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6LoWPAN and CoRE: How to get the next billion nodes on the **net** and into the **web**

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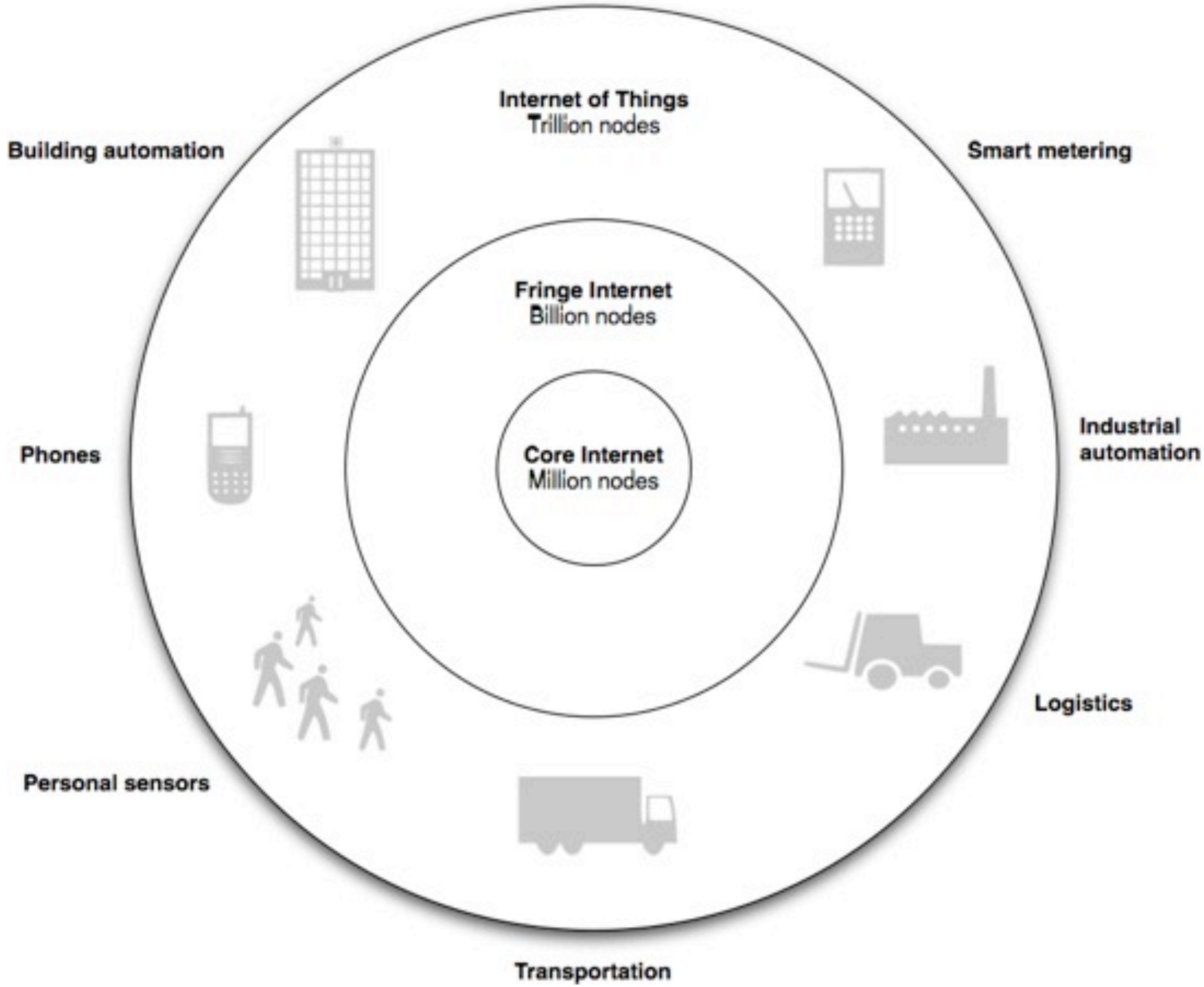
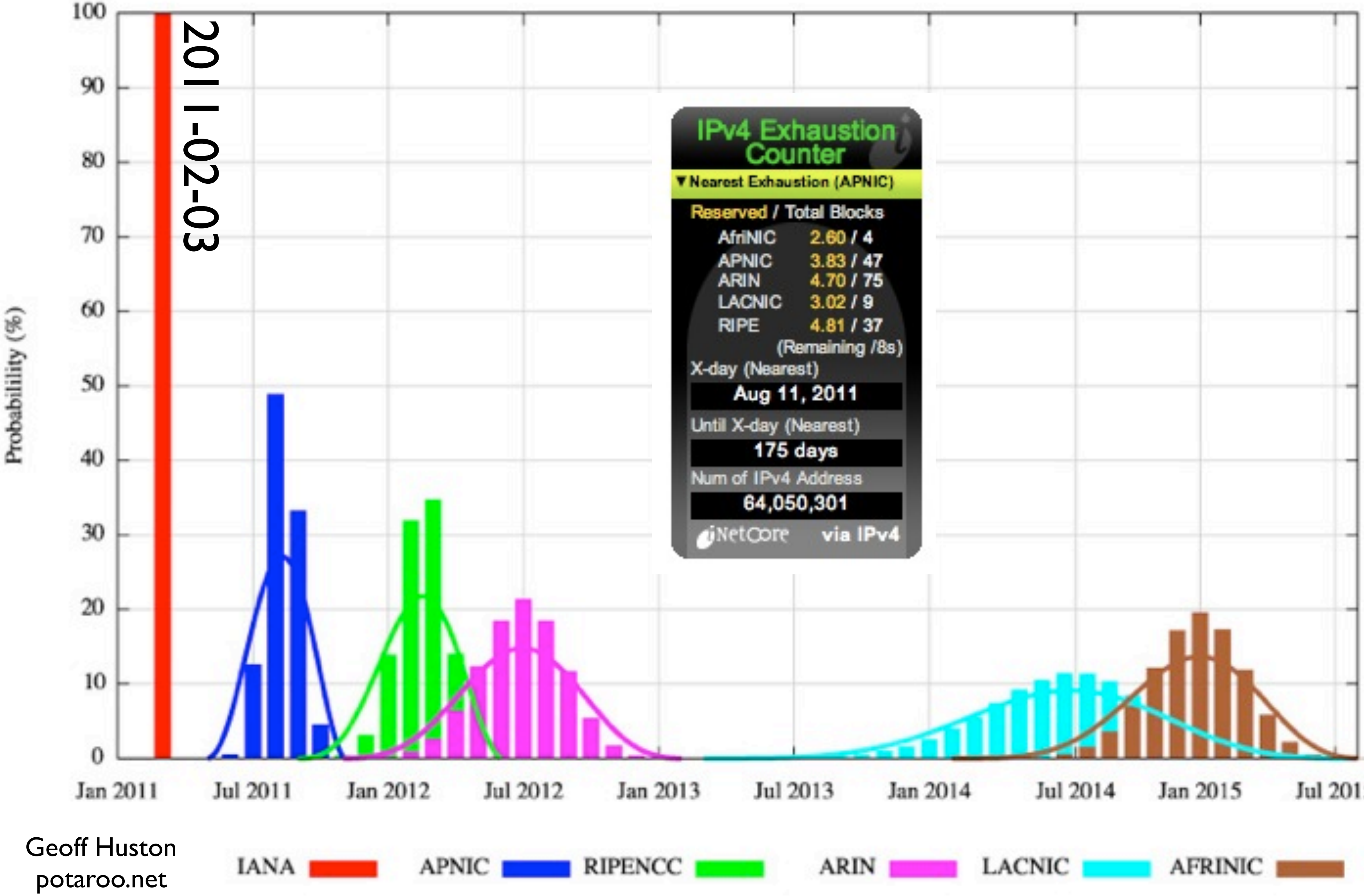

