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IPv6 and 6LoWPAN in Home Automation Networks

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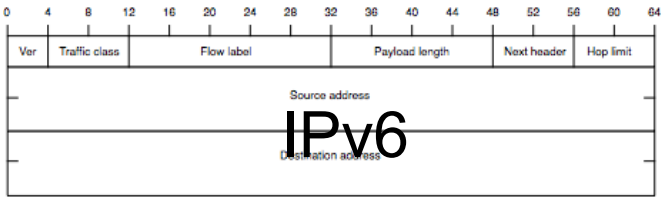
Overview

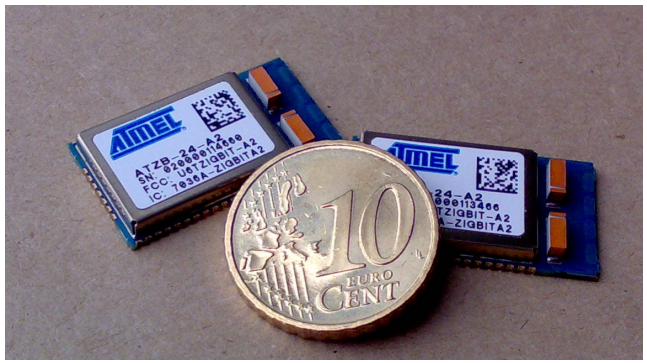
- IPv6 and 6LoWPAN in Home Automation Networks
  - 6LoWPAN
  - Application & Network Architecture
  - Measurements
  - Summary

What is 6LoWPAN?

IPv6 over Low-Power Wireless Personal Area Networks

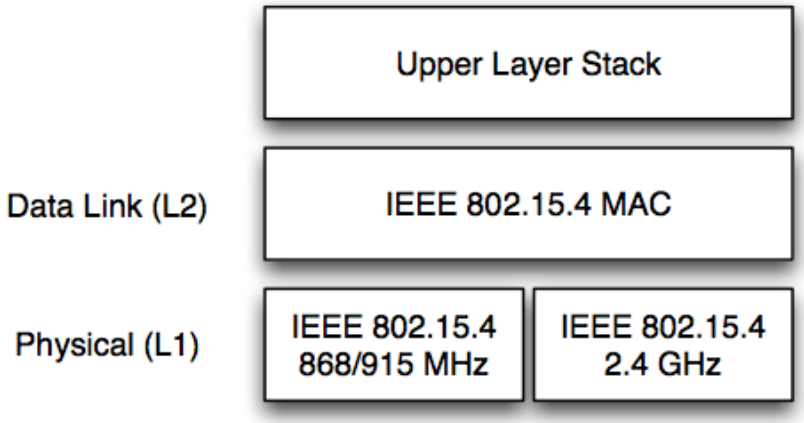
- Defined by IETF standards
  - RFC 4919, 4944
  - draft-ietf-6lowpan-hc and -nd
  - draft-ietf-roll-rpl
- Stateless header compression
- Minimal use of code and memory
- Direct end-to-end Internet integration
  - Multiple topology options





