Get Ready for a Mixed World

Economic Factors Affecting IPv6 Deployment

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Research questions

- What economic incentives affect decisions by network operators to deploy IPv6?
- What factors can best explain the observed levels of IPv6 adoption?
- How do translation/tunneling technologies alter the economic incentives to remain with IPv4 or deploy IPv6?

The economics of network migration

Network externalities and the migration

- Convergence, lock in and inertia
- No one can “secede” from IPv4
- Mutual compatibility is double-edged

The dual stack model

- Does not reduce demand for IPv4 numbers
- Imposes costs of transition on IPv6 deployers

Last mover advantage?

The economics of network migration

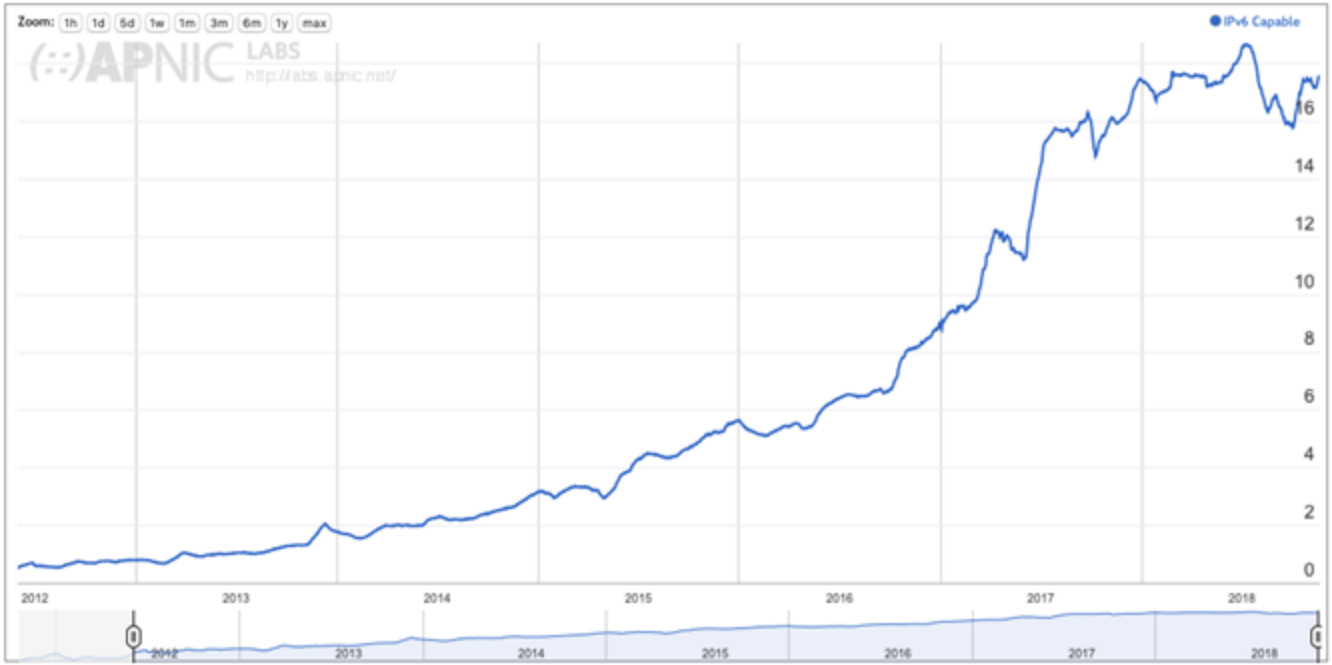
Network growth

- IPv4 constrains growth, and rising IPv4 prices make it increasingly expensive
- IPv6 facilitates less constrained growth, but backwards compatibility requires IPv4

Cost of Growth (GC) in IPv6 vs IPv4

- For IPv6 deployers, GC_6 = Initial Costs (IC) + Cost of Compatibility (CC) + Cost of Acquiring IPv6 (v6$)
- For non-deployers, GC_4 = Cost of Extending (CE) + Cost of Acquiring IPv4 (v4$)

