Internet of Things

Thomas C. Schmidt

t.schmidt@haw-hamburg.de

HAW Hamburg, Dept. Informatik

Credits for visualizations go to Zach Shelby, Carsten Bormann

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Hamburg University of Applied Sciences

Agenda

- The Internet of Things
- IP in the Internet of Things: 6LoWPAN
  - Architectural Challenges
  - 6LoWPAN Contributions
- Application-Layer Protocols

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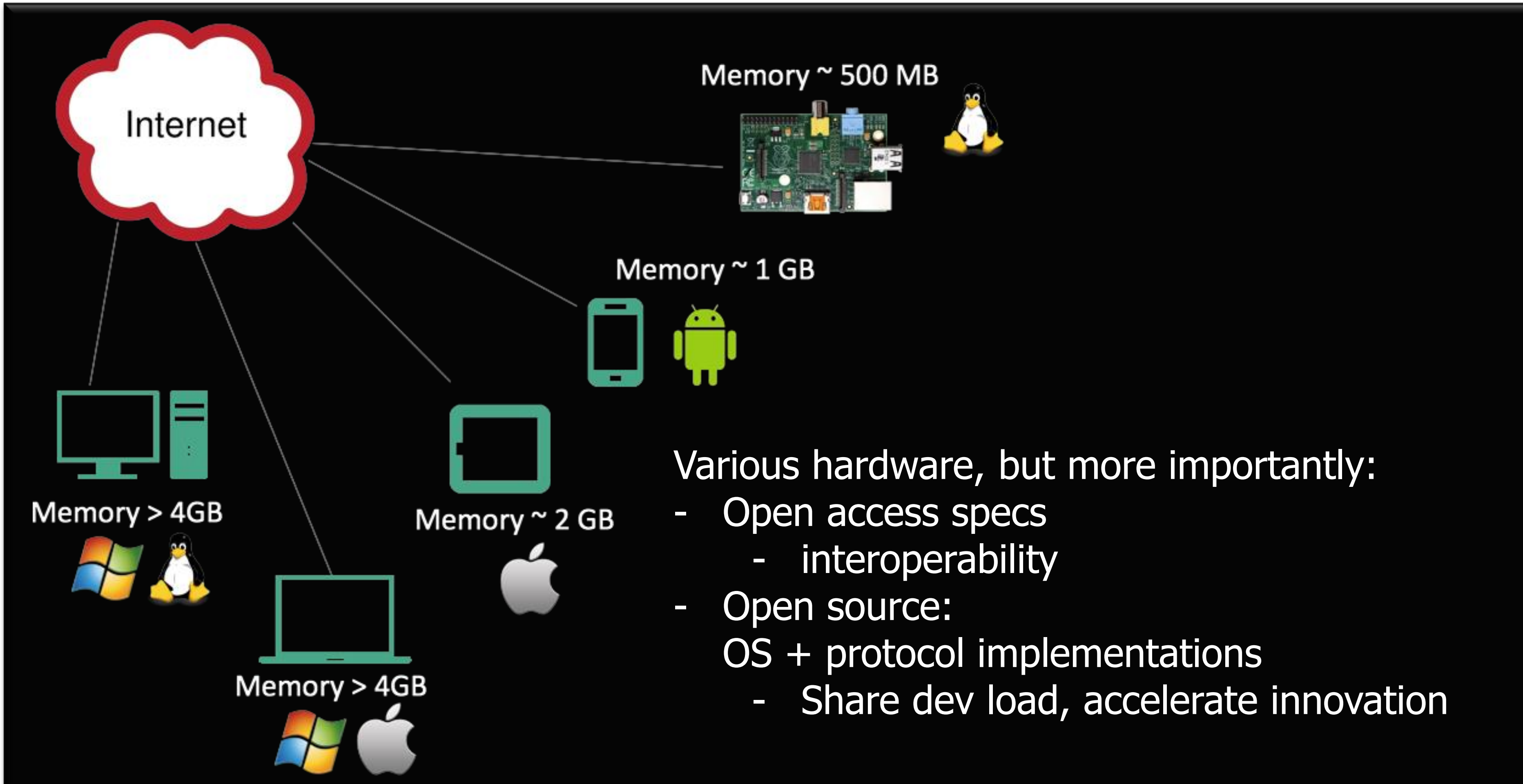
What is the Internet of Things?

A system in which objects in the physical world can be connected to the Internet by sensors and actuators (coined 1999 by Kevin Ashton)

Key aspects:

- E2E communication via Internet standards
- Machine-to-machine communication
- Embedded devices, often constrained and on battery
- Typically without user interface
- Very large multiplicities, w/o manual maintenance

The Internet (as we know it)



Various hardware, but more importantly:

- Open access specs
  - interoperability
- Open source:
  OS + protocol implementations
  - Share dev load, accelerate innovation

