Providing Multiple Data Rates in Infrastructure Wireless Networks

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Abstract - **In this paper, we will discuss how to provide multiple-data-rate transmissions in a contemporary IEEE 802.11 infrastructure wireless network. According to the characteristics of modulation schemes, the highest data rate between a pair of mobile stations will be inversely proportional with the transmission distance. Therefore, a moving mobile station is requested to dynamically adjust its modulation scheme to achieve maximal network throughput as well as to keep the connection alive. In this paper, we will propose a hybrid handshake protocol with a simple broadcasting protocol to help mobile stations to obtain the necessary location information. The critical fairness problem of multi-rate wireless network is also being discussed and solved in this paper.**

1. Introduction

So far, the adaptive transmission techniques are often used to enhance the transmission performance in either wired or wireless communications. The basic concept of these techniques are varying the transmission power, transmission packet length, coding rate/scheme, and modulation technology over the time-varying channel. In [1], authors proposed the concept that throughput would be improved by permitting mobile stations, which near the center of the cell, to use the high-level modulation scheme. In contract, mobile stations near the fringes of cell must adopt a low-level modulation to cope with the lower signal-to-noise ratio (SNR).

The same concept has also been applied on the IEEE 802.11 wireless local area networks (WLANs) [2,3]. Companies Harries and Lucent had proposed high data rate modulation scheme "Complementary Code Keying" (CCK) [4,5]. The IEEE 802.11 working group finally adopted CCK to support data rate up to 11Mbps. To provide the interoperability with existing 1/2Mbps networks, Harris proposed a baseband processor, which has the ability to provide four different modulation schemes (DBPSK/DQPSK/CCK/MBOK) and four data rates (1/2/5.5/11Mbps) in contemporary WLAN. In a WLAN with multiple data rates, all mobile stations (MS) should insist on using the highest-level modulation scheme to achieve the maximal channel utilization. However, it is hard to achieve the highest data rate all the time since the data rate is inversely proportional with the transmission distance between a pair of MSs. The general concept is that a high-level modulation scheme requires a higher SNR to obtain the same specified BER in respect to a low-level modulation scheme. Consequently, only when the transmission distance between transmitter and receiver is short enough, the maximal data rate will be obtained. Paper [2] illustrates the relationships between data rate and transmission distance in WLAN as shown in Figure 1.

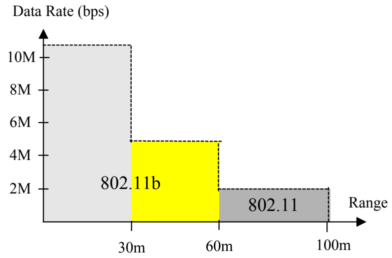

Figure 1. The data rate versus transmission range in IEEE 802.11 standard.

Since there are two types of network configurations defined in the IEEE 802.11 standard [6]. One is called as *Ad Hoc* WLAN and the other is the called as *infrastructure* WLAN (IWLAN). An IWLAN connects MSs to a wired network via access point (AP). Basically, the AP is a fixed station that provides MSs the access to the Distribution System (DS). In the case of two neighboring MSs desire to communicate to each other, their packets have to be relayed by AP no matter how close they are.

In our previous work [7], such multi-rate and multi-range WLAN is denoted as "Tower of Hanoi" networks (THN) as shown in Figure 2 where the 'coverage range' and 'data rate' of modulation scheme can be treated as the 'size' and 'height' of plate. (In the "Tower of Hanoi", the height and the size of plates are gradually reduced and increased from inner to the outer respectively.) This is because that a modulation scheme with shorter (longer) transmission range will provide a higher (lower) data rate. Therefore, a MS in IWLAN network may dynamically change its modulation scheme according to the distance between AP and itself. To do this, a MS needs be aware of such distance information to make a right decision. This introduces the location detection problem (LDP) [7]. Besides, the inner-side MS will share a more bandwidth quota than an outer-side MS. We name this unfairness as the network fairness problem (NFP) in THN. Unfortunately, the standard did not pay any attention on these two problems. In this paper, we will propose a hybrid handshake protocol with the broadcasting protocol for solving the LDP and Sub-Frame Period Assignment Strategy for NFP in THN.

