzed in Section 3. Section 4 introduces a conventional handoff algorithm based on received signal strength (RSS) for hybrid networks. Bandwidth algorithm of IEEE 802.16 network and IEEE 802.11 network is deduced in section 5. A bandwidth based adaptive fuzzy logic handoff approach in IEEE 802.16 and IEEE 802.11 hybrid network is proposed in section 6. The handoff mechanism is analyzed in section 7. Section 8 concludes this paper.

2. Handoff in hybrid networks

In hybrid network, which consists of large WMAN cells and several small WLAN cells inside of them, handoff may take place in four cases (Figure 2) [4-9].

1) Handoff from a WMAN to a WLAN (case 1)
2) Handoff from a WLAN to another WLAN (case 2)
3) Handoff from a WLAN to a WMAN (case 3)
4) Handoff from WMAN to WMAN (case 4)

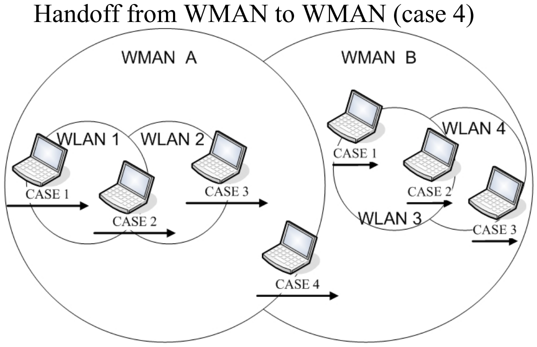


Figure 2.Handoffs in WMAN and WLAN hybrid network

When MH in the coverage of a WMAN enters a WLAN, handoff from WMAN to WLAN occurs (case 1). Even though the RSS from the WMAN is usually greater than WLAN, this type of handoff is done with high priority since connecting to WLAN is more desirable because it provides more bandwidth and is cost effective and power efficient and reduces interference in the mobile network. But when WLAN has heavy traffic or the MH velocity is too high, it's better not to make handoff to WLAN. When MH leaves WLAN coverage and enters another WLAN, handoff from WLAN to WLAN occurs (case 2). When MH leaves WLAN coverage and enters a WMAN, handoff from WLAN to WMAN occurs (case 3). This type of handoff is done with low priority and it's desirable that MH remains connected to WLAN as long as possible. Finally, when MH leaves the coverage area of a WMAN and enters another WMAN, handoff from WMAN to WMAN occurs (case 4).

Handoff from a WMAN to a WLAN (case 1) and handoff from a WLAN to a WMAN (case 3) are vertical handoffs. Handoff from a WLAN to another WLAN (case 2) and handoff from WMAN to WMAN (case 4) are horizontal handoffs.

3. The challenge in vertical handoff

IEEE 802.16 and IEEE 802.11 work at different frequencies band and have different bandwidths. IEEE 802.16 networks connected to the Internet with base stations and use point-to-multipoint technique in MAC layer. In IEEE 802.11 networks, the points of attachment to the internet are access points and MAC protocol is based on carrier sense multiple access with collision avoidance (CSMA/CA).Compared with the horizontal handoff, the vertical handoff faces some challenges to roaming across the heterogeneous networks because of the differences [6]:

- When a mobile host moves from WMAN to WLAN, the handoff cannot be triggered by the conventional way of monitoring connection quality through the physical layer measurement since no sign of losing the connection will be detected.
  Some decision algorithm based on subjective criteria such as personal preference, connection qualities, or cost may be necessary for the handoff from IEEE 802.16 network to IEEE 802.11 network.
- In vertical handoff between WMAN and WLAN, there is no comparable signal strength available to aid the decision as in horizontal handoff because the received signal strength samples from WMAN and WLAN are heterogeneous quantities that cannot be compared directly.
- During a handoff procedure, the metrics, which upper-layer applications are really interested in, are network conditions, rather than the physical layer parameters such as received signal strength and signal-to-interference ratio.
- IP handoff completion time is much uncertain in heterogeneous networks, which adds extra complexity to estimate IP handoff timing correctly.

