Routing and Addressing with Length Variable IP Address

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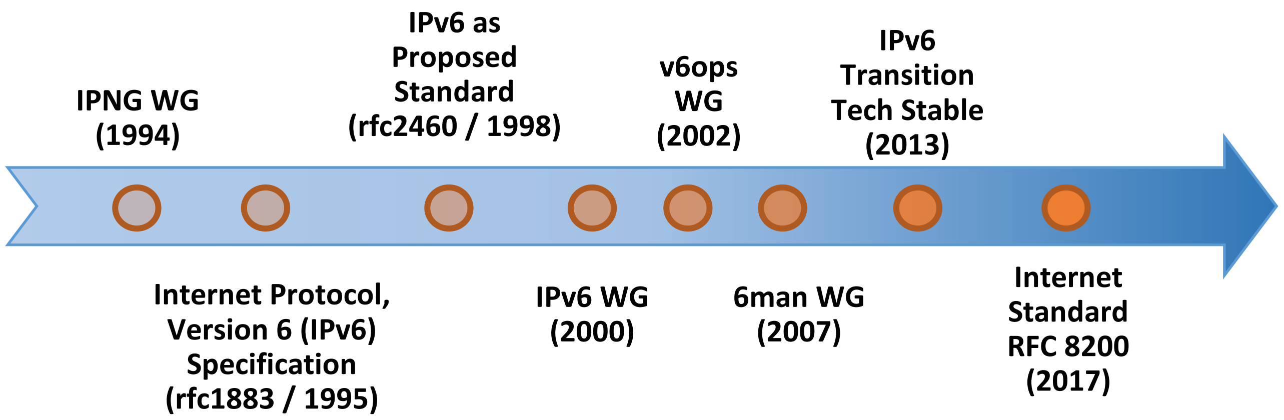
Backgrounds and Motivation

- Address exhaustion of IPv4
  - IPv4 address is 32 bits length
  - Provide limited address space (less than 4.3billion available addresses)
  - The last two /8 address blocks of IPv4 were assigned by IANA in 2011
- IPv6 was designed to solve the problem of address exhaustion
- However…

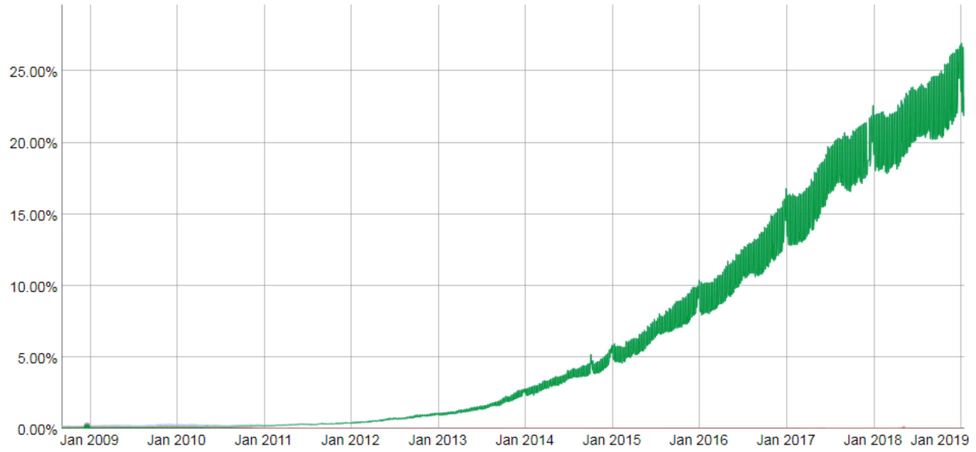
Backgrounds and Motivation

- **Poor compatibility with IPv4**
  - IPv4/6 are with separated address space and completely different protocol formats
  - More than one billion devices need to update, high costs
  - Information asymmetry with patching solution, like NAT64

- **IPv6 is NOT infinite**
  - Applied and assigned with prefix size of /32
  - By July 2017, 215959 blocks of /32 assigned （more than 1/20000 of all the available IPv6）



The percentage of users that access Google over IPv6.



