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RBSRA: RSSI based statistical Rate Adaptation for IEEE 802.11 WLANs

By

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In the name of ALLAH, the most Beneficial, the most Merciful.

Dedicated to Almighty ALLAH, to His Prophet (P.B.U.H)& to my dear Parents

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ABSTRACT

In past few years, rate adaptation for wireless multimedia applications has been a subject of wide research. Rate adaptation can be achieved at MAC/PHY layer by making the accurate decision to choose available data rates. The motivation to adapt suitable data rates of 802.11 wireless LANs explores the synchronized cooperation of application and MAC/PHY layer. At application layer, adjustments for deciding quality of multimedia entirely depend upon sound transmission conditions of the channel. Therefore, precise assessment of channel condition is an issue of significant consideration. In recent research, estimations for condition of channels are based on following approaches (i) use physical layer parameters (e.g. SNR, RSSI, SINR, PSNR) (ii) use the statistics of transmitted data (e.g. no of retransmissions, throughput, PER).

Our research evaluates that depending upon one approach entirely while ignoring other can lead to loss of valuable information about adaptation of rate to send data. This in turn can highly degrade throughput.

In view of this, the proposed scheme, RBSRA, defines channel assessment as the function of combining PHY layer parameter with statistical metrics. RBSRA estimates accurate assessment of fluctuating channel conditions, so it leads to the substitution of data rates to yield higher throughput. RBSRA uses the PHY layer parameter RSSI in cooperation with the statistical metric that is number of received ACKs. In our scheme RSSI is being used to assess the variations of the channel conditions, which has been incorporated with the statistics of received ACKs to decide the data rate for the stream. So, RBSRA avoids unnecessary fluctuations in data rates and provides more realistic selection amongst the available link speeds. Performance of RBSRA depicts that the data rate selection has been precisely synchronized with ups and downs of the channel conditions along with statistics of transmitted stream. Results show that the proposed scheme increases the overall throughput.

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Chapter 1

INTRODUCTION

1.1 Introduction

In the Scenario of 802.11 wireless networks, the rate adaptation is an active research topic in order to explore the better approaches to help the multimedia streaming between the mobile nodes. As the number of wireless clients is increasing, the swift demand for the high quality multimedia streaming has been observed. There are number of video encoders and decoders that provide the efficient encoding in order to increase the quality of video. Along with the efficient encoders we also need to investigate the link parameters and channel statistics to extract the valuable information in order to provide the high quality video. These Parameters are RSSI (Signal strength Indicator), SNR (Signal to Noise Ratio), and channel statistics include Mac level ACKs, number of received/dropped packets, delay etc. A detailed study can be performed in order to observe the role of different link parameters that can provide the better solution of rate adaptation.

In 802.11 WLANs, different data rates are available for example, in 802.11a there are 8 data rates that provide different modulation and coding schemes. In 802.11b there are 4 different data rates. Due to the changes in wireless channel conditions the transmission can be affected. These data rates are helpful in varying channel conditions in streaming of the multimedia between wireless clients. Multimedia transmission is more sensitive in terms of delay whereas the reliability of data can be compromised. In file transfer applications, reliability of data transfer is a very critical issue as the loss of data packets can cause the corruption of whole file. This scenario is entirely opposite in case of transmission of multimedia. The time of packet inflow is more important than its reliable provision. Due to varying channel conditions, efficient switching to data rates that provide maximum throughput is more critical.

The increasing use of wireless LAN stimulated the increased demand of streaming of video over wireless networks. This requires the efficient way to provide the desired quality of video, which can be affected due to changing channel conditions. Multimedia applications are delay sensitive so the reliable data transmission is an issue of least importance. TCP provides the reliable data transmission; this takes sufficient time which is not convenient for delay sensitive multimedia applications. UDP provides a non-reliable data transmission which is best suited for multimedia applications. Time is main factor for streaming of multimedia applications. On time delivery of a packet is more crucial than a reliable delivery which yields delays hence affecting the quality. So errors and loss of packets can be endured during multimedia streaming which makes the selection of UDP more suitable. If a packet is received after its play time, the packet is useless and must be dropped at receiver buffer.

Table 1.1 802.11a Data Rates

Data Rate	Modulation Scheme	Coding Rate	Bits per Subcarrier
6	BPSK	1/2	1
9	BPSK	3/4	1
12	QPSK	1/2	2
18	QPSK	3/4	2
24	16-QAM	1/2	4
36	16-QAM	3/4	4
54	64-QAM	3/4	6

802.11 support multiple data rates by using different modulation and channel coding schemes. For example 802.11a has 8 different modes with varying data rates from 5Mbps to 54 Mbps. Table1.1 shows the available modulation schemes and coding rates of IEEE 802.11a [1].Considering these available data rates, researchers are working on standardizing some adaptive schemes so that quality of multimedia traffic on the network can be improved. The efficient modulation schemes provide higher data rates.

Table 1.2 802.11b Data Rates

Data Rate	Modulation Scheme	Coding Rate	Bits per Subcarrier
1	DBPSK	1/2	1
2	DQPSK	3/4	1
5.5	CCK	1/2	2
12	CCK	3/4	2

Table1.2 shows the available modulation schemes and coding rates of IEEE 802.11b [2].Link adaptation refers to the selection of one data rate from available data rates e.g. in 802.11a, selecting 1 out of 8 data rates. The design and complexity of link adaptation schemes depends on the number of available data rates. With high data rate, the frame can be transmitted in less time. But it is necessary to tradeoff the data rate depending upon the channel conditions, in order to reduce the retransmission rate [3].

1.2 Problem Statement

- Explore suitable statistical rate adaptation schemes for wireless networks in order to determine implementation of most suitable approach for the accurate channel estimation, to select suitable data rate.
- Design and implement an efficient RBSRA methodology using appropriate language to cater for the following
  - Correct and speedy channel estimation
  - Suitable selection of data rates
  - Increased throughput
- Carry out detailed result analysis of the proposed scheme RBSRA
- Compare performance of the proposed approach with the other researcher's work in the rate adaptation technique

1.3 Objectives

Main objective of this thesis is to explore, link adaptation in view of link speeds that have been facilitated by IEEE 802.11 standard. To accomplish it a detailed study and analysis of existing link adaptation mechanisms have been performed. Our is focus to suggest and develop an architecture that can provide link adaptation methodology, which can provide better performance in terms of speedy and timely estimation of status of wireless link and increased throughput. The performance of the system is followed by detailed analysis of results.

1.4 Thesis Organization

Sections of this thesis have been organized into the following units. Chapter 2 provides detailed study and concepts of adaptation to various link speeds in scenario of IEEE 802.11 WLANs. Existing techniques in view of link adaptation have been discussed with their possible shortcomings. Chapter 3 illustrates problem description and architecture of proposed system has been discussed in detail. Various aspects of the proposed system have been deliberated with help of flow chart diagrams and algorithms. In chapter 4 simulation topology and configuration parameters have been described. Brief introduction of Network simulator (NS-2), which has been used to implement the proposed system, has been provided. Chapter 5 presents a detailed study and analysis of results that have been produced to validate the proposed system. The performance of proposed system has been discussed in detail. Conclusion and future work has been described in chapter 6.

1.5 Summary

In this chapter the concept of rate adaptation has been discussed. Rate adaptation has been invoked as the efficient utilization of the data rates, which are provided by the IEEE 802.11 standard. Rate adaptation is a mechanism to predict the state of wireless link and select suitable data rate to accommodate the varying conditions of the wireless link.

Chapter 2

LITERATURE REVIEW

2.1 Rate and Quality adaptation in Wireless Networks

The bandwidth in wireless networks is usually shared by a number of wireless nodes. The channel capacity depends upon the number of accessing nodes, time, environmental conditions and location of nodes. Due to varying channel conditions, several issues are observed in the transmission of real time multimedia. The existing research on multimedia streaming can be classified into adaptation techniques at the Physical and MAC layer, cross layered architecture, application layer coding techniques and frames scheduling.

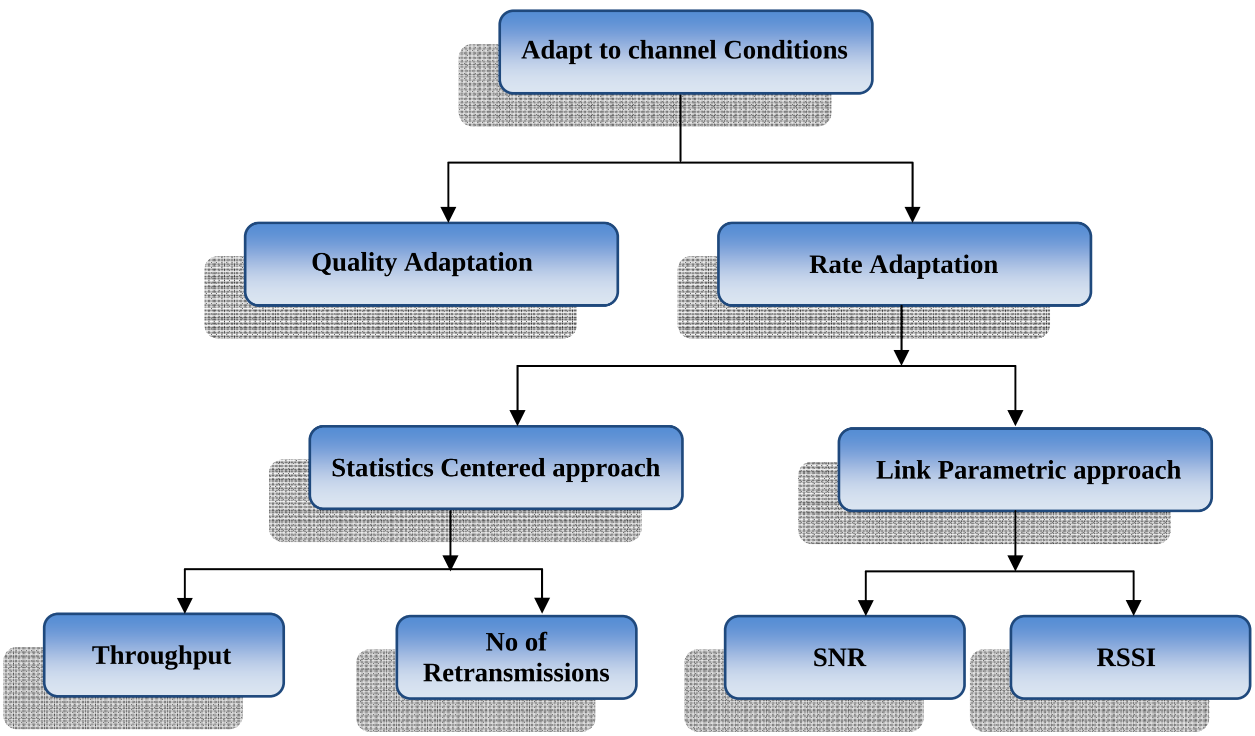

Figure 2.1 Adaptation categories

Figure 2.1 illustrates different adaptation techniques. The adaptation techniques use various metrics such as signal to noise ratio (SNR), Bit Error Rate (BER) for rate adaptation and available bandwidth estimation to adapt source coding rate at application level. Moreover, there exist certain network layer parameters such as packet delay, packet losses and jitter to achieve the required QoS for multimedia traffic.

2.1.1 Rate Adaptation

Conditions of wireless channels tend to change due to factors like interference, noise, fading etc. This fact makes the transmission of video difficult over wireless medium. To compensate these changes, the rate to send data is adjusted, to get better quality of video by increasing the throughput and utilization of link. In 802.11 WLANs the rate adaptation is known as the process of switching to the rate that is more suitable to the channel condition. If channel is in good condition to send and receive data, with less ratio of noise, it can support higher data rates. If there are channel errors then low data rates are more applicable for selection. Two kinds of rate adaptation approaches have been researched.

2.1.1.1 Channel statistics centered approach

This approach makes the selection criteria based on the wireless link statistics e.g. number of received and dropped packets, number of acknowledgements received, number of successful transmissions, considering the number of received ACK frames, counting the number of retries to send a frame etc.

2.1.1.2 Link parameter centered approach

The second approach is a function of rate adaptation in terms of link parameters such as are RSSI (Signal strength Indicator), SNR (Signal to Noise Ratio) etc. So the current research to adapt the rate according the link quality upshots the schemes which utilize either statistical information or link quality metrics.

2.1.2 Quality Adaptation

Quality adaptation scheme synchronizes the encoding rate of video with the data sending rate to fulfill the bandwidth limitations over wireless networks. Variations in quality of video can be triggered by the link capacity and selected data rate [4].

2.2 IEEE 802.11 Wireless LANs

IEEE 802.11 was defined as a pioneer standard for wireless LANs. IEEE 802.11 defines the implementation of MAC layer and three different kind of physical layers. Main focus of IEEE WLAN was to provide the services of throughput, reliability and uninterrupted connections as provided by wired networks. IEEE 802.11a was presented as an implementation of OFDM physical layer with capability of maximum data rate of 54Mbps. IEEE 802.11b, with maximum of 11Mbps data rate, was provided as extension of DSSS operating in 2.4GHz frequency band. Lately an addition to 802.11b was introduced, which provided the combination of OFDM competencies and properties of radio operating in 2.4GHz band. This new standard was introduced as IEEE 802.11g providing maximum data rate up to 54Mbps [5]. IEEE 802.11n has been provided with concept of OFDM and MIMO with the focus on increased throughput up to 600Mbps [6].

2.3 PHY and MAC layers of IEEE 802.11 WLANs

Physical layer is concerned with converting bits in a packet to symbols. These symbols are converted into analog signal that propagates through wireless medium. SNR and RSSI of a received signal can be measured at physical layer. Mac layer is focused on sharing wireless medium amongst contending nodes. MAC layer parameters are PER, average size of packet and rate to send packets etc.[7]. Frame propagation and reception is performed by physical layer whereas MAC layer is responsible for the coordination functionalities to access the wireless link. In other words frames produced by MAC layer are propagated by physical layer.MAC and physical layers have been divided into two sub layers as shown in figure 2.2. Following is a brief description of both layers.

2.3.1 Physical Layer

First layer of the OSI protocol stack is physical layer. Different implementations for PHY layer have been provided that are FHSS, DSSS and OFDM implementation. Physical layer has been distributed into two sub layers as given below:

2.3.1.1 Physical Layer Convergence Procedure

Physical layer convergence procedure PLCP can be defined as a substitution between MAC and PHY layer, which is used to control the interchange of frames between these layers. Frame assembly comprising of header, preamble and trailer is managed by PLCP. It also interchanges frames among Physical and MAC layers. Transmission functionalities including encoding, modulation etc. are controlled by PLCP layer.

2.3.1.2 Physical Medium Dependent

When data has been encoded it comprises of symbols that are being transmitted over wireless link. PMD is responsible to transmit these symbols over the wireless medium. Frequency related issues e.g. power to transmit are the subject of PMD sub layer. At destination, PMD forwards these symbols to PLCP layer. It provides the functionality that has been used to sense the channel state [8].

In the IEEE 802.11 standard multiple physical layers have been introduced for 802.11a, 802.11b and 802.11g etc. Link conditions are evaluated by physical layer which are then reported to MAC. The independent relationship between Physical and MAC layer is helpful to introduce higher link speeds.Incoming MPDUs from MAC are tendered to PMD, which specifies the mechanism to propagate and receive the frames via wireless medium. The primary function of PLCP is to sense the signal from transmitter and assess the channel state to initiate a new transmission. Each PHY layer provides different PMDs [9].

2.3.2 Link Layer

As shown in figure 2.2, data link layer has been separated into two sub layers that are LLC and MAC layer. Both sub layers are common to all variations of physical layer. Here is a brief description of LLC and MAC layer.

2.3.2.1 Logical Link Layer

LLC provides interface to the upper layer that is network layer [10]. For the implementation of various wireless LAN protocols, same LLC layer makes it easy to connect with higher layers. At MAC layer there is a variety of defined wireless LAN protocols, so the concept of exactly one LLC layer is associated with the transparency of MAC related functionalities (e.g. method to access medium, coding schemes etc.) to higher layers. Use of LLC is optional as it depends on higher layers. For reliable data delivery when TCP is used, functionalities provided by LLC are deactivated. Similarly when reliability is not an issue of concern, LLC services are used [11].

2.3.2.2 Medium Access Control Layer

Wireless medium is shared amongst various nodes that are competing to access the channel for their transmissions. MAC layer specifies the approach to access the wireless link. Wireless nodes, which are contending for wireless link, follow CSMA/CA mechanism to access the channel using DCF. Mac Layer enables wireless nodes to sense the channel before transmission. For an idle channel transmissions start after waiting for DIFS time period, whereas for busy channel, wireless node has to wait till transmission is accomplished [12].

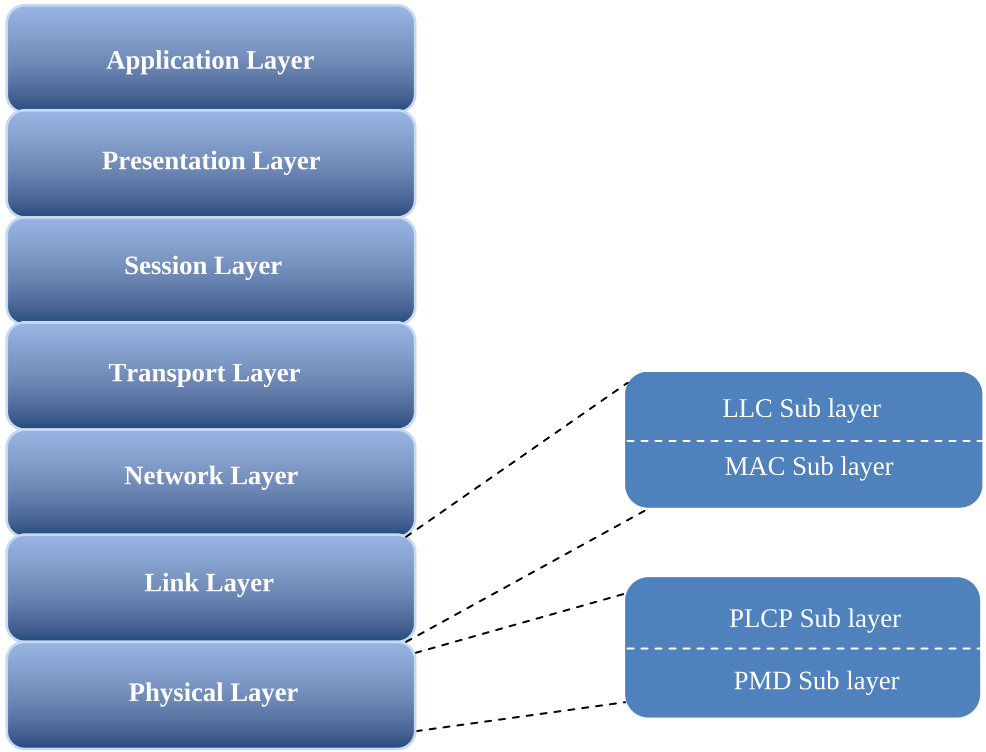

Figure 2.2 Link and PHY Sub layers

DCF is a primary routine to access the wireless link. The channel state is perceived whenever a wireless node needs to transmit data. If channel is busy then node has to wait till transmission completes. Figure 2.3 describes the mechanism to access the channel with DCF mechanism. If channel is found futile, distributed interframe space (DIFS) time is used to wait and then transmission starts. There are many nodes that compete for wireless link. So in the mechanism of DCF, a back-off counter is announced for all nodes, which is random and different for all nodes. When there is no transmission detected over channel, there will be many wireless nodes that want to access the channel. Each frame has to wait for time period defined as DIFS. After that the access to channel is granted to nodes that waited for DIFS time and channel was detected free. When frame is received at receiver, a time period that is short interframe space (SIFS), is used to wait after that receiver sends ACK frame. This ACK frame is a response to successful data delivery. As shown in figure 2.2, if ACK frame is not received properly or it is missing then sender node will wait for ESIFS time period to access medium to send the frame again. [13].