IEEE 802.15.4

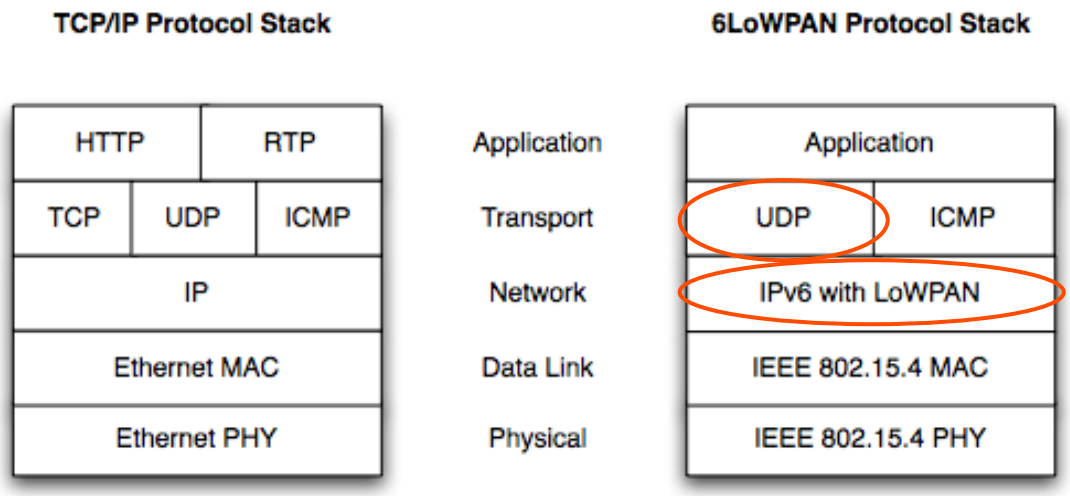
- Important standard for home networking, industrial control and building automation
- Three PHY modes
  - 20 kbps at 868 MHz
  - 40 kbps at 915 MHz
  - 250 kbps at 2.4 GHz (DSSS)
- Beaconless mode
  - Simple CSMA algorithm
- Beacon mode with superframe
  - Hybrid TDMA-CSMA algorithm
- Up to 64k nodes with 16-bit addresses
- Extensions to the standard
  - IEEE 802.15.4a, 802.15.4e, 802.15.5



(Source: www.6lowpan.net)

