IPv4 Address Allocation and Evolution of BGP Routing Tables

- Xiaoqiao Meng, xqmeng@CS.UCLA.EDU
  - Zhiguo Xu, zhiguo@CS.UCLA.EDU
- CJ Wittbrodt, cjw@packetdesign.com
  - Songwu Lu, slu@CS.UCLA.EDU>
  - Lixia Zhang, lixia@cs.ucla.edu

Overview

- Regional Internet Registries (RIRs) allocate and assign IP address blocks
- Do prefixes show up in the routing as allocated?
- The evolution of the routing table over the last 4 years
- What can we conclude from this info?

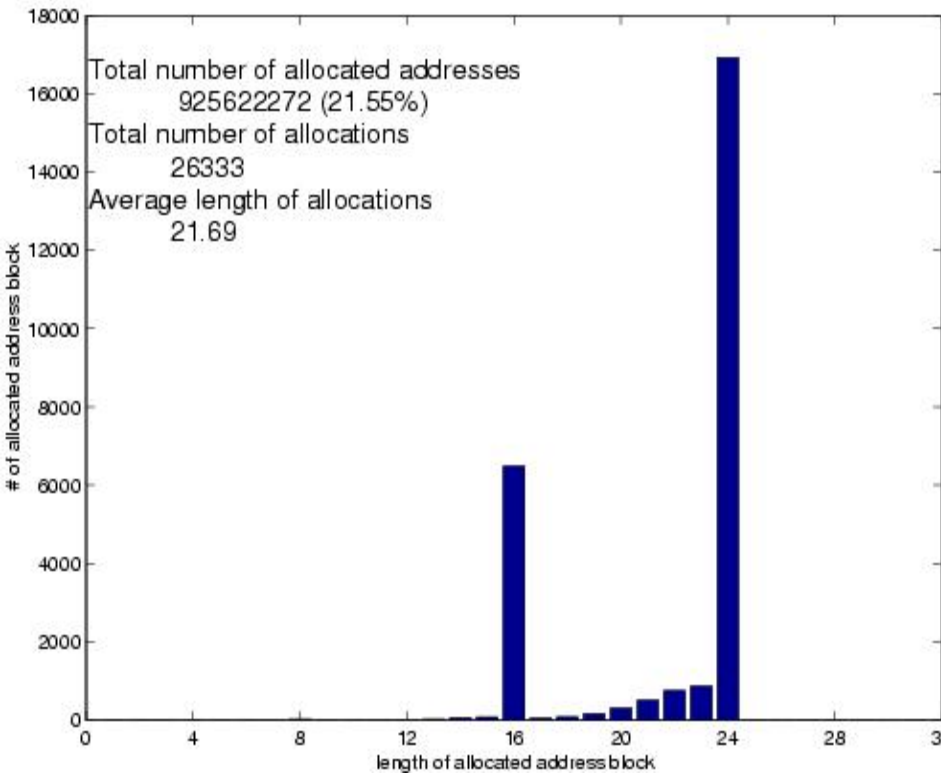# IPv4 Address Allocation

- In hierarchy fashion
  - Four regional Internet Registries (RIR)
  - ISP, Large enterprises
  - End-Users
- Policy changes
  - Classless Inter-domain Routing (CIDR)
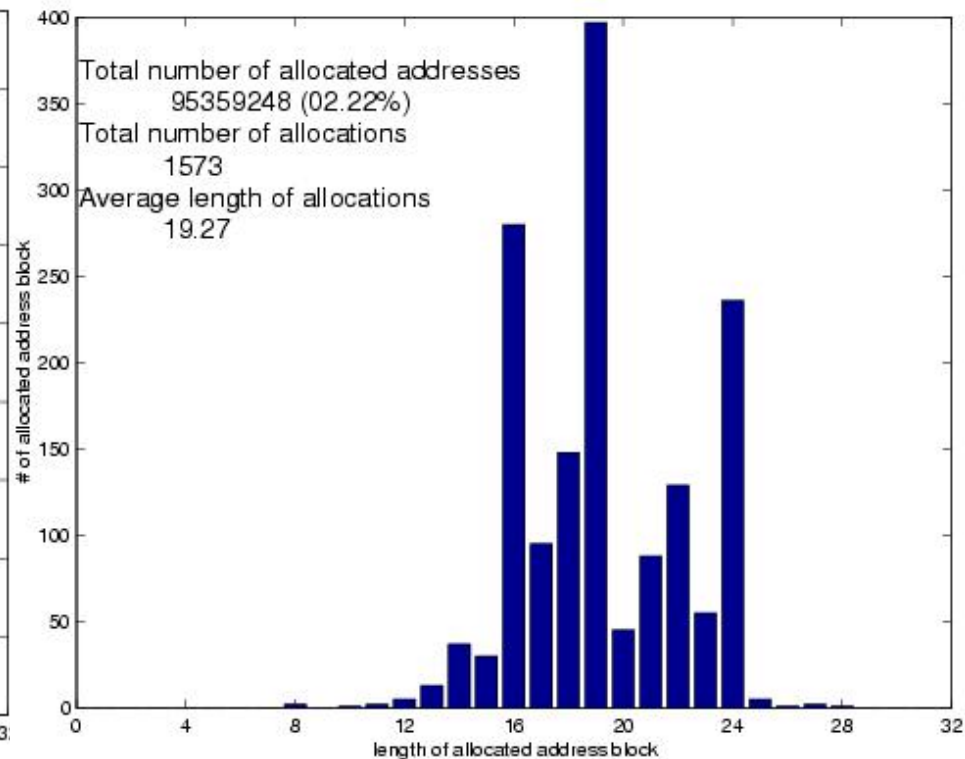 - Default allocation size from /19 to /20 (2000)

Migration of Address Allocation Policy

- How has IPv4 address allocation/assignment been performed?
  - Block Sizes and bit alignment
- What is distribution of prefix lengths over time?

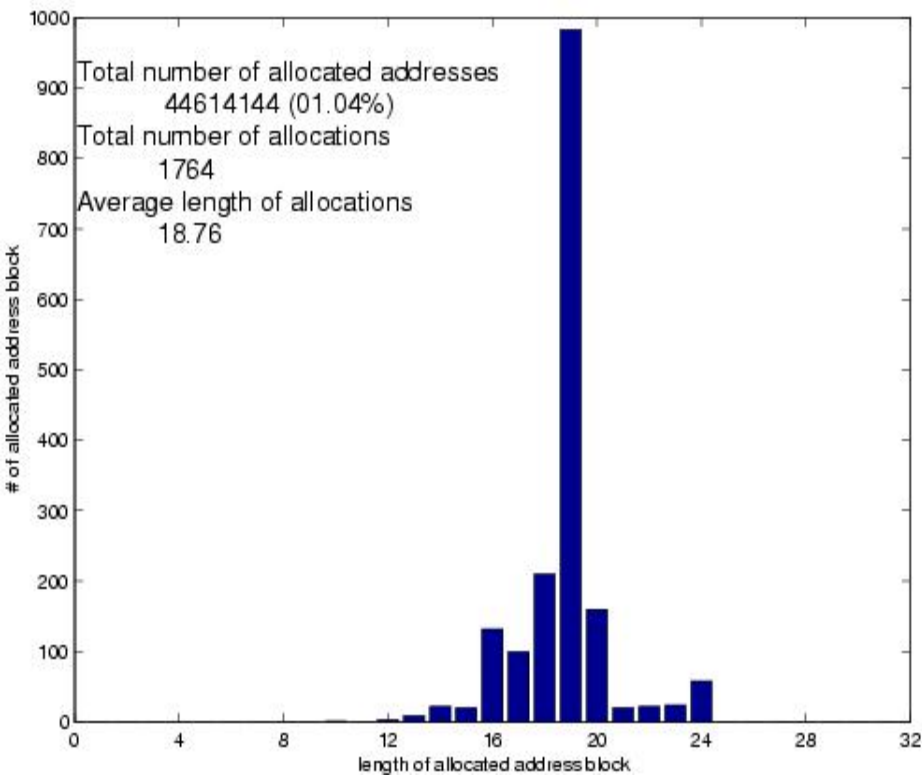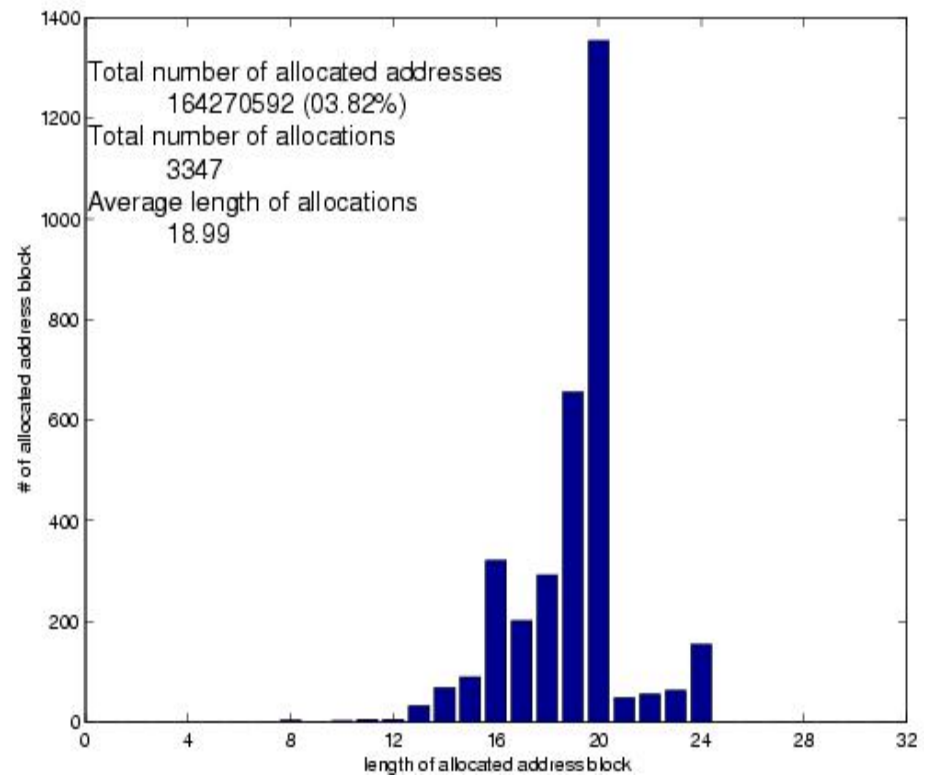# Distribution of Address Allocation (before and after CIDR deployed)