The rest of this paper is organized as follows. The system model is described in Section 2. In Section 3, we will describe problems LDP and NFP in THN. The frame format of designed protocol is addressed in Section 4. In Section 5, we will describe the analytic method of guaranteeing the fairness among MSs. Section 6 illustrates the simulation

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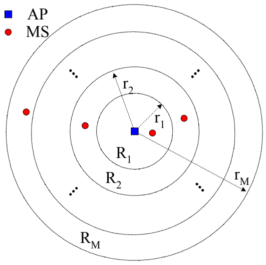


Figure 2. The network architecture of THN.

models, performance measures and simulation results. Finally, some conclusions are given in Section 7.

2. System Model of THN

If the WLAN adapter can provide M different modulation schemes, the THN can be logically segmented into M concentric circles surrounded with AP as shown in Figure 2. Let TR_i denote the highest data rate of the i-th modulation scheme with the distance restriction r_i ($1 \le i \le M$). We have $TR_m > TR_n$ and $r_m \le r_n$, $\forall m < n$ ($1 \le m,n \le M$). We further divide the THN into M disjoint regions: the innermost circle (R_1) and a number of M-1 'doughnut' like regions which are numbered as R_2, R_3,…, R_M from inner to outer. Let $l(i)$ denote the location of MS_i in THN. If MS_i locates in region R_j, we have $l(i)=j$ if $r_{j-1} \le d_i < r_j$, where d_i is the distance between MS_i and AP and $r_0=0$.

For simplicity, the transmission condition over wireless channel is considered as symmetry. A MS locates in R_j can transmit/receiver data to/from AP with the transmission rate TR_k if $r_k \ge r_j$. Generally speaking, MS in R_j can transmit data at the transmission rate TR_k ($j \le k \le M$). Therefore, we define a Boolean function $h(j,k)$ as follows:

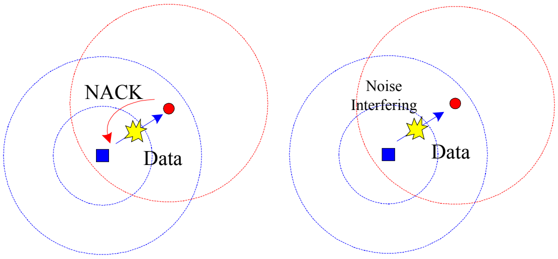
$$h(j,k) = \begin{cases} 1 & \text{if } r_j \le r_k \\ 0 & \text{otherwise} \end{cases} .$$

We can find that MS_i is allowed to transmit data at transmission rate TR_k only when $h(l(i),k)=1$.

3. Two Problems in THN

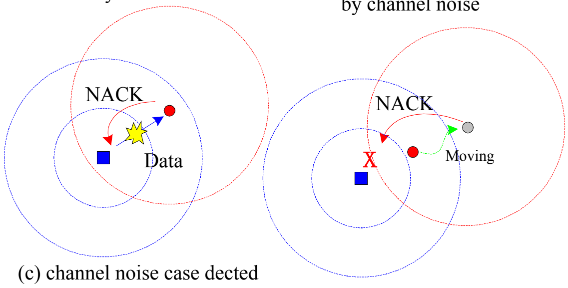
In THN, the distance between MS and AP may frequently change. This implies the network performance and transmission quality become quite unpredictable. When a MS moving toward AP, the network throughput can be further improved by using an adequate modulation scheme. Contrarily, the connection quality can also be guaranteed by adopting an adequate modulation scheme when the MS moving away from AP. The problem we need to solve is how to inform the MS the distance between AP and itself. Therefore, it is desired to design a new protocol to provide sufficient location information for MSs. In addition to the connection quality problem, how to maximal the network throughput is also an important problem. Therefore, in the following subsections, we will discuss these two interesting problems : location detection problem (LDP) and network fairness problem (NFP) in THN.

3.1. Location Detection Problem (LDP)



(a) channel noise case dected by HHP

(b) Transmission failed caused by channel noise



(c) channel noise case dected by HHP

(d) mobility case detected by HHP

Figure 3. Examples of transmission failed caused by the moving problem and channel noise in THN

In THN, once MS moves from one region to another region, it needs adjust its modulation scheme. Of course, the adjustment is relying on the region information provided by network. This can be done by slightly modifying the basic MAC protocol in IEEE 802.11.