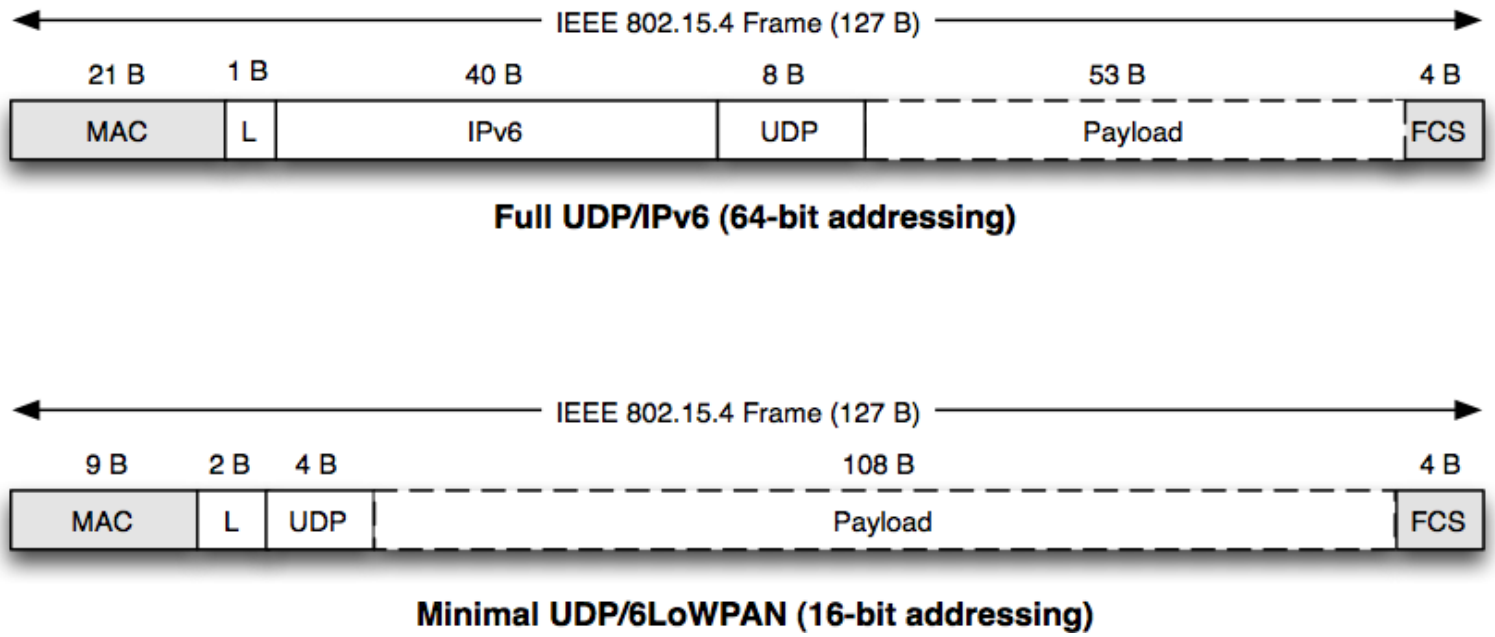
The 6LoWPAN Format

- 6LoWPAN is an adaptation header format
  - Enables the use of IPv6 over low-power wireless links
  - IPv6 header compression
  - UDP header compression
- Format initially defined in RFC4944
- Updated by draft-ietf-6lowpan-hc (work in progress)



(Source: www.6lowpan.net)

6LoWPAN Frame Format



(Source: www.6lowpan.net)

Idea

- Build our own networked home-appliance
  - Use standard IP-Stack (IPv6)
  - Use standard application protocols (HTTP)
  - Network-enable existing electrical device
  - Provide a user story (not another Internet toaster)

Building Blocks

Atmega 1284P

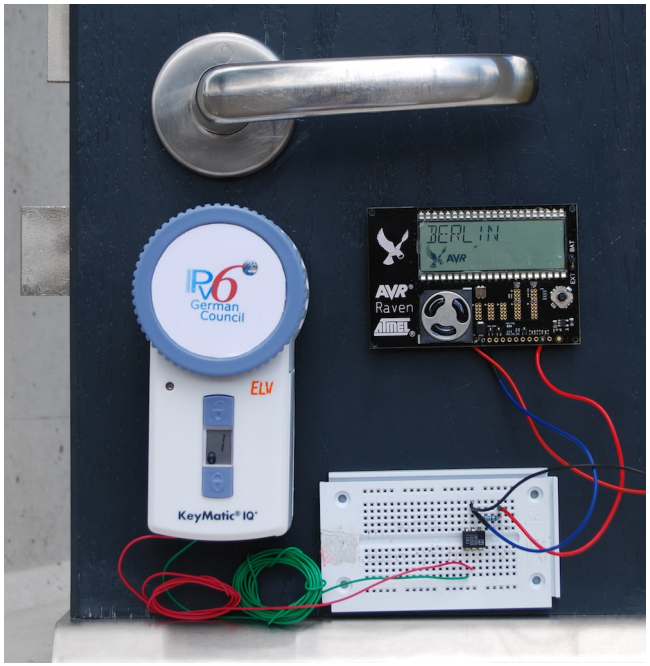
- 8-Bit RISC
- 20-MHz operation
- 128-KB Flash
- 16-KB SRAM
- IEEE 802.15.4 (2,4 GHz)