What has been presented in the above shows that the configurations of handoff threshold and timing variables become hardly successful in vertical handoff. A new proactive and adaptive perspective to decide the handoff threshold and timing is required in heterogeneous wireless networks.

4. Conventional handoff algorithm

In this section, a conventional handoff algorithm, which is based on RSS threshold, is presented. Figure 3 illustrates the algorithm.

First, in sampling intervals RSS values are measured and their averages are computed in the averaging window. Then, handoff initiation mechanism indicates if handoff process will be started or not. This mechanism, when the current cell is a WLAN, compares current RSS (RSSc) with a threshold value (TH_L), if RSSc is less than TH_L, handoff will be started. When the current cell is a WWAN, this mechanism will start handoff in two cases: either current RSS (RSSc) is less than a threshold (TH_W) or RSS from a WLAN is more than a threshold (TH_L). If handoff is started, cell selection mechanism selects best available WWAN ("W") and best available WLAN ("L") by comparing all RSS values. The handoff decision mechanism is the main part of the algorithm.

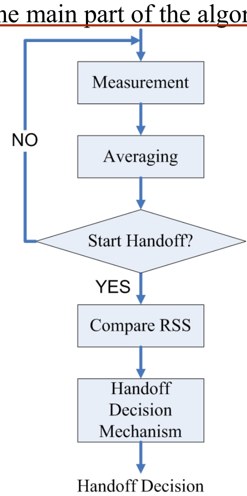


Figure 3. Conventional handoff algorithm

This conventional algorithm cannot meet many requirements of hybrid networks. It doesn't have minimum number of handoffs and short handoff delay since it uses a fixed RSS averaging window. For a fixed averaging window, if MH velocity is high, handoff delay is long and this delay may result in poor signal quality and possibly disconnection before making handoff, but if mobile host velocity is low, handoff delay is short and number of unnecessary handoffs is increased. So a fixed averaging window only in a certain velocity has optimum performance. In addition, this algorithm doesn't consider traffic conditions in the WLAN, also it doesn't prevent fast users from connecting to WLAN.

5. Bandwidth of IEEE 802.16 network and IEEE 802.11 network

Theoretically IEEE 802.16 [1, 2] can provide single-channel data rates up to 75 Mbps on both the uplink and downlink, but it is less in practice especially with users and traffic increasing. The IEEE 802.11n technology is based on MIMO-OFDM and its maximum data rate is 110 Mbps. Consequently, we can use IEEE 802.16 networks to provide a wireless alternative to cable, DSL and T1/E1 for last mile broadband access to the Internet and IEEE 802.11 networks to provide last 100 meters broadband access to the Internet in hot spots.

Triggered by the MAC layer can initiate registration before the handoff of network layer, which reduces the access delay and aids the handoff decision for better connectivity [3]. The bandwidth cannot be obtained directly from MAC layer. Instead, we can get some indirect information, e.g., by listening to and collecting the network allocation vector (NAV) in MAC layer. NAV [3] is the main scheme used in IEEE 802.11 to avoid collision by setting a busy duration on hearing frame transmissions from other mobile hosts. Thus, the NAV can well reflect the channel busy status.

The available bandwidth and access delay from the NAV for the IEEE 802.11 with DCF mode (Figure 4) is as follows [7].

$$BW_L = B_0 - \lambda L = B_0 - L\frac{NAV}{T_n + \frac{T_{n,c}(N-1)}{2}} \qquad (1)$$

Where L is the mean frame size, B_0 is the total system bandwidth, T_n is the NAV duration for a successful frame transmission, $T_{n,c}$ is the duration for a collision and N is the average number of trials of a transmission.

