The Evolution of the Internet Architecture and IPv6

Geoff Huston
APNIC

Firstly, thanks

to Steve Deering for some of the material I’ve used in the first part of this presentation on the architectural changes in IP

And, of course,

these are (probably) the speaker’s views and opinions!

Does IP even have an "Architecture"?

One view is that the Internet is an
Architecture-Free technology

- The Internet today is a product of a process of incremental short term feature creep rather than deliberate design
- There is no process of imposition of architectural standards onto deployed networks
- Each Internet Service provider is at liberty to deploy an architecture of choice (or, in the case of the carriers, use no coherent architecture at all!)

The "Adaptation" view of IP