Worldwide aggregate IPv6 adoption



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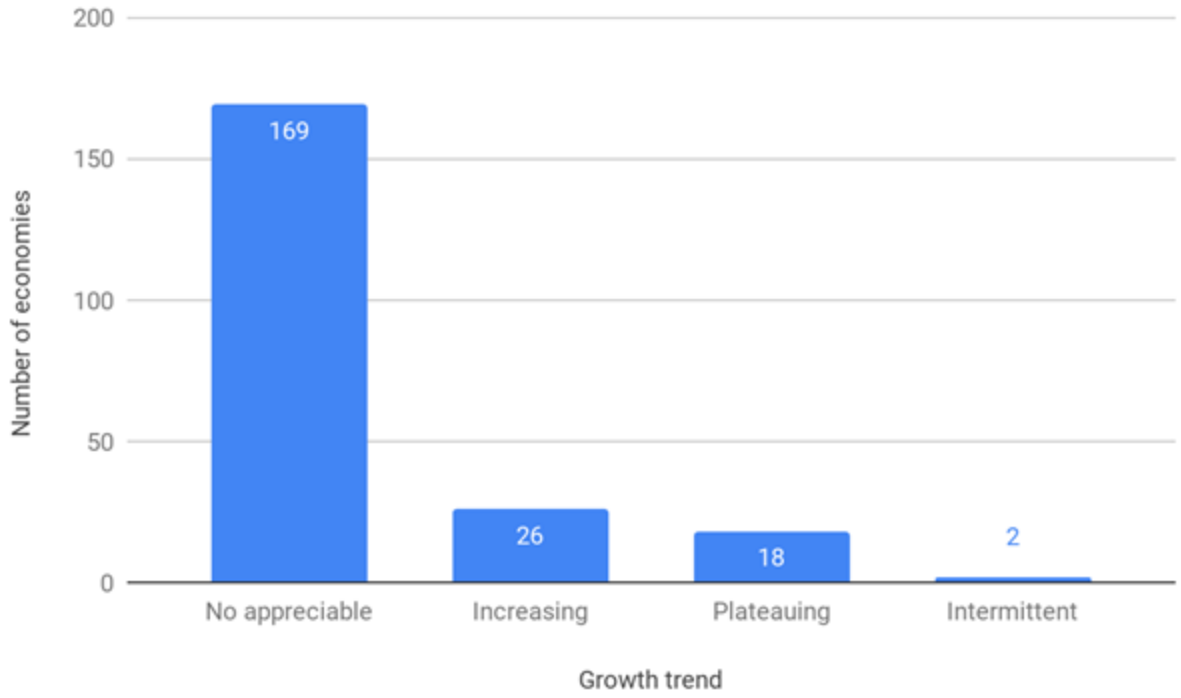
Economy-level growth trends



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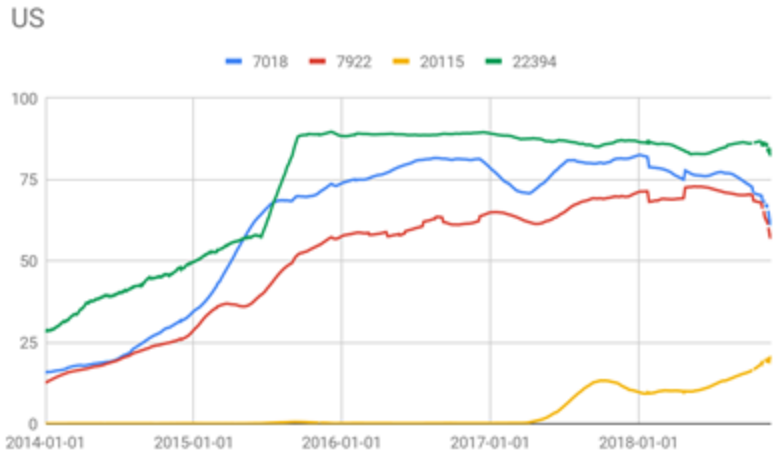
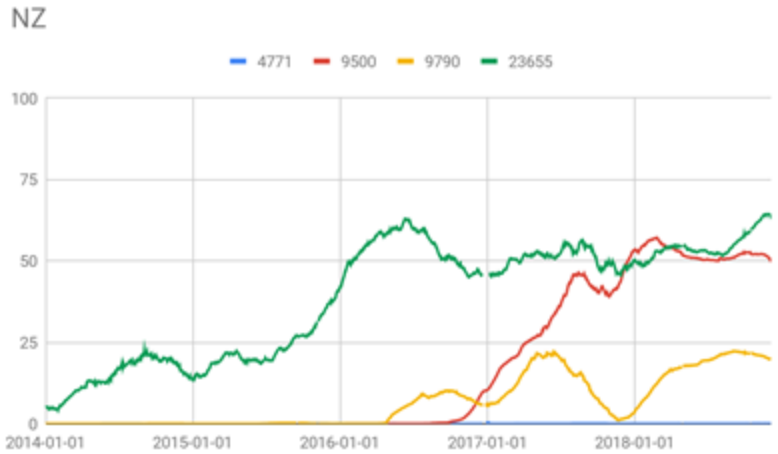
AS-level graphs by country: increasing

