A Measurement Study for ARQ-based Reliable Data Transmission for IEEE 802.15.4 Wireless Sensors on Fast Rotating Structures

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Extended Abstract

Wireless sensors capable of sensing, processing, and wireless communication have been adopted for monitoring purposes in a variety of contexts, many of which feature challenging radio propagation characteristics. Fast rotating structures are commonly found in mechanical and vehicular systems, and the challenges of using wireless sensors on such structures have not been adequately addressed. In a previous study [1], the authors examined the IEEE 802.15.4 sensor radio's communication errors with respect to rotation speeds and sensor locations on a fast rotating wireless sensor testbed. The study revealed an eminent dependency of packet error rates on rotation speeds, bursty bit errors, periodic variation in received signal strengths, and dominance of multipath effects in the testbed. To develop a reliable data transmission approach for such a rotating sensor system, this paper presents early results from a measurement study using a simple reliable transmission method based on automatic repeat request (ARQ). As a precursor to more complex reliable transmission strategies, the paper assesses the efficacy of the ARQ approach in terms of its transmission success rate, retransmission overheads, and reliable transmission throughput with respect to different packet sizes and packet generation intervals.

Rotating sensor testbed: The testbed was built with two wireless sensors mounted inside a computer controlled rotating lathe machine, with one base station placed outside the machine for issuing commands and retrieving data from the wireless sensors. The wireless sensors adopted were the IEEE 802.15.4 compatible MicaZ motes from Crossbow Inc. The machine was the Hardinge Talent 6/45 CNC lathe with a 60~6000 rpm speed-controllable rotating spindle enclosed in a metallic chamber. Figure 1 shows a photograph and a projected view along the spindle axis. The transmitter mote was tape-bound to the spindle surface, with its antenna perpendicular to the surface. The receiver mote was placed on the metallic side board (location 1) next to the spindle, aligned with the transmitter on the plane perpendicular to the spindle. The experiment control base station was composed of a MicaZ mote interfaced with a personal computer for data logging over an UART serial cable.

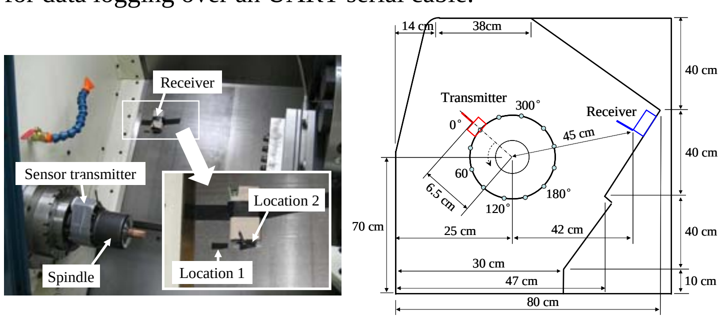

Figure 1. Rotating sensor testbed photograph and projected view from the right side [1].

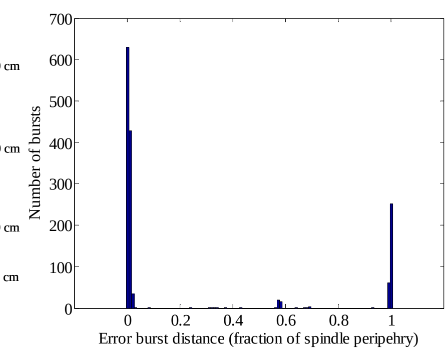

Figure 2. Error burst distance distribution at 2054 rpm.

Motivation: In [1], the bit errors were found to occur in bursts; for each packet, an error burst was defined as the minimum set of consecutive bits containing all error bits. An analysis of the inter-arrival times of error bursts suggested that the error occurrences closely coincided with certain location(s) around the spindle periphery. In [1], the normalized error burst distances was defined as

$$\text{Error burst distance} = \frac{\text{Error burst inter-arrival time} \mod \text{Rotation period}}{\text{Rotation period}}.$$

Figure 2 shows the error burst distances observed during 2054 round-per-minute (rpm) rotations. As seen, the error burst distances concentrated on a few localized ranges, suggesting a close correlation of the error-prone locations around the periphery. In the experiment, 13473 packets were transmitted at constant 15 msec intervals; out of them 1457 packets were received with bit errors, and the packet error rate (PER) was 11.8% (including lost packets and packets with errors). Similar patterns were observed for other rotation speeds as well. The finding suggested that at a certain rotation speed, a set of “error-prone regions” could be identified, and among them would be interleaving “low-error” regions. A reliable transmission scheme must identify these regions and control its transmission times accordingly. Prior to the development of an adaptive precision location tracking and transmission timing control method on the sensor devices, this paper studies a simple ARQ implementation and assesses its efficacy over the testbed.

