# Growing Pains: IPv6 and the Future of IPv4

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## Agenda

- How did we get here?
  - Brief history of IPv4 and IPv6.
- Where are we, anyway?
  - IPv4 market trends (costs, availability).
  - IPv6 adoption progress worldwide.
- Bridging the gap
  - How are ISPs transitioning?
  - Protecting the Client Experience.
- Why embrace IPv6?
  - Do we *really* have to?
  - Final thoughts.

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# How did we get here?

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## Brief History

1969 – First public packet-switched computer network, ARPANET.

- Utilized Network Control Protocol (NCP), a predecessor of TCP/IP.

1974 – TCP protocol introduced, RFC 675. Vinton Cerf, Bob Kahn.

1977 – IEN 2 – “Internet Experimental Note”

- Separated transport and network layers. TCP/IP protocol distinction born.

1980 – TCP/IP adopted as DOD Standard Internet Protocol, RFC 760.

1981 – IPv4 codified. RFC 791.

1983 – ARPANET, other major networks transitions to TCP/IP. Internet born.

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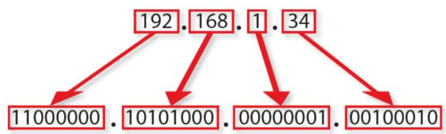
# Brief History

IPv4 Addressing

- 32-bit address, composed of four 8-bit octets.




- Allows for 4,294,967,296 unique addresses.
- That's plenty, *right*?

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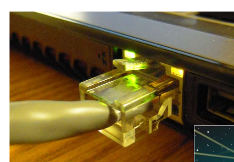
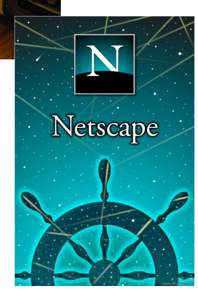
# Brief History






1985 – IEEE ratifies the Ethernet standard.
1991 – The World Wide Web goes public.
1992 – First dial-up Internet commercially available.
1996 – Cable home Internet commercially available.
1997 – First 802.11 Wi-Fi protocol introduced.
2000 – DSL Internet becomes commercially available.

… we may have a problem.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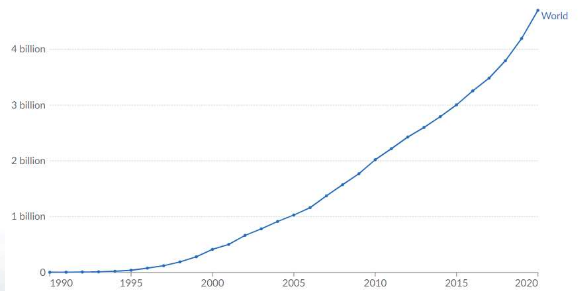
## Internet Growth Continues

Estimated Internet Users

- 2000 – 0.4 billion (6% world pop)
- 2020 – 4.7 billion (60% world pop)




Source: https://ourworldindata.org/internet

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## Internet Growth Continues

2001 – First commercial 3G cellular network launched.
2004 – IEEE ratifies EPON fiber-to-the-prem standard.
2007 – Apple iPhone introduced.
2009 – First 4G LTE networks launch.

Other advances:

VDSL, DOCSIS 3.0, GPON, XGS-PON, etc.

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# “Addressing” the Problem

1994 – RFC 1631 – Network Address Translation (NAT)

- “The two most compelling problems facing the IP Internet are IP address depletion and scaling in routing. Long-term and short-term solutions to these problems are being developed. The short-term solution is CIDR (Classless InterDomain Routing). The long-term solutions consist of various proposals for new internet protocols with larger addresses.”

1996 – RFC 1918 – Private IPv4 Addressing

- “The Internet has grown beyond anyone's expectations. Sustained exponential growth continues to introduce new challenges. One challenge is a concern within the community that globally unique address space will be exhausted.”

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# A Long-Term Solution Proposed

1995 – RFC 1883 – IPv6 codified.