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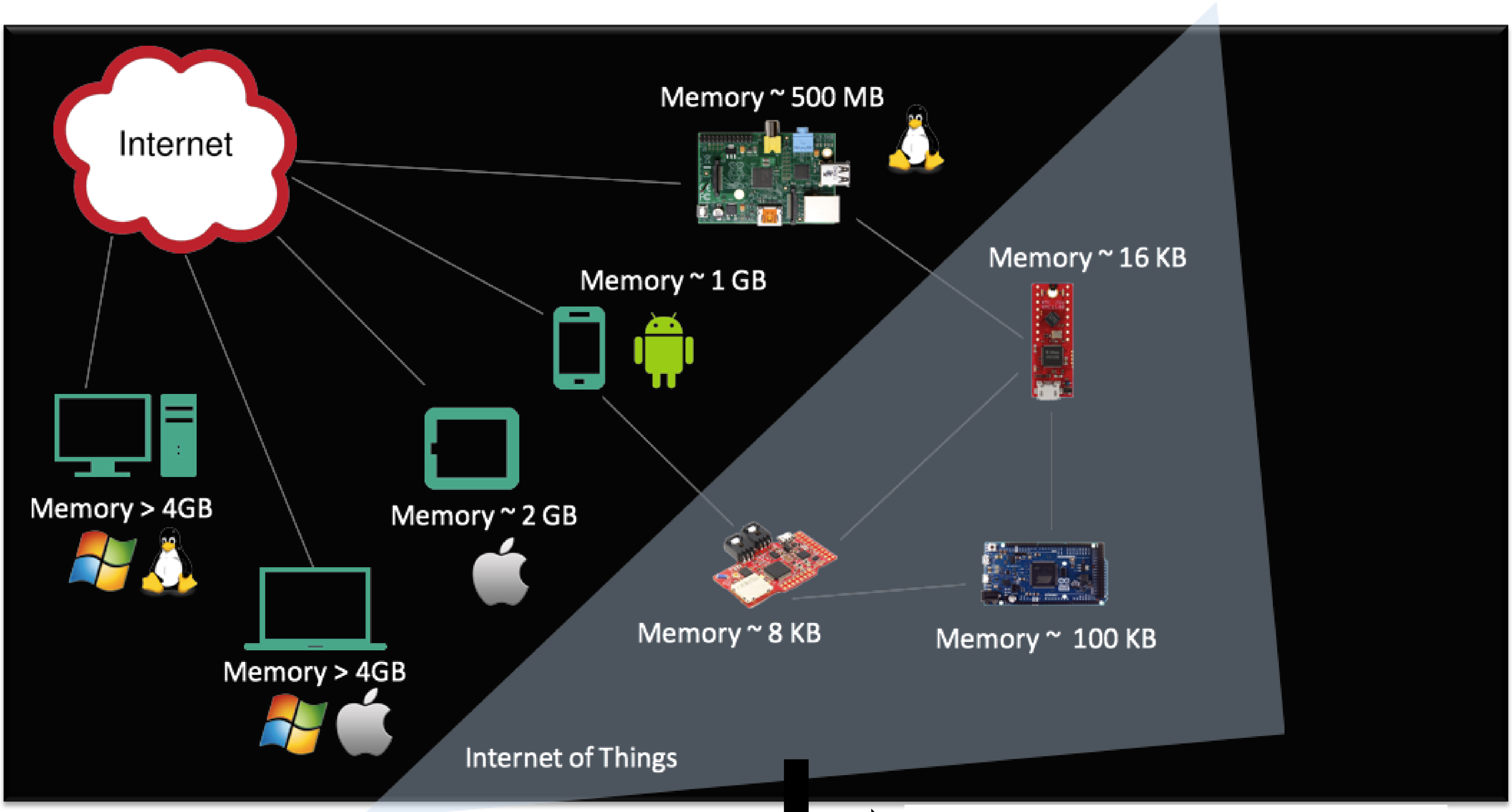
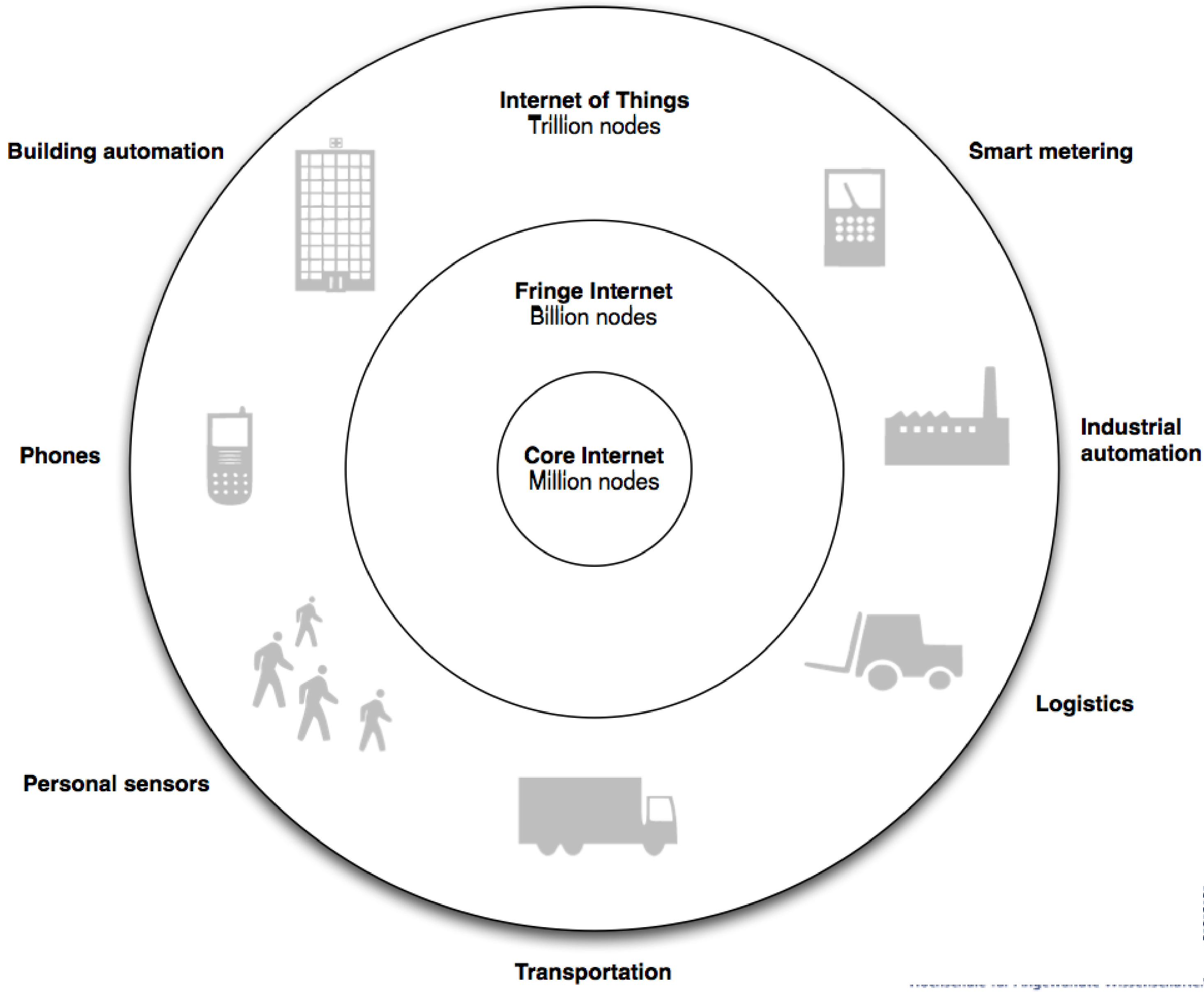
The Internet of Things (IoT)



Constrained + Wireless!