ARQ implementation and experiment setup: With the IEEE 802.15.4 acknowledgement option enabled, a transmitting radio is notified of a failed transmission when an acknowledgement packet is missing. Upon each failed transmission, the ARQ function schedules an immediate retransmission, i.e., to retransmit the packet after the IEEE 802.15.4 random back-off interval. Without precise location tracking, a failed transmission could have begun and ended anywhere within an error-prone region, and its retransmission may not necessarily take place within a low-error region. The probability of a successful retransmission depends on the width of the error-prone and low-error regions with respect to the chosen packet size.

The ARQ experiments were conducted at 2054 rpm with the configuration shown in Figure 1 (transmitter at location 1). In each experiment, packets of a chosen packet size (30, 60, 92 bytes, 10 byte header size included) were generated at a chosen constant interval (0, 100, 150, and 250 msec). The radio transmit power was -25 dBm. The 0 msec interval experiment refers to a link saturating operation where the sender has an infinite backlog and sends a new packet for transmission whenever the previous packet has been transmitted/retransmitted successfully or the maximum retry limit (9) is reached. The throughput thus achieved is referred to as the *saturated reliable throughput*.

Results and conclusions: Table 1 summarizes the experiment results, including the first transmission error rate and the average retransmissions per error packet with respect to different packet sizes and packet generation intervals. With 0 msec intervals, the saturated reliable throughput was found to be 25.8, 50, and 67.9 kbps with 30, 60, and 92 byte packet sizes. The high error rate of the first transmissions and high success rate of the following retransmissions suggest that the retransmissions have most probably taken place in low-error regions. The transmission and retransmission success rates both increased as the packet size decreased. The received signal strength indication (RSSI) of each transmitted packet was also examined, revealing the RSSIs’ increasingly stronger correlation with the transmission success probability as the packet size decreased. The saturated reliable throughput is an upper bound for the feasible packet generation rate. The 100, 150, and 200 msec packet generation intervals were far below the limit and all have reliably delivered all generated packets. Additional experiments were conducted with higher transmit powers and higher rotation speeds and showed no clear correlation with the radio performance.

Table 1. Experiment results.

Packet generation interval = 0 msec				Packet generation interval = 100 msec		
Packet size	1st trans. error rate	Retrans. count mean /standard deviation		Packet size	1st trans. error rate	Retrans. count mean /standard deviation
30 bytes	0.098	1.026/0.159		30 bytes	0.067	1.000/0.000
60 bytes	0.137	1.253/0.435		60 bytes	0.136	1.000/0.000
92 bytes	0.151	1.191/0.424		92 bytes	0.171	1.140/0.365
Packet generation interval = 150 msec				Packet generation interval = 200 msec		
30 bytes	0.059	1.000/0.000		30 bytes	0.067	1.000/0.000
60 bytes	0.143	1.000/0.000		60 bytes	0.087	1.046/0.209
92 bytes	0.181	1.042/0.202		92 bytes	0.220	1.112/0.316

Future work: The study’s primary objective is to determine the achievable reliable throughput with a simple ARQ mechanism with respect to the choice of packet sizes and packet generation intervals. The study also serves to experimentally assess the region-dependent channel qualities and the feasibility of controlling the packet transmission times with respect to such regions. Further work involves analysis of the bit error patterns in time, RSSI variations, and rotation-aware transmission methods.

References:

1. K.-C. Wang, L. Tang, and Y. Huang. Wireless sensors on rotating structures: performance evaluation and radio link characterization. In Proceedings of the WinTECH Workshop at ACM MobiCom, 2007.