BARA: A Sender Based Rate Adaptation in Wireless Networks

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ABSTRACT

Wireless communications benefit from multiple data rates under unstable channel conditions. More efficiently modulated user information results in higher overall data rates, but more error-prone information is received. Thus, it is highly important to adaptively choose a proper data rate so as to optimize network performance based on instantaneous channel condition. This procedure is named as rate adaptation. This paper presents a sender-based rate adaptation proposal named Beacon Auto Rate Adaptation, dubbed BARA, to determine proper instantaneous data rate, especially in the case where control frames such as RTS/CTS are not available. Beacon Auto Rate Adaptation is a suite of mechanisms. Firstly, periodic mandatory control frame beacon is used to estimate the initial data rate for sender at the beginning of a transmission. Then data rate is appropriately adapted during the transmission. Moreover, an innovative scheme is proposed to minimize the number of retransmissions. Our simulation with IEEE802.11 demonstrates that, although the improvement for single node is not remarkable, the throughput for network can improved more than 100% in high density network.

1. INTRODUCTION

With the development of modulation theory and physics technologies, user data bits can be modulated with different objective levels of efficiency and robustness. Highly efficient modulation methods, like 64QAM or 16QAM, yield higher data rates [12]. These modulations encode user data with more delicate slice of frequency, phase, and/or amplitude of wireless carrier signal. Current advanced electronic components at a receiver are able to support high data rate due to the ability to differentiate those modulated symbols in the wireless signal. Thus with the same carrier signal, there are more bits patterns to represent more symbols with more efficient modulation. However, these modulations are vulnerable to wireless signal fading and poor channel conditions resulting from channel interference, weather or distance. Due to station mobility, its wireless communication channel status significantly varies. Thus, it is difficult to transmit and receive data at a constant data rate. Lower data rate, from low efficiency modulation like BPSK [12], is more robust to interference and fading. However, if only the low data rate is applied for the entire communication while higher data rate is available, the overall efficiency will be low. Therefore, to achieve the optimal performance (e.g., throughput, delay or delay jitter), the modulation (and consequently the transmission data rate) should be adjusted dynamically according to current channel conditions. This dynamic procedure is called data rate adaptation in wireless network.

As IEEE802.11 [5] protocol gains in popularity and gets widespread in wireless local area network and mobile ad-hoc networks in recent years, its physical layer multi-rate capability makes data rate adaptation necessary for MAC protocol in these networks. IEEE802.11 does not describe rate adaptation. Some papers proposed strategies to adapt data rate at the sender. Other adaptation proposals work at the receiver. These proposals include [1, 3, 6–8, 10, 11]. In IEEE802.11, mobile stations access the medium with CSMA/CA protocol in MAC layer. The optional control frames of RTS/CTS provide “space” for data rate adaptation in receiver based schemas. However, without RTS/CTS control frames, only the sender based data rate adaptation can work. Our proposal is different from other sender based protocols in that it uses an adaptive method to predict the data rate at the sender. Besides this, it exploits the periodic control frame Beacon to estimate data rate for the initial transmission at the very beginning. In general, other proposed protocols do not consider what data rate is used for initial data rate. Also, if a transmission overlaps multiple Beacon frames, this transmission could benefit from estimations from each Beacon frame. At last, this paper proposes Basic Rate Retransmission that reduces the average number of retransmissions to a minimum—only once. To our knowledge, our proposal is the first one to consider this special scenario.

The remaining of this paper is organized as follows: Section 2 describes the relation between modulation and data transmission rate, the previous work on data adaptation, Beacon frame in IEEE 802.11 and the motivation for our work. The proposed scheme is then explained at length in Section 3. Following that, Section 4 derives the theoretic analysis, describes the simulation configuration, and presents the results. Section 5 concludes this paper.

2. BACKGROUND AND MOTIVATION
With breakthroughs in modulation and communications technologies, user information symbol can be modulated with different levels of redundancy to support multiple data rates under different channel conditions. The wireless transmission is always influenced by physical disturbance (e.g., weather, distance, and power, etc.). Also, these influences are dynamically changing no matter whether the wireless station is roaming or stationary. Data rate adaptation attempts to determine the best supported data rate with the appropriate modulation for a wireless communication channel. Generally, rate adaptation strategies can be categorized into sender based and receiver based. To facilitate our explanation, we have following definitions. By basic data rate, we mean the lowest data rate that a sender and receiver can actually support. For example, if system operates at 2 Mbps, 5.5 Mbps, and 11 Mbps, the basic data rate is 2 Mbps. Heuristic data rate denotes the data rate at which a system operates in last time communication. Instantaneous data rate is the data rate at one specific moment, which is compared to the adapted rate over a period.