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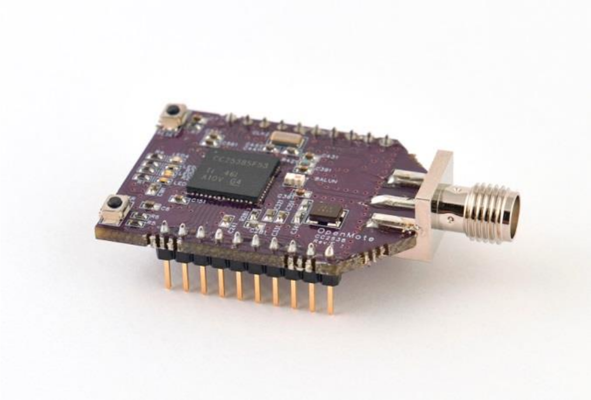
IoT Applications

- o Facility, Building and Home Automation
- o SmartCities & SmartGrids
- o Personal Sports & Entertainment
- o Healthcare and Wellbeing
- o Asset Management
- o Advanced Metering Infrastructures
- o Environmental Monitoring
- o Security and Safety
- o Industrial Automation



IoT Challenges

The five key issue areas from ISOC:

1. Security
2. Privacy
3. Interoperability and standards
4. Legal, regulatory, and rights
5. Emerging economies and development

No Internet without Open Standards

W3C®

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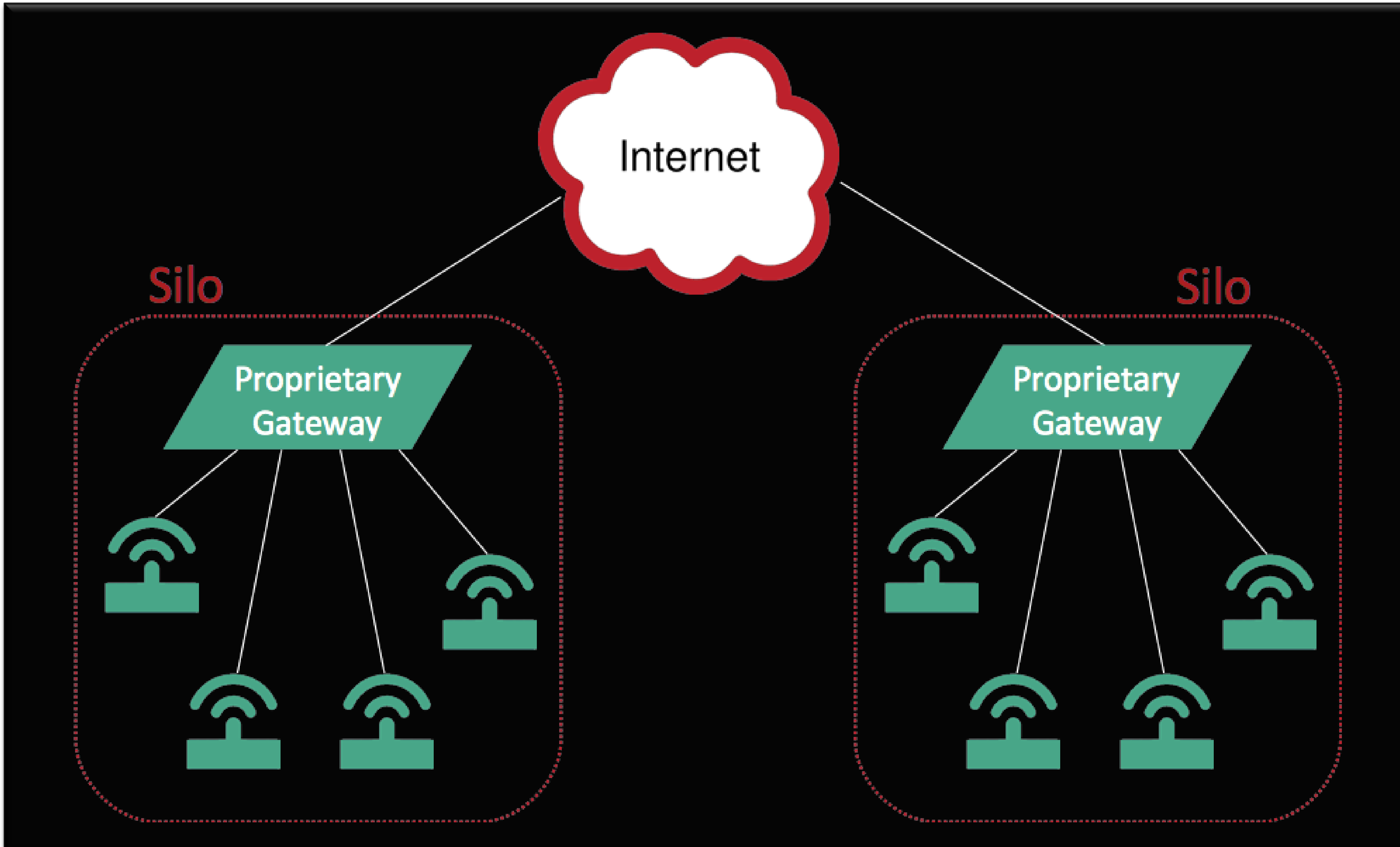
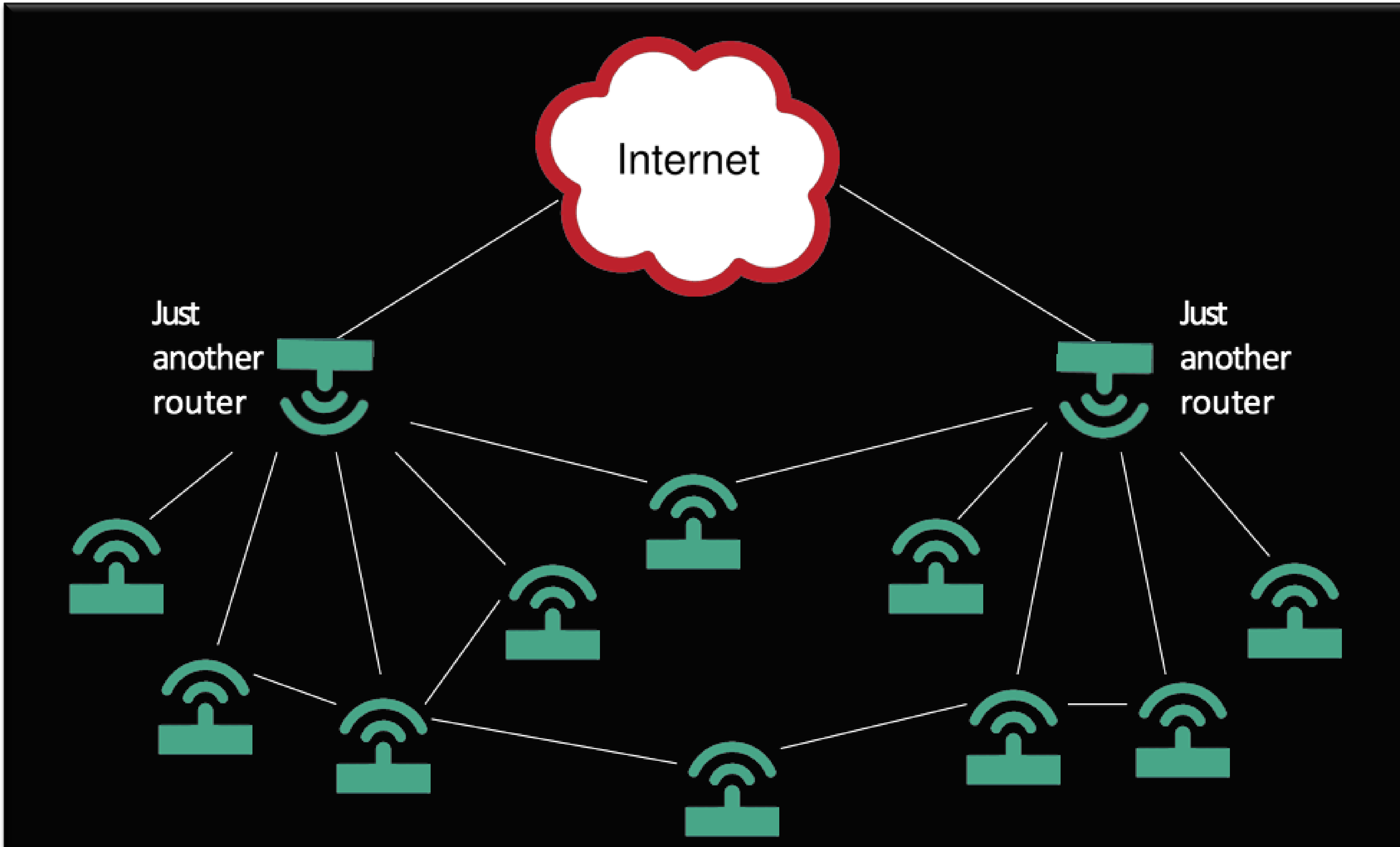
IEEE