United States and New Zealand





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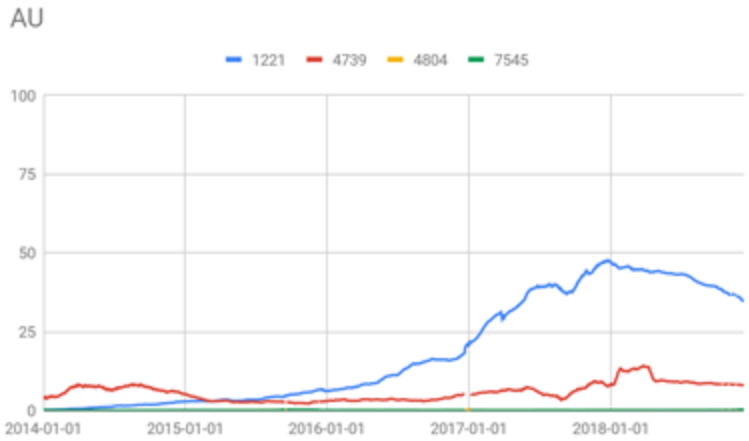
AS-level graphs by country: plateauing

Australia and Belgium



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AS-level graphs by country: plateau or decrease?

Czech Republic and Ecuador

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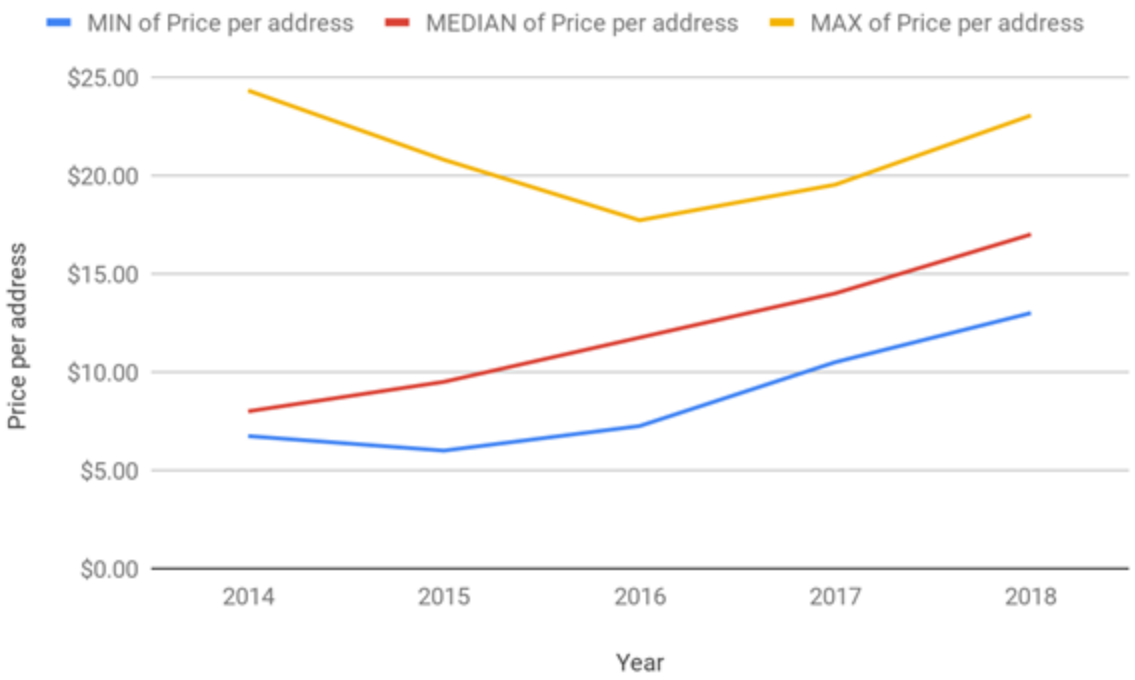
IPv6 adoption and macrosocial variables