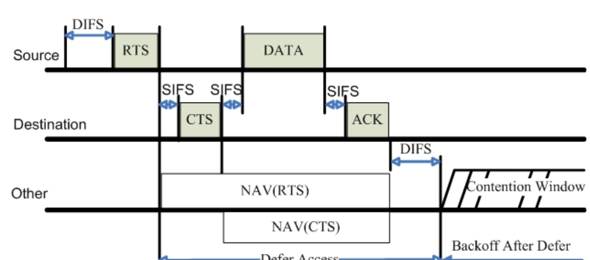


Figure 4. IEEE 802.11 with DCF mode

IEEE 802.16 [1, 2] technology allows different levels of QoS to be applied to the different connections carrying MAC management traffic. Increasing (or decreasing) bandwidth requirements are necessary for all services except incompressible constant bit rate UGS connections. The requirements of compressible UGS connections may increase or decrease depending on traffic. Demand Assigned Multiple Access (DAMA) services are given resources on a demand assignment basis, as the need arises. When an SS needs to ask for bandwidth on a connection with BE scheduling service, it sends a message to the BS containing the immediate requirements of the DAMA connection. QoS for the connection was established at connection establishment and is looked up by the BS. The bandwidth that the 802.16 network assigns to the mobile host is supposed to be BW_W.

6. Bandwidth based adaptive fuzzy logic handoff algorithm

When a mobile host connected to the Internet moves into a new IEEE 802.11 network, it would like to change the connection to WLAN to obtain higher bandwidth. Since the WMAN is always on, the handoff cannot be triggered by signal decay of the IEEE 802.16 network. We can utilize the bandwidth as handoff metric.

In this section the adaptive fuzzy logic based handoff algorithm for hybrid networks [8] is presented. Figure 5 depicts the algorithm. The difference from the conventional decision mechanism is that, here the metric is bandwidth not RSS and HYS_L and HYS_W values are updated by a fuzzy logic system.

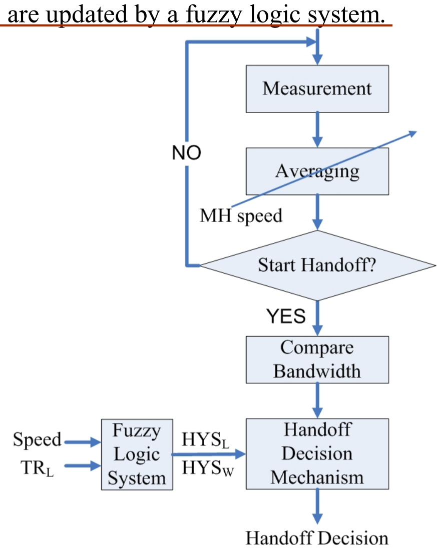


Figure 5. Bandwidth based adaptive fuzzy logic handoff algorithm for hybrid networks

Handoff decision mechanism is illustrated in Figure 6 and Figure 7.

1) When the current cell is a WMAN (Figure 6), since the priority is to make handoff to WLAN, first bandwidth of the suggested WLAN is checked. If BW_L exceeds the threshold (TH_L) by an amount HYS_L, handoff will be done to the best WLAN; otherwise handoff to the best WMAN is investigated. If BW_W exceeds the current bandwidth (BWc) by an amount HYS_W, handoff is made to the best WMAN, otherwise no handoff occurs.

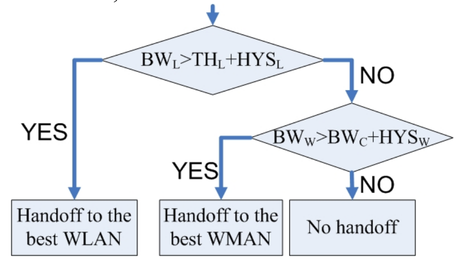


Figure 6. Handoff decision method (current WMAN)

2) When the current cell is a WLAN (Figure 7), first the best WLAN is investigated. If BWL exceeds BWc by an amount HYSL, handoff will be done to the best WLAN; else an attempt is made for handoff to the best WMAN. If BWW exceeds THW by an amount HYSW, handoff will be done to the best WMAN, otherwise no handoff occurs.