Electric Door Lock

- Batterie powered
- Remotely controllable
- Compatible with existing locks

Application

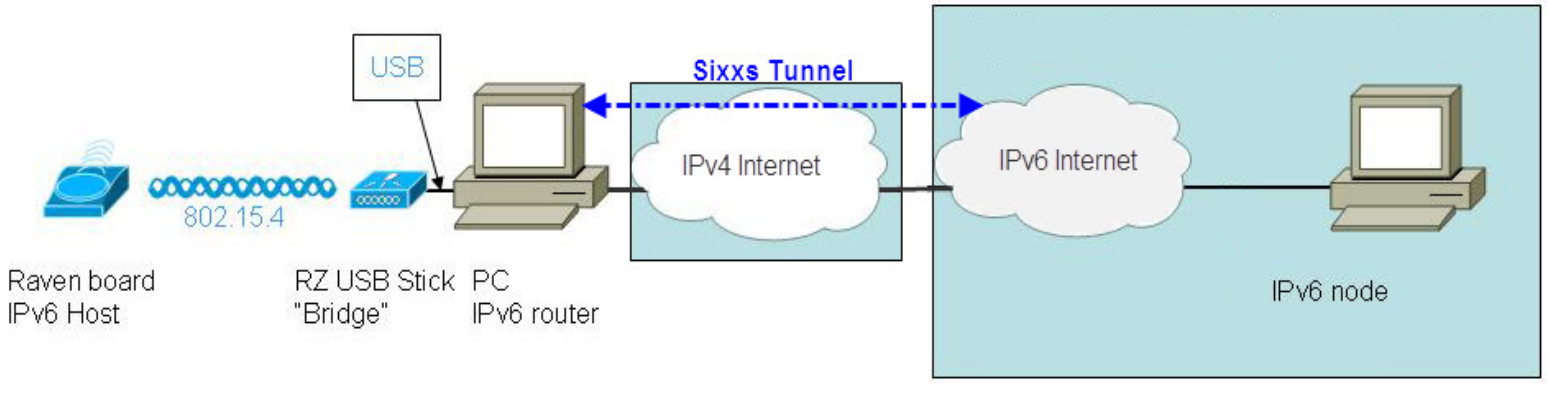
IPv6 Door-Lock



Application

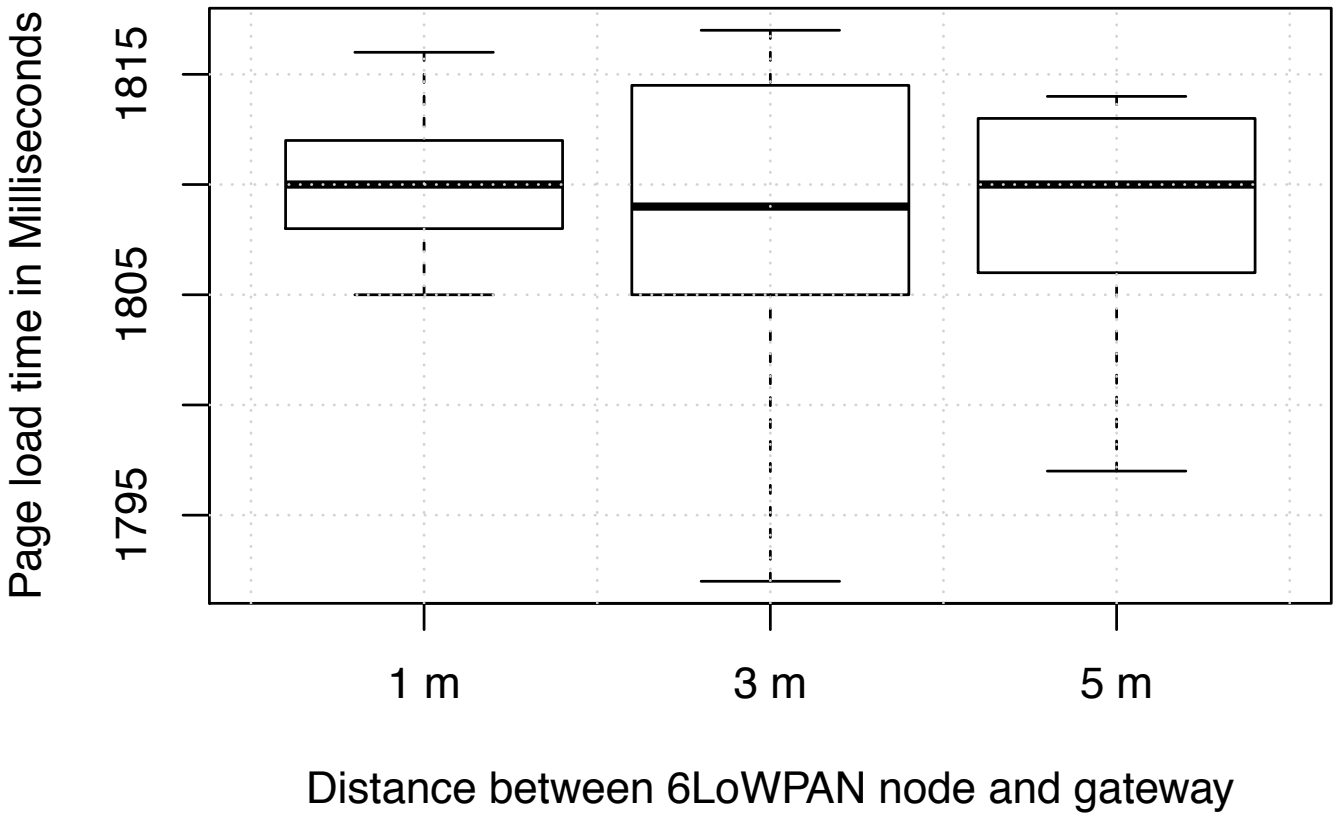
- IPv6 Webserver directly on the Microcontroller-Board
  - based on Contiki OS (http://www.sics.se/contiki/)
  - End-to-End Connectivity

