HIGH-RATE ULTRASONIC DATA COMMUNICATION THROUGH METALLIC BARRIERS USING MIMO-OFDM TECHNIQUES

By

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ABSTRACT

Although recent advances in wireless technologies have enabled high rate communication in the dynamic wireless air channel, these technologies are not effective at communication through metallic enclosures due to Faraday shielding. Existing solutions for wireless communications through metallic enclosures have achieved one way communication through metallic barriers at achievable data rates under 20 Mbps, which is relatively low compared to the rates achieved in the wireless air channel. The first portion of this thesis presents a low-rate ultrasonic through-wall communication system which allows for simultaneous two-way data transmission through metallic barriers. A frequency tracking algorithm is also presented which allows the system to adapt to changing channel conditions. Such a system could enable the wireless configuration of sensors and monitoring of data in hermetically sealed enclosures and other environments where conventional wireless techniques are ineffective. The next portion, and majority of this thesis investigates the use of methods to achieve higher data transmission rates using ultrasonic signalling techniques on frequency selective acoustic-electric channels. The nature of the acoustic-electric channel is discussed and compared to the characteristics of other communication media including the wireless air channel as well as wired channels, highlighting some similarities and notable differences. The use of rate maximization techniques such as bit-loading and power allocation in a multicarrier modulation signalling scheme are investigated. Orthogonal frequency division multiplexing (OFDM) is employed which achieves high spectral efficiency in frequency selective channels. Next, the use of multiple-input multiple-output (MIMO) techniques is explored as a method of further increasing the achievable data transmission rates in ultrasonic channels. Co-channel interference (crosstalk) is significant in the MIMO acoustic-electric channel and, without the use of crosstalk mitigation techniques, the aggregate theoretical capacity of multiple closely-spaced channels will produce marginal capacity performance increases or decreases compared with that of the single channel alone, depending on the average signal-to-noise (SNR) level.

Several crosstalk mitigation structures are then investigated including the zero forcing receiver, eigenmode transmission, and the minimum mean-square-error (MMSE) receiver, and their theoretical capacity performances are compared for specific multichannel configurations including a two channel system and seven channel system. With the use of crosstalk mitigation techniques, the aggregate multichannel capacity approximately scales with the number of channels used, with capacity performance exceeding 1 Gbps for the seven-channel configuration at high average SNR levels. Once the theoretical capacity performance results are obtained for multiple channels under various configurations, a similar investigation is conducted to see what rates are achievable using various rate maximization techniques such as bit-loading and power allocation. The throughput performances achieved by employing these rate maximization techniques are then compared with each other and to the multichannel theoretical capacity performances. Results are also presented which show the performance of each crosstalk mitigation technique to be effective under vary degrees of transducer misalignment. The results of this thesis suggest that using a slowly adaptive crosstalk mitigation structure having minimal complexity may be most appropriate in quasi-static MIMO acoustic-electric channel arrays. The MMSE receiver, which is implemented using the least mean square (LMS) algorithm in a decision directed mode, may be used while achieving similar data transmission rates to those achieved by more complex structures such as eigenmode transmission which require feedback.