Poster Abstract: Towards the Benchmarking of Ultra-Low Latency Communication Protocols for Wireless Sensor and Actuator Networks

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ABSTRACT

Novel protocols that can enable ultra-low latency communication in wireless multihop sensor and actuator networks have recently been presented in the literature. These approaches achieve ultra-low latencies in packet delivery notwithstanding the unreliability of the wireless channel. A systematic methodology to analyze and compare the performance of ultra-low latency communication protocols is however still missing. This work presents our first steps towards the definition of such a methodology. Building upon this work, we aim at designing and implementing a comprehensive benchmarking framework for ultra-low latency communication protocols.

Categories and Subject Descriptors

C.3 [**Special-purpose and Application-based Systems**]: Real-time and embedded systems; C.2.1 [**Network Architecture and Design**]: [Wireless communication]

Keywords

Packet Delivery Time; Wireless Sensor and Actuator Networks; Ultra-low Latency; Real-Time; Benchmarking

1. INTRODUCTION

Energy-efficient protocols able to deliver packets over a wireless multihop network within ultra-low delay bounds are being actively investigated in the wireless sensor and actuator networks research community [2, 5]. These protocols can be used to support a variety of critical applications like, e.g., automotive systems or industrial automation [1, 4]. Wireless multihop network of sensors, actuators and controllers (called *nodes* thereafter), can for instance be used to instrument a large manufacturing plant [4]. However, the inherent unreliability of wireless multihop communication hampers the possibility to provide for formal guarantees on delay bounds. Table 1 shows typical delay bound requirements for industrial automation applications [6].

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Our work aims at providing a comprehensive methodology to measure the performance of ultra-low latency communication protocols in simulators, testbeds, and real deployments. The obtained measurements can be used to compare protocols to each other and to parameterize statistical models that describe their performance. As a first step towards such the realization of such a benchmarking system we identify the parameters that influence the delivery time of a packet and quantify their influence on the overall delay. This allows to estimate the lower and upper delay bounds of packet delivery times.

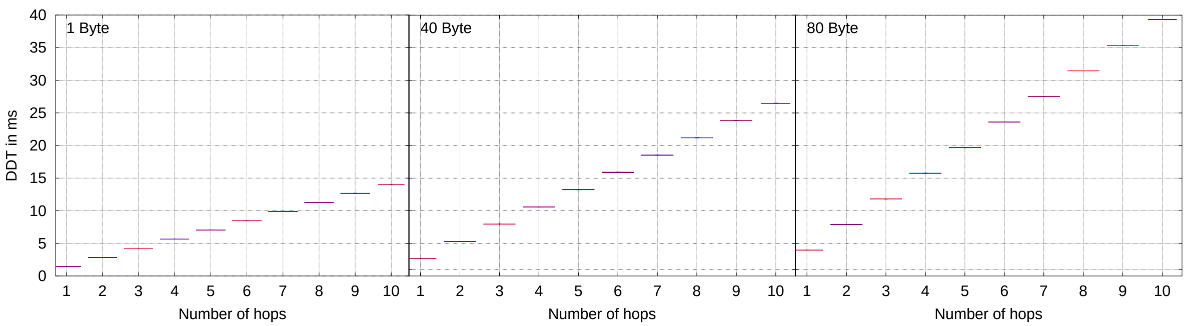
2. MEASUREMENT METHODOLOGY AND PRELIMINARY RESULTS

We define the *Packet Delivery Time* (PDT) Δt_{P_i} of a packet i as the difference between the time instant t_S at which the first bit of a packet is transmitted from the source and the time instant t_D at which the last bit of the packet is received at the destination. We divide the PDT in a deterministic part Δt_D and a non-deterministic part Δt_{ND}, such that $\Delta t_{P_i} = \Delta t_{D_i} + \Delta t_{ND_i}$. The *Deterministic Delivery Time* (DDT) Δt_D can be measured or calculated. Parameters that influence the DDT are, e.g., the number of hops in the path, the distance between the nodes, the packet size, or the actual data rate. The DDT determines the lower bound of the packet delivery time. The *Non-Deterministic Delivery Time* (NDDT) Δt_{ND} of the PDT can only be measured. Possible causes of variations of the NDDT are, e.g., radio duty cycling, the occurrence of interrupts or the specific traffic load. NDDT is used to estimate the lower upper bound of the packet delivery time. The unpredictability of the wireless channel and the random delays that accumulate at each hop make this bound hard to estimate.

