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KUMAR ET AL. (2020)

Presented by Alex Gavin

OUTLINE

- Background information and motivation
- Proposed solution and features
- Evaluation
- Questions

BACKGROUND INFO

WIRELESS SENSOR NETWORKS

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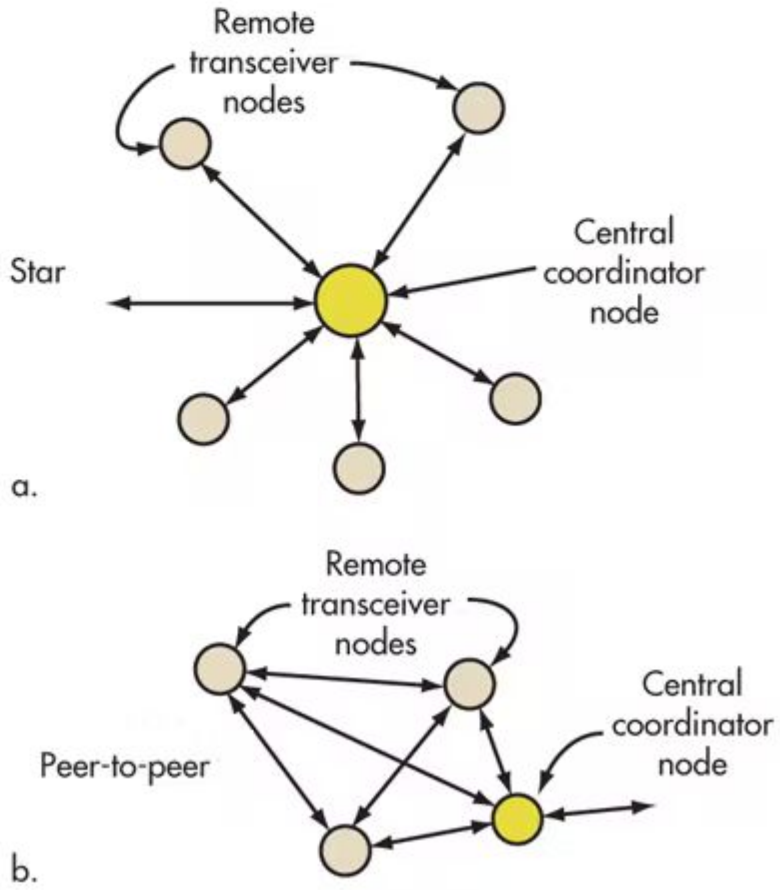
LOW-POWER AND LOSSY NETWORKS (LLNs)

IEEE 802.15.4 Network



SOMETIMES NEED RELIABLE COMMUNICATION

E.G. VOICE COMMANDS

SEVERAL EXISTING PROTOCOLS

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FEW ARE TCP-BASED

WHY NOT TCP?

DEEMED TOO HEAVYWEIGHT

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LLN TCP ISSUES

1. Memory usage non-deterministic
2. TCP headers take up half of IEEE 802.15.4 frames
3. Expected power usage poor

EXISTING TCP LACK STANDARD FEATURES

HENCE UDP-BASED PROTOCOLS

UNFORTUNATELY...

UDP-BASED HAS DRAWBACKS

SENSORS NOT FIRST-CLASS CITIZENS

APPLICATION SPECIFIC PROTOCOLS

REQUIRE DEDICATED BASESTATIONS

CUE TCPIp!

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WHAT MAKES IT UNIQUE?

FULLY COMPATIBLE TCP

INTEROPERABLE W/ OTHER DEVICES

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INCLUDES STANDARD TCP FEATURES

MUCH BETTER PERFORMANCE

HOW IS THIS ACCOMPLISHED?