1993

1996

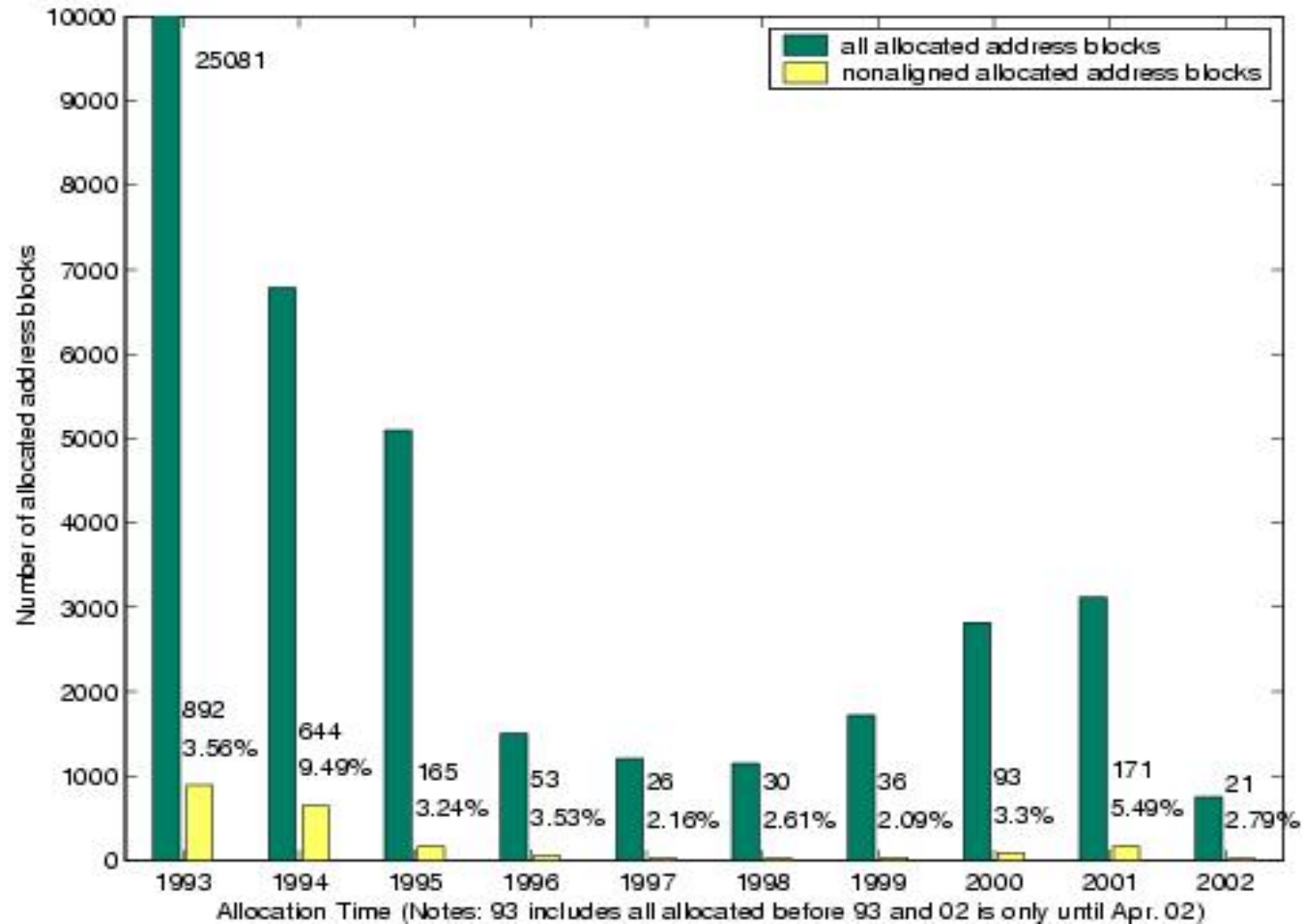# Distribution of Address Allocation (before and after "/19 to /20")

Total number of allocated addresses
44614144 (01.04%)
Total number of allocations
1764
Average length of allocations
18.76

Total number of allocated addresses
164270592 (03.82%)
Total number of allocations
3347
Average length of allocations
18.99

1999   2001

Allocated Blocks Over Time

Allocation Time (Notes: 93 includes all allocated before 93 and 02 is only until Apr. 02)
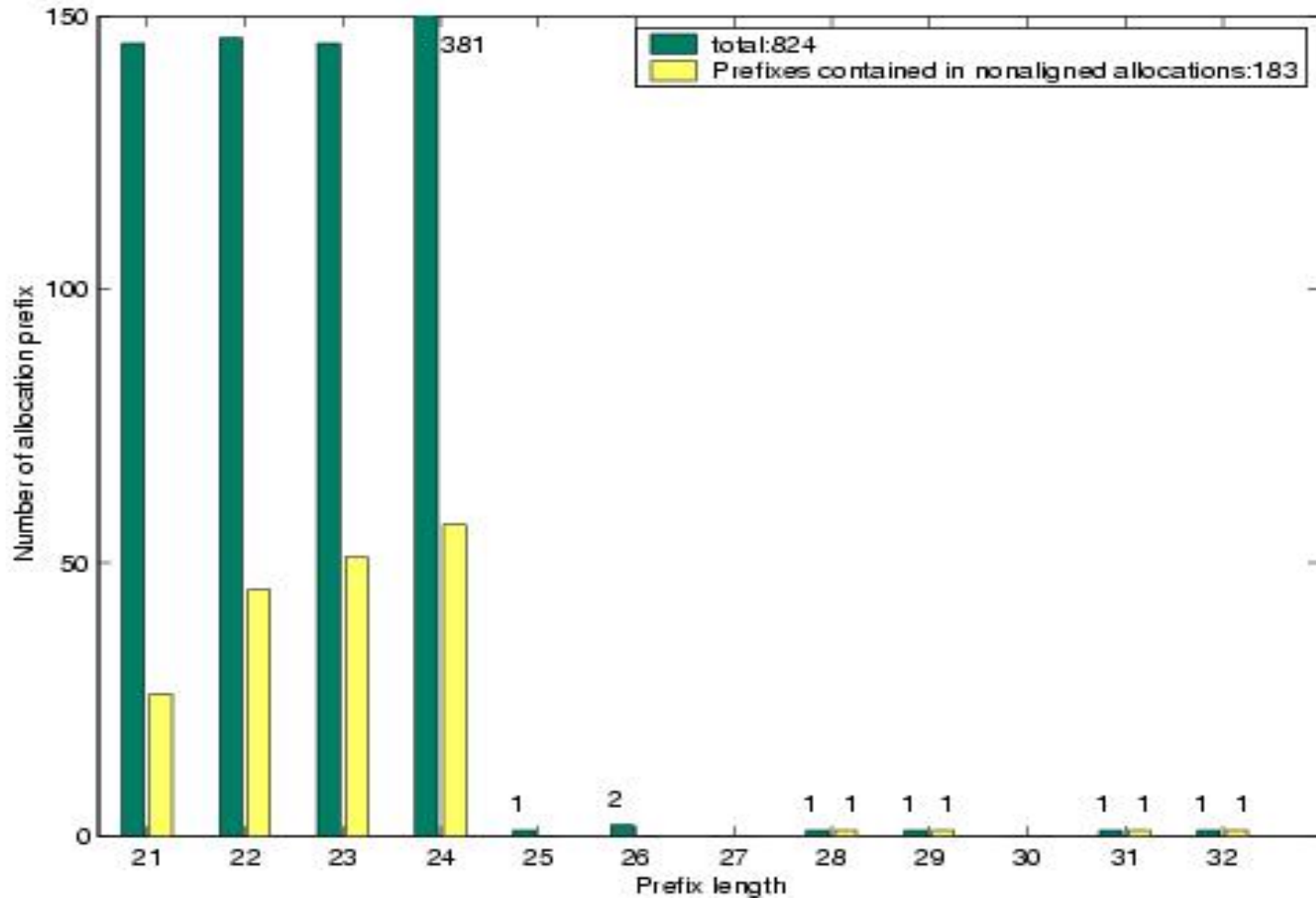
Small Allocated Blocks (01/01/1998-04/30/2002)

Non-Aligned Prefixes?

