An LED-to-LED Visible Light Communication System with Software-Based Synchronization

Stefan Schmid[1,2], Giorgio Corbellini[2], Stefan Mangold[2], Thomas R. Gross[1]

[1]ETH Zurich, [2]Disney Research Zurich

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Disney Research

Motivation – Networking Toys

- **Requirements:**
  - Low bit rate communication
  - Short distances
  - Cost-effective
- **LED-to-LED communication:**
  - Fulfills requirements
  - Communication is visible
  - No radio waves
  - Reuses already existing components
  - Low-complexity

Outline

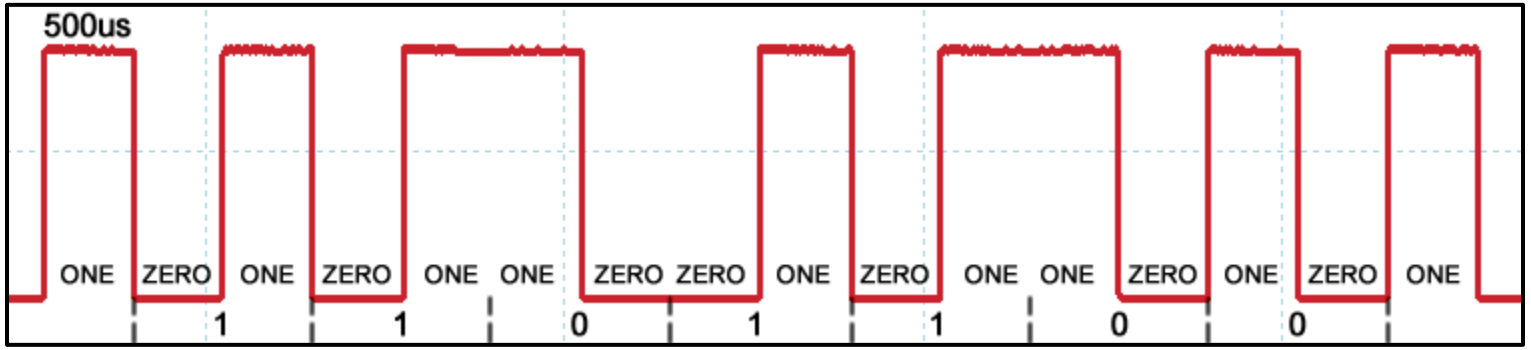
- Motivation
- **Technology**
  - LED as a Transmitter
  - LED as a Receiver
  - Synchronization
- **Implementation and Platform**
- **Evaluation**
- **Conclusions**

Transmitter

- **On-off keying**
  - LED on → symbol ONE
  - LED off → symbol ZERO
- **Requirements:**
  - No flickering
  - Constant brightness
- **Example: Encode 1 bit directly with a symbol**
  - 1-byte message: **1**000 000**1** → **ON** OFF OFF OFF OFF OFF OFF **ON**
  - Long OFF-sequence changes the perceived brightness
  - Even longer OFF-sequence introduces flickering

Manchester Coding

- 0 → 1 0 →ONE ZERO
- 1 → 0 1 → ZERO ONE
- Uniform distribution of ONE and ZERO symbols
- Redundancy



LEDs as Light Receivers

- **LEDs can be used as light receivers [Dietz et al, 2003]**
- **LED used as a receiver:**
  - Reduces complexity
  - Cost-effective
- **Limited light sensitivity**

