

A Rate-Adaptive Multimedia Multicasting Mechanism in Multi-Rate 802.11 Wireless LANs*

Youngsam Park¹, Yongho Seok¹, Taekyoung Kwon¹,
Yanghee Choi¹ and Jean-Marie BONNIN²

¹School of Computer Science and Engineering
Seoul National University, San 56-1, Shillimdong, Gwanak-gu, Seoul, Korea

Email: {yspark, yhseok, tk, yhchoi}@mmlab.snu.ac.kr

²Network and Multimedia Department

ENST Bretagne, 2, rue de la Chataigneraie - CS 17607

35576 Cesson Sevigne Cedex - FRANCE

Email: jm.bonnin@enst-bretagne.fr

Abstract

IEEE 802.11 WLAN service is broadening its service area rapidly. One of the major driving factors of WLANs is multimedia services such as VOD or HDTV delivered by multicast protocols. However, there have been little research on how to efficiently operate multicast protocols in IEEE 802.11 WLANs. The most widespread variants of IEEE 802.11 standards, 802.11b and 802.11a, are characterized by the rate adaptation mechanism depending on time-varying wireless link conditions. However the current IEEE 802.11 WLAN standard does not utilize the rate adaptation function for multicast transmissions. In this paper we propose a new rate adaptation mechanism for multimedia multicasting in IEEE 802.11 WLAN environments, called SARM (SNR-based Auto Rate for Multicast). SARM is based on the RBAR (Receiver Based Auto Rate) protocol. Therefore SARM adapts its transmission rate based on the SNR values of mobile nodes. In order to obtain SNR values, since there are no RTS-CTS messages or MAC layer ACK messages in multicast transmissions, SARM needs an additional signalling method by which the AP can estimate channel quality (SNR). By adapting multicast transmission rate based on SNR, SARM guarantees the best quality of multimedia service depending on the mobile nodes' link conditions. Moreover the proposed protocol minimizes the portion of wireless channel resource for multimedia multicasting, so that it can allocate more bandwidth to other unicast traffic.

Keywords: Rate Adaptation, IEEE 802.11, Multicast, Multimedia

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1 Introduction

IEEE 802.11 Wireless LAN standards [1][2] are now helping people stay connected to internet while they are away from home and office. With laptops or PDAs, people can easily access internet at HotSpot locations. Currently wireless LAN service providers are actively increasing the number of HotSpot locations to enhance internet accessibility. According to the investigation provided by Gartner, Inc.[3], the number of HotSpot users worldwide will increase to total 30 million in 2004, up from 9.3 million users in 2003. It also states that the number of HotSpot locations in USA has increased rapidly in recent 3 years, to 71,000 in 2003 from 14,753 in 2002 and 1,214 in 2001. In Korea, wireless LAN service called "Nespot" was launched in 2001. Currently it provides more than 16,000 HotSpot locations.

One of the major driving factors of wireless LAN service is multimedia streaming. With the help of several key technologies such as MPEG4 and H.263, wireless LAN service provides various multimedia contents including HDTV or Video On Demand (VOD). The most essential technology in these services is the ability to broadcast or multicast identical multimedia contents to a group of users simultaneously. Multicast is an efficient transmission method since it reduces the demand on bandwidth resources in networks. It will play a key role in delivering multimedia contents shared by many users, such as pay-per-view broadcasts of sporting events, as well as interactive multimedia applications, such as interactive television and video conference.

Compared to traditional application traffic, multimedia traffic requires more bandwidth and QoS (Quality of Service) support. These restrictions are more critical and more difficult to fulfill in wireless environments, since WLANs have relatively low bandwidth and unstable wireless link channel. However, IEEE 802.11 WLAN does not provide any mechanisms to overcome these restrictions. In fact, since multicast transmission shows quite different characteristics from unicast transmission in several ways, it is difficult to provide such mechanisms in IEEE 802.11 WLAN environments.

