LEDcomm Protocol Data-Rate Optimization

Robert Koch Dr. Thomas Briggs

The LEDcomm Protocol

In personal technology and other embedded systems, low-cost and/or low-power designs present a significant advantage. ***LEDcomm*** is an extremely low-cost and low-power wireless communications technology which achieves its cost and power goals by using a single, software-controlled light-emitting diode to transmit and receive data[1]. As a result, LEDcomm can often be integrated into a low-power design, using an existing indicator LED as a transceiver, at **no material cost**[1].

The current LEDcomm specification imposes strict data-rate limits, similar in speed to the earliest available dial-up modems. However, the authors of the specification speculate that further research will improve the protocol's efficiency, making it more suitable for widespread adoption[1].

Talking LEDs

All diodes, including LEDs, are photosensitive: when light of the proper wavelength strikes the diode junction, a small current is generated in the reverse-bias direction. In an LED, this *photocurrent* is strongest for light from a similarly-colored LED[2]. In the presence of such a photocurrent, any charge accumulated in the diode junction will rapidly discharge to a 'logic-low' level. This effect is exploited by LEDcomm to use one LED for bidirectional communication[1].

Two LEDcomm devices take turns alternately transmitting or receiving a single bit at a time. To transmit data, the microcontroller pulses the LED – a short pulse to represent “zero”, or a long pulse for “one”. To receive data, the LED is reverse-biased. This causes a small amount of charge to accumulate, similarly to a capacitor. The microcontroller then enters a sensing state, where the discharge rate is measured to determine the presence and value of an incoming signal[1].

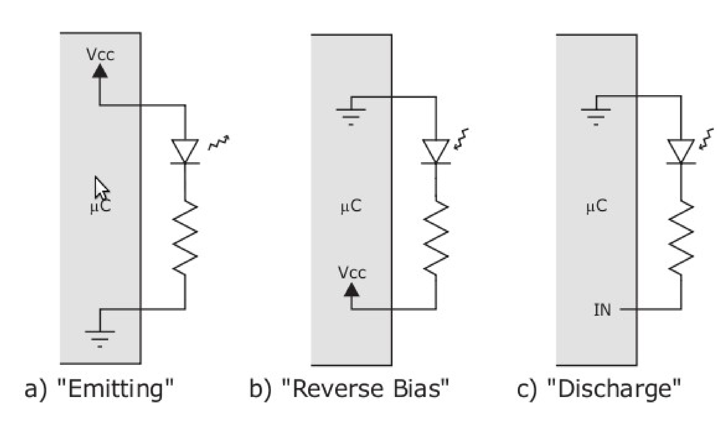


Diagram of LEDcomm LED states (image from (1))

To compensate for noise, the LEDcomm specification calls for a sampling duration of 100μs, and takes ten samples of the incoming light level in order to determine the value of a single incoming bit[1]. These parameters directly control the data transfer rate, however adjusting them to increase the data transfer rate may result in an unacceptable bit error rate.

Hypothesis

The data transfer rate of the LEDcomm specification may be improved by decreasing the sampling duration and decreasing the number of samples per bit. If these changes represent an improvement in the protocol's efficiency, then there will be no statistically significant increase in bit error rate accompanying this improvement in data transfer rate.

Experimental Design

The experiment consisted of multiple independent trials, in which a dataset was transmitted via the LEDcomm protocol from one custom LEDcomm transceiver to another.

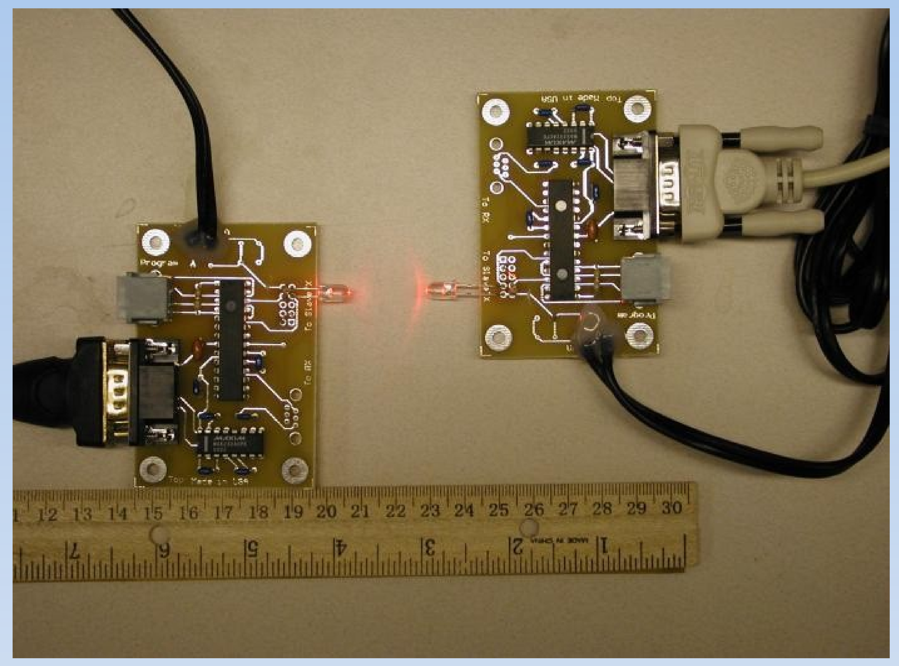
The transmitted dataset, light-sampling duration, and number of samples per received bit were varied between trials, and for each trial, the received data were compared to the transmitted dataset to determine the bit error rate.

