

An Iterative SNR Estimator for Link Adaptation in IEEE 802.11n System

Min Li Huang, Jin Lee and Sin-Chong Park
Information and Communications University
119, Munji-ro, Yuseong-gu, Daejeon, 305-732, Korea
E-mail: {minli.huang, mygenie, scpark}@icu.ack.kr

Abstract: A dynamic and reliable link adaptation algorithm is essential to achieving higher throughput limits in a distributed and diverse wireless network. However, SNR based Link Adaptations reported in literature thus far assume that SNR estimation is always ideal. In this paper, ideal is defined as the absolute performance of the SNR estimator which approaches the Cramer-Rao Bound (CRB) with almost no bias or variance. In real wireless communication systems, this assumption doesn't hold true. We extend the SNR estimator for Single Input Single Output (SISO) system to a Multiple Input Multiple Output (MIMO) Physical Layer (PHY) model, and show the actual performance of a cross layer SNR based link adaptation. Simulation results prove that the SNR estimates are unstable and fluctuate in a multi-path Rayleigh fading channel, degrading the effectiveness of link adaptation algorithm. This motivates us to propose an iterative SNR estimator for link adaptation algorithm that allows the efficient utilization of channel bandwidth to achieve a throughput gain for IEEE 802.11n based system.

1. Introduction

The quest for a higher throughput wireless communication system is now more important than ever, with the introduction of IEEE 802.11n standard. The newly drafted IEEE 802.11n standard defines up to 76 Modulation and Coding Schemes (MCSs) with over 45 data transmission rate [1]. To exploit the multi-rate capability of 802.11n based system, a wireless station should possess the capability to dynamically select the best transmission rate based on the network condition and channel quality. Thus an investigation on the SNR based link adaptation algorithm targeted for IEEE 802.11n system is necessary.

Over the decade, numerous link adaptation algorithms [2-7] have been studied and proposed in literature, with the Automatic Rate Fallback (ARF) rate adaptation algorithm by Lucent Tech [2] being the most well-known scheme implemented in real-life wireless system. Generally, link adaptation algorithms adapt the transmission rate as a function of the channel quality between the source and destination stations. Transmission rate is often adjusted based on feedback metrics, such as consecutive success and failed transmissions [2, 3, 6], probe packets [2, 3], and SNR estimates [4, 5, 7], obtained from the destination station.

In this paper, we explore and analyze the performance of SNR based link adaptation algorithm. Link adaptation based on SNR is a PHY-aware Medium Access Control (MAC) implementation which allows the MAC layer to select a PHY data rate based on estimated SNR and desired Packet Error Rate (PER). Theoretically, an ideal SNR estimation may indeed lead to an effective rate adaptation. However, this assumption is not true in practical IEEE

802.11 systems. To support our claim, a Data-aided (DA) SNR estimator known as Maximum Likelihood (ML) estimator [8] is adapted to the MIMO Orthogonal Frequency Division Multiplexing (OFDM) PHY simulator presented in Section 3. Simulation results computed in a Rayleigh fading channel model reflect a pessimistic and fluctuating SNR estimation that significantly degrades the throughput performance under the contention-based EDCA protocol.

Hence, an iterative SNR estimation method is proposed for link adaptation algorithm. The proposed algorithm overcomes the aforementioned instability issue and enhances the throughput of IEEE 802.11n based system. In addition, the inclusion of High Throughput (HT) Control field in the IEEE 802.11n standard with no rules or regulations imposed on the decision making of transmission rate selection makes our proposed iterative SNR based link adaptation an attractive and viable solution for any future wireless platform that supports the IEEE 802.11n standard.

This paper is organized as follow. Section 2 gives an overview of the link adaptation mechanism in the IEEE 802.11n MAC layer. Section 3 describes the IEEE 802.11n based PHY simulator accompanied by a statement of the SNR estimation model. The mathematical equations of ML SNR estimator is presented in Section 4. The iterative SNR technique for link adaptation algorithm in IEEE 802.11n system is proposed in Section 5. Last but not least, the performance of our proposed link adaptation algorithm is compared in Section 6 before concluding the paper in Section 7.

2. The IEEE 802.11n MAC

The IEEE 802.11n MAC includes the IEEE 802.11e MAC which defines the Hybrid Coordination Function (HCF) mechanism for Quality of Service (QoS) enhancement [10]. HCF is always present in a QoS station (QSTA). Under HCF, a new basic unit of time allocation that gives a station the right to initiate a transmission onto the wireless channel called Transmission Opportunity (TXOP) is introduced. In this paper, we focus on the HCF contention-based channel access (EDCA) TXOP channel access protocol.

