

An Adaptive On-demand Channel Estimation for Vehicular Ad Hoc Networks

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Abstract— Various vehicular communication technologies have been proposed to provide reliable and seamless wireless communications. Short-range vehicular communications can be established using IEEE 802.11p, and the range of these protocols can be extended using mobile multi-hop ad hoc networks. To provide consistent Quality of Service (QoS) with maximum achievable transmission rate, many algorithms assume that the Signal to Noise Ratio (SNR) of the receiver is known, or can be obtained by modifying protocols. In this paper, we present an efficient on-demand adaptive channel estimation technique. Using simple UDP messages without changing protocols, the estimator predicts the SNR with minimum signaling overheads. Extensive experiments in vehicular environments along the I-85 highway and residential areas in Atlanta, Georgia reinforce that the proposed algorithm is efficient and reliable channel estimation technique for next generation wireless mobile networks.

Index Terms— Channel Estimation, SNR, VANETs

I. INTRODUCTION

Third generation networks support wide coverage, seamless mobility, and quality of service for mobile users. However, these connection-oriented networks require expensive infrastructure for deployment, and they are effective mostly in voice traffic applications. To meet demands of high data rate users, many companies have provided wireless local area networks (WLAN) that theoretically give up to 54 Mbps. Users in the future are expected to use both types of networks, one for wide coverage and reliable seamless connection, and the other for high data rate with low cost.

Recently, the IEEE 802.11n that uses multiple-input multiple-output (MIMO) to provide data rates from 74 Mbps to 248 Mbps has been approved. Short-range vehicular communications can be established using the IEEE 802.11p [1], specifically Wireless Access in Vehicular Environments (WAVE) for the Dedicated Short Range Communications (DSRC). The technology is efficient to exchange data between vehicles or vehicles to road side in the licensed 5.9 GHz band. Since the range of these protocols can be extended using mobile multi-hop ad hoc networks, it is important to adapt the physical and MAC layer properties to complete data transaction in very

short time for high-speed vehicle communications. In addition, to provide Quality of Service (QoS) with high data transmission rates, such as real time multimedia streaming services, wireless systems should work well in typical wireless environments, characterized by the path loss of the signals, multipath fading, interference to adjacent channels, and random errors.

A link adaptation strategies [2] [3] is studied to select the optimal combinations of the 802.11a PHY mode and the fragment size to achieve the best throughput performance for different SNR conditions using Received Signal Strength (RSS). These approaches have a detailed analysis of Distributed Coordination Function (DCF) with fragmentation and shows how the fragmentation affects throughput with different physical modes and SNR. The Receiver-Based Auto Rate (RBAR) [4] uses the samples of RSS from RTS frames to estimate the channel quality. All these estimation methods in [2, 3] and [4] assume that the RSS has a linear relationship with the SNR of the receiver. However, this assumption is not valid when the AP supports multiple rates for downlink channels. Since mobile nodes may have different network cards, the transmission power of each user may be different. Therefore, SNR estimation with RSS for each station is different, and the AP is not able to select proper rates individually for the stations. Furthermore, in the presence of interference at the receivers, strong RSS at the AP does not guarantee better SNR, and each user may experience different profile of interferences.

In [5] [6], received SNR estimation is used for channel estimation. These approaches primarily use diverse fading and shadowing channel models to obtain channel conditions in mathematical formula. In Opportunistic Auto Rate (OAR) [5], time-varying SNR model for transmission power is used to predict channel conditions with the consideration of a time-varying multi-path propagation model. Dynamic fragmentation protocol [6] combines a log-normal shadowing channel model and a long-term SNR model to obtain the SNR of the received signal. However, the overhead and the complexity of computation are problems to implement these algorithms in reality. Furthermore, these algorithms use a modified RTS/CTS exchange to feed back the channel conditions of the receiver, which requires modifications of the protocols.

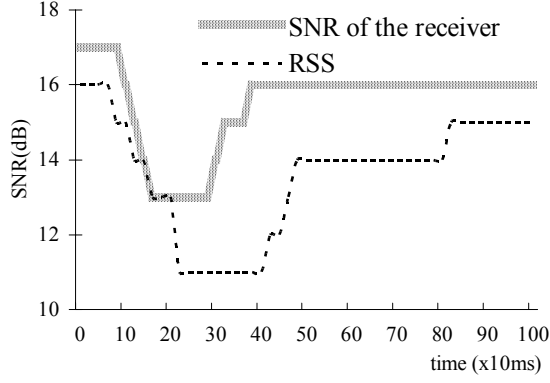


Fig. 1. Measurement of SNR and RSS with Tx power -10 dBm in a typical office environment.

