Demo: WiChronos: Energy-Efficient Modulation for Long-Range,Large-Scale Wireless Networks

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Abstract

Power efficient wireless communication has become a bottleneck for long range and large scale deployments. We propose and prototype WiChronos, an energy efficient modulation technique for long range wireless communication in a large scale network. Using off-the-shelf (OTS) components, we demonstrate that WiChronos achieves an impressive 60% improvement in battery life compared to state-of-the-art LPWAN technologies at distances over 800 meters. We also show that more than 1000 WiChronos senders co-exist with less than 5% probability of collisions in low traffic conditions.

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1 Introduction

Wireless communication to enable real time data collection [1–3] and in-situ monitoring applications that utilize Low Power Wide Area Networks (LPWANs) share the following needs: 1) Long battery life, 2) Large communication range, 3) Scalability and co-existence, and 4) Low cost. It has been shown that existing LPWAN technologies such as LoRa [4], SigFox [5], NB-IoT [6] cannot satisfy all the above requirements [7–9]. Existing technologies do not leverage reduced latency and datarate requirements of monitoring and other Internet of Things applications, which typically have small payloads.

In this work we propose WiChronos, a modulation technique that encodes information in the time duration between two symbols referred to as anchor symbols. WiChronos achieves energy efficiency by minimizing the number of symbols transmitted for a payload. They are sent over an ultra narrowband (UNB) to enhance the range. The reduced time-on-air aids in system scalability.

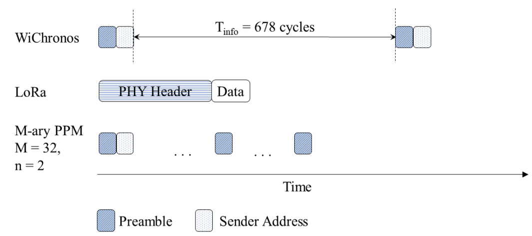

Figure 1. WiChronos illustration

This work is motivated by Pulse Position Modulation [10–17], a timing based modulation. Existing works on timing modulation do not consider the challenges in the practical implementation in wireless networks such as symbol design, energy consumption, range, collisions, and timing errors. To the best of our knowledge, WiChronos is the first attempt at implementing timing interval modulation in wireless networks using OTS components.

2 WiChronos: Interval Modulation

WiChronos stems from the insight that a modulation technique can be energy efficient if it reduces the number of symbols required per message without increasing the energy per symbol. Fig 1 illustrates WiChronos through an integer data of 678 obtained from a 10 bit sensor. A WiChronos transmitter sends a unique preamble, waits in sleep mode exactly for 678 clock cycles and then sends a unique postamble. The receiver, upon receiving the preamble (or postamble) starts (or stops) the counter operating at the same clock as the transmitter. In the absence of timing errors, this count is same as that of the transmitter, which is the data itself.

Anchor symbol design. Anchor symbols serve two purposes: indicate the start/stop of a message and uniquely identify a transmitter. Energy efficiency demands anchor symbols to be short but the rate of false positives increases as the length of anchor symbols decreases. Optimal length is the shortest that enables reliable decoding at the receiver.

Range - Energy Tradeoff. The communication range depends on the sensitivity of the receiver. The noise floor of a receiver operating in UNB is much lower, thereby allowing for longer distances. WiChronos is able to employ UNB transmitters despite their longer symbol duration without

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a significant increase in power due to the inherently small time-on-air. Moreover, the time-on-air and the energy is only a function of anchor symbols and does not depend on the payload size.

Medium access control. Longer time-on-air and/or increase in traffic will result in collisions at the receiver. WiChronos is less vulnerable to collisions because of its low time-on-air. Moreover, the channel is unoccupied once the preamble/postamble has been sent enabling multiple transmitters to send simultaneously without collisions. Therefore, WiChronos is able to leverage the simplicity of ALOHA without getting penalized by collisions.