But

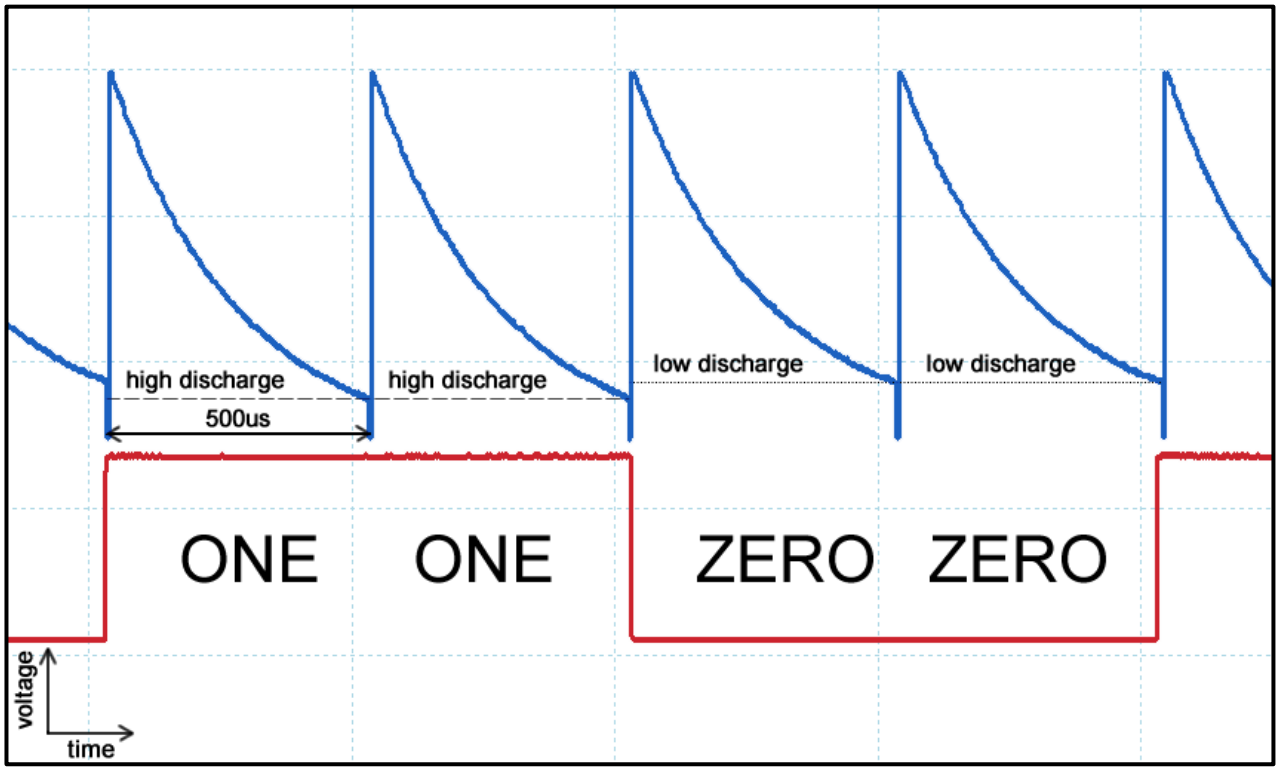
- Short range communication
- Low data rates

still possible

P. Dietz, W. Yerazunis, and D. Leigh, “Very low-cost sensing and communication using bidirectional LEDs,” in UbiComp 2003: Ubiquitous Computing. Springer, 2003, pp. 175–191.

Receiver

- LED is used in reverse bias → capacitor
- LED (cathode) is periodically charged
- Measure residual voltage after a certain time period