Dynamic link adaptation algorithms in [7] [8] use success/fail thresholds to measure channel conditions. The number of successes/fails is counted by observing the acknowledgments of transmitted frames. If the number of consecutive successful transmission reaches beyond a certain threshold, the algorithm assumes that the channel quality is good and therefore senders transmit data at a higher rate. Otherwise the senders transmit data at a lower rate. Although this channel estimation scheme is simple and easy to implement, the method has inherent limitations for estimating channel conditions in time varying wireless channels. Especially, during the time interval between consecutive acknowledgments, channel estimation is not available, and the transmission rate cannot be determined. Moreover, the metric of channel condition measurement is not enough to determine how much the transmission rate should be increased or decreased. Therefore this algorithm is not proper to estimate the channels accurately.

In [9] [10], indicators to predict SNR and Packet Error Rate (PER) are illustrated. The indicators can be derived from channel transfer functions to estimate channel conditions. However, the channel transfer function of time varying channels is not generally known and the process of calculating the indicators is too complex to be used in reality with many assumptions.

In this paper, a new approach to estimate time varying

vehicular mobile channels is presented. The algorithm is designed to estimate the SNR of the receiver using UDP messages while reducing frequent message overheads between vehicles. The performance of the estimator is verified in residential and highway mobile environments in Atlanta, Georgia. The remainder of this paper is organized as follows. The design of the proposed estimator is presented in the following section. The measurements of SNR in a typical office environment are illustrated to show that RSS is different from the SNR of the receiver. Then we elaborate our experiments performed in vehicle-to-vehicle environments with the validation of the SNR estimator in residential and highway mobile channels. Finally, we conclude with discussion in the last section.

II. ON-DEMAND ADAPTIVE ESTIMATOR

Design of an adaptive real time estimator for ad hoc vehicular networks is a challenging problem. First of all, existing protocols should be used to avoid modifications of the protocols. In [5] and [6], modified RTS/CTS is used to exchange to feed back the channel conditions of the receiver, which requires modifications of the protocols. Secondly, the margin of the estimation error should be acceptable to perform desired networking tasks. Link adaptation strategies, [2] and [3] are studied to select the optimal combinations of the 802.11a PHY mode by using Received Signal Strength (RSS). Given that the uplink and downlink channels are not always symmetric even in the line of sight propagation path, the estimation by only using the observed received signal strength is not valid, even though no interferences or hidden terminals exist at the receiver. In Fig. 1, the difference between SNR of the receiver and the RSS at the sender can be observed for the same transmission power of -10 dBm with Line Of Sight (LOS) in a typical office environment. Total 50 packets of 1500 bytes MSDU are used to measure the SNR of the receiver and RSS at the sender for the same noise power (-95 dBm) using Mad-Wifi driver. Lastly, the overhead of the estimator needs to be minimal to avoid wasting bandwidth. Modified RTS/CTS in [5] and [6] is required to estimate the channel even if the channel is perfect without hidden terminals.

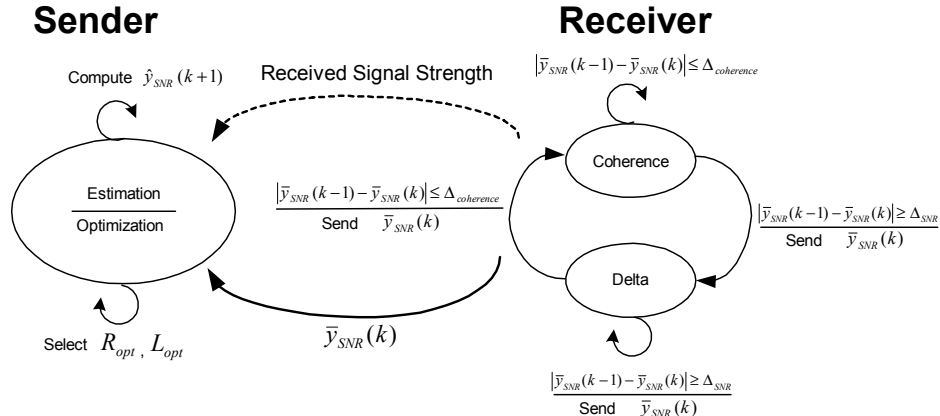


Fig. 2. State diagram of the on-demand adaptive estimator.