From https://www.google.com/intl/en/ipv6/statistics.html

Backgrounds and Motivation

☐ Why IPv4 was designed with 32bits

- only for experiments, easy for processing, and no special reason

At the Google IPv6 Conference 2008, he hosted a panel discussion titled *What will the IPv6 Internet look like?* during which he recounted:

> The decision to put a 32-bit address space on there was the result of a year's battle among a bunch of engineers who couldn't make up their minds about 32, 128 or variable length. And after a year of fighting I said — I'm now at ARPA, I'm running the program, I'm paying for this stuff and using American tax dollars — and I wanted some progress because we didn't know if this is going to work. So I said 32 bits, it is enough for an experiment, it is 4.3 billion terminations — even the defense department doesn't need 4.3 billion of anything and it couldn't afford to buy 4.3 billion edge devices to do a test anyway. So at the time I thought we were doing a experiment to prove the technology and that if it worked we'd have an opportunity to do a production version of it. Well — [laughter] — it just escaped! — it got out and people started to use it and then it became a commercial thing.

Then we said "**how many countries are there?**" (two networks per country, how many networks?) and we didn't have Google to ask, so **we guessed at 128** and that would be 2 times 128 is 256 networks (that's 8 bits) and then we said "**how many computers will there be on each network?**" and we said "**how about 16 million?**" (that's another 24 bits) so we had a 32-bit address which allowed 4.3 *billion* terminations — which I thought in 1974/3 was enough to do the experiment!

By Vint Cerf, @ Google's IPv6 conference in 2008

☐ The address size was once discussed as a key issue in 1990s

- IETF IPng
  - 16 bytes scheme, typical proposal SIPP[1] (finally became IPv6)
  - 20 bytes scheme [2]
  - Variable length address scheme, typical proposal PIP[3]
- OSI (Open System Interconnect)
  - Variable length address scheme, typical proposal NSAP

[1]Robert Hinden. 1994. Simple internet protocol plus white paper
[2]S. Bradner and A. Mankin. 1995. The Recommendation for the IP Next Generation Protocol
[3]Paul F Tsuchiya. 1992. Pip Overview and Examples. Technical Report.

Backgrounds and Motivation

- None of the above proposals were wrong or others were right
- Some failed just because of the technique limitation at that time
- However, time is different now…

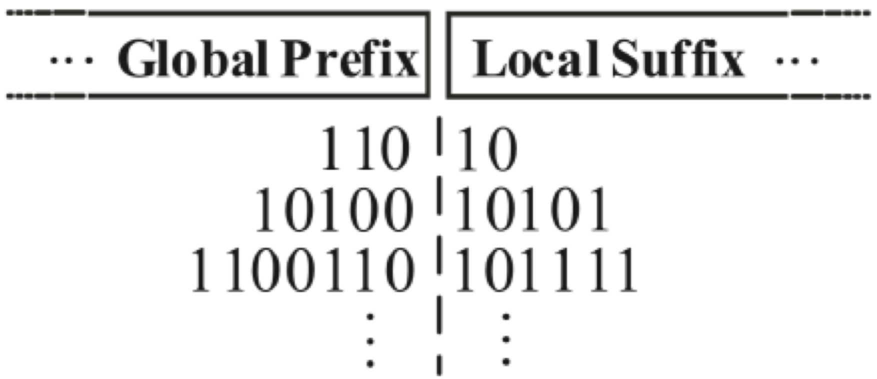
Backgrounds and Motivation

- Stronger and more powerful devices
- Demands for different address length are real
  - The number of Internet devices is growing faster than we think
    - 32bits -> 128bits, a long and hard transition way
    - 128bits -> longer ?
  - Many scenarios (especially IoT) requires shorter addresses
    - Closed scenario with short address
    - Light packet header in LLN
    - Many patching methods have been proposed to compress the 128bits, e.g. 6LoWPAN
- Why not to design a flexible address space that can
  - evolve smoothly itself, avoiding updates and transition
  - accommodate to different demands, avoiding patching

