

## **TR-MAC: An Energy-efficient MAC Protocol for Wireless Sensor Network**

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The medium access control (MAC) protocols play an important role in minimizing the overall energy consumption in a typical wireless sensor network (WSN). Using transmitted reference (TR) modulation in the underlying physical layer opens up new possibilities and challenges to be investigated in the upper MAC layer. Hence we propose a new energy-efficient MAC protocol, called TR-MAC, to exploit the benefits provided by the TR modulation in the physical layer while minimizing the drawbacks.

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. Furthermore, TR modulation enables several transmitters to transmit simultaneously using different time or frequency offsets and allows the receiver to synchronize fast without any rake receiver or channel estimation [1]. 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.

TR-MAC is a preamble sampling protocol that has three states to have better capability to adapt to the situation, namely (1) first time communication; (2) unsynchronized state; and (3) synchronized state. In first time communication stage, one pair of nodes discover each other, exchange the full MAC address, and establish a link identifier by agreeing upon the frequency offset to be used for future communications, thus proceed to the next unsynchronized state.

In unsynchronized state, the transmitter transmits a preamble combined with small data packet, then listens for a potential acknowledgement from the receiver, and continues this cycle until it receives an acknowledgement from the receiver. Thus the transmitter has the opportunity to shorten its preamble length from the maximum duration of two consecutive sampling intervals of the receiver, hence minimizing the energy at the transmitter. TR-MAC saves energy on receiving side by sleeping most of the time, only waking up to detect any activity in the channel to shorten its idle listening.

In synchronized state, the transmitter and receiver pair wakes up to communicate in the previously agreed time instance in a known frequency offset. Thus the transmitter can optimally minimize the data-listen cycle length to as minimum as possible. Consequently the nodes can communicate in a very energy-efficient manner in this state together with the opportunity of multiple access using multiple frequency offsets. If the transmitter wakes up at a future time mentioned by the receiver, then receiver-driven communication takes place. Alternatively, transmitter-driven communication is also possible for broadcasting or ripple effect. Depending on the available energy on the node, one node can request its pair to follow its wake up time and can also adapt their future duty cycles for communication. This phenomenon is referred as energy-driven communication.

However, at low data rates the energy consumption between a pair of nodes sometimes may be more than expected because of the potential clock drifts between the pair of nodes and the last time of communication. We also provide an optimization technique in the synchronized state for TR-MAC to minimize the effect of clock drift.

We modeled TR-MAC analytically together with two reference protocols X-MAC [2] and WiseMAC [3]. We compared the protocols for both unsynchronized and synchronized state and observed that TR-MAC with optimized check interval consumes less energy for various packet arrival rates for a system of a realistic number of nodes. TR-MAC periodic listening is not affected by overhearing transmission for other receivers, as in the case of WiseMAC. Furthermore, similar to X-MAC but contrary to WiseMAC, TR-MAC needs very little energy to receive a packet.

Transmitting a packet in TR-MAC is more costly than in X-MAC, especially due to the characteristics of TR modulation, but this can be compensated by choosing a shorter check interval. Also TR-MAC successfully mitigates the energy wastage by idle listening, overhearing, control packet overhead and collisions. Overall, TR-MAC is very promising for energy-efficient communications in noisy environments where only a limited amount of data is transmitted between a single pair of nodes.

TR-MAC enables both transmitter-driven and receiver-driven communication in the WSN, allows a pair of nodes to use individual frequency offsets for multiple access, and is capable of achieving fast synchronization in the receiver to reduce energy consumption. In short, TR-MAC is an energy-driven MAC layer communication protocol for asynchronous low data rate applications that enables nodes to adapt their duty cycle based on the available energy in the node.

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