Summary of Current Research

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With the tremendous growth of the internet, the demand for wireless multimedia data communications is rapidly increasing. The data rate and quality of service requirements for the multimedia applications are orders of magnitude higher than those currently available for voice communications. Considering the limited amount of available bandwidth, high rate and highly reliable communication requires large spectral efficiencies for future wireless systems. On the other hand, in order to maintain a reasonable battery life for wireless devices, the power consumption per unit of transferred data also needs to decrease, requiring higher power efficiencies. The challenge is dealing with the highly random channel conditions due to the multipath and multiple access interferences as well as additive thermal noise at the receiver. Moreover, wireless users expect to be able to use their wireless devices in high mobility environments, e.g., while driving in the highways or in high-speed trains, in which case the wireless channel will be also rapidly varying in time, a phenomenon often referred to as fading.

My broad research interests are in the areas of wireless communication systems and networks, information and coding theory, and multiuser communications. My current research is focused on designing high-rate low-power wireless communication systems for high-mobility scenarios. Below, I will briefly summarize my previous and current research work.

Multiple-Antenna Systems

Exploiting spatial diversity by using multiple antennas at the transmitter and receiver has been shown to provide significant gains in the capacity and performance of the wireless systems. However, depending on the amount of channel state information available at the receiver, the achievable rates and also code and constellation design criteria for multiple-antenna systems are different. My previous and current research at Rice on multiple-antenna systems covers both ends of the spectrum, i.e., complete channel state information at the receiver (coherent systems) and no channel state information at the receiver (non-coherent systems), as well as the intermediate case of partial channel state information at the receiver (partially coherent systems), as explained below.

- **Coherent Space-Time Codes**: In a slowly fading channel, where the fading coefficients remain approximately constant for many symbol intervals, the transmitter can send training signals that allow the receiver to accurately estimate the fading coefficients. Assuming perfect channel state information at the receiver, the design criteria for space-time codes are well known. Nevertheless, finding a systematic design technique for good space-time codes with reasonable decoding complexity is still a challenge. In a joint work with a colleague at Rice, we have proposed a concatenated space-time code structure, which uses a single-antenna multi-dimensional TCM or MTCM scheme as the outer code and an orthogonal transmit diversity scheme as the inner code, and achieves significant performance improvement over the existing space-time trellis codes with similar complexity.

- **Non-coherent Space-Time Codes and Constellations**: In fast fading scenarios, fading coefficients can change into new, almost independent values before being learned by the receiver through training signals. Even if the channel does not change very rapidly, for applications which require transmission of short control packets (such as RTS and CTS in IEEE 802.11), long training sequences have a large
overhead (in terms of the amount of time and power spent on them), and significantly reduce the efficiency of the system. The problem becomes even more acute if a large number of transmit antennas are used, in which case long training sequences are required to train all of the channels between transmit and receive antennas. A non-coherent system is more suitable for these scenarios. In my research at Rice, I have proposed a new design criterion for non-coherent space-time constellations based on the Kullback-Leibler (KL) distance between distributions. Based on the new criterion, I have designed and evaluated power-efficient non-coherent space-time constellations for high spectral efficiencies. The proposed constellations show significant performance improvement over existing non-coherent constellations with similar decoding complexity. I have also proposed a recursive construction method for designing low-complexity real single-antenna constellations.

- Partially Coherent Space-Time Codes and Constellations: In practice, even if the fading is not very fast and channel training is possible, due to the finite length of the training sequence there will always be some errors in the channel estimates. In order to maintain a given data rate, one would need shorter training sequences for more rapidly fading channels, resulting in even less reliable channel estimates. The problem becomes even more acute when low power concerns are also taken into account, prohibiting transmission of the training sequence at a higher power to improve the channel estimation quality. Therefore, the usual assumption of perfect channel information at the receiver in designing coherent codes and constellations is not exactly valid in practice. In my research, I have derived the design criterion for partially coherent space-time codes and constellation based on the KL distance between distributions. The proposed design criterion bridges the gap between the coherent and non-coherent systems, and reduces to the existing and proposed criteria for these two extreme cases. For a given amount of channel estimation error, the partially coherent constellations designed based on the proposed criterion show significant performance improvement over the existing coherent constellations.

Multiuser Communications

- CDMA Systems: Code-division multiple-access (CDMA) is the accepted technology for the next generation of cellular systems. Since, in CDMA systems, the signals of all of the users occupy the same bandwidth at the same time, the user capacity of the system is limited by the amount of multiple access interference (MAI) that can be tolerated by the receiver. Multiuser signal processing techniques can effectively combat the MAI. While the optimal multiuser detection has exponential computational complexity in the number of users, several attractive sub-optimal performance-complexity trade-offs can be achieved. As part of my previous research at Rice, I have developed a computationally efficient suboptimal receiver for CDMA systems in fast fading multipath environments based on the canonical representation of the signals and the channel. The proposed receiver uses the iterative Expectation Maximization algorithm, and its performance approaches the optimal receiver as the number of iterations increases.

- Multi-Carrier CDMA Systems: In the presence of frequency-selective fading due to multipath, the performance of wideband CDMA systems is not as promising as it is in the flat-fading scenarios. Application of maximal ratio combining (MRC) with RAKE receiver does not provide a satisfactory performance especially for heavily loaded systems or at high spectral efficiencies. Even more advanced techniques such as chip equalization and parallel interference cancellation fail to meet the high rate requirements of the future wireless systems. A multi-carrier CDMA system can combat multipath effects by providing narrow-band almost flat-fading channels at different sub-carriers, and also exploit the available frequency diversity by interleaving the spread signals across frequency bins. During my internships at Nokia Mobile Phones, I have developed efficient channel estimation and signal detection algorithms for multi-carrier CDMA systems. These algorithms especially take into account the effects of the transmit pulse-shaping filter and receive filter. I have also developed efficient receiver algorithms for multiple-input multiple-output (MIMO) MC-CDMA systems.