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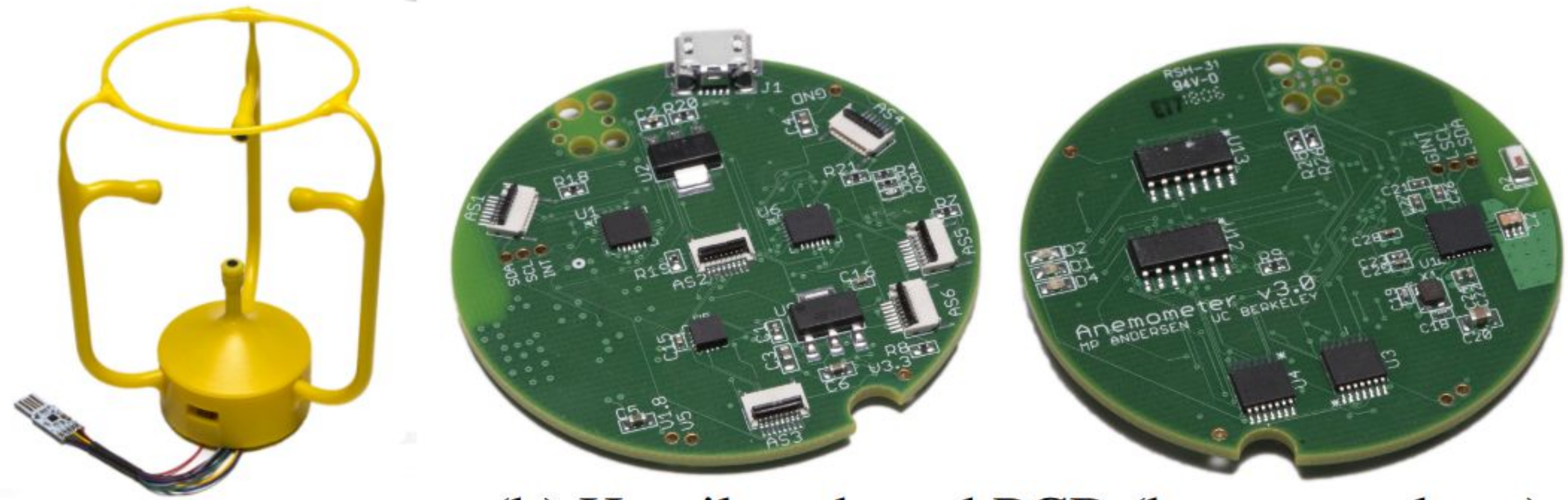
BUILT USING FREEBSD TCP-STACK

BUILT INTO TWO RTOSes

USES REPRESENTATIVE HARDWARE

USES REPRESENTATIVE HARDWARE



(a) Anemometer

(b) Hamilton-based PCB (bottom and top)

Figure 13: Hamilton-based ultrasonic anemometer

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HOWEVER...