The most critical component which influences the performance of communication in a wireless environment is the transmission rate adaptation mechanism [4], [5]. Currently, IEEE 802.11b provides channel rate up to 11Mbps and IEEE 802.11a/g provide up to 54Mbps. To utilize this multi-rate capability, AP needs to select adequate channel rate through channel estimation. In unicast transmissions, AP can collect channel state information of MNs (Mobile Nodes) through feedback signals such as MAC layer ACK or RTS-CTS messages and adapt its transmission rate based on those feedback signals. However, in multicast transmissions there are no feedback signals because of the one-to-many communication scenario of multicast transmission. This means that AP cannot easily collect state information of MNs which are participating in a multicast group. Therefore traditional transmission rate adaptation mechanisms such as ARF (Auto Rate Fallback) [6] or RBAR (Re-

ceived Based Auto Rate) [7] cannot be used in multicast transmissions since these mechanisms are based on wireless link states of MNs. As the current IEEE 802.11 standards provide up to 11 or 54Mbps channel rate, multicast transmission at the channel rate of basic rate set (e.g., 1 or 2 Mbps in 802.11b) is a significant waste of wireless channel resource.

In this paper, we propose transmission rate adaptation mechanism, called SARM (SNR-based Auto Rate for Multicast). This mechanism aims to maintain adequate quality of multimedia streaming while using minimum wireless channel resource.

The rest of this paper is organized as follows. Section 2 gives a brief overview of traditional transmission rate adaptation mechanisms as well as the motivation behind our work. We describe our transmission rate adaptation mechanism, SARM, in section 3, and present experimental results in section 4. Finally, we conclude our paper in section 5.

2 Background and Motivation

2.1 Problems of Multicast in IEEE 802.11 Wireless LAN

In this section we briefly investigate the problems of multicast transmission in IEEE 802.11 WLAN environment. Before proceeding, we will describe main features of multicast transmission in IEEE 802.11, which is handled quite differently from unicast transmission.

First, there is no MAC layer ACK and therefore no retransmission mechanism in multicast transmission in IEEE 802.11. This means that all multicast frames have only one chance to be transmitted from AP to MNs. If bit errors occur while transmitting a multicast frame, it is dropped and never recovered. In wireless environments, it is essential to minimize occurrence of bit errors during data frame transmission. Therefore, in the current 802.11 standards, the AP transmits the multicast frame at basic rate set to minimize bit error rate.

Second, multicasting aims at multimedia contents service. Generally, a little distortion caused by a few bit errors in multimedia contents are considered tolerable by service subscribers.. In the case of MPEG video, the quality is measured by PSNR value, where a value over specific level is considered acceptable [8]. This means that absolute error-free transmission is not necessary in multimedia multicast. Therefore in multimedia multicast transmission it is more effective to use error-contained frame instead of just dropping them.

Third, multimedia multicast traffic generally requires relatively higher bandwidth than unicast traffic and it can lead to traffic congestion in AP. It is impossible to apply the over-provisioning policy to IEEE 802.11 WLANs, because it has strictly limited bandwidth resource. Therefore the QoS mechanism in the MAC layer is required for the transmission of multicast frames in IEEE 802.11.