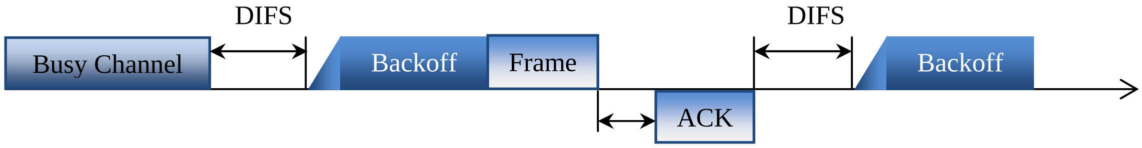

Figure 2.3 Accessing wireless link with DCF mechanism

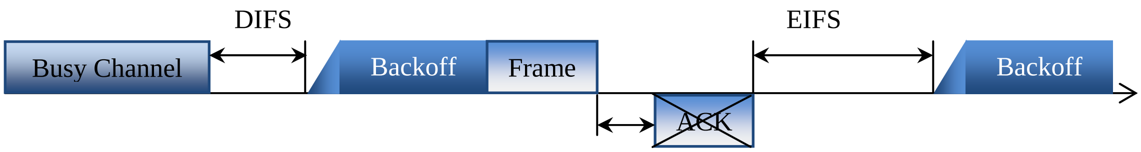

Figure 2.4 Retransmission of frame due to lost ACK frame

2.4 Adaptation Requirements

Adaptive design classifies status of wireless medium at receiver and then chooses the encoding scheme conferring link speed to transmit data, so that bandwidth capacity at receiver can be fully exploited without instigating the congestion on the receiver side to reduce delay and data loss. Numerous schemes, which provide adaptation to suitable transmission speed, need to be equipped with various metrics. Examples of these are as follows:

- RSS (Received Signal Strength)
- Estimations for delay and Doppler spread
- channel estimation,
- CRC (Cyclic Redundancy Check)
- Information regarding SNR (Signal to Noise Ratio)
- Estimation for bit error rate.

In wireless communication system, the factors that cause variation in the received signal strength are as follows:

- Space between the source and destination nodes

- Shadowing triggered by the huge obstructions
- Reflection inducing fading
- Scattering and diffraction
- Traffic load
- Kind of services

Adaptive techniques are a necessity to address problems resulting from rapid changes in interference conditions in the system and statistical characteristics of the channel which rely greatly on environment. These adaptive applications differ depending on type of application and services involved in the transmission process. In wireless networks, the most crucial criteria for adaptation to wireless link are constant BER and throughput in scenario of fixed bandwidth. In case of constant BER, anticipated average value is defined for an adequate signal quality. Adaptation to link and interference variations is performed such that value of BER does not exceed the specified threshold. To accomplish it the fluctuations in power to transmit, coding rate, modulation order spreading factor etc. are made by system. As a result the channel quality is changed and so does its resultant throughput [14].

2.5 Literature Review

Traditional rate adaptation mechanism follow the auto rate fall back scheme which was settled for Lucent Technologies' WaveLAN-II WLAN devices. The methodology can be defined as:

- It keeps track for missing ACK frames
- Link speed is reduced when two consecutive ACK frames are missing
- Increases data rate when consecutive 10 ACKs are received
- It is slow in response to channel conditions

Performance can be degraded due to numerous factors e.g. 1) If consecutive ACKs are not received after increasing data rate then data rate is immediately dropped to lower values 2) Collisions due to multiple stations 3) Channel errors cannot be identified due to collisions [14].

In wireless environment, collisions occur due to conflict between transmitting nodes. Originally rate adaptation was targeted for contention free environment e.g. CDMA etc.

Therefore, wireless environment rate adaptation needs a special consideration for competing nodes in a dispersed environment. Many channel errors can be assorted with frame losses due to collisions. In IEEE 802.11 standard DCF is used to access the wireless medium. One of the mechanisms used in DCF to avoid collisions is to use RTS/CTS frames. Practically in WLANs, RTS/CTS is not used extensively, as it is used voluntarily when data frame is large or the there is a chance for hidden nodes. Two sections of MAC data frame can be observed: a header and a body section respectively. Type of frame is defined by the header in combination with addresses of sending and receiving nodes. Body of frame carries data that needs to be delivered. Header has small size in contrast with body and can be received more precisely as compared to body of the frame. If frame is misplaced and header has been received properly then the source and end point of the frame can be determined easily. In state of a collision, if header is notcaptured received nor is its body, both get misplaced. So if header has been received successfully and body is misplaced then loss of frame can be considered as an error in link. The basic concept provided in this study is to not drop the data rate when collisions are made. It is an extension to the ARF, where data rate is reduced when acknowledgement frame is not received. An extra frame structure, similar to ACK frame, has been included as DCF mechanism. It is used to differentiate link errors from collisions. Reception of NAK frame indicates that transmission has been failed due to errors in wireless link. So this methodology avoids unnecessary decrease in data rate. Hence data rate is not decreased when collision occurs. The overhead is to use the extra frames and it does not satisfy existing IEEE 802.11 standard [16].

Higher link speeds can be defined as the function of robust modulation mechanisms. Modulation is known as a digital transformation which makes data equivalent to digital ciphers that can propagate through wireless medium. Amount of bits to represent each cipher in this process is varied depending upon the modulation structure. Competence of modulation technique can be determined through its capability to sustain correctness of bits that have been used to encode data. Chance of larger gain BER is expected with high link speeds. For different modulation methods, thevalues of SNR and BER are inversely proportional to each other. So for a certain SNR value, increase in BER can be experienced while switching to higher link speed.Hidden terminal problem can be described as, in the communication of sender and receiver there is a third node that can only notice the receiver and do not know about the presence of sender. Sender is transmitting data to receiver and also another node start to send data. In this case collision can occur. The functional resolution to this problem is RTS/CTS frame conversation before transmitting data to other node.Here the assessment for subjective link state of receiver is performed at receiver instead of sender. For each packet, the switching decision for link speed is made via RTS/CTS frames. After that suitable link speed is activated to transmit the packet. Quick response to varying link state has been optimized by assessments made at receiver which are interchanged with sender via RTS/CTS frames. Mechanism to use specific frames to share the link information is expensive in terms of bandwidth and time. Link speed and size of data packet is summarized in RTS by sender. Receiver of RTS makes assessment to measure the link state and the appropriate rate and packet size is inserted in CTS frame. Receiver of CTS then propagates frames on the suggested link speed. With the help of NAV, reservation for requesting nodes is made. As there are many nodes that are competing to send data to a particular node. Network Allocation Vector is used to manage all these requests. Introducing the changes in the RTS/CTS mechanism makes RBAR not submissive to IEEE 802.11 standard [3].

Furthermore to distinguish between channel errors and collisions another technique has been proposed. Scenario with multiple stations better explores the issue of collision. SNR is used to estimate wireless link status with consideration of time that is taken to access the wireless medium. Extra counter has been incorporated with Management Information Base (MIB) to collect information that is useful in estimation of state of wireless link. For a specific data rate, status of wireless link has been estimated to evaluate the expected throughput. Rate adaptation mechanism is then applied to select data rate. Special consideration for collisions and inconstant time to access the channel explores the reasons for loss of frames [17].

When higher data rate is used to transmit a frame it takes less time as compared to lower data rate. A simple table contains the data to be used to select data rate for transmission of data frame. Throughput for each data frame is estimated by deriving the ratio of the payload size, which has been expected, to the time required for transmission. Total time for transmission can be concluded as time consumed during back-off process, retransmission delays, reception of acknowledgement frames and overhead imposed by MAC/PHY layer. Three parameters have been summarized in table that are extent of payload, link state and counter to hold the record for retransmissions. This composes a table to be referred during the transmission of a frame. So most appropriate matching entry in table is found and related data rate is selected for transmission of frame. Link speeds for 802.11a has been explored for adaptation of rate [12].

Deciding data rate on the basis of each packet points towards low latency systems whereas episodic observation for transmitted data is required for high latency systems. With higher data rate overall throughput achievement is higher and PER (packet error rate) increases as well. The increasing PER for higher data rate can increase the retransmissions which can degrade the throughput. So PER is increased when number of retransmission increases. In scenario when a wireless node is least active, the consistency of higher data rates is important. Therefore, history of the previous received acknowledgements is important. When a transmission has been completed successfully the related time interval between it and a new upcoming transmission should be equal to DIFS. In case of transmission, that was not successfully terminated, timeout for acknowledgement frame is also added. When data rate is decreased due to misplaced ACKs, a methodology has been adopted to immediately raise the number of expected ACKs so that switching to higher data rates is made rapidly. For example successive ACKs have been multiplied with two to calculate a threshold value. Throughput has been considered excluding the overhead of MAC and PHY overheads [18].

When signal propagates, noise is added which makes the signal weak. When receiver accumulates the signal, it decodes it with all the noise. So the received signal can determine quality of the channel. When a channel quality is good, more packets are transmitted at higher link speeds. Different throughput for various nodes is achieved depending upon their link states. Link status is evaluated with help of a rate adaptation technique. When high data rate is achieved more packets are transmitted as compared to lower data rate. The idea for generating more packets increases the throughput for high link speeds [19].

Rate adaptation is defined as a function of sender and receiver interaction. The channel conditions related to receiver are recorded at receiver and then shared with sender. Sender node uses the information to adapt to data rates according to link status. The data rate is predefined as recommended by the receiver. It depends upon the receiver whether it accepts the recommendation or rejects it. In case of rejection sender adapts to data rate according to its own observations. Channel state information has been used at both sender and receiver to evaluate channel conditions. Sender uses the transmission history to keep record of successful and failed transmissions. Receiver uses the strength of the signal that has been received for the approximation of link state. The data rate that has been suggested by the receiver is propagated to the sender by sending the ACK frame at that link speed. After ten successive received frames, the ACK at the selected link speed is sent to tell the receiver about data rate. For higher link speeds that are communicated by receiver, it takes high bandwidth to send acknowledgement frame. In this case, extra bandwidth gets consumed by sending acknowledgement frame at higher data rates [20]. The techniques that can degrade throughput have been studied in real scenario. The observation consideration to drop packets, overhead of extra frames to estimate the rate, using figures related to failure or success of the transmission, evaluating link speed by using link parameters. The experimental study has been provided to observe the performance degradation due to projected techniques. The overheads have been suggested to overcome with idea of selective practice of RTS frames and percentage for transmission failure over little time span. FPGA are used to evaluate the methodology to adapt to link speeds [21].

Concept of rate variations related to acknowledgement frames have been introduced as an object of study in this research. Channel conditions at receiver are projected which trigger the variation in data rate to send ACK frame. This is an indication for the receiver to make selection for the next data rate to conduct next transmission.For upright link state, receiver selects different data rate, to propagate acknowledgement frame, than the rate that was used previously. Link adaptation according to receiver’s perspective can be achieved using RTS/CTS frames that are altered according to conditions. An alternative way to adapt to link speeds does not consider response from receiver and rate is revised according to approximations at sender. When channel state found in better condition and data has been transmitted at higher rates, then ACK for the received frame is sent at basic link speed (lower link speed). This is an indication to receiver to continue next transmissions at similar rate [22].

Errors that have been observed at link can be described in terms of bit error rate. Involving the feedback from the receiver to adapt to data rate is time consuming, especially with the perspective of streaming the multimedia over wireless link. Packet aware link adaptation has been considered as amount of retransmissions for every important packet has been calculated.Here adaptation to channel conditions has been defined in terms of adapting the encoding rate of video at application layer.

Four tasks have been focused which are approximating the recent state of link, adjusting the buffer settings at application layer, scheming the rate of transcoding of video based on information mined from earlier two tasks , computing the redundancy of the FEC (forward error correction) packets, which relies on state of wireless medium [23].

Bit errors can cause the whole packet to be discarded. In case of providing multimedia on the wireless link, such type of bit errors can be endured as time is main restraint to retain the adequate quality of multimedia. The main idea is to eliminate the bit errors such that packets with errors are not dropped and transmitted. The error checking policy at PHY layer i.e. CRC functionality has been ignored in order to avoid loss of frames due to bit errors. With this approach extensive retransmissions have been avoided in order to reduce delay and collisions that are originated from MAC layer due to revised transmission of frames [24].

Interval between sending and receiving data is relative to size of frame but it reduces with increasing link speeds. Header placed by physical layer (e.g. PLCP header) is also another factor that can produce delay if it is large [25].

It is important to focus on differentiating between channel errors and collisions. Main focus has been provided to discriminate the frame losses invoked by channel errors and collisions. In the environment of so many contended nodes, collisions can occur and performance is degraded due to collisions. So RTS/CTS mechanism was introduced to avoid collisions. Solution proposed can be described as:

- To differentiate between channel errors and collisions RTS/CTS mechanism is used to avoid the chance for collision
- Rate adaptation mechanism used is ARF but extended with the use of RTS/CTS mechanism
- Loss of consecutive ACK frames can be considered as channel errors
- Dropping data rate is according to channel error not collision

Problems that have been observed can be described 1) Use of RTS/CTS mechanism for each transmission degrades overall throughput 2) Not compliant to existing IEEE 802.11 standard due to use of RTS/CTS mechanism for each data transmission 3) RTS/CTS frames are transmitted more frequently, hence consuming more bandwidth [26].

RSSI (Received Signal Strength Indicator) is used as a parameter to estimate the channel strength. Based on RSSI, sender chooses one of the data transmission modes by means of RSSI threshold lookup. Here the concept of efficient sender is utilized and all estimations about link status of receiver are made at receiver. An interesting technique has been used in SARA scheme for appraisal of link status of the receiver.Link metric used here is RSSI and experiments have been performed to differentiate between the RSSI at sender and receiver. It has been experienced that RSSI of the transmitter and receiver are approximately same. This idea has been used to capture the RSSI associated with acknowledgement frame that have been received from the receiver after successful data delivery. This RSSI value is almost identical to the value of RSSI, with which frame from sender was received at receiver. The assessments that are made after receiving acknowledgement frames form receiver are used to decide the link speed to send data next time. Two problems have been focused. First one includes the dramatically changing channel conditions are controlled by using link parameter (RSSI). Second is overhead of RTS/CTS mechanism for each data transmission is reduced by using selective RTS/CTS mechanism to avoid collisions. Problems that are identified here are 1) channel statistics have been ignored totally, which leads towards the loss of valuable information about channel condition and 2) All the receiver are assumed to have same bandwidth capability [4].

Revision to different link speeds can be performed by considering throughput, packet error rate or revised transmission of frames. In each case the opportunity to transmit multimedia is not considered. Higher data rate afford better quality of video if PER is low.Existing algorithms for link adaptation make extensive use of the retransmission mechanism at the MAC layer in order to improve the error-free data throughput without taking into account the bounded delay requirements of real-time video applications.

Improved PSNR can be obtained if high bit rates are selected with increase in signal to noise ratio. Considering the transmission of video data, the decision to switch to different link speeds has been made by estimating the alteration, which can be experienced on current link speed. Alteration for video at current mode and successive lower and higher modes is assessed in accordance to current link state estimation [27].

Link adaptation can be defined as an adaptation technique of transmission parameters (i.e. coding and modulation). Generally they include a set of algorithms and protocols that help control adaptive coding and modulation of transmissions. Effective throughput for a user requires link adaptation by varying the link speeds and changing the size of packet as a function of channel conditions. Link adaptation becomes a challenge when complexities arise in the physical layer due to joint utilization of OFDM along with multiple antennas and convolutional codes [28]. Supervised learning requires a powerful road plan for adapting the modulation and coding in view of MIMO-OFDM. This adaptation requires certain conditions of channels for its adaptation [29].

Adaptation Scheme for MANET (video) has been proposed in [30]. According to this study, human eye cannot notice negligible changes of mathematical measurements such as signal to noise ratio (SNR), which calculate the error in sequence of images. So MPQM (moving picture quality metric) is used here. Due to congestion, RTP is used as QoS parameter of the streams for adaptation can be measured with the help of RTP e.g. loss and jitter/delay. When discussing about QoS the packet loss can occur due to congestion in the network and channel error. Multimedia applications often reduce its sending rate, e.g. from 256kbps to 128kbps, in case of congestion causing packet loss. To accommodate these channel errors, applications need same or more bandwidth for implementing FEC (Forward Error Correction) and ARQ (retransmissions) eliminating need to reduce its data rate.

In [31] Adaptive Streaming of MPEG-based Audio/Video Content over Wireless Networks describes a unicast protocol for robust streaming which includes different codec such as MPEG-2,MPEG-4, H.264 and uses RTP protocol over TCP/UDP and which can be modified for multicasting. The objective of this scheme is to keep the desired transmission bit rate constant without compromising the audio/video quality. In a packet scheduling scheme, I-Frame Delay (IFD), are introduced for adaptation in bit rate. A priority based frame dropping is performed in case of insufficient bandwidth.

Link adaptation is associated to MAC-PHY layer while application rate adaptation takes place at application layer. Rate adaptation at application layer can be stimulated by the informatione.g. available bandwidth or delay obtained from MAC-PHY whereas link adaptation at MAC-PHY can be triggeredby information from application layer e.g. packet priorities affecting modulation and coding schemes. Some mechanisms have been adapted for rate adaptation in wireless networks based on the statistics (transmit time, back off time, idle time) which are obtained from MAC-PHY layer and passed to application layer. Using Modulation and coding schemes, it can be calculated as to how many bytes of data should be transmitted at a certain transmission time. These values can be used for rate adaptation at application layer e.g. deciding how many bits of data need to be transmitted over the next interval in time. When channel gets idle, data rates on channel can be used to increase the bandwidth for a multimedia stream using a controlled mechanism avoiding traffic bursts. This idle time must be intelligently divided amongst all nodes accessing the same channel [32].