Internet of Things
Trillion nodes
Building automation
Smart metering
Fringe Internet
Billion nodes
Core Internet
Million nodes
Phones
Industrial
automation
Logistics
Personal sensors
Transportation

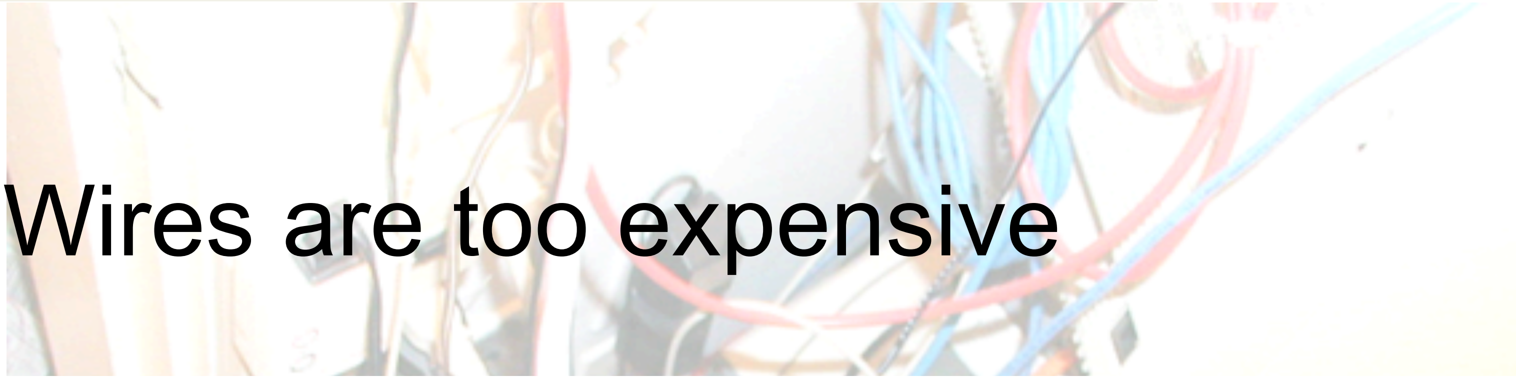
IPv4 Registry Exhaustion Dates



Geoff Huston
potaroo.net

IPv6 = $\underset{340282366920938463463374607431768211456}{3.4\times10^{38}}$ addresses

- There are only ~ 10^{25} grains of sand on the earth
- Let’s settle for a billion (**10^{9}**) objects on the net
- Danfoss (EU): 0.4×10^{9} thermostats so far
- Walmart (US): 0.1×10^{9} CFL light bulbs **per year**



Wires are too expensive

- Electrical wall socket + installation = $80
- Cat5 socket + installation = $150

- 1 billion nodes = GDP of Kuwait

Wireless?

Technology	Range	Speed	Power Use	Cost
WiFi	100 m	nn Mbit/s	high	$$$
Bluetooth	10–100 m	n Mbit/s	medium	$$
802.15.4	10–100 m	0.n Mbit/s	low	$

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Constrained node/networks

Internet of Things IoT
Low-Power/Lossy LLN
IP Smart Objects IPSO

- **Node**: a few MHz, ~10 KiB RAM, ~100 KiB Flash/ROM
- Often battery operated — must sleep a lot (μW!)

- **Network**: ~100 kbit/s, high loss, high link variability
- May be used in an unstable radio environment
- Physical layer packet size may be limited (~100 bytes)

- IETF WGs to date:

6LoWPAN	ROLL	**CoRE**
INT area (Internet) L2/L3 interface	RTG area (Routing) L3 routing	APP area (Applications) L7 application

6lowpan: IPv6 over Low-Power Area Networks (IEEE 802.15.4)

- IETF WG chartered in 2005 to define IPv6 over **802.15.4**
  - popular low-power (~ 1 mW) radio for 0.9 and 2.4 GHz bands
  - 20–256 kbits, up to 127-byte packets

- Two initial deliverables approved 2007-05-01
  - RFC 4919: Problem statement (“Goals and Assumptions”)
  - **RFC 4944**: Format specification (“IPv6 over 802.15.4”)
    - Encapsulation
    - Fragmentation
    - Minimal use of MAC (more than 802.15.4)