2.1 Background and Previous Work

Auto Rate Fallback (ARF) [6] was originally proposed on Lucent WaveLan-II wireless networking 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 reduces (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 rate and thus upgrades its data rate to a higher level. This original data rate adaptation protocol definitely experiences data rate fluctuations. This is obvious from the following illustration. When the channel condition is good for 5.5 Mbps but not good enough for 11 Mbps and when the sender successfully transmits ten consecutive times at 5.5 Mbps, it upgrades to 11 Mbps rate. Then if a packet transmission fails twice at the new rate (11 Mbps). It falls back to 5.5 Mbps, and so on to repeat these procedures. Thus, data rate fluctuates. It is straightforward from Figure 1.

The proposal Received Signal Strength Link Adaptation [10] is based on the RSS (Received Signal Strength) and specifically targets WLAN. It assumes the RSS is the only indication of channel conditions. During the transmission, the packet transmitter monitors and catches communication packets. Then, based on the RSS of sensed packet, the mobile station estimates and adjusts its transmission data rate dynamically during transmission to its remote communication station. The new estimation of next instantaneous data rate is based on history estimations and the new detected instantaneous channel data rate from RSS, with a constant low pass filter coefficient: \[ R_i = (1 - \alpha) \cdot R_{i-1} + \alpha \cdot r \]

where \( R_i \) is the \( i \)th estimated data rate and \( r \) is the instantaneous rate retrieved from latest received packet RSS. This uses a constant coefficient which is needed to preset to proper value before the communication. At the same time, it does not consider initial data rate estimation and minimization of retransmissions after packet loss.

Mechanisms discussed above are sender based data rate adaptation protocols. In work Receiver Based Rate Adaptation [3], the authors propose the Receiver Based Rate Adaptation (RBRA) to adapt data rate with the cooperation from the receiver for transmission of data and acknowledgement packets. This protocol is based on the exchange of RTS/CTS control frames between sender and receiver stations before data/acknowledgement packets are transmitted in IEEE802.11 protocols. The RTS and CTS are transmitted at basic rate so that they are accessible to all stations in carrier sense range. When the receiver gets the RTS, based on the physical layer measurement, it calculates the best data rate that it can support under instantaneous wireless channel condition. Then it feeds back the selected data rate embedded in the CTS frame. In this way, the sender infers the agreed data rate with these forward-and-backward exchange of control frames. This proposal can work in both WLAN and Ad Hoc networks, only if control (probe) frames like RTS/CTS precede the data packets communication.

Most data rate adaptation protocols proposed are either sender based or receiver based. Some are hybrid such as the Full Auto Rate (FAR) protocol [7] recently proposed to combine the two categories of protocols to achieve full data rate adaptation. The authors of FAR argue that, in receiver based protocols, like RBRA, if the RTS/CTS can be transmitted at instantaneous data rate that wireless channel can support, rather than at heuristic or basic rate, more improvement can be achieved because in general the instantaneous data rate should be more accurate than heuristic and higher than basic rate. Since sender based data rate adaptation allows a sender to estimate the transmission rate before it starts, then transmission data rate for RTS/CTS control frames could also be adequately estimated. Therefore, Full Auto Rate suggests using sender based data rate protocols to estimate data rate for RTS/CTS control frames, and then using receiver based rate adaptation protocols for data rate at which the data packet and acknowledgement packets are transmitted. The authors verified that it can adapt rate fully with combination of both sender base protocols and receiver based protocols.

2.2 Beacon Frame in IEEE802.11

In IEEE802.11, Beacon frame works for following purposes:

- **Synchronization:** The Access Point (AP) periodically broadcast Beacon frame to synchronize the client stations in a WLAN. In ad-hoc networks, each mobile station in the IBSS shall transmit beacons to synchronize all its neighbors.
- **Power Management:** In WLAN, all beacons generated
by an access point (AP) may contain an element called TIM (Traffic Indication Map) to administrate the traffic to those stations in power saving mode. The power management in ad-hoc networks is similar to that in WLAN except the element of ATIM (ad hoc Traffic Indication Map).

