A RELAXED PROBING RATE ADAPTATION IN IEEE802.11 WLANS

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Abstract: The availability of multiple rates in IEEE802.11 WLANs and instability of wireless channel conditions call for data rate adaption algorithms to optimize network performance. Rate adaption is the process of assessing instantaneous channel conditions and determining the most appropriate data rate. This paper presents a relaxed *probing* rate adaptation scheme to determine the most appropriate instantaneous data rate for both downlink and uplink channels, especially in the case where control frames such as RTS/CTS are not available. For this goal, the proposed scheme exploits the mandatory management *beacon* frame, thus without requiring probing frames like RTS/CTS necessary for other so far proposed schemes. Ns-2 simulations with IEEE802.11b of the proposed scheme yield more than 100% throughput improvement in high density networks. Also, simulations show that the proposed scheme is insensitive to beacon interval.

1 INTRODUCTION

Wireless signals are by nature instable and sensitive to distance and disturbances (e.g. other wireless source, temperature and humidity, etc.). Therefore, multiple rates (modulation schemes) are necessary to enhance wireless communications. When a wireless channel is in good condition, it can support high data rates, otherwise it requires more robust modulation schemes yielding low data rates. Rate adaptation is the process of estimating the instantaneous wireless channel conditions and then determining the most appropriate data rate the channel could support.

Generally, rate adaptation strategies can be categorized into *probing* or *non probing* channel schemes. Non probing rate adaptation algorithms usually are driven by some metrics such as frame loss rate that indirectly reflects the channel conditions. These adaptation schemes do not use control frames such as RTS/CTS to probe wireless channel conditions. Representatives of this category include *Auto Rate Fallback* (Kamerman and Monteban, 1997), and *Adaptive Auto Rate Fallback* (M. Lacage, M. Manshaei, and T. Turletti, 2004). These schemes increase the data rate if multiple consecutive data frames are successfully transmitted. If the data frame transmission fails for several times, then the data rate is decreased. These schemes are appealing because they do not require control frames to probe the channel conditions.

For *probing* rate adaptation schemes, the sender sends out a probing frame such as RTS, and then gets a feedback frame from a receiver to complete the negotiation of an appropriate data rate. Proposals Sadeghi, *et al* (B. Sadeghi, V. Kanodia, A. Sabharwal, and E. Knightly, 2002), Qiao, *et al* (D. Qiao, and S. Choi, and K. Shin, 2002), Pavon and Choi (Pavon and Choi, 2003), and Holland *et al* (Holland et al., 2001) are typical probing schemes. Probing data rate schemes estimate better the channel state than non probing schemes because non probing schemes get an implicit information on the channel condition. Moreover, the implicit information may be misleading. For example, the schemes that monitor frame loss rate conclude that channel conditions are poor when the frame loss rate increases. This may be wrong if frames are lost due to congestion. The disadvantage of probing schemes is that probing frames incur some communications overhead.

This paper proposes a relaxed probing data rate adaptation scheme. The key difference between

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the proposed scheme and other probing schemes is the channel probing mechanism used. The proposed strategy does *not* use probing frames such as RTS/CTS that are required by the other schemes, but rather exploits the mandatory broadcast *beacon* frame. Note that RTS/CTS control frames are optional in IEEE 802.11 standard and are not always used, especially for short data frames. The contributions of this work are: 1) a beacon based probing data rate scheme. This scheme is characterized as “relaxed” because it does not require control frame overhead such as RTS/CTS; 2) rate estimation for the very first frame of a communication session ; 3:) this work evaluates the impact of beacon interval on the accuracy of the proposed data rate adaptation scheme.

The remaining of this paper is organized as follows: Section 2 outlines the related work in data rate adaptation. Section 3 discusses the motivation. Section 4 details the proposed scheme. The simulation results are presented in Section 5. Section 6 concludes this paper.