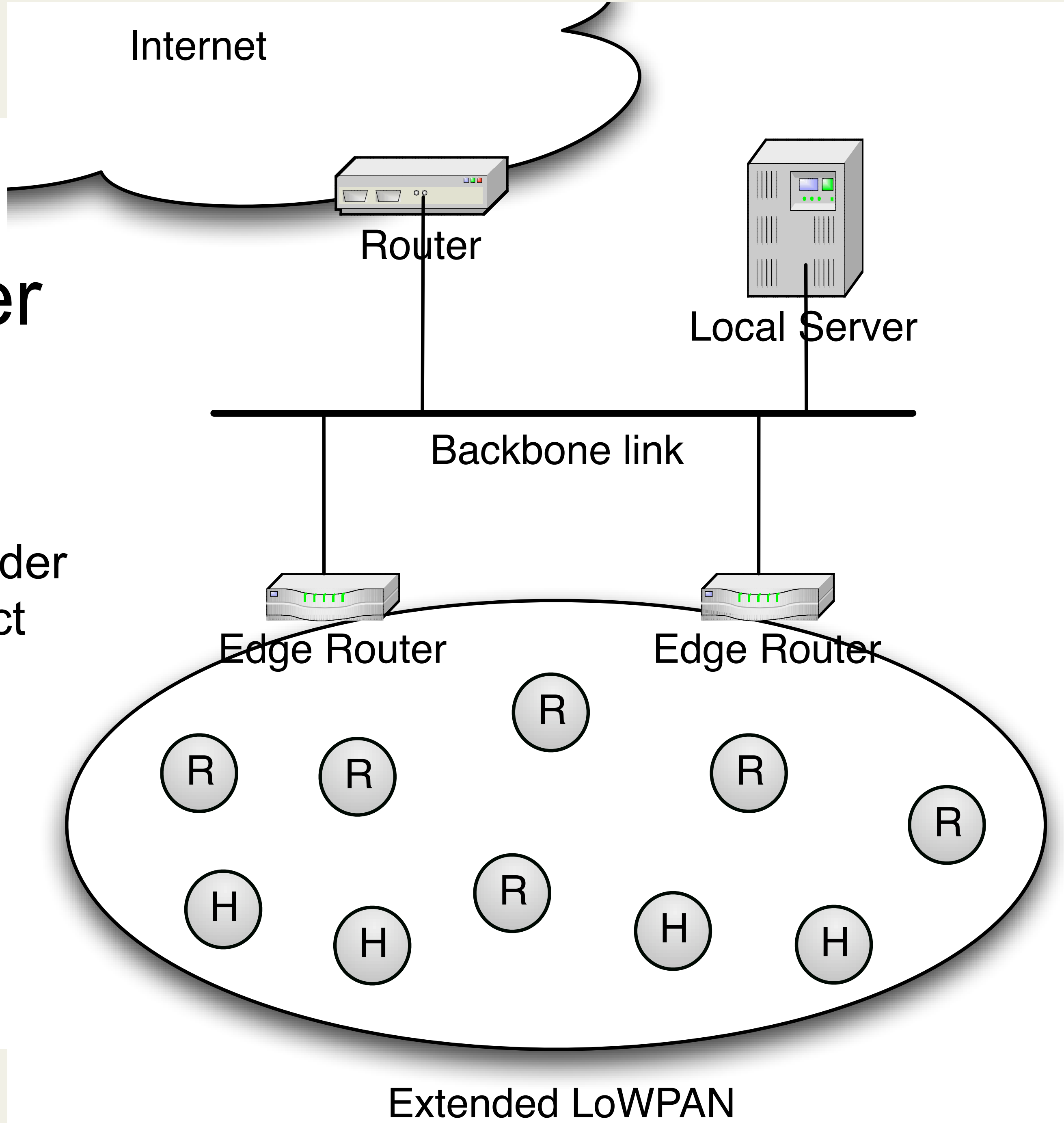
~~HC1 Header Compression~~

6LoWPAN-ND

- Classic IPv6: link ≡ multicast domain
  - can be realized by **mesh-under** (L2 routing) protocol
  - can be substituted by less multicast-reliant ND
- RFC 5889: **ad-hoc link model**
  - Alternative: confine link to radio domain
  - multicast is local only
  - need **route-over** (L3 routing) protocol to build larger 6lowpan
- Both mesh-under and route-over covered by single architecture

Route-Over

- One or more **Edge Routers** (6LoWPAN border routers) connect 6LoWPAN to global Internet
- 6LoWPAN comprises routers (6LRs) and hosts



6LoWPAN-ND elements beyond 4861

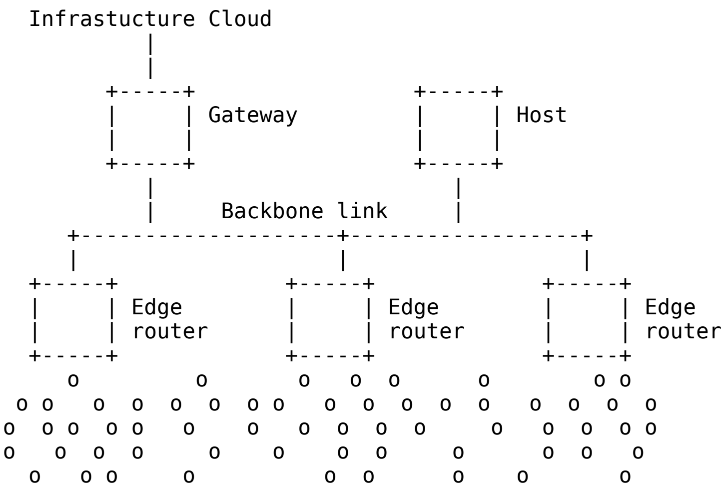
- **ARO** (address registration option):
  - hosts register their addresses to routers (6LRs): NS/NR
  - 6LRs can check the address with edge router (6LBR):
    new ICMP messages **DAR/DAC**
  - replaces NS/NR use for address resolution (off-link model),
    but keeps NS/NR intact for NUD (neighbor unreachability detection)
- **ABRO** (authoritative border router option)
  - distribute information about available 6LBRs (edge routers)
- **6CO** (6LoWPAN Context Option)
  - distribute header compression context in entire LoWPAN

6LoWPAN-HC: Header Compression

- RFC 4944 header compression is **stateless**
- Traditional header compression (ROHC, RFC 3095 etc.) is **flow-based stateful**