Based on these features, we can draw the following problem of IEEE 802.11 in

transmitting multimedia multicast traffic. All commercial APs provide only fixed (relatively very low) transmission rate for the multicast transmission. In fact, the rate adaptation mechanism in IEEE 802.11 is not standardized by any documents, making each manufacturer to choose its own rate adaptation mechanism. In the case of unicast transmission, a few rate adaptation mechanism have been implemented and deployed. However, due to the absence of feedback signal such as MAC layer ACK frame or RTS-CTS message frame in multicast, the rate adaptation mechanism for multicasting has never been proposed. Currently some APs provide manual configuration functionality which enables administrators to select transmission rate for multicasting. On the other hand, some APs only provide transmission rate fixed by manufacturer, in which case the rate is usually the basic service rate, 1Mbps or 2Mbps. Though rate adaptation is one of the critical components to enhance throughput, the natural feature of multicast in IEEE 802.11 limits the method for the channel estimation, which in turn, strictly prohibits the rate adaptation mechanism. According to several researches on multirate capability of IEEE 802.11, it is a well known fact that each device needs to adapt its transmission rate dynamically to achieve high performance in wireless environments. To maximize resource utilization and quality of multimedia contents in wireless environments, it is essential to adapt multicast transmission rate dynamically. Therefore the rate adaptation mechanism for multicast transmissions is the major issue of this paper.

Based on the discussion above, we propose a new rate adaptation mechanism which efficiently supports the multimedia multicast traffic. The proposed mechanism aims to enhance performance of multicast transmission which delivers multimedia contents. It is designed to maintain adequate quality of multimedia contents transmitted through multicast, and also to achieve the throughput gain for unicast transmission by allocating minimum channel resource on multicast transmission.

3 Multicast Transmission Rate Adaptation Mechanism

Transmission rate adaptation mechanism for multicast traffic should be executed differently from traditional mechanism for unicast. In traditional mechanism, an AP collects channel states information of MNs using MAC layer ACK or RTS-CTS messages. Through these feedback signals, AP collects channel states information such as SNR value or the number of successful/failed transmission between AP and specific MN. Based on this information AP dynamically determines the transmission rate for specific MN from 1Mbps up to 11Mbps in IEEE 802.11b or up to 54Mbps in IEEE 802.11a/g. However in multicast, due to absence of traditional feedback signaling an AP cannot collect channel states information of MNs in the same way as in unicast transmission.

In our proposed transmission rate adaptation mechanism, SARM, we add supplementary signaling method through which AP can collect the state information of MNs which are participating in a multicast group. In this scheme, AP uses SNR

information between AP and MNs as a criterion of transmission rate selection. By using feedback signal transmitted from MNs, AP collects SNR information for all MNs participating in some multicast group and then determines transmission rate for multicast. This kind of rate adaptation methods based on SNR information has been proved to be feasible in several researches conducted before [7], [12], [14].

3.1 Channel Probing Mechanism in SARM

The key part of rate adaptation mechanism is for each MN to measure the channel state, and to inform the information to the AP. To make this possible, we introduce an additional signaling method. Algorithm 1 describes the scheme of signaling method which is conducted from MN and AP.