3.1.1. Broadcasting Approach

Periodically, AP generates (broadcasts) the Beacon (B) and every MS must hear it to perform timing synchronization or to make the joining decision. In paper [7], a simple broadcasting approach has been proposed. In this approach, a number of M Sub-Beacons (SB) are also broadcast and are distributed between two consecutive Beacons. To provide the range information, these M SBs are broadcast with M modulation schemes one for each modulation scheme. They are broadcast in the order from the highest transmission rate to the lowest transmission rate in each cycle. Accordingly, MS locates in R_j will detect the SB at TR_k ($j \le k \le M$). By this methodology, MS can easily detect its location and use the best modulation scheme.

Even though broadcasting approach periodically updates every MS's location, it is still possible that a moving MS fails in transmission due to the late updating. In the following subsection, we will propose a hybrid handshake protocol to solve it.

3.1.2 Hybrid Handshake Protocol (HHP)

The simplest way of an MS to detect whether it has leave its original region is to monitor the transmission status. However, in real case, either channel noise or moving out transmission range will fail the transmission. An MS would confuse about what kind of situation happened. Traditionally, the handshake protocol is used to guarantee the success of transmission. Two categories of handshake protocols are often used: *positive/negative acknowledgements*. The former asks receiver to reply an ACK packet whenever it receives a

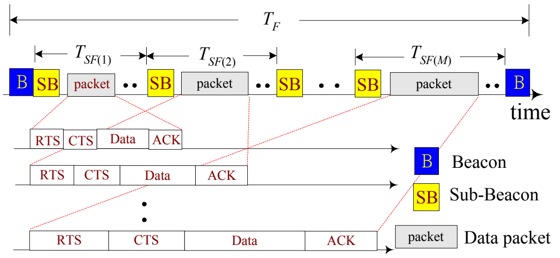


Figure 4. The frame format of THN.

correct data packet. The latter enforces receiver to reply an NACK packet only if an incorrect packet has been detected. Generally, the *positive acknowledgement* approach is more suitable for wireless networks. In this paper, we will employ both approaches for THN.

In standard, if transmitter MS_t wants to transmit data to receiver MS_r, the MS_t will first transmit RTS packet to MS_r. (of course, one of MS_t and MS_r is AP) When MS_r receives the RTS packet, it replies CTS packet to MS_t right away. After then, MS_t will start transmitting data to MS_r. At this moment, either MS moves away from its original region (Figure 3(a)) or the transmission is interfered by the noise (Figure 3(b)), the MS_r will fail in receiving data and it will not reply any ACK packet to MS_t. As soon as MS_t detects the failure, it will retransmit it. However, the retransmission process should be done in the case of channel noise. The hybrid handshake protocol makes the receiver reply ACK (NACK) packet in the case of successful (failure) reception. Therefore, MS_t will receive the ACK packet when the transmission is successful. Otherwise, MS_t will receive the NACK packet and it can retransmit the data in the same data rate (Figure 3(c)). (In this paper, we assume the control packets are hard to be corrupted due to their short packet length [3]) On the other hand, if the error is caused by the mobility, MS_t will not receive any packet even though the MS_r had transmitted the NACK packet (Figure 3(d)). This is because the distance between MS_t and MS_r is out of the transmission bound. Consequently, MS_t knows that MS_r already moves out previous range and the retry process must be terminated. For the sake of consistency, once MS finds that the modulation scheme is not suitable, it will stop the transmission until its new location (range) is detected. After detecting the new location, the MS would transmit data by using the new modulation scheme.

3.2. Network Fairness Problem (NFP)

Another unexpected side effect is that MSs in THN may share unequal bandwidth from time to time. This reason is the distance between MS and AP may different from each other. For a practical MAC protocol, the bandwidth should be equally shared. To achieve this goal, a frame-based MAC protocol with broadcasting approach is designed for THN.

In the frame-based protocol, each frame consists of M sub-frame periods and each sub-frame is allocated for one specified modulation scheme. In detail, all MSs in R_i will access channel during the i-th sub-frame with data rate TR_i. Since the number of user in a region is different from the others, the sub-frame period assignment will significantly affect the performance and fairness. In section 5, we will propose a fairness assignment strategy for THN.