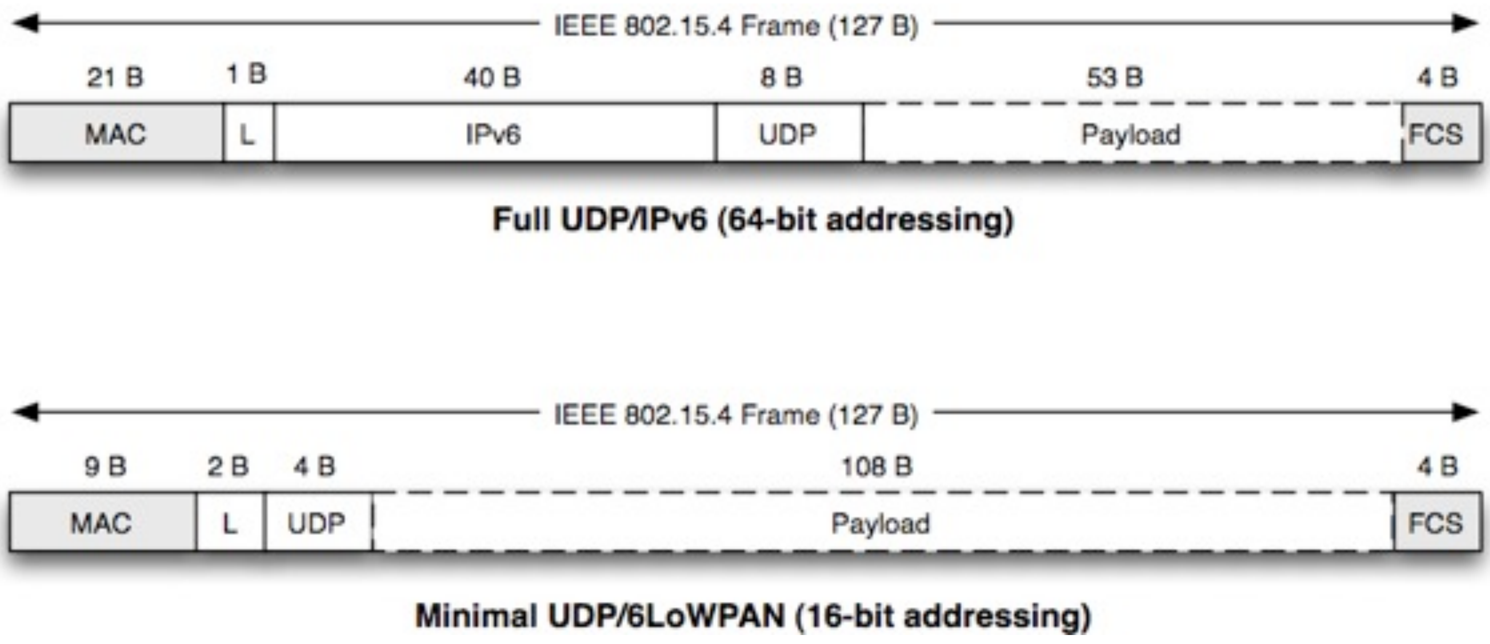
- Is there a middle ground?

- draft-bormann-6lowpan-cbhc (2008-07): maintain a single **area context state** for an entire 6LoWPAN

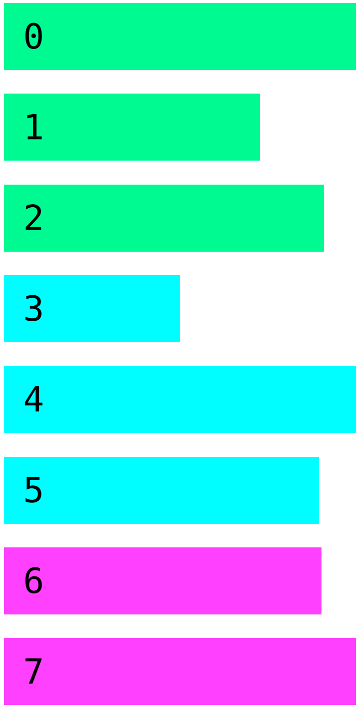


6LoWPAN Headers

- Orthogonal header format for efficiency
- Stateless header compression



Area context state



- up to 16 contexts, each with
  - a prefix (up to 128 bits), given by value and length
- Used in **6LoWPAN-HC** compression methods:
  - carry the variable bits in packet
  - infer variable bits from L2 addresses
  - special method for multicast addresses
- **6LoWPAN-ND** Context Option (6CO)
  - distribute context throughout 6LoWPAN
  - defined as part of 6LoWPAN-ND