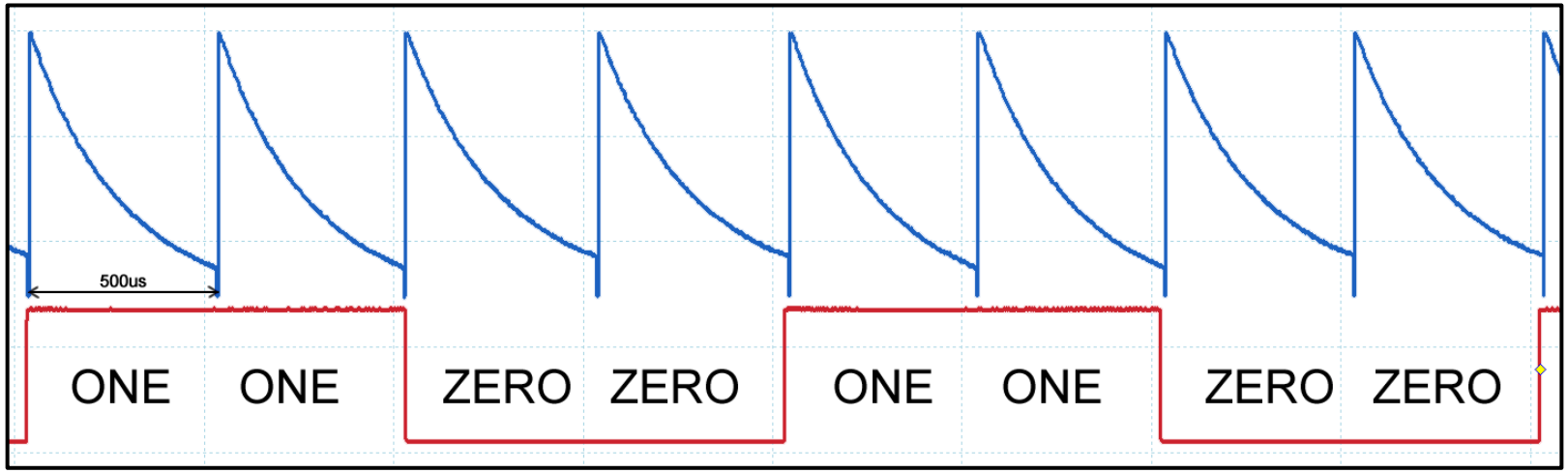


Threshold

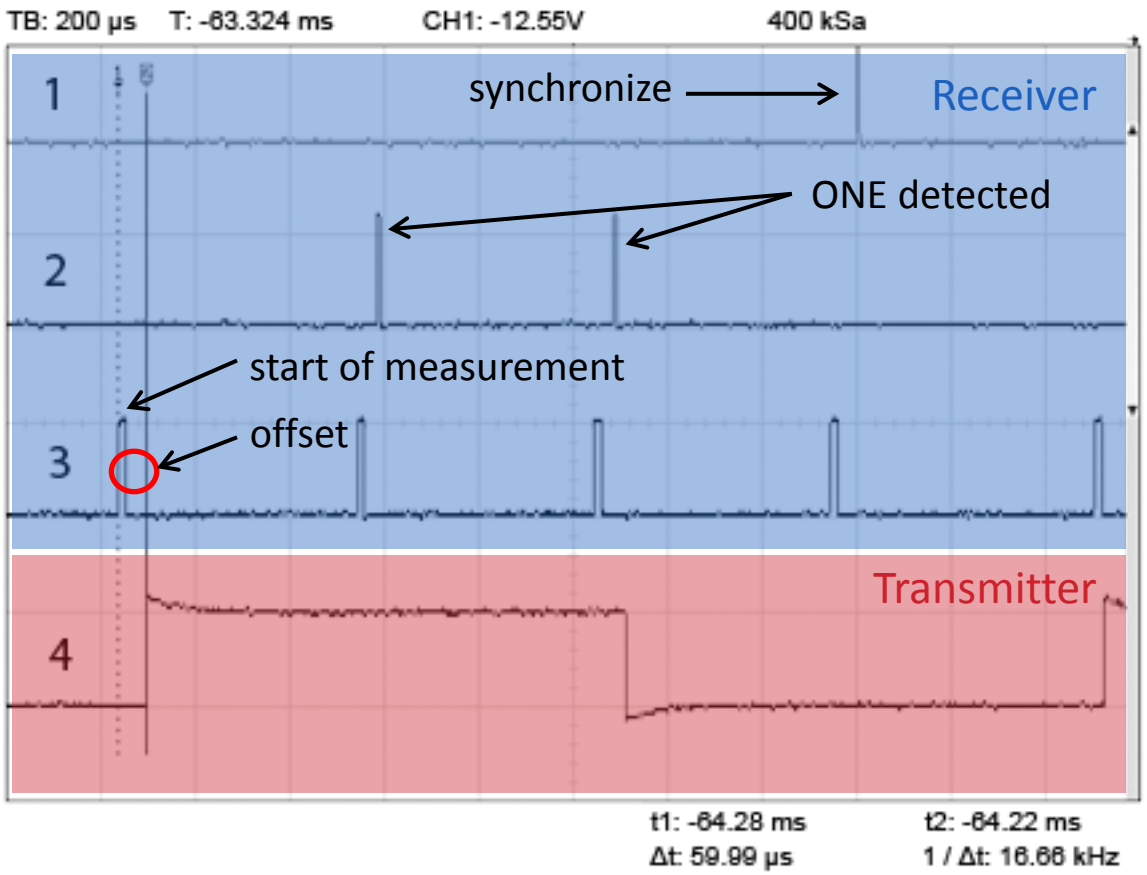
- **Receiver needs a threshold to decode the residual voltage level to a ZERO or ONE**
- **Requirements:**
  - Largest distance from both ZERO and ONE symbol
  - Adaptive to ambient light
- **Mean of recent measurements:**
  - Contains ZEROs (ambient light) and ONEs (LED generated light)
  - ZEROs and ONEs are uniformly distributed (Manchester)
  - Provides a good threshold if constantly updated