2.1 EDCA TXOP

EDCA TXOP allows the EDCA mechanism to access the wireless medium in a differentiated and distributed manner, and transmit frames using TXOP.

TXOP limit is a parameter which limits the number of MAC Service Data Units (MSDUs) within an EDCA TXOP. The TXOP limit for Voice Access Category (AC_VO) and Video Access Category (AC_VI) are provided in Table 1. TXOP limit is updated by Quality of

Service Access Point (QAP) through Beacon and Probe Response Frame.

AC	TXOP limit	
	802.11b PHY	802.11a PHY
AC BK	0	0
AC BE	0	0
AC VI	6.016ms	3.008ms
AC VO	3.264ms	1.504ms

Table 1. The maximum TXOP limit as specified in IEEE 802.11e

2.2 The 802.11n Link Adaptation Mechanism

The IEEE 802.11n MAC standard fully exploits the MIMO channel variations by providing a mechanism that allows a source station to request a destination station for MCS feedback. Based on this standard, an SNR based link adaptation may be supported by immediate response, delayed response or unsolicited MCS feedback as described below [1].

- **Immediate:** In an immediate response, the MCS Feedback (MFB) responder (or destination station) transmits the response in the TXOP obtained by the TXOP holder, allowing MFB requester (or source station) to obtain the benefit of dynamic link adaptation within the same TXOP.

- **Delayed:** In a delayed response, the MFB responder shall transmit the response in the role of a TXOP holder in response to an MCS request in a previous TXOP obtained by the MFB requester.

- **Unsolicited:** In an unsolicited response, a station sends MCS feedback independent of any preceding MCS request.

The detailed description on IEEE 802.11n link adaptation is well explained in the IEEE 802.11n standard [1].

3. The IEEE 802.11n PHY

The DA SNR estimators used in this paper is based on the pilot symbols in IEEE 802.11n system.

3.1 Transmitter

In IEEE 802.11n, the OFDM symbols are transmitted over a 20MHz or 40MHz channel bandwidth. Each OFDM symbols contains 4 pilot subcarriers for 20MHz transmission and 6 pilot subcarriers for 40MHz transmission, $a_{i,j}(n)$ with unit magnitude, where i is the index of N_{TX} transmit antenna, j is the index of receive antenna, and $n = 0, 1, \dots (N_{SC}-1)$ is the pilot subcarrier index. The pilot subcarriers are modulated using a pseudo-random cover sequence [1, pp.283] and transmitted over the wireless channel as PSK complex signals after IFFT.

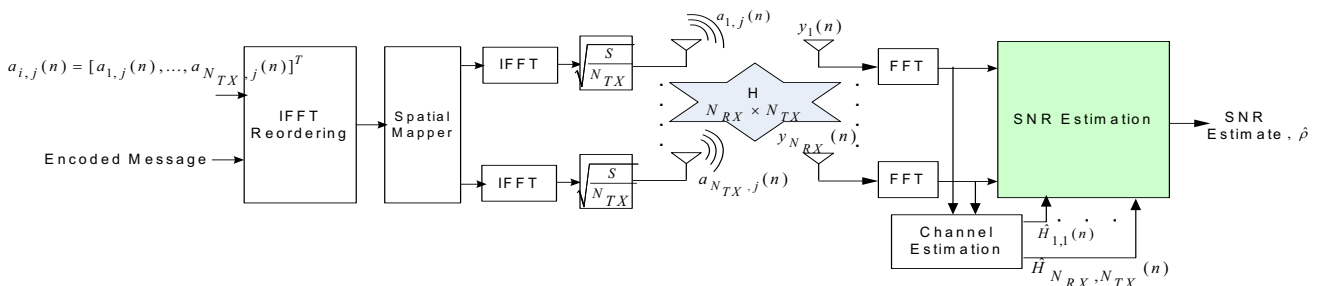


Figure 1. Abstract block diagram of IEEE 802.11n system

3.2 Channel Model

We consider a time-variant channel based on Rayleigh fading model. We investigate a two-cluster Non Line-of-sight (NLOS) Rayleigh fading channel with 15ns Root Mean Square (RMS) delay spread, as given in Table 2.