- 128-bit address instead of IPv4’s 32-bit address.
- Functionally limitless address space.
- Subsequent RFCs fleshed out IPv6 further.
    - 1995 – RFC 1885 – ICMPv6
    - 1998 - RFC 2462 – Stateless Address Autoconfiguration (SLAAC)
    - 2003 – RFC 3315 – DHCPv6

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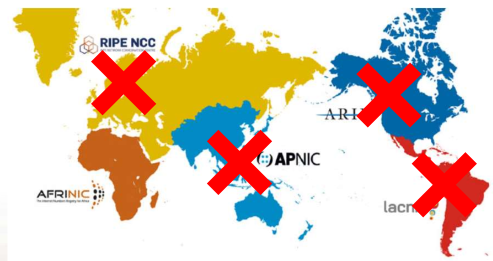
# Exhaustion Becomes Reality

2011 – IANA (Global) announces exhaustion.
2011 – APNIC (APAC) announces exhaustion.
2011 – First commercial transfer of IPv4 addresses ($11.25/IP).
2012 – First "serious" IPv6 deployments – World IPv6 Launch Day.
2014 – LACNIC (SA) announces exhaustion.
2015 – ARIN (US) announces exhaustion.
2019 – RIPE (EU) announces exhaustion.

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# Summing Up

- Even before broadband internet was born, it was already evident that IPv4 could not sustain the future.
- Though IPv6 was codified in 1995, the internet continued to grow up on IPv4.
  - What good is IPv6 if all the content is on IPv4?
  - Hardware, applications built upon IPv4.
  - IPv4 a proven, DOD-sanctioned standard.
  - NAT and Private IP addressing greatly mitigated the problem.
- Historically no incentive for ISPs to force the issue of IPv6.
  - No consumer demand + No financial demand + No technical demand = No Action Required.
- Since 2011, IPv6 adoption has slowly advanced.

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# Where are we, anyway?

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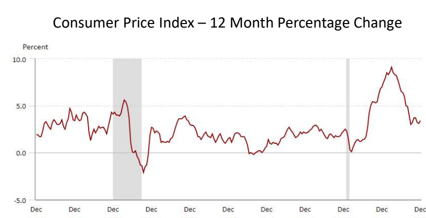
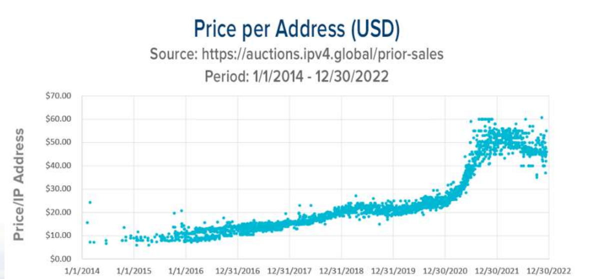
## Where are we?

### IPv4 Market

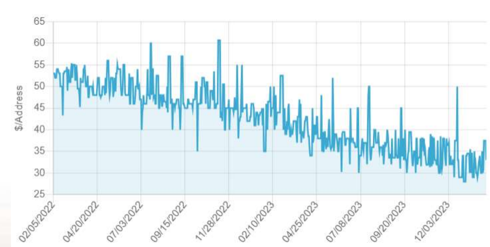
- Pricing peaked Q1 2022 around $55 per IP.
- Current pricing around $35 per IP.
- IPv4 prices out-paced US inflation prior to 2021.




Source: U.S. Bureau of Labor Statistics




Source: https://ipv4.global/blog/ipv4-address-prices/




Source: https://auctions.ipv4.global/prior-sales

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# Where are we?

## What’s happening in telecom (broadly-speaking)?

- Rapid XGS-PON expansion nationwide, funded by federal programs and venture capital.
- Cable providers rolling out DOCSIS 4.0 / DAA, and even XGS-PON in greenfield markets.
- More WFH users. SDWAN. More demand for backup internet.
- Fixed Wireless Internet encroaching on wired broadband market.
- ISPs tightening the belt on IPv4 leases, reclaiming unused space.
  - 2/1/24 – AWS begins charging for IPv4 usage.
- More users, applications, servers, and things = More IP demand!