Accuracy and data rate. Loss and/or bit error in anchor symbols, as well as timing errors in the hardware will reflect as bit errors in a WiChronos transceiver. We implement a state-ful receiver that tracks the last transmitted anchor symbol by each transmitter with a timestamp. Clock counts for each transmitter if it crosses a timeout, thus detecting anchor losses. Bit errors due to clock inaccuracies and processing time fluctuations are corrected using simple Forward Error Correction(FEC). Given the accuracy of the clock we use is 30ppm, there can be a 1 cycle difference between the transmitted and received values. Our FEC maps sensor data to timing information with a minimum difference of 3 cycles, thus correcting up to 1 cycle error. This principle can be extrapolated to any clock with prior knowledge of clock tolerance. Fluctuations in processing time, including radio wake-up time, can be corrected with prior knowledge on their upper bound. In our implementation, we verify experimentally these bounds and the accuracy of our FEC at the receiver for the worst case timing error.

3 Prototype Description

We implement WiChronos using the TI CC1125 radio module and TI MSP430FR2355 microcontroller (MCU). The radio employs 2-FSK at a center frequency of 915MHz. The MCU includes an external oscillator that provides a 32.678 kHz clock at an accuracy of 30ppm. This accuracy translates into an error of 1 clock cycle which is corrected by redundant data mapping as described in section 2. We use omni-directional general purpose whip antennas. TI CCStudio is used to program the MCU and to read register values from it. We have an alternate implementation using the Linx NT-915 radio module. While CC1125 requires the MCU to program and control it, Linx allows hardware programming which is easy to implement. However, Linx transmits integer multiples of bytes, the minimum being 1 byte. CC1125 allows a minimum of 4 bits with bit-wise increments to the anchor symbol. Theoretically a 10 bit anchor provides reasonable accuracy and reliability [18]. Because of hardware limitations, the Linx version uses a 2 byte anchor and CC1125 uses a 10 bit anchor. The minimum bandwidth on Linx is 100kHz whereas CC1125

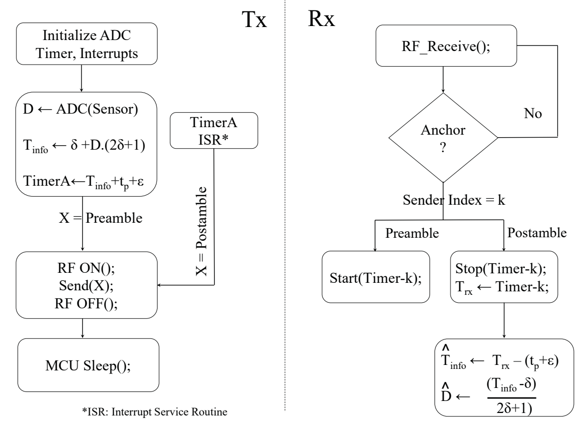

Figure 2. System implementation flow diagram

has the flexibility of reducing it to 19.2kHz which helps in attaining longer range. MSP430 is an ultra low power MCU with sleep current of 3 μA. CC1125 and Linx have a power down current of 100s of nA. Low sleep currents are key to the promise of low power operation by WiChronos.

Fig. 2 details our implementation. On reading analog data from the sensor, the transmitter converts it to a digital value (D), maps to clock cycles T_{info} to correct for timing errors and sets TimerA to T_{info}. The MCU triggers the radio to send the preamble and then goes to sleep. The MCU is in sleep mode with TimerA running in the background. After T_{info} cycles, TimerA interrupts the MCU to turn on the radio to send postamble. Unique preamble and postamble values are assigned to each transmitter during set up. The receiver is interrupted when an anchor symbol is received. Upon receiving the preamble (or postamble) the receiver starts (or stops) Timer-k. The receiver identifies the transmitter using a look-up table of the unique pre(and post)amble assigned.

We will present a functional prototype of WiChronos and demonstrate the low power, time-on-air capabilities. We will also desmonstrate the error correction capabilities that we described in section 2 for various distances of operation.

4 Conclusion

We propose and prototype WiChronos, a time based modulation technique that offloads some of the communication complexity on to counters/timers that are a simple and low power resource available readily in all MCUs. WiChronos reduces the time-on-air and improves the spectral efficiency which helps in achieving low power as well as scalibility.

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