



BEUTH HOCHSCHULE FÜR TECHNIK BERLIN
University of Applied Sciences



Using IPv6 and 6LoWPAN for Home Automation Networks

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ICCE-Berlin

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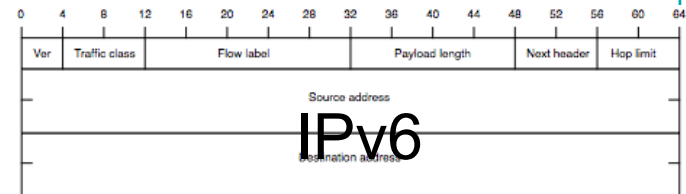
- IPv6 and 6LoWPAN for Home Automation Networks
 - 6LoWPAN
 - Application & Network Architecture
 - Measurements
 - Summary

What is 6LoWPAN?



IPv6 over Low-Power Wireless Personal Area Networks

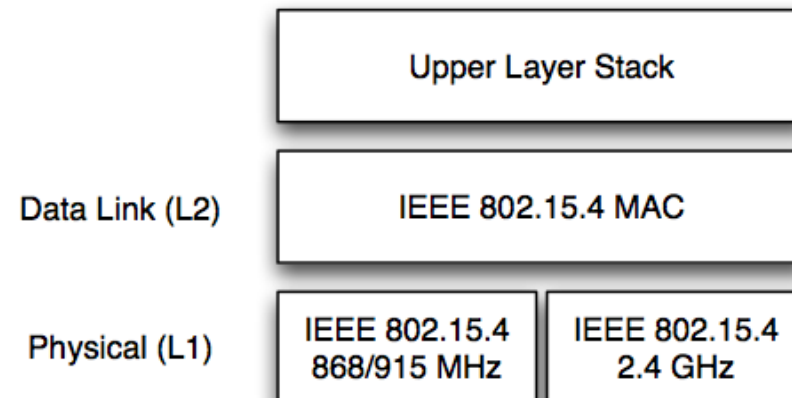
- Defined by IETF standards
 - RFC 4919, 4944
 - draft-ietf-6lowpan-hc and -nd
 - draft-ietf-roll-rpl
- Stateless header compression
- Minimal use of code and memory
- Direct end-to-end Internet integration
 - Multiple topology options



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

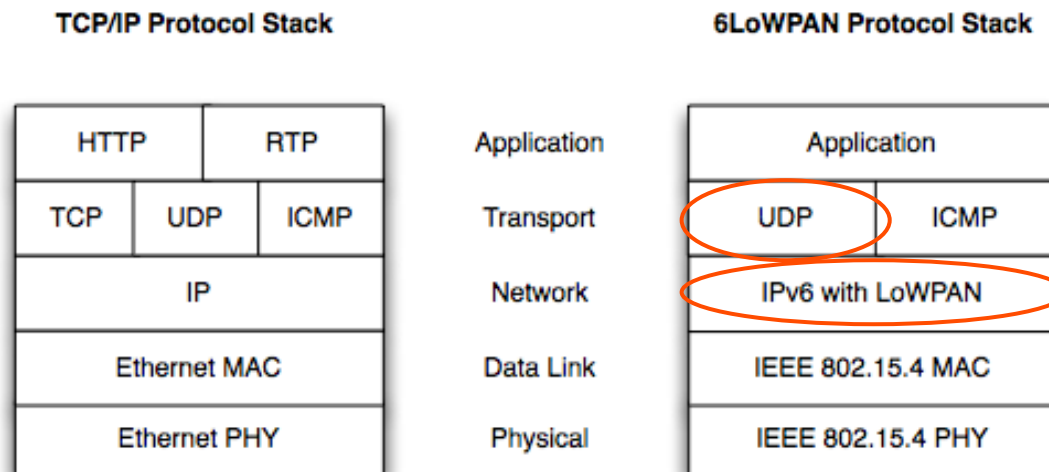


(Source: www.6lowpan.net)

The 6LoWPAN Format

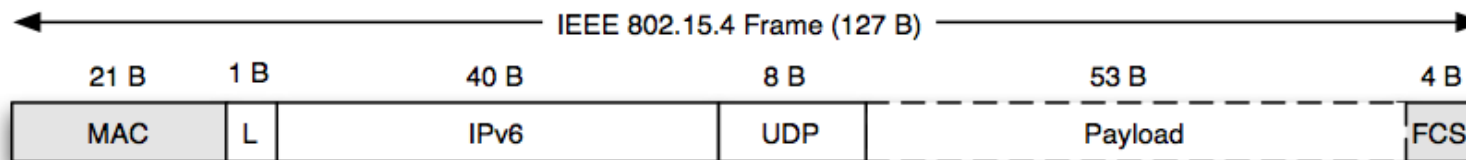


- 6LoWPAN is an adaptation header format
 - Enables the use of IPv6 over low-power wireless links
 - IPv6 header compression
 - UDP header compression
- Format initially defined in RFC4944
- Updated by draft-ietf-6lowpan-hc (work in progress)