In our paper, a new approach that uses RSS on the top of the on-demand UDP message is designed. The main idea is that the received signal strength is not totally irrelevant to the SNR of the receiver. It provides a rough figure of the SNR in different time scale and amplitude in dB. Thus, the adaptation algorithm should be informed of the initial average SNR of the receiver so that it tracks the SNR while reflecting the variation of the RSS on it. In addition, by using on-demand UDP messages, modification of existing protocols can be avoided with minimum overhead.

In the estimator, the received signal strength from the receiver is defined as $y(k)$. Suppose any mobile stations can overhear $y(k)$ as long as they are in the communication range. If the average received signal strength up to $k-1$ th frame is denoted as $\bar{y}_{RSS}(k-1)$, and the SNR estimation of the $k+1$ th frame is defined as $\hat{y}_{SNR}(k+1)$. Since the sender can overhear the RSS of the receiver, exponential moving average of the RSS can be represented as $\alpha \bar{y}_{RSS}(k-1) + (1-\alpha)y(k)$. This exponential moving average of RSS is added to the current average SNR of the receiver with the parameter γ , which is to decide how much moving average of the RSS is added to the average SNR of the receiver in the estimation. Consequently, the estimation of the SNR can be represented as

$$\hat{y}_{SNR}(k+1) = (1-\gamma)\{\alpha \bar{y}_{RSS}(k-1) + (1-\alpha)y(k)\} + \gamma \bar{y}_{SNR}(k). \quad (1)$$

where $\bar{y}_{SNR}(k)$ is the average SNR of the receiver, and $0 \leq \alpha \leq 1$. Details of the estimation algorithm are illustrated using the state diagram in Fig. 2. The receiver informs the sender of $\bar{y}_{SNR}(k)$ using UDP messages in two events, i.e., when the difference between the averages of SNRs is greater than Δ_{SNR} (i.e., $|\bar{y}_{SNR}(k-1) - \bar{y}_{SNR}(k)| \geq \Delta_{SNR}$), or $\bar{y}_{SNR}(k)$ stays longer than the channel coherence time T_c [11], the time duration over which the channel impulse response is essentially invariant. That is

$$T_c = \sqrt{\frac{9}{16 \pi f_m^2}} = \frac{0.423}{f_m}. \quad (2)$$

where f_m is the maximum Doppler shift. T_c may vary with respect to the BER performance of the modulation schemes and maximum Doppler shift. How quickly the estimator tracks the SNR can be determined by choosing the parameters α , γ , Δ_{SNR} and $\Delta_{coherence}$ in the equation (1). As α increases, the estimator relies more on the past RSS samples than new sample, which results in smooth transition in the estimation. Similarly, when γ increases, the estimator depends more on the average SNR of the receiver than the exponential moving average of the RSS.

Typically, ad hoc vehicular networks in highways suffer from multipath fading with high Doppler shift, resulting in severe

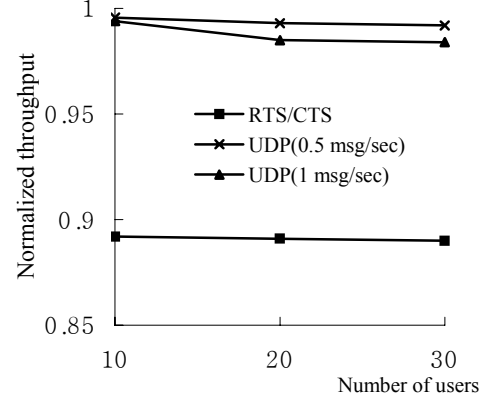


Fig. 3. Influence of overheads on throughput for On-demand adaptive estimator and RTS/CTS method.

SNR variation with Rayleigh fading. To prevent frequent UDP message exchange in such an environment, the parameters in the estimator need to be selected carefully. Note that it is the receiver that informs the average SNR to the sender with UDP message. Therefore, by increasing Δ_{SNR} and $\Delta_{coherence}$ values, the UDP overhead can be effectively reduced. In addition, sampling frequency and the number of samples used for averaging the SNR can be determined differently depending on the channel characteristics. For example, assume the receiver samples the SNR in every 20ms and averages 50 samples. If average SNR of the receiver is 20dB and Δ_{SNR} is 0.4dB, only when a new SNR sample is greater or equal to 40dB, the receiver transmits the UDP message for the estimator at sender. However, this 20dB difference in 20ms rarely happens in highway mobile environments, and we have found that the estimation overhead yields less than a two-byte message in a second in general. These UDP messages, nevertheless, can still influence the system throughput, and sacrifice bandwidth in the network.