Link adaptation at physical and MAC layer consider channel characteristics neglecting characteristics of effective video streams. Due to which low quality videos get transmitted. To avoid this, a cross layered structural design was proposed. Different cross layer protocols have been proposed for bandwidth management. They also include different bandwidth adaptive protocols used in wireless networks. Timely adaptive resource management designs consist of wireless access points and wireless backbone. It handles resource reservation for individual flows, advanced reservation before back-off, resource adaptation, and priority aware transport protocol. Owing to hidden node problems, node mobility and false route admission flow, they pose certain limitations.

Moreover, lack of coordination between the flows during admission controls causes various implementation problems in real time traffic [33].

In [34] Link Adaptation in subject of Joint PHY/MAC for Wireless LANs has been explored with the consideration of Multipath Fading addresses, suitable payload size for maximum throughput and adjusting physical data rate based on the current channel conditions. Varying payloads sizes are verified for diverse voice codec such asH.264, web browsing and FTP. Experiments are conducted to evaluate the effects of selective frequency values and variations in the length of payload on the throughput of a distinct user.

Effects of selective frequency values and variations in the length of payload on an individual user throughput were calculated in experiments. The empirical results of which indicated that the certain thresholds for link adaptation were found to rely on fading environment and size of payload. Such factors are highly sensitive and greatly affect received SNR requiring measurement accurate SNR highly essential.

2.6 Summary

In this chapter related studies have been reviewed, which explore rate adaptation methods. Detailed study has been performed in order to explore the effect of channel conditions on the data transmission. Various techniques have been proposed that provide efficient mechanism for rate adaptation. With the help of rate adaptation the available data rates for IEEE 802.11 LANs can be efficiently utilized to achieve higher throughput.

Chapter 3

RSSI BASED STATISTICAL RATE ADAPTATION (RBSRA)

3.1 Introduction

This Chapter gives the description of the proposed system, its architecture and its underlying algorithm. It delivers the valuable information about the problem, and manipulates its detailed solution. Different aspects of the proposed scenario have been explained. It also reveals the detailed study of the scenario of the proposed system, thus helping in understand the problem and leading towards a better solution.

3.2 Problem Description

In the rate adaptation, the data rates are selected according to the channel conditions either on the basis of statistical data or the parametric approach (As discussed in chapter 1). In this scenario ignoring any one of both approaches can lead to loss of valuable information about adaptation of rate to send data. The number of received ACKs contains useful information about received frames. It ensures that data has been received at receiver successfully. Received signal strength indicator (RSSI) contains information about link state. Detailed study of rate adaptation has revealed that data rate assignments, which are purely based on the RSSI value, can cause different problems. Consider a scenario of wireless network in which a node is transmitting video to other 2 mobile nodes. Listed below are some problems that have been identified.

3.2.1 Allocation of same data rates to nodes with different bandwidth requirements

In figure 3.1 there are two nodes with different bandwidth capabilities. In wireless scenario where nodes move randomly, both nodes come at equal distance, from the sender. If channel condition is estimated based on RSSI then rate is simply increased or decreased according to value of RSSI. Hence data rate assigned to both nodes will be same, in spite of the fact that the received number of ACKs for the Node 2 will be higher than that of Node1.

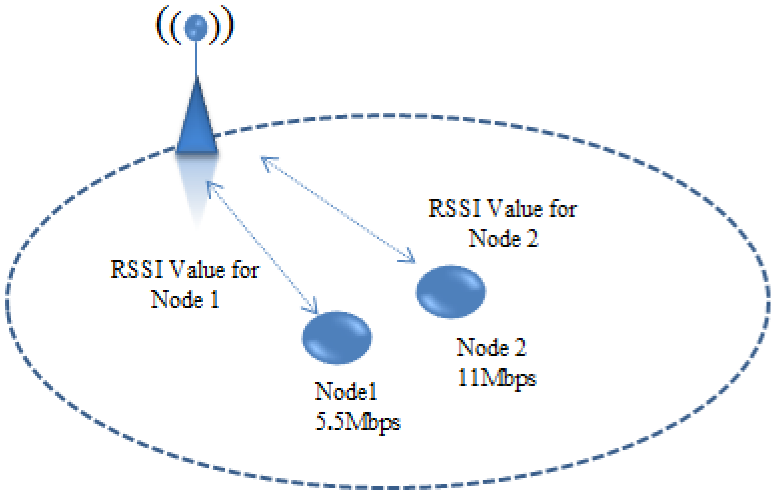

Figure 3.1 RSSI values of two nodes at same distance

As shown in Table 3.1, sender node assign equal data rates to the nodes when their RSSI values are same. So this scenario considers all receivers having same bandwidth requirements and totally ignores the statistical information which can lead to severe disorder.

Table 3.1 Data rate allocation to nodes with different bandwidth configuration

Node	Bandwidth (Mbps)	RSSI Value	Assigned Data rate (Mbps)
1	5.5	High	5.5
2	11	High	5.5

3.2.2 Allocation of high data rates to nodes with low bandwidth capacity

In figure 3.1 node1 has less distance from sender and node2 is far as compared to node1. RSSI value for node1 will be higher than that of node2. So node1 will be assigned higher link speed than the node2.

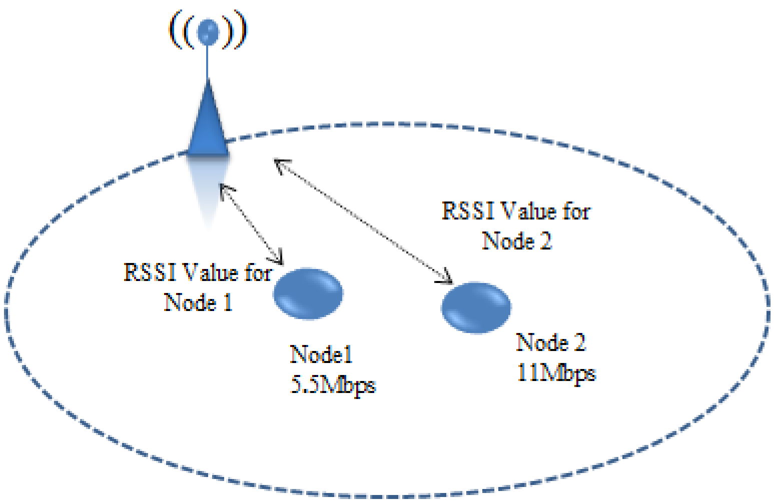

Figure 3.2 RSSI values of two nodes at different distances

Table 3.2 Data rate allocation to nodes with different bandwidth configuration

Node	Bandwidth (Mbps)	RSSI Value	Assigned Data rate (Mbps)
1	5.5	High	5.5
2	11	Low	2

3.2.3 Unnecessary decrease/increase in data rates

Figure 3.3 elaborates that node1 was first placed near to source of data transmission and then moved away from it. When node1 moves away from sender, RSSI values are decreased and data rate has been dropped accordingly. Due to reduced link speed, transmitted number of frames are reduced such that, leading towards throughput degradation. It is possible that when RSSI value is decreased then there is no need to drop the data rate as the receiver is receiving the frames correctly. In this situation dropping the data rate may lead towards the throughput degradation.

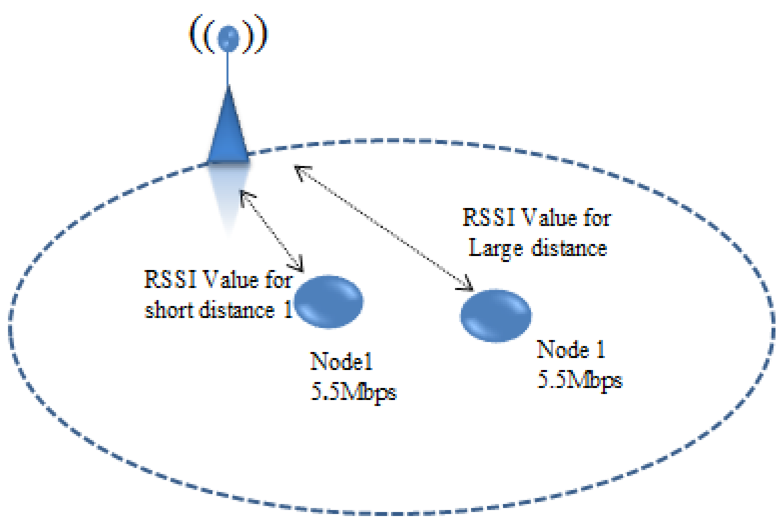

Figure 3.3 RSSI values of a node at two distances

Table 3.3 Data rate allocation to nodeat different distances

Node	Bandwidth (Mbps)	RSSI Value	Assigned Data rate (Mbps)
1	5.5	High	5.5
1	5.5	Low	2

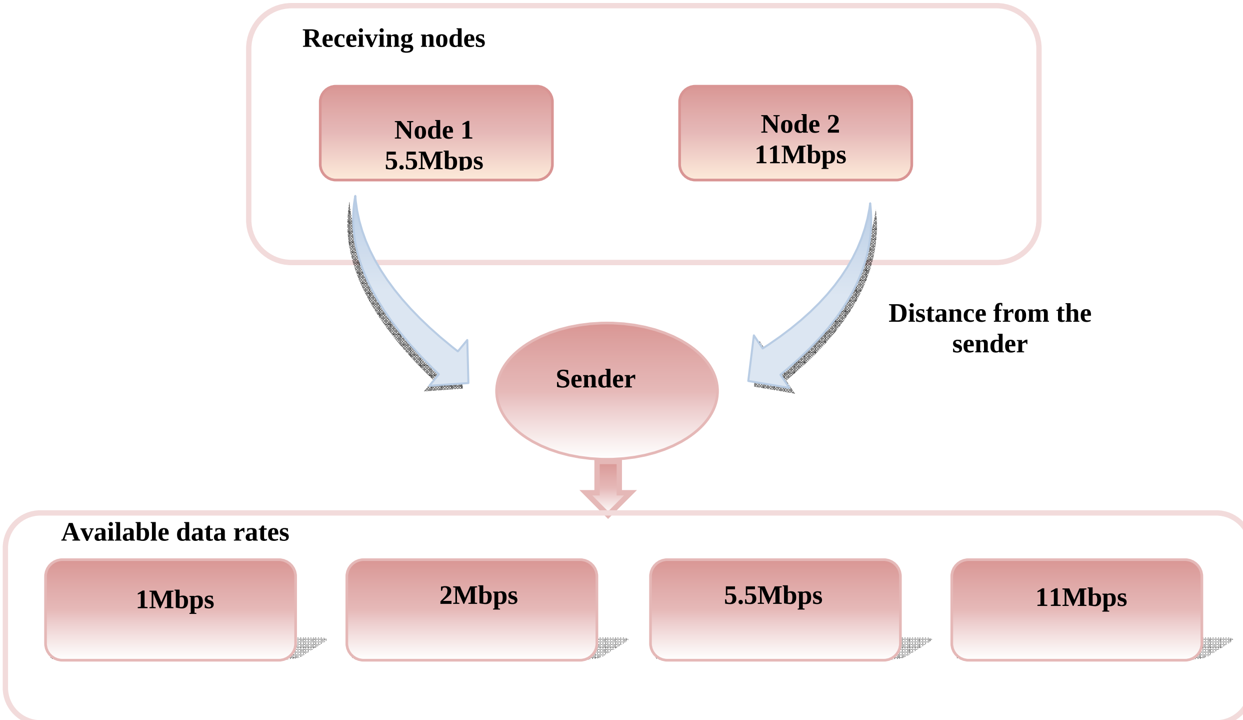

Figure 3.4 Data rate selection for different nodes at same distance

Figure 3.4 summarizes the mechanism to assign data rates in view of the scenarios that have been explored above. Nodes placed at different distances with different bandwidth capability are assigned data rates that can actually degrade performance. Sender chooses link speed just relying on the distance or RSSI value and bandwidth capacity of nodes is ignored. Similarly, if there is throughput gain within a certain range and node are moving away from the sender but remain within range then data rate is switched to lower one and throughput is reduced.

3.3 RSSI based Statistical Rate Adaptation (RBSRA)

In proposed RSSI based Statistical Rate Adaptation, the selection criteria for different data communication rates is based on both the statistical as well as channel quality considerations. The hybrid of statistical and PHY level constraints comprises an informative and flexible structure to extract more accurate information for the adaptation of data rates. Statistical and PHY level parameters have been utilized to assess link state are 1) number of ACKs after successful data delivery and 2) RSSI values respectively.

In RBSRA the RSSI values are used with the number of ACKs of received frames. In other words, it can be stated that MAC layer parameters (e.g. Received ACKs) have been utilized jointly along with PHY layer metrics (RSSI). In this state the RSSI value provides the information about the signal quality at the receiver side and number of ACKs provides the information about data received by receiver. The statistical information about the number of ACKs is used to control the rate selection in order to provide a state of equilibrium in which the higher data rates will be allocated to the higher link capability nodes and lower data rates will be allocated to the low link capability nodes. In wireless scenario the channel state keeps changing due to many factors, mainly due to collisions, attenuation and interference. These changing channel states also invoke loss of data frames. When RTS/CTS mechanism is enabled for data exchange, channel errors due to the collision are avoided which makes the number of ACKs of received frames more useful for data rate selection.

3.4 RBSRA System Architecture

Figure 3.4 demonstrates the architecture of the proposed scheme. Proposed rate adaptation module considers the IEEE 802.11 a/b/g/n wireless LANs and serves at the link and PHY layer, where channel estimations are made by joint cooperation of MAC and PHY layers. The proposed scheme has been designed to adapt the data rate according to the channel conditions. When there is data to transmit, the RSSI value is required to initially adjust the data rate. After a data transmission, the number of ACKs for transmitted data rate calculated. The thresholds are generated to define the boundaries to switch between existing link speeds.

During the transmission sender is supposed to assess the channel conditions of receiver with help of available information that has been provided by MAC and PHY layer metrics. Channel estimations on behalf of sender are made hence channel estimator is used for this purpose. Wireless medium circumstances for sender can be evaluated through channel statistics of the transmitted data and RSSI with which signal is being captured at receiver. So RSSI value is measured and ACKs that have been sent by receiver are analyzed. Measurements are then passed to Threshold calculation module. Here thresholds are calculated that have been used for further important comparisons.

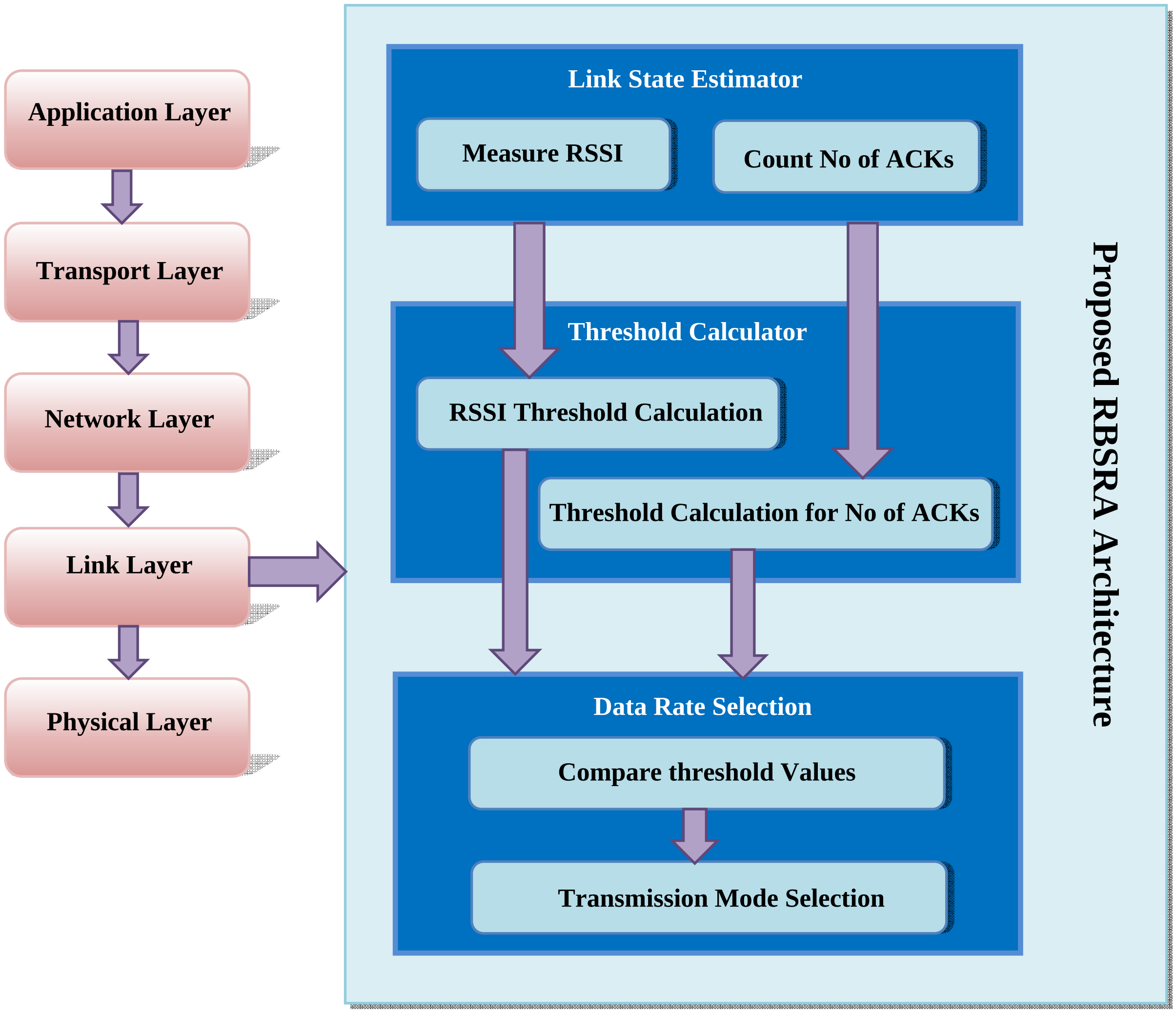

Figure 3.5 RBSRA System Architecture

Measurements for RSSI and number of ACKs are then passed to threshold calculation module. Here thresholds are calculated that have been used for further important comparisons. Calculated threshold values are then submitted to data rate selection module.

Comparison of thresholds is then made in order to evaluate the link state. Depending upon the comparisons, the status of RSSI and number of ACKs is set either low or high. This information is then forwarded to data rate selection module which selects a suitable data rate for next transmission.

3.5 Link State Estimator

Link state has been estimated using the RSSI values and the number indicating total received ACKs for a transmission. Link state estimator has been divided into two sub modules that are RSSI calculation and Channel Statistics Calculation.

