A new Energy-efficient MAC Protocol with Noise-based Transmitted-Reference Modulation for Wireless Sensor Network

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Energy-constrained behavior of sensor nodes is one of the most important criteria for successful deployment of wireless sensor networks. The medium access control (MAC) protocol determines to a large extent the time a sensor node transceiver spends listening or transmitting, and hence the energy consumption of the overall node. Moreover, transmitted-reference (TR) modulation as the underlying physical layer provides new opportunities to be explored in the MAC layer. Considering these goals, a new energy-efficient MAC protocol with TR modulation using noise as a carrier for robust wideband links is proposed to be implemented on a single CMOS chip in the Wireless Ad-hoc Links using robust Noise-based Ultra-wideband Transmission (WALNUT) project.

TR modulation sends the reference signal with a known time or frequency offset along with the modulated signal. Therefore a receiver can restore original data by correlating received signal with a delayed version of itself since all multipath components will contain identically distorted pulses with consistent mutual delay. In addition, noise can be used as information carrier as TR modulation also sends the reference signal [1]. Furthermore, TR modulation not only allows the receiver to synchronize fast without any rake receiver or channel estimation, but also enables several transmitters to transmit simultaneously using different time or frequency offsets. However, TR modulation consumes more power to transmit individual bits since reference signal is also sent. This motivates the authors to design a new energy-efficient MAC protocol for this context.

Existing MAC protocols in literature can be classified roughly into three categories: reservation based, protocols with common active period, and asynchronous preamble sampling MAC protocols [2]. Among them the preamble sampling protocols have more energy saving capability with less network-wide management, hence suitable for asynchronous low data rate applications. In preamble sampling protocol, a sensor node sleeps most of the time and periodically wakes up only to sample the channel. The transmitter precedes the data packets with a preamble of maximum length equal to the receiver's sleep interval, and the receiver continues to listen if it detects the preamble in the channel during its wake up time.

The preamble sampling technique can be realized in three different ways as mentioned in [2], and references therein. Firstly, the transmitter can replace the long preamble by short packet bursts with destination address to allow the targeted receiver to wake up later to receive data, whereas a non-targeted receiver can go back to sleep after receiving a single burst. Alternatively the transmitter can send preamble-listen bursts to shorten its preamble length by an acknowledgement from the intended receiver if it wakes up. However, preamble length adaptation is not possible in this technique for future transmissions. Secondly, the transmitter can adapt its preamble length by remembering the receiver's wake up time for forthcoming communications. However,

these receiver-driven protocols are unfavorable for broadcast traffic where one transmitter has to wake up multiple times for its multiple neighbors. Finally, the sensor node can adapt its duty cycle based on requests from the neighborhood, traffic load, or topology information. Nevertheless these protocols are suitable only for application specific scenario, but not for all scenarios.

In this context a new energy-efficient protocol has been proposed that will combine the best characteristics from all three categories of preamble sampling protocols without actually sending any preamble. Primarily, data can be sent right away replacing the preamble utilizing the benefit of TR modulation that sends reference signal together with modulated signal. In addition, data may be transmitted multiple times to deal with uncertainty regarding receiver's wake up time. Moreover, short data-listen bursts can be used to minimize the number of repetitions for first-time communications. Furthermore, both transmitter and receiver can store each other's next periodic wake up time to reduce data-listen burst length for upcoming communications. Finally, multiple access can be realized using different time or frequency offsets, whereas traditional MAC protocols may need to adapt transmit times to deal with multiple transmitters accessing the channel simultaneously. The main contributions of this protocol are: transmission can be either transmitter-driven or receiver-driven, and duty cycle can be adapted based on either application requirement or available energy in nodes.

The use of both transmitter-driven and receiver-driven duty cycling gives some powerful tools to realize energy efficient multi-hop communications at the network level. For instance, the new protocol will be able to create a so-called ripple effect while broadcasting and still can maintain its energy efficiency. The transmitter can command its first hop neighbors to follow its lead and those can in turn inform their respective neighbors to follow them in order to broadcast more efficiently by saving energy and time. Furthermore, a system of green waves [3] can be created to deliver packets to their destinations with limited delay. Finally, energy harvesting will be incorporated to allow transmitters and receivers to adapt their duty cycle based on locally available energy.

In short, the goal of the WANUT project is to combine energy-efficient protocol operation with underlying robust noise-based radio link using low power ICs, thus implement an efficient communication system all together in a wireless sensor network environment.

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