The objective of this thesis is to develop a framework of transmission timing-based modulation framework for improving energy efficiency, security, and information transfer capacity in embedded wireless networks with very thin energy budgets. The key idea is to modulate both intra-PDU (Protocol Data Unit) and inter-PDU timing for addressing energy, security, and information transfer capacity in wireless embedded networks. As for energy efficiency, we developed a novel pulse position-coded PDU (PPCP) paradigm. The core idea is to encode a protocol data unit (PDU) in terms of the silence duration between two sets of delimiter pulses, whose positions are modulated based on the value of the PDU. This PPCP architecture achieves significant energy savings by using a lesser amount of bit/pulse transmissions, and by eliminating long multi-bit preambles and headers, which are normally used in traditional packets. The proposed multi-access pulse-based PDU scheme enables medium sharing among many sensor nodes without requiring per-PDU frame synchronization. As for security, we developed the concept of a novel chaotic pulse position coded protocol data unit (CPPCP) for secure embedded networking. The core idea of CPPCP is to encode a protocol data unit (PDU) with a wideband pulse train with chaotically-varied inter-pulse intervals. The architecture ensures communication security by introducing randomness between data symbols, noise-like frequency spectrum, and significant energy savings by using a smaller number of pulse transmissions compared to existing secure coding schemes such as Bluetooth Low Energy (BLE). Compared with the traditional key-based cryptographic techniques, CPPCP suppresses decipherable information by eliminating symbol periodicity. The mechanism can also be piggy-backed on traditional cryptography solutions to achieve higher levels of security. Finally, for enhancing the information transfer capacity, we developed a data packet position modulation (DPPM) paradigm. Packet transmissions in low duty cycle networks are often scheduled as TDMA slots, whose periodicity is determined based on application sampling requirements and the energy in-flow, often in the form of energy harvesting. The key idea of DPPM is to modulate the inter-packet spacing for coding additional information without incurring additional transmission energy expenditures. We first developed a have a DPPM based networking solution for single-hop transmit-only networks in which a number of low-energy nodes transmit data to an aggregator. The architecture is developed for a two-node point-to-point link, followed by a multipoint-to-point multi-access network. Detailed analytical and simulation models are developed to demonstrate the performance of a symmetric and an asymmetric version of DPPM.

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