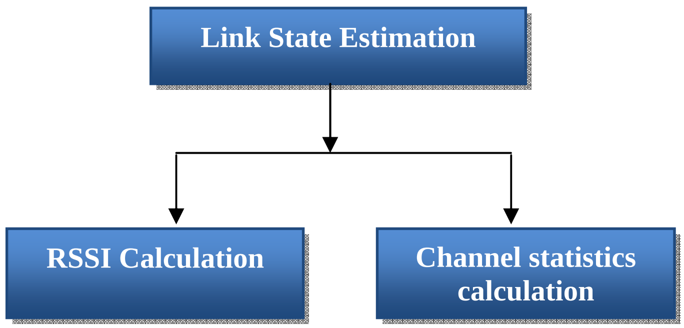

Figure 3.6 Link state estimation

3.5.1 RSSI calculation

In the proposed scheme the calculation of RSSI is an important function. RSSI calculation is one of the core functions that produce the valuable input for the data rate selection mechanism. As described in figure 3.7, RSSI values are calculated to estimate the channel conditions at the receiver side so that the data rate can be adjusted accordingly. Output of the RSSI calculation module is used as input to the threshold calculator module. Figure 3.8 illustrates the algorithm for RSSI calculation. ACK frames that have been targeted for sender are extracted and associated RSSI values have been calculated. These values are then forwarded to threshold calculation module.

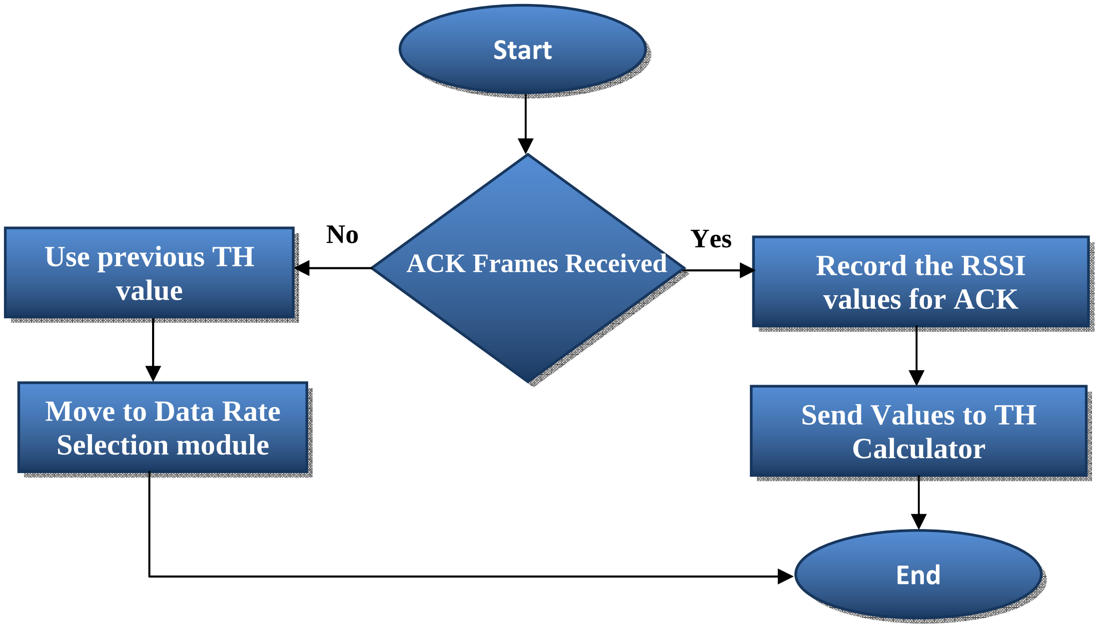

Figure 3.7 Calculation for RSSI values

```
1       recentRSSI=0
2       ACK count=0
3   If recv_ACK_frames then
                •  filter ack_for_sender()
                •  Extract RSSI for received ACK frames
                •  assign values to recentRSSI
                •  threshold_calulator(recentRSSI)
        else
            use previous values
        Data_rate_selection()
        end
```

Figure 3.8 Link state estimation Algorithm

3.5.2 Channel Statistics Calculation

When the data is transmitted successfully, the number of received ACKs can be counted to analyze the ratio of received data. Number of ACKs at MAC layer can indicate the receiving state of receiver, which can be helpful when used with RSSI value.

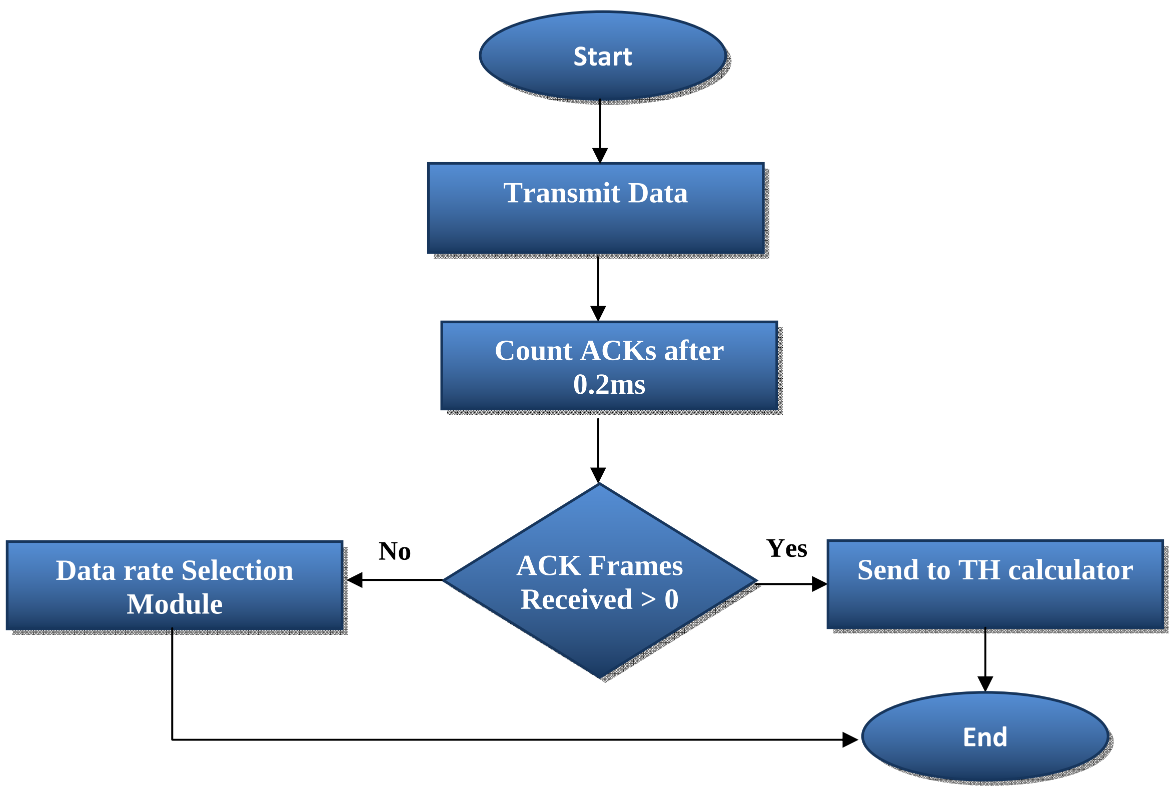

Figure 3.9Calculate received Acknowledgement frames

1 ACK_count=0
2 If ACK frames are received then
- filter ack_for_sender()
- count ACK frames
- increment ACK_count
- threshold_calulator(ACK_count)

else
ACK_count=0
    Data_rate_selection ();
end

Figure 3.10Channel Statistics Calculation Algorithm

In figure 3.9 calculation steps for channel statistics have been elaborated. These calculations produce the input for threshold calculator module for further comparisons. Algorithm to calculate number of ACKs has been described in figure 3.10.

3.6 Threshold Calculation

Threshold values for RSSI and number of ACKs are calculated. These values are used to decide the data rates that are best suited to the channel condition. Minimum and maximum values are decided.

3.6.1 RSSI Threshold calculation

As in [4] the RSSI calculated for each frame. RSSI is calculated at sender with the concept that sender and receiver both have the RSSI values approximately equal to each other. When a frame is transmitted to receiver, the respective ACK frame arrives. The signal strength at which the ACK frame has been received is utilized to calculate the RSSI value that will be used for link state estimation. Figure 3.11 describes the equations to calculate average RSSI value and high and low threshold values. These values are further used for comparisons that decide the status of RSSI as high or low.

$$AvgRSSI = 0.8 * AvgRSSI + 0.2 * RecentRSSI$$

$$HighRSSITH = \frac{AvgRSSI\ (Current\ Mode) + AvgRSSI\ (Next\ Mode)}{2}$$

$$LowRSSITH = \frac{AvgRSSI\ (Previous\ Mode) + AvgRSSI\ (Current\ Mode)}{2}$$

$$LowRSSITH\ (Next\ Mode) = HighRSSITH\ (Current\ Mode)$$

$$HighRSSITH\ (Previous\ Mode) = LowRSSITH\ (Current\ Mode)$$

3.11 Equations to calculate RSSI Threshold

When the transmission starts, the current value of RSSI is used to calculate AvgRSSI for the current mode. There are some previously calculated values for AvgRSSI value for next higher transmission mode and AvgRSSI of previous transmission mode. As described in chapter 1, there are many transmission modes that provide different data rates (e.g. 1, 2, 5.5, 11Mbps), so the current, previous and next mode in the equations represents the data rates that will be used for transmission of data.

Previous mode indicates the previous low mode with lower data rate and next mode indicates the next mode with high data rate. The high RSSI threshold will be adjusted as the low RSSI threshold of the next mode with higher data rate. Similarly the high RSSI threshold of the current mode will be the low RSSI threshold for the next transmission mode that is providing high data rate than the current mode. It is important to note that RSSI value is increased when higher data rates are selected and it is decreased when lower data rates are used for transmission. So higher RSSI values can be observed while transmission takes place at higher data rates and vice versa.

```
1.  current_RSSI = calculateRSSI()
2.  compute RSSI_avg as (current_RSSI + RSSI_avg_prev)/2
3.  if RSSI_avg< = HighTH then
        set RSSI_status as high
else if RSSI_avg< =LowTH then
set RSSI_status as low
end
```

Figure 3.12 Algorithm to assign Status of received ACKs by comparing with Thresholds

In figure 3.12, the algorithm to set the status of RSSI value and received ACKs has been described. If average value of RSSI is less than or equal to high threshold value then RSSI status is set as high. If average value of RSSI is less than the lower threshold value then status of RSSI is marked as low.

3.6.2 Statistics Threshold calculation

When input is received as the total number of ACKs for the previous transmission, it is used to calculate the threshold values. High threshold and low threshold values are calculated. Their values are used for important comparisons, which are crucial for deciding the data rates. Equations to calculate average value, high and low threshold values of received ACKS are described in figure 3.13.

$$AvgACK = (AvgACK + ACKCount) / 2$$

$$HighACKTH = \frac{AvgACKCount\ (Current\ Mode) + AvgACKCount\ (Next\ Mode)}{2}$$

$$LowACKTH = \frac{AvgACKCount\ (Previous\ Mode) + AvgACKCount\ (Current\ Mode)}{2}$$

$$HighACKTH\ (Previous\ Mode) = LowACKTH\ (Current\ Mode)$$

$$LowACKTH\ (Next\ Mode) = HighACKTH\ (Current\ Mode)$$

Figure 3.13 Equations to calculate Threshold for received ACKs

The data rate will be the higher as we move towards the higher modes, so the ACKs will be increased. With higher data rates more number of frames get transmitted, which will automatically increase the reception of ACKs at MAC layer. HighACKTH is calculated using the average of the current mode and next mode. In the start of transmission the default threshold values are used for each mode. These threshold values have been decided after observing the data transmission many times and average values have been extracted for each mode. Figure 3.14 illustrates that high threshold for ACK count of the lower transmission mode will be the low threshold for the next higher data transmission mode. Similarly the low ACK threshold for high transmission mode will be the high ACK threshold for the adjacent low data transmission mode.

Table represents the high and low threshold values that have been used for each data transmission mode. For example considering the data rate of 1Mbps, the low threshold value is 15 and high threshold value is 24.

For data rate of 2Mbps, low threshold has been set 24 which is high threshold of previous mode. Similarly values have been calculated for all transmission modes. These values have been calculated by considering the fact that number of ACKs increases when transmission rate is increased.

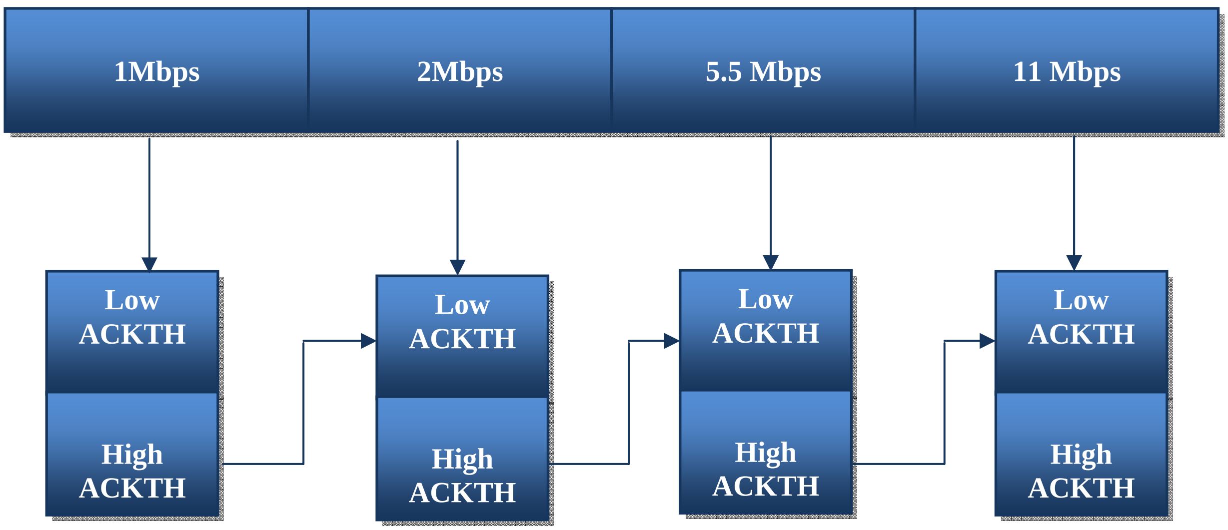

Figure 3.14 ACK threshold values for different data rates

Table 3.4ACK Threshold values for different data rates

Data Rates (Mbps)	Low ACK TH	High ACK TH
1	15	24
2	24	45
5.5	45	75
11	75	100

Status of received ACKs is set after comparisons with the threshold values. As described in figure 3.15, the average value for received ACKs is compared with high threshold value. If it is less than or equal to high threshold value then status is set as high. If average value of received ACKs is less than or equal to low threshold value then status is marked as low.

```
1.  Ack_count = CalculateACK()
2.  get value of ACK_prev_avg
3.  calculate ACK_avg as (Ack_count + ACK_prev_avg)/2
4.  if ACK_avg <= HighACKTH then
        set ACK_status as high
else ACK_avg < =LowTH then
set ACK_status as low
end
```

3.15 Assign Status of received ACKs by comparing with Thresholds

3.7 RBSRA Data Rate Selection Algorithm

Given below are four scenarios that are possible while selecting the data rate to deliver the data for particular receiver.

- If the RSSI value is high and number of ACKs is low then the data rate should be maintained.
- If RSSI value is low and number of ACKs is high then current data rate should be increased. In context of above scenario if only RSSI is used to decide data rate then data rate will be decreased whereas it has been maintained because number of received ACKs is high.
- If RSSI value is low and number of ACKs is also low, then drop to the lower data rate.

- If RSSI is high and number of ACKs is also high then data rate should be increased.

Discussion about decision of data rates can be summarized by the algorithm illustrated by figure 3.16.

```
1.  RSSI_status= RSSIthcalculator()
2.  ACK_status= ACKthcalculator()
3.  If RSSI_status & ACK_status is high then
    assign higher data rate
    else If RSSI_status & ACK_status is low then
    drop to lower data rate
    else If RSSI_status is high & ACK_status is low then
            maintain data rate
```

Figure 3.16 Algorithm to decide data rate based on RSSI and ACK status

Figure 3.17 describes the data rate selection algorithm in detail. Status of RSSI and received ACKs is decided after threshold calculations and forwarded to data rate selection module. Here comparisons are made to analyze the channel state in order to select data rate for transmission of data.

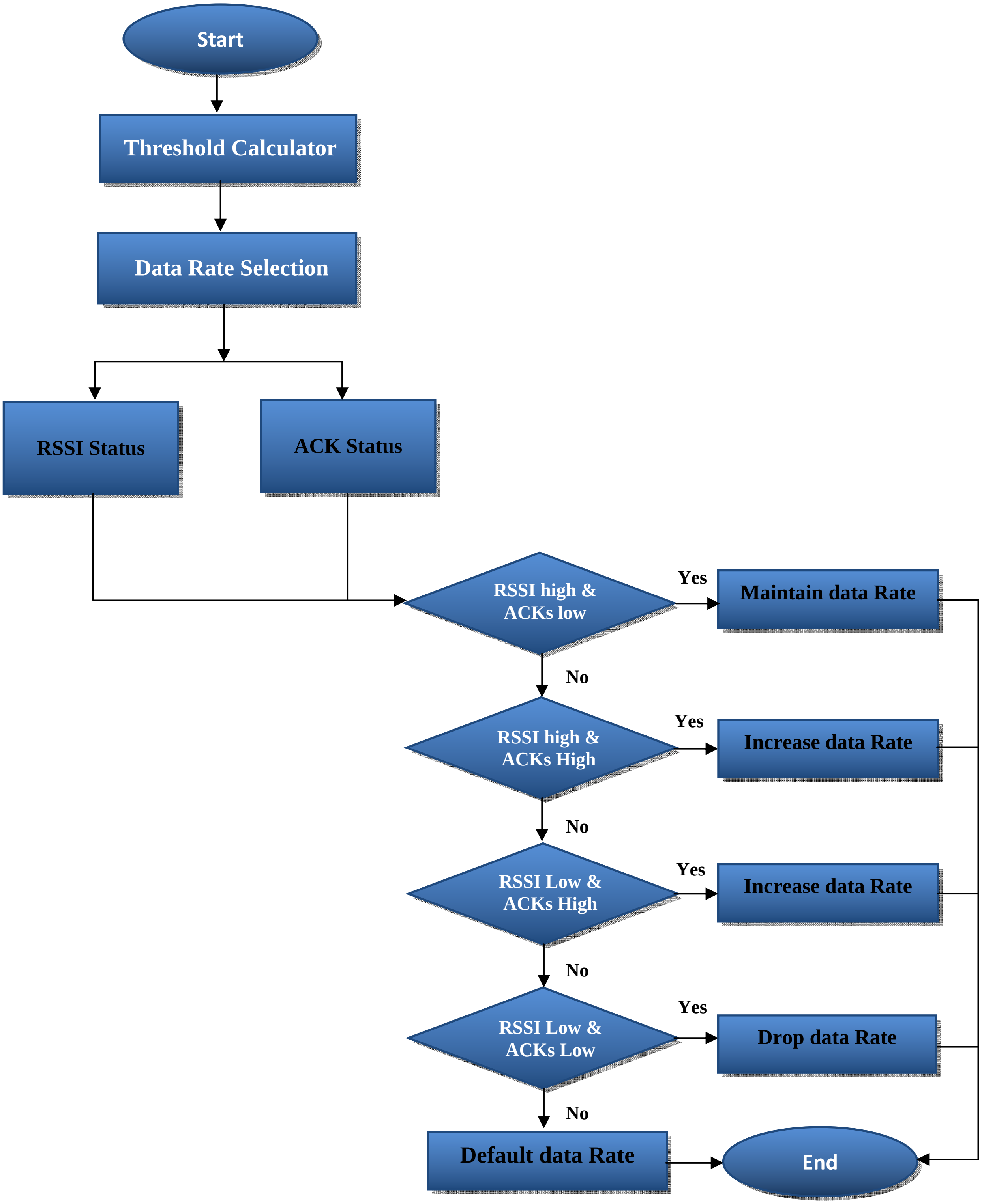

Figure 3.17 Data rate selection

The schemes that do not consider the statistical information can yield the following conditions.