- IPv6 deployment is expensive!
  - Variations in per capita GDP explains half (49.9%) of variation in IPv6 capability
  - Correlation is statistically strong p = <.01
- IPv6 does better in less concentrated markets!
  - Higher country-level IPv6 capability rates were correlated with lower levels of concentration in wireless (27%) and broadband (35%) markets
  - Negative correlation is statistically strong p = <.01

Market for IPv4 numbers: prices

Figure 8: Hilco Streambank IPv4 address block transfers



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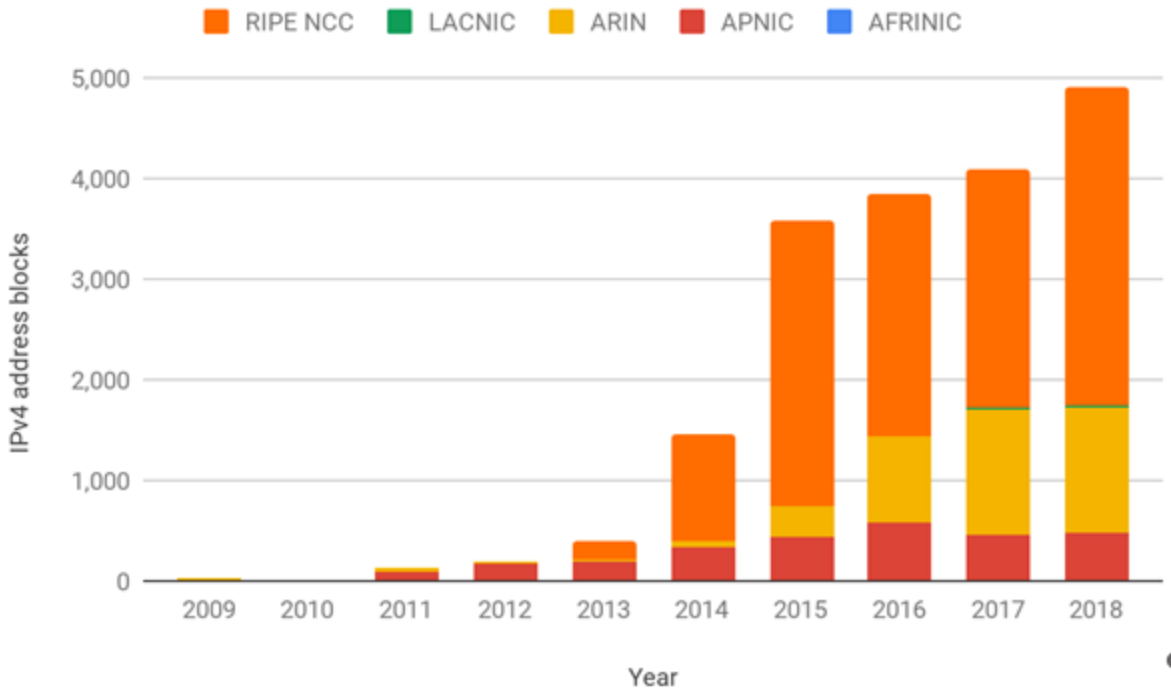
Market for IPv4 numbers: number of transactions