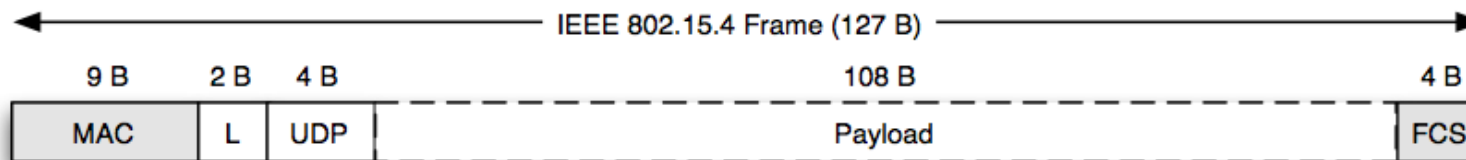


(Source: www.6lowpan.net)

6LoWPAN Frame Format



Full UDP/IPv6 (64-bit addressing)



Minimal UDP/6LoWPAN (16-bit addressing)

(Source: www.6lowpan.net)



- 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)



Atmega 1281

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



Electric Door Lock

- Batterie powered
- Remote-Control
- Compatible with existing locks





IPv6 door-lock





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

Heimgeräte steuern per Internet
Informationen unter: www.beuth-hochschule.de

Vernetzung mittels 6LoWPAN und IPv6

Prinzipieller Aufbau des Systems

IPv6

- Abbildung für IPv4
- IPv4 Adressen sind fast vollständig aufgebraucht
- 2^{128} = 340,28 Sextillionen mögliche IPv6-Adressen
- Automatische Konfiguration der IPv6-Adresse
- Nutzung von Multicast Adressen für Multimedia – Inhalte

Eine IPv6-Adresse besteht aus einem Präfix (Netzanteil) und einem Interface-Teil.

MAC – Adresse: 00:16:CB-D1-90-A4

2001:0db8:fed7:0000:716:cbf:fed1:90a4
Präfix Interface-Teil aus MAC – Adresse

6LoWPAN

- IPv6 – Pakete über 802.15.4 Netzwerke
- 6LoWPAN = IPv6 over Low power WPAN
- Standardisiert in RFC 4919 sowie RFC 4916
- Komprimierung des IPv6 Header möglich
- Routingprotokoll = RPL (Routing Protocol for Low power and Lossy Networks)