Network Architecture

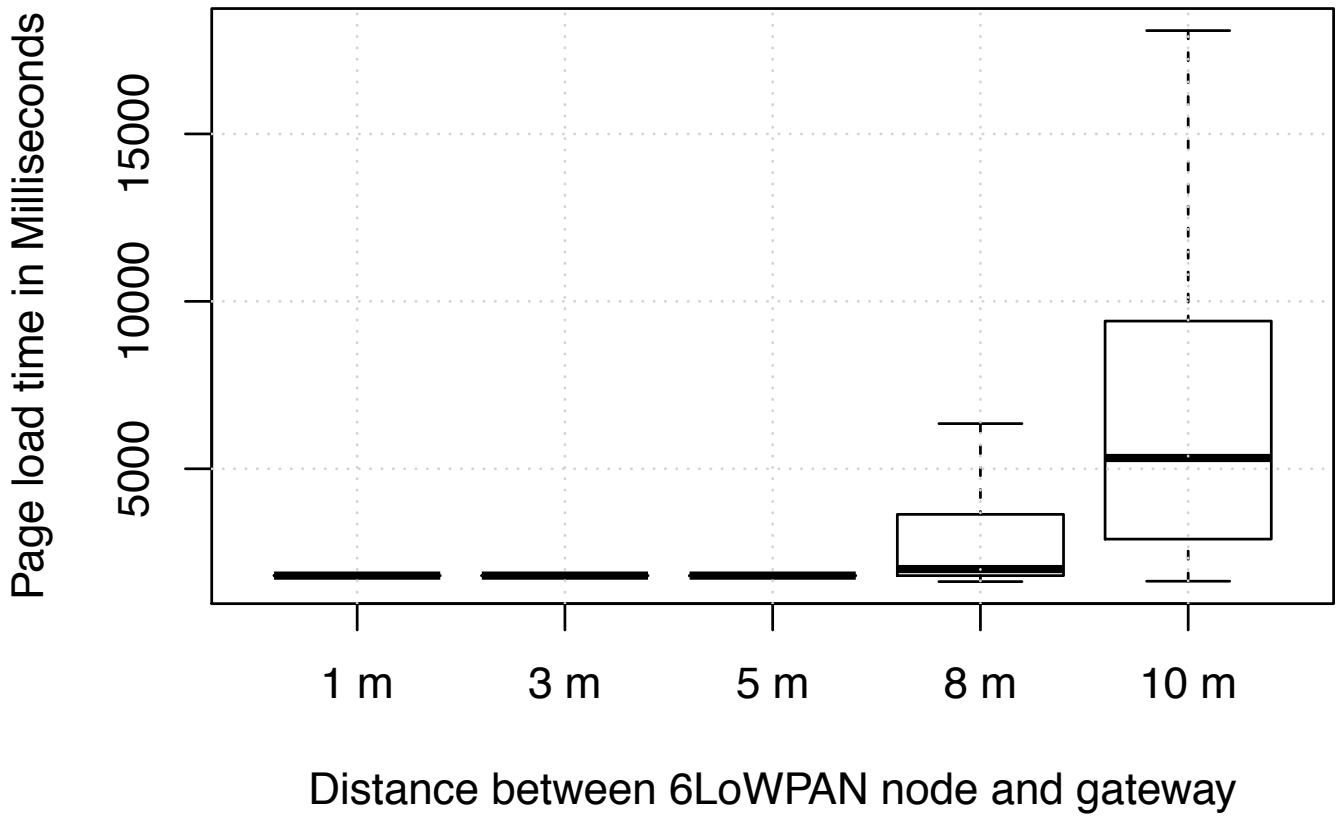


- Simple network topology - 6LoWPAN Gateway
  - creates Sixxs IPv6-in-IPv4 tunnel
  - advertises IPv6 prefix into 6LoWPAN subnet
  - routes packets between 6LoWPAN and IPv6 Internet

