Analysis of Various Parameters for Link Adaptation in Wireless Transmission

R.G. Purandare, S.P. Kshirsagar and S.M. Koli

Abstract Choosing a correct parameter from RSSI, SINR, PDR, and BER to estimate status of the wireless link is of paramount importance for link adaptation. RSSI may not point out interference effectively, whereas SINR thresholds are hardware dependant and require calibration. PDR and BER are measurable metrics with many considerations. It may project wrong status of link quality if not analyzed properly. Since reception of erroneous packet is frequent in wireless domain, cause has to be pinpointed accurately for pertinent remedial action. But two different causes require two different corrective actions, exponential back off for collisions, and change of transmission data rate or power for signal attenuation.

Keywords Channel state information matrix · Packet loss differentiation · Link adaptation

1 Introduction

Interference, collisions, and fading are inherent characteristics of wireless channel making the faithful delivery of data to the receiver difficult [1]. To improve the robustness and reliability of wireless transmissions, link adaptation techniques are

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employed. The effectiveness of which is dependent on true estimation and feedback of channel state information conveyed by the receiver to the transmitter.

The analysis in this paper covers rate adaptation. Earlier systems like Automatic Rate Fallback (ARF) used this without differentiating between signal fading and collisions. ARF uses the statistics of transmission success or failure. Adaptive ARF (AARF) [2] updates the thresholds for using higher or lower data rate. Automatic Rate Fallback (ARF) Collisions Aware Rate Adaptation (CARA) [3] uses RTS/CTS to develop collision aware systems but by increasing overheads in return. Robust Rate Adaptation Algorithm (RRAA) [4] uses frame error rate to rate change the decision. In Effective Rate Adaptation (ERA) [5] authors have proposed fragmentation to combat collisions. Some authors have proposed change in IEEE 802.11x standards Receiver Based Auto-Rate (RBAR) [6] whereas some have developed application specific solutions. Signal-to-noise ratio or received signal strength based approaches are faster adapting to dynamic channel conditions whereas transmission success or failure based approaches may take longer to adapt.

2 Metric for Channel State Information

Channel state information is a mandatory input for adaptive link measures. The four primary metrics which are considered for capturing the quality of a wireless link are:

2.1 RSSI (Received Signal Strength Indication)

According to commercial NICs available, RSSI is measured during the Physical Layer Convergence Protocol (PLCP) header and preamble which are sent at commonly supported lowest data rates. Once the header is transmitted, rest of the data received from higher layers, also called as the PLCP Service Data Unit (PSDU) is transmitted at the rate specified in the header. If PLCP header and preamble are not received due to interference, RSSI may not be recorded at all. There is also a possibility that PLCP header and preamble are not affected by interference but rest of the packet which may be sent at higher data rate is corrupted due to interference. In both cases, measurement of RSSI will not be a correct indictor of signal power received at the receiver. Experiments carried out [7] indicate that RSSI measured during simultaneous transmission from many transmitters remain stable and does not reflect the effect of interference and channel fluctuations accurately.

Figure 1a indicates that trend of RSSI may not point out interference effectively whereas (b) shows that interferer's power may directly affect packet delivery ratio.