2 RELATED WORK

Data rate adaptation has been extensively studied in last several years in wireless networks from advanced CDMA network (Bender and et al, 2000) to wireless local area network like IEEE802.11 (IEEE802.11, 1999). Non probing data rate adaptation schemes estimate the data rate without using probing frames such as RTS/CTS frames. For example, Auto Rate Fallback (**ARF**) (Kamerman and Monteban, 1997) was proposed for Lucent WaveLan-II WLAN product. In this protocol, the data rate adaptation is completed independently at the sender side without any information from the receiver. When the sender fails twice to transmit a data packet, it automatically decreases (falls back) its data rate to the next lower level, (for instance from 5.5 Mbps to 2 Mbps). If the transmission succeeds for ten consecutive times at the same data rate, the sender infers that the channel condition is good enough to support higher data rates and thus increases its data rate to a higher level. **ARF** definitely suffers from data rate fluctuations. For instance, when the channel condition is good for 5.5 Mbps, but not good enough for 11 Mbps, the sender will successfully transmit ten consecutive times at 5.5 Mbps. Therefore, the sender will increase the data rate to 11 Mbps and will likely fail transmissions at that rate, leading to a decrease to 5.5 Mbps. This scenario will likely repeat itself leading to fluctuations.

In Receiver Based Rate Adaptation (**RBRA**) (Holland et al., 2001), the authors propose a probing algorithm to adapt the data rate with the cooperation from the receiver. This protocol requires the exchange of RTS/CTS control frames between sender and receiver stations before data/acknowledgement packets are transmitted. The RTS and CTS control frames are transmitted at the lowest rate so that they are accessible to all stations in carrier sense range. When the receiver gets the RTS, it determines the best data rate that it can support under current wireless channel conditions, based on physical layer measurements. Then it feeds back the selected data rate embedded in the CTS frame. This proposal can work in both WLAN and Ad Hoc networks as long as control (probe) frames such as RTS/CTS precede the data frames.

A hybrid algorithm named Full Auto Rate (**FAR**) (Z. Li, and A. Das, and A.K. Gupta and S. Nandi, 2005) integrates probing and non probing concepts to achieve full data rate adaptation. The authors of FAR argue that receiver based protocols like **RBRA** (Holland et al., 2001). can dramatically be improved if the RTS/CTS can be transmitted at an appropriate data rate that the wireless channel can support rather than at some heuristic or lowest rate. Thus, it determines the rate for RTS/CTS control frames transmission using a non probing scheme.

In a previous work (Wu and Biaz, 2007), we propose to estimate the initial rate by sniffing the periodic beacon frame for the first time. This work differs from that one in three aspects: first, we consider the data rate estimation for both downlink and uplink of the wireless channel; Second, we evaluate the impact of beacon period on the rate estimation accuracy; Third, we compare the role of different coefficients in the adaptive estimation of the data rate.

3 PROBLEM FORMULATION

Although the rate adaptation is well studied, there still exists some unaddressed problems.

3.1 Problem #1: How to Probe without RTS/CTS Control Frames?

In wireless network, when two nodes that can not sense each other transmit to the same receiver, the transmissions get collided at the receiving station. This is called hidden terminal problem. To mitigate such collision, In IEEE802.11 networks, RTS/CTS is introduced to clear the channel before the data frame. However, RTS/CTS control frames are pure overhead for data frames. These control frames are *optional* and are recommended only for large data frames. If a data frame is small, (which is highly possible in real time applications such as VoIP, video and so on,) the use of RTS/CTS dramatically increases the overhead. According to Garg and Kappes (Garg and Kappes, 2003), if a unique 802.11b station transmits VoIP traffic with 160 byte frames, the data packet efficiency drops to about 12% in 802.11b (IEEE802.11b, 1999) networks at 11 Mbps with RTS/CTS control frames. Therefore, RTS/CTS frames are recommended only when the size of data packet exceeds a certain threshold (2347 recommended in IEEE 802.11). For communications not using RTS/CTS frames, most probing data rate adaptation schemes can not work as they require RTS/CTS frames. However, probing schemes can estimate the data rate more promptly and accurately than non probing schemes. Therefore, communications not using RTS/CTS frames call for a new probing scheme with minimal overhead.

3.2 Problem #2: Rate Adaptation for RTS/CTS Frames

In multi-rate IEEE802.11, the recommended rate for the control frames RTS/CTS is the lowest data rate so that they can be captured by every station in transmission range. Full Auto Rate (Z. Li, and A. Das, and A.K. Gupta and S. Nandi, 2005) scheme has analyzed and concluded that throughput improvement can be achieved if the RTS/CTS frames are transmitted at an appropriate data rate, rather than at the lowest data rate. Thus, a well-predicted instantaneous data rate for RTS/CTS benefits the entire network performance.