Synchronization (1)

- **Goal: Match the start of a transmitted symbol with the start of a measurement period**
- **Synchronization pattern: Pairs of ONE and ZERO symbols**
- **Shift until measured light for *ONE symbols* is equal**



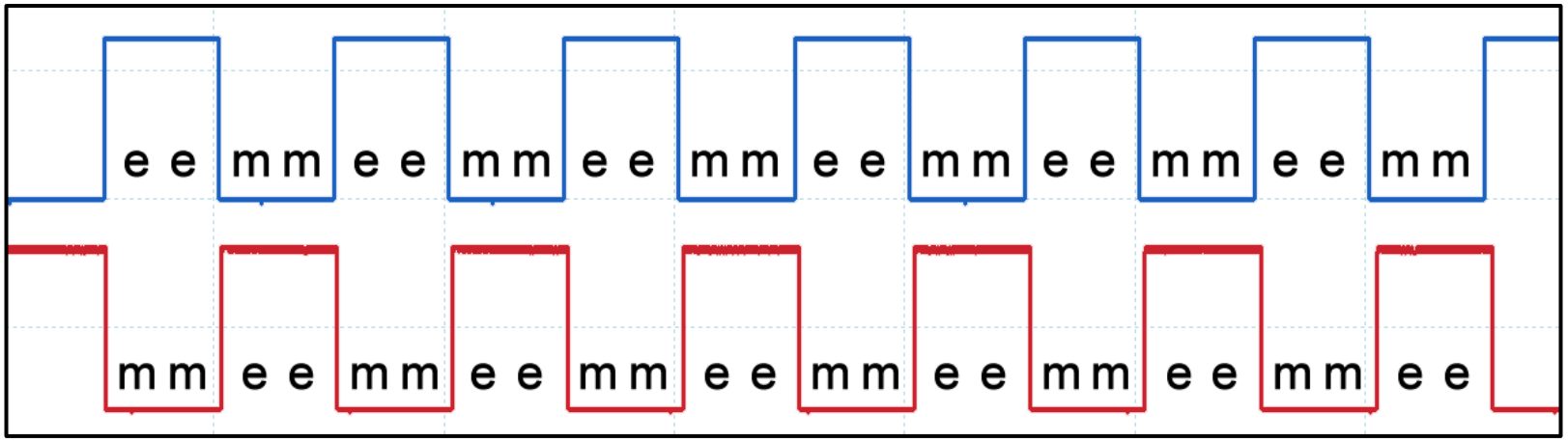
Synchronization (2)



Always «on»

