

Reliable Adaptive Modulation Using Long-Range Prediction at a Different Carrier Frequency¹

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Abstract – For fast vehicle speeds, reliable adaptive transmission requires prediction of future channel state information (CSI) since the channel conditions are rapidly time-variant. In this paper, we propose to use past channel observations of one carrier to predict future CSI and perform adaptive modulation for another correlated carrier. Statistical model of the prediction error that depends on the frequency and time correlation is developed and is used in the design of reliable adaptive modulation methods. Significant gains relative to non-adaptive techniques are demonstrated for sufficiently correlated channels and realistic prediction range. Both Jakes fading model and a novel realistic physical model of frequency selective fading are used to validate performance of the proposed method.

SUMMARY

Adaptive modulation (AM) methods provide higher bit rates than conventional signaling, but depend on accurate CSI at the transmitter [1-3]. Both in open-loop (e.g., time-division duplex) and in closed loop (using feedback) adaptation, current CSI is not sufficient since future channel conditions need to be known to adapt transmission parameters for rapidly varying mobile radio channels. To realize the potential of adaptive transmission methods, the channel variations have to be reliably predicted at least several milliseconds ahead.

Recently, a novel *adaptive long-range prediction* method was proposed [3]. The algorithm employs an autoregressive (AR) model to characterize the fading channel and computes the minimum mean-square-error (MMSE) estimate of a future fading coefficient based on a number of past observations. The advantage of this algorithm relative to conventional methods is due to its low sampling rate, which results in longer memory span and further prediction into the future for a fixed filter length.

In this paper and [5], we investigate the scenario where we observe a received uplink signal at the carrier frequency f^1 and attempt to predict a downlink signal at the carrier frequency f^2 without feedback from the mobile. Alternatively, a signal at frequency f^1 can be fed back and a signal at adjacent frequency f^2 is predicted without feedback. To accomplish this prediction, the predicted samples must be sufficiently correlated with the observations in both time and frequency. This technique can be applied in correlated uplink and downlink channels, in orthogonal frequency division multiplexing (OFDM) systems (where narrow correlated sub-channels are employed) or other wideband systems to reduce feedback and overhead requirements.

The complex fading coefficients $c(f^2, t)$ and $c(f^1, t)$ at two frequencies are modeled as correlated complex Gaussian random variable. The cross-correlation function is derived under the assumption that the excess delay is exponentially distributed as in [4] with given rms delay spread σ . The objective is to predict future values of $c(f^2, t)$ given the outdated observations of $c(f^1, t)$. If the channel statistics, such as the time and frequency domain correlation, are known, the optimum linear MMSE channel prediction can be employed. However, as the Doppler shifts vary, the model coefficients need to be updated continuously based on the observations. Since we are not able to observe the fading coefficients at frequency f^2 , we modify our approach as follows. We predict future channel coefficient $c(f^1, t)$ first as in [3] and then to use the frequency correlation function to select the transmitter

parameters at f^2 . The Least Mean Squares (LMS) adaptive tracking method can be used to update the model coefficients since the observations at frequency f^1 are available at the transmitter. It is demonstrated that this robust method achieves near-optimal performance, while maintaining the ability to adapt transmission parameters to the time-variant channel conditions.

Once the predicted coefficient $\hat{c}(f^1, n)$ is found, the AM parameters for transmitting at f^2 at time n are selected. We employ variable rate square quadrature amplitude modulation (M-QAM) [1] with $M=0, 2, 4, 16, 64$. Given fixed average Signal-to-Noise ratio (SNR) and a target bit error rate $BER_{ig}=10^{-3}$, we adjust the modulation level according to the predicted instantaneous channel gain $|\hat{l}(f^1, t)|$. The procedure for selecting thresholds is derived using the probability density function (pdf) of the accuracy factor [2] given by the ratio of the actual channel gain at f^2 and the predicted channel gain at f^1 . In addition to this fixed power method, variable power techniques were explored in [5].

We analyzed the average bits per symbol (BPS) of AM as a function of normalized frequency separation $\Delta f\sigma$ ($\Delta f=f^1-f^2$). It was determined that adaptive modulation is primarily beneficial when $\Delta f\sigma$ does not significantly exceed 0.1 (e.g. the frequency separation is 100kHz for typical outdoor channel rms delay $\sigma = 1\mu s$.) For example, for $\Delta f\sigma=0.1$, about 17dB is required to obtain 1 BPS for adaptive M-QAM as opposed to 24dB for non-adaptive transmission (2-QAM or Binary Phase Shift Keying (BPSK)). As the frequency separation increases, the BPS approaches that of non-adaptive transmission. Hence, *the frequency separation and the multipath delay (or the coherence bandwidth) are the factors that determine the performance of the proposed adaptive modulation method.*

To implement the proposed method in practice, the rms value σ needs to be tracked and updated. We investigated the bit rate as a function of the rate of variation and update of σ [6]. A novel realistic physical model was created to generate typical and challenging propagation conditions. It is shown that in most cases the rms variation is slow, and tracking of the rms value does not result in significant additional computational and feedback load.

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