3.3 Problem #3: Rate Adaptation For First Transmission

None of the data rate adaptation schemes addresses the estimation of the data rate at the very beginning of a communication. Suppose station *X* wants to initiate packet transmission to station *Y*. If station Y is inactive for a long time (e.g. several minutes), the sender station *X* is unaware of the link status to station *Y*. It does not know which data rate is suitable to restart transmissions. Thus, the initial data rate must be somehow estimated.

To address the above problems, this work proposes a relaxed probing data rate adaptation scheme based on the periodic *Beacon* frame. Note that although the simulation is based on IEEE 802.11 standard, this strategy is also applicable to all other wireless networks with periodic broadcast frames.

4 PROBING RATE ADAPTATION WITH BEACON

This section details the procedure of the proposed data rate adaptation with beacon frame. The adaptation of *initial* data rate consists of uplink and downlink rate adaptation depending on the location where rate adaptation occurs (at access point or client station). Uplink is denoted as the wireless link from a client station to its access point. And the downlink refers to the opposite direction. After the initial transmission, either the access point or the client station can adapt the data rate based on received data or acknowledgement frames.

4.1 Uplink Initial Rate Adaptation

When a client station needs to initiate a communication to its access point, it has to adopt an appropriate data rate for the initial transmission. In a 802.11 WLAN, the beacon is a mandatory management frame. It is broadcast periodically by an access point for synchronization and association purposes. Therefore, this periodic frame offers an opportunity for the wireless client stations to estimate the uplink data rate. Since the beacon frame is mandatory, it does not introduce any overhead for channel condition probing. When a client station receives the beacon frame, it retrieves the statistics of the channel conditions (e.g. signal to noise ratio, signal strength, and error rate) from the physical adapter. Based on such wireless channel information, the client station can determine the best data rate and record it for immediate or future use. The recorded information includes the modulation level or data rate and the time when the last beacon was received. When this station needs to transmit a data frame, it looks up for the data rate it can use. Then it instructs the physical layer to transmit the data packet with the appropriate modulation. This scheme is especially accurate for slow fading channels. Although such estimation might be out of date for fast fading channels in case of long beacon interval, it is still better than a random selected initial rate.

4.2 Downlink Initial Rate Adaptation

While there are beacon frames from an access point to the client stations there are none towards the access point. If the access point needs to initiate a transmission to a particular client station, two options are possible: the first is the lowest data rate, and the second is the rate most recently used. Furthermore, if the lowest rate is selected, we propose to fragment the first data frame so that the length of the short fragment is equal to the length of an RTS frame. This short fragment functions as a channel reservation and probing as RTS does. Since the the frame is short, even it is transmitted at the lowest rate, the transmission time is negligible and does not impact much the network performance. Then, the new data rate for the remaining large fragment can be estimated from the acknowledgment frame.

4.3 Adaptive Rate Adaptation After Initial Rate

After initial rate is adopted, both the access point and its client stations can adapt their transmission rate from the exchanged frames. Also, the client station still can adapt its data rate from the periodic beacon. We propose an adaptive algorithm for the ongoing communications.

For instantaneous data rate adaptation, if the rate is estimated only from the last received frame, the data rate will fluctuate due to instantaneous channel condition variations. The performance suffers especially when a mobile station is experiencing the ping-pong effect in handoff, where the data rate might fluctuate between two levels of rates. This results in costly (in power) retransmissions. Multiple spurious retransmissions definitely hurt the network performance. Therefore, to solve the above data rate fluctuations problem, the data rate should be adjusted from the latest frame, but adaptively from multiple past frames information.

Compared to the available discrete data rate levels(e.g. 2, 5.5, 11.), channel statistics like signal strength has better granularity for adaptive algorithm. Thus, signal strength is employed in the following formula. An adaptive low pass filter coefficient is introduced to smooth signal strength impacted by the wireless channel upon history signal strength information.

$$RSSI_t = (1-\alpha) * RSSI_{t-1} + \alpha * rssi \qquad (1)$$

where $0 < \alpha < 1$.

Here, the $RSSI_t$ is the adopted signal strength. It predicts the channel variation trend. $rssi$ is the instantaneous signal strength obtained from a received frame.