Application	XDI, CBOR, RDF, XHTML, JSON, Telnet, CoAP, HTTP, XMPP
Transport	UDP, TCP, TLS/SSL
Network	OSPF, RPL, DHCP, BGP, OLSR, IPv6, SLAAC, IPv4
Link	IEEE802.15.4, LoRa, Ethernet, BLE

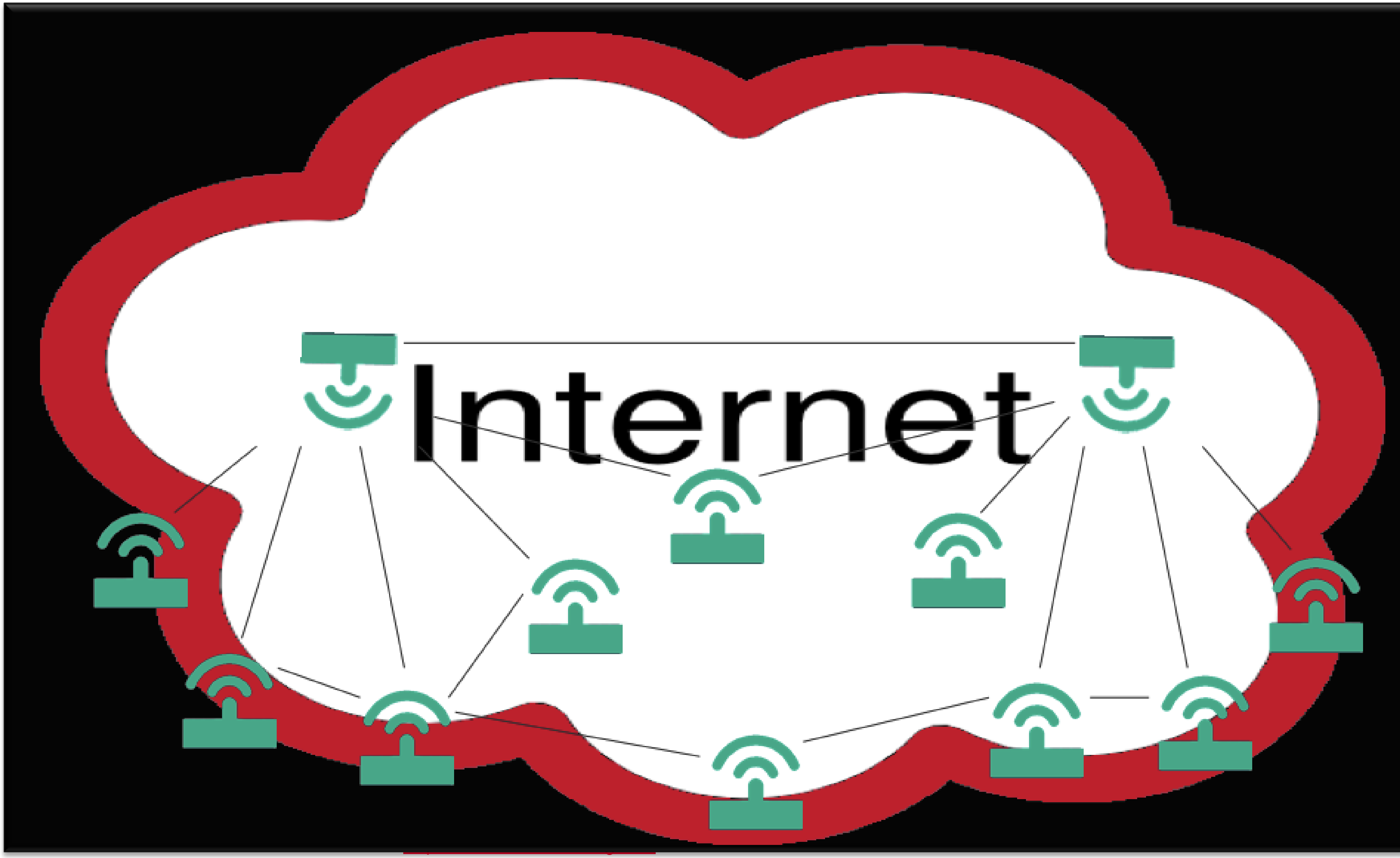
The IoT today looks mostly like this



The IoT we want looks more like that



The IoT we want is… the Internet!



The Difference

- o Network level interoperability
  - End-to-end connectivity per default
  - Device-to-device connectivity

  => No more walls!

- o System level interoperability
  - Efficient hardware-independent software
  - No device lock-down

  => No more waste!