- Arin|US|ipv4|209.243.9.128|27|19980717|assigned
  - This can be broken into 4 prefixes
    - 209.243.9.128/28, 209.243.9.144/29, 209.243.9.152/31, 209.243.9.154/32
  - Another allocation was a /16 assigned all except last /24.
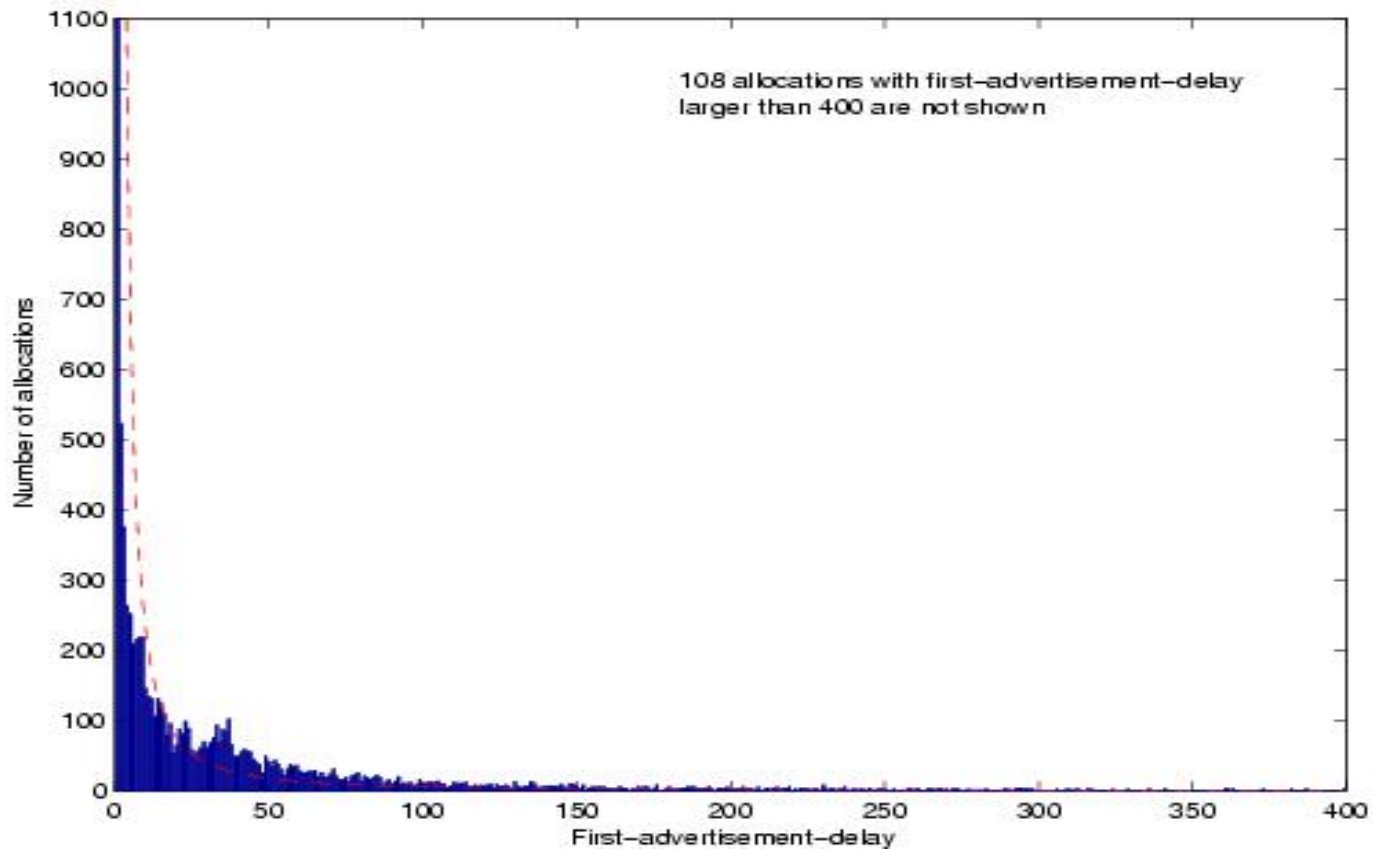 - Some just look non-aligned because of database representation

Appearance in Routing Table

- Do allocated/assigned blocks always appear?
- How long after they are allocated do they appear?
- How do they appear? Aggregated? Fragmented?
- Our study period: 1/1/98 -- 4/30/02
  - total allocated prefixes: 9,554

Do All the Allocated Prefixes Appear?
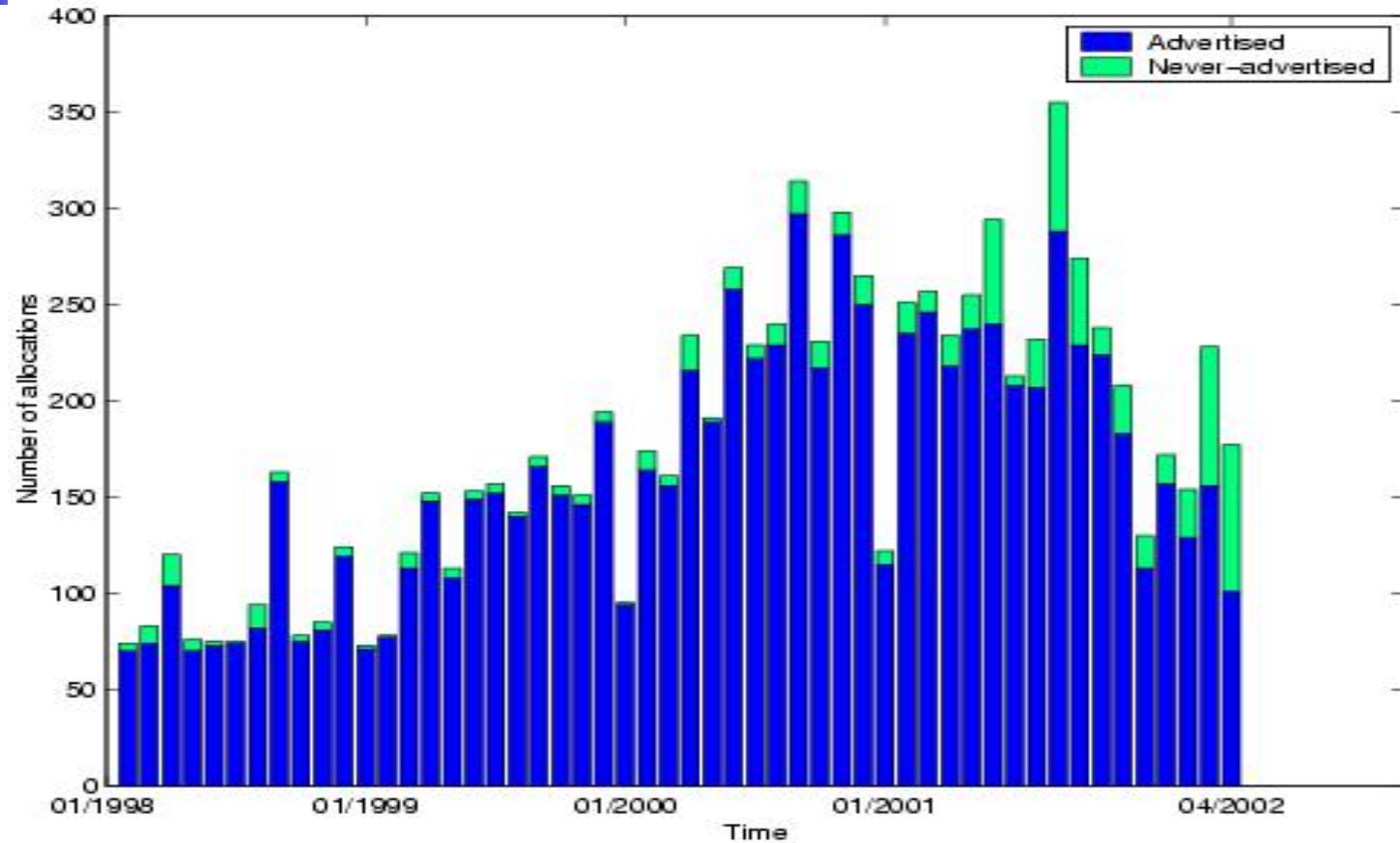
First-Advertised-Delay

The interval between allocation time and the first time the block appears in the routing table

First-Advertisement-Delay - Negative?

