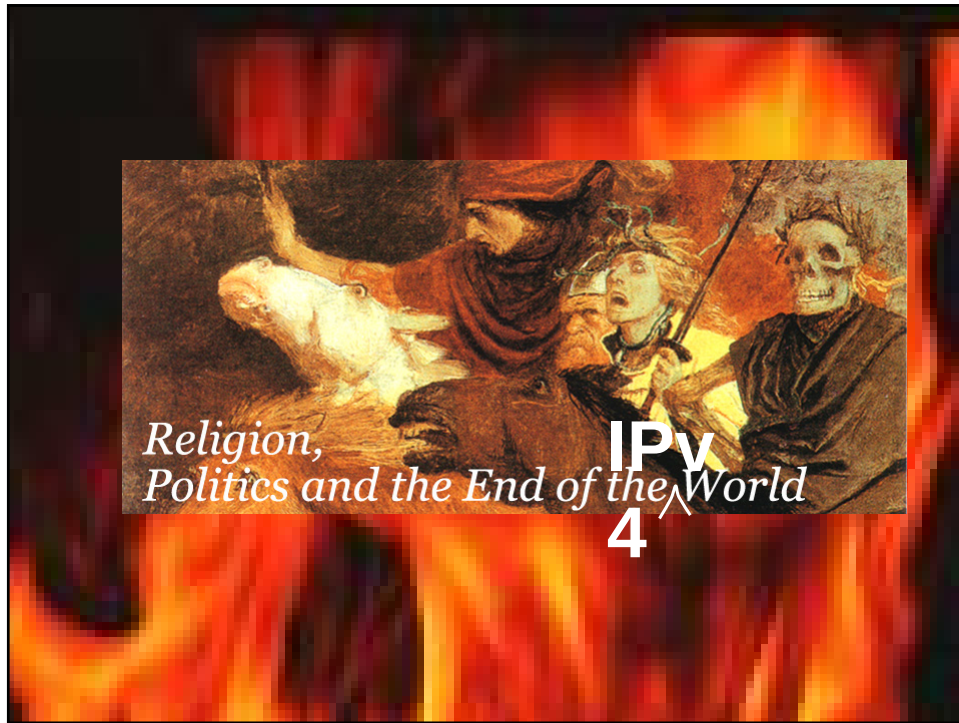




The End of the World is nigh (er) !

Geoff Huston
Chief Scientist
APNIC



In the beginning....

- 32 bits of address seemed to be infinitely huge
- So we used a fixed 8 / 24 address partition
 - And we were going to run out of network IDs
- So then we divided the world into Class A, B and C addresses
 - And we were going to run out of Class B addresses in 1995
- So then we moved to Classless addressing
 - And we are still going to run out of addresses



If IPv4 address exhaustion is inevitable
then the key question for many is:

When?



IPv4 Exhaustion Prediction Technique

- Assemble daily data for the past 1000 days on:
 - IANA to RIR allocations
 - RIR allocation rates
 - Advertised address pool
 - Unadvertised pool



Prediction Technique

1. Fit a mathematical model over the advertised address pool data as a function of time
2. And then model the unadvertised address pool size as a function of the advertised pool
3. Derive industry demand as the sum of the two pools
4. Then model RIR actions by simulating allocations to match demand
5. Then model IANA actions by simulating IANA to RIR policies
6. Then model the operation of the address distribution system
7. Until the IANA pool exhausts!

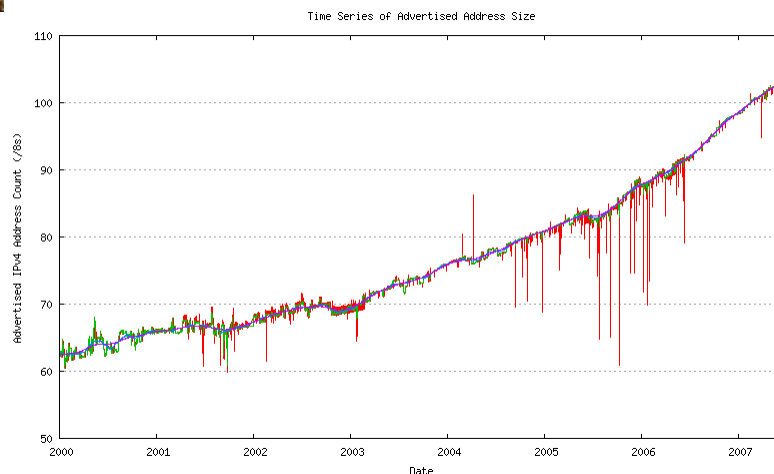


Underlying Assumptions

- Tomorrow is a lot like today
- Trends visible in the recent past continue into the future
- This model assumes that there will be no panic, no change in policies, no change in the underlying demand dynamics, no disruptive externalities, no rationing, and no withholding
 - No, really!