IP in the Internet of Things

- 100+ Billion microcontrollers exist worldwide
  (in contrast to several hundred million Internet devices)
  - Rapid growths and demands for *scalable* connectivity
  - Integrate into the global Internet with E2E data flows
  - Interoperable, long-lived, reliable standards required: IP++
- Link-layers are different
  - All wireless (traditionally wired unavailable or too expensive)
  - Dedicated technologies: 802.15.4, Power-Line, Z-Wave (home automation), Sub-GHz Industrial, Scientific and Medical radios
- Constraint Communication: Low Power Lossy Networks (LLN)
  - Measures of Bytes … instead of Megabytes
- Constraint Devices: Microcontrollers
  - Measures of kHz and kByte

What is 6LoWPAN

- IPv6 over Low-Power (⊃ Personal) wireless Area Networks
- A transparent way to integrate embedded devices into the global Internet
  - Global addressing
  - E2E transport between embedded and core devices
- IPv6 adaptation to LLNs
  - Stateless and stateful header compression
  - Optimized neighbor discovery
  - Standard Socket API

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Link Layer Excursion

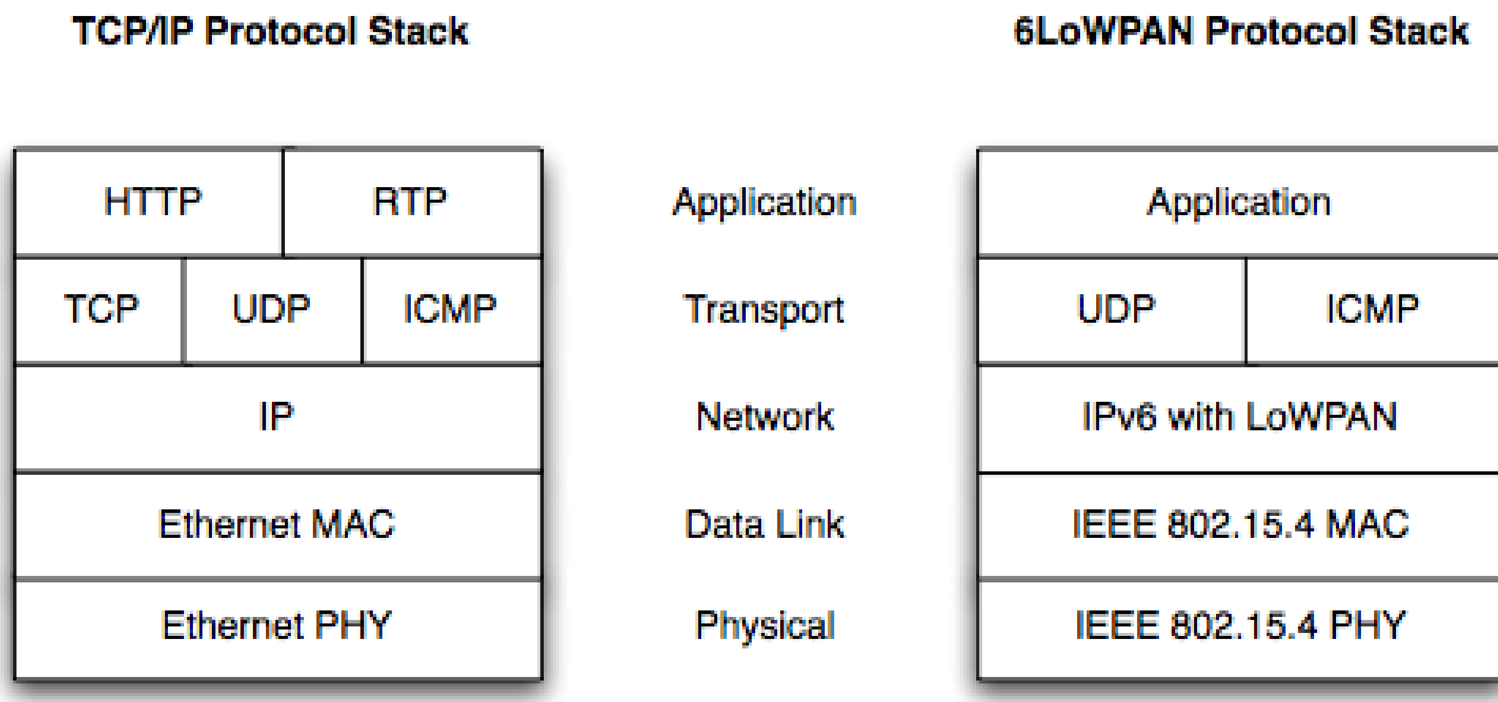
- Low power, typically battery operated
- Relatively low cost
- Inherently unreliable due to wireless medium
- Small packet size: ~100 Bytes
- Low bandwidth: ~100 kbit/s
- Topologies include star and mesh
- Networks are ad hoc & devices have limited accessibility
- Characteristics of 802.15.4:
  - 16-bit short or IEEE 64-bit extended MAC addresses
  - Entire 802.15.4 frame size is 127 bytes, 25 bytes frame overhead
  - Bandwidth ranges from 20 to 250 kbit/s
  - 802.15.4 subnets may utilize multiple radio hops

Challenges of LoWPAN

Impact Analysis	Addressing	Routing	Security	Network management
Low power (1-2 years lifetime on batteries)	Storage limitations, low overhead	Periodic sleep aware routing, low overhead	Simplicity (CPU usage), low overhead	Periodic sleep aware management, low overhead
Low cost (<$10/unit)	Stateless address generation	Small or no routing tables	Ease of Use, simple bootstrapping	Space constraints
Low bandwidth (<300kbps)	Compressed addresses	Low routing overhead	Low packet overhead	Low network overhead
High density (<2-4? units/sq ft)	Large address space – IPv6	Scalable and routable to *a node*	Robust	Easy to use and scalable
IP network interaction	Address routable from IP world	Seamless IP routing	Work end to end from IP network	Compatible with SNMP, etc