4. The Frame Format of THN

Assume the channel is divided into frame F of duration T_F as shown in Figure 4. Each frame F is composed of one *Beacon* and M sub-frames (each sub-frame starting by *SB*). The *Beacon* carries the information of the frame, duration of each sub-frame and other network parameters. The *Beacon* is transmitted in the lowest transmission rate TR_M to make sure all MSs can receive the information.

Here, we define a Boolean function $\xi(j,k,s)$ to indicate whether the MS in R_j is able to transmit data with TR_k in sub-frame SF_s. Moreover, we define another Boolean function $\eta(i,k,s)$ to indicate whether MS_i can transmit data with transmission rate TR_k in SF_s. That is, we have $\eta(i,k,s) = \xi(l(i),k,s) \times h(i,k)$. In this paper, we only permit these MSs in R_j to access SF_j with the transmission rate TR_j. That is, we let $\xi(j,k,s)=1$ for all $j=k=s$.

5. The Sub-Frame Period Assignment Strategy (SFPAS)

The Markov chain model for the backoff window size in IEEE 802.11 standard is referred from [8]. The maximal backoff window size W_i of state i is defined as $W_i = 2^i W$, where $i \in (0,m)$ and W is the initial backoff window size of each transmission. Let τ_s be the probability that an MS transmits in a Slot_time (ST) of sub-frame SF_s and p_s be the probability that a transmitted packet collides with others in sub-frame SF_s. From paper [8], these two values of τ_s and p_s can be derived by solving the following two equations.

$$\tau_s = \frac{2(1-p_s)}{(1-2p_s)(W+1)+p_s\cdot W\cdot(1-(2p_s)^m)}\text{, and}$$

$$p_s = 1-(1-\tau_s)^{N_s-1},$$

where N_s denote the number of MSs having the right to access channel during SF_s. As mentioned above, we have

$$N_s = \sum_{k=1}^{M}\sum_{i=1}^{N}\eta(i,k,s).$$

We emphasize that, the AP can easily calculate the N_s by the defined authentication procedure in standard. Thus, we can calculate the probability P_s^{tr} that there is at least one transmission in ST within SF_s.

$$P_s^{tr} = 1-(1-\tau_s)^{N_s}.$$

Moreover, the probability P_s^S that the transmission is successful in a ST within SF_s can be obtained by the following equation.

$$P_s^S = \frac{N_s\cdot\tau_s\cdot(1-\tau_s)^{N_s-1}}{1-(1-\tau_s)^{N_s}}.$$

The mean idle slots $E[\Psi_s]$ between two consecutive transmissions in sub-frame SF_s can also be derived by

$$E[\Psi_s] = \frac{1}{P_s^{tr}}-1.$$

Now, we can obtain the normalized saturation throughput S_s of sub-frame SF_s as the fraction of the time that the channel is sensed busy by successful transmissions. That is

$$S_s = \frac{P_s^S \cdot E[T_s^{payload}]}{E[\Psi_s] + P_s^S \cdot T_s^S + (1 - P_s^S) \cdot T_s^{US}},$$

where T_s^S and T_s^{US} denote the average time intervals (in *ST*) of successful and unsuccessful transmissions in SF_s respectively. Since we use the hybrid handshake protocol, we have

$$T_s^S = T_{RTS} + T_{CTS} + T_{H_{PHY}} + T_{H_{MAC}} + E[T_s^{payload}] + T_{ACK} .$$
$$T_s^{US} = T_{RTS} + T_{NACK}$$

Notations T_X denote the transmission time of packet *X*, and $E[T_s^{payload}]$ denote the average time period of transmitting a packet in transmission rate TR_s. From previous definition, we obtain $E[T_s^{payload}] = L/TR_s$, where *L* is the average packet length.