- **Rate support**: The Beacon frame also indicates multiple data rates and modulations the access point (AP) can support (in WLAN) or the mobile station can support (in Ad hoc network).

- **Others**: The Beacon frame is used by a mobile station to find an access point (AP) in BSS or mobile station in IBSS when it enters the network for the first time. Based on the parameters in the beacon frame, it can associate with an access point in BSS or mobile station in IBSS.

### 2.3 Motivation

RTS/CTS control frames are optional in 802.11 standard to improve the data packet throughput. If the size of data packets to be transmitted is too small, which is highly possible in real time applications such as VoIP, real time video and so on, the use of RTS/CTS dramatically increases the overhead. Following the analysis of work [2], if only one mobile station is transmitting VoIP traffic with payload of 160 bytes, the packet efficiency drops to about 12% in 802.11b [4] networks at 11 Mbps with RTS/CTS control frames. Therefore, the RTS/CTS are optionally used only when the size of data packet exceeds a certain threshold (2347 recommended in IEEE802.11). When RTS/CTS packets are not used, the sender based data rate adaptation is the only choice for data packet data rate adaptation.

In multi-rate wireless networks, when a mobile station needs to send packets to an access point (in WLAN mode) or other mobile station (in Ad-Hoc mode), generally the sender has the following options for the transmission rate: the basic data rate, heuristic rate, or an estimated data rate. In IEEE802.11, the recommended rate for the control frames RTS/CTS is the basic data rate so that they can be captured by every station in transmission range. The Full Auto Rate [7] scheme has analyzed and verified that throughput improvement can be achieved if the transmission of RTS/CTS runs at an estimated data rate, rather than at the basic data rate. Thus, a well-predicted instantaneous data rate at the sender can benefit the transmission of RTS/CTS and thereof the entire network performance.

Even for current sender based data rate adaptation schemes, one scenario is often omitted. Suppose station A wants to initiate packet transmission to station B. If station B does not transmit packets for a long time (e.g. several minutes), the sender station A is unaware of the link status to station B. It does not know what data rate is suitable to restart transmissions. Thus, the initial data rate is necessary to be estimated somehow.

To address the above problems, we proposes data rate adaptation for initial data rate with periodic frame Beacon in this paper. This strategy is essentially a sender based data rate adaptation. Although our simulation is implemented on IEEE802.11, this strategy is also applicable to all other wireless networks with periodical broadcast frames.

Beyond this for initial rate estimation, we also propose two other mechanisms to enhance throughput and delay jitter. One is to catch all sensed packets to estimate channel conditions, instead of only the beacon frame. At this point, it is similar to the idea in Received Signal Strength Link Adaptation [10] for WLAN. This is especially efficient to adapt data rate with ongoing communication. But our proposal is different from Received Signal Strength Link Adaptation [10] in that ours uses adaptive coefficients and also targets ad-hoc network, not only for WLAN network.

So far, there is no protocol yet taking into consideration minimization of the retransmissions when a transmission failure happens due to mismatch between the estimated data rate and the appropriate channel data rate. This situation happens frequently in wireless networks. Thus another mechanism called basic rate retransmission is proposed for packet retransmission after packet loss.

### 3. BEACON AUTO RATE ADAPTATION

In this section, we at first explain the estimation of the initial rate with Beacon frame, then we illustrate an adaptive rate adaptation during an ongoing communication. Finally, we discuss the basic rate retransmission after a packet loss.

#### 3.1 Rate Adaptation with Beacon

Since the Beacon frame is broadcast periodically, this leaves “room” to estimate data rate without introducing overhead. In whatever network mode, infrastructure or infrastructure-less, Beacon is mandatory. These periodic beacon frames received at a mobile station allow to determine the statistics of the channel conditions (e.g. signal to noise ratio, signal strength, and error rate). Based on such wireless channel information, the mobile station can calculate the best data rate to the source mobile station who initiates the beacon (in ad hoc, it is another mobile station). In WLAN it is the access point, and then records this data rate information into a table for later use. The table may be indexed by the destination mobile station address. Each tuple may include the modulation level or data rate as content. When this mobile station needs to transmit data packet to some mobile station, it looks up the rate table for data rate that it can utilize to communicate with the target mobile station. It instructs its physical layer to transmit the data packet by making use of the associated modulation corresponding to that data rate. The main drawback of this basic strategy is the estimated rate might not be exactly real-time because estimation is only adjusted every beacon interval. But this mechanism is good for the initial rate estimation, because the estimated rate is still fairly more precise than a randomly selected data rate at the beginning of the transmission. It is also more efficient than the basic data rate.