α is further dynamically updated as follows:

$$\alpha = \frac{rssi - Threshold_{low}}{Threshold_{high} - Threshold_{low}} \qquad (2)$$

$Threshold_{low}$ and $Threshold_{high}$ are the signal strength thresholds for the current rate.

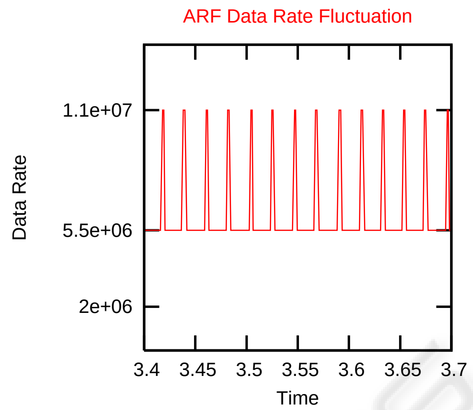

Figure 1: Auto Rate Fallback rate fluctuation.

5 SIMULATION RESULTS

Simulation configuration: Simulations are performed on ns-2 (NS2, 2006) version 2.30. Three levels of data rates are used: 11 Mbps, 5.5 Mbps and 2 Mbps. The data rate 2 Mbps is defined as the basic rate. Channel fading is configured as Ricean model. These simulations compare the proposed scheme against the **ARF** proposal and evaluate the impact of the beacon interval and the low pass filter parameters used in formula 1. The IEEE 802.11 cell is a 500mx500m square with the access point located at the center. The radio range is 250m. In all experiments, each client sends UDP CBR traffic to the access point at 4 Mbps.

Data Rate Smoothing: Figure 1 and Figure 2 show the data rate adaptation resulted from **ARF** and our scheme respectively. The channel condition is stable for 5.5 Mbps in the experiment with **ARF**. From Figure 1, data rate in **ARF** fluctuates heavily because it adapts the data rate based on frame loss that is vaguely reflect channel conditions. With dynamic channel conditions, the proposed scheme is tested and depicted in Figure 2. As expected, its adaptive ability reduces the sensitivity to channel variations and overcomes rapid fluctuations.

Throughput performance: Figure 3 illustrates the improvement of network upon network density (different number of client stations). The X-axis represents the network density and Y-axis stands for improvement over **ARF**. In this scenario, all nodes are stationary at their specified positions, which are uniformly distributed along the four diagonal lines to the center of square. One example of the layout with 8 client stations is shown in Figure 4 (access point is at the center). It can be observed from Figure 3 that as the density increases, our scheme can improve

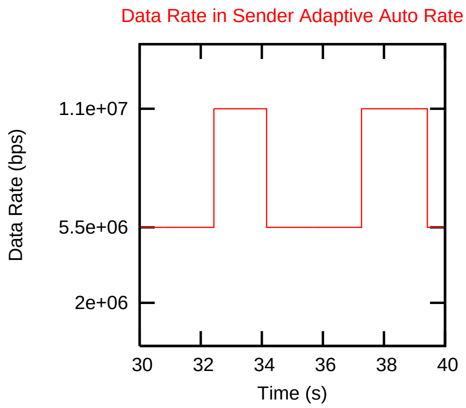

Figure 2: Data Rate Adaptation.

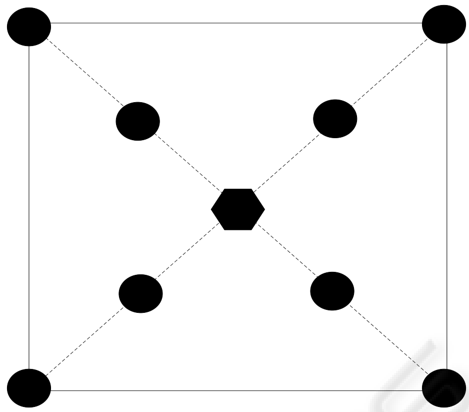

Figure 4: network layout with 8 client nodes.

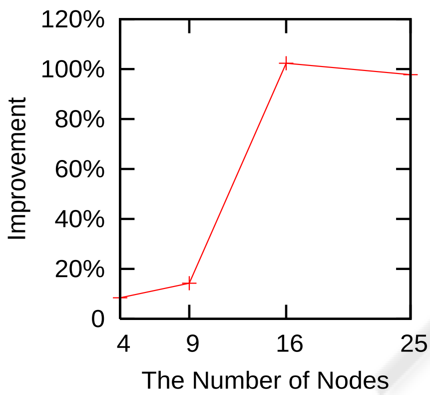

Figure 3: throughput improvement with stationary location.