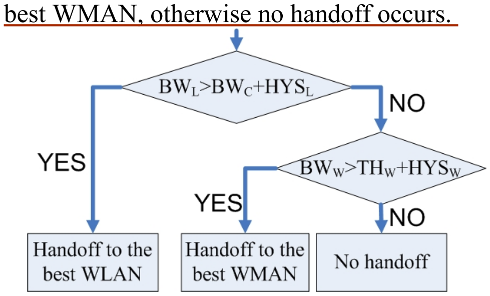


Figure 7. Handoff decision method (current WLAN)

In this algorithm mobile host speed and traffic in the WLAN are used as input parameters. Methods for estimating the speed of mobile hosts, which are based on Doppler frequency, are proposed in [9]. Averaging window is adapted according to mobile host speed. When mobile host speed is high the window will be reduced, so the handoff delay is decreased. When the mobile host speed is low averaging window will be increased, so unnecessary handoffs are avoided. We define the initial value of mobile host speed is v_0 and the corresponding averaging window is w_0. The function of averaging window is $w(v)$, then

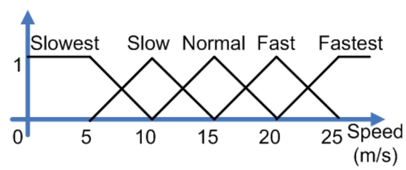
$$w(v) = \frac{v_0}{v} w_0 \qquad (1)$$

Where v is the variable of mobile host's speed.

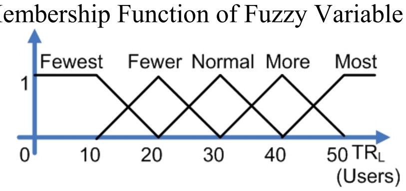
Inputs of the fuzzy logic system are mobile host's speed and traffic in the best WLAN (TR_L). The fuzzy logic system is designed to meet special requirements of hybrid networks. When the speed of the mobile host is fast or the traffic in the WLAN is heavy, handoff to WLAN should be discouraged; otherwise handoff to WLAN should be encouraged. The fuzzy logic system increases HYS_L and decreases HYS_W when handoff to WLAN must be discouraged and handoff to WMAN be encouraged. It decreases HYS_L and increases HYS_W when handoff to WMAN should be discouraged and handoff to WLAN be encouraged.

Figure 8 to 9 illustrate the membership functions of the input and output fuzzy variables.

1) The input fuzzy variable "speed" has five fuzzy sets: Slowest, Slow, Normal, Fast, and Fastest (Figure 8).
2) The input fuzzy variable "TR_L" has five fuzzy sets: Fewest, Fewer, Normal, More, and Most (Figure 8).



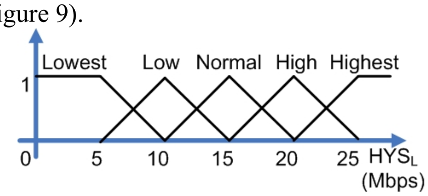
(a) Membership Function of Fuzzy Variable Speed



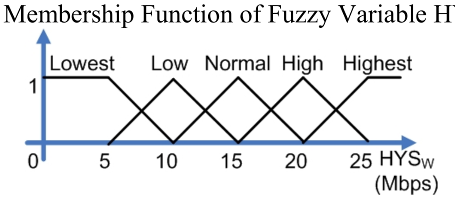
(b) Membership Function of Fuzzy Variable TR_L

Figure 8. Membership Function of Input Variable

3) The output fuzzy variable "HYS_L" has five fuzzy sets: Lowest, Low, Normal, High, and Highest (Figure 9).
4) The output fuzzy variable "HYS_W" has five fuzzy sets: Lowest, Low, Normal, High, and Highest (Figure 9).



(a) Membership Function of Fuzzy Variable HYS_L



(b) Membership Function of Fuzzy Variable HYS_W

Figure 9. Membership Function of Output Variable

It should be noted that modifying the membership functions will change the sensitivity of fuzzy logic system output to its inputs. Also increasing the number of fuzzy sets of the variables will provide better sensitivity control but also increases computational complexity of the system.

Table 1 shows the rules used in the fuzzy logic system. For example when speed has the "Fastest" value and TR_L is "Most", handoff to WMAN should be encouraged and handoff to WLAN should be avoided, so HYS_L is increased ("Highest") and HYS_W is decreased ("Lowest"), this is rule No. 1 in the table. When speed is "Slowest" and TR_L is "Fewest", handoff to WLAN should be encouraged, so HYS_L is decreased ("Lowest") and HYS_W is increased ("Highest"), this is rule No. 25 in the table.