Cluster	Tap	1	
	Cluster 1	Delay (ns)	0
	Power (dB)	0	
Cluster 2	Tap	1	2
	Delay (ns)	0	50
	Power (dB)	-2.28	-11.3

Table 2. Parameters for multi-path Rayleigh fading channel

3.3 Receiver

The output of the FFT at the receiver can be formulated as below:

$$y_j(n) = \sqrt{\frac{S}{N_{TX}}} \sum_{i=1}^{N_{TX}} H_{i,j}(n) a_{i,j}(n) + \sqrt{N} n_j(n) \quad (1)$$

where j is the index of N_{RX} receive antennas, $n_j(n)$ are i.i.d. zero mean complex Gaussian noise and $H_{i,j}(k,n)$ are complex channel coefficients normalized to unity for convenience. S and N is the signal and noise power scale factor respectively.

3.4 SNR Estimator Model

In this IEEE 802.11n MIMO system, the SNR estimates are generated by averaging the observable properties of N_{SC} pilot subcarriers for one receive antenna and averaged across N_{RX} receive antennas.

$$\hat{\rho} = \frac{1}{N_{RX}} \sum_{j=1}^{N_{RX}} \frac{\hat{S}_j}{\hat{N}_j} \quad (2)$$

4. SNR Estimators

To-date, DA SNR estimators have been well studied for Single Input Single Output systems, such as ML estimator in [8], Minimum Mean Square Error (MMSE) estimator in [11,12] and Shousheing He's (SH) estimator [13]. We will demonstrate how the proposed iterative SNR technique with ML estimator stabilizes and improves the SNR estimation for a MIMO system.

The equation for estimated signal power \hat{S}_j and noise power \hat{N}_j for ML estimation may be written as equation (3) and (4). Derivation omitted due to lack of space.

$$\hat{S}_j = N_{TX} \left[\frac{1}{N_{SC}} \sum_{n=0}^{N_{SC}-1} \text{Re} \{ y_j(n) \sum_{i=1}^{N_{TX}} \hat{H}_{i,j}^*(n) a_{i,j}^*(n) \} \right]^2 \quad (3)$$

$$\hat{N}_j = \frac{1}{N_{SC}} \sum_{n=0}^{N_{SC}-1} |y_j(n)|^2 - \frac{\hat{S}_j}{N_{TX}} \quad (4)$$

$\text{Re}\{\cdot\}$ denotes the real part of a complex quantity, and $\hat{H}_{i,j}(n)$ is the estimated channel coefficient.

5. Iterative SNR for Link Adaptation

To achieve a stable and reliable SNR estimate, we propose an iterative SNR estimation algorithm as follows:

- **Step 1:** When a k th data packet is received, compute the new SNR estimate, $\hat{\rho}(k)$.
- **Step 2:** Current SNR estimate, $\hat{\rho}_{cur}(k)$ is defined as $\hat{\rho}_{cur}(k) = (\hat{\rho}_{low} + \hat{\rho}_{high})/2$, where $\hat{\rho}_{low} = \hat{\rho}(k)$ and $\hat{\rho}_{high} = \hat{\rho}_{cur}(k-1)$ if $\hat{\rho}_{cur}(k-1) \geq \hat{\rho}(k)$ and vice versa.
- **Step 3:** Substitute $\hat{\rho}_{low} = \hat{\rho}_{cur}(k)$ obtained from Step2 and compute $\hat{\rho}_{cur}(k) = (\hat{\rho}_{low} + \hat{\rho}_{high})/2$ again. Repeat Step3 until an optimal $\hat{\rho}_{cur}(k)$ value is achieved.

We applied the proposed iterative SNR estimation method on the extended ML estimator in section 4 and compared it with the non-iterative ML estimator. Simulation result in Figure 2 shows that the averaging and iterative technique has smoothened and reduced the bias of ML estimator. An almost straight line parallel to the true SNR value can be achieved with an 8-iteration algorithm.

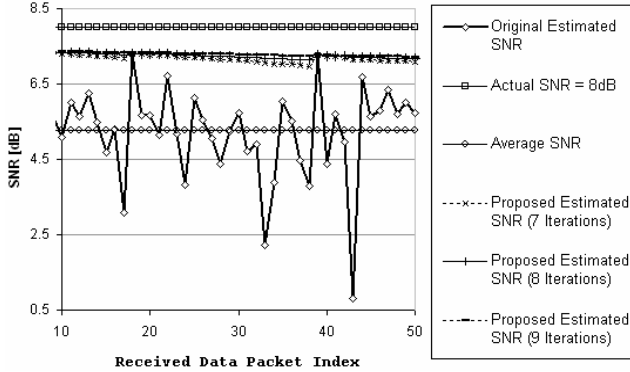


Figure 2. Performance comparison between the proposed Iterative SNR Estimation Algorithm against the original non-iterative SNR estimations (data packet length = 1000 bytes for 2x2 antenna configuration).