Algorithm 1 Channel Probing Mechanism Description

```

Multicast MN
1: ReceiveBeacon() {
2:   if Beacon Frame Contains No Multicast Information then
3:     < InitializationPhase >
4:     MeasureReceivedSNR();
5:     TransmitFeedback();
6:   else
7:     < NormalPhase >
8:     MeasureReceivedSNR();
9:     if PreviousMinimumSNR > ReceivedSNR then
10:      TransmitFeedback();
11:    else if CurrentNode == PreviousMinimumSNRNode then
12:      TransmitFeedback();
13:    end if
14:  end if
15: }

AP
1: ReceiveFeedback() {
2:   Update Multicast Node Entries;
3:   Pick Out An Entry Which Has The Minimum SNR Value;
4:   Determine Multicast Transmission Rate;
5: }
6: Periodically Transmit Beacon Frame With A Selected Entry;

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In initialization phase all MNs which are participating in multicast group measure their channel state by measuring received SNR value of beacon frame periodically broadcasted by AP. A periodic time of beacon signal is set as 100 ms in default. If received beacon frame does not contain additional information about multicast transmission rate of its own multicast group, then each MN transmits feedback signal which contains received SNR value. To minimize the possibility of collision

between feedback signals from MNs, each MN adjust its backoff time according to the received SNR value. Because the length of backoff time is adjusted according the received SNR value, MN with low received SNR has relatively higher priority than MN with high received SNR. In this mechanism, multicast transmission rate is determined based on the lowest SNR value of MNs.

On receiving feedback signal frame from MNs which are participating multicast group, AP constructs channel-states table for each multicast group. To enable this, AP need to snoop IGMP messages from MNs. Each channel-states table has list of entries of hardware address and received SNR of each MN. After constructing channel-states table, AP picks out an entry with minimum SNR value and adapt multicast transmission rate based on selected minimum SNR value.

After initialization phase, it is necessary for AP to inform the minimum SNR value and hardware address of the MN which has reported the minimum SNR value to all MNs which are participating in multicast group. When AP transmit beacon frame, those information are piggybacked on original beacon frame. Each MN which has received beacon frame measures the channel state repetitively and compares current received SNR value with previous minimum SNR value noted through beacon frame. If currently measured SNR value is greater than previous minimum SNR value then MN does not transmit feedback signal to AP. However if currently measured SNR value is smaller than previous minimum SNR value then this MN need to update minimum SNR value with current one so it transmits feedback signal to AP. Meanwhile the MN which has proved to have the minimum SNR by previous received beacon frame needs to transmit feedback signal whether current received SNR value is smaller than previous one or not. This is for reducing contention overhead on wireless channel caused by transmission of the additional feedback signal frame. If AP does not receive feedback signal frame from the MN with minimum SNR value for specific time, like 3 beacon interval time, then AP considers that the MN has no connection with it any more and restart initialization phase.