802.15.4 Netzwerke

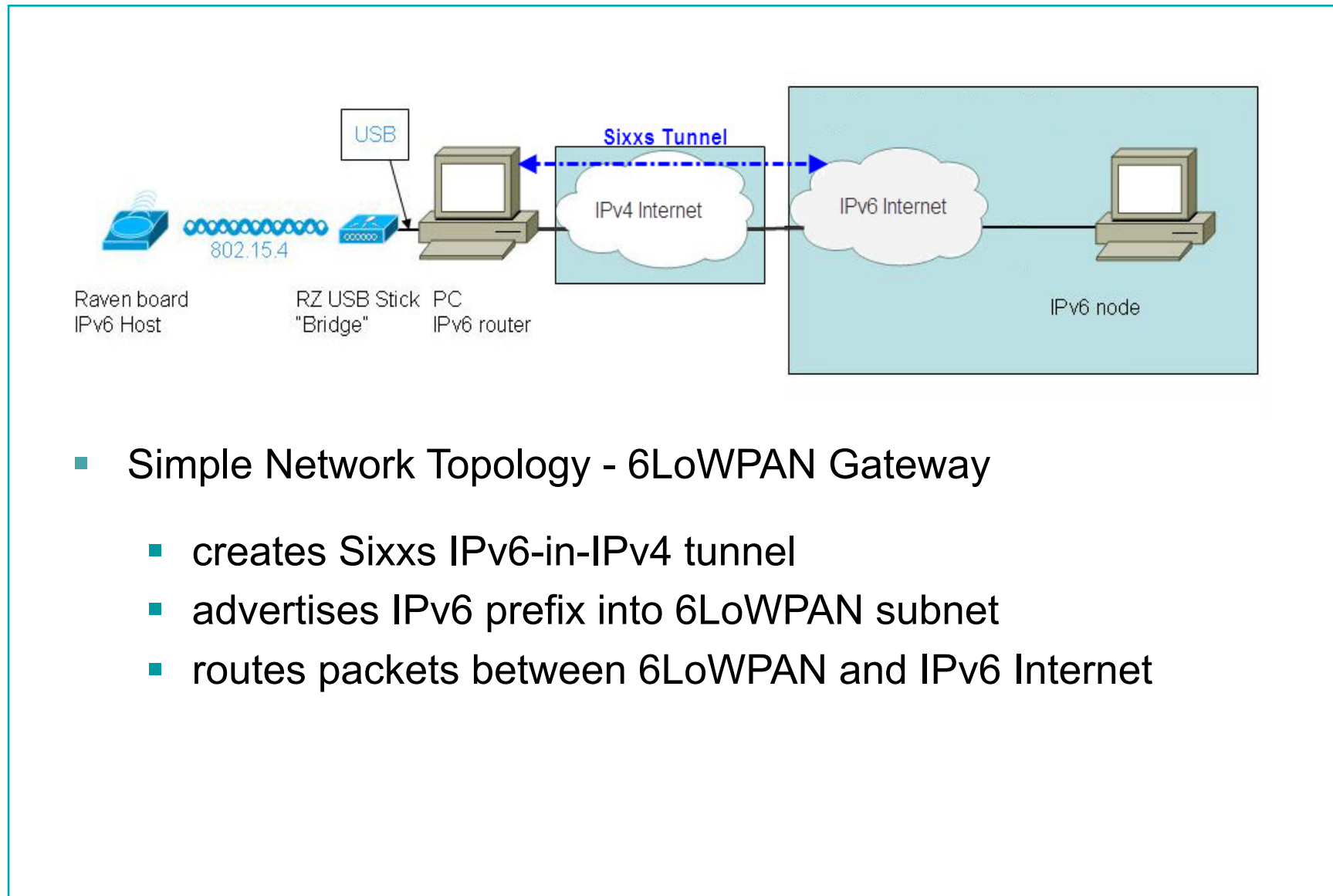
Der Standard 802.15.4 ist für Mikrocontroller-Netzwerke ausgelegt. Es kann zwischen unterschiedlichen Frequenzen gewählt werden und mit möglichst wenig Stromverbrauch Daten übertragen werden.

Anwendungen:

- Smartmeter
- Leistungszähler
- Steuerung von Haushaltsgeräten

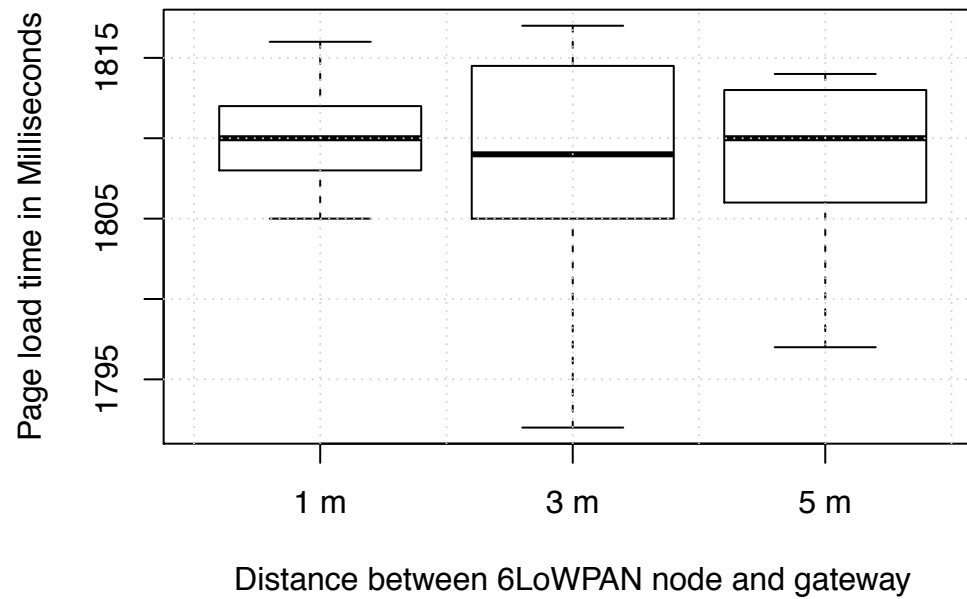
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Fachbereich VII
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Kommunikations- und Informationstechnik