- If the RSSI value is larger than the low threshold the simple RSSI based schemes will maintain the data sending rate
- If RSSI value is low then, depending upon this information, RSSI based schemes will decrease the data rate.

Therefore, increasing data rates when number of ACKs is low will not benefit the data transmission hence resulting in a decreased number of ACKs which means more data frames will be dropped. Similarly, decreasing the data rates will decrease the number of ACKs of received frames which will increase the packet loss at receiver and condition will be worse. The combination of PHY and MAC layer parameters provide valuable information that can be used to explore channel state at receiver adequately.

Figure 3.18 represents a complete flow chart that describes flow of operations in proposed system. Whenever there is new data stream, default data rate is selected to send data. After transmission when ACKs are received, the respective RSSI value has been captured and number of ACKs is calculated. This information is then passed to threshold calculation module. Where thresholds are calculated and comparisons are made to verify the status of RSSI and ACKs. This information is sent to data rate selection module which then performs a detailed analysis of PHY and MAC level parameters in order to select data rate that is suitable for next data transmission. Sequence diagram in figure 3.19 elaborates these operations more clearly.

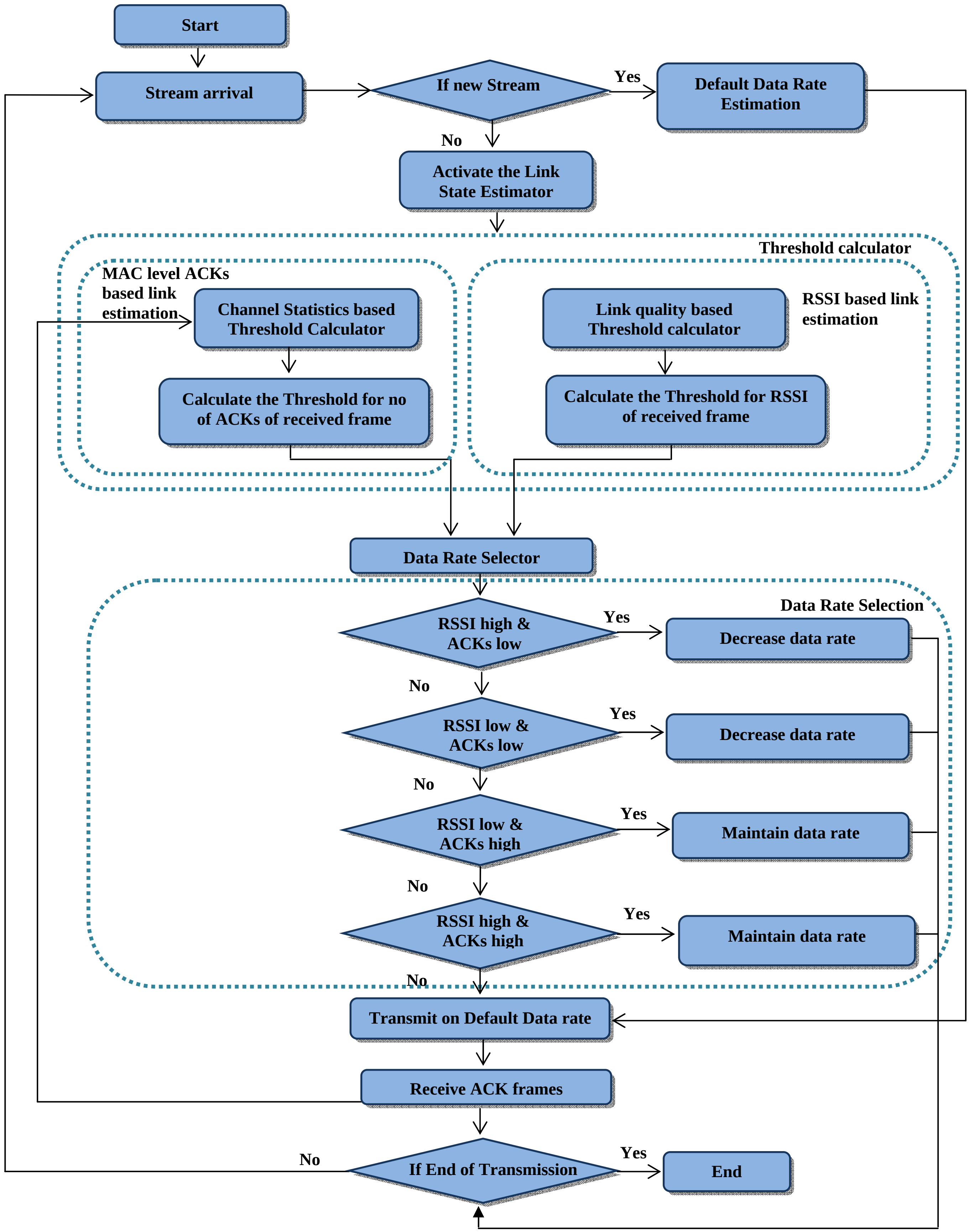

Figure 3.18 Flow chart for the operations of proposed system

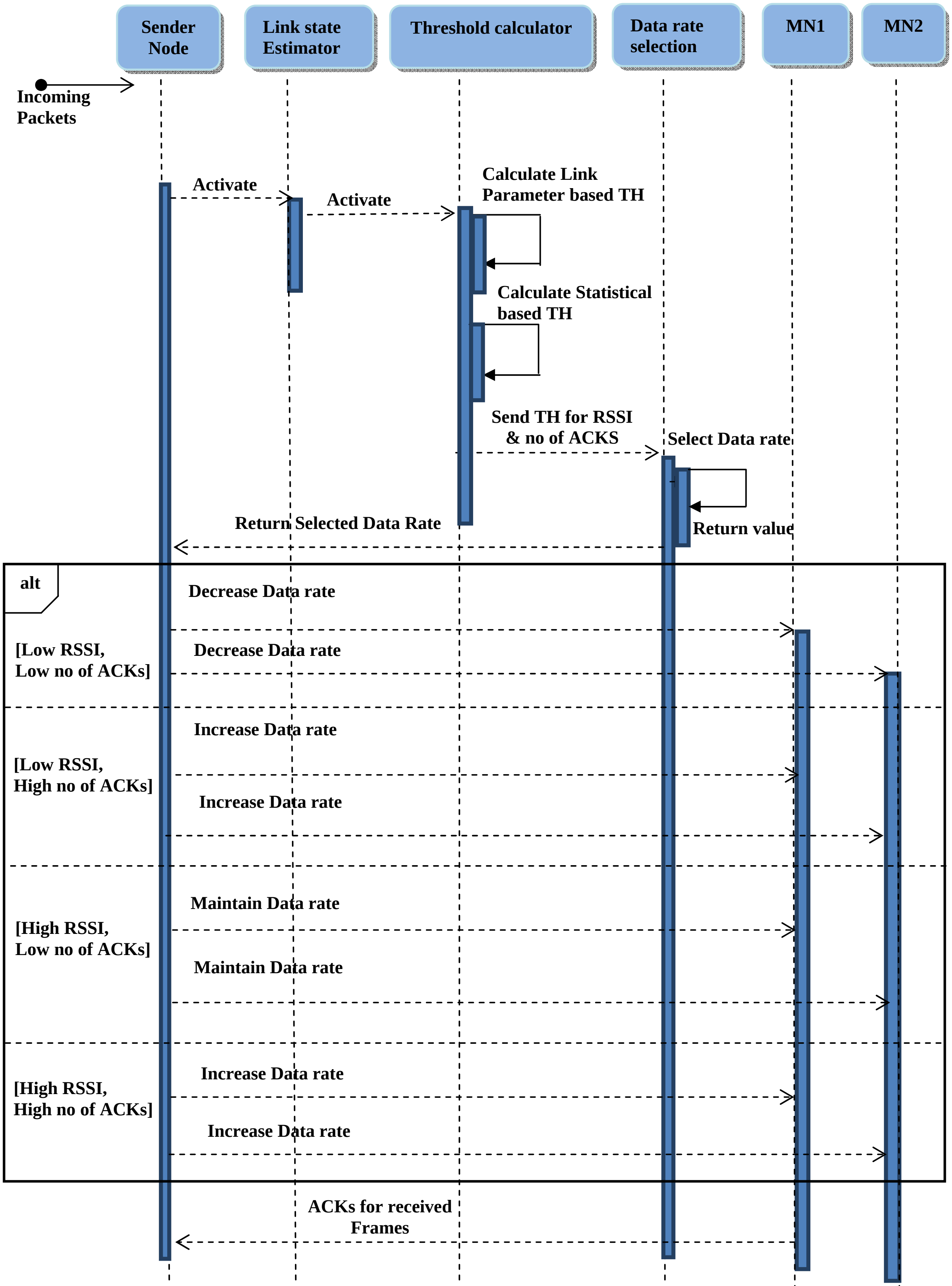

Figure 3.19 Sequence diagram for the operations of proposed system

3.8 Summary

In this chapter details of problem description and proposed system have been provided. Problems related to data rate selection have been discussed and Architecture of Proposed system has been elaborated. Various modules have been described along with algorithms and flow chart. System flow chart and sequence diagram provide details of functions of proposed system.

Chapter 4

SIMULATION AND IMPLEMENTATION OF RBSRA

4.1 Introduction

In chapter 3, the details of the proposed system have been discussed. This chapter describes the simulation configurations and implementation of the proposed system. The simulation scenarios and parameters have been described in detail.

4.2 Rate Adaptation Scenario

Consider the scenario in which the wireless nodes have been connected in ad-hoc mode. UDP traffic has been generated between sender and receiver. While receiving the data, receiver node continuously moves, representing the real world scenario. The sender node has been assumed to move less frequently as compared to the receiver nodes so that we can clearly observe the channel conditions at the receiver.

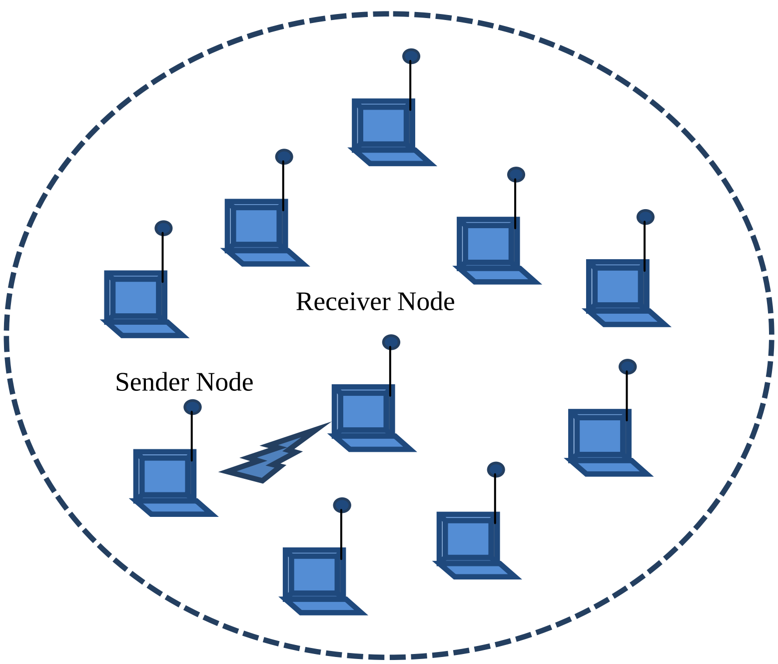

Figure 4.1 Simulation Topology

This scenario can help us to handle multiple receivers with different bandwidth capabilities and channel conditions. The focus is on varying link conditions at the receiver side and then accommodation to those variations at the sender node has been proposed. The presence of other mobile nodes also affects the channel conditions of the sender and receiver. The receiver node has been moved away so that it is out of the range of sender node. Similarly, the receiver nodes are moved towards the sender node. Also, other interfering nodes have been introduced in order to observe the channel conditions that are closely related to real world scenario. The bad channel conditions cause the following problems

1) RSSI values are decreased

2) Overall throughput is decreased

3) Due to channel errors the received ACKs at MAC level are decreased

To accommodate the bad channel conditions it is required to observe the RSSI value and channel statistics so that the suitable data rate should be selected. In figure 4.2 the simulation scenario has been represented.

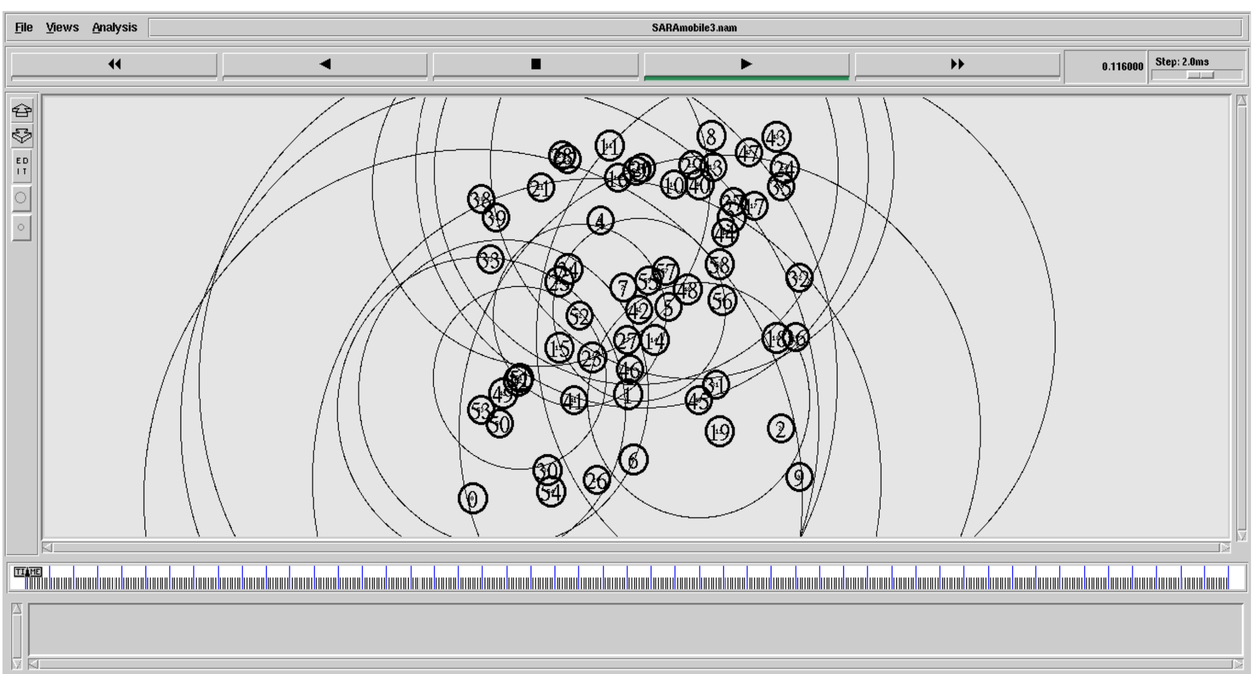

Figure 4.2 Simulation screenshot

4.3 Simulation Configuration

The proposed scheme has been implemented using the Network Simulator (NS-2) [35], using Linux (UBUNTU 9.10) environment. NS-2 is worldwide researcher's recognized network simulator for simulation of wired and wireless networks. The researchers most probably use NS-2 due to its open source nature because it provides better facility to simulate the wide variety of wireless and wired network scenarios. C++ libraries can be modified according to the simulation requirements. IEEE 802.11b standard has been used to simulate the proposed scheme. The CBR traffic has been generated to test the performance of the proposed scheme RBSRA. The simulation has been run for 50 seconds and nodes are moved away and then moved nearer to the sender.

Table4.1 Simulation Configuration

NS2 Configuration	Values
Data Rate	1-11Mbps
Basic Data Rate	1Mbps
Frequency	2.4e+9
RXThreshold	9.50808e-11
Transmit Power	15dbm
Range to transmit	250m
Carrier Sense Range	550m
Propagation	TwoRayGround
Antenna	OmniAntenna

The transmission power of each wireless node has been considered 15dbm. Carrier sense range has been set 550m, so that the other nodes can be sensed by the sender and receiver. The CBR traffic starts and the data transmission starts at the default rate. When RSSI values are recorded, the channel condition is defined as good or bad. The suitable data rate is decided which is further authenticated with the help of recorded number of ACKs. So the rate adaptation is performed side by side as the data transmission takes place.

4.4 NS2 Simulation

NS2 simulator is based on the events so it is called event driven simulator [36]. NS2 has been developed in C++ and supported with OTCL interpreter to allow the user to create the objects that are required to perform the simulations. The object instantiation in the interpreter invokes the C++ objects through the defined methods in class TCLObject. To simulate the wireless Scenario the MAC and PHY layer modules have been included which can be extended further by the researchers for desired functionality.

The interpreter is normally slower than the compiler so combination of both has been adopted in NS2. The interpreter provides better facility when we need to change the model or the scenario of simulation whereas the processing of algorithms and packet headers and bytes need fast execution which has been provided by C++ [36]. Complete process from simulation to result comprise of the following steps.

4.4.1 Tcl Script Generation

NS2 Simulation starts from tcl scripts. The tcl script contains main information about the simulation scenario. All the simulation parameters are defined in the tcl script, which include routing protocol, propagation model, network interface and MAC type etc.

4.4.2 Trace File generation

When we execute tcl script, the trace file is produced as a result which contains important information about the simulation. It is a print that contains what was inside the simulator during the execution. The values of variable at different times are stored in trace file to better analyze the simulation and its behavior.

4.4.3 Data Extraction

Trace file can be analyzed with the help of different scripting languages e.g. AWK, pearl etc. The trace files are massive output files that contain a huge number of values that exist during execution. These files can be explored using AWK or pearl scripts in order to extract valuable information from the trace file. This information can be further utilized e.g. to calculate throughput and jitter etc. For example, in our simulation, the received events of a receiver nodes have been searched from trace file using AWK script. Then the records against receive event get captured to calculate overall throughput at receiver node and received number of ACKS at MAC level for specific time duration.