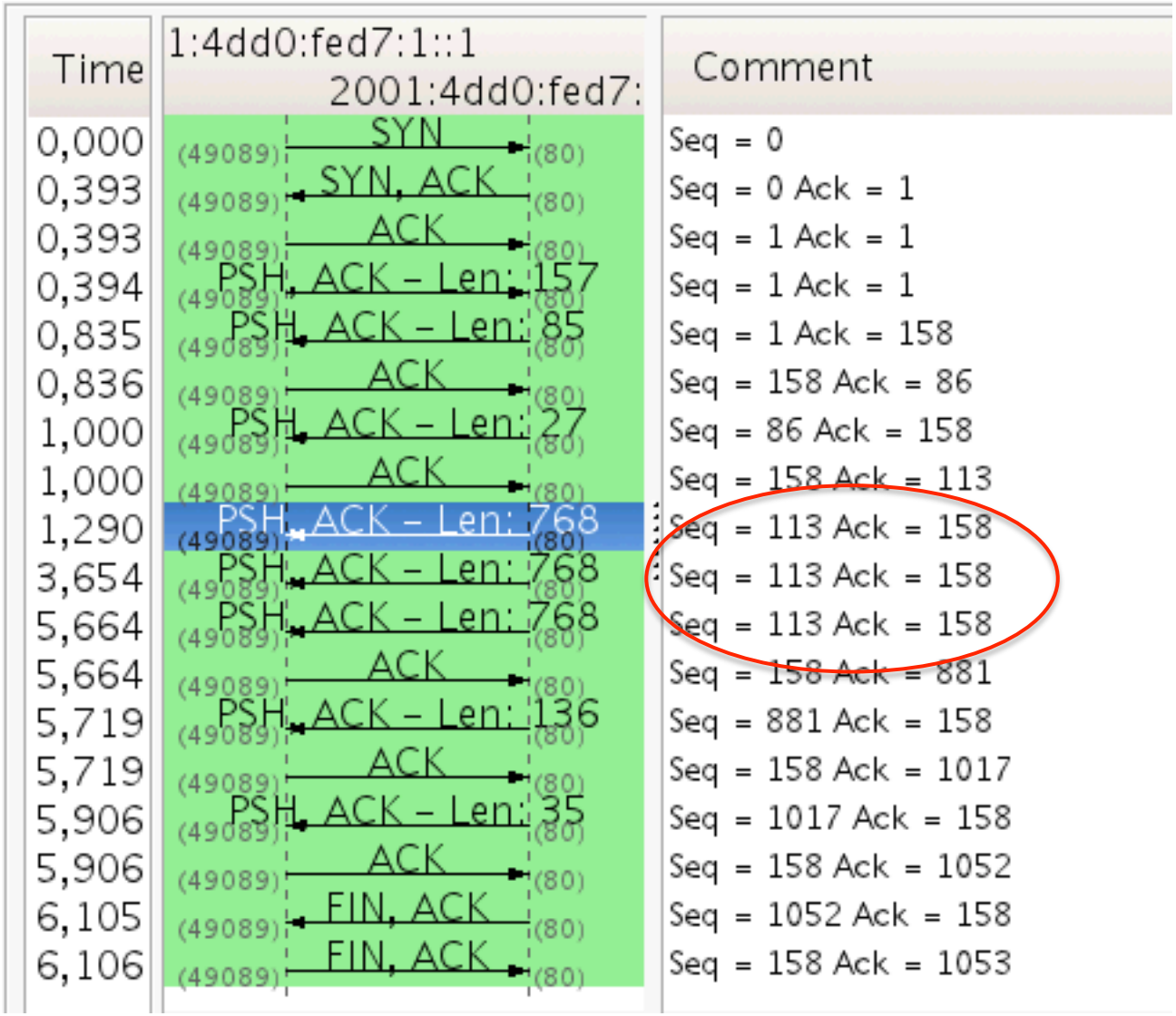
Some Measurements



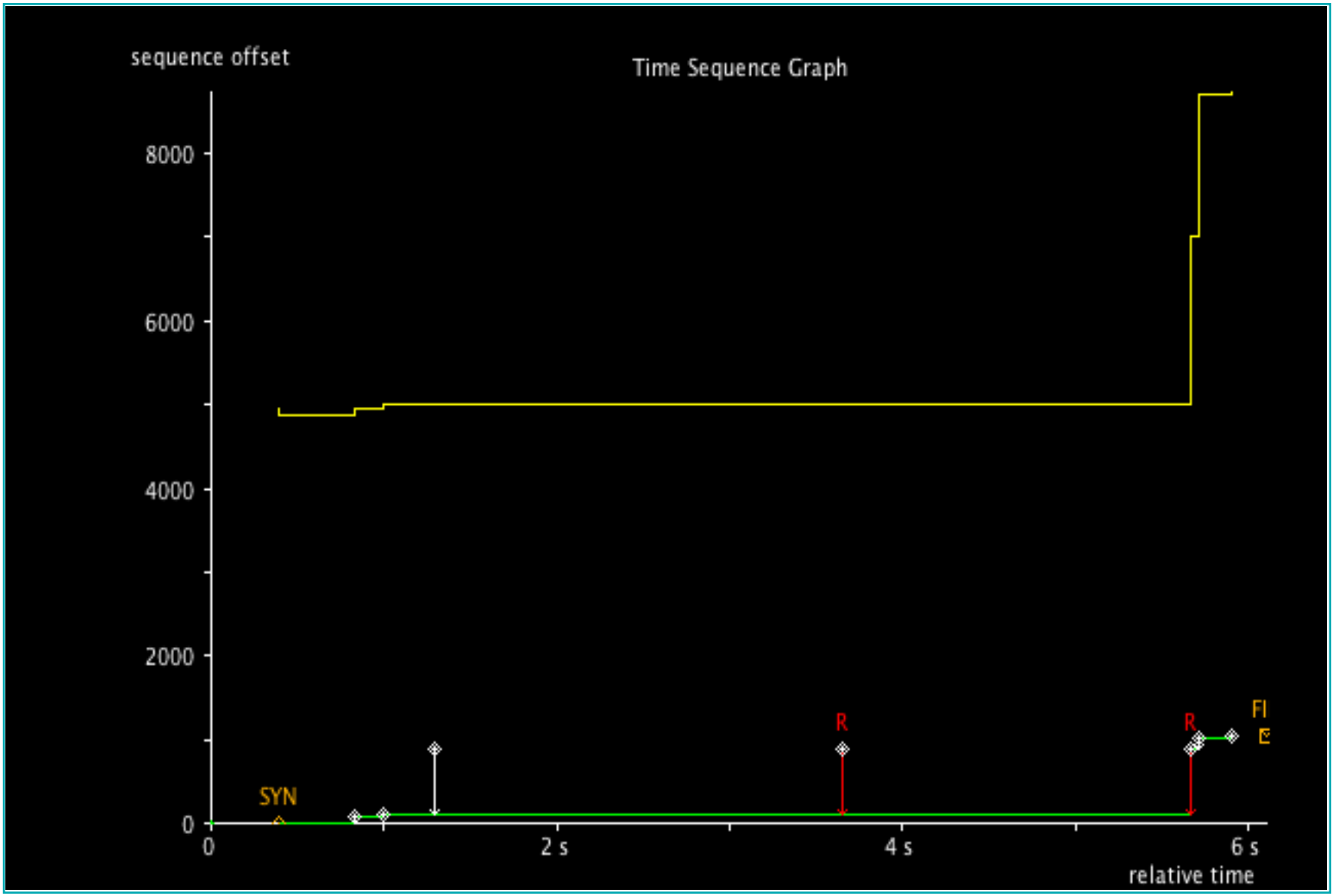
Some Measurements



Looking deeper – TCP Flow Graph



Looking deeper – Time/Sequence Graph



Looking deeper – Wireshark Frame Analysis

No.	Time	Source	Destination	Protocol	Length	Info
21	[illegible]	2001:4dd0:fed:	2001:4dd0:fe	TCP	74	49089 > http [ACK] Seq=158 Ack=881 Win=6144 Len=0
22	1.178712	02:12:13:ff:fe	02:11:22:ff:	IEEE 802.	94	Data, Dst: 02:11:22ff:fe:3344:56, Src: 02:12:13ff:fe:1415:16, Bad FCS
23	1.202715	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	134	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
24	1.212720	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
25	1.223734	02:11:22:ff:fe	02:12:13:ff:	IEEE 802.	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56, Bad FCS
26	1.232730	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
27	1.246739	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
28	1.260749	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
29	1.268752	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
30	1.277758	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
31	1.285762	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	102	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
32	1.289766	2001:4dd0:fed:	2001:4dd0:fe	HTTP	842	Continuation or non-HTTP traffic
33	3.580023	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	134	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
34	3.588026	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
35	3.597024	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
36	3.605026	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