- Block   date   RIR   F.A.D.
- /20   2001-11-14   ARIN   -143
- /20   2001-09-25   ARIN   -19
- /16   1998-05-15   RIPE   -188
- /24   1997-11-08   ARIN   -1
- /19   2001-07-13   ARIN   -1343
- /19   2002-02-06   ARIN   -1551
- /20   2001-08-20   ARIN   -270
- /13   2001-11-15   APNIC   -1205
- /10   2001-10-31   APNIC   -680

Advertisement modes

- Allocated prefixes announced in routing tables in different ways:
  - Identical
  - Fragmented
  - Aggregated (encouraged by CIDR)
  - Identical + Fragmented
  - Identical + Aggregated
  - Fragmented + Aggregated
  - Identical + Fragmented + Aggregated

Example

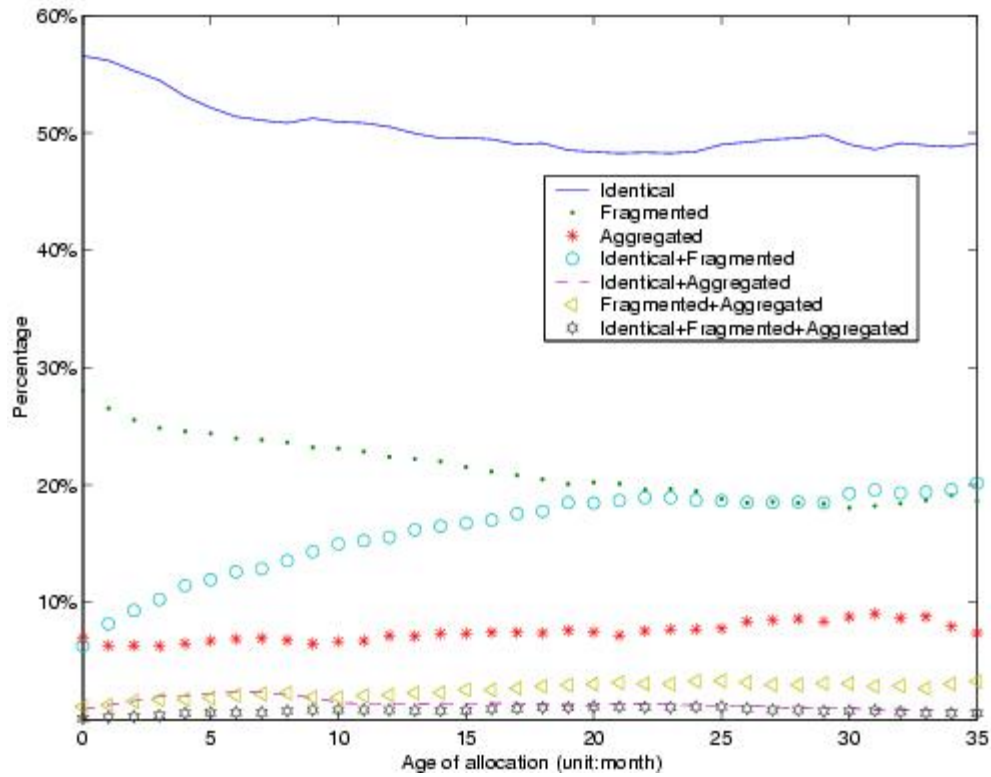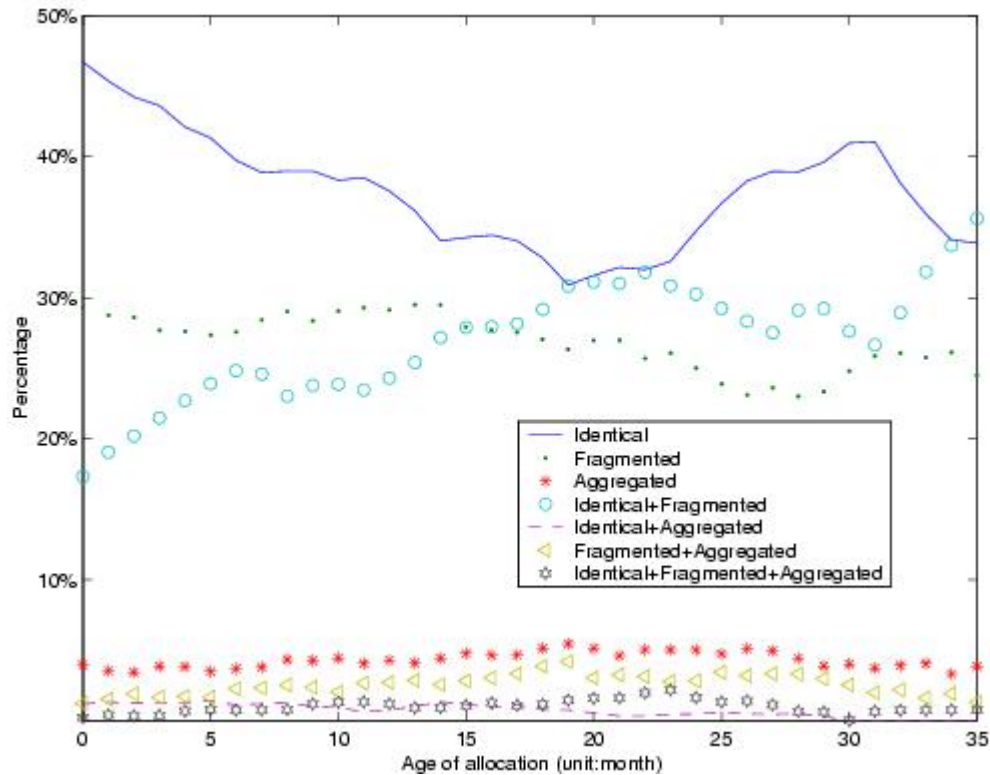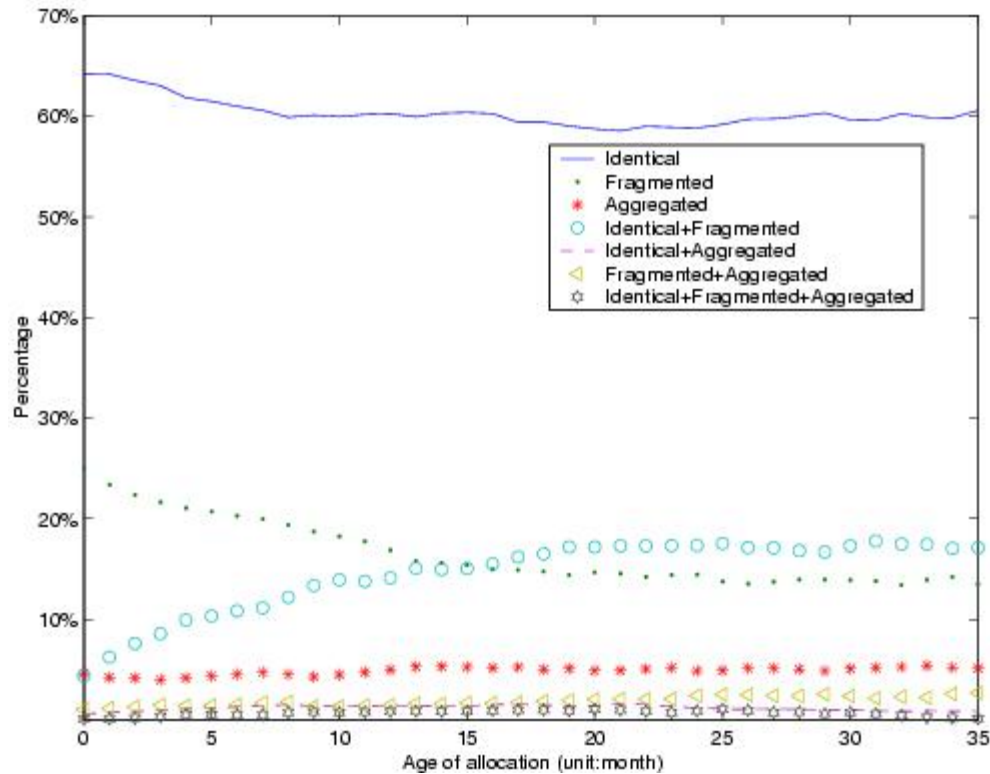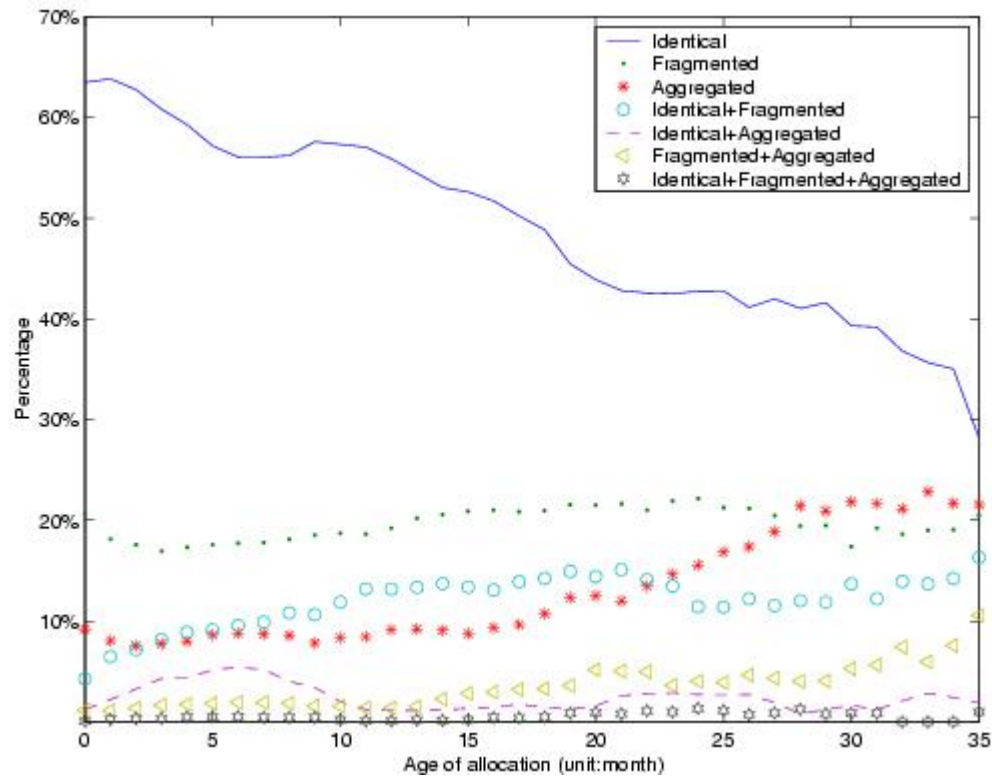|	Allocated blocks	Routing prefix
•Identical	1.1.0.0/16 ⟶	1.1.0.0/16
•Fragmented	1.1.0.0/16 ⟶	1.1.1.0/24 1.1.2.0/24
•Aggregated	1.0.0.0/16 1.1.0.0/16 ⟶	1.2.0.0/15