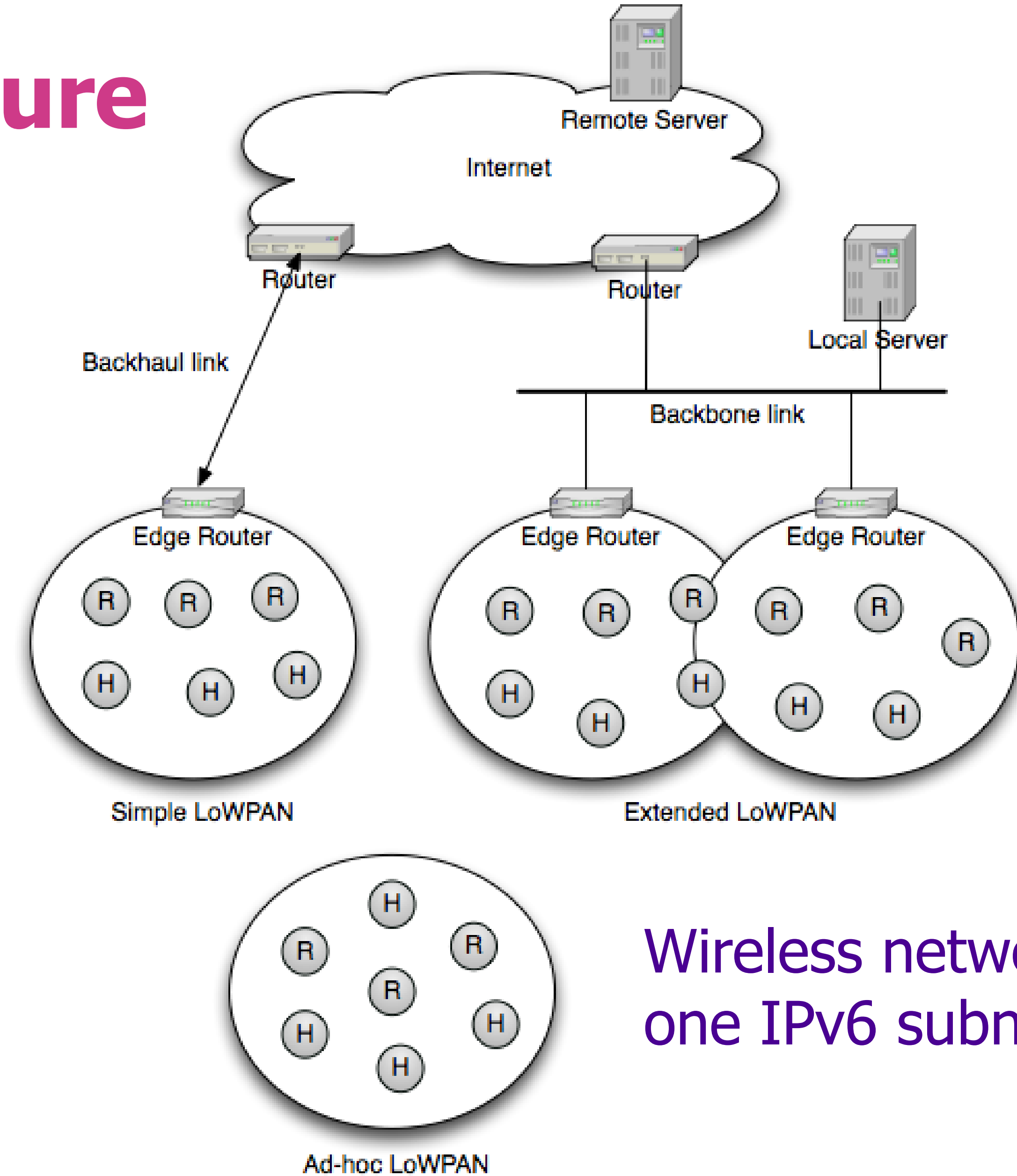
Source: Kushalnagar/Montenegro@IETF62

Protocol Stack



Source: Shelby & Bormann – 6LoWPAN, Wiley 2011

Architecture



Wireless network is one IPv6 subnet

Source: Shelby & Bormann – 6LoWPAN, Wiley 2011

Architecture

- o LoWPANs are stub networks
- o Simple LoWPAN
  - Single Edge Router
- o Extended LoWPAN
  - Multiple Edge Routers with common backbone link
- o Ad-hoc LoWPAN
  - No route outside the LoWPAN
- o Internet integration issues
  - Maximum transmission unit
  - Application protocols
  - IPv4 interconnectivity
  - Firewalls and NATs
  - Security

IPv6	
Ethernet MAC	LoWPAN Adaptation
	IEEE 802.15.4 MAC
Ethernet PHY	IEEE 802.15.4 PHY

IPv6-LoWPAN Router Stack

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Key Problems

- Efficient use of available bits in a packet
  - Frame: 127 bytes – 25 bytes L2 header
  - IPv6 header: 40 bytes, UDP header: 8 bytes …
- IPv6 MTU size ≥ 1280
  - IP packets need transparent fragmentation on frames
  - Lost fragments cause retransmission of entire packet
- Wireless ad hoc networks can be multihop
  - No direct router link ↔ Router Advertisement
  - Multicast is only local ↔ Neighbor Discovery

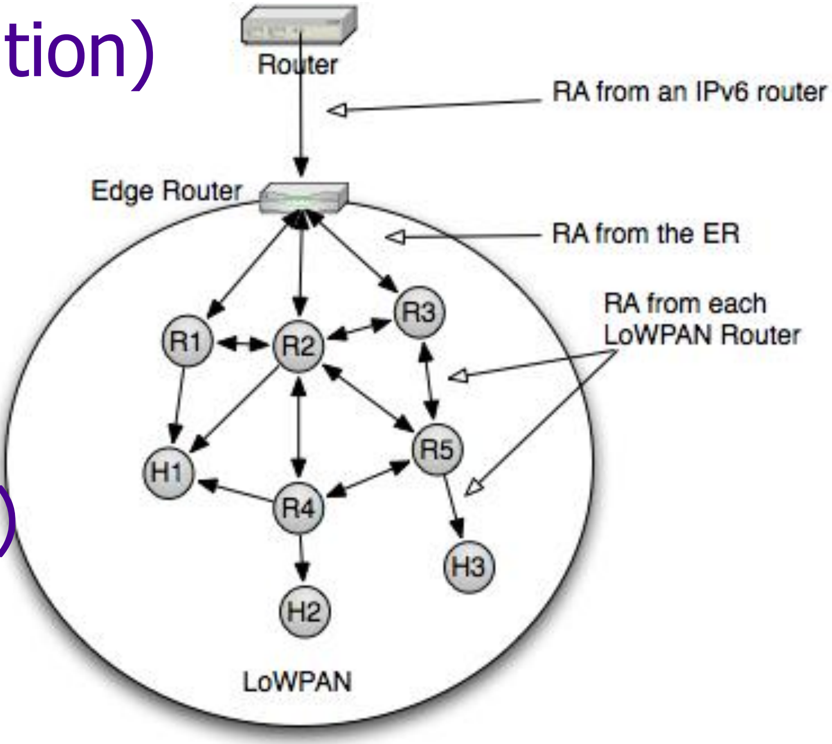
Base Solution: RFC 4944

Makes 802.15.4 look like an IPv6 link:

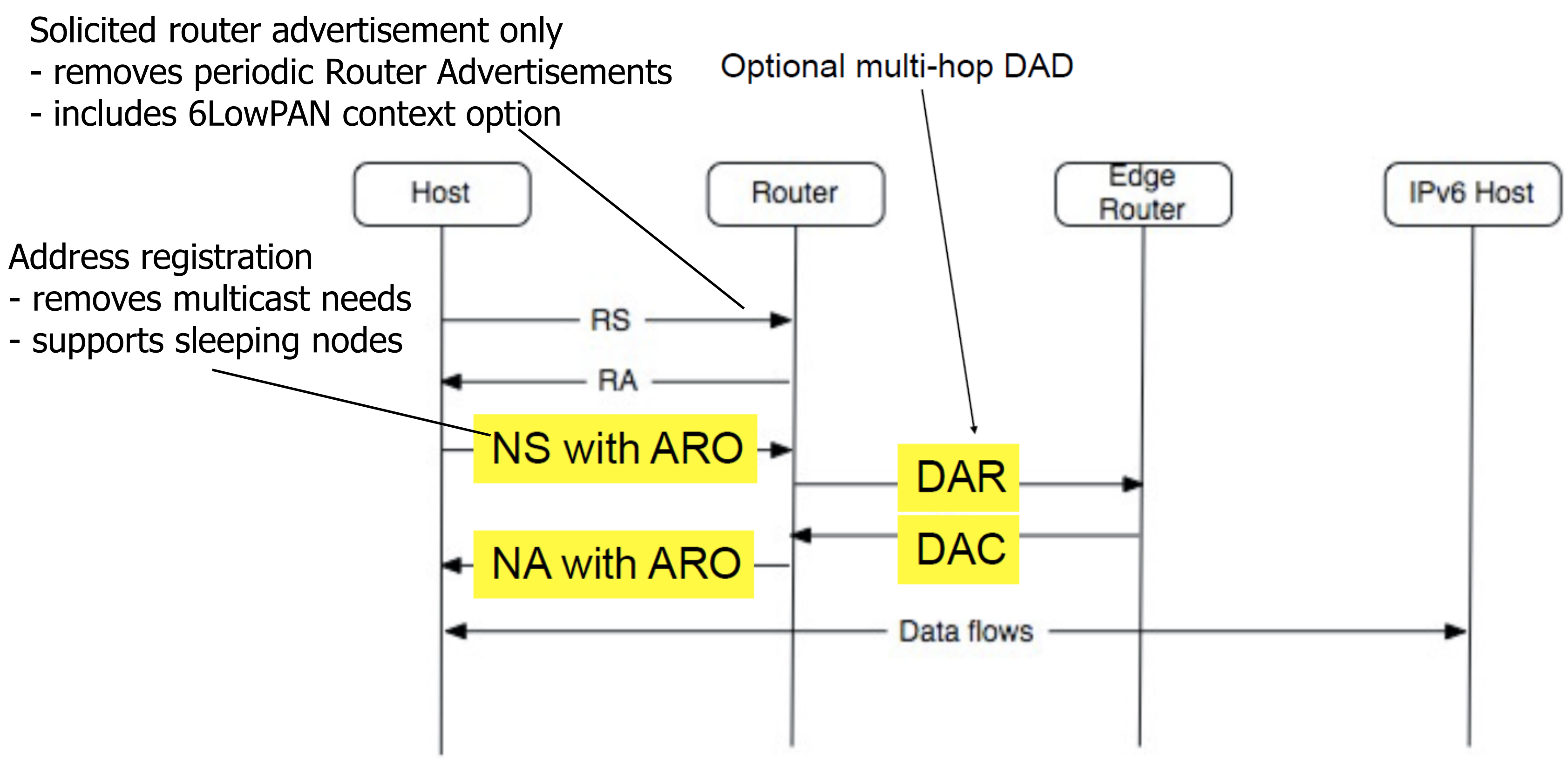
- o Efficient encapsulation
  - Stateless IP/UDP header compression of intra-packet redundancy
  - Unicast + Multicast address mapping
- o Adaptation layer for fragmentation (1280 MTU on ~100 bytes packets)
  - Fragmentation: Datagram tag + offset
  - No dedicated fragment recovery
- o Mesh forwarding
  - Link generated by „mesh-under" (L2) routing
  - Identify originator and final destination

Adaptive Neighbor Discovery RFC 6775

- Includes „route-over" (L3 routing)
- Multihop forwarding of Router Advertisements (GW and prefix dissemination)
- Address Registration and Confirmation at Router
- Router keeps track of wireless nodes (incl. DAD)



Typical 6LowPAN-ND Exchange



- o Authoritative Border Router Option (ABRO) to distribute prefix and context across a route-over network

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Improved Header Compression RFC 6282

- Router Advertisements distribute a well-known area context
  - Common prefix – LoWPAN is a flat network
  - 6LoWPAN-HC – header compression methods
- No addresses – Interface Identifiers derived from MAC addresses
  - Optional unicast and multicast address fields (compressed)
- Remaining IPv6 header fields compressed or elided
  - Length derived from frame, ToS and Flow Label elided
- Stateless UDP header compression including short ports and selected checksum removal
  - Length derived from frame length

LoWPAN UDP/IPv6 Headers

LoWPAN IPv6 UDP

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Dispatch with LOWPAN_IPHC   |   LOWPAN_NHC  |  Src  |  Dst  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          UDP Checksum         |          UDP Payload       ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Payload

6 Bytes!

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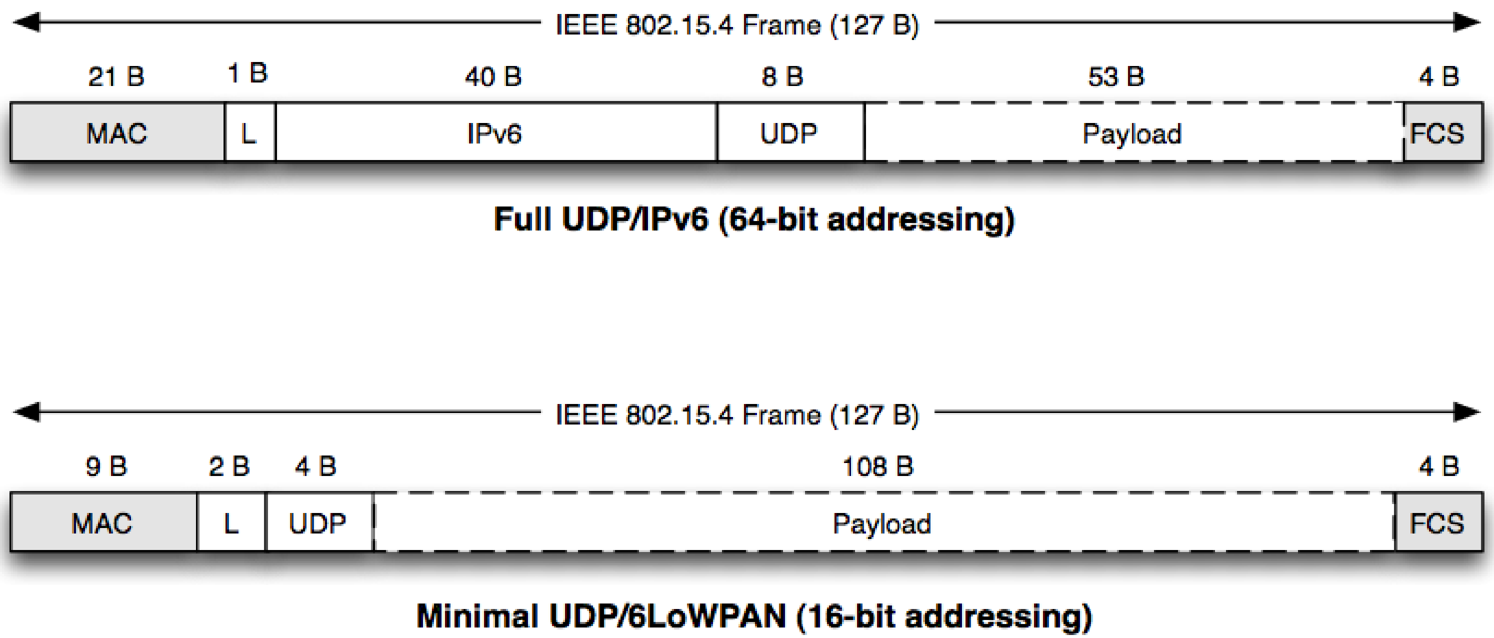
6LoWPAN Headers