37	3.614034	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
38	3.624057	02:11:22:ff:fe	02:12:13:ff:	IEEE 802.	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56, Bad FCS
39	3.634048	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
40	3.643048	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
41	3.650049	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	102	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
42	3.654072	2001:4dd0:fed:	2001:4dd0:fe	HTTP	842	[TCP Retransmission] Continuation or non-HTTP traffic
43	5.588128	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	134	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
44	5.597110	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
45	5.606116	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
46	5.615118	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
47	5.624125	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
48	5.632128	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
49	5.643132	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
50	5.652149	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	138	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
51	5.660146	02:11:22:ff:fe	02:12:13:ff:	6LoWPAN	102	Data, Dst: 02:12:13ff:fe:1415:16, Src: 02:11:22ff:fe:3344:56
52	5.664152	2001:4dd0:fed:	2001:4dd0:fe	HTTP	842	[TCP Retransmission] Continuation or non-HTTP traffic
53	5.664220	2001:4dd0:fed:	2001:4dd0:fe	TCP	74	49089 > http [ACK] Seq=158 Ack=881 Win=6144 Len=0

Fragmentation

- IPv6 requires underlying links to support Minimum Transmission Units (MTUs) of at least 1280 bytes
  - IEEE 802.15.4 has 127 bytes frame length