Advertisement Mode for Allocated Prefixes (all)

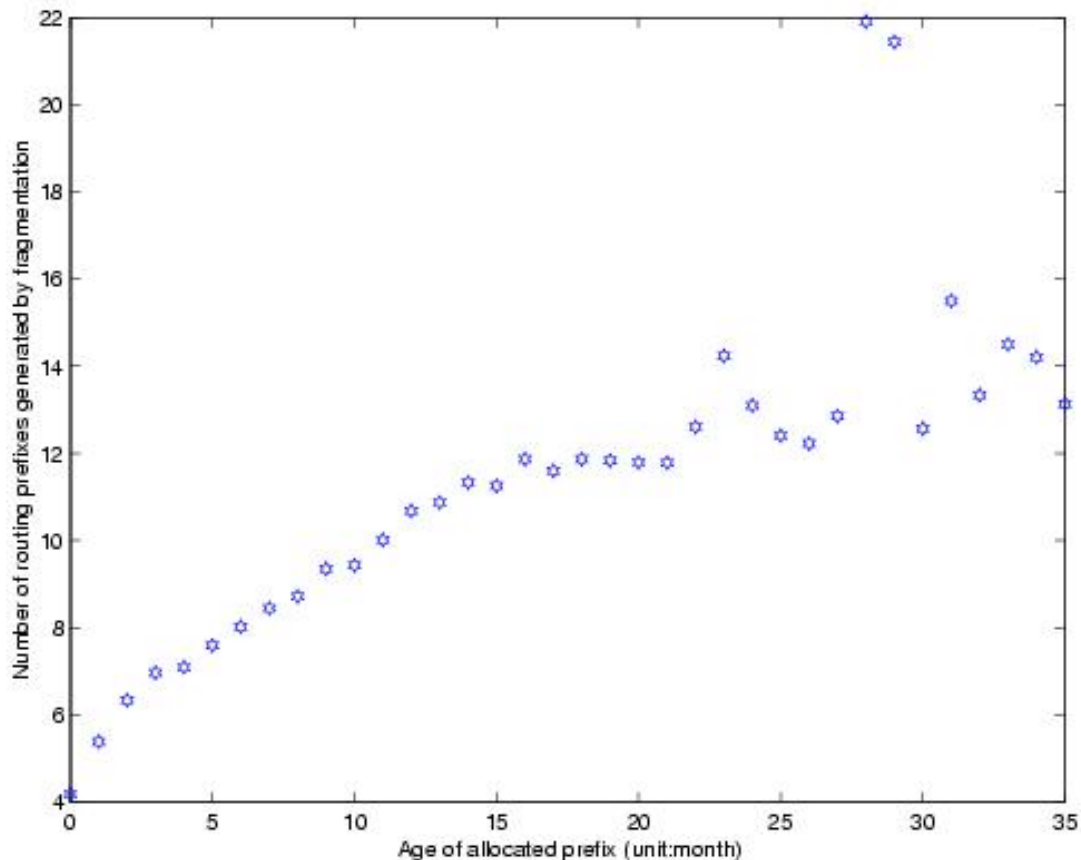# Advertisement Mode for Allocated Prefixes (/16)

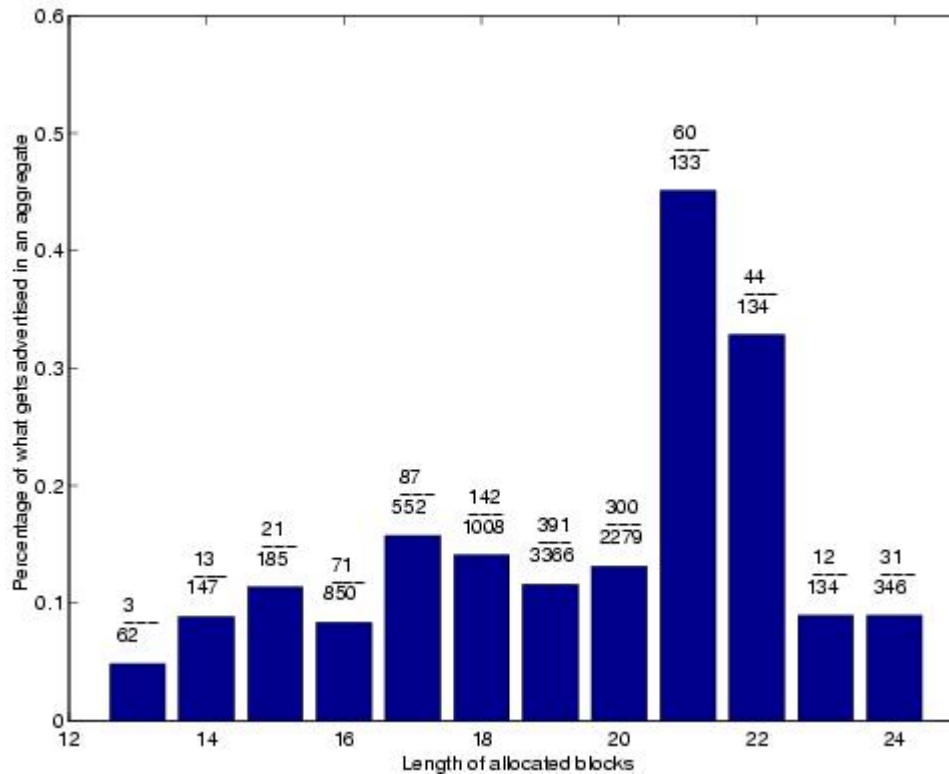# Advertisement Mode for Allocated Prefixes (/19)