The following algorithm describes this strategy:

```plaintext
When a packet is received:

if (FrameType == Beacon) {
    Index = GetFrameMacAddress();
    ChannelStatistics = GetChannelStatisticsFromPhy();
    if (ChannelStatistics > ThresholdRate_11)
        Rate = 11Mbps
    else if (ChannelStatistics > ThresholdRate_5_5)
        Rate = 5.5Mbps
    else if (ChannelStatistics > ThresholdRate_2)
        Rate = 2Mbps
}```
This is helpful especially in two scenarios both beacon frame and all other data the station can receive stations based on the channel conditional statistics. They can dynamically estimate the data rate to those transmitting. Communication can be used to estimate data rate the estimation is estimated at any time of all packets flying during communication. Beacon frame can only be sensed every beacon interval not with only beacon frame might not be real time because mobile station is experiencing the ping-pong effect in handoff where the data rate might iterate between two levels of rates. It results in retransmissions. Multiple retransmissions definitely hurt the network performance. Therefore, to solve the above rate fluctuation problem, the data rate should be adjusted per packet, but also adaptively from multiple history packets information. It is more important to predict the trend of the channel conditions variations to adjust data rate before the channel changes than instantaneous rate.

The rate adaptation core procedure in Adaptive Rate Adaptation is still the same as in Rate Adaptation with Beacon strategy. The only difference is an adaptive coefficient introduced to smooth the data rate on wireless channel with history rate information.

One low pass filter $\alpha$ is introduced in the data rate prediction:

\[
\text{ChanStat}_t = (1 - \alpha)\text{ChanStat}_{t-1} + \alpha \times \text{ChannelStatistics} \tag{1}
\]

(0 < $\alpha$ < 1)

It can also be expressed as:

\[
\text{ChanStat}_t = \text{ChanStat}_{t-1} + \alpha(\text{ChannelStatistics} - \text{ChanStat}_{t-1}) \tag{2}
\]

Here, the ChanStat is the cumulative prediction of potential channel status. It is used to predict the channel variation trend. ChannelStatistics is the instantaneous channel status, which is calculated from the packet just received.

The $\alpha$ is not constant: it is dynamically updated as following:

\[
\alpha = \frac{\text{ChanStat} - \text{Threshold}_{low}}{\text{Threshold}_{high} - \text{Threshold}_{low}} \tag{3}
\]

Here $\text{Threshold}_{low}$ and $\text{Threshold}_{high}$ are the corresponding channel statistic thresholds for rate estimation at each data rate level. These thresholds vary for different data rates. For instance, $\Phi$ is the low threshold for 5.5 Mbps. If the 2 Mbps and 5 Mbps are two neighbor data rate levels in our data adaptation, $\Phi$ also is the high threshold for 2 Mbps.

From the Formula (3), as the cumulative channel signal strength $\text{ChanStat}$ approaches to $\text{Threshold}_{high}$, $\alpha$ increases, and thus instantaneous channel signal strength contributes more to the adapted rate. This helps data rate adaptation quickly increase to higher data rate levels if more packets are transmitted successfully under good channel conditions. This cumulative prediction can also alleviate rate fluctuation in case of heavily fluctuating channel conditions, for example during a handover. Therefore, the channel data rate is smoothed to a certain degree.

Adaptive Rate Adaptation operates with all sensed packets, including both broadcast control packets like Beacon packet, even though it is not the receiver station, it can still get channel conditions information between itself and the packet sender. Therefore, data rate of wireless channel can be adapted. Each station in power save mode still needs to wake up for beacon frame periodically. Thus, even in Adaptive Rate Adaptation, periodic beacon frame is still necessary and helpful to estimate the channel conditions.

For instantaneous rate adaptation, if the rate is estimated per packet, the data rate might frequently fluctuate due to instantaneous channel condition variations, when only the latest single received packet is used to predict channel data rate for next transmission. This happens especially when mobile station is experiencing the ping-pong effect in handoff where the data rate might iterate between two levels of rates. It results in retransmissions. Multiple retransmissions definitely hurt the network performance. Therefore, to solve the above rate fluctuation problem, the data rate should be adjusted per packet, but also adaptively from multiple history packets information. It is more important to predict the trend of the channel conditions variations to adjust data rate before the channel changes than instantaneous rate.