Figure 9: Number of IPv4 address block transfers, by recipient RIR



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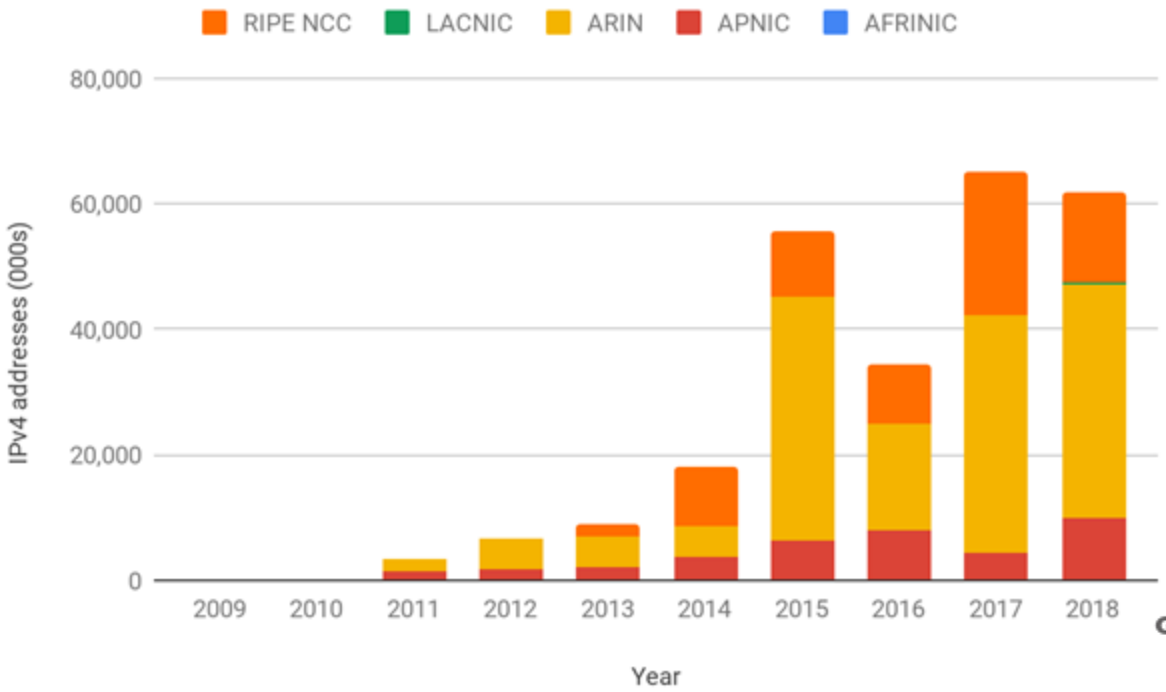
Market for IPv4 numbers: number of IP's transferred

Figure 10: Total IPv4 address numbers transferred, by recipient RIR



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Market for IPv4 numbers: CSPs as buyers

Table 4.1: Top 10 Recipient Organizations in ARIN region of Transferred Addresses

Recipient Org	Number of Transfers	Number of Addresses	% of Total Addresses Transferred	Operator Type
Amazon Technologies Inc.	30	61,275,974	35.91%	Cloud
Microsoft Corporation	6	30,998,482	18.16%	Cloud
Charter Communications	33	8,386,444	4.91%	ISP
Amazon.com, Inc.	21	6,753,160	3.96%	eCommerce
Google LLC	3	5,243,389	3.07%	Cloud
Alibaba.com Singapore E-Commerce Private Limited	1	5,242,878	3.07%	Cloud
Frontier Communications Corporation	1	4,718,581	2.77%	ISP
Google Inc.	3	4,194,299	2.46%	Cloud
Alibaba.com LLC	7	3,014,634	1.77%	Cloud
Reliance Jio Infocomm Pte Ltd	5	2,162,672	1.27%	ISP
Google Fiber Inc.	1	2,097,151	1.23%	ISP
Oracle Public Cloud	5	1,441,771	0.84%	Cloud
VODAFONE AMERICAS INC.	2	1,118,202	0.66%	ISP
Windstream Communications LLC	1	1,048,575	0.61%	ISP