- **Problem:**
  - LED appears as «off» in reception mode
  - Not possible to measure the photo-current while the LED is on
- **Solution:**
  - LED multiplexing → alternating measuring and light emitting slots
  - No change in transmitter, thanks to Manchester coding (redundancy)
  - LED perceived as «on» → 1 kHz signal

Challenges (1)

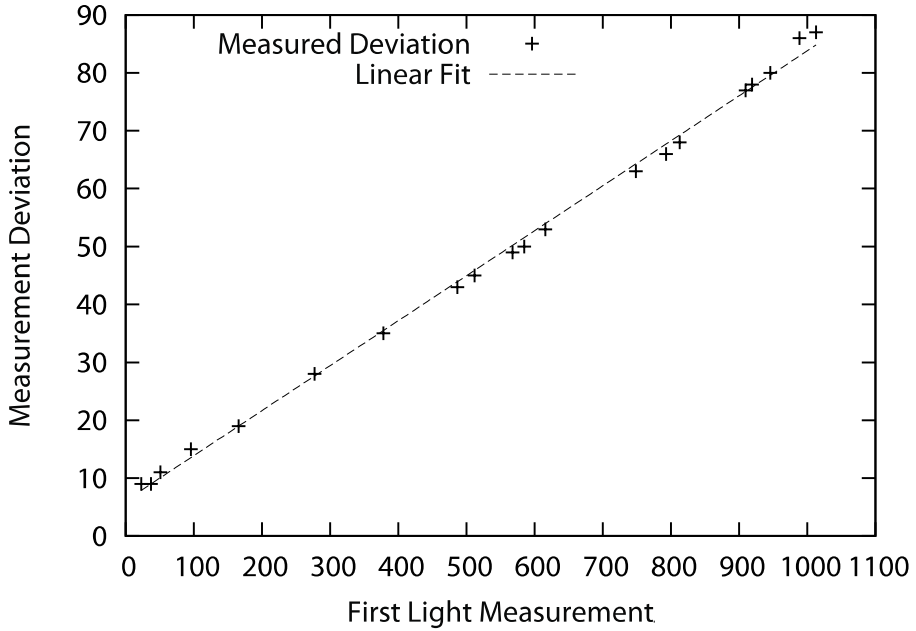


- **Receiver only measures light slots:**
  - Ambient light never measured
  - Computed threshold is equal to the symbol ONE
  - Decoder cannot detect all ONEs anymore
- **Halving the computed threshold provides a good approximation (ambient light value 0)**

Challenges (2)

Broken synchronization:

- Two consecutive measurements are different for the same amount of received light
- Different preconditions for measuring circuit (ADC)
- Measurement deviation depends on LED



Correction:

- Deviation is a linear function
- Correction computed from preceding measurement

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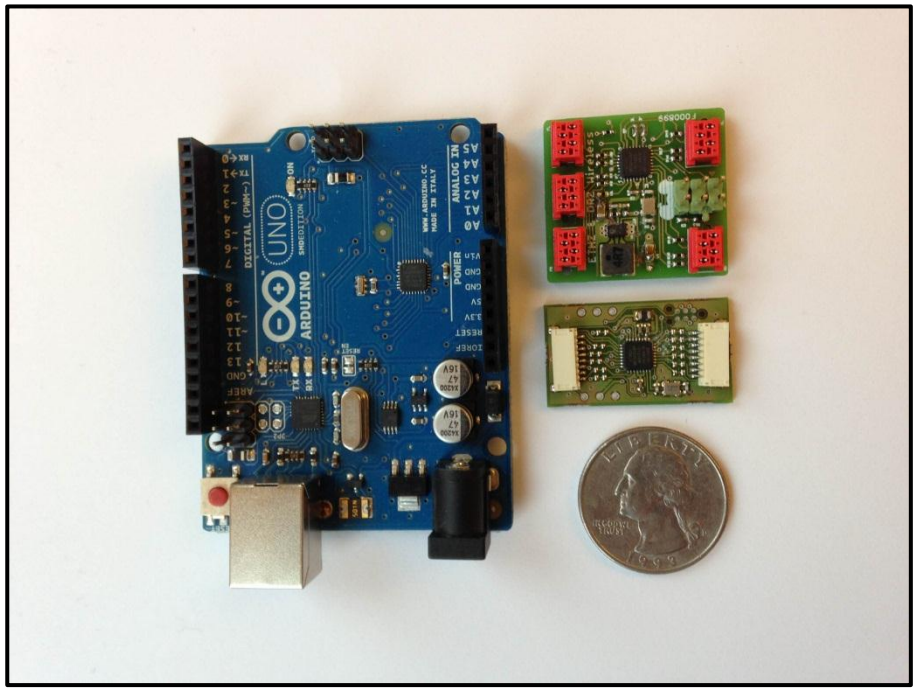
Hardware Platform