6. Performance Evaluation

In this paper, we consider an Infrastructure Basic Service Set (IBSS) system with saturated network condition, i.e., data queue is never empty. There are N contending stations randomly distributed within the distance of 1m to 50m from the QoS Access Point (QAP), constantly generating the Best Effort traffic under the EDCA TXOP wireless medium access protocol.

6.1 Link Adaptation Algorithm

The SNR-based link adaptation algorithm used in this paper is based on a table-driven model. A best transmission rate (r) that achieves 0.1 PER based on the SNR estimates ($\hat{\rho}$) from PHY and packet length (L) value from Logical Link Control (LLC) is always selected.

6.2 Throughput Calculation

The analytical throughput (Thr) in unit Mb/s of a single successful EDCA TXOP transmission is calculated using eq. (5) below. It is dependant on the n Number of Burst Transmission within the TXOP. A sufficiently large $n=100$ burst transmissions was chosen to achieve a level of estimation confidence.

$$\text{Thr} = \frac{n \times L}{\text{BK} + \text{RTS} + \text{CTS} + n \times \text{TxDATA} + \text{BAR} + \text{BA} + (n+3) \times \text{SIFS}} \quad (5)$$

where BK represents the backoff duration, BAR is the Block Ack Request duration, BA represents Block Ack frame duration, TxDATA is the duration of transmitted data packet and SIFS takes 16 us.

6.2 Simulation Results

In this section, we compare our proposed link adaptation based on iterative SNR estimation with (a) link adaptation without iterative SNR estimation (Non Iterative) and (b) Original (ideal) SNR.

6.2.1 Case Study 1 (N = 1)

Figure 3 illustrates the throughput performance of a single QSTA in a the varying channel condition. The QSTA is allowed to move around the QAP in a 1m-step increment within a 100m diameter circle. Figure 3 shows that at a shorter distance of less than 10 meters from QAP, the small channel variation coupled with strong received signal strength allows both Iterative and Non Iterative SNR estimators to perform close to the true SNR value. However, as the QSTA moves further away from the QAP, our proposed algorithm clearly outperforms the Non Iterative ML based link adaptation scheme at the 10m to 40m range with as high as 3 times throughput increment at the of 30m from QAP, displaying a throughput close to the true, unbiased SNR.

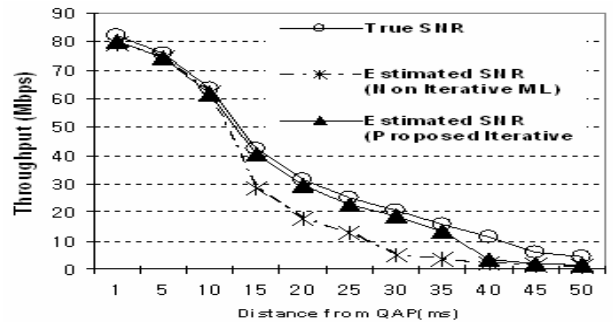


Figure 3. Throughput performance of link adaptation using Iterative vs Non Iterative ML estimator for case study 1 (in 2x2 antenna configuration)

6. 2. 2 Case Study 2 (N = 1-15)

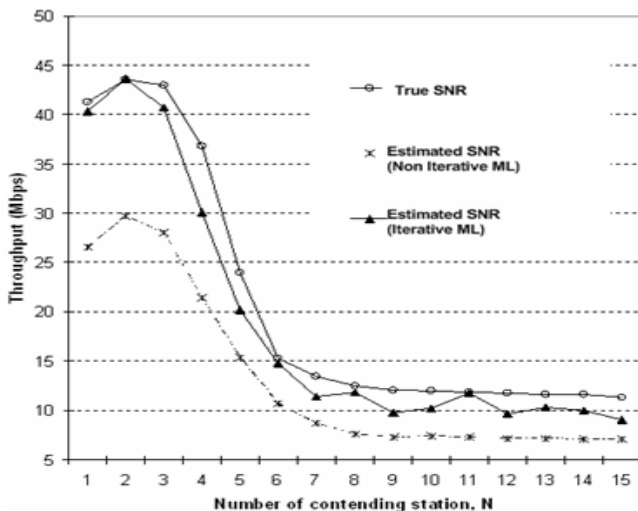


Figure 4. Throughput performance of link adaptation algorithm using Iterative vs Non Iterative ML estimator for case study 2 (in 2x2 antenna configuration)