Modeling IPv4 requirements under dual stack and conversion

Assumptions

- 15 yr timeframe
- Dual stack (separate IPv6, IPv6 networks) vs. conversion (464XLAT approach, 90% IPv6 devices)
- NAT scaling properties (80% active Subscribers during peak traffic, deterministic port sharing w/ 1024 reserved ports, compression ratio = 8)

Variables

- Subscribers
- IPv6 Traffic matrix ratio
- Growth patterns: flat, linear, plateauing, accelerating, S-curve
- Operator types: mobile ISP, enterprise, cloud service provider

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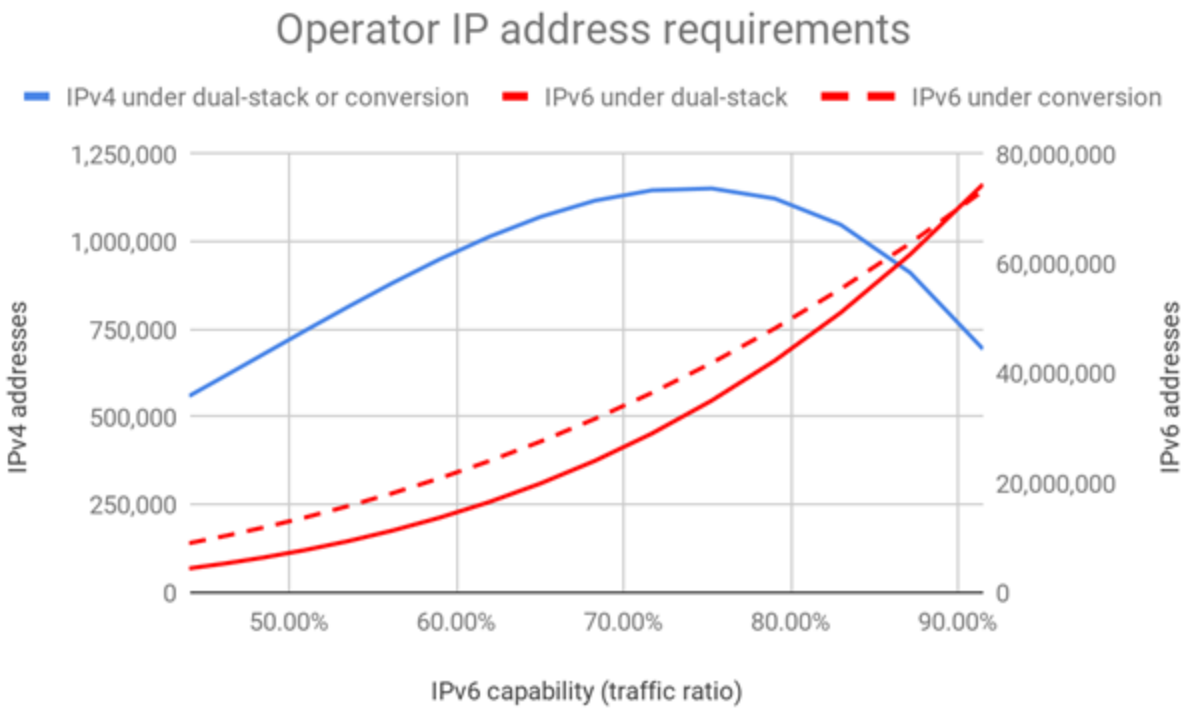
Modeling dual stack vs. conversion...

Figure 11: Scenario 1 (mobile ISP, high subscriber growth, low traffic ratio growth)