4.4.4 Produce results

Information retrieved from trace file can be utilized to produce results. These results can be used to analyze the proposed system.

4.5 Calculation of RSSI in NS2

RSSI value has been calculated by modifying the C++ class. The sendup method of the wireless-PHY class basically contains information about RSSI. As illustrated in figure 4.3, this value has been captured and printed in trace file. Trace file has been modified so that RSSI values for the nodes can be seen. Basic variable is in the packet header that has been used to

- Write the value of RSSI in sendup method.
- Print the value in trace file against the node for which it has been recoded.

…

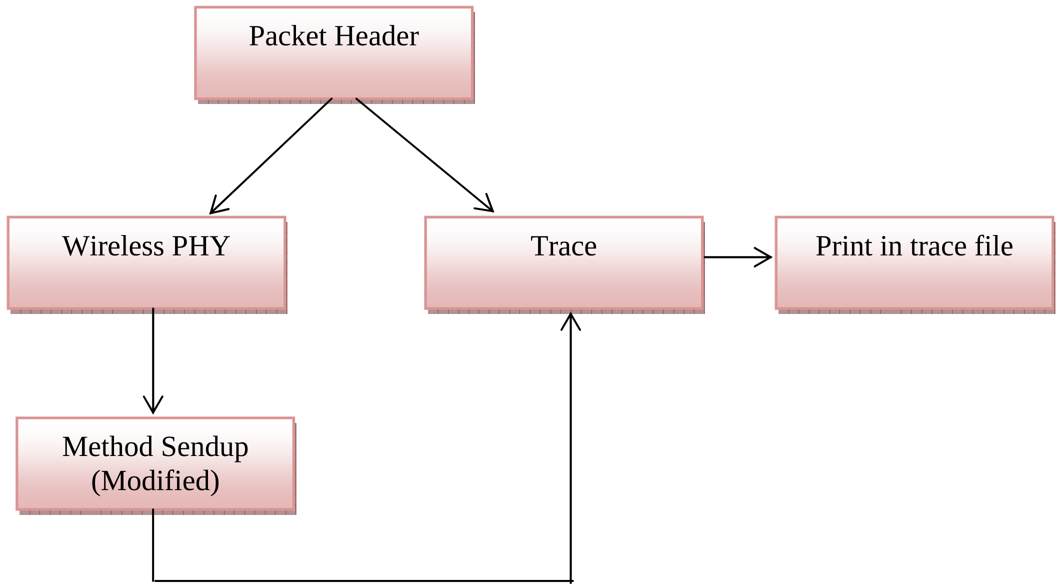

Figure 4.3 RSSI value extraction from C++ Class files of NS-2

These values of RSSI are very important in order to analyze the channel conditions. The RSSI calculation defines the core functionality that is important to adapt the data rates.

4.6 ACK calculation

Number of ACKs received, are calculated from the trace file. In NS2 the 802.11 mac class, the ACKs can be calculated by counting the ACK frames for target node which is receiver node.

The following steps have been performed to calculate number of ACKS

1) Search all receive events for trace file that belong to the sender node.
2) Search MAC entries to find number of ACKs.
3) Search the entries that have the packet type ACK.
4) Calculate number of ACKs.

Figure 4.4 describes the AWK script to calculate number of ACKs received after a data transmission.

```
    BEGIN {
    recv = 0
     }

          {
    event = $1
                node = $3
                Agent_type = $4
                Pckt_type = $7
                pkt_size = $8

    if(event == "r" && node == "_0_" &&Agent_type == "MAC"
    &&Pckt_type == "ACK" )
          {
                ACK_count += 1
          }
}
 END {
printf ("No of Acks %10g \n",ACK_count)
 }
```

Figure 4.4 The AWK script to calculate number of ACKs received by the Sender

4.7 RSSI threshold calculation

Threshold for RSSI has been calculated that is used to set the data rate. The algorithm has been discussed in chapter 3. The high RSSI threshold of the low data rate is set as low RSSI threshold of the high data rate. When the ACK frames have been received the RSSI of the ACK frames have been recorded and that value is used for further threshold calculations. The RSSI value for a frame is approximately same at sender and receiver.

4.8 Throughput calculation

Throughput calculation is performed with the help of AWK script. After each 0.2ms, ACK frames are counted; throughput is also calculated for previous transmission. This helps to understand the effect of switching data rates.

```
BEGIN {
recv = 0
 }
          {
event = $1
pkt_size = $8
          type = $4

if (event == "r" && type == "AGT") {

recv += pkt_size
pkt_cnt +=1
          }
}

 END {
printf("%10g %10g\n",(pkt_cnt/50)*(8/1000),(recv/50)*(8/1000000))
 }
```

Figure 4.5 AWK Script to calculate throughput

AWK script to calculate throughput has been presented in figure 4.5. Packets against receive event in trace file are considered to calculate throughput.

4.9 Summary

This chapter has described the simulation scenario and simulator. RSSI calculation has been discussed. AWK scripts have been discussed to calculate ACKs and throughput. Threshold calculation is an important issue in order to get the precise data rates, therefore details of the threshold calculations have been discussed here.

Chapter 5

RESULTS AND PERFORMANCE OF RBSRA

5.1 Introduction

In this chapter, a detailed discussion about the results has been included. Performance of RBSRA has been discussed with help of simulation results. The results describe the enhanced throughput and stability of data rates. For all data rates, CBR rates have been decided, that provide the maximum throughput. Simulations have been performed to evaluate the following scenarios.

- Determine Number of Nodes
- Determine CBR values for each data rate
- Observe Number of ACKs for each data rate
- Observe Throughput for each data rate
- Observe RSSI with distance
- RBSRA Rate adaptation
- SARA Rate adaptation
- Throughput measurements

5.2 Number of Nodes for simulation

To simulate the proposed scheme number of nodes is verified, that can influence the transmission between sender and receiver. Starting from three nodes, the simulations have been performed up to 100 nodes. Number of nodes was increased gradually to observe the behavior as the nodes are added in the surroundings of the sender and receiver.

The figure 5.1 indicates the behavior of data transmission with increased number of nodes. When the number of nodes was increased the throughput started to decrease slowly. Data rate here is 1Mbps. Increasing the number of node actually increases the interference as the wireless nodes are sensing each other and data is transmitted between them. Due to this interference the signal strength is decreased and frames are dropped. Increasing nodes can affect the throughput till a certain limit after that the throughput is stable.

In the figure 5.1 we can see that after 50 nodes the throughput becomes stable. 50 nodes have been selected to perform the simulations to implement the RBSRA. These nodes are placed randomly and can move freely.

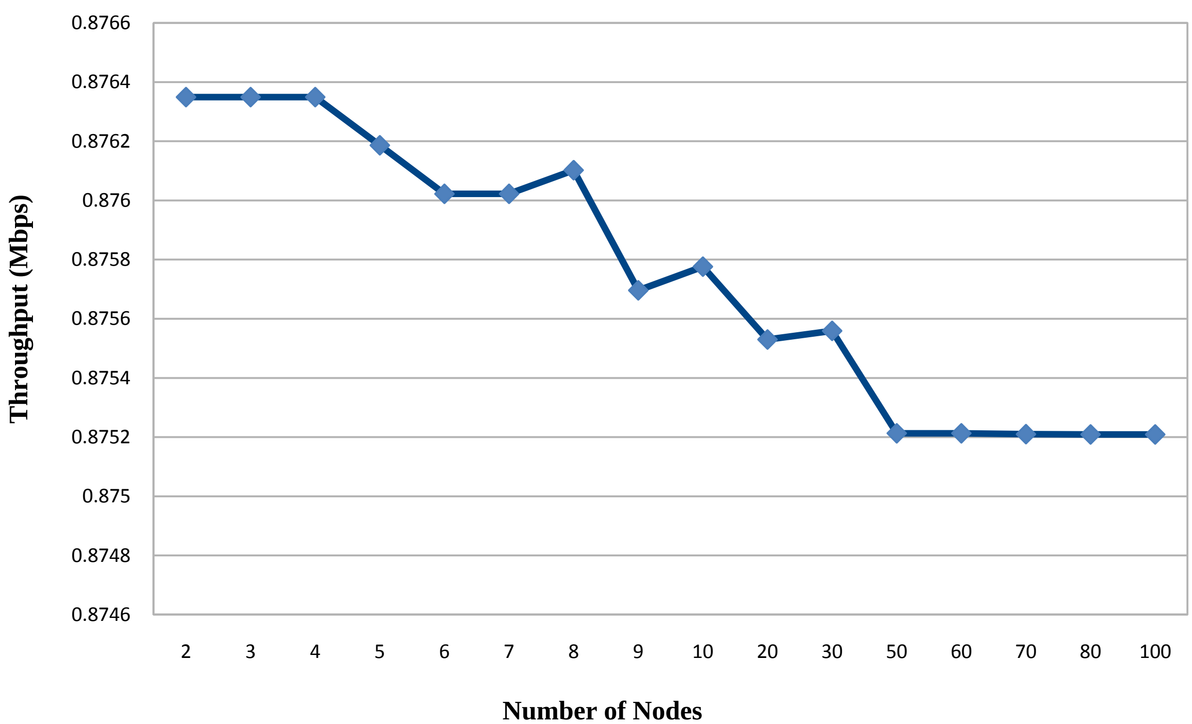

Figure 5.1 Simulation to determine number of Nodes for 1Mbps

5.3 CBR rates vs. different data rates

Different data rates of the standard IEEE 802.11b have been simulated using NS2. In NS2, CBR rates are set to generate the traffic. So for each data rate CBR rate will be different.

To study the behavior of CBR rates with different data rates a series of simulations have been performed to explore the suitable CBR rates for each data rate. It has been observed that CBR rates provide maximum throughput for a specific data rate till a certain extent. After that limit if the CBR rate is increased, the throughput is decreased.

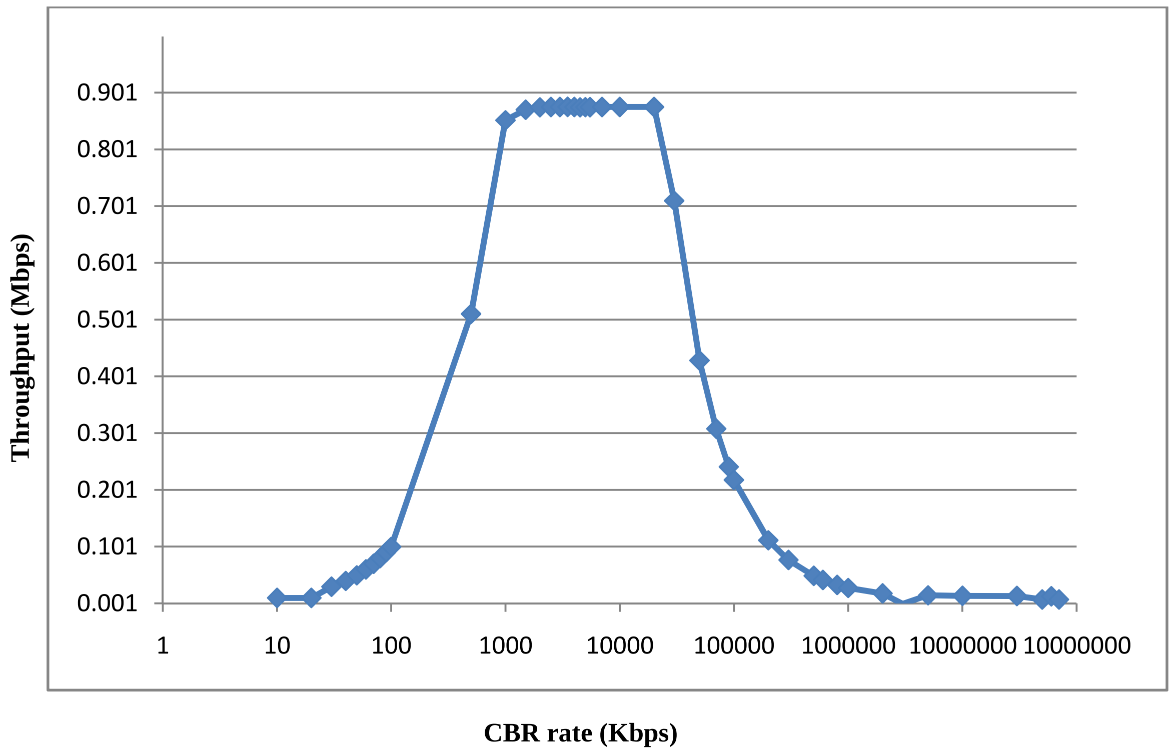

Figure 5.2 Simulation to determine CBR rate for 1Mbps CBR rate vs. Throughput (Mbps)

In figure 5.2 it can be observed that increasing CBR rate can increase the throughput but after a certain value of CBR rate, the throughput starts to decrease. One reason for decreased throughput can be due to transmission of large number of packets there can be bottleneck so packets are dropped at large scale. As the result overall throughput starts to decrease.

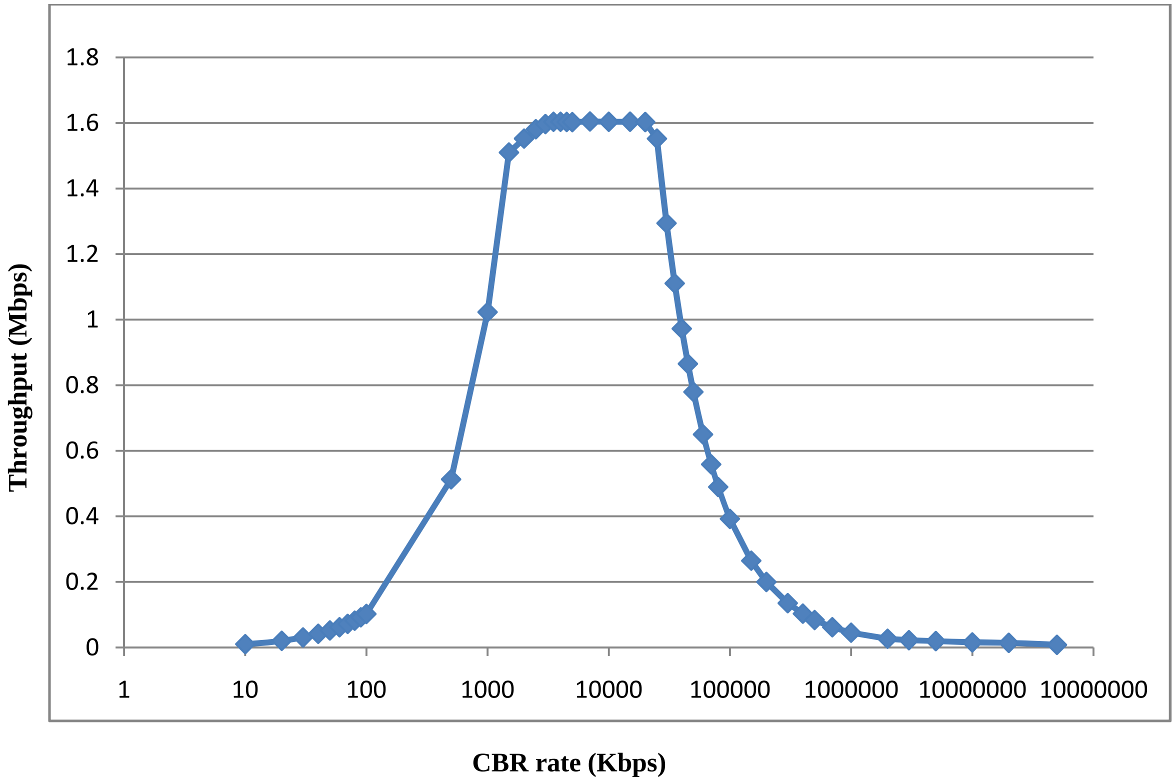

Figure 5.3 Simulation to determine CBR rate for 2 Mbps CBR rate vs. Throughput (Mbps)

As it has been discussed in chapter 1, 802.11b provides four data rates, so for all the data rates, corresponding CBR rates have been evaluated experimentally. The objective was to find appropriate CBR rate that provides high throughput. In the figure 5.3 the CBR rate to achieve the maximum throughput for the data rate of 2Mbps is 3500Kbps which can provide the throughput round about 1.6Mbps. It means that the maximum throughput for data rate of 2Mbps can be achieved at CBR rate 3500Kbps. This maximum throughput is only 80% of the data rate 2Mbps.

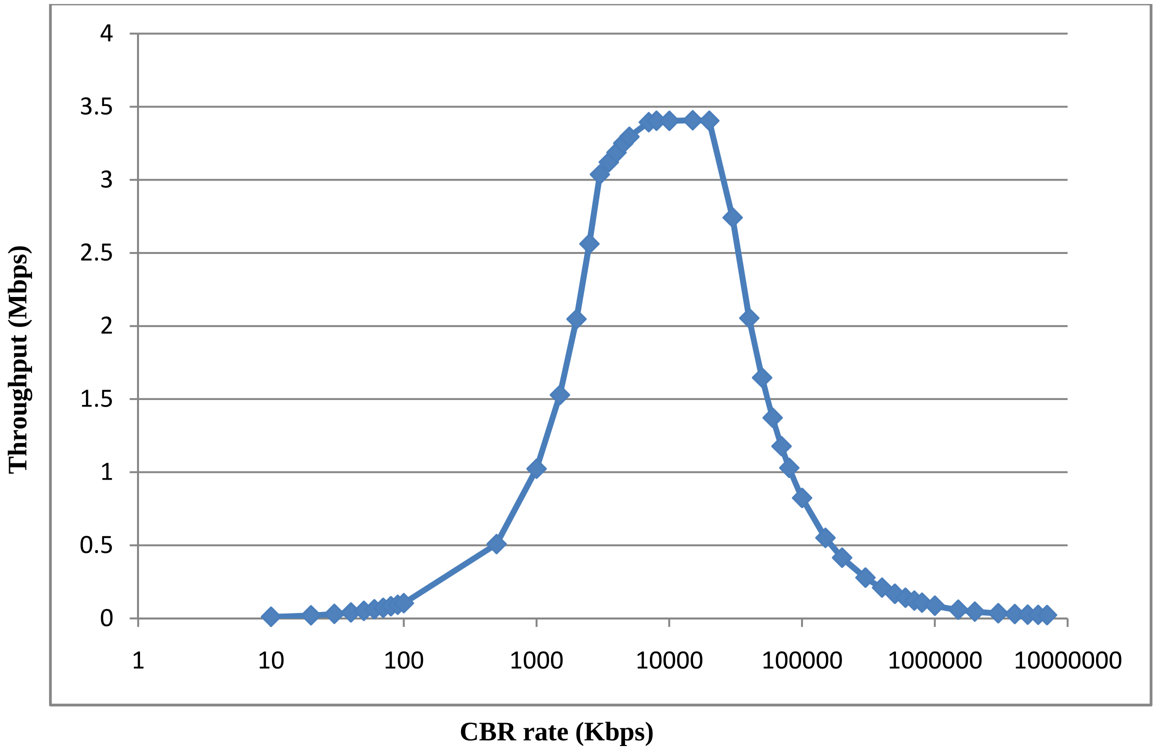

Figure 5.4 Simulation to determine CBR rate for 5.5 Mbps CBR rate vs. Throughput (Mbps)

In figure 5.4, CBR rate is 20,000 Kbps for the data rate 5.5Mbps. Maximum throughput is 3.4Mbps. In this case the maximum throughput is approximately 62% of the data rate 5.5Mbps. In figure 5.5, suitable CBR rate for 11Mbps data rate is 15000Kbps. Maximum throughput achieved is 5Mbps which is 45% of the data rate. We can note that with higher data rates, we cannot achieve 100% throughput according to the data rate. Higher data rates are more open to the channel errors hence making them candidates of least priority for the reliable data transmission. Low data rates are more suitable for reliable transmission as the channel errors are minimized. The applications that require reliable data transmission e.g. file transfer etc. can be accommodated at lower data rates. For the applications like video streaming where the reliability of data is not required, higher data rates can be used. Table 5.1 summarizes the evaluated CBR rates for all data rate of 802.11b.