For the *s*-th sub-frame, we define a parameter α_s to decide its proper $T_{SF(s)}$. This parameter α_s is defined as the desired sub-frame period with respect to the last sub-frame period $T_{SF(M)}$. Thus, we have $T_{SF(s)} = \alpha_s \times T_{SF(M)}$ $(1 \le s < M)$. In order to make the amount of transmitted bits of each MS is equal, the following equation must be satisfied :

$$\frac{\alpha_s \cdot T_{SF(s)} \cdot S_s \cdot TR_s \cdot ST}{N_s} = \frac{T_{SF(M)} \cdot S_M \cdot TR_M \cdot ST}{N_M},\ 1 \le s < M.$$

After performing reduction, we derive the following equation.

$$\alpha_s = \frac{N_s \cdot S_M \cdot TR_M}{N_M \cdot S_s \cdot TR_s}, \quad 1 \le s < M.$$

Given $T_{SF(M)}$, the other sub-frame period T_{SF} can be derived. In this SFPAS, the sub-frame period $T_{SF(M)}$ is defined as follows

$$T_{SF(M)} = C \times (2^m W + E[T_M^{payload}]),$$

where *C* is a positive integer. This definition will reserve sufficient bandwidth for users, which are located in region R_M, to transmit *C* packets if no collision occurs.

6. Simulation Model and Results

In this section, we consider two simulation models to evaluate the efficiency of proposed protocol. The first one is to evaluate the network fairness. Another one is designed for observing the mobility effects on throughput. For both simulation models, the simulation time is 10 million slot times. The other system parameters are listed in Table I.

Table I. Parameters of simulation.

Parameter	Nominal Value
Slot time (us)	20
Packet length (bytes)	2312
PHY header (bits)	192
MAC header (bits)	272
RTS length (bits)	160
CTS length (bits)	112
ACK length (bits)	112
NACK length (bits)	112
Beacon length (bits)	248
Sub-beacon length (bits)	248

In the first model, we assume there are 20 heavy loaded MSs in network and they are unequally located in three regions. To obverse the SFPAS's efficiency, the numbers of MSs in different regions are changed during the simulation time *T*. Five different combinations and proportion α of each sub-frame are listed in Table II.

Table II. The numbers of MS is regions and derived α.

	$0 - \frac{T}{5}$	$\frac{T}{5} - \frac{2T}{5}$	$\frac{2T}{5} - \frac{3T}{5}$	$\frac{3T}{5} - \frac{4T}{5}$	$\frac{4T}{5} - T$
Region 1	5	5	8	10	8
Region 2	5	10	7	8	10
Region 3	10	5	5	2	2
α_1	0.128	0.256	0.409	1.265	1.023
α_2	0.213	0.842	0.594	1.697	2.105

Figure 5 shows the simulation results when *C*=10. We can find that the average throughput of MS is very close each other no matter which region it locates. We also note that the average throughput of MS would be improved when more MSs are in the high transmission rate region. Figure 6 shows the throughput of each region when *C*=10. The maximal network throughput (4.5 Mbps) is derived when lots of MSs are locating in 11Mbps and 5.5Mbps regions. Figures 7 and 8 show the simulation results as *C*=3. From these figures, we conclude that the fairness is also depending on the factor *C*. In fact, a larger enlarge factor is, a highly fairness will be.

Figure 9 illustrates the network throughput derived by both simulation and analysis when *C*=10. The difference between these two curves is very small. This implies that network throughput analysis in SFPAS is a good measurement for evaluating the network performance.

6.1 The Mobility Effect

In the second simulation model, we demonstrate how the network performance affected by the mobility. We assume there are 15 fixed stations (generating background traffic) in network and they are fairly distributed among network. Moreover, we consider the number of MSs increasing from 12 to 33 in a step of 3. Each mobile station has the probability *mp* to move from one region to another region. The data arrival rate of each station is following Poisson distribution with mean 0.1. Figure 10 shows the network throughput versus the number of stations under different moving probability *mp*. Obviously, the network throughput is degrading as increasing *mp*. The reason is that once MS moves during transmission, the distance between the AP and itself may increase and the connection may be broken. Such retransmission will certainly degrade throughput.

7. Conclusions

In this paper, we pointed out two potential problems in the THN : the location detection problem (LDP) and network fairness problem (NFP). The former can be solved by proposed broadcasting approach with hybrid handshaking protocol. The latter problem is completely solved by the proposed sub-frame period assignment strategy (SFPAS). Simulation results demonstrated that the proposed strategies achieve a high network throughput as well as fairness under different network conditions and moving probabilities.