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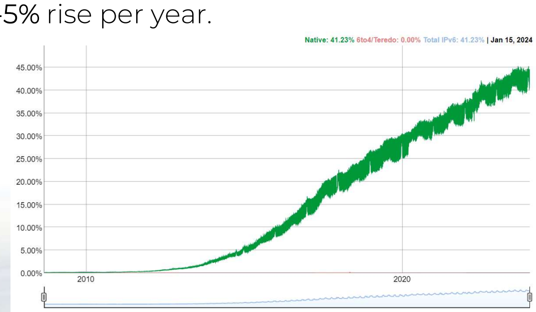
# Measuring IPv6 Adoption

## Google Estimates

- Data based on JavaScript HTTP detection methodology, not actual traffic measurements.
- USA national adoption rate around 49%.
- Worldwide average around 41%.
- Trends indicate 3-5% rise per year.




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

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# Measuring IPv6 Adoption

## Other Measurements

- Out of the Alexa Top 1000 Most Visited sites, only about **50%** are IPv6-enabled. Of all Alexa-queried sites, only **38.5%** are IPv6-enabled.[1]
- W3 Techs estimates **22.7%** of all "relevant" websites are IPv6-enabled.[2]
- Cloudflare observes about **36%** of all HTTP/HTTPS traffic is IPv6.[3]
- APNIC estimates about **36.5%** of worldwide user hosts are IPv6-capable.[4]

1. Why No IPv6? – https://whynoipv6.com/
2. W3 Techs – Web Technology Surveys, https://w3techs.com/technologies/details/ce-ipv6.
3. Cloudflare Radar – https://radar.cloudflare.com/adoption-and-usage
4. APNIC Labs – https://stats.labs.apnic.net/ipv6/XA

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# Measuring IPv6 Adoption

## APNIC - Top 20

| CC | Country | IPv6 Capable | IPv6 Preferred |
|---|---|---|---|
| IN | India, Southern Asia, Asia | 81.80% | 81.18% |
| MY | Malaysia, South-Eastern Asia, Asia | 69.30% | 67.05% |
| FR | France, Western Europe, Europe | 68.93% | 68.56% |
| BE | Belgium, Western Europe, Europe | 66.72% | 66.40% |
| DE | Germany, Western Europe, Europe | 66.18% | 65.77% |
| AX | Aland Islands, Northern Europe, Europe | 65.03% | 64.94% |
| SA | Saudi Arabia, Western Asia, Asia | 64.27% | 62.77% |
| VN | Vietnam, South-Eastern Asia, Asia | 60.92% | 59.59% |
| BL | Saint Barthelemy, Caribbean, Americas | 60.59% | 60.59% |
| UY | Uruguay, South America, Americas | 60.25% | 60.09% |
| IL | Israel, Western Asia, Asia | 60.21% | 56.24% |
| MS | Montserrat, Caribbean, Americas | 59.83% | 59.74% |
| TW | Taiwan, Eastern Asia, Asia | 59.02% | 54.36% |
| GR | Greece, Southern Europe, Europe | 58.62% | 58.30% |
| US | United States of America, Northern America, Americas | 55.93% | 55.27% |
| JP | Japan, Eastern Asia, Asia | 54.31% | 52.56% |
| LK | Sri Lanka, Southern Asia, Asia | 53.67% | 52.80% |
| AE | United Arab Emirates, Western Asia, Asia | 52.12% | 51.20% |
| HU | Hungary, Eastern Europe, Europe | 51.78% | 51.58% |
| PR | Puerto Rico, Caribbean, Americas | 51.42% | 51.01% |

Source: APNIC Labs – https://stats.labs.apnic.net/ipv6/xa

## Observations

- India
  - Government mandate required ISPs to be IPv6-capable by end of 2022.[1]
  - Reliance Jio aggressively deployed IPv6.
- European Union
  - No EU-wide mandate, but European Commission encouraging adoption.[2]
- Malaysia
  - Very low IPv4 inventory forced innovation.[3]
- Top 5 adopters all seem to involve some collaboration between government and private sector – with or without formal mandates.
- Felt shortage of IPv4 and a growing user demand seem to be the drivers for change.

