Compressing IP Forwarding Tables for Fun and Profit

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MŰEGYETEM 1782

ERICSSON

A Router in the DFZ

- Holds info on the whereabouts of every single IP address
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- So a DFZ router must be *huuuuuge*

Cisco CRS-3 line card
up to 8 Gbyte memory
533 MHz DDR2
>300 Watt

http://www.cisco.com/en/US/docs/routers/crs/crs1/4_slot/system_description/reference/guide/10805.pdf

A Router in the DFZ

- Holds info on the whereabouts of every single IP address
- That ought to be a huge amount of information
- So a DFZ router must be *huuuuuge*
- **Or must it?**

ASUS WL 500G Deluxe
32 Mbyte memory
4 Mbyte flash
200 MHz CPU
10 Watt

IP Forwarding Information Base

- A real FIB taken from `taz.bme.hu` (univ. access)
- Stores more than 410K IP-prefix-to-nexthop mappings
- Consulted on a packet-by-packet basis at line speed
  - Longest prefix match
- Takes several Mbytes of fast line card memory
- Some people argue that's a scalability barrier

Report from the IAB Workshop on Routing and Addressing, RFC 4984, 2007.

Zhao et al. *Routing scalability: an operator's view*, JSAC, 2010.

- Some people disagree

Fall et al. *Routing tables: Is smaller really much better?*, HotNets, 2009.

- Don't want to make this a debate on Internet routing scalability

How much information does a FIB actually need to store?

Can we achieve the storage size lower bound, retaining fast lookup?

Towards Compressed IP FIBs

- Store an IP FIB in as small space as possible
  - below 256–512 Kbyte
  - fit FIB into fast memory (SRAM/CPU cache)
  - maintain full forwarding equivalence
  - retain fast lookup!
- Our approach is systematic
  - identify redundancy in common FIB representations
  - eliminate it
  - attain entropy bounds
  - prototype and test on real traffic

Conventional FIB Representations

- Next-hops indexed on the alphabet $\Sigma = [0, K]$, $K \ll N$
- **FIB table:** lookup needs looping through all *N* entries
- Memory size is ~20 Mbytes on `taz`

Address/prefix length	Label
-/0	2
0/1	3
00/2	3
001/3	2
01/2	2
011/3	1

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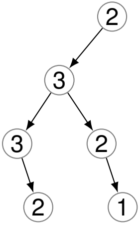
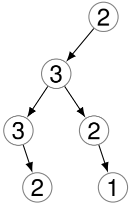


- **Binary trie:** search tree over the address space
- Lookup improves to optimal $O(W)$ for W bit address size
- ~4 Mbyte on `taz`

Redundancy in Binary Tries

- **Semantic redundancy:** entries superfluous due to longest prefix match



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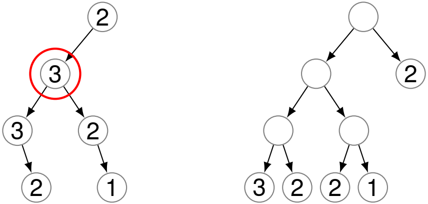

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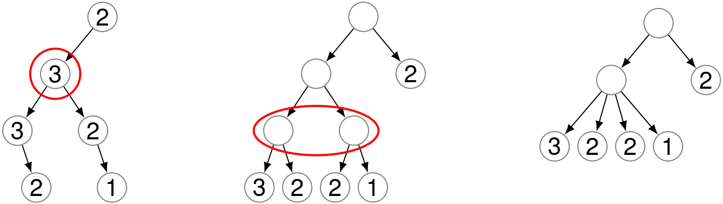
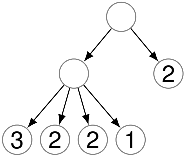


- Leaf-pushing: push interior labels down to leaves
  - ~1.3 Mbytes on `taz`
- **Structural redundancy:** remove excess levels
  - multibit tries have nice structure
  - $<$1 Mbytes

Information-theoretical Redundancy

- Certain labels appear frequently, encode these on fewer bits like Huffman-coding



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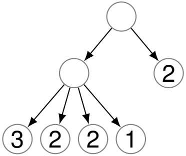

i	S_{last}	S_α	
1	1	0	level 0
2	0	0	level 1
3	1	2	
4	0	3	level 2
5	0	2	
6	0	2	
7	1	1	

- **Multibit Burrows-Wheeler transform:** serialize the trie in breadth-first-search order into two strings
  - S_{last}: bitstring encoding the tree structure
  - S_α: string encoding the labels
- Compress S_{last} and S_α to attain entropy bounds

Navigating MBW

- **String self-indexing:** a revolution is going around in TCS
- It is now possible to encode a string to higher-order entropy
- And provide O(1) operations on the compressed form!
  - the encoder supports simple navigational primitives in O(1)
  - lookup on MBW can be implemented in terms of these
- We use `RRR` on S_{last} and `Wavelet trees` on S_α
- Size is optimal in terms of the FIB entropy

$$H_0(p_c) = \sum_{c \in \Sigma} p_c \log \frac{1}{p_c}$$

- p_c is the empirical probability of next-hop labels in the FIB
- In fact, we can even attain higher-order entropy

Experiments on a Linux Prototype

- User space FIB compression, kernel module does lookup
  - could acquire only two real FIBs from the DFZ
  - rest is from collectors that obscure next-hop info
  - contain more than 410K entries

We need your help!
We need your FIBs!

Please, upload any FIB you can put your hands on to
`http://lendulet.tmit.bme.hu/fib_comp`

Output of `show ip bgp` or `show ip route` from a production DFZ router is preferred (but basically anything flies)

Experiments on a Linux Prototype

- User space FIB compression, kernel module does lookup
  - could acquire only two real FIBs from the DFZ
  - rest is from collectors that obscure next-hop info
  - contain more than 410K entries
- MBW compresses beyond zero-order entropy
  - 60–120 Kbytes (!) on FIBs with few next-hops
  - 256–400 Kbytes on FIBs with several hundred next-hops
  - 2–6 bits per prefix
- 3–10 complete rebuilds per second
- Churn out ~100 MBit/sec at 30-50 Kpps/sec

Demo

Discussion

- Contemporary FIBs can be encoded to 256–512 Kbytes with pointerless data structures
  - this is optimal, up to lower order terms
  - well below SRAM/cache size bounds of today
- And lookup is still *theoretically* optimal
  - in practice, two orders of magnitude worse than required
  - but this is only a proof-of-concept

Future?

- Entropy-compressed FIBs with linespeed lookup?
  - can we trade optimized HW away for optimized SW?
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  - how to get rid of it from the outset?

Future?

- Entropy-compressed FIBs with linespeed lookup?
  - can we trade optimized HW away for optimized SW?
  - that is, better FIB compression algorithms in SW
- FIBs contain vast redundancy
  - why?
  - how to get rid of it from the outset?
- Historic analysis of FIBs entropy
  - how has entropy changed throughout the years?
  - hard to do without real data

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