LLN TCP INEFFICIENT W/O MODIFICATIONS

TCP-STACK MODIFICATIONS

LLN TCP ISSUES

1. Memory usage non-deterministic
2. TCP headers take up half of IEEE 802.15.4 frames
3. Expected power usage poor

1. MEMORY USAGE

TCP SEND/RECV BUFFERS

STANDARD: BUFFERS SHRINK/GROW

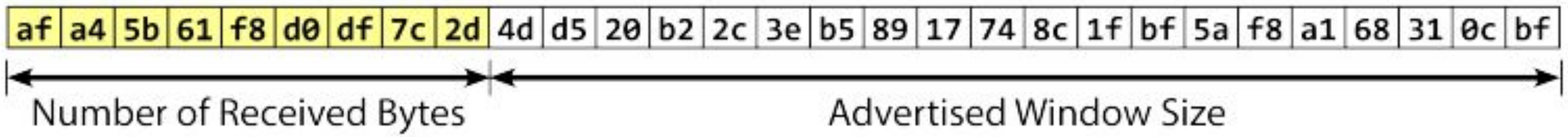
DANGEROUS FOR EMBEDDED DEVICES

TCPIp: SIZES DEFINED AT COMPILE TIME

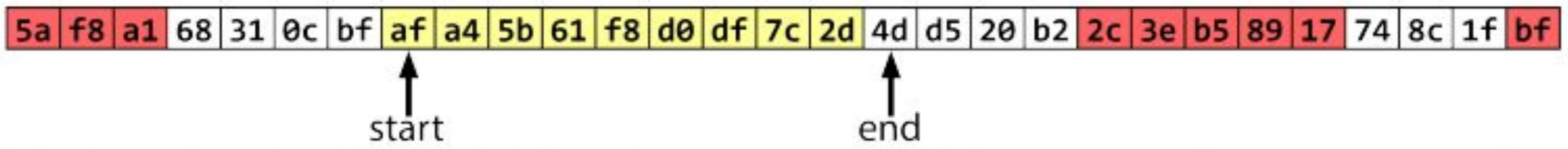
ZERO-COPY SEND BUFFER

IN-PLACE REASSEMBLY FOR RECEIVE BUFFER

IN-PLACE REASSEMBLY



(a) Naïve receive buffer. Note that size of advertised window + size of buffered data = size of receive buffer.



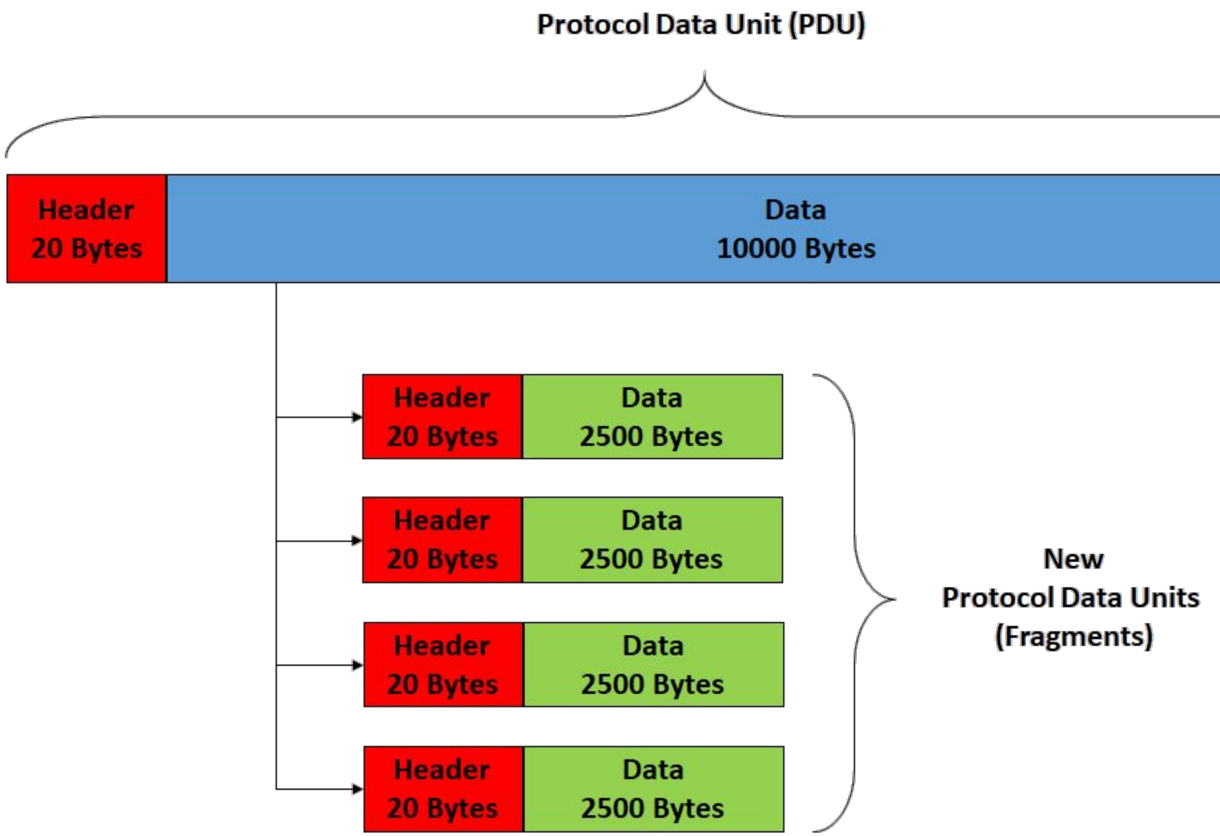
(b) Receive buffer with in-place reassembly queue. In-sequence data (yellow) is kept in a circular buffer, and out-of-order segments (red) are written in the space past the received data.