References

[1] P. Dietz, W. Yerazunis, and D. Leigh. Very low-cost sensing and communication using bidirectional LEDs. *Mitsubishi Research Laboratories*, July, 2003.

[2] F. Mims. *LED Circuits and Projects.* Howard W. Sams and Co., Inc., New York, NY, 1973.

Implementation



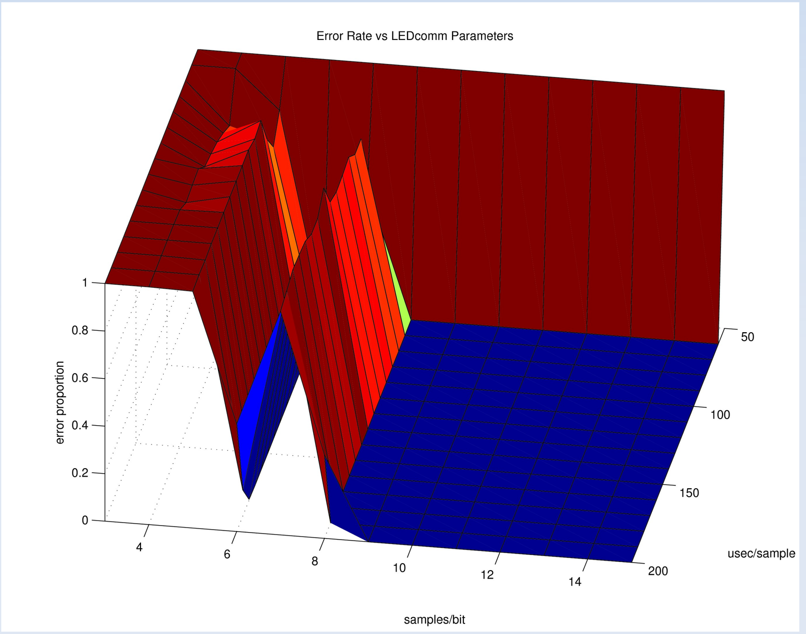
Example LEDcomm transceivers (Image from (1))

LEDcomm transceivers were implemented on Microchip PIC16F690 microcontrollers. A variety of LEDs were examined for use in the transceiver, with varying success. For data collection, the transceivers used inexpensive red gallium arsenide light emitting diodes with 'water-clear' epoxy lenses.

The LEDcomm protocol was implemented in C using the HITECH C compiler for 14-bit PIC MCUs. The protocol implementation was designed to accommodate changes to the sampling duration and number of samples per bit at runtime.

Results

The data gathered in this experiment appear to strongly support the research hypothesis: the protocol operated with a sampling duration of 80μs, at 6 samples per bit, with no discernible increase in bit error rate – approximately doubling the data transfer rate associated with the parameters described in the LEDcomm specification.



Research results gathered during the experiment. Note the trough at 6 samples per bit – logic/synchronization threshold levels have integer values at multiples of three samples/bit.

However, further decreasing either parameter led to a sudden increase from no discernible error rate to approximately 100% error, instead of the expected gradual increase. Consequently, these data are effectively qualitative, and are not suitable for statistical analysis.

Quantitative results are expected to be attainable by increasing the size of the sample dataset (by several orders of magnitude), and possibly by reproducing the experiment on a platform capable of finer-grained manipulation of the protocol parameters.

Limitations

Several limitations were encountered during the experiment, most notably the sensitivity of the LEDcomm protocol to several variables not controlled for in this research. The type of LED used appeared to be more important than discussed in the LEDcomm specification. This experiment did not study the effect of LED luminance, field-of-view, or relative positioning on error rate.

Ambient lighting also had an effect on the minimum sample duration – in low light conditions, a sample duration of 60μs was sustainable (at six samples per bit) with no discernible bit error rate.

Future Work

An obvious avenue of future research is to duplicate this experiment in such a way as to obtain quantitative results (as described in “Results” above). Other areas to explore are the range and positioning attainable at these speeds, and the effect of LED properties on the LEDcomm protocol.

Lastly, the existence of multicolor (RGB) LEDs opens the possibility of multichannel LEDcomm as an area of future development.