Flexible Address System (FAS)

Flexible Address Model

- FAS is composed of Global Prefix (GP) and Local Suffix (LS)
- GP is a centralized allocated unbounded-hierarchy, facilitating packet forwarding between multiple public connectivity providers
- Can be simply treated as a natural number and its size varies accordingly
- LS is a flexible address, assigned by the local network
- Both GP and LS are with infinite space



Flexible address space

Flexible Address System (FAS)

Textual Representation

- Flexible address can be uniformly divided into several units
- Flexible address can be represented textually with the conventional *dotted decimal form*
  - Auxiliary zeros can be added on the most left side，enabling the longest matching algorithm
  - $\underbrace{\underline{10}}_{\text{GP}}\ \underbrace{0100\ 0110}_{\text{LS}}$ $(\underline{2}.4.6) \rightarrow$ $\underbrace{\underline{0010}}_{\text{GP}}\ \underbrace{0100\ 0110}_{\text{LS}}$ $(\underline{0.2}.4.6)$
- As to flexible routing prefixes, denoted as *flexible-address/prefix-length*
  - 10 0100 0000, with 4 bits as mask number → 2.4.0/6 or 0.2.4.6/10
- Effective address v.s. expression address
  - $\underline{10}$ 0100 0000: effective address, 10 bits effective length
  - $\underline{0010}$ 0100 0000: expression address, 12 bits expression length

Flexible Address System (FAS)