For our preliminary experimental evaluation, we first focus on determining possible PDTs in IEEE 802.15.4-based networks. In particular, we prepare our simulation environment so as to eliminate the NDDT. This allows us to measure how the influence of specific parameters of the DDT on the PDT. We use Contiki's simulator COOJA [3] for our experiments. We set the communication channel to be interference-free and force the nodes to build a chain to avoid unpredictable routing behaviours. The node at the one end of the chain is set to be the source node and send packets to a destination node with a frequency of 1 packet/s. The destination node is the node at the other end of the chain. Intermediary nodes forward the received packets. We vary the number of nodes from 2 to 10 and test with packet sizes

Table 1: Typical requirements for factory and process automation applications [6].

Application area	Application	Max. delay	Update time	Packet loss rate[1]
Factory automation	Control of machine and production cell “local”	10..20 ms	20..30 ms	$<10^{-9}$
	Control in production hall “global”	20..30 ms	30..100 ms	$<10^{-9}$
	Monitoring and diagnostics	>100 ms	>500 ms	10^{-3} – 10^{-9}
	Mobile operators, safety	10..20 ms	10..30 ms	$<10^{-9}$
Process automation	Open-loop/closed-loop control	50..100 ms	100..5,000 ms	$<10^{-4}$
	Operation “local”	>100 ms	<1,000 ms	$<10^{-3}$
	Monitoring and diagnostics	>100 ms	>10,000 ms	$<10^{-4}$



(a) 1 byte payload. (b) 40 bytes payload. (c) 80 bytes payload.

Figure 1: Deterministic Delivery Time (DDT) for different payload sizes.

of 1, 40, and 80 bytes (to determine the total packet size, a header and footer overhead of 22 byte must be added). The processing delay of the packets is eliminated by measuring the DDT directly on the radio driver (CC2420). We set a start-up delay of 0μs to enable synchronisation between the nodes. Our measurements show a synchronisation variation of 30,52μs during one simulation (which 70s long). This value corresponds to the resolution of Contiki's RTIMER. The radio stays active to prevent unpredictable duty cycles.

Table 2: Relevant parameters of the experimental setup.

Parameter	Values
Number of hops in the path	[1..10]
Processing time	fixed
Interrupts	Not predictable
Packet size	1, 40, 80 Byte
Data rate	fixed
Packet loss	No

Table 2 summaries the experimental setup. Figure 1 shows an excerpt of the obtained results. In particular, the figure shows – for three different payload sizes – how the DDT varies as the number of nodes (and thus, hops) in the network increases.

3. CONCLUSIONS

This poster abstract presents our first steps towards the design and development of a benchmarking framework for ultra-low latency, multihop communication protocols for wireless sensor and actuator networks. In particular, we discuss the dependency of the packet delivery time from a number of parameters. Our future work includes the design of a more comprehensive test environment and the extension of our work to testbeds and real deployments.

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Towards the Benchmarking of Ultra-Low Latency Communication Protocols for Wireless Sensor and Actuator Networks

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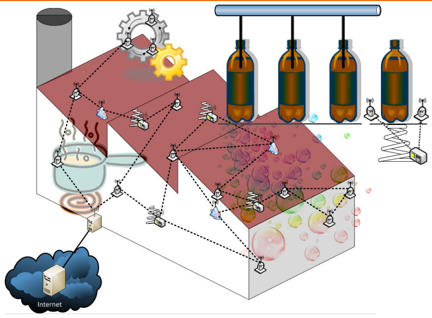
Motivation and Research Question



- Energy-efficient, multi-hop, ultra-low latency communication protocols for time-critical applications
  - E.g., factory automation, automotive systems, and intelligent traffic control
- Protocols to enable time critical communication in wireless single-hop [1, 2] or multi-hop [3, 4] networks exist

How to compare protocols performance?

Typical timing requirements for factory and process automation applications [5]

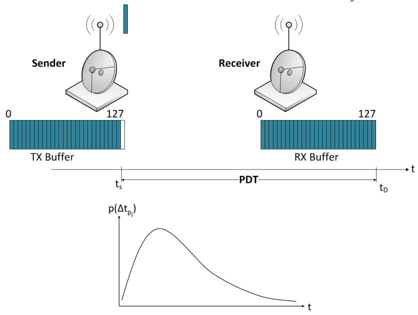
Application Area	Application	Max. transmission delay [ms]	Update time [ms]	Telegram loss rate or timeout
Factory automation	Control of machine and production cell "local"	10..20	20..30	$< 10^{-9}$
	Control in production hall "global"	20..30	30..100	$< 10^{-9}$
	Monitoring and diagnostics	> 100	> 500	$10^{-3} – 10^{-9}$
	Mobile operators, safety	10..20	10..30	$< 10^{-9}$
Process automation	Open-loop/Closed-loop control	50..100	100..5000	$< 10^{-4}$
	Operation "local"	> 100	< 1000	$< 10^{-3}$
	Monitoring and diagnostics	> 100	> 10000	$< 10^{-4}$