  - This leaves approximately 80-100 bytes of L3-payload
  - Leads to heavy fragmentation and reassembly at the link-layer
- The performance of large, fragmented IPv6 packets over noisy low-power wireless networks is poor
  - Lost fragments cause whole packet to be retransmitted
  - TCP-Stack characteristic (only 1 packet in flight) requires retransmission-timer to fire (2 second delay in Contiki OS)

  Effect: low bandwidth and very high delay on the wireless channel!

Fragmentation

How to cope?

- 6LoWPAN application protocols should avoid fragmentation
  - Use application protocols with small packet size
  - Use UDP and specifically designed transport protocols
  - Compression should be used on existing application protocols when used over 6LoWPAN

- Fragment recovery is currently under IETF consideration
  - Problem is accentuated when wireless mesh networks emerge
  - Solution: include acknowledge/selective retransmission at link-layer to provide a reliable 6LoWPAN link
  - LoWPAN fragment forwarding and recovery (draft-thubert-6lowpan-simple-fragment-recovery-07)

- Summary

Summary

- **First observations:**
  - IPv6 implementations in the embedded area are working, but are still somewhat experimental
  - Security is currently not an important feature (performance?)
  - Low entry barriers:
    - Free operating systems (Contiki, Tiny-OS)
    - Low-cost hardware

- **IPv6 offers new perspectives for an *Internet of Things*:**
  - Interesting hardware concepts, but open issues:
    - Routing performance in mesh-networks
    - Space and energy usage
    - Dedicated application protocols

Discussion

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