- **Various Arduino boards for prototyping**
- **ATmega 328P microcontroller**
  - 8 bit
  - 32K program storage
  - 2K RAM
  - 8 ADC pins (multiplexed)
- **In-house PCB solution**
  - Based on Arduino layout
  - Smaller form factor for toy integration

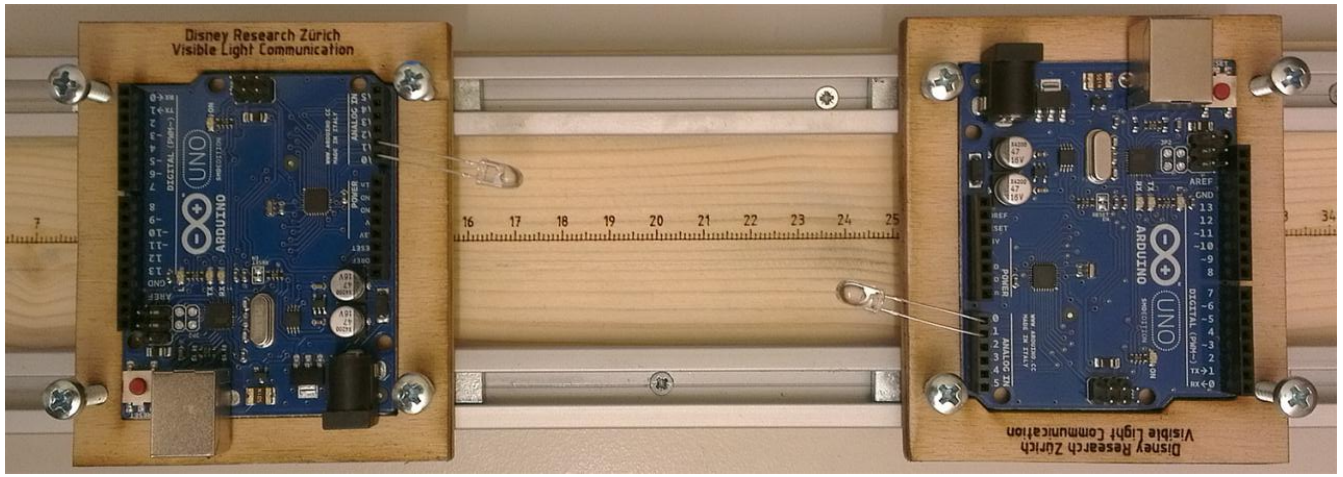


Implementation

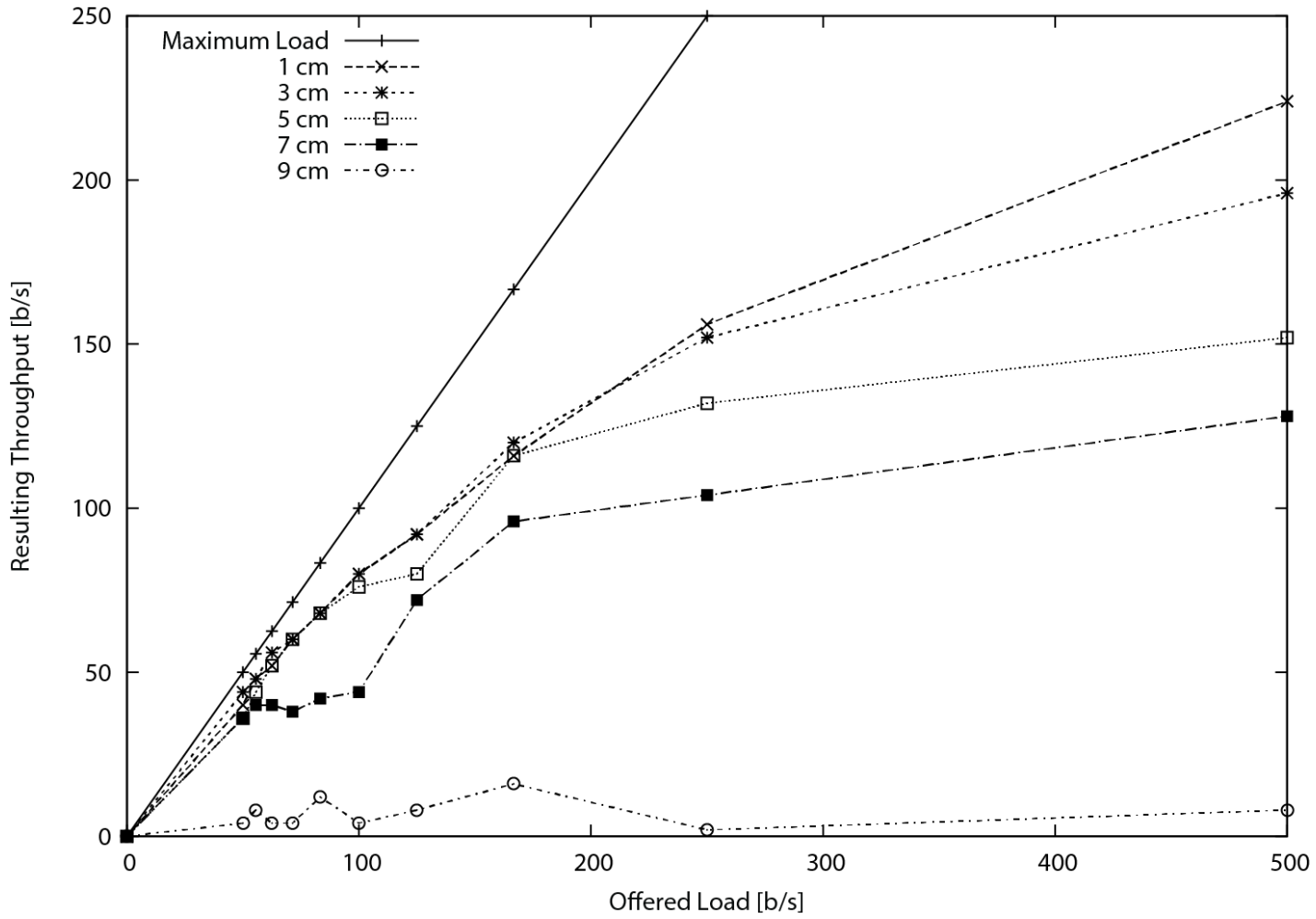
- **Flexible software implementation (C++, AVR-g++) of physical and MAC layer**
- **Hardware:**
  - ADC
  - Timers
- **Software:**
  - Synchronization
  - Encoding / Decoding
  - MAC
- **MAC**
  - Acknowledgments/ Retransmissions
  - CRC

Evaluation

- **Robustness for typical toy scenarios**
- **Data throughput for:**
  - Different (short) distances
  - Different data rates
- **Testbed setup:**



Evaluation Results



Conclusions

- **Short-range communication system for toys**
- **VLC based on only LEDs**
  - Low-cost
  - Low-complexity
- **Software driven physical/MAC layer**
- **Short distance communication**
- **100-200 b/s data rates**

Thank you!