Network Architecture

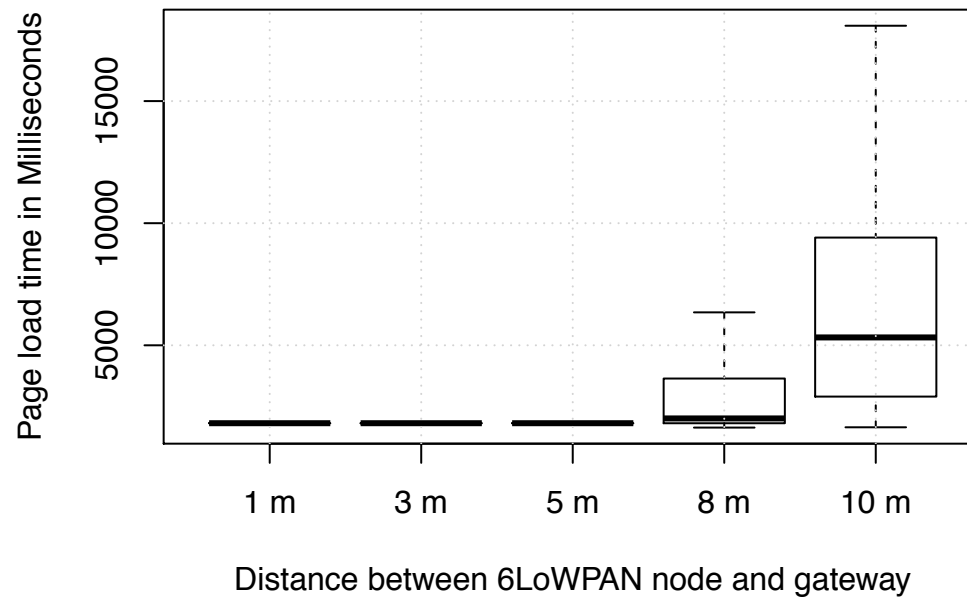


- Simple Network Topology - 6LoWPAN Gateway
 - creates Sixxs IPv6-in-IPv4 tunnel
 - advertises IPv6 prefix into 6LoWPAN subnet
 - routes packets between 6LoWPAN and IPv6 Internet