Figure 2: Naïve and final TCP receive buffers

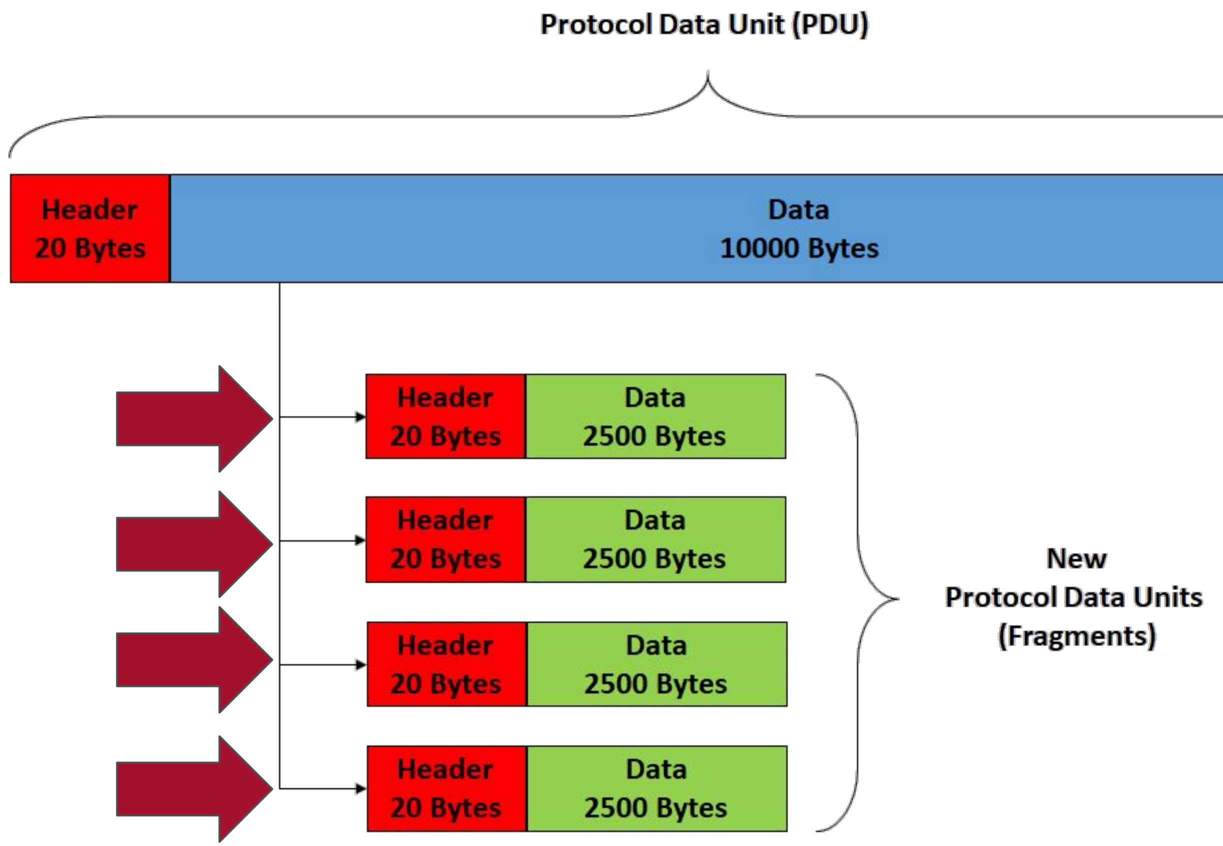
2. TCP HEADERS

STANDARD: TCP FRAGMENTS

TCP FRAGMENTATION



TCP FRAGMENTATION