1. India Times - https://economictimes.indiatimes.com/industry/telecom/telecom-news/dot-fixes-december-2022-deadline-for-transition-to-new-ip-addresses/articleshow/87541911.cms
2. EU Commission - https://ec.europa.eu/information_society/doc/factsheets/066-ipv6-en.pdf
3. Telecom Review Asia – https://www.telecomreviewasia.com/news/interviews/2790-ipv6-adoption-to-leapfrog-digital-growth-in-asia-pacific

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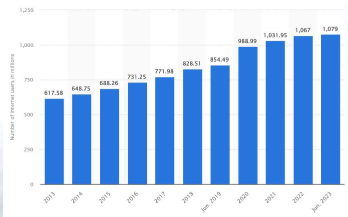
# Measuring IPv6 Adoption

## What's up with China?

- Google estimates 4.8% adoption.
  - HTTP measurement based on search queries.
- APNIC estimates 33.2% adoption.
  - HTTP measurement based on ad services.
- Likely due to government control to certain services.
- 351 million IPv4 addresses[1], over 1 billion users.

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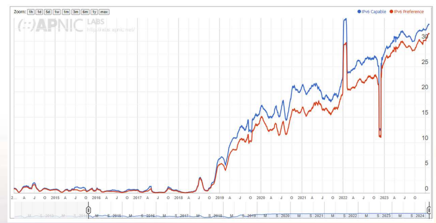

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1. IP2Location – https://lite.ip2location.com/china-ip-address-ranges
2. Statista – https://www.statista.com/statistics/265140/number-of-internet-users-in-china/
3. APNIC Labs – https://stats.labs.apnic.net/ipv6/CN

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# Measuring IPv6 Adoption

## What's up with China?

- Aggressive IPv6 conversion plan announced by government in 2021.[1]
- End of 2023 – All new home routers to utilize IPv6 by default; no new IPv4 networks allowed.[2]
- End of 2025 – All existing applications, facilities, systems to be fully established on IPv6. All new networks, applications to be deployed IPv6 single stack.
- End of 2030 – Fully converted to single stack IPv6.
  - The only country known to be pursuing this goal.

1. The Register – https://www.theregister.com/2021/07/26/china_single_stack_ipv6_notice/
2. Stackscale – https://www.stackscale.com/blog/china-plan-ipv6-adoption/

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# Measuring IPv6 Adoption

## What about applications?

- Major OS support for IPv6 generally strong. Applications, IoT OS's hit or miss.
- Difficult to quantify.
- Anecdotes:
  - Chrome OS supports IPv6 and SLAAC, but not DHCPv6 due to embedded container architecture.
  - Steam still lacks native IPv6 support.
  - Netflix on LG webOS TV does not support IPv6.
  - Some Roku devices do not support IPv6.
- Same basic question: What's the impetus to change?

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# Measuring IPv6 Adoption

## US Internet Service Providers

- Cellular providers lead IPv6 adoption in the US.
  - T-Mobile above 91% adoption as of Q4 2021.[1]
- 39% of rural providers have no existing plan to transition to IPv6, and 27% plan to transition within two years.[2]
- No federal mandate for private sector.
- M-21-07 - Federal agency mandate:
  - At least 80% of IP-enabled assets on Federal networks are operating in IPv6-only environments by the end of FY 2025.[3]

1. IPXO - https://www.ipxo.com/blog/detailed-ipv6-adoption-review/
2. A10 Networks, Gatepoint Research, Insights 2024: Rural Broadband Business Sustainability
3. nlrb.gov, https://www.nlrb.gov/sites/default/files/attachments/pages/node-175/m-21-07.pdf

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## Summing Up

- IPv4 remains the dominant protocol, but with a cost, and is simply unavailable in some parts of the world.
- Website and application support for IPv6 are coming along, but still lagging due to ambiguity of demand.
- Major progress in worldwide IPv6 adoption expected in next 3-6 years.