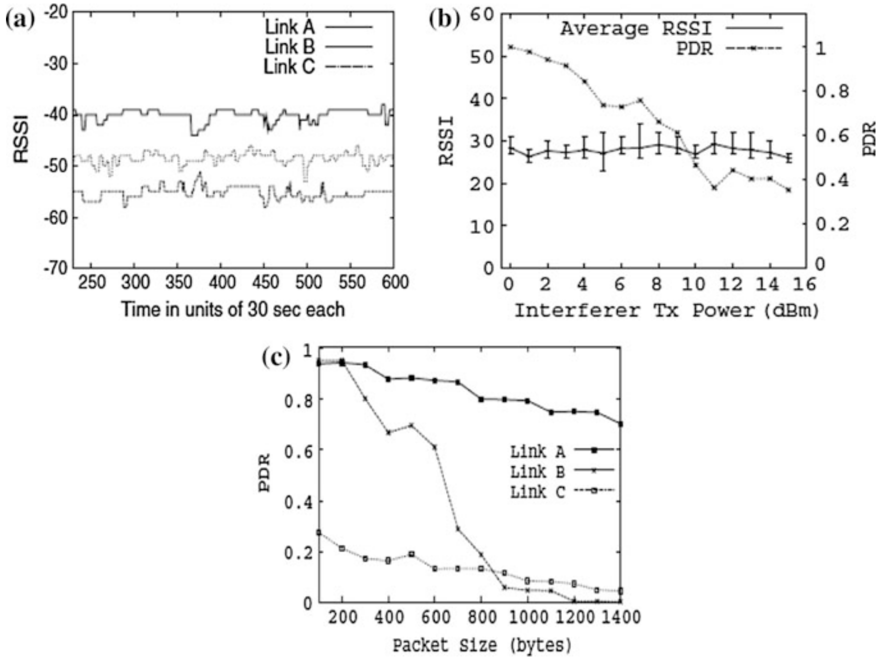


Fig. 1 **a** RSSI as interferer's power is increased on different links [7]. **b** Effect of interference on RSSI [7]. **c** Dependency of PDR packet size [7]

2.2 SINR (Signal-to-Interference-Plus-Noise Ratio)

This is one of the best parameters to evaluate the instantaneous characteristics of the link and its effect on the signal received. But SNR thresholds, low and high corresponding to 10 and 90 % frame delivery ratio respectively are, hardware dependant. This requires calibration for a pair of transmitter and receiver BERs with parameters directly proportional to channel condition which is the function of SNR. There exists a range of SNR/SINR values for which frame delivery ratio may switch from 0 to 1. But in practice all NIC cards give RSSI measurements and not SINR. Further, RSSI is measured only during preamble, that too if received, it does not reflect correct extent of interference present on the link. Trials by [7] show that PDR *(Packet-Delivery Ratio)* is directly proportional to it and is a better measure of interference than RSSI.

2.3 PDR (Packet-Delivery Ratio)

PDR is a measurable metric prevalent in accessing the link quality. But it is highly dependent on packet size. Smaller the size, higher the probability that only few bits are in error. Therefore, with heterogeneous links operating with different protocol packet sizes, PDR may not be able to represent a consistent estimate of the link quality. PDR is also dependent on the bit rate used. In lossy environment higher bit rates may have lower PDR than robust low bit rates. Figure 1c shows the same with three different links.

2.4 BER/PER (Bit/Packet Error Rate)

Analyzing the bit and packet error rate may be useful to characterize the link quality. For analysis of bit errors and packetization of errors the Markov models are widely used. BER of 10^{-5} is acceptable for wireless LAN applications. The PER values vary on different transmission parameters such as transmission power, modulation scheme (transmission rate) used, and packet size. Logically, it appears that BER will increase with higher data rates as dense constellation is prone to interference but due to fading, the BER or PER may not always monotonically decrease as the transmission rate is reduced. A practical rule for correctly estimating a BER of the order of 10^{-p} is that we need to transmit 10^{p+2} bits. This ensures approximately, an accuracy of two significant digits in the computation of BER. The BER is computed only from the received packets (correct or corrupted). Since PER is computed from received packets, packets lost due to interference and noise will not be accounted for and it may project wrong picture of link quality.

Random bit errors can be attributed to various reasons and may not provide sufficient information regarding the status of channel. But a number of either consecutive bits or packets lost or in error may indicate a poor connectivity between source and destination due to severe fading or variable length coding (VLC) techniques [8].

For a given PER single bit errors may be more damaging than a cluster of errors. This is so because a number of single errors have more number of corrupted frames leading to degradation of received video.