New proposal: 6LoWPAN-GHC

- Generic compression of remaining headers
  and header-like payloads: ICMPv6, ND, RPL; DHCP; ...
- draft-bormann-6lowpan-ghc: simple LZ77 based on **bytecode**
  - **single-page** specification: simple
  - **stateless** (but can use 6LoWPAN-HC context)
- provides modest compression factors
  between 1.65 and 1.85 on realistic examples
- fits in 6LoWPAN-HC's NHC
- (WG adoption to be decided)

code byte	Action	Argument
0kkkkkkk	Append k = 0b0kkkkkkk bytes of data in the bytecode argument (k < 96)	The k bytes of data
0110iiii	Append all bytes (possibly filling an incomplete byte with zero bits) from Context i	
0111iiii	Append 8 bytes from Context i; i.e., the context value truncated/extended to 8 bytes, and then append 0000 00FF FE00 (i.e., 14 bytes total)	
1000nnnn	Append 0b0000nnnn+2 bytes of zeroes	
1001nnnn	reserved	
101nssss	sa += 0b0ssss000, na += 0b0000n000	
11nnnkkk	n = na+0b00000nnn+2; s = 0b00000kkk+sa+n; append n bytes from previously output bytes, starting s bytes to the left of the current output pointer; set sa = 0, na = 0	

Example: ND Neighbor Solicitation

- Payload:

```
 87 00 a7 68 00 00 00 00 fe 80 00 00 00 00 00 00
 02 1c da ff fe 00 30 23 01 01 3b d3 00 00 00 00
 1f 02 00 00 00 00 00 06 00 1c da ff fe 00 20 24
Pseudoheader:
 20 02 0d b8 00 00 00 00 00 00 00 ff fe 00 3b d3
 fe 80 00 00 00 00 00 00 02 1c da ff fe 00 30 23
 00 00 00 30 00 00 00 3a
copy: 04 87 00 a7 68
4 nulls: 82
ref(32): fe 80 00 00 00 00 00 00 02 1c da ff fe 00 30 23
 -> ref 101nssss 1 2/11nnnkkk 6 0: b2 f0
copy: 04 01 01 3b d3
4 nulls: 82
copy: 02 1f 02
5 nulls: 83
copy: 02 06 00
ref(24): 1c da ff fe 00 -> ref 101nssss 0 2/11nnnkkk 3 3: a2 db
copy: 02 20 24
Compressed:
 04 87 00 a7 68 82 b2 f0 04 01 01 3b d3 82 02 1f
 02 83 02 06 00 a2 db 02 20 24
Was 48 bytes; compressed to 26 bytes, compression factor 1.85
```

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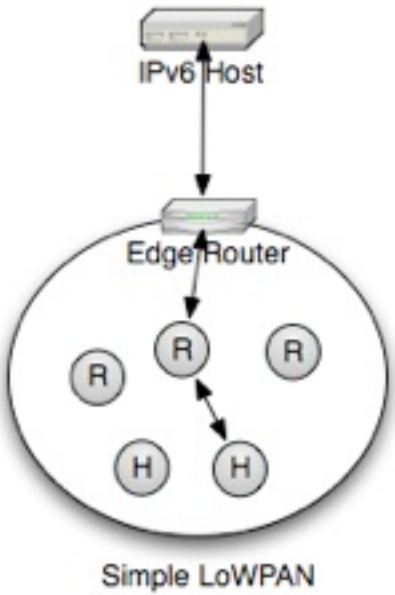
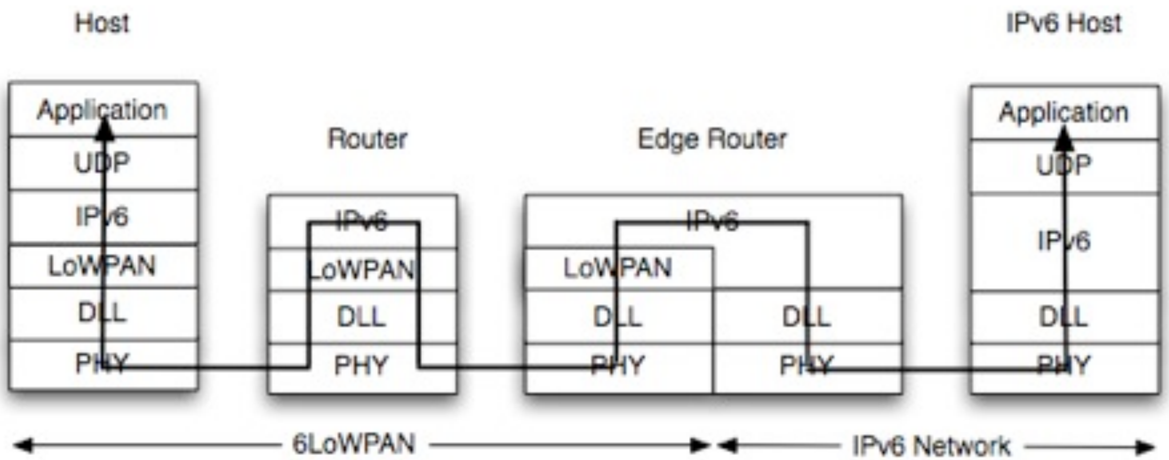
6LoWPAN =