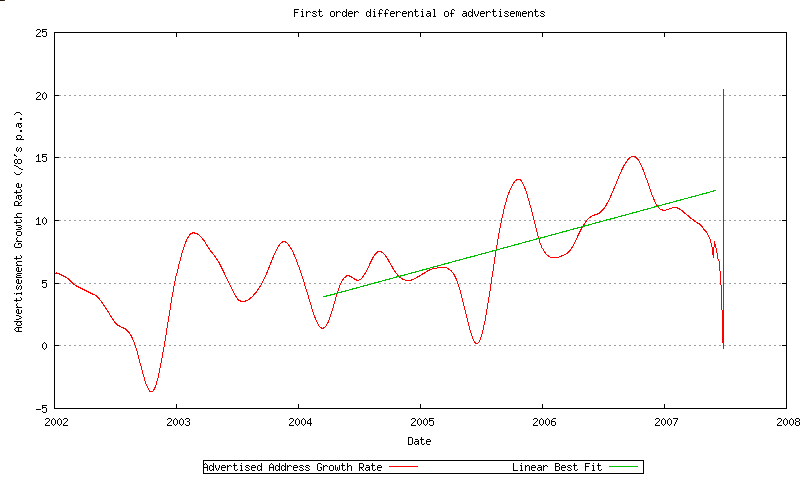


Modelling Data – IPv4 Advertised Address pool since 2000

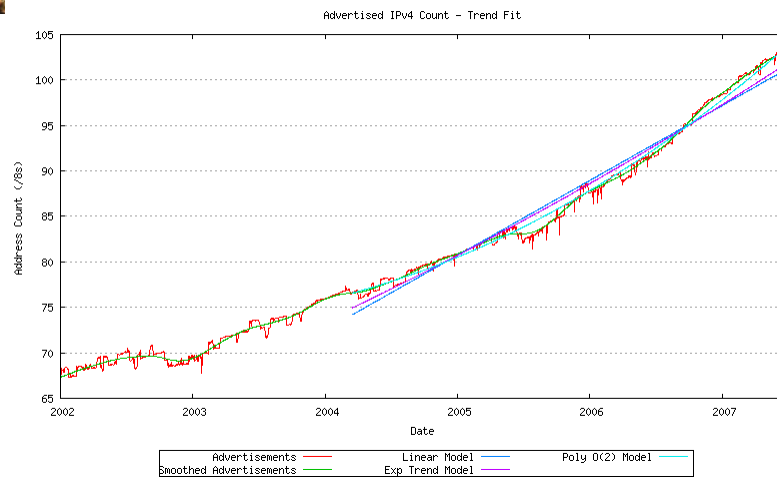




1st Order Differential

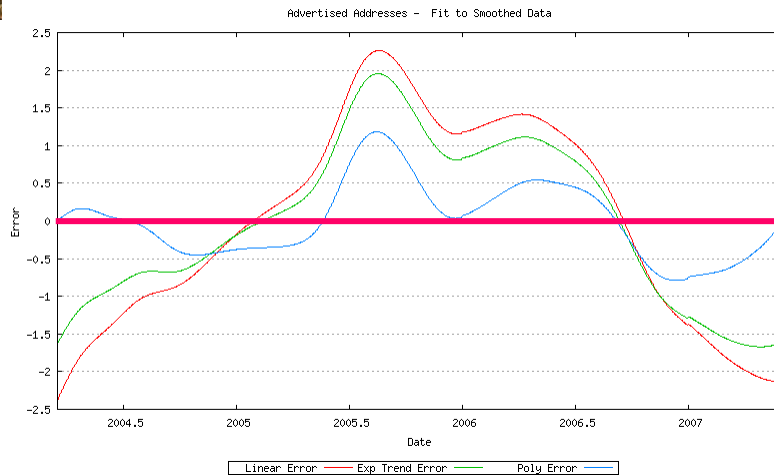


Curve Fitting





Curve Fitting Error

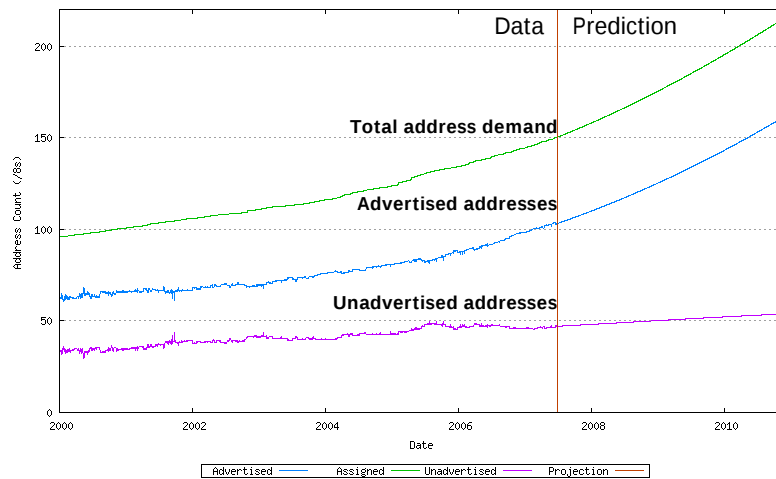


Selecting a model

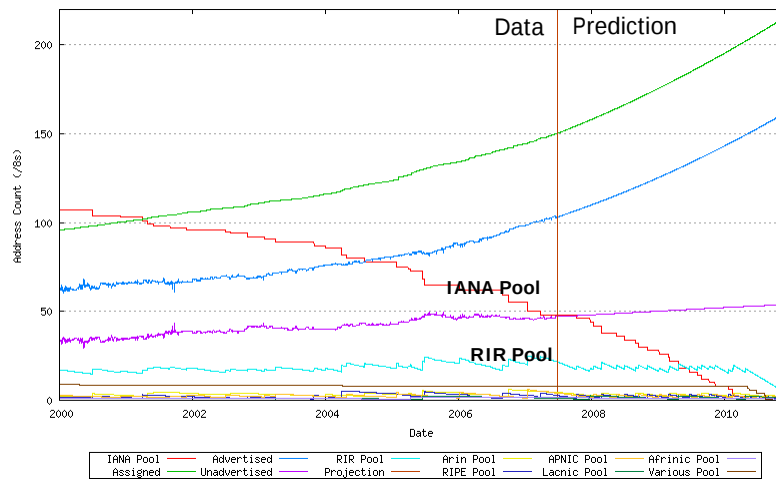
- Lowest error on fit to data is the quadratic growth model
 - Linear and exponential growth models indicate a worse fit to recent data
 - i.e Address demand is increasing at a constant rate



Address Consumption Model

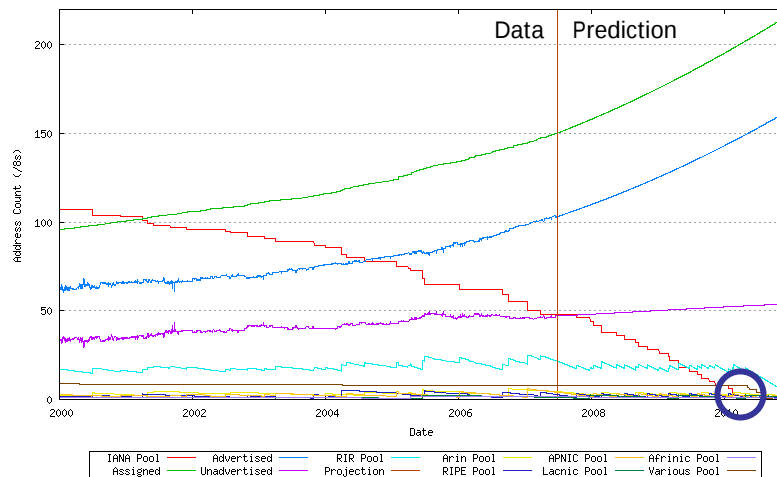


Address Consumption Model





The Current IPv4 Model



So -- when?

In this model, IANA allocates its last IPv4 /8 to an RIR on the 24th April 2010

This is the model's predicted exhaustion date as of the 29th June 2007. Tomorrow's prediction may be different!



But ...

This curve fitting is just an exercise in numbers

Reality often turns out to be different

Just how different reality will be is something
you need to determine *for yourself*

<http://ipv4.potaroo.net>



What Then?

What are our choices?

- ⇒ **IPv4 + NATs**
- ⇒ **IPv4 trading markets**
- ⇒ **IPv6 deployment**



NAT-PT + IPv4?

- Deploy more NAT-PT units within the network
 - How much will it cost? Can the cost be externalized?
 - What services can / cannot be offered? Can these services adapt to NATs?
 - How long / how large can such a NAT strategy last?



Are NATs short-term viable?

Yes!

- Deployment costs are externalized away from network operators
- They support a viable subset of Internet services
- They are already extensively deployed
- They have already influenced all current application architectures



Are NATs long-term viable?

Hard to tell - Probably not

The major problem with NATs from an application implementation perspective is the non-uniformity of NAT behaviour

- this could be fixed

The major problem with NATs from an application architecture perspective is complexity bloat:

- application-specific identification domains,
- NAT-mediated application-specific rendezvous functions,
- multi-party distributed state application behaviours
- multi-ganged NAT behaviours
- there is no easy fix for this



IPv4 Trading?

- Redistribution of IPv4 address blocks through the operation of trading markets?
 - How can such markets operate?
 - How much will IPv4 addresses cost now?
 - How much will IPv4 addresses cost later?
 - Can the outcomes continue to be routed?