In Fig. 3, the influence of the UDP messages on the system throughput of the IEEE 802.11b mobile users is described. The vehicles transmit UDP control messages to estimate the SNR of the receiver during the TCP data transmission with 1500 bytes MSDU for 4% of packet error rate in NS-2 simulator. Even in the worst situation of 30 vehicles transmitting one UDP messages per second in average respectively, the performance loss that the on-demand adaptive estimator introduces is less than 1.6 % compared to the normalized throughput of the basic operation. However, RTS/CTS based channel estimation incurs 11% of the throughput loss with the modifications of the protocols. Note that the proposed SNR estimation algorithm also can be incorporated with any link adaptation algorithms and optimal fragmentation technique [12], which provide substantial amount of performance benefit. Furthermore, the UDP packet is relatively very short compared to data packet, and therefore it has better chance to survive in hostile environments. If the UDP packet is lost, the sender simply maintains the previous SNR until next update is arrived



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Fig. 4. Interstate-85 North, Georgia, Exit 99 to 102 for the first passing scenario.

successfully. Further overhead reduction of the estimator can be made by adjusting parameters in equation (1), if a coarse estimation is more desirable by sacrificing the accuracy in certain circumstances. In most cases, the average of less than one UDP messages per second can be obtained in the vehicle-to-vehicle communication by using the proposed on-demand adaptive SNR estimator.

III. EXPERIMENTS

A. Configuration of the Experiments

To verify the performance of the estimator, real time estimation is executed in residential areas and I-85 North Exit 99 to 102 in Atlanta, Georgia. The network card is externally connected to the antenna, which is placed using magnetic base on the center of the roof in the car. To record exact location and speed of the vehicles during the experiment, GPS antenna with a pocket PC is installed in each vehicle. In the pocket PC, GPS2PDA is installed to download GPS data to store in the PC.

For the parameters of the estimator in Fig. 2, we performed heuristic approach to select the parameters based on our experiments and observation. α and γ values are set to 0.9 respectively. In this experiment, Δ_{SNR} is set to 0.2 dB and $\Delta_{coherence}$ is 0.1 dB. To reduce the UDP overhead, Δ_{SNR} and $\Delta_{coherence}$ can be further increased. The SNR and the RSS are sampled in every 10 ms, and the average of 50 samples are used to calculate $\bar{y}_{RSS}(k-1)$ and 20 samples for $\bar{y}_{SNR}(k)$ respectively. As mentioned earlier, the number of samples for averaging the SNR also can be increased to reduce the UDP overhead.

The channel coherence time T_c is set to 50 ms. If the relative speed of vehicles is 5 m/s, T_c is approximately 10.6 ms, which means that the channel impulse response is essentially invariant for the duration. Therefore, to reduce frequent UDP message overhead, only when the average SNR of the receiver stays within $\Delta_{coherence}$ for at least 5 times longer than the channel coherence time, the receiver transmits the UDP message to inform the sender of the stable channel status in this experiment. By reducing T_c , the receiver can update the SNR of the receiver

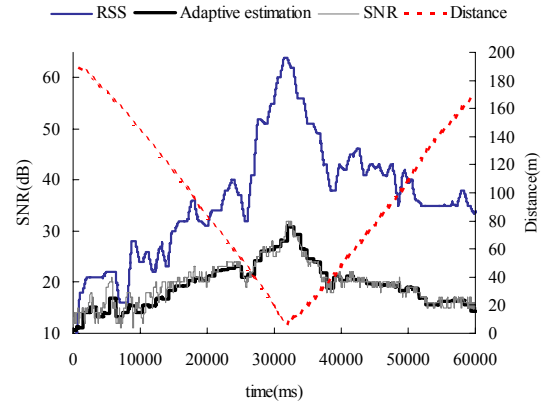


Fig. 5. Adaptive channel estimation for the passing scenario in Interstate-85 North, Georgia, Exit 99 to 102.

more frequently, if more precise estimation is desirable with the sacrifice of the bandwidth.