RFC4944 – HC1 +
6LoWPAN-HC +
6LoWPAN-ND

6LoWPAN Routing

- Here we consider IP routing (at layer 3)
- Routing in a LoWPAN
  - Single-interface routing
  - Flat address space (exact-match)
  - Stub network (no transit routing)

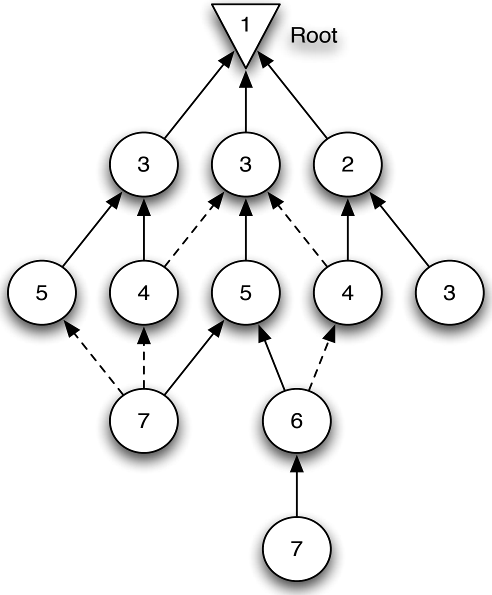


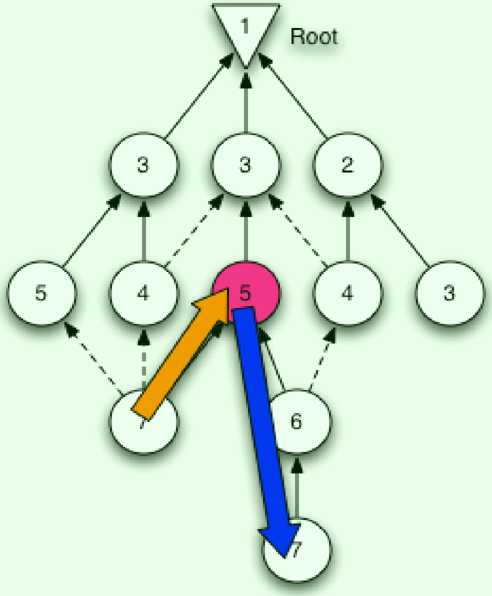


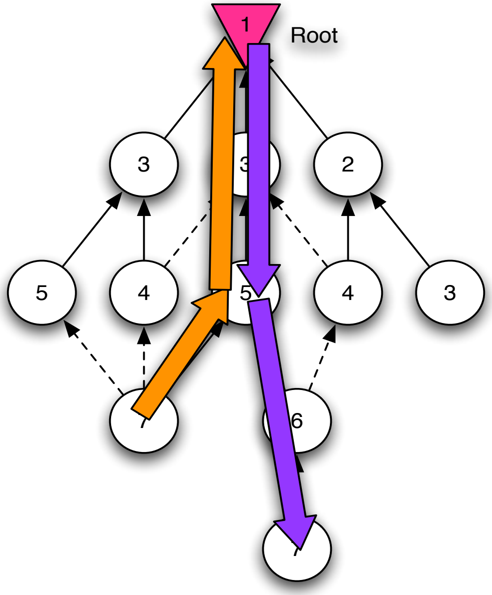
Routing for CN/N

Metrics: e.g., ETX

- ROLL WG: Specialized routing protocol RPL – Rooted DAGs (directed acyclic graphs)
  - **redundancies** in the tree help cope with churn
  - “**rank**”: loop avoidance
  - **Storing** Mode: Every router has map of **subtree**
  - **Non-Storing** Mode: Only **root** has map of tree







CoRE WG:
Constrained RESTful Environments

- Application protocol for constrained node/networks: **machine-to-machine (M2M)** applications
- Modeled after HTTP
  - but not just a “compressed HTTP” or a “HTTP over UDP”
  - sharing HTTP’s **REST** model that is underlying the Web

- **Simple** protocol, datagram only (UDP, DTLS)
- 4-byte header, compact yet simple options encoding
- GET, PUT, DELETE, POST; media type model

CoAP Examples

- GET coap://temp1.25b006.floor1.example.com/temperature
  - ASCII string: `22.5 C`
  - could use JSON, e.g. as in draft-jennings-senml-04.txt
- PUT coap://blue-lights.bu036.floor1.example.com/intensity
  - ASCII string: `70 %`
- GET coap://25b006.floor1.example.com/.well-known/core
  - `</temp>;n="TemperatureC",</light>;ct=41;n="LightLux"`
  - see draft-ietf-core-link-format-01.txt