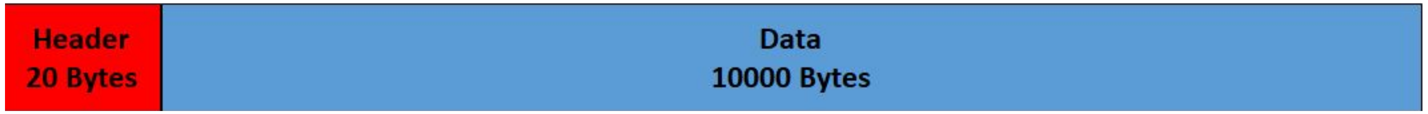


IN LLNs HALF EACH FRAME IS TCP HEADER

TCPIp: LOWER LAYER FRAGMENTS INSTEAD

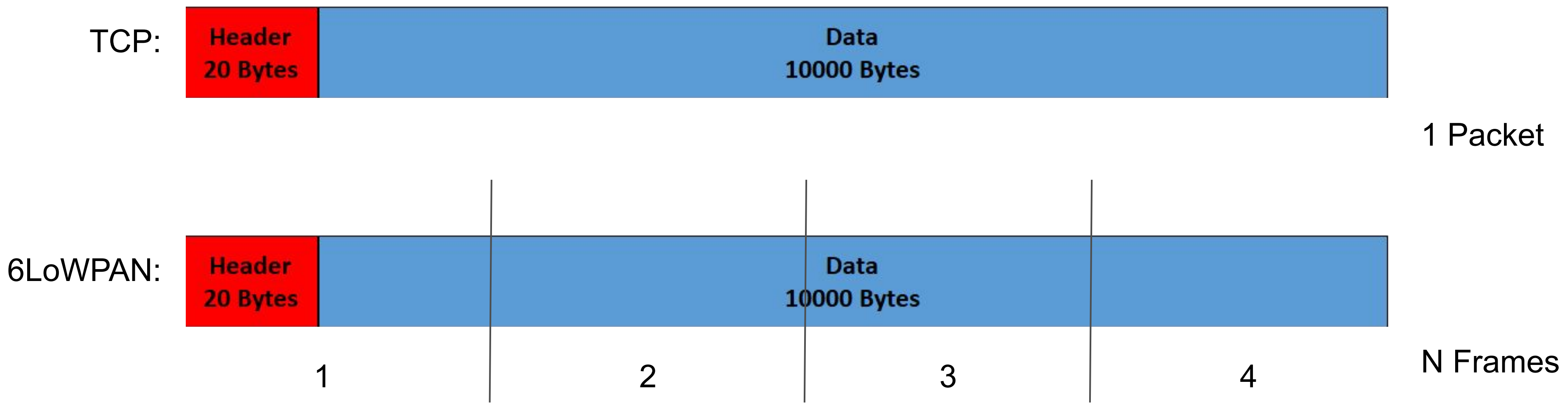
TCP FRAGMENTATION

TCP:



1 Packet

TCP FRAGMENTATION



ONLY ONE TCP HEADER

HEADER ONLY IN FIRST FRAME, REST DATA

DECREASES RELIABILITY, BUT GENERALLY NOT MUCH

3. POWER USAGE

LLN DEVICES DUTY CYCLE

STANDARD DUTY CYCLING INEFFICIENT W/ TCP

LEAF NODES POLL FOR DATA

NO DATA => SLEEP, RETRY

E.G. ESTABLISHING CONNECTION

WAIT FULL DUTY CYCLE INCREASES LATENCY

TCPIp: MODIFY TO MAKE EFFICIENT FOR TCP

ADAPTIVE DUTY CYCLE

TCPIp: KEY POINTS

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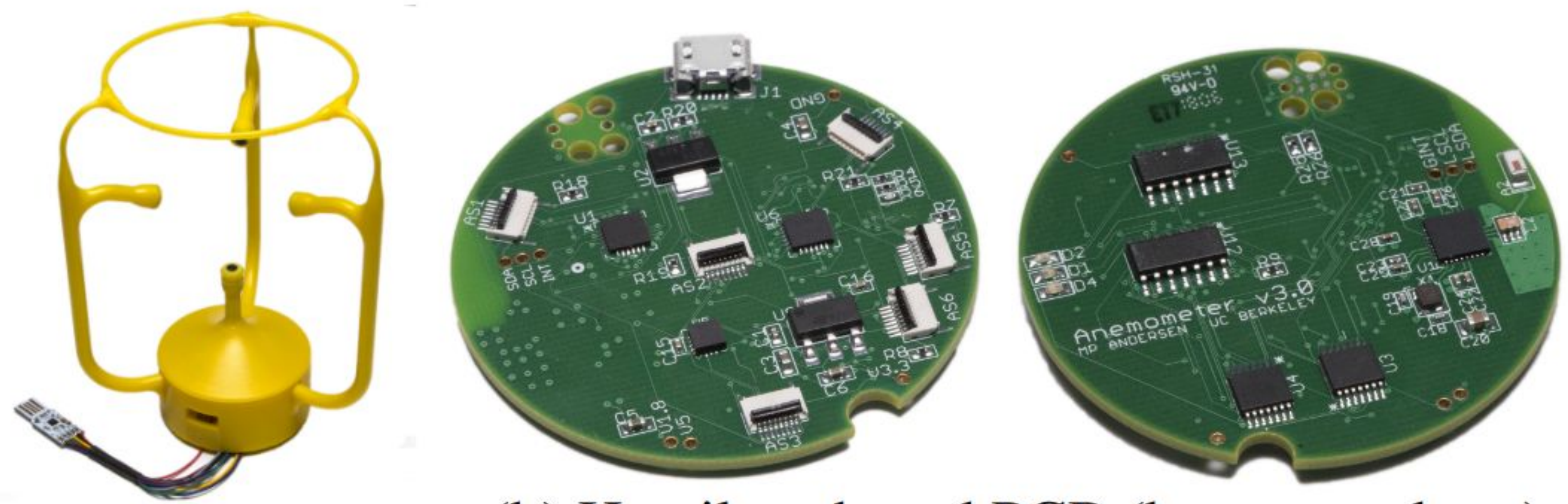
TCPIp KEY POINTS

- Deterministic memory usage
- TCP headers not a problem
- More efficient power usage

*Microbenchmarks for these in paper

EXPERIMENTAL SETUP

HARDWARE



(a) Anemometer (b) Hamilton-based PCB (bottom and top)