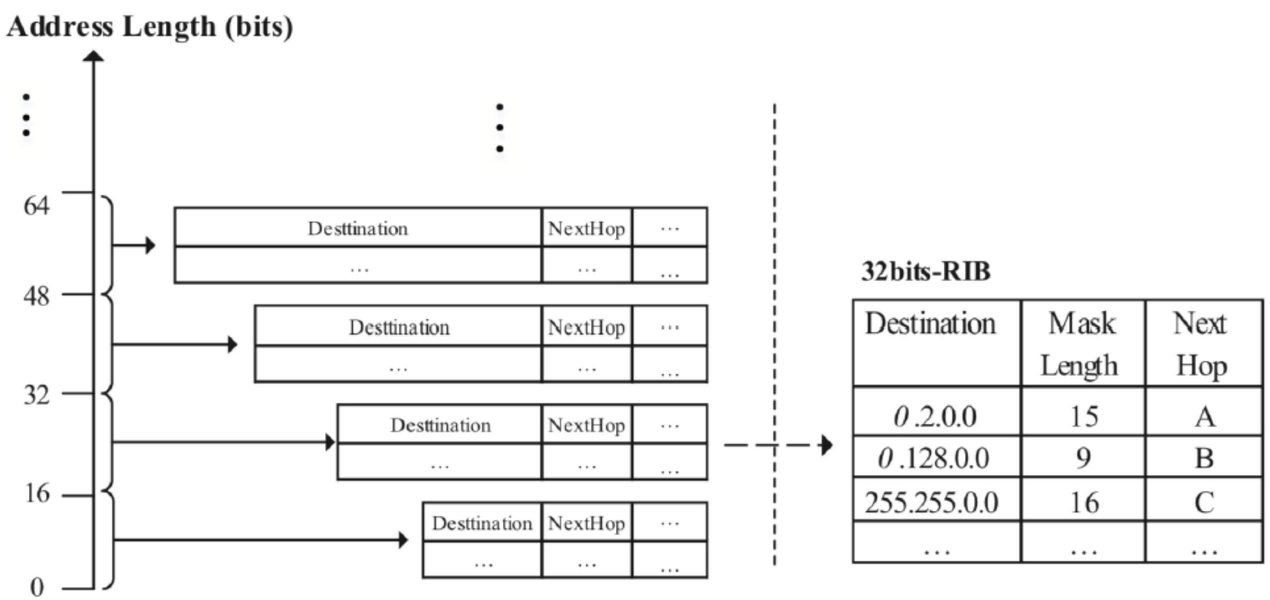
Basic Allocation Principles

- Centralized allocated by organization like IANA
- The value of *GP* and the size of *LS* need to be prescribed
- *LS* can be further divided into smaller subnets or assigned as specified local addresses
- A *GP* can be assigned to multiple organizations with different size of *LS*
  - *e.g.*, $\underbrace{\underline{2}}_{\text{GP}}.\underbrace{0.0}_{\text{LS}}$ → organization A $\underbrace{\underline{2}}_{\text{GP}}.\underbrace{0.0.0}_{\text{LS}}$ →organization B
- One address block can NOT be assigned twice, even with different *GP*
  - *e.g.*, if $\underbrace{\underline{2.2}}_{\text{GP}}.\underbrace{\underline{0.0}}_{\text{LS}}$ → *organization A*, <u>2.2.0</u>.0 or <u>2</u>.2.0.0 cannot be assigned

Routing and Addressing

Storing Routing Entries with Multiple Routing Information Bases (RIBs)

- FAS space is divided into continuous and disjoint intervals according to address length
- Each interval is bound to a RIB, routing entries belonging to same interval will be stored into a same RIB
- RIB-width: maximum address length of each interval

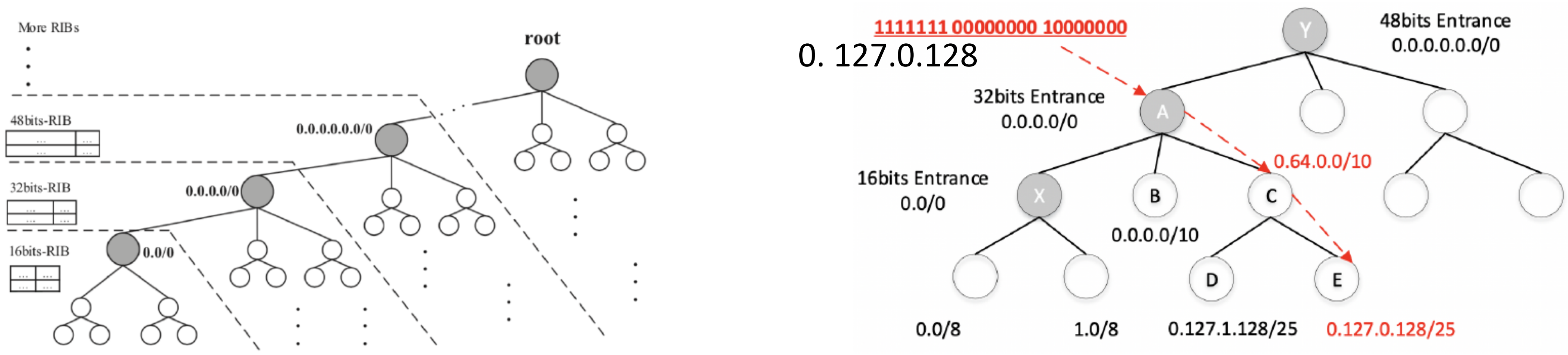


An example for multiple RIBs

Routing and Addressing

Lookup with *Multi-Entrance-Trie*

- RIBs are organized based on a new data structure, i.e., ***Multi-Entrance-Trie (METrie)***
- Multiple entrance nodes, represented by solid circles
- Each part stores routing information of its corresponding RIB, while the solid circle is the lookup entrance to that RIB
- Descendant nodes stores searching keys with the same RIB-width, each part is organized in Trie
  Lookup procedure is relatively straightforward
  - Effective length determination →RIB selection with RIB-width → longest prefix matching