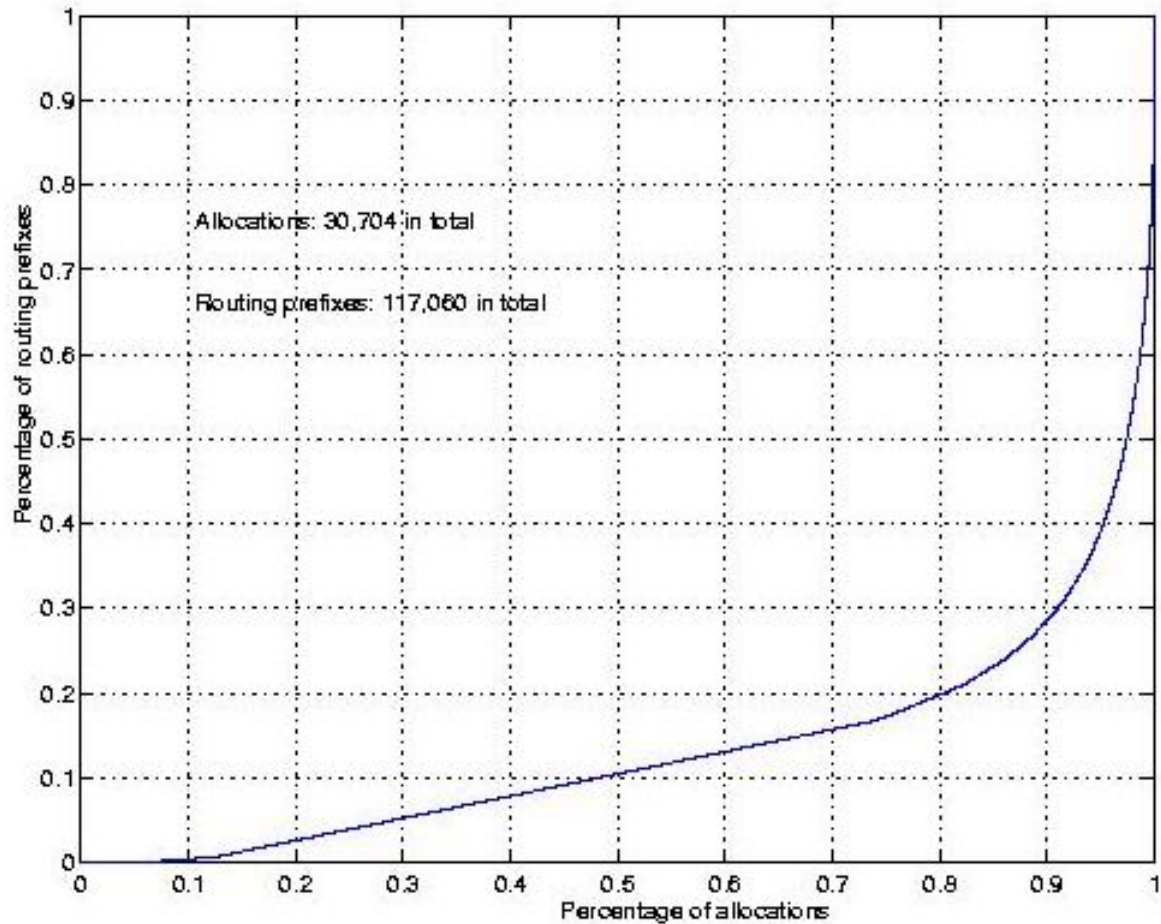# Advertisement Mode for Allocated Prefixes (/20)

How many routing prefixes are fragmented from the allocated prefixes?

Announced Allocations that are Aggregated into Shorter Prefixes

Allocation Contribution to Routing Table

/24s Advertised as Allocated
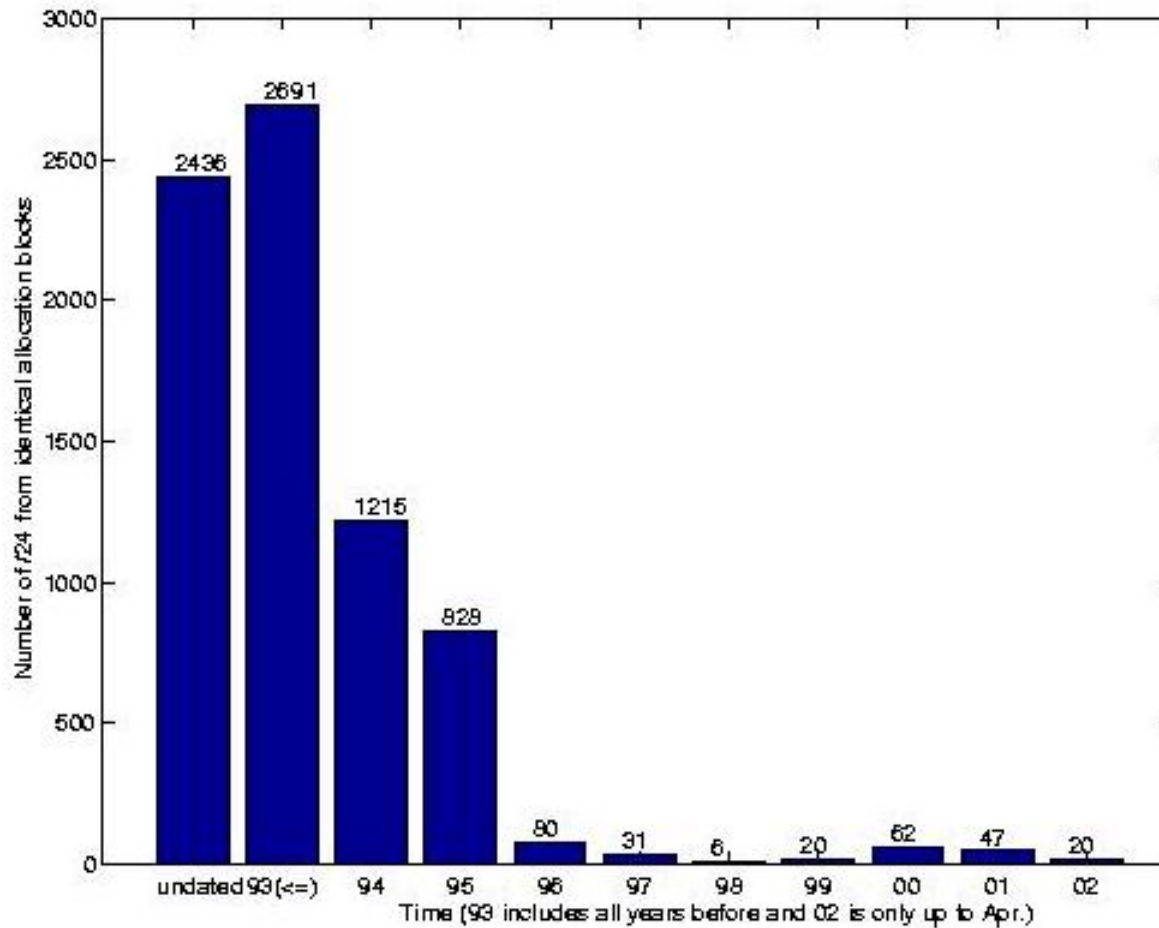
/24s Fragments of Larger Allocations
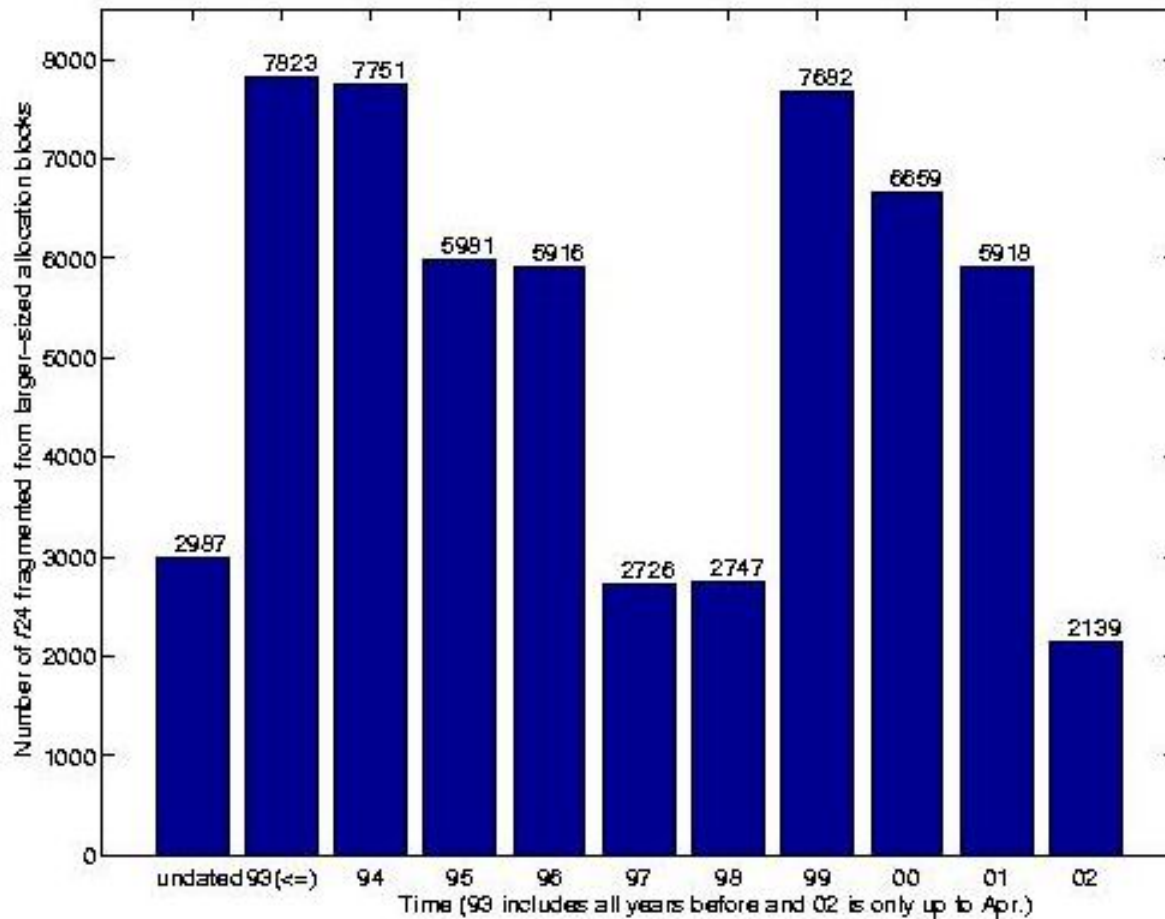
/24 Fragments
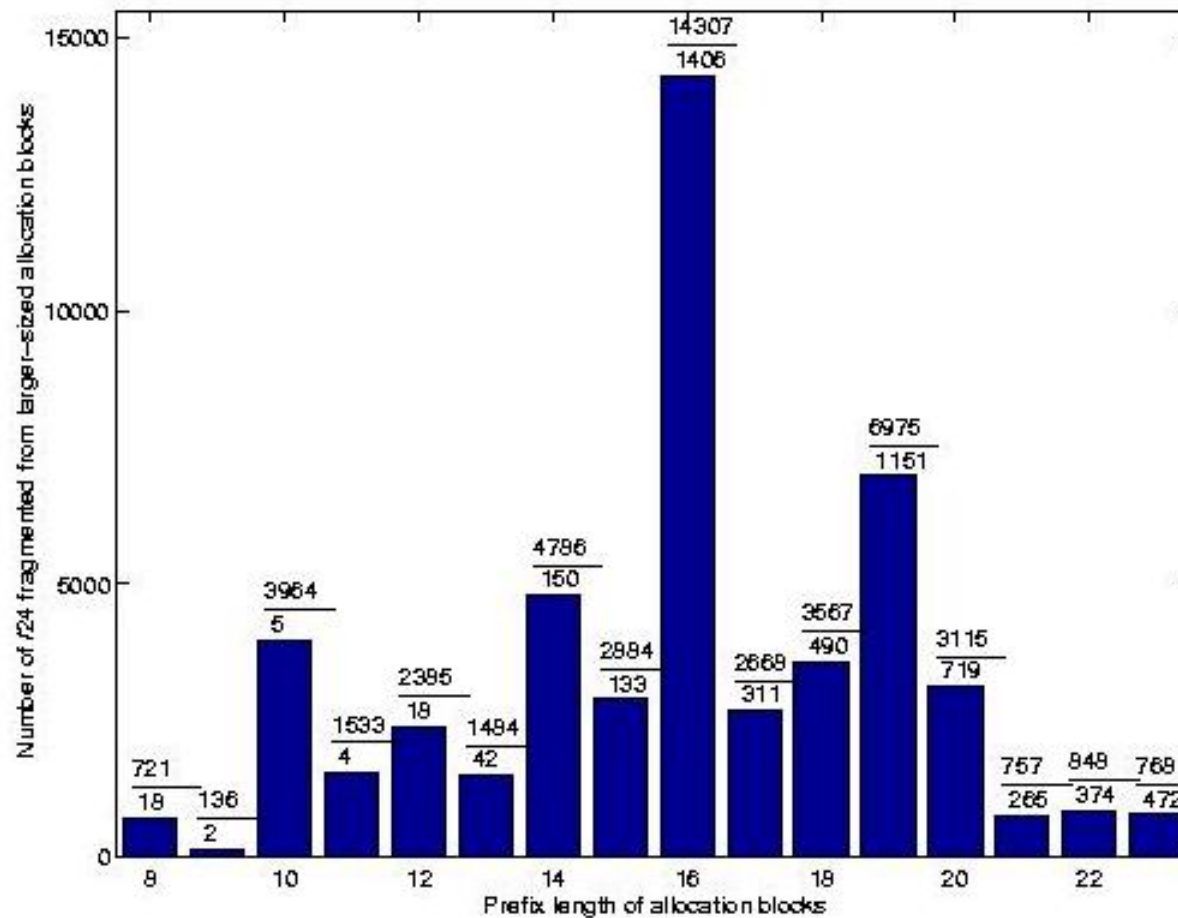
Average Number of Fragments Per Allocation