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Here, the ChanStat is the cumulative prediction of potential channel status. It is used to predict the channel variation trend. ChannelStatistics is the instantaneous channel status, which is calculated from the packet just received.

The $\alpha$ is not constant: it is dynamically updated as following:

\[
\alpha = \frac{\text{ChanStat} - \text{Threshold}_{low}}{\text{Threshold}_{high} - \text{Threshold}_{low}} \tag{3}
\]

Here $\text{Threshold}_{low}$ and $\text{Threshold}_{high}$ are the corresponding channel statistic thresholds for rate estimation at each data rate level. These thresholds vary for different data rates. For instance, $\Phi$ is the low threshold for 5.5 Mbps. If the 2 Mbps and 5 Mbps are two neighbor data rate levels in our data adaptation, $\Phi$ also is the high threshold for 2 Mbps.

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Adaptive Rate Adaptation operates with all sensed packets, including both broadcast control packets like Beacon
and data transmission packets. Thus, the algorithm for Adaptive Rate Adaptation evolves from algorithm for Rate Adaptation with Beacon as following.

When packet is received:

\[
b = \text{constant}; \\
\text{Index} = \text{GetFrameMacAddress}(); \\
\text{ChannelStatistics} = \text{GetStatFromPhy}(); \\
\text{Threshold}_h = \text{GetCurrentHighThreshold}(\text{Rate}); \\
\text{Threshold}_l = \text{GetCurrentLowThreshold}(\text{Rate}); \\
a = b^*(\text{ChanStat} - \text{Threshold}_l)/(\text{Threshold}_h - \text{Threshold}_l) \\
\text{ChanStat} = \text{ChanStat}+a^*(\text{ChannelStatistics} - \text{ChanStat}); \\
\text{if} \ (\text{ChanStat} > \text{ThresholdRate}_11) \\
\quad \text{Rate} = 11\text{Mbps} \\
\text{else if} \ (\text{ChanStat} > \text{ThresholdRate}_5.5) \\
\quad \text{Rate} = 5.5\text{Mbps} \\
\text{else if} \ (\text{ChanStat} > \text{ThresholdRate}_2) \\
\quad \text{Rate} = 2\text{Mbps} \\
\quad \text{else} \\
\quad \text{Rate} = 0\text{Mbps}; \\
\quad \log(\text{signal is too weak. No channel to destination mobile station}); \\
\}
\]
\[
\text{RecordRateToTable}(\text{Rate}, \text{Index});
\]

3.3 Basic Rate Retransmission

Whatever the sender based rate adaptation is, it is impossible to accurately predict the actual data rate all the time. In other words, there is definitely a mismatch between the predicted data rate and the actual data rate that the channel supports through entire transmission. In such case, the receiver does not successfully receive the data packet, therefore does not generate the acknowledgement. But the sender is waiting for an acknowledgement to estimate the actual data rate for the next transmission. A deadlock happens in this scenario. The only way to solve this mismatch is to retry the same packet at a lower data rate. Thus, minimizing the retransmissions after a transmission failure is not trivial. Thus we propose Basic Rate Retransmission that can efficiently address the above problem. When transmitting a data packet, if the sender fails to transmit a packet, the sender does not retry the transmission at the same data rate used during the failed transmission, because the channel condition might have deteriorated. Instead, it retries at the basic data rate just as for RTS/CTS frames, at which the receiver can certainly receive the packet, if it is still in communication range. The reason we retry directly at basic rate (and not at the next lower level rate), is to avoid more failures. For example, if a transmission fails at 11 Mbps and the channel can only support the 2 Mbps basic rate temporally, the transmission at 5.5 Mbps, will still fail. But, the packet at 2 Mbps data rate is still accessible, even in case that the channel condition is robust enough for 5.5 Mbps. Then, when the sender catches the acknowledgement packet for the basic rate data packet, the sender is able to adapt its instantaneous data rate for next packet transmission based on the channel information of acknowledgement frame. With this strategy, the transmission is immediately recovered with a retransmission at the basic data rate. The number of retransmissions after a transmission failure can be reduced to only one. Basic Rate Retransmission improves the network performance especially when network load is heavy, because multiple retransmissions result in more delay between two successful successive transmissions due to the binary exponential backoff in MAC protocol. It should be stated that although this variant can be combined with the previous two mechanisms that we propose, it also can work individually with any other rate adaptation strategy to minimize the retransmission in case of transmission failure.