IPv4 Trading?

- Balancing supply and demand through an open market with price signals
 - For a seller – the ability to capitalize the value of under-used resources
 - For a buyer – place a utility efficiency value on access to the resource
- Risks:
 - Market distortions
 - Price uncertainty
 - Captive buyers
 - Speculative market players
 - Regulatory intervention
 - Routing load through address block fragmentation



Is an IPv4 trading market viable for the short term?

Probably yes

This is a conventional distribution function which could be undertaken through interactions between address sellers and buyers

Price signals could provide motivation for greater levels of efficiency of address deployment

Within such a framework there are potential implications for the viability of the routing system which are not well understood



Is an IPv4 trading market viable for the long term?

Hard to tell...

An IPv4 address trading market can provide a short term incentive to expose unused addresses for reuse, and can provide incentives for high address utilization efficiencies

An IPv4 market exposes additional risk factors in variability of supply availability and pricing that are expressed as cost elements to the service provider

An IPv4 market does not create new IPv4 addresses. An address trading market cannot fuel network growth indefinitely.

Markets cannot make the finite infinite.



IPv6 Deployment

- Deploy IPv6
 - How much will it cost?
 - How long will it take?
 - When will customers and services transition?
 - When does the dual-stack overhead go away - can we stop also supporting IPv4?



IPv6 short term viability?

Still extremely uncertain

- Few immediate commercial incentives to drive ISP deployment
- No ability to externalize deployment costs
- No dense service base and few compelling services to drive consumer-level demands

It's a critical mass problem – until a sizeable proportion of the market takes IPv6 up, IPv6 remains an uneconomic proposition



IPv6 – long term viable?

Given the state of the current alternatives - it had better be!

It offers leverage into larger networks with stronger characteristics of utility service models. It has the potential to reduce some of the complexities of network service architectures.

But the potential gains here are in possible long term outcomes, while the transition costs are immediate



What's the problem?

- Deregulated markets react effectively to short term pricing signals
- We've managed to create a highly competitive price sensitive Internet market based on IPv4 + NATs
- Customers are not willing to pay a premium for IPv6 dual stack services
- No single industry player can readily afford to make longer term investments in dual stack support of IPv6 as long as all other players are deferring this cost
- So the industry has managed to wedge itself into an uncertain situation!



Implications

- IPv4 will not get “turned off” any time soon...
 - There is no “flag day” for transition out of IPv4
 - IPv4 addresses will continue to be in demand beyond the date of exhaustion of the unallocated pool
 - But the mechanisms of management of the address distribution function will change
 - Scarcity is typically expressed in markets as a price premium for the resource
 - Would adding pricing signals in address availability be helpful or chaotic in this environment?



Implications

- IPv4/IPv6 dual stack deployment is not an easy proposition
 - Dual routing protocol operation
 - Dual tools
 - Protocol-based connectivity divergence
 - User visible application behaviour differences
 - And automated client OS behaviour of IPv6 connection preference can make the problem worse!



Implications

For network managers:

Understanding growth requirements and matching this to address accessibility

Forward planning to minimize disruption risk

For product and service vendors:

Planning ahead of demand rather than lagging

For regulators and policy makers:

Phrasing clear and achievable objectives with unambiguous regulatory signals to industry players



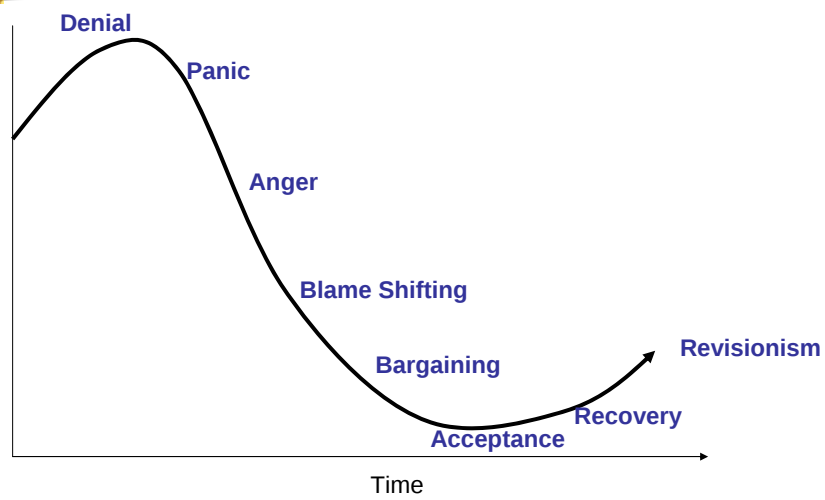
Implications

It is likely that there will be some disruptive aspects of this transition that will impact the entire industry

This will probably not be seamless nor costless



Coping with Crises





Coping with Crises – IPV4 Exhaustion