3 Separating Signal Attenuation from Collisions

In a wireless domain, reception of weak/no signal or packets received with errors is very frequent. This may happen due to collision of concurrent transmission or signal attenuation and fading. Corrective action is initiated to arrest further loss [9]. But two different causes require two different corrective actions, exponential back off for collisions, and change of transmission data rate or power for signal attenuation. But design of 802.11 is such that it provides only a binary feedback of success or failure for packet transmission. It implements a back off on packet loss and subsequent failures implement rate adaptation. This absence of cause detection may in fact lower the network capacity. It is suggested that metric consisting of bit, symbol error pattern, errors per symbol, and joint distributions of these could be used to separate collision losses from weak signal loss. Since this requires analysis of entire packet received in error, the packet in error has to be sent back to the sender. In [10] authors have shown experimental data analysis with interesting results.

- Figure 2 shows that if CDF of BER and SER are plotted then statistics of collision has spread over a wider range than the data from a weak signal.
- Figures 3 and 4 demonstrate that there is more number of errors per symbol in case of collision than a weak signal with larger bursts of contiguous symbols in error.

As this complex technique requires feedback to be sent to the sender, a novel method is used to make a skilled guess of loss differentiation by analyzing parameters of received signal. It is categorized as channel error if low SNR signal is received. If preamble was not received correctly then it is classified as collision

$$\text{Error Score ES} = \sum_{k=1}^{n} (\text{length of symbol error burst } k)$$

Fig. 2 CDF of BER [10]

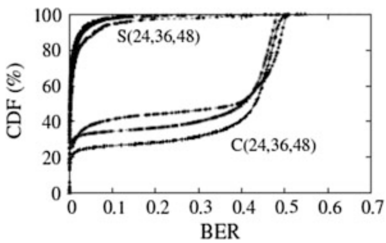


Fig. 3 CDF of error rate per symbol [10]

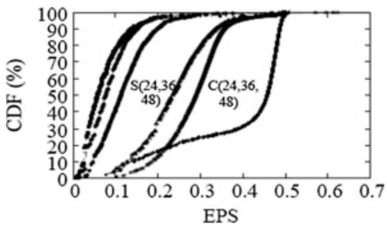
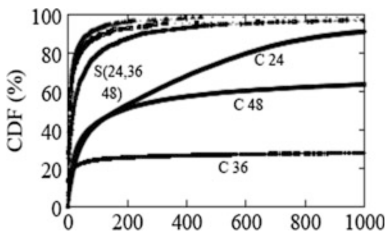


Fig. 4 CDF of Length of Symbol Error Burst for packets in error [10]



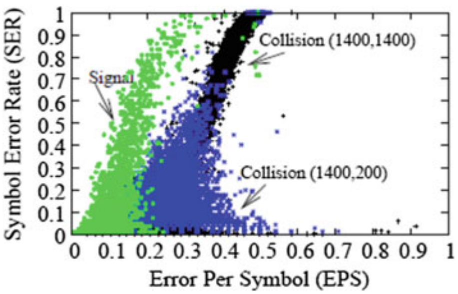


Fig. 5 Scatter plot of SER versus EPS [10]

But if preamble was received but data could not be decoded then it is an asynchronous loss. Although this procedure is straightforward there is always a possibility of false positive.

- *Joint Distribution of SER and EPS*: It is logical that packet in error due to collision has more number of errors per symbol and higher symbol error rate. Figure 5 underlines the same.

In CSMA based networks, it could be concluded [11] that

a. If interfering signal is already present when desired source starts transmission then it is taken as a class of interference for which threshold for detecting interfering signal should be reduced.
b. If interfering signal occurs after desired source starts transmission then power of signal should be increased so as to dominate and avoid corruption of source signal already started.
c. But if interfering signal starts at the same time as the desired signal then it is taken as collision and exponential back off and contention window optimized algorithm could be invoked

Another novel way that authors have tried with success is to append Cyclic Redundancy Check (CRC) after every small data segment in data packets [12]. If at the receiving end, a number of erroneous data packets go beyond a certain threshold then decision is taken in favor of collision otherwise the damage is due to channel errors. It is argued that if it was collision then chunk of sequential data would be affected and not disjointed.

Use of RTS and CTS has been used to differentiate between losses due to collision and due to channel error. But it leads to increased overheads especially in high speed wireless data transfer. But this technique can only be used for 802.11 standard and its flavors [13].