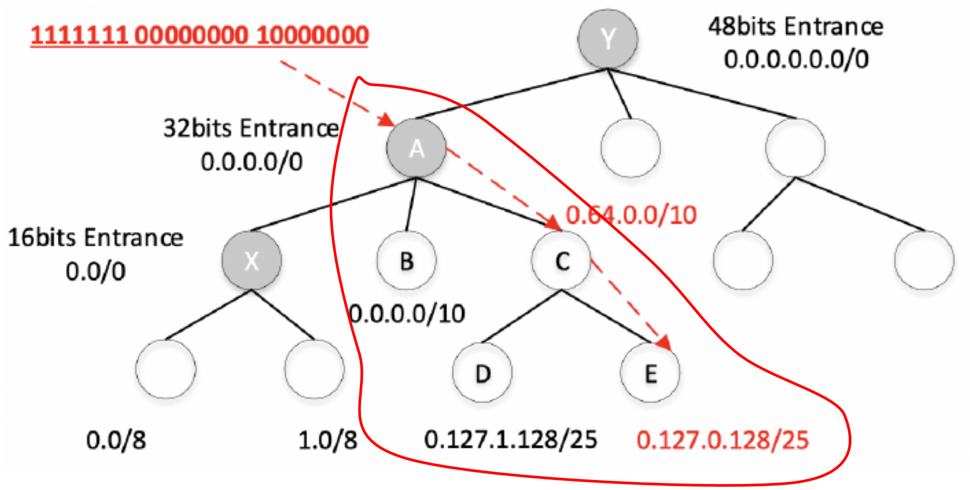


An example for Multi-Entrance-Trie

Routing and Addressing

Dynamically Pruning and Expanding *METrie*

- Pruning obsoleted branches
  - In some cases, routing entries stored in an existing RIB might be obsoleted
  - Corresponding branches need to be deleted

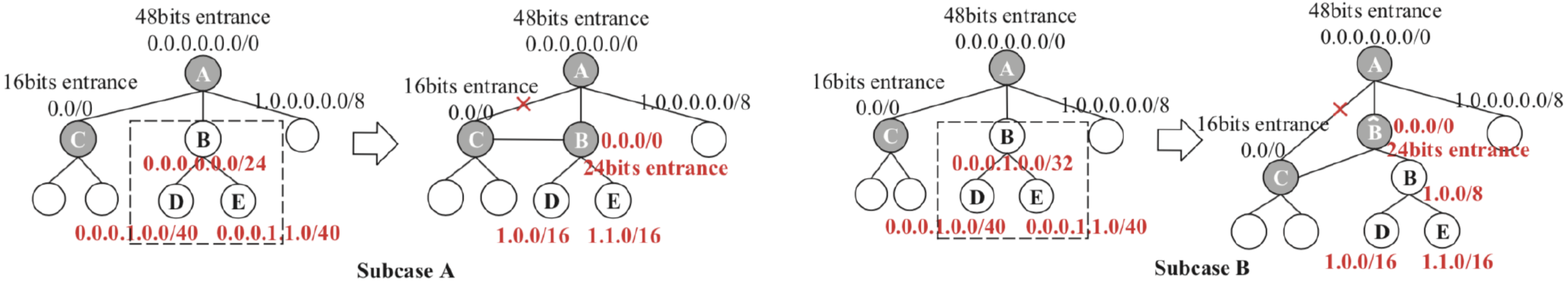


- Expanding upper branches
  - If an address or prefix is longer than the biggest RIB-width, existing *METrie* will be expanded with a new root

Routing and Addressing

- Inserting new entrance node in the middle of *METrie*
  - a router may need to create a new RIB which is 'smaller' than its biggest RIB-width for lookup efficiency reasons
  - a new entrance node needs to be added on the mountainside of the current *METrie*