3.2 Transmission Rate Selection Criterion in SARM

When AP determines multicast transmission rate based on received SNR values of MNs, it needs specific criterion to adapt its transmission rate adequately. As referred before, proposed mechanism especially aims to maintain adequate quality of multimedia contents transmitted by multicast protocol while using minimum wireless channel resource. Therefore we introduce the concept of PSNR (Peak Signal-to-Noise Ratio) as a criterion for rate selection. In several works which focused on the effect of bit errors on video quality [8][9], PSNR metric has been generally used as a measure of video quality. Moreover, the results state that the PSNR value over 30 should be guaranteed to maintain adequate quality of multimedia contents. Figure 1 shows some examples which show varied quality according to their PSNR values.

Therefore, SARM aims to maintain PSNR value of received multimedia contents such as MPEG above 30. To enable this, it is need to construct database which



(a) 28.2437 PSNR with 10^{-5} BER (b) 19.8604 PSNR with 10^{-4} BER (c) 12.9043 PSNR with 10^{-3} BER

Figure 1: Video Quality at various PSNR values

contains the relationship between SNR and PSNR on each transmission rate from 1Mbps to 11Mbps. We conducted preliminary experiment to acquire SNR-PSNR relationship database and this work will be presented in section 4.1. The result from the experiment is showed in Table 1.

Table 1: SNR-Transmission Rate Mapping Table

	Required SNR		
	SARM with FCS OFF	SARM with FCS ON	RBAR
11Mbps	26	30	30
5.5Mbps	21	24.5	25
2Mbps	17.5	21	21

3.3 Quality Enhancement for Multimedia Contents

With SARM, we also propose one simple method which enhances the quality of multimedia contents and the utilization of wireless channel resource. Due to the absence of the retransmission mechanism in multicast, dropping error-contained frame at MN results in waste of wireless channel resource and also degrades the quality of multimedia contents significantly. In this mechanism, all MNs which receive multimedia multicast traffic do not drop any error-contained multicast frame. This process is possible by turning off FCS (Frame Check Sequence) in MAC layer and setting UDP checksum to zero. With this method our rate adaptation mechanism exploits higher multicast transmission rate at the same channel condition. Details of this method will be presented in section 4.1.

4 Experimental Results

4.1 Experiment for SNR-PSNR mapping database

In this section we present and analyze experimental results. We implemented simplified multicast testbed system which delivers MPEG stream from multicast server to MNs. This experiment has two primary goals. First is to acquire the database which shows the relationship between SNR and PSNR values for each transmission rate and second is to analyze the effect on the PSNR of received multimedia contents when we do not drop error-contained frames in a MN.