More in draft-vanderstok-core-bc-02.txt

Example Interchange

Option

Payload

C: CON + GET coap://server/resource

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| 1 | 0 |   2   |     GET = 1     |            MID=1234           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| +5  =5 |   6   |          "server" (6 Bytes) ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| +4  =9 |   8   |         "resource" (8 Bytes) ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

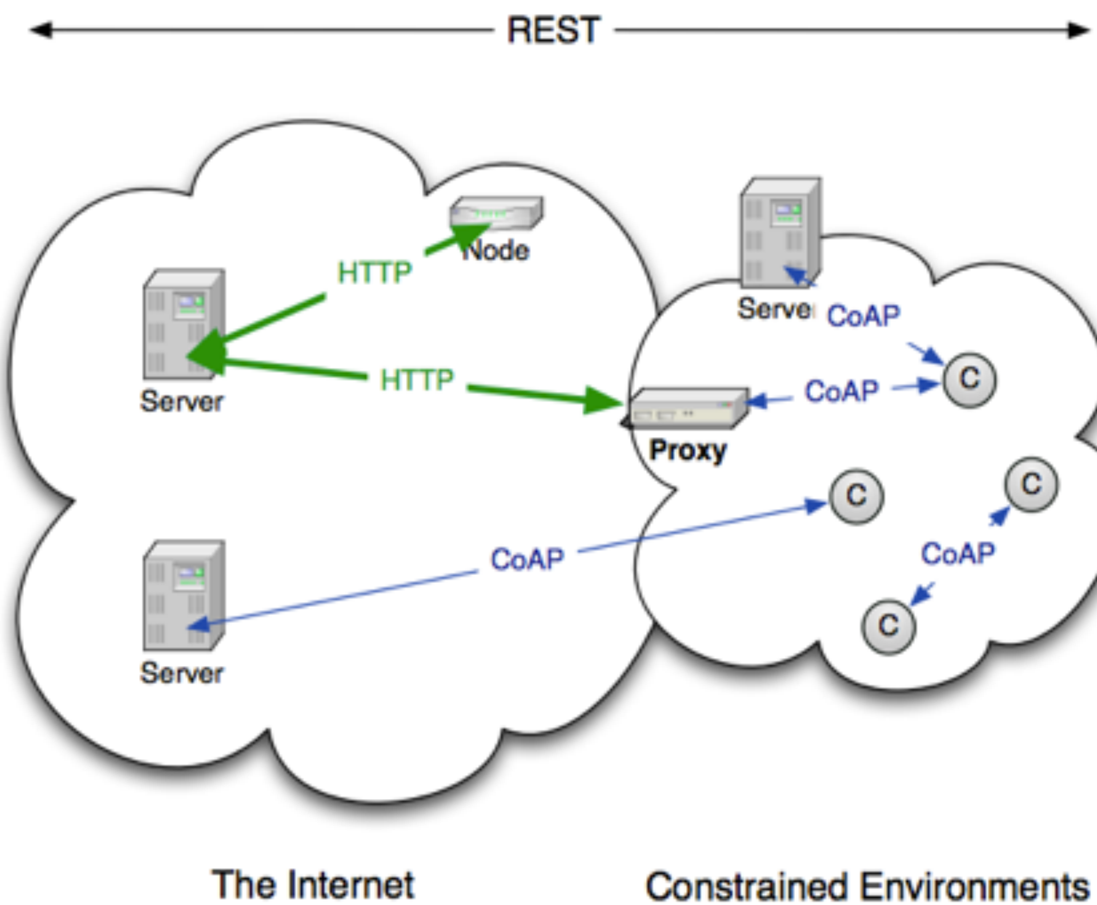
S: ACK, ct=text/plain, payload: Hello World

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| 1 | 2 |   1   |   S_OK = 2.00   |            MID=1234           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| +1  =1 |   1   |        0        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  "Hello World" (11 Bytes) ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Content-Type = 0 (text/plain)

Combining CoAP and HTTP

- CoAP is used in constrained environment
- CoAP and HTTP share proxy model based on REST
- Enables standard, application-independent proxy



http://tools.ietf.org/wg/6lowpan
http://tools.ietf.org/wg/core

6LoWPAN and CoRE status

- 6LoWPAN widely accepted as the way to run IP on 802.15.4
- Recent interoperability events for both 6LoWPAN-ND/ 6LoWPAN-HC and CoRE CoAP: 10+ implementations each
- 6LoWPAN-HC has passed working group last call (HC-14)
- 6LoWPAN-ND went through first WG last call
  - remaining technical details covered in stable ND-15
- CoRE CoAP in active WG work
  - base protocol quite stable (10+ implementations, interoperable)
  - “satellites” already interoperable, but refinement work continues: block segmentation, observation/notification, resource discovery