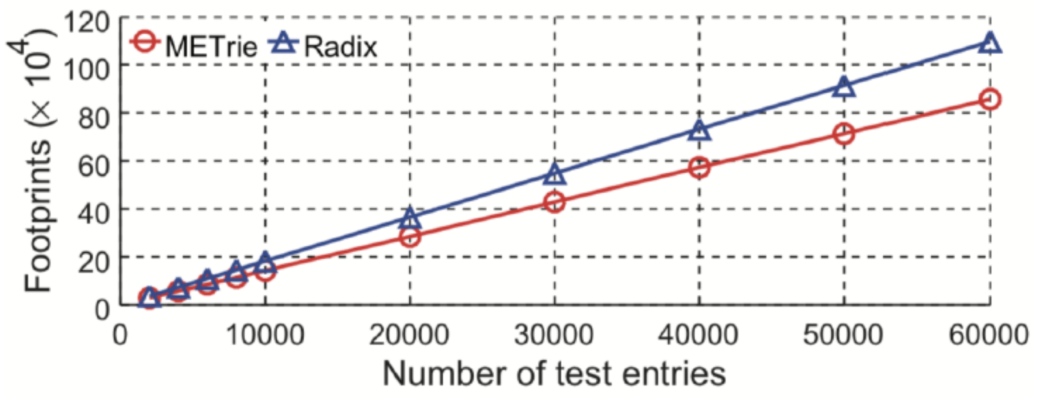
- Case A: the new entrance node already exists as a child node
- Case B: the new entrance node doesn't exist on current *METrie*



Inserting a new entrance node on METrie

Performance Evaluation

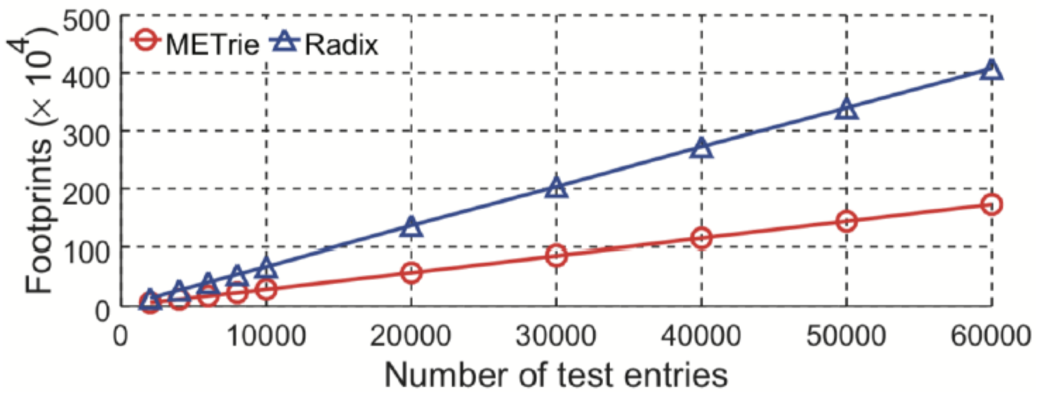
- Setup – for comparison with IPv4
  - 50,000 routing entries are generated randomly to initiate the METrie with length in 16 ~32 bits
  - *METrie* is designed with four entrance nodes while the corresponding RIB-width are 20bits, 24bits, 28bits and 32bits
  - The radix tree for IPv4 is also initiated and constructed with 50,000 randomly generated IPv4 routing entries
- Criterion
  - The number of nodes on *METrie* and radix tree that have been visited when searching routing entries



lookup performance of FAS and IPv4

Performance Evaluation

- Setup – for comparison of IPv6
  - 50,000 routing entries are generated randomly to initiate the METrie with length in 32 ~128 bits
  - *METrie* is designed with four entrance nodes while the corresponding RIB-width 32bits, 64bits, 96bits and 128bits
  - The radix tree for IPv6 is also initiated and constructed with 50,000 randomly generated IPv6 routing entries
- Criterion
  - The number of nodes on *METrie* and radix tree that have been visited when searching routing entries



lookup performance of FAS and IPv6

Conclusion & Future work

- Many applications propose different demands on IP addresses, while fixed length addresses cannot accommodate to them well

- A flexible address space benefits the long-term evolution of the Internet in the following aspects, this paper only proposes a candidate solution on this direction
  - Evolve and extend smoothly, without defining new address space and protocol formats
  - Allows people to apply for an address space with suitable length
  - Addresses with different length can communicate with each other

- We are now working on a flexible Internet protocol than can provide
  - Length variable IP address
  - More flexible and power functions than conventional IP

- A demonstration is also under developing

THANK YOU