SNR and PDR are strongly correlated. There is a steady rise in PDR after threshold SNR. It becomes stable at certain SNR and saturates. This high SNR threshold can also be measured. This correlation is disturbed in presence of interference and losses could be separated from the ones due to signal attenuation.

4 Considerations for Link Rate Adaptation

To combat dynamic characteristics of wireless channel which causes packet loss, high bit error rate and delay, sending node can adapt its modulation and coding according to instantaneous channel status. But parameters required to study the channel quality, e.g., SNR fluctuates with time. It is seen in the Fig. 6a, b.

One of the techniques for link adaptation uses variable transmission or coding rate [14]. By increasing the coding rate system throughput increases but it may cause network congestion due to high bit rate. It leads to further delay and distortion. Power to be transmitted is also higher for this data rate. This calls for well designed optimum thresholds for encoding rate.

Most bit rate adaptation techniques use either frame receptions or SNR. Channel conditions that have effect rate adaptation are (i) coherence time (ii) delay spread (iii) interference, and (iv) physical layer capture.

Frame-level techniques consider percentage of lost frame and hence require several frames, to predict the channel condition. Known as loss triggered, these techniques tends to be slow especially for highly dynamic channels.

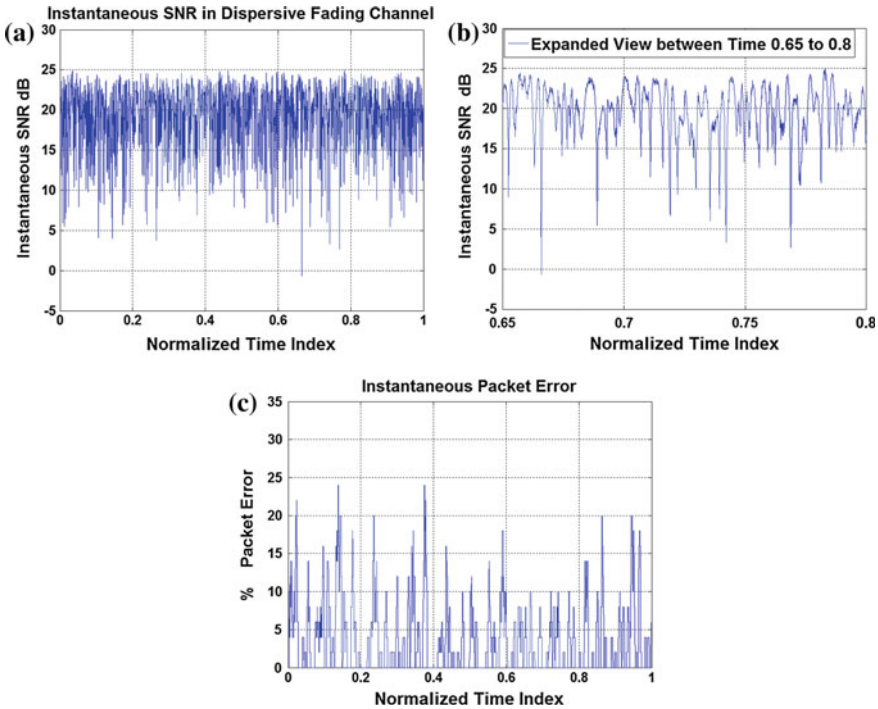


Fig. 6 **a** Continuously changing SNR in dynamic channel conditions. **b** Expanded view of SNR w.r.t. time. **c** Variable packet error rate in dynamic channel conditions

- BER and SNR are interrelated. SNR could also be used as a trigger for rate adaptation. But mobility has great impact on SNR. If it is measured at the start of the packet, reading may not be the same towards the end of the packet. Due to heterogeneous networks and dynamic channel conditions periodic training and tracking are mandatory for these protocols. It has been observed that collision losses adversely impact the performance of rate adaptation protocols. Some cross-layer wireless bit rate adaptation algorithm estimates the interference-free BER of received frames
- Figure 7 show that different frequencies undergo different fading. Heavily faded frequencies will require robust modulation, strong coding, and higher power for sufficient packet delivery ratio.