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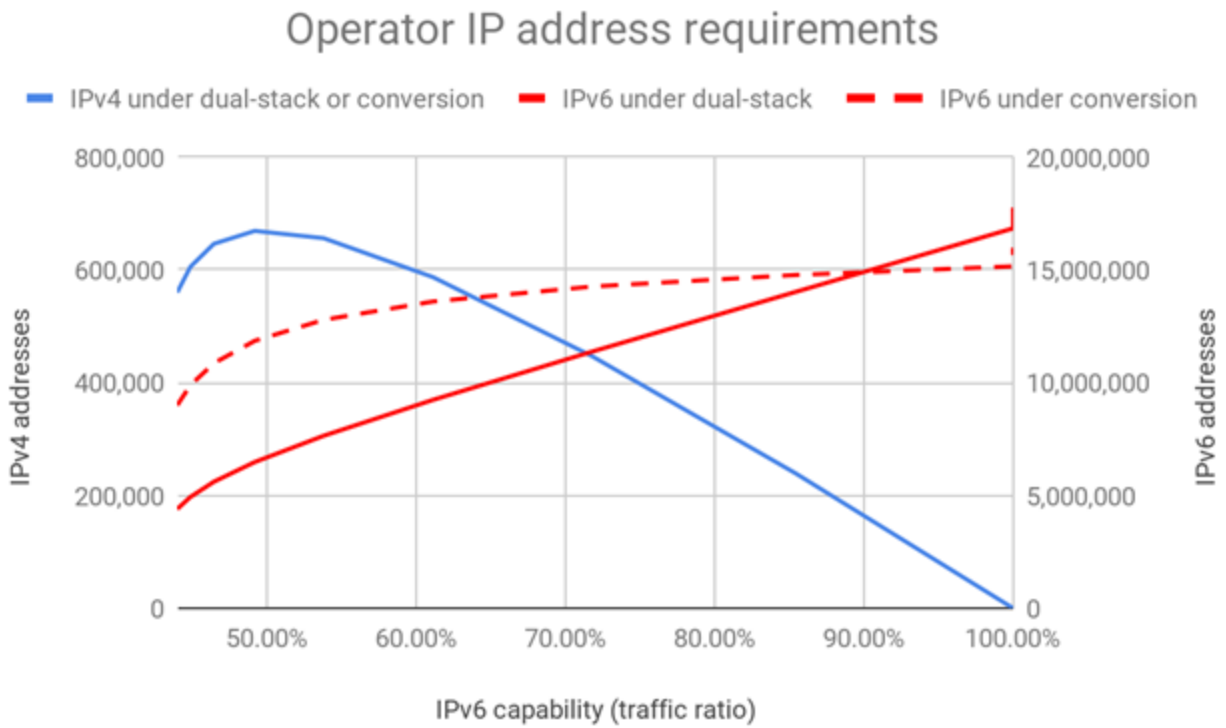
Modeling dual stack vs. conversion...

Figure 12: Scenario 2 (mobile ISP, different growth patterns)



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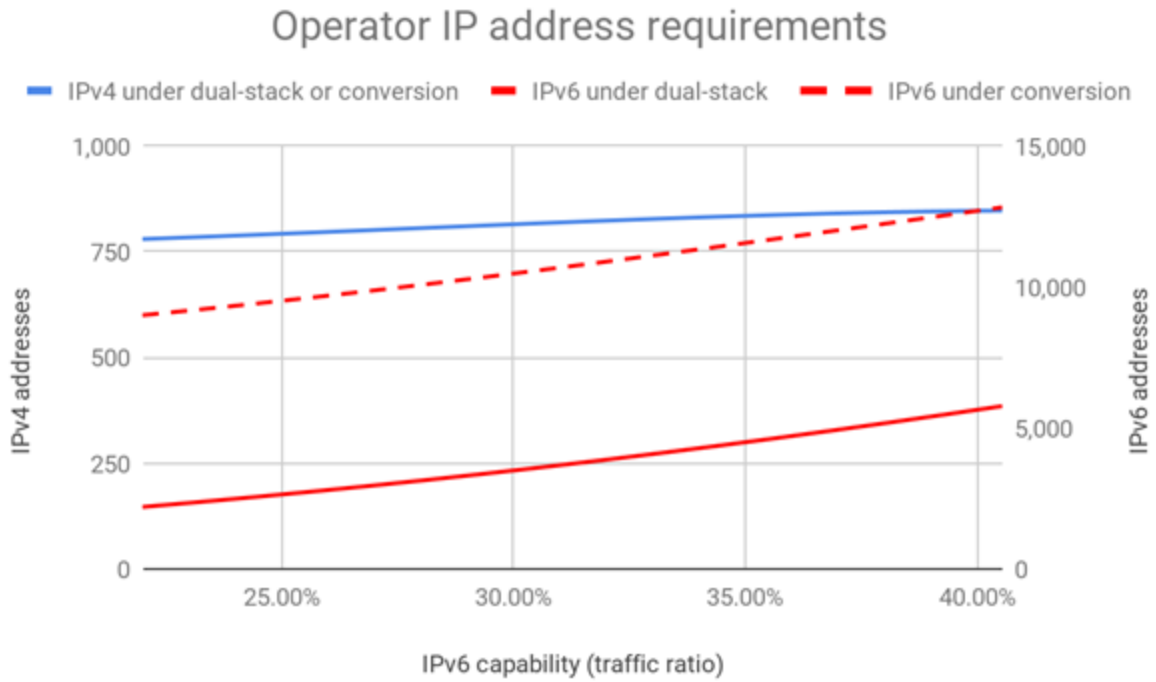
Modeling dual stack vs. conversion...