Table 1. Fuzzy Logic System Rules

	INPUT		**OUTPUT**	
No.	**Speed**	**TR_L**	**HYS_L**	**HYS_W**
1	Fastest	Most	Highest	Lowest
2	Fastest	More	Highest	Lowest
3	Fastest	Normal	Highest	Lowest
4	Fastest	Fewer	High	Low
5	Fastest	Fewest	High	Low
6	Fast	Most	Highest	Lowest
7	Fast	More	Highest	Lowest
8	Fast	Normal	High	Low
9	Fast	Fewer	Normal	Normal
10	Fast	Fewest	Normal	Normal
11	Normal	Most	High	Low
12	Normal	More	High	Low
13	Normal	Normal	Normal	Normal
14	Normal	Fewer	Low	High
15	Normal	Fewest	Low	High
16	Slow	Most	Normal	Normal
17	Slow	More	Normal	Normal
18	Slow	Normal	Normal	Normal
19	Slow	Fewer	Lowest	Highest
20	Slow	Fewest	Lowest	Highest
21	Slowest	Most	Normal	Normal
22	Slowest	More	Normal	Normal
23	Slowest	Normal	Low	High
24	Slowest	Fewer	Lowest	Highest
25	Slowest	Fewest	Lowest	Highest

7. Analysis

When roaming across IEEE 802.16 and IEEE 802.11 hybrid networks, it is not reasonable to initial handoff soon when the WLAN service is available because both IEEE 802.16 networks and IEEE 802.11 networks can provide high bandwidth and good performance.

We utilize the bandwidth of WLAN and WMAN to make handoff decision. Triggered by the MAC layer can initiate registration before the handoff of network layer, which reduces the access delay and aids the handoff decision for better connectivity.

The handoff algorithm is a bandwidth based adaptive fuzzy logic algorithm that adapts the averaging window and the hysteresis values dynamically by using the mobile speed estimation and the traffic the WLAN as input parameters. This algorithm decreases handoff delay and number of unnecessary handoffs by changing the bandwidth averaging window according to mobile host's speed. The hysteresis values is updated according to mobile speed and the traffic in WLAN ,so it can meet special requirements of hybrid networks, such that the high speed users remain connected to WMAN and are prevented from connecting to WLAN. When WLAN traffic is heavy, handoff to WLAN is avoided. The handoff approach is able to void the unnecessary handoff.

The proposed handoff approach can meet the requirement of handoff in hybrid networks.

- Handoff is done fast and its delay is as less as possible.
- Number of handoffs is less, which avoids degradation in signal quality and additional loads on the network.
- Handoff procedure is reliable and successful and after handoff the signal quality is good.
- Handoff algorithm is simple and has less computational complexity.
- Usage of WLAN is as more as possible and handoff to WLAN is done with high priority, which can provide users more bandwidth and can save power and cost.
- Fast users remain connected to WMAN since WLAN is designed for low velocity users and has small coverage.
- When traffic in the WLAN becomes too high and overflow occurs, handoff to WLAN is avoided.

Therefore, the handoff method is reasonable to utilize it in WLAN and WMAN hybrid networks.

We can use IEEE 802.16 networks to provide a wireless alternative to cable, DSL and T1/E1 for last mile broadband access to the Internet and IEEE 802.11 networks to provide last 100 meters broadband access to the Internet in hot spots.

8. Conclusion

In this paper, handoff in hybrid networks which consist of IEEE 802.11 networks and IEEE 802.16 networks was investigated. The suggested algorithm, is a bandwidth based adaptive fuzzy logic algorithm that adapts the averaging window and the hysteresis values dynamically by using the mobile speed estimation and the traffic the WLAN as input parameters, so better efficiency in hybrid networks is achieved and special requirements of hybrid networks is met. Analysis shows that the proposed scheme can provide higher performance and reduce the unnecessary handoff probability.

This handoff scheme can be extended to other heterogeneous networks .We are currently working on the hybrid networks including IEEE 802.16 networks and ad hoc networks, IEEE 802.11 networks and ad hoc networks and so on into this prototype system. The QoS and security will be considered in future.

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