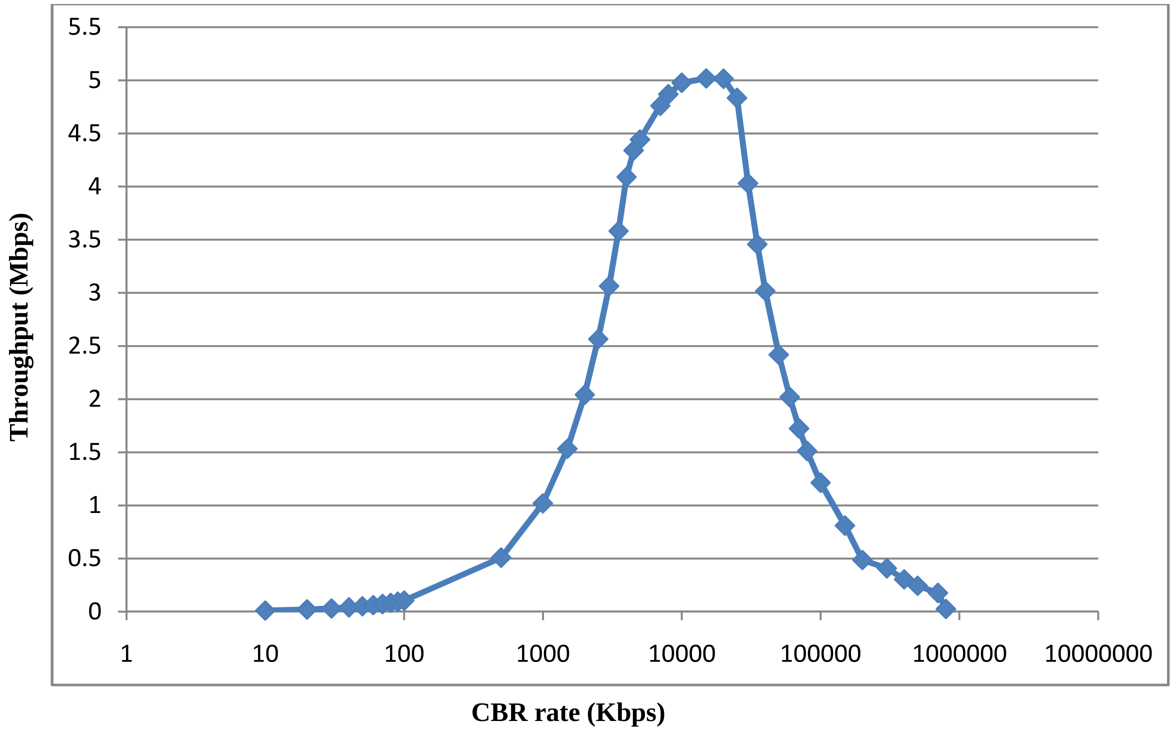

Figure 5.5 Simulation to determine CBR rate for 11Mbps CBR rate vs. Throughput (Mbps)

Table 5.1 CBR rates for different data rates of 802.11b

Data Rate (Mbps)	CBR Rate (Kbps)
1	3500
2	3500
5.5	20000
11	15000

5.4 ACKs vs. different data rates

As data rates are increased more number of packets can be sent. With increasing data rates the number of received ACKs was observed. In the figure 5.6, number of ACKs has been plotted against the data rates. It clearly indicates that, as we increase the data rate, number of ACKs increase accordingly. This is an important observation as it has been used to decide the suitable data rate. Number of ACKs plays an important role to make the decisions to switch between the data rates. When the receiver receives the data properly overall throughput is increased and data rate can be increased by sender in order to capably consume the available data rates. So the received number of ACKs is important information that has been used for the implementation of RBSRA. MAC level ACKs are not the subject to reliability, as the ACK frames can be dropped when channel conditions are not good. Therefore, for a data frame whose ACK frame has not been received, it cannot be assumed that the frame was lost. ACK frames that are received at MAC layer can be used to estimate the channel conditions at the receiver.

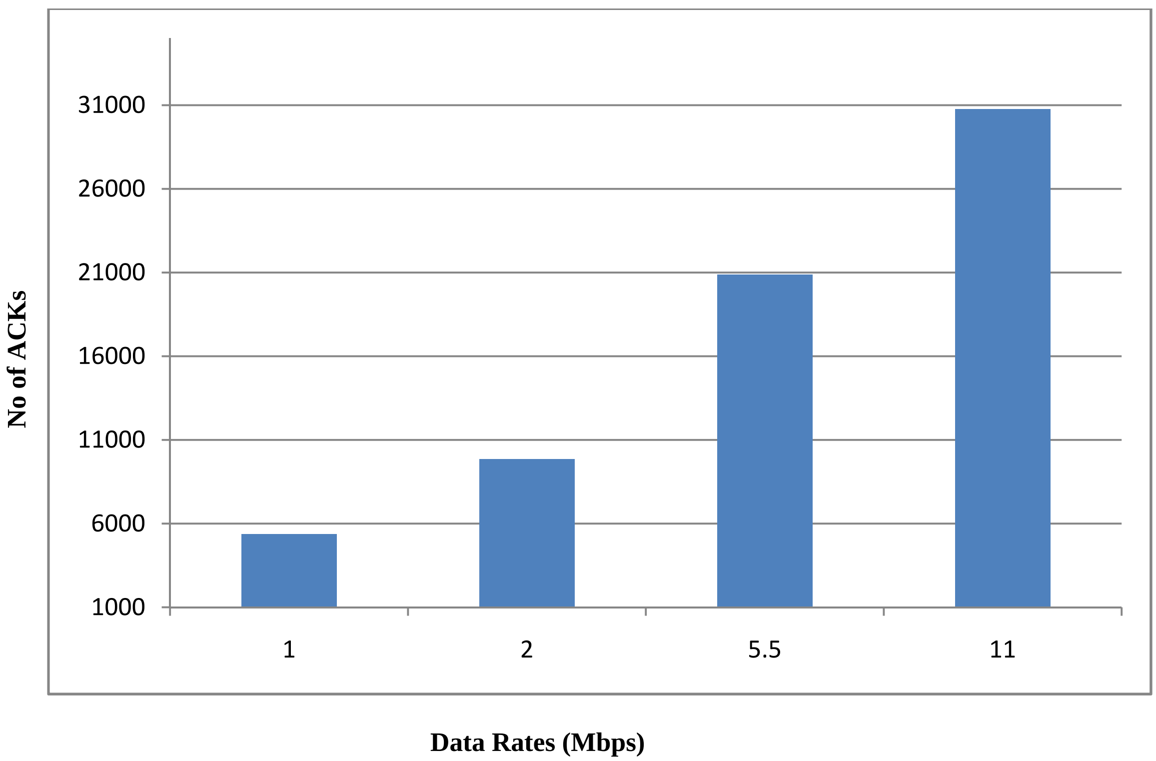

Figure 5.6 Simulation to determine number of ACKs for all Data Rates

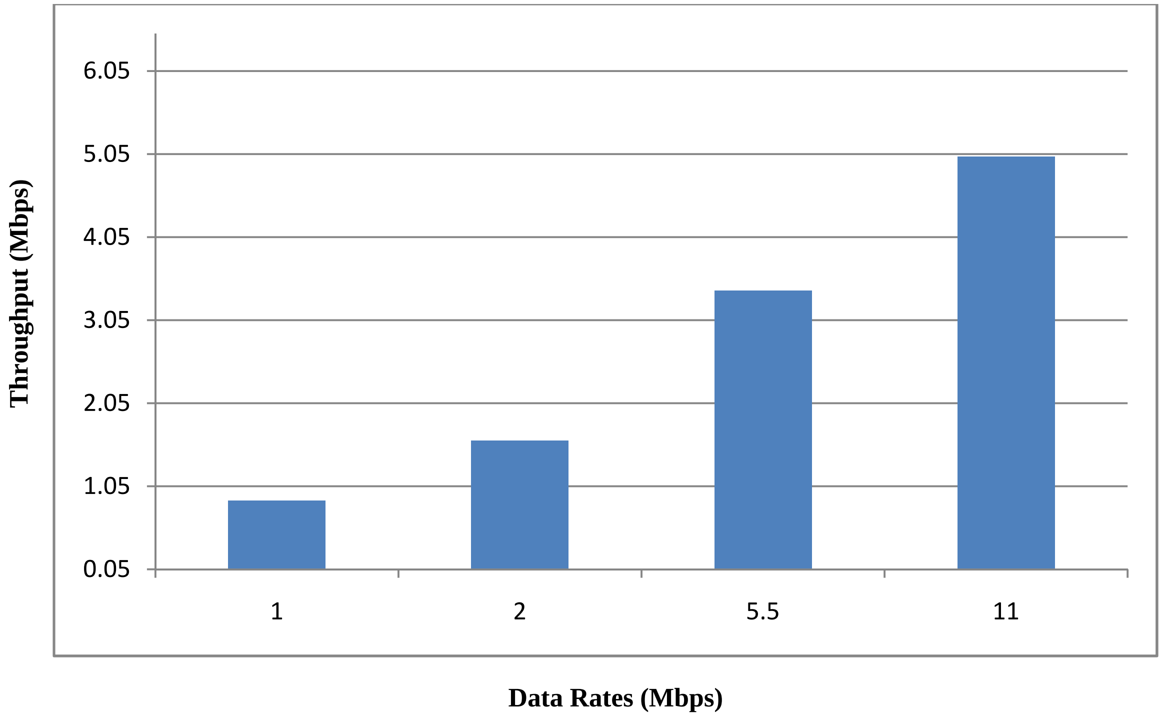

Figure 5.7 Simulation to determine throughput for all Data Rates

5.5 Throughput vs. different data rates

Higher data rates provide higher throughput. This has been assessed by simulating different data rates of IEEE 802.11b. For a data transmission, different data rates were selected and a detailed study has been performed in order to observe the behavior. Increasing the data rate yields higher throughput. Figure 5.7 reveals the fact that higher data rates provide higher throughput as compared to the lower one. All the data rates were used to send data at their evaluated CBR rates to make a clear picture for the throughput at different data rates. Each data rate provides higher throughput than its immediate lower data rate.

5.6 RSSI vs. Distance

RSSI value has been evaluated for different distances. It has been observed that RSSI value is increased when distance between sender and receiver node is reduced and RSSI is decreased when distance is increased. So RSSI and distance are inversely proportional to each other. Evaluation of RSSI for changing distance reveals that variations in distance between sender and receiver have major impact on channel conditions. Figure 5.8 describes the behavior of RSSI with varying distance. It can be observed clearly that as distance is small RSSI value is high. When distance increases RSSI value decreases gradually. Increasing distance causes the signal to drop its energy due to its propagation over large distance. This is an important observation that has been evaluated here experimentally. It is helpful to understand the one of reasons that can destabilize the wireless link conditions. It is an important consideration that helps to make decision for switching link throughputs.

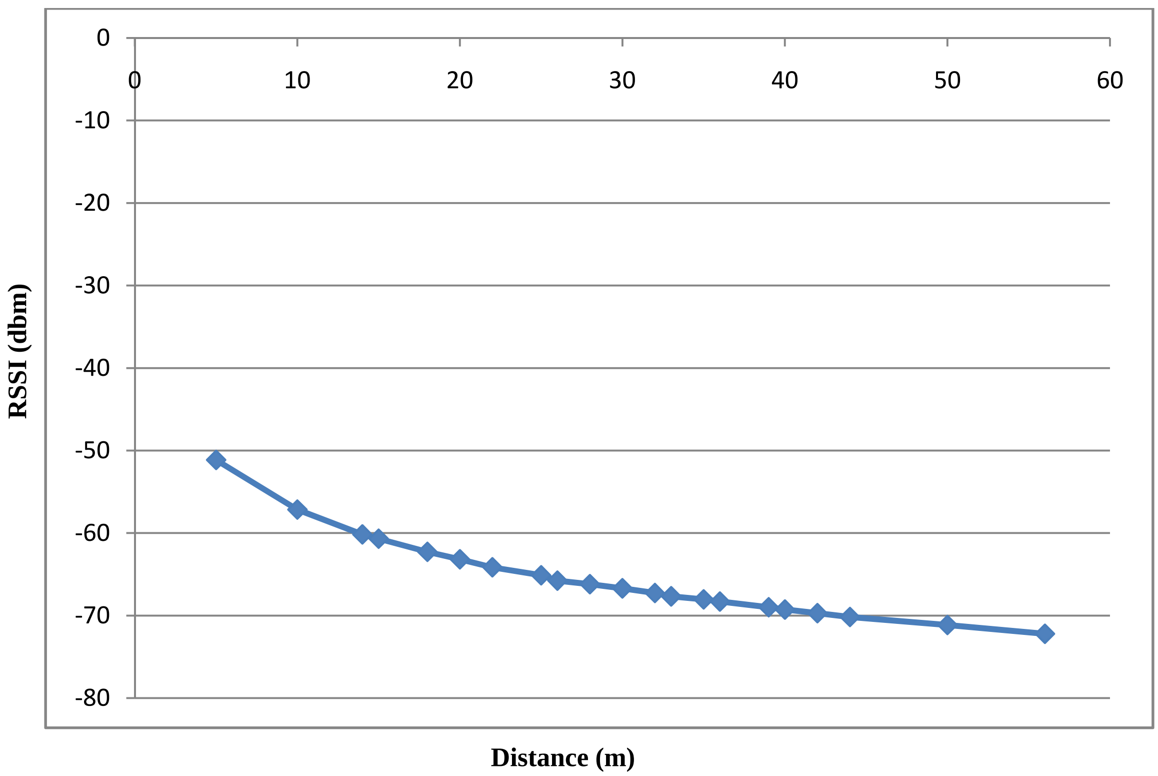

Figure 5.8 RSSI vs. Distance

5.7 Mobility Scenario for RBSRA

To implement RBSRA, the RSSI of a mobile node is changed by moving it continuously near and away from the sender. The mobile node that has been receiving the data transmission continuously moves.

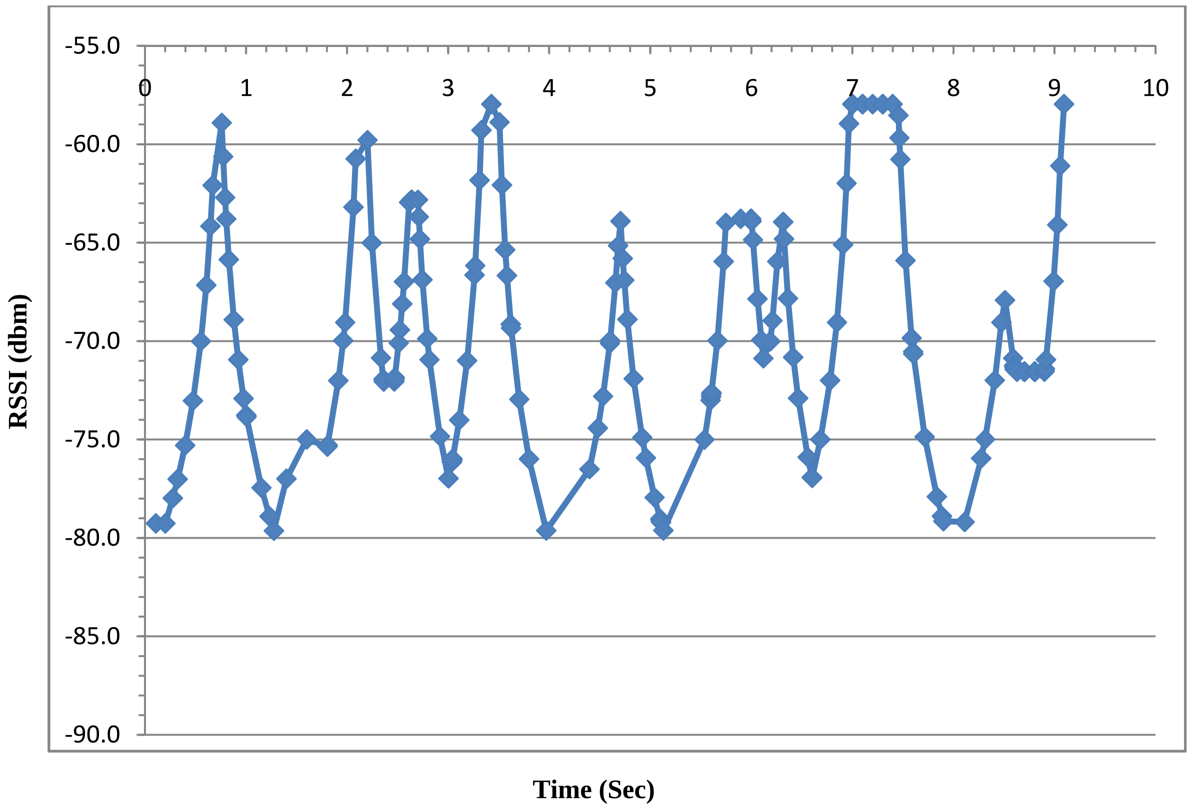

Figure 5.9 Variations in RSSI at receiver node

The RSSI value of the mobile node is changed mainly due to two factors

- The interference of other mobile nodes.
- Distance from the sender is increasing and decreasing continuously.

In figure 5.9, the receiver node has been presented with different RSSI values. At time 0 seconds, it is away from the sender and then it starts moving towards sender. The RSSI value of a mobile node is low when the distance of the receiver from sender node is large. When node starts moving towards sender the RSSI value is increased. At 0.7ms (milliseconds), the receiver nodes is closest to the sender node. At the RSSI values that exist in range from -75dbm to -80dbm, the receiver node is almost escaped from the range of sender node. Most packets have been dropped here and throughput is almost 0. At values -65dbm to -65dbm, the receiver is close to the sender and maximum throughput has been observed here. The sender node has been moved less frequently in order to study the channel conditions of the receiver node.