- o Orthogonal header format for efficiency
- o Stateless header compression



Source: Shelby & Bormann – 6LoWPAN, Wiley 2011

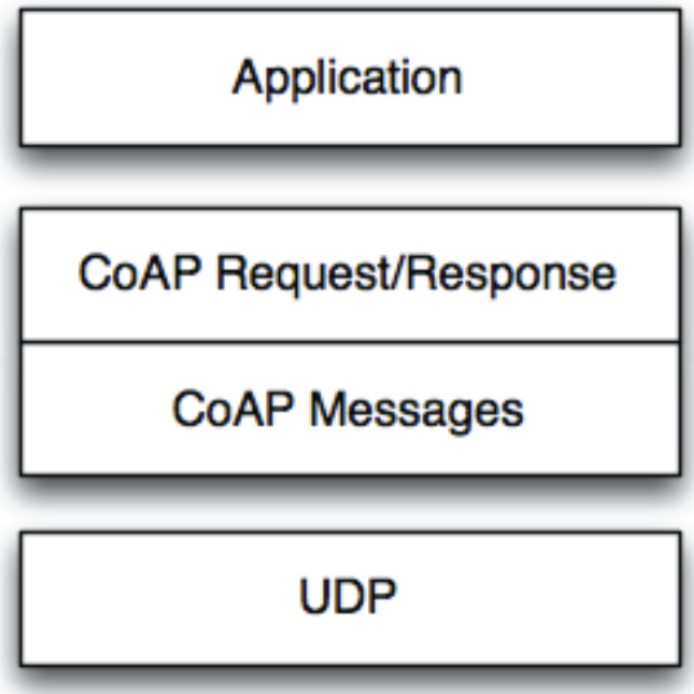
COAP: Constrained Application Protocol

- Constrained machine-to-machine Web protocol
- Representational State Transfer (REST) architecture
- Simple proxy and caching capabilities
- Asynchronous transaction support
- Low header overhead and parsing complexity
- URI and content-type support
- UDP binding (may use IPsec or DTLS)
- Reliable unicast and best-effort multicast support
- Built-in resource discovery

COAP Message Semantic

Four messages:

- Confirmable (CON)
- Non-Confirmable (NON)
- Acknowledgement (ACK)
- Un-processing (RST)



REST Request/Response piggybacked on CoAP Messages

Methods: Get, Put, Post, Delete

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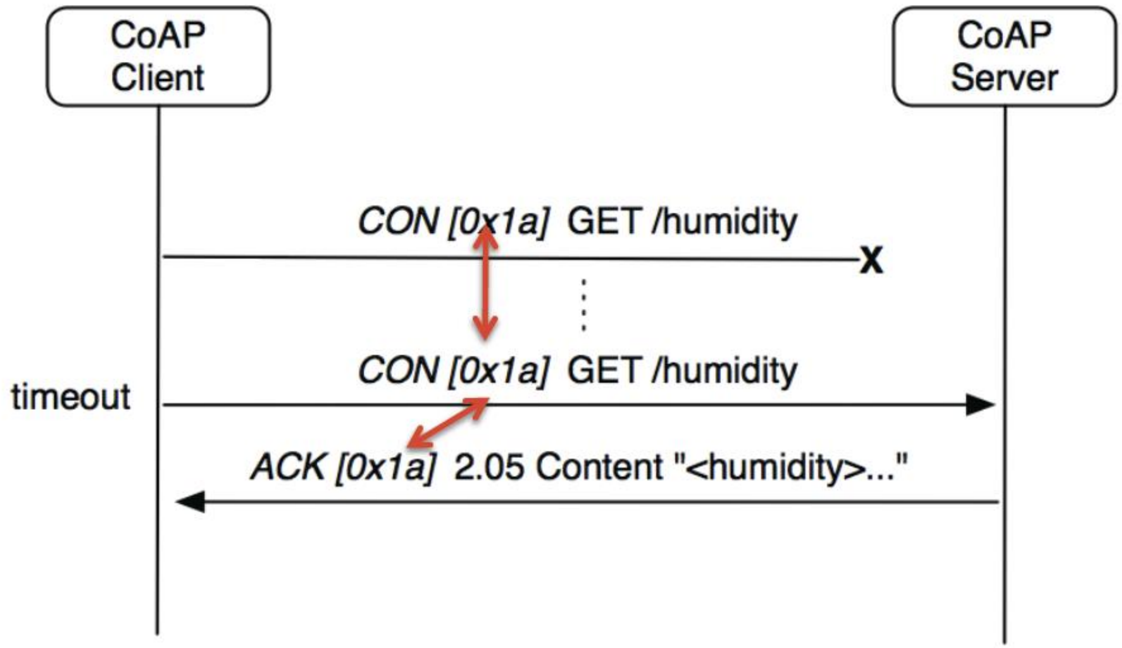
Message Transactions, Packet Loss



- Each message carries an ID (transactional processing) and an optional token (for asynchronous matching)
- Stop and Wait approach
- Repeat a request in case ACK (or RST) is not coming back

Further Aspects & Activities

- 6LoWPAN on Blue Tooth Low Energy
- Application Layer Encoding: CBOR
  - RFC 7049 Concise Binary Object Representation
  - Minimal code size, small message sizes
  - Based on the JSON data model
- Widely implemented:

Contiki

Bibliography

- Internet Society: *The Internet of Things: An Overview,* White Paper, Oct. 2015
  http://www.internetsociety.org/doc/iot-overview
- Zach Shelby, Carsten Bormann: *6LoWPAN: The Wireless Embedded Internet,* Wiley & Sons, 2009.
- Drafts, RFCs: tools.ietf.org, http://www.rfc-editor.org