	Allocated Prefixes	Allocated addresses	Average number of routing entries fragmented (aggregated) from single allocated block
U.S.	3,194	214,809,088	6.8 (0.3)
Canada	293	7,461,632	2.4 (0.4)
China	165	21,010,432	6.7 (0.5)
Japan	105	25,952,512	6.2 (0.3)

Changes in the Global Routing Table

- Comparing the routing table entries between 1 Jan. 1998 – 31 Dec. 2001
  - How many new prefixes added?
  - How many prefixes disappeared?
- Changes in consumed address space
  - An IP address is "consumed" if it is contained in existing routing prefixes

Routing Table Size vs. Address Consumption
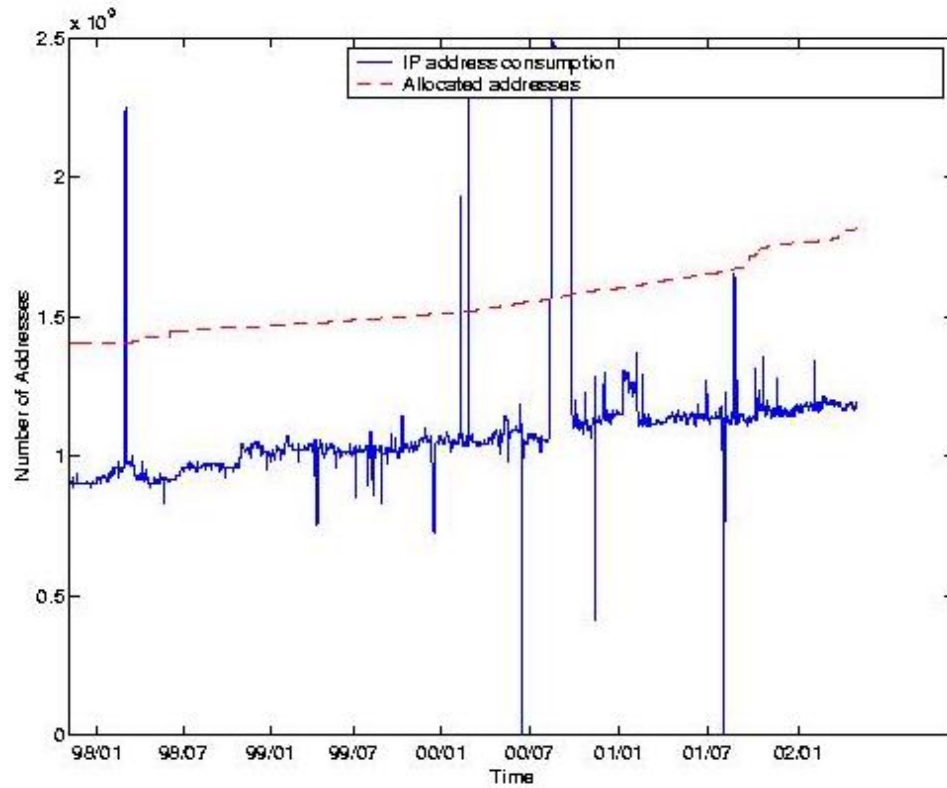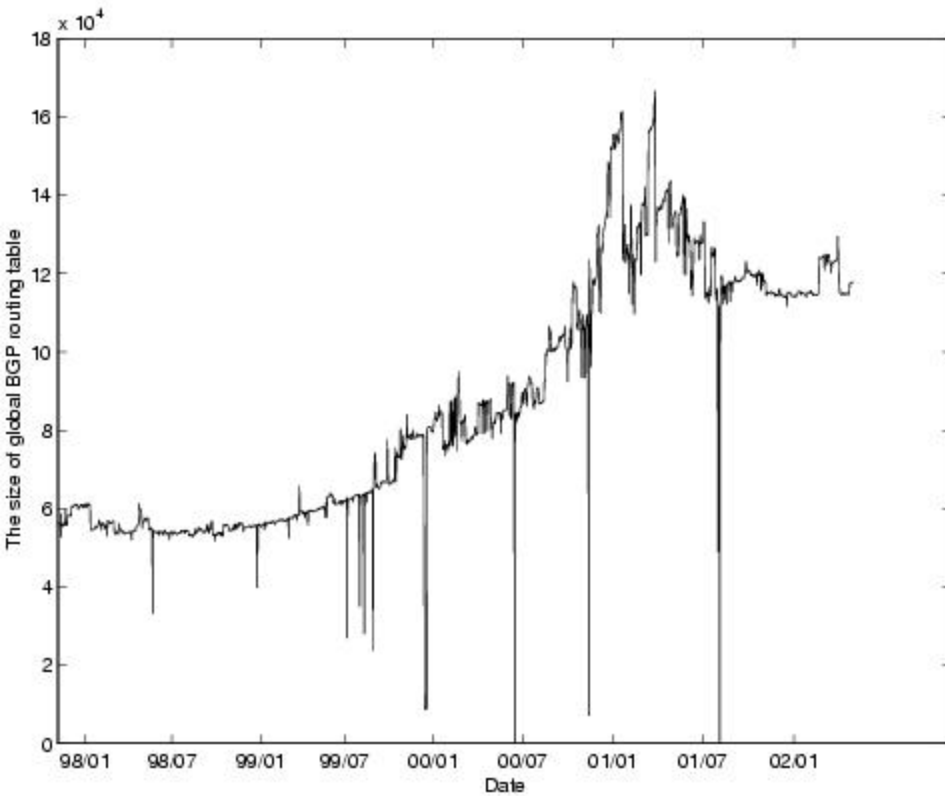
Overall Change (Jan. 98 – Jan.02)