4. SIMULATION RESULTS

Simulation configuration: The simulation is performed on NS-2 [9] version 2.29 for both WLAN and ad-hoc modes. Only three levels of data rates are chosen in simulation: 11 Mbps, 5.5 Mbps and 2 Mbps, which can be used as the basic rates. These simulations use two-ray ground model as channel fading. All motion scenarios are generated by CMU mobile scenario program “setdest” in NS2 package. And all application flows for ad-hoc network simulation are generated by CMU scripts “chgen_tcl” also in NS2. In following result figures, we mainly compared our mechanism with ARF proposal unless there is special explanation.

Data Rate Smoothing: Compared to Figure 1 in section 2.1, data rate does not fluctuate heavily with our proposed strategy. The result can be observed from Figure 2.

Throughput performance: The improvement for WLAN network is really dramatic, as illustrated in Figure 3 and in Figure 4. Figure 3 represents the improvement for multiple nodes operating in rate adaptation with only beacon frame. Figure 4 shows the improvement on a network with multiple nodes with different fixed adaptive coefficients. In both figures, the X-axis represents the number of nodes (including one access point) in a fixed area of 100x100. The Y-axis is the improvement by percentage(%). As network density increases, more than 100% improvement can be achieved. However, the Figure 5 shows that BARA with adaptive coefficient in formula 3 does not perform so well as with constant coefficients as illustrated in Figure 4.

Figure 7 shows the improvement from data rate adaptation with only beacon frame in Ad-Hoc network mode. The X-axis represents the number of nodes in network and the Y-axis represents the throughput improvement by percentage. There are 3 scenarios for different network sizes in this figure: 100x100, 150x150 and 200x200. As can be observed in Figure 7, the improvement increases as the network density increases. It is because BARA adapts its data rate with
The proper signal strength (or communication distance) regardless of packet loss from collision. But ARF strategy is impacted extensively by packet loss. When the network density increases, so does packet collision. Thus, BARA can achieve more improvement.

The simulation result for BARA with different constant coefficients in Ad-Hoc network is illustrated in Figure 8. The X-axis denotes the number of nodes in the network area of 100x100 and the Y-axis represents the throughput improvement. The different results lines in Figure 8 show the result for different coefficients used in BARA adaptive mechanisms. From Figure 8, we can observe that, unlike in WLAN mode, BARA with constant coefficient is outperformed by BARA with adaptive coefficient of formula 3. Also, we can see that the different fixed coefficients do impact on the improvement, the result of coefficient 0.3 is better than other four counterparts.

**Delay Jitter Improvement:** The delay jitter improvement is shown in Figure 6, in which only one access point (AP) and one mobile station communicate with each other with continuous CBR traffic. In this figure, the X-axis represents the two mechanisms that are compared and the Y-axis is the percentage of improvement. It can be observed that: although the Delay Jitter improvement by BARA with only Adaptive Coefficient mechanism (SAAR in figure) is not noticeable, only a little more than 10%, there is still marginal improvement by Basic Rate Retransmission (BRR in figure). It can improve the delay jitter as much as 25% for station. This supports our statement on Basic Rate Retransmission for improvement delay and jitter because it minimizes the delay to just once retransmission.

5. CONCLUSION

In this work, broadcast Beacon frame is utilized to adapt the initial rate without any extra overhead. Then data rate can be dynamically adapted from the ongoing wireless communication channel statistics at the sender. Innovative basic data rate retransmission is introduced to minimize packet retransmissions when a packet loss occurs (from rate mismatch). Although these strategies in this paper initially target data transmission without RTS/CTS control frames, they are also applicable for protocols with RTS/CTS. They can even work collaboratively with other auto rate protocols in rate adaptation for wireless network.

6. REFERENCES