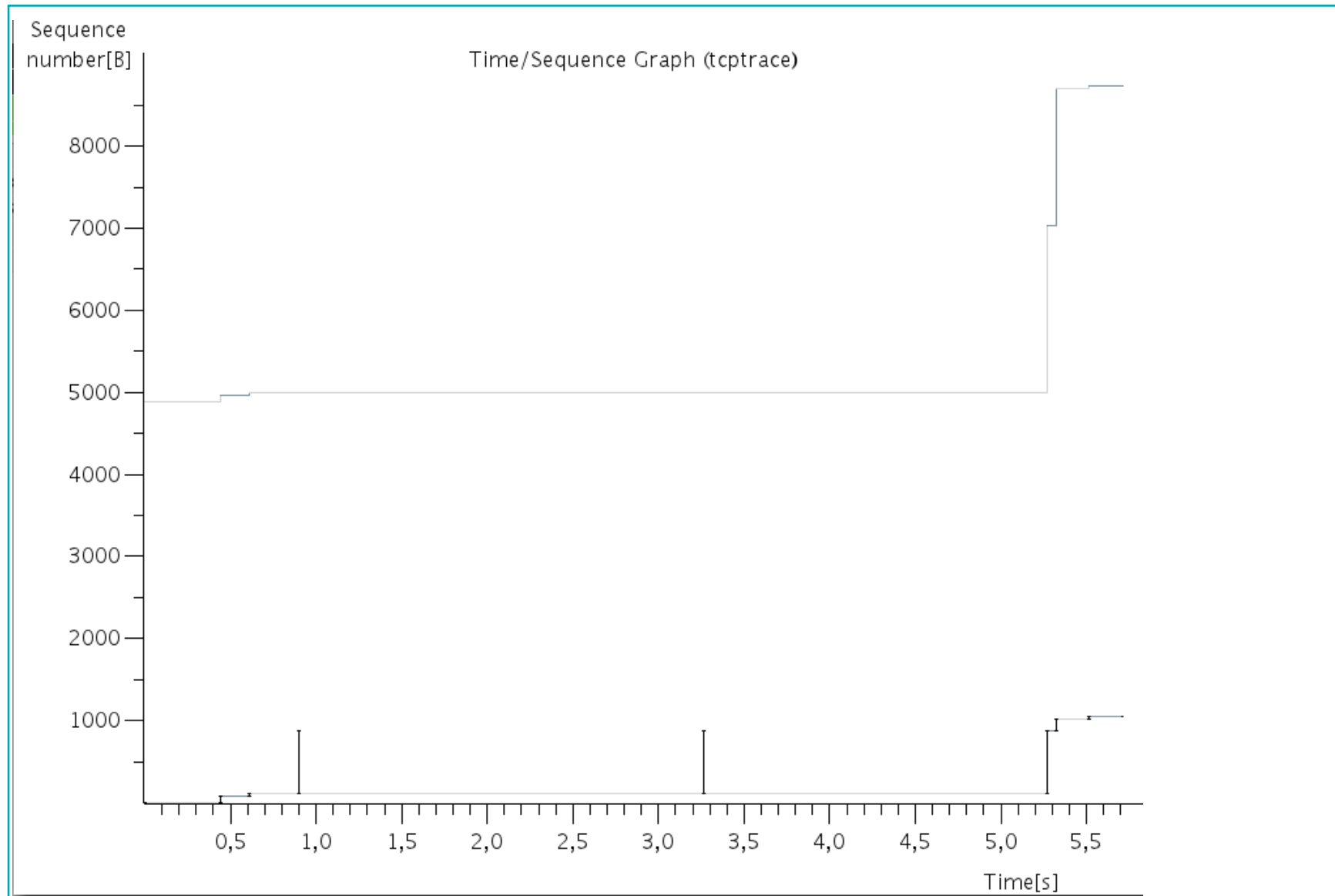
Some Measurements



Some Measurements



Looking deeper – Time/Sequence Graph



Looking deeper – TCP Flow Graph



Time	1:4dd0:fed7:1::1 2001:4dd0:fed7:	Comment
0,000	(49089) → SYN → (80)	Seq = 0
0,393	(49089) ← SYN, ACK → (80)	Seq = 0 Ack = 1
0,393	(49089) → ACK → (80)	Seq = 1 Ack = 1
0,394	(49089) → PSH, ACK - Len: 157 → (80)	Seq = 1 Ack = 1
0,835	(49089) → PSH, ACK - Len: 85 → (80)	Seq = 1 Ack = 158
0,836	(49089) → ACK → (80)	Seq = 158 Ack = 86
1,000	(49089) → PSH, ACK - Len: 27 → (80)	Seq = 86 Ack = 158
1,000	(49089) → ACK → (80)	Seq = 158 Ack = 113
1,290	(49089) → PSH, ACK - Len: 768 → (80)	Seq = 113 Ack = 158
3,654	(49089) → PSH, ACK - Len: 768 → (80)	Seq = 113 Ack = 158
5,664	(49089) → PSH, ACK - Len: 768 → (80)	Seq = 113 Ack = 158
5,664	(49089) → ACK → (80)	Seq = 158 Ack = 881
5,719	(49089) → PSH, ACK - Len: 136 → (80)	Seq = 881 Ack = 158
5,719	(49089) → ACK → (80)	Seq = 158 Ack = 1017
5,906	(49089) → PSH, ACK - Len: 35 → (80)	Seq = 1017 Ack = 158
5,906	(49089) → ACK → (80)	Seq = 158 Ack = 1052
6,105	(49089) ← FIN, ACK → (80)	Seq = 1052 Ack = 158
6,106	(49089) → FIN, ACK → (80)	Seq = 158 Ack = 1053

Looking deeper – Wireshark Frame Analysis



No.	Time	Source	Destination	Protocol	Length	Info
21	0.999702	2001:4dd0:fed:2001:4dd0:fe	2001:4dd0:fed:2001:4dd0:fe	TCP	74	49089 > http [ACK] Seq=158 Ack=113 Win=4338 Len=0
22	1.178712	02:12:13:ff:fe:02:11:22:ff:fe	02:11:22:ff:fe:02:12:13:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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:fe	02:12:13:ff:fe:02:11:22:ff:fe	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	2001:4dd0:fed:2001:4dd0:fe	HTTP	842	[TCP Retransmission] Continuation or non-HTTP traffic
53	5.664220	2001:4dd0:fed:2001:4dd0:fe	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 leaves approximately 80-100 bytes of payload
 - Leads to heavy fragmentation and reassembly at the link-layer
- The performance of large IPv6 packets fragmented 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)

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



- 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 IP application protocols when used over 6LoWPAN

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

IPv6 and 6LoWPAN for Home Automation Networks



- 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 (Mesh-Networks)
 - Space and energy usage (Atmel ATZB-24-A2)
 - Applications (SNMP)



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