Main hardware devices used in experiment consist of AP, multicast server and MNs. Multicast server is Pentium 4 desktop PC with RedHat linux 7.3. This server encodes MPEG2 data from original YUV format data at the encoding rate of 1Mbps and transmits MEPEG2 data at the rate of 1Mbps. The AP used for our experiment is Orinoco AP-1000 model. This AP can monitor received SNR value for specific MN by transmitting and receiving a kind of probing packet. Also this can set up the multicast transmission rate at fixed rate, by administrator. MN is Pentium 3 Laptop PC with RedHat linux 7.3 and wireless interface card using Intersil chipset[10]. While receiving MPEG2 data from AP it disables any checksum mechanism such as FCS (Frame Check Sequence) in MAC layer or UDP Checksum so that it can use error-contained frames.

Experiment is executed as follows. We locate receiver node so that it can maintain specific level of received SNR. SNR value is monitored and logged by AP. And we set multicast transmission rate of AP at 2, 5.5 or 11Mbps. Then multicast server transmits MPEG2 data to receiver nodes through AP. After receiving MPEG2 data, receiver node decodes MPEG2 to YUV format data and calculates PSNR value by comparing with original YUV format data. Through all the experiment, multicast process which operates beyond MAC layer such as multicast group joining is not considered for convenience. By repeating this procedure with different location of MN each time and different multicast transmission rate of AP, we can get the result of SNR-PSNR relationship at each transmission rate.

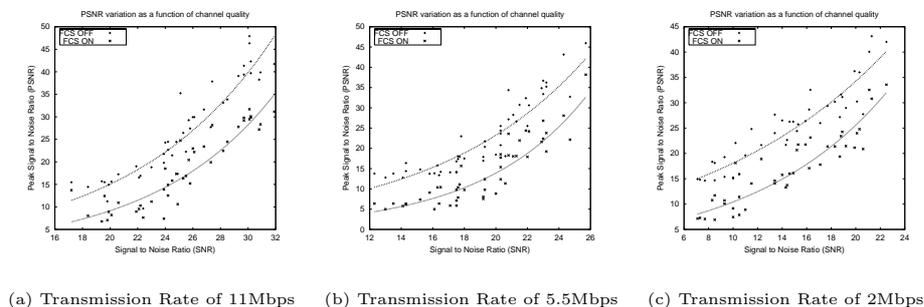


Figure 2: SNR-PSNR Relationship

Figure 2 shows the relationship between SNR and PSNR values. This result shows similar trend with well-known SNR-BER graphs. Based on this result we can acquire required SNR values to maintain PSNR value over 30 at each transmission rate. And ultimately we can construct SNR-Transmission rate mapping database for multicast transmission rate determination in AP. Table 1 shows the SNR-Transmission rate mapping database. Criterion of RBAR[7] based rate adaptation is derived from analytic results from [7], corresponding to the SNR points which meets bit error ratio of 10^{-5} . The result shows that SARM mechanism with FCS OFF exploits almost 1 level higher multicast transmission rate than RBAR and SARM with FCS ON under the same channel condition. This means that wireless channel resource occupied by multicast transmission is significantly reduced.

4.2 NS simulation - Protocol implementation

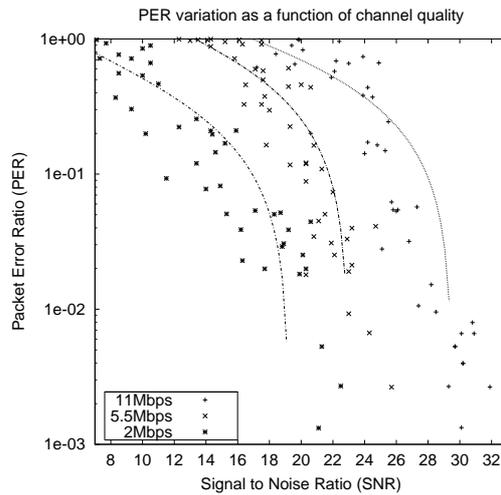


Figure 3: PER Variation as a function of SNR

In this section we evaluate the performance of proposed MAC-layer multicast protocol as compared to fixed-rate multicast transmission and RBAR based multicast transmission. We implemented proposed protocol using NS-2 simulator. All experiments use Ricean propagation model[11][12] as the channel propagation model for IEEE 802.11 PHY and we use NOAH ns-extension[13] to enable infrastructure mode communication. The values for received power thresholds for different data rates were chosen based on the distance ranges specified in the Orinoco 802.11b card data sheet. Also we use the channel error model derived from 4.1 to simulate realistic wireless channel error model of IEEE 802.11b. Figure 3 shows actually measured Packet Error Rate (PER) as a function of SNR for several data rates. Figure 4 (a) and (b) show Probability Density Function (PDF) and Cumulative Density Func-

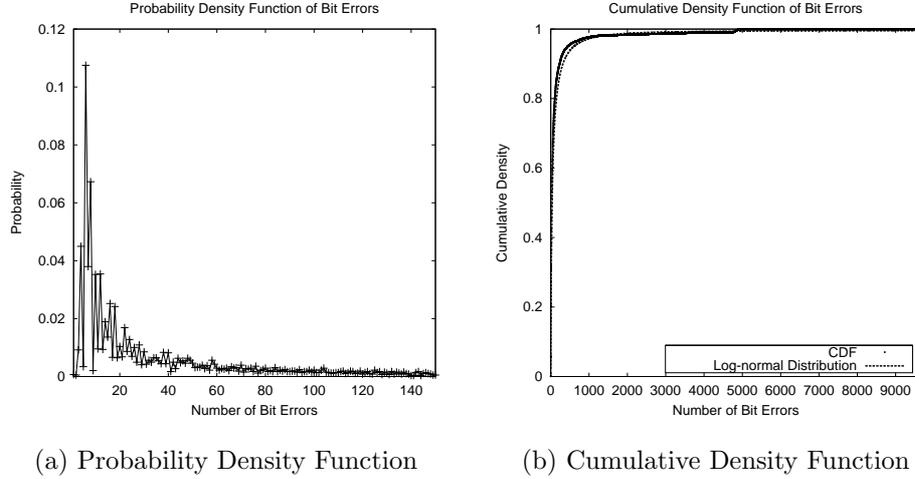


Figure 4: Bit Error in Each Transmitted Frame

tion (CDR) of bit errors in each transmitted frame from AP, respectively. Through the CDF of bit errors, we can know that the bit errors in each transmitted frame is modeled by log-normal distribution. It means that the most corrupted packets have a few bit errors. Based on these results we created IEEE 802.11 WLAN channel error model.

Simulation topology consists of multicast server and AP which are connected in wired channel, and 3 MN which are connected to AP in wireless channel. Multicast server transmits MPEG2 video data at the rate of 1Mbps and packet sizes are set to 1220 bytes which is exactly same as in 4.1.

Figure 5 shows PSNR variation of each transmission methodologies for different distance from AP, which is corresponding to received SNR. Result shows high fluctuation tendency because of the randomness of channel error model, however proposed protocol with FCS OFF always maintains PSNR value over 30 which is most critical issue in transmitting multimedia multicast traffic. Also proposed protocol with FCS OFF shows outperforms over RBAR based rate adaptation except for the SNR range from 26 to 30. In this SNR range, multicast transmission rate of proposed protocol is 11Mbps and that of RBAR based rate adaptation is 5.5Mbps thus RBAR based rate adaptation show better quality compared to proposed protocol. In the SNR range below 26, proposed protocol with FCS OFF outperforms all other methodologies including 2Mbps fixed rate transmission. This shows that not dropping error-contained packet frame can be better method in the case of multimedia multicast transmission.

Figure 6 shows throughput of background TCP traffic for each multicast rate adaptation methodologies. Proposed protocol outperforms over RBAR based rate adaptation and 2Mbps fixed rate transmission. By adapting multicast transmission

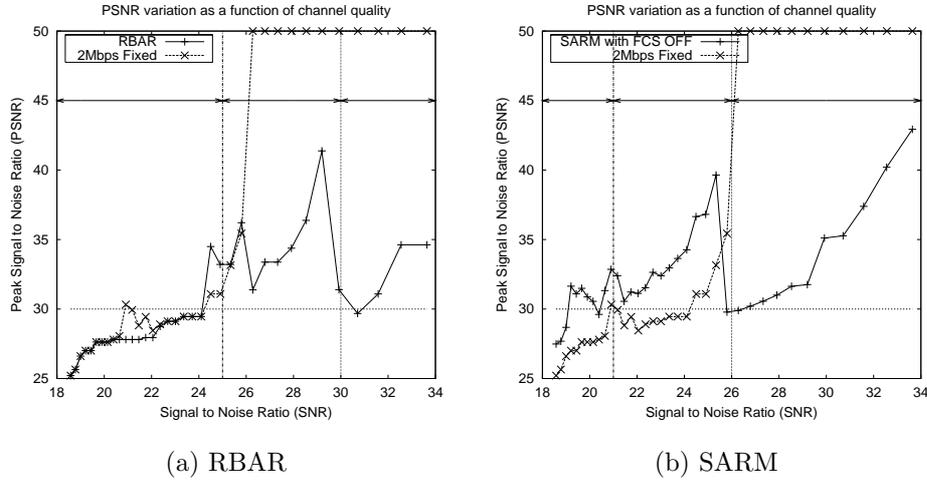


Figure 5: PSNR Variation as a function of SNR

rate to satisfy the limitation of PSNR 30, proposed protocol minimized its usage of wireless channel resource. This factor derives higher throughput for TCP based unicast traffic such as FTP file transfer or P2P communication.

5 Conclusion

In this paper we proposed a MAC layer multicast mechanism which utilizes multi-rate transmission capability. By enabling rate adaptation in multicast transmission based on the SNRs of MNs, the proposed mechanism eliminates the waste of wireless channel resource. The proposed mechanism can guarantee the best quality of multimedia contents depending on multicast receivers' wireless link conditions. Moreover it can minimize the usage of wireless channel resource for multicasting compared to the fixed rate transmission or other protocol such as RBAR. Finally we performed experiments using the testbed and simulation using ns-2 simulator. Through experimental and simulation results it is proved that the proposed mechanism outperforms fixed rate transmission and RBAR.

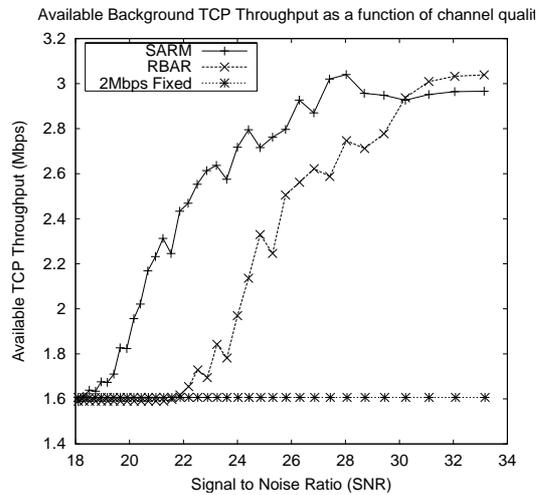


Figure 6: Background TCP Throughput

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