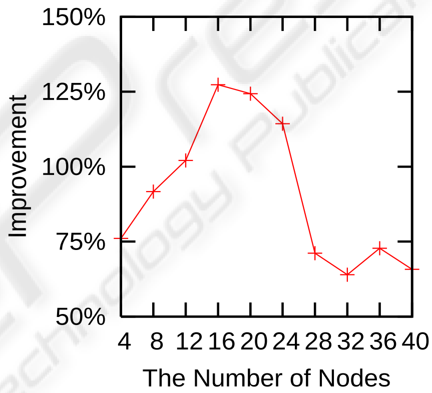

Figure 5: throughput improvement with roaming nodes.

throughput sharply and eventually achieve more than 100% improvement over **ARF** in such nodes layout. This can be explained by the robustness of our scheme to frame loss. When network density increases, the frame loss rate will increase due to more collisions. *ARF* will decrease its rate in case of frame loss regardless of the cause of the losses. Our scheme is insensitive to frame loss rate, and reacts only to received signal strength variations. Thus, more throughput improvement can be achieved in denser scenarios.

In the second throughput experiment, all client stations are roaming in the square ground with speed from 2 m/s to 20 m/s randomly. We still test the improvement upon network density. The result is demonstrated in Figure 5. Generally, our strategy can achieve more than 50% improvement over **ARF**. In some density, the improvement is even more than 100%. As might be observed, when the network density becomes too high, the improvement decreases dramatically. This falling is caused by the increased frame loss from the collision, which can not be discriminated from channel fading by this strategy.

Then, we evaluate the beacon interval impact on the effect of the performance of our adaptation scheme. Figure 6 depicts the result. In this figure, the X-axis denotes throughput and the Y-axis represents the beacon interval varying from 20 ms to 200 ms. The result are promising and surprising: the performance is insensitive to the beacon interval. This observation suggests that even if the rate estimation interval is not short, the estimation is still pretty up-to-date on slow fading channel.

Figure 7 depicts the throughput improvement with the adaptive low pass filter and different constant low pass filters with formula 1. The X-axis denotes the number of nodes in the network area of 500x500 and the Y-axis represents the throughput improvement. The different lines in Figure 7 show the improvement results for different coefficients used. From this figure, we can observe that, the adaptation scheme using a constant low pass filter is outperformed by that of the adaptive filter in formula 2. Also, note that different fixed coefficients do impact on the improvement.

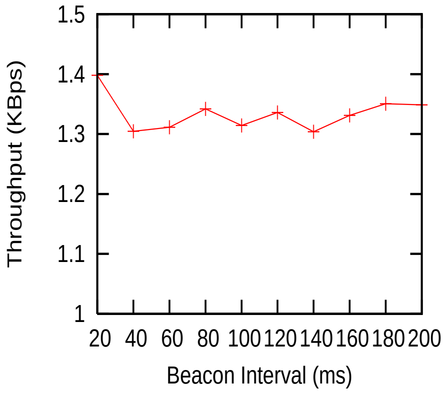

Figure 6: throughput of different beacon intervals.

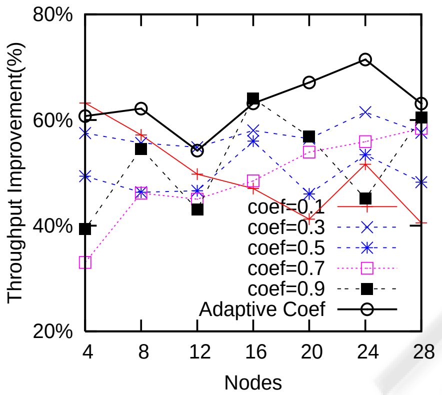

Figure 7: Impact on improvement by coefficients.

6 CONCLUSION

This work proposes a relaxed probing rate adaptation to exploit the broadcast management *beacon* frame in 802.11 networks. The scheme includes also an adaptive algorithm designed to smooth out the data rate during temporary variations of channel conditions. The simulations yield promising throughput improvement over **ARF** and reveal that the beacon interval has little impact on the performance improvement on slow fading channel.

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