As the rate adaptation has been performed on the basis of link state of the receiver node, so the channel conditions of the sender are considered constant. When node moves it causes to change 1) certain distance from the sender and 2) interference, which is initiated by other nodes. As the result RSSI value of the receiver is changed. This RSSI value can be estimated at the sender, when ACK frame is sent after a data frame has been received successfully.

5.8 Rate Adaptation of RBSRA

The figure 5.10 shows rate adaptation outcomes performed by RBSRA. Data rates have been decided on the basis of threshold values of RSSI and acknowledgement frame count. Higher data rates have been maintained even the RSSI was decreased. The acknowledgment frame count reveals the fact that with decreasing RSSI values transmission can be continued with same data rate. There is no need to drop the data rate. In statistical rate adaptation, the whole transmission takes place and then data rate is decided for next transmission. This is a slow procedure and channel conditions can change frequently. So after 0.2ms the RSSI values are recorded and acknowledgement frames are counted. The threshold values are calculated and data rate is estimated.In the start of simulation as the receiver is at large distance from the sender the low data rate is selected that is 2Mbps.The RSSI value and number of acknowledgement frames are counted after 0.2ms.

Comparison with threshold value has been made in order to decide next data rate. At 0.6ms the acknowledgement count and RSSI value is maximum, so the highest data rate has been set that is 11Mbps. At 1.2 seconds, the acknowledgement count is found lower than the threshold value and also the RSSI has been decreased, as the node is moving away from the sender node. Data rate is now dropped to 5.5Mbps.

At 1.4 seconds the RSSI value is dropped and acknowledgement count is zero. In this situation the data rate is dropped to 1Mbps. At the time 2.0 seconds the RSSI and acknowledgement frame count is maximum so the data rate will be maximum. From time duration 2.0ms to 2.9ms the data rate has been maintained due to the maximum acknowledgement frame count. If we see in figure 5.9, in the duration 2.0ms to 2.9ms the receiver node has moved towards the sender and then started to move away. But in this duration the node was not moved out of the range of sender node. The RSSI value of the receiving mobile node was dropped up to -70dbm and then started to increase again.

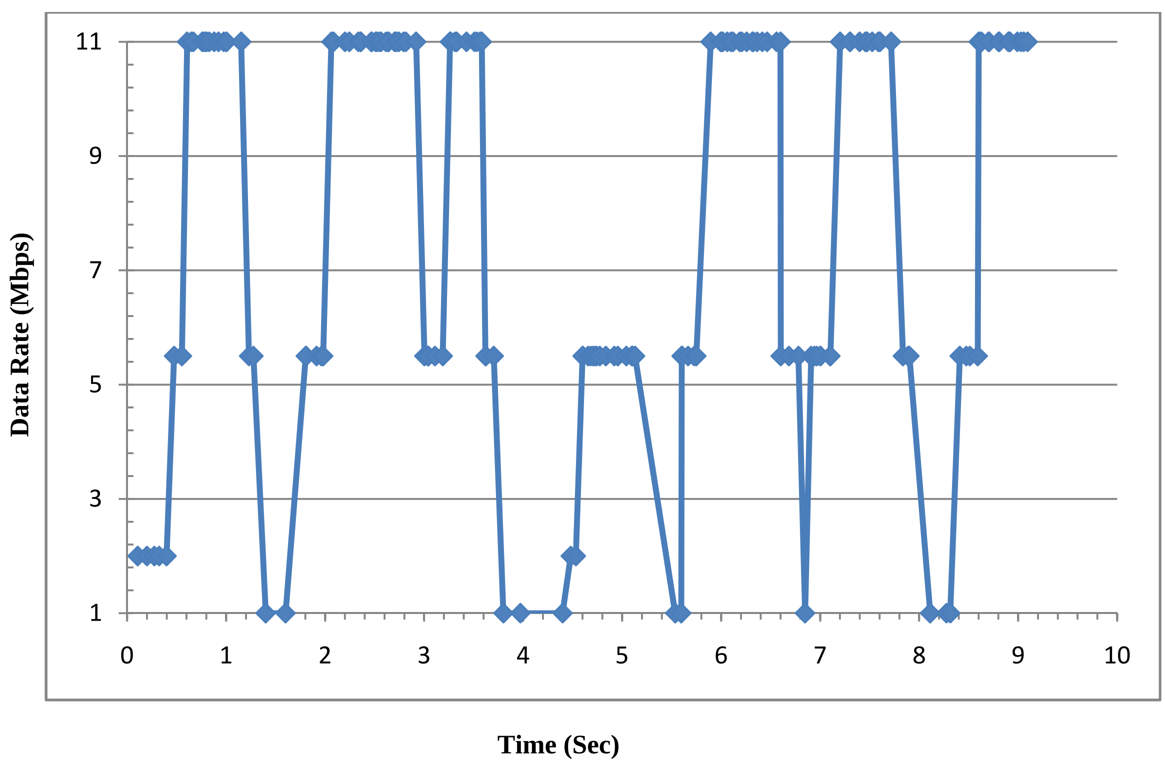

Figure 5.10 Rate Adaptation using RBSRA scheme

Here, the RSSI value is increasing and decreasing but the receiver node is within the transmission range of the sender node. This indicates data has been transmitted successfully and the acknowledgement frame count was high. This is the reason for which the data rate was maintained at 11Mbps. With decreasing RSSI value, it was not necessary to decrease the data rate when receiver node was with in the transmission range of the sender node. Here transmitting data at 11 Mbps from 2.0ms to 2.9ms increases the overall throughput.

5.9 Rate Adaptation by SARA Scheme

In figure 5.11, rate adaptation by SARA scheme has been simulated.Here data rate has been dropped with decreasing RSSI values. The acknowledgement for received data is not considered. Data rate will be simply increased or decreased according to RSSI values.

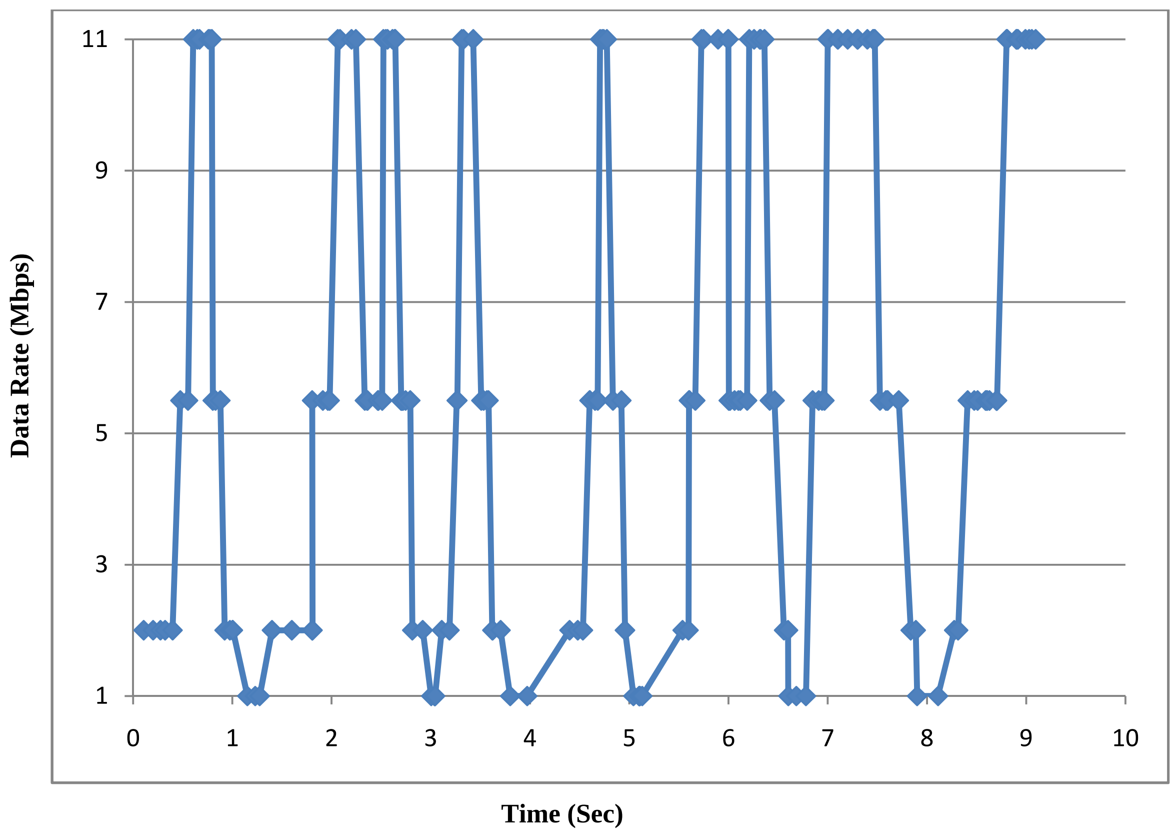

Figure 5.11 Rate Adaptation using SARA scheme

Here, the data rate has been decreased when RSSI value is decreased. In the time duration from 2.0ms to 2.9ms data rate has been dropped twice to 5.5Mbps and then to 2Mbps.Dropping the data rate considers only decreasing RSSI values. So as compared to figure 5.10, here the throughput decreases due to decrease in data rate.

5.10 Rate Adaptation by CARA Scheme

In figure 5.12 rate adaptation by CARA scheme has been simulated. Here adaptation to different link speeds has been performed by considering received ACKs. Data rate selection depends upon number of ACKs that has been received after a successful delivery of frames at receiver. RTS/CTS mechanism is enabled to avoid frame losses due to collisions.

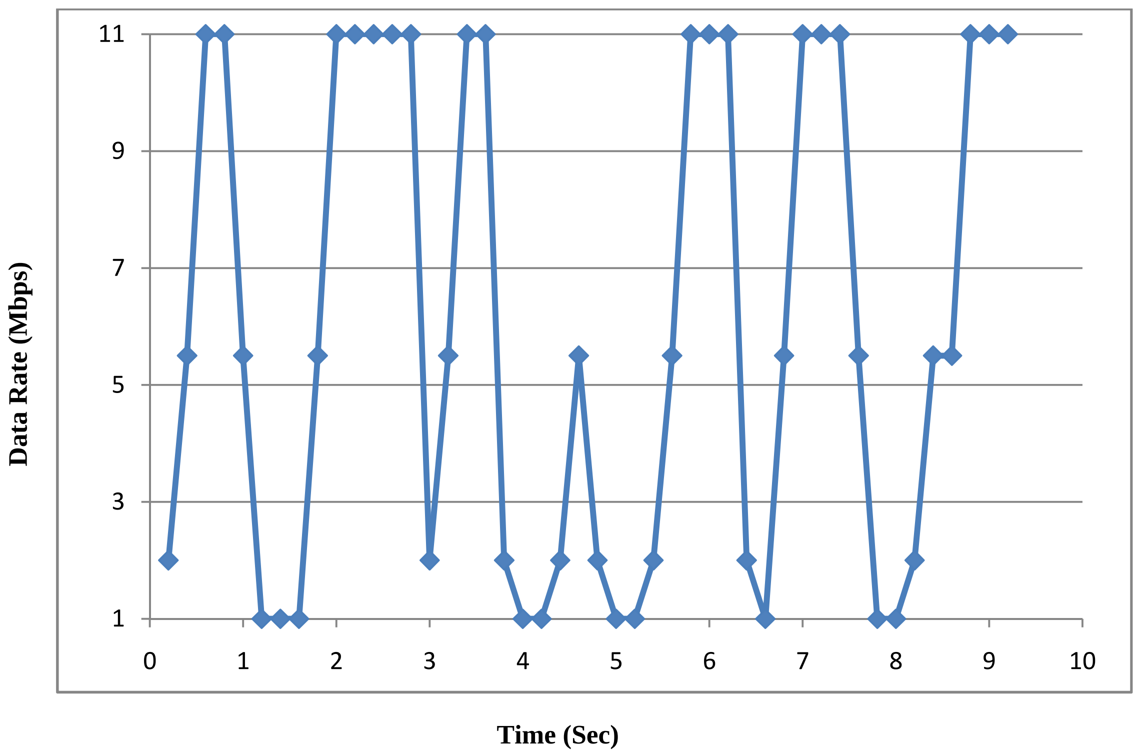

Figure 5.12Rate Adaptation using CARA scheme

5.11 Throughput Evaluation

In figure 5.13 the performance of RBSRA can be compared with SARA and CARA schemes. As the use of RTS/CTS mechanism in CARA consumes bandwidth which in turn degrades the throughput. In case of SARA data rate selection is made by estimating channel conditions on the basis of RSSI. As it has been discussed that switching link speeds only due to RSSI values and ignoring statistical information can lead to decrease in data rate when it was not necessary and ACK frames were received properly. This element has been observed in experimental evaluation of SARA scheme. Taking advantage of proper increase or decrease of link speed, RBSRA comes with increased throughput as compared with SARA and CARA.

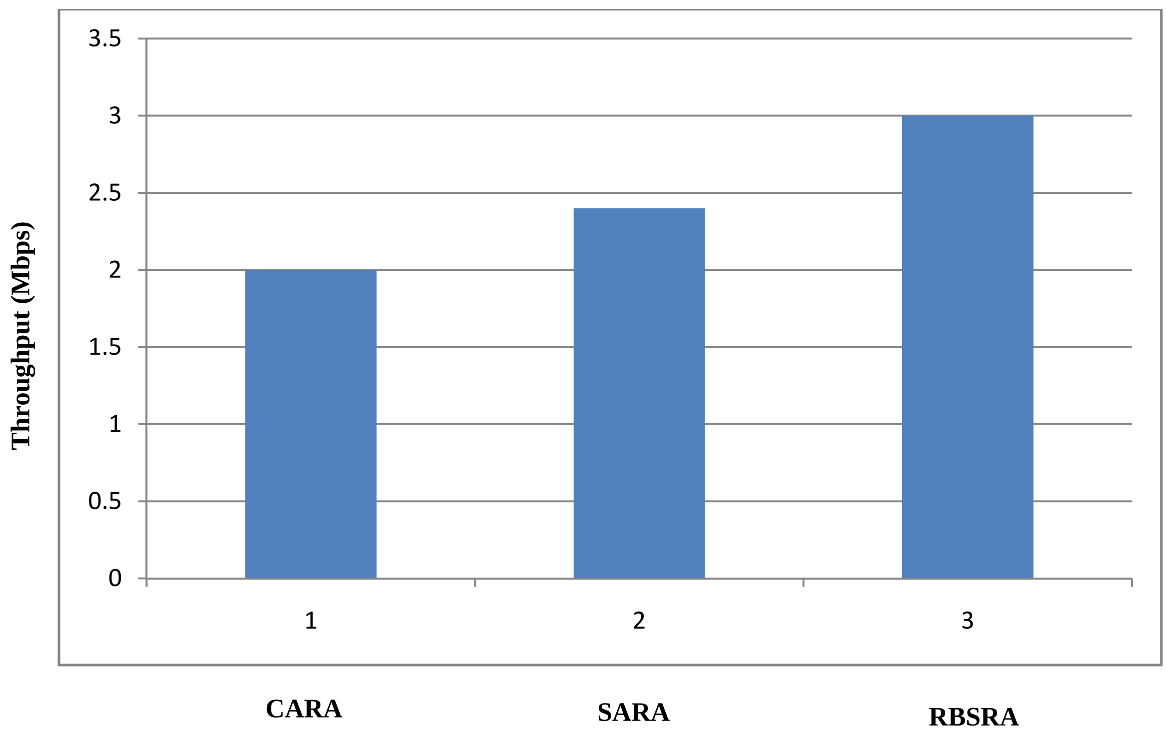

Figure 5.13Throughput comparison of RBSRA, with SARA &CARA

5.12 Summary

A detailed analysis of results shows that the RBSRA provides better rate adaptation in order to maximize throughput. The efficient mechanism to make accuratedata rate selection has been focused. With RBSRA, the throughput was increased as compared to another approach providing the rate adaptation mechanism. In order to gain the unambiguousness in results, proper simulations have been performed to define CBR rates, number of nodes, ACKs for each data rate and throughput against each link speed. Results show that data rates were selected appropriately and unnecessary decrease in data rate was avoided. Maintaining data rates at suitable time increases the number of packets that are sent. Hence overall throughput has been increased.

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

The focus of this thesis is to explore the rate adaptation mechanisms that provide utility to efficiently consume available data rates for IEEE 802.11. The main objective of the thesis is to design and implement an efficient methodology that provides rate adaptation with accurate channel estimation. This accuracy to estimate link state leads towards the most appropriate data rate selection, which gives the higher throughput. Goal is to analyze the correct channel estimation mechanism for more appropriate data rate selection that can provide the increased throughput.

To explore the concept of rate adaptation for research purpose many research papers, journals have been reviewed that were related to rate adaptation for IEEE 802.11 standard. System model has been developed to define the objectives. To meet the defined goals, detailed simulation has been performed. The main task of thesis is to implement a rate adaptation scheme that provides precise assessment of link state and adapts to the data rate which is best suited to the increase the throughput. For the estimation about the state of wireless link, RSSI value and number of acknowledgement frames has been calculated. To decide best data rate, threshold values are calculated in order to make comparison with recently calculated values of RSSI and acknowledgement frames. With the help of comparisons, state of wireless link can be estimated and then suitable data rate according to that state has been selected. Data rate selected through this mechanism increases the throughput.

The system has been implemented using Linux (UBUNTU 9.10) environment with the network simulator NS-2.34. The link state estimation and data rate selection mechanisms are implemented in NS-2. Trace file are analyzed using AWK scripts.The performance of the proposed system has been analyzed through the simulations. Detailed study of results indicates a remarkable increase in the throughput.

6.2 Future Work

Rate Adaptation has been considered as an efficient mechanism in order to utilize available data rates. There are many issues in rate adaptation that can be further explored to provide the efficient rate adaptation mechanism over the WIMAX standard and IEEE 802.11 standard with multiple input multiple output (MIMO).

Providing video streaming over wireless networks is a challenging task. The video data requires to be delivered at time. In video streaming adaptation to channels is facilitated at application layer and MAC layer. The proposed scheme RBSRA can be jointly used with application layer to adapt link speedsfor video streaming, according to channel conditions.

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APPENDIX

MAC	Medium Access Control
SNR	Signal to Noise
BER	Bit Error Rate
PER	Packet Error Rate
PSNR	Peak Signal to Noise Ratio
RTS	Request to Send
CTS	Clear to Send
BPSK	Binary Phase Shift-Keying
QPSK	Quadrate Phase Shift-Keying
QAM	Quadrature Amplitude Modulation
DCF	Distributed Coordination Function
DIFS	Distributed Inter-frame Space
SIFS	Short Inter-frame Space
PLCP	Physical Layer Convergence Procedure
PMD	Physical Medium dependent
MIMO	Multiple-Input Multiple-Output
DSSS	Direct Sequence Spread Spectrum
FHSS	Frequency Hopping Spread Spectrum
OFDM	Orthogonal Frequency Division Multiplexing