- Routing table size: 53,929 to 114,324
  - Growth: 112%
  - 87,941 prefixes added
  - 34,012 prefixes removed
- Address Consumption: 921,694,960 to 1,163,961,392
  - Growth: 26.3%
  - 35416 new prefixes (40.6% of 87,941) cover existing consumed address space
  - 311 new prefixes originally existed as longer prefixes

Where do the new advertisements come from?

- Total number: 87,941
- Relationship with allocations
  - Fragments of larger allocations (88.4%)
  - Allocations of equal size (10.0%)
  - Aggregation of multiple smaller allocations (0.7%)
  - Others. (No matched allocation records)

Where do the new advertisements come from? (cont.)

- ## Allocation Time

Allocation Time	before 93	94	95	96	97	98
Numbers	10117	7405	7290	8139	4109	5316
Allocation Time	99	00	01	02	No Time Info	
Numbers	10670	14257	10363	3248	5659	

Table 3. Distribution of newly-appeared prefixes in terms of the time when the matched allocations are made

- ## Geographic location

Allocation Country	US	AU	FR	CA	DE
Numbers	49446	3913	3907	3264	1937

Table 4. Distribution of newly-appeared prefixes in terms of the country to which the matched allocations are made

Where do the advertisements go?

"Aggregated": disappeared prefixes that are aggregated into shorter prefixes.
"Fragmented": disappeared prefixes that are fragmented into longer prefixes
"Discarded": disappeared prefixes whose address space entirely goes out of use.

Discarded

Fragmented

Aggregated
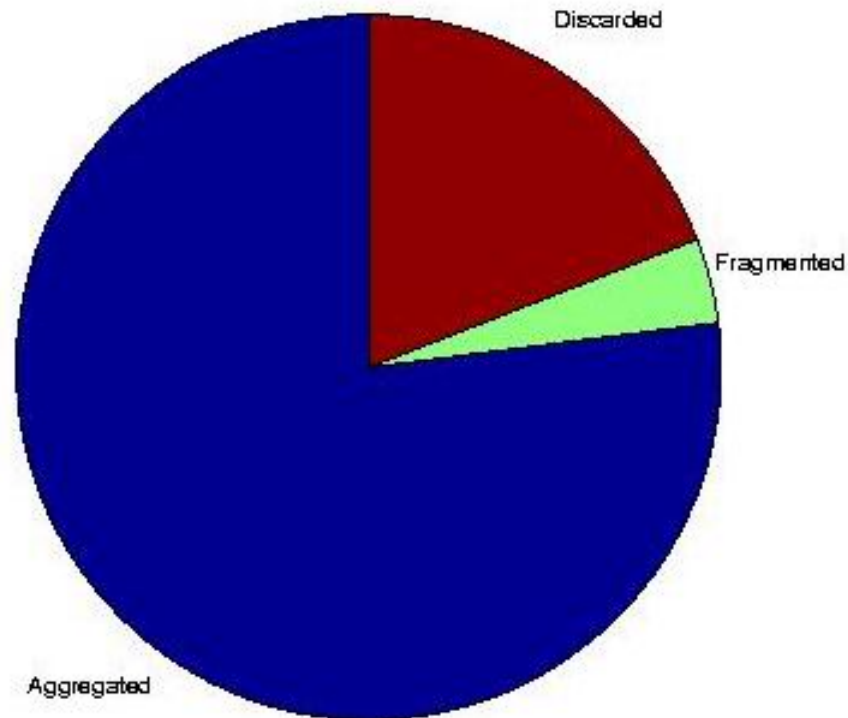
Distribution of New Announced Prefixes (total: 87, 941)

Prefix Len	/8	/9	/10	/11	/12	/13
Number	4	4	4	5	23	57

Prefix Len	/14	/15	/16	/17	/18	/19
Number	128	249	1959	1107	1942	5694

Prefix Len	/20	/21	/22	/23	/24	/25
Number	5461	3816	6106	7635	50917	582

Prefix Len	/26	/27	/28	/29	/30	/32
Number	784	335	279	229	436	155

Distribution of Disappeared Prefixes (total:34,012)

Prefix Len	/8	/9	/10	/11	/12	/13
Number	6	1	2	4	7	8

Prefix Len	/14	/15	/16	/17	/18	/19
Number	34	55	1095	117	279	704

Prefix Len	/20	/21	/22	/23	/24	/25
Number	753	1050	1668	2635	22166	53

Prefix Len	/26	/27	/28	/29	/30	/32
Number	67	89	66	17	2832	304

Impact on Address Consumption

Address space represented by the "Aggregated" prefixes.
Address space represented by the "Fragmented" prefixes and is still in use
Address space represented by the "Fragmented" prefixes and goes out of use
Address space represented by the "Discarded" prefixes

22%

37%

23%

18%
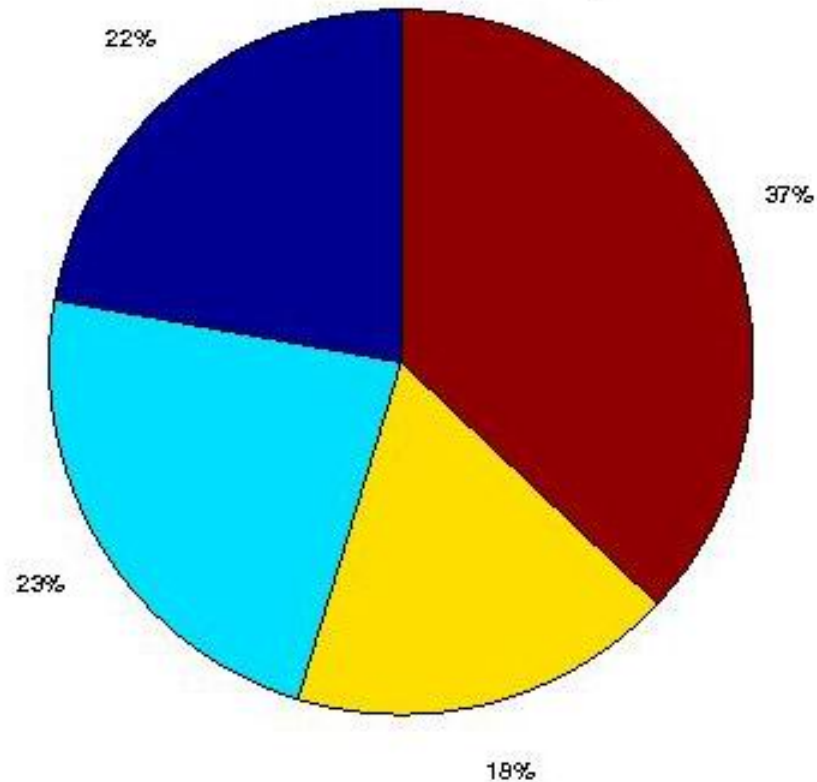
Observations

- New allocations play a dominant role in the global routing table

- Did the /19 to /20 change have an impact?

- There is no requirement that allocations have to be advertised as allocated

What Next?

- What other questions should we be answering?
- Comments? Questions?

IPv4 Address Allocation and Evolution of BGP Routing Tables

- Xiaoqiao Meng, xqmeng@CS.UCLA.EDU
  - Zhiguo Xu, zhiguo@CS.UCLA.EDU
- CJ Wittbrodt, cjw@packetdesign.com
  - Songwu Lu, slu@CS.UCLA.EDU>
  - Lixia Zhang, lixia@cs.ucla.edu