B. Passing Scenario

For the first passing scenario, the sender in the first lane passes the receiver in the last lane in Fig. 4. The initial distance between each vehicle is approximately 200 meters. The transmission power is set to the default power of 17 dBm. To measure the exact location and the speed of the vehicles, GPS receivers are equipped in each vehicle. The average speed of the receiver is approximately 58.4 mph while the sender passes the receiver with the average speed of 70.4 mph. The channel is saturated by 1500 byte MSDU in TCP connection, and the SNR is measured by pooling iwspy from the driver in every 10 ms. Proxim 802.11b cards with external antennas are used.

In Fig. 5, the estimation tracks quite precisely to the SNR of the receiver with only 46 UDP messages in 60 seconds, which is 0.76 messages per second. This is extremely low overhead taking into consideration of a typical passing scenario in highways with trucks, different curvature and elevation of the road. As explained earlier in Fig. 3, the IEEE 802.11 channel is shared medium and fully saturated by data traffic. No other mobile vehicles can transmit any data or UDP message at the same time when mobile stations capture the channel and transmit data or UDP message, if no hidden terminal exists. Therefore, the frequency of UDP message is more dependent on the behavior of the sender and receiver pair at the moment of transmission rather than the number of total mobile vehicles in the ad hoc networks. Thus, the UDP overhead is not directly proportional to the number of mobiles in the network. Note that the simulation in Fig. 3 has 30 users with 1 UDP message overhead between each pair of transmitters and receivers in the same channel. Normally, just a two bytes UDP message is enough to represent the SNR for 0.1 dB scale. The estimation error in this experiment is 0.373 dB for 6000 samples.

C. Crossing Scenario

For the second scenario, two vehicles cross each other in residential areas in Fig. 7. All the parameters in the estimator are



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Fig. 6. State street at Atlanta, GA for the second scenario, crossing vehicles in residential areas.

the same as the first passing scenario. The average speed of the vehicles is approximately 38 mph in opposite direction. Thus, there is 76 mph speed difference, and this will introduce severe Doppler frequency shift and SNR variation compared to the previous experiment. The estimation results are depicted in Fig. 8. The peak SNR of the channel reaches approximately 30 dB when the two vehicles are crossing each other, and it is roughly the same as the previous passing scenario. However, the time duration that may ensure reliable connection between the vehicles is much shorter than the previous passing scenario. For example, the time interval that the SNR exceeds 20 dB for the crossing scenario in residential areas is just 20% of the passing scenario in Interstate highways. Thus, crossing vehicle-to-vehicle communication in Interstate highways is much more susceptible to the link failure, and it produces challenging routing problems to be solved in a short time.

IV. CONCLUSIONS

In this paper, a novel on-demand adaptive estimator is developed and experimented to provide the SNR of the receiver in wireless vehicle-to-vehicle environments. The estimator has extremely low overheads of an average of less than one 2 bytes UDP messages per second in highway driving experiments. Additionally, the average estimation error is less than 0.373 dB per sample. The adjustable parameters of the estimator yield more flexible adaptability for tracking various wireless environments, such as WLANs, ad hoc networks, and vehicle-to-vehicle networks. Extensive experiments in vehicular environments at Atlanta, Georgia reinforce that the proposed algorithm is a practical technique with no modification of existing protocols and efficient and reliable channel estimation for next generation wireless mobile networks.

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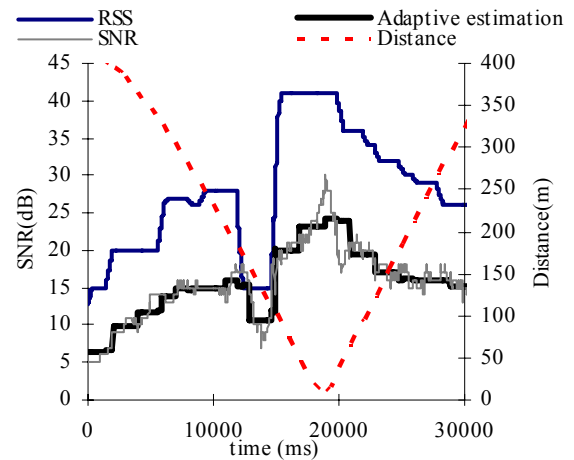


Fig. 7. Adaptive channel estimation for the crossing scenario in residential area, State st. NW, Atlanta, Georgia.

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