Methodology

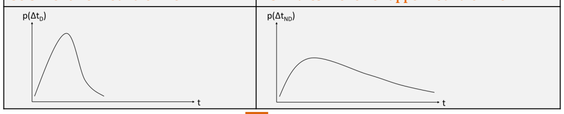
Benchmarking wireless multi-hop communication

- Identify parameters that influence the delivery time of a packet
- Quantify their influence on the overall delay
- Determine delay upper and lower bounds
- Eliminate parameters that cause high delay uncertainties

Packet Delivery Time (PDT) Δt_{P_i}:



Deterministic Delivery Time (DDT) Δt_D	Non-Deterministic Delivery Time (NDDT) Δt_{ND}
Number of hops (processing time)	Number of hops (interrupts, duty cycle)
Packet size	Traffic load in the network
Data rate	Routing
Distance between nodes	Software delays
Hardware specifications	
Sets the lower bound of the PDT	Estimates the lower upper bound of the PDT

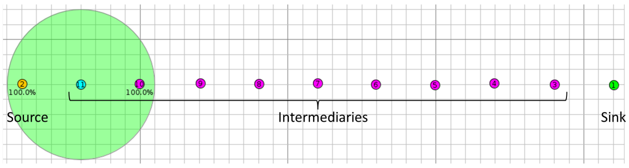


$$\Delta t_{P_i} = \Delta t_D + \Delta t_{ND}$$
$$\Delta t_{P_i} = f_{D_1}(\dots) + f_{D_2}(\dots) + \cdots + f_{D_n}(\dots) + f_{ND_1}(\dots) + f_{ND_2}(\dots) + \cdots + f_{ND_n}(\dots)$$

Preliminary Results

Focus on IEEE 802.15.4-based networks

- Measure DDT part of PDT
- Eliminate factors causing NDDT

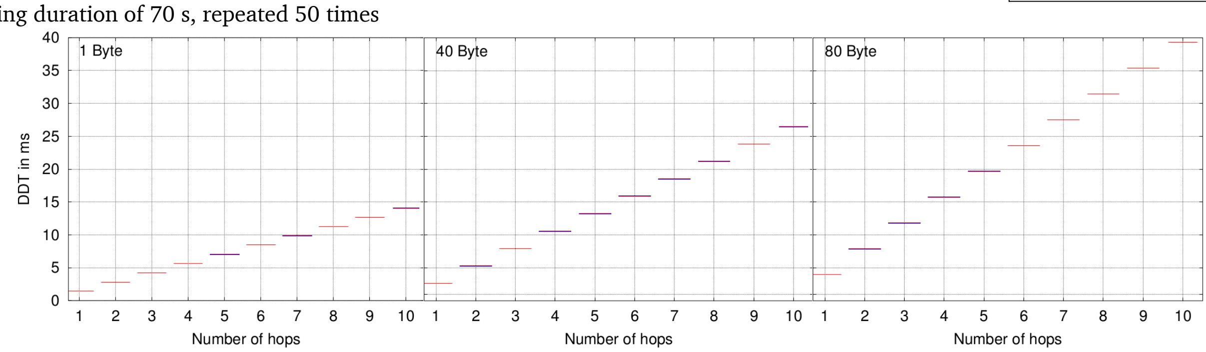


Setup

- Contiki / Cooja
- Interference-free communication channel
- Source node sends 1 packet/s to sink node
- Measuring directly on radio driver (CC2420)
- Synchronization variation of 30,52 μs between nodes
- Measuring duration of 70 s, repeated 50 times

Relevant parameters of the experimental setup

Parameters	Values
Number of hops in the path	[1..10]
Processing time	Fixed
Interrupts	Not predictable
Duty cycle	100%
Distance between nodes	40 m
Packet size (excl. 22 byte header and footer)	1, 40, 80 Byte
Data rate	Fixed
Packet loss	No
Number of source nodes	1
Route change	No



Future Work

- Conduct the experiments on real testbeds (e.g., TUDμNet)
- Quantify influence on delay of errors and number of retransmissions as well as number of communicating nodes
- Determine statistical properties of NDDT
- Long-term goal: provide framework to test and compare protocols

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