Figure 13: Scenario 3 (small, low growth enterprise network)



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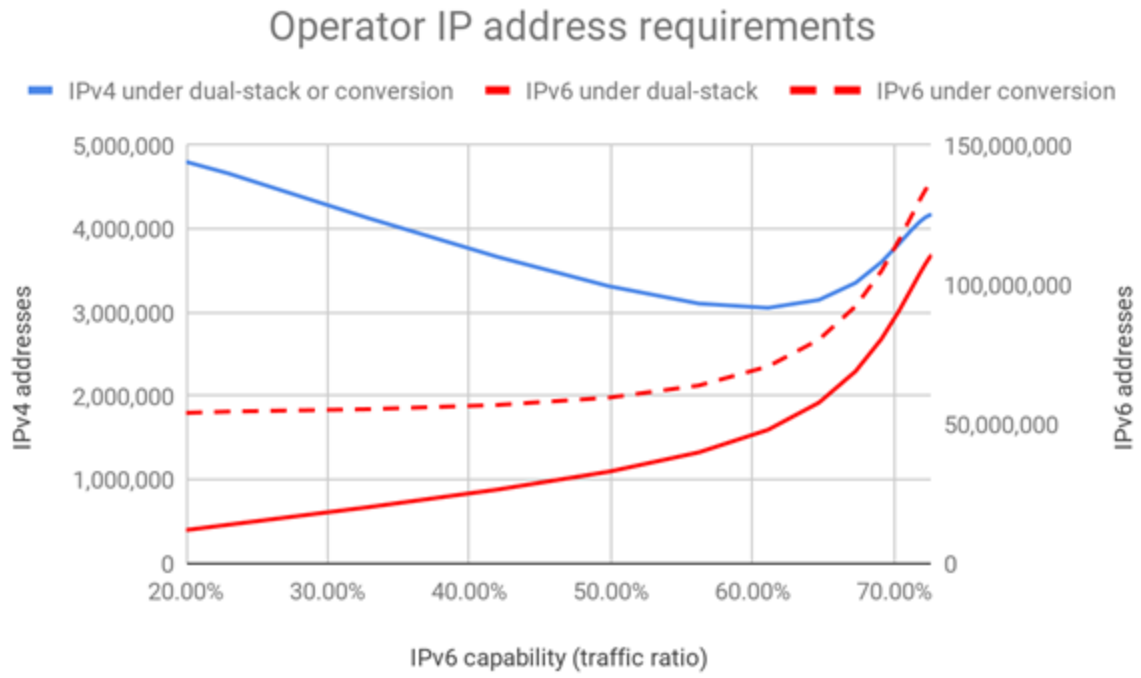
Modeling dual stack vs. conversion...

Figure 14: Scenario 4 (cloud service provider)



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Conclusion: Get Ready for a Mixed World

IPv6 won't become an orphan

- But many network operators don't need it

Shift in traffic ratio crucial to future demand for IPv4 numbers

Limited network effects, slow growth networks, additional IPv4 resources

Hard to posit scenarios that lead to global convergence on IPv6 within 20 years

- What are architectural, economic and political implications of a mixed world?