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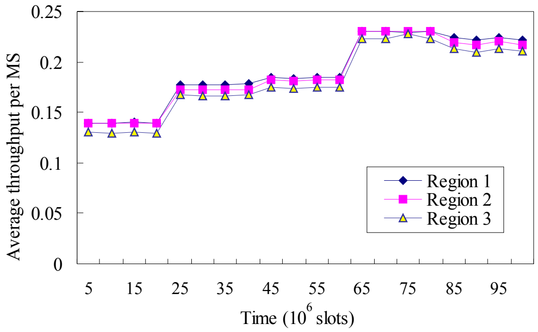

Figure 5. The average throughput of MS in each region when *C*=10.

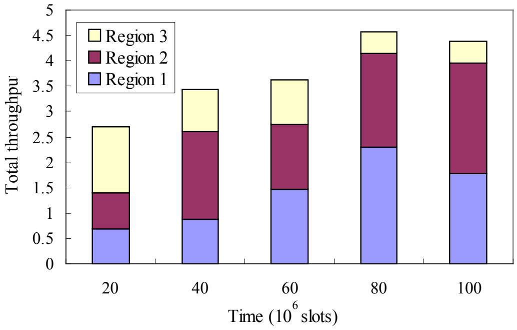

Figure 6. The summary throughput of MSs in each region when *C*=10.

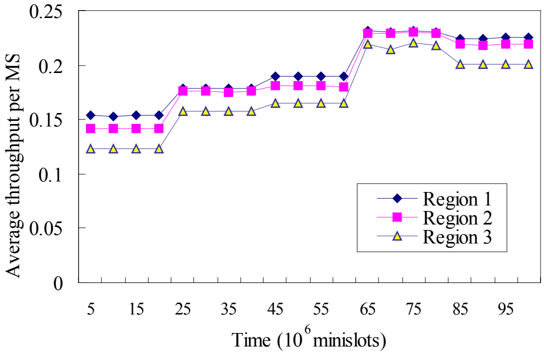

Figure 7. The average throughput of MS in each region when *C*=3.

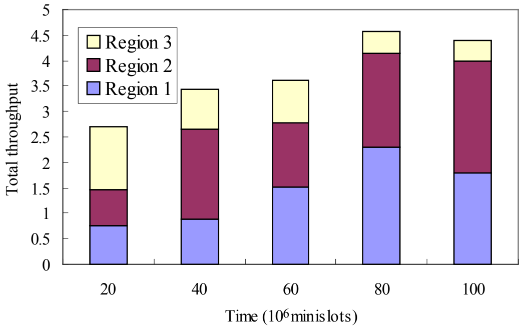

Figure 8. The summary throughput of MSs in each region when *C*=3.

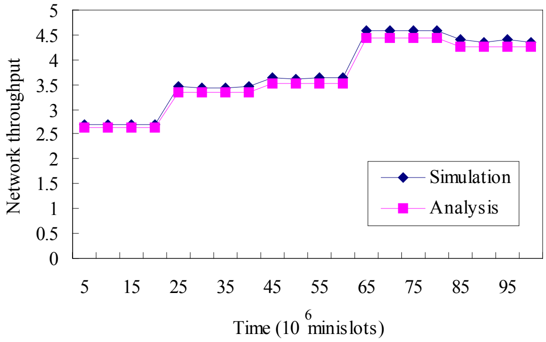

Figure 9. Comparisons of derived throughput and analyzed throughput when C=10.

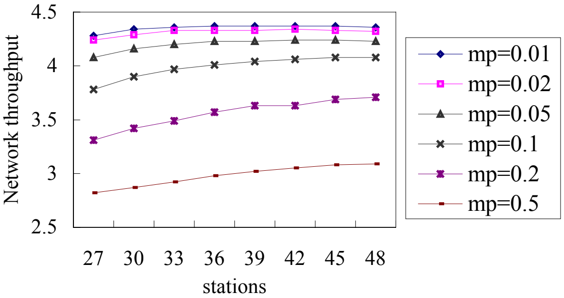

Figure 10. The network throughput under different Moving probability (mp).