Figure 8a shows a distinct relation between SNR and PDR. Picking bit rates using SNR/BER thus estimated can be used to select appropriate bit rate. It enables to react quickly to channel variation without requiring any environment-specific calibration. BER thus estimated can be applied to a variety of wireless cross-layer protocols that, for example, allocate frequency or transmit power, or perform efficient error recovery.

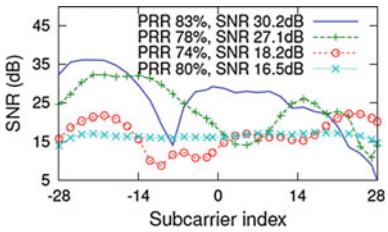


Fig. 7 Frequency selective fading for OFDM for four links with 80 % of packet delivery at 52 Mbps [15]

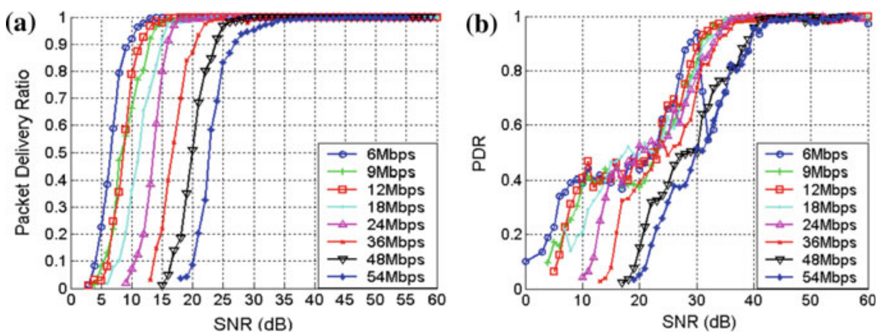


Fig. 8 **a** FDR as a function of SNR [13]. **b** Impact of Interference [13]

Different transmission rates have corresponding SNR thresholds which in turn are decided by the proprietary hardware. Higher rate requires higher SNR to sustain. There is a "transition band" in SNR where FDR goes from zero to 100 %. This transition band can be 5–7 dB wide. If interference exists in the environment, the SNR–FDR relationship may be distorted and will cause many frame losses. The transition bands are stretched and the SNR–FDR curves become irregular as seen in Fig. 8b.

SNR-based data rate adaptation based on channel state information requires Received Signal Strength (RSS) at the receiver along with estimation of noise and interference encountered. Some adaptations consider explicit feedback coming from the destination node in form of RTS/CTS but amounting to increased overhead. Authors [16] passively monitor destination, as all nodes inform other nodes in the range about the interference encountered and power they transmit. Final data rate could be decided upon removing transient fades occurring in the SINR. Adaptations, in general, quickly switch to lowest supported rates to get the packet through and extract vital information about channel state from acknowledgement received.

5 Conclusion and Future Scope

The four primary metrics which are considered for capturing the quality of a wireless link are RSSI, SINR/SNR, PDR, and BER/PER. RSSI is measured during the PLCP header and preamble sent at commonly supported lowest data rates. Tendency of RSSI may not point out interference effectively. It is one of the best parameters to evaluate the instantaneous characteristics of the link but is difficult to measure. PDR and BER are useful if analyzed correctly as they are dependent on numerous parameters and conditions.

Packet loss or corruption may be due to the collision of concurrent transmission or signal attenuation and fading. But two different causes require two different corrective actions to arrest further loss. Incorrect measure may in fact lower the network capacity.

In link adaptation bit rate selection enables to react quickly to channel variation without requiring any environment-specific calibration. It uses SNR or BER for decision making. But SNR thresholds are hardware dependant and calibration is needed for a pair of transmitters and receivers.

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Many designs suggested, need to be evaluated in real world at public sites, taking into consideration traffic pattern, user density, hidden nodes interference, etc. Mostly uplink traffic from a node to AP is considered for adaptation. But real need is at AP where massive downlink traffic, which may constitute 80 % of the total traffic, is handled. These new algorithms need to combat the link impaired due to signal fading and collisions equally well. Lastly they have to be systematically compared based on performance metrics.

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