論 文 の 内 容 の 要 旨

論文題目　A Physical-layer Approach for Realizing Real-time and Reliable Industrial Wireless Communications
（物理層に着目した産業用高信頼リアルタイム無線通信に関する研究）

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This thesis focuses on physical-layer approaches for realizing real-time and reliable industrial wireless communications. To achieve industrial wireless communications, wireless systems are required to operate in real-time and reliable performance. Conventionally, industrial control systems (ICS) has been implemented by wired systems. This incurs several disadvantages including high wiring and maintenance costs, restricted machine deployment, and low reachability. Realizing industrial wireless communications is still a challenging task in terms of real-time capability, reliability, security, and low power consumption. In particular, current wireless standards are limited to satisfy the real-time and reliability requirements due to their constraints in physical-layer designs, which are originally intended for traditional wireless applications. Therefore, this thesis aims to improve the real-time capability and the reliability via physical-layer approaches.

Specifically, this thesis aims to reduce physical-layer transmission overheads for improving the real-time capability while maintaining good reliability. For realizing real-time and reliable wireless communications, the system should simultaneously adopt multiple mechanisms including forward error correction, interference avoidance, single-hop topology, contention-free channel access, channel equalization, and diversity. However, the transmission overheads, which are usually required for achieving the channel equalization and the diversity, affects real-time capability. In particular, preamble transmission overhead is required to learn about wireless channels, which in turn is used in a channel equalization algorithm to eliminate negative effects of the channels. In addition, transmit diversity requires some levels of cooperation among multiple transmitters in order to realize constructive signal combination at a receiver. The cooperation also incurs the overhead to the system. Both preamble transmission and transmit cooperation are considered as a large overhead for short data payloads of ICS. Therefore, this thesis studies methods to (1) shorten the preamble transmission and (2) reduce the transmit cooperation.

(1) By exploiting the fast and frequent transmissions in ICS, we propose a subcarrier-selectable short preamble for channel estimation in an OFDM (orthogonal frequency division multiplexing) system. To shorten the preamble transmission in traditional wireless systems, the well-studied blind estimation and scattered-pilot schemes might be applied to estimate the channel by exploiting long payload transmission time. However, for the small payloads of ICS, a short preamble is necessary for acquiring channel information in a short amount of time. In this thesis, we introduce the subcarrier selectivity to the preamble design in such a way that the preamble can provide full sampling coverage of all subcarriers with only several preamble transmissions. By doing so, the channel correlation in both time and frequency domain can be utilized to obtain accurate channel estimation. The preamble shortening method performed at a transmitter as well as the preamble recovery method performed at a receiver are described accordingly. In addition, we introduce adaptability to the channel estimation algorithm for the proposed short preamble so that it conforms to both fast and frequency-selective channels. The proposed algorithm adopts the correlation of two preambles to determine the degree of channel variation in time, and select the operation for channel estimation of non-selected subcarriers. The proposed short preamble and the channel estimation algorithm are evaluated by computer simulation based on IEEE 802.11 OFDM specifications. Our simulation results verify that the proposed short preamble can improve the real-time capability of ICS in time and frequency correlated channels.

(2) To reduce the transmit cooperation while achieving good reliability, we propose symbol-level packet combining using RSSI (received signal strength indicator) to make naturally real-time concurrent transmission (CT) become reliable. CT is real-time cooperating scheme and thus promising for ICS. CT makes all transmitters transmit an identical signal at the same time without any other cooperation. However, compared to beamforming-based and orthogonal precoding schemes which require additional channel sounding or frequency and phase

synchronization, CT cannot guarantee the non-destructive combination of signals at a receiver and may cause reliability degradation in the reception. In CT, a fading-like beat problem occurs, because of the carrier frequency offsets among transmitters, and leads to a high packet error rate. The beat-induced fast fading causes extremely fast fluctuation of signal magnitude, which is even faster than that of the fast fading caused by mobility. To cope with the beat problem, we adopt receive diversity to perform symbol-level packet combining using RSSI. By this way, not only the low-latency characteristic of CT can be preserved, but the extremely fast fading can also be solved. Two important parameters including combining cycle period and RSSI averaging period are studied in CT environments. The proposed method is evaluated by simulation and experiments based on IEEE 802.15.4 and IEEE 802.11 DSSS standards. The results verify our analysis on the two parameters and the feasibility of the proposed method in both standards.

In summary, this thesis addresses the real-time capability and reliability aspects of industrial wireless communications via physical-layer approaches. The main contributions of this thesis include a novel design of short OFDM preambles utilizing not only frequency but also time correlated channels, and symbol-level packet combining using RSSI for reliable CT. Our studies verify that the proposed methods can potentially contribute to the improvement of the real-time capability and reliability in industrial wireless communications.