Figure 13: Hamilton-based ultrasonic anemometer

MULTI-HOP NETWORK

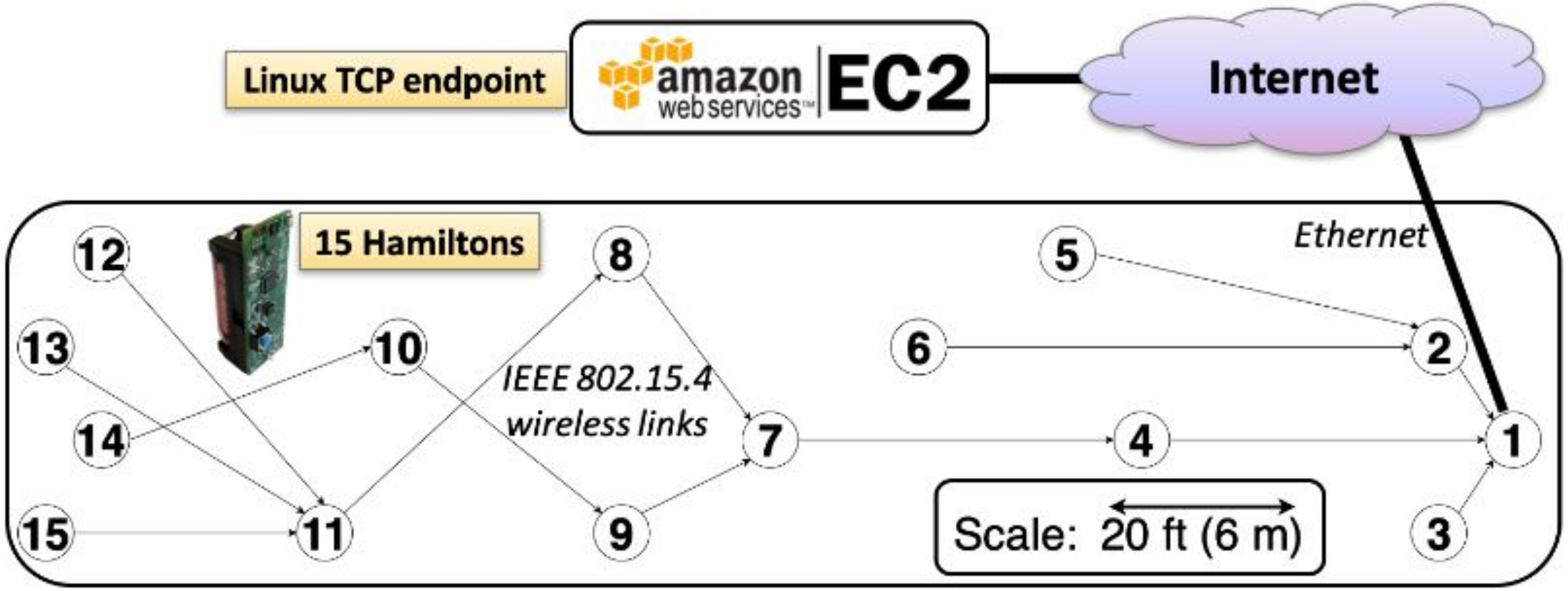


Figure 1: Snapshot of uplink routes in OpenThread topology at transmission power of -8 dBm (5 hops). Node 1 is the border router with Internet connectivity.

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EVALUATION

“NETWORK STUDIES OVER IEEE 802.15.4 NETWORKS”

NETWORK STUDIES OVER IEEE 802.15.4 NETWORKS

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	[144]	[22]	[67]	[86]	[69, 70]	This Paper (Hamilton Platform)
TCP Stack	uIP	uIP	uIP	BLIP	Arch Rock	*TCPlp* (RIOT OS, OpenThread)
Max. Seg Size	1 Frame	1 Frame	4 Frames	1 Frame	1024 bytes	5 Frames
Window Size	1 Seg.	1 Seg.	1 Seg.	1 Seg.	1 Seg.	1848 bytes (4 Seg.)
Goodput (One Hop)	1.5 kb/s	≈ 6.4 kb/s	≈ 12 kb/s	≈ 4.8 kb/s	15 kb/s	75 kb/s
Goodput (Multi-Hop)	≈ 0.55 kb/s	≈ 1.9 kb/s	≈ 12 kb/s	≈ 2.4 kb/s	9.6 kb/s	20 kb/s

Table 6: Comparison of *TCPlp* to existing TCP implementations used in network studies over IEEE 802.15.4 networks.[6] Goodput figures obtained by reading graphs in the original paper (rather than stated numbers) are marked with the ≈ symbol.

RECAP

RECAP

- TCPlp
  - Fully-compatible TCP implementation for LLNs
- Contributions:
  - Performant TCP implementation for LLNs in two embedded OSes
  - TCP optimizations for LLN implementations
  - Evaluation of TCPlp in several common scenarios

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QUESTIONS?