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## Bridging the gap

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# How are ISPs transitioning?

You can't just flip a switch!

- Client network hardware may not support IPv6.
- Client software/applications may not support IPv6.
- Any IPv6 deployment strategy <u>must</u> include some kind of mechanism to ensure users can reach both IPv4 and IPv6 content.

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# How are ISPs transitioning?

Strategies

- IPv4 + IPv6 dual stack
  - Delivers both a public IPv4 and an IPv6 address to the subscriber.
  - Pros/cons:
    - Satisfies all connectivity needs.
    - Doesn't address the problem of IPv4 exhaustion.
- CGNAT IPv4 + IPv6 dual stack
  - Utilizes Carrier-Grade NAT (CGNAT) for IPv4, allowing providers to serve multiple subscribers on a single IPv4 address (1:32 – 1:128).
  - Pros/cons:
    - Addresses IPv4 exhaustion (or shifts/mitigates the expense).
    - Subscribers unable to host public-facing services via IPv4.

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# How are ISPs transitioning?

## Strategies

- IPv6-only + NAT64
  - Delivers IPv6 single-stack to the subscriber, utilizes CGNAT64 at the provider core.
  - Pros/cons:
    - Subscribers unable to host public-facing services via IPv4.
    - Creates trouble for IPv4-only applications or hardware.
- IPv6-only + 464XLAT
  - Delivers IPv6 single-stack, utilizes CGNAT64, and involves a "tunneled" IPv4 layer at the customer device.
  - Pros/cons:
    - Addresses IPv4-only application issues, provided CPE can support CLAT.
    - Subscribers unable to host public-facing services via IPv4.
    - Hugely successful on mobile networks.

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# How are ISPs transitioning?

## Strategy Summary

- Most IPv6 transition strategies involve CGNAT at some level.
- CGNAT shifts expense from IPv4 acquisition to CGNAT appliances and architecture.
  - Continuing to buy IPv4 space is a gamble.
  - Asset value of IPv4 will eventually bottom out as IPv6 takes the lead.
  - CGNAT has matured. Solid, turnkey product solutions now exist.
- If a subscriber requires IPv4 public addressing for public-facing services, CGNAT is not a good fit.
- Providers must be cognizant of the needs of their subscribers when choosing a strategy.*

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# Protecting the Client Experience

## Important Considerations

- Make no assumptions about your provider network. Test everything!
  - Do not rely on datasheets. Lab it up!
  - Thoroughly vet <u>all</u> hardware in each layer of your network.
    - Firmware updates. Replace antiquated CPE.
  - Actual applications must be tested.
  - No cutting corners!
- Learn from other providers who are further along in the journey.
  - We're all in this one together!
  - All telecom providers have a shared interest in the success of IPv6.
  - Article: Telekom Malaysia's IPv6 readiness journey
    - https://blog.apnic.net/2023/03/17/telekom-malaysias-ipv6-readiness-journey/

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# Why embrace IPv6?

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## Do we *really* have to?

"Necessity is the mother of invention."

- *Some wise person*

Change becomes necessary when we encounter…

- Consumer demand
  - Customers wants something we can't offer.
- Financial demand
  - There's a cost obstacle hindering our ability to provide what the customer wants.
- Technical demand
  - There's a technical obstacle hindering our ability to provide what the customer wants.

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## Do we *really* have to?

What about consumer demand?

"I've never had a client come to me asking for IPv6."

- The consumer's need is not IPv6. The consumer's need is a functioning Internet!

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# Do we *really* have to?

## Final Thoughts

- Embracing IPv6 is an inevitable next step in protecting the integrity of the Internet.
- Embracing IPv6 is necessary to ensure service providers can meet user demand in the years and decades to come.
- Embracing IPv6 sooner rather than later is an important step for service providers to manage and fortify their costs.
- Embracing IPv6 will help your organization maintain competitive relevancy.
  - Don’t be the guy that falls behind!

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