Figure 4 compares the throughput performance of the link adaptation algorithm that uses the proposed Iterative SNR scheme against the Non Iterative SNR in a varying network load environment. As the number of contending QSTAs increases, the throughput performance degrades in a steeply manner due to increased transmission failures caused by frame collisions. The graph shows an average 50% throughput performance decline for Non Iterative SNR method. On the other hand, our proposed 8-Iteration SNR method consistently gives a higher throughput performance which enhances the network capability to near true SNR value performance, under a varying network condition.

7. Conclusion

The performance of a SNR-based link adaptation algorithm for the IEEE 802.11n system depends on a number of factors, namely the distance between source and destination stations, the received packet length, the type of SNR estimators (for example DA based SNR estimator performs better than non-DA based SNR estimator), the wireless channel condition and transmit-receive antenna configurations. Simulation results have clearly showed that the proposed link adaptation algorithm with Iterative SNR estimation is capable of overcoming the SNR instability issue under the multi-path fading channel model to successfully achieve the goal of enhancing the wireless network throughput under varying network load and channel condition for the up-coming IEEE 802.11n based wireless communication system.

With that said, the implementation choice of the link adaptation algorithm for IEEE 802.11n system is also influenced by the design complexity, for example the SNR-based link adaptation is more complex than the ARF scheme.

Last but not least, our investigation gives an insight on the impact of a typical SNR estimator on cross layer based

link adaptation algorithm and further work to compare the throughput performance of the proposed iterative SNR based link adaptation algorithm with other link adaptation schemes under different antenna configurations and channel models such as a Rician fading model can provide a more complete picture on the effectiveness of our proposed iterative SNR scheme for link adaptation algorithm.

References

- [1] IEEE P802.11n/D3.00 Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancement for Higher Throughput, February 2007.
- [2] A. Kamerman and L. Monteban. WaveLAN II: A high-performance wireless LAN for the unlicensed band. Bell Labs Technical Journal, Summer 1997
- [3] M. Lacage, M. H. Manshaei, and T. Turletti. "IEEE 802.11 Rate Adaptation: A Practical Approach", ACM MSWiM, 2004
- [4] G. Holland, N. Vaidya, and V. Bahl. "A Rate-Adaptive MAC Protocol for Multihop Wireless Networks", ACM MOBICOM, 2001
- [5] B. Sadeghi, V. Kanodia, A. Sabharwal, and E. Knightly. "Opportunistic Media Access for Multirate Ad Hoc Networks", ACM MOBICOM, 2002
- [6] D. Qiao, S. Choi, and K. Shin. "Goodput Analysis and Link Adaptation for IEEE 802.11a Wireless LANs", IEEE TMC, 1(4), October 2002
- [7] I. Haratcherev, K. Langendoen, R. Lagendijk and H. Sips. "Hybrid Rate Control for IEEE 802.11", ACM MobiWac, 2004
- [8] Pauluzzi, D.R., Beaulieu, N.C., "A comparison of SNR estimation techniques for the AWGN channel", in IEEE Transactions on Communications, Oct. 2000, pp.1681-1691.
- [9] IEEE 802.11. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. IEEE, June 2007
- [10] IEEE 802.11e. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements, Nov. 2005.
- [11] Huilin Xu, Guo Wei, Jinkang Zhu, "A novel SNR estimation algorithm for OFDM" in Vehicular Technology Conference, VTC 2005-Spring, 30 May - 1 June 2005, pp. 3068-3071.
- [12] Dong-Joon Shin, Wonjin Sung, In-Kyung Kim, "Simple SNR estimation methods for QPSK modulated short bursts" in Global Telecommunications Conference, GLOBECOM 2001, 25-29 Nov. 2001, pp. 3644-3647.
- [13] Shousheng He, Torkelson, M. "Effective SNR estimation in OFDM system simulation" in Global Telecommunications Conference, GLOBECOM 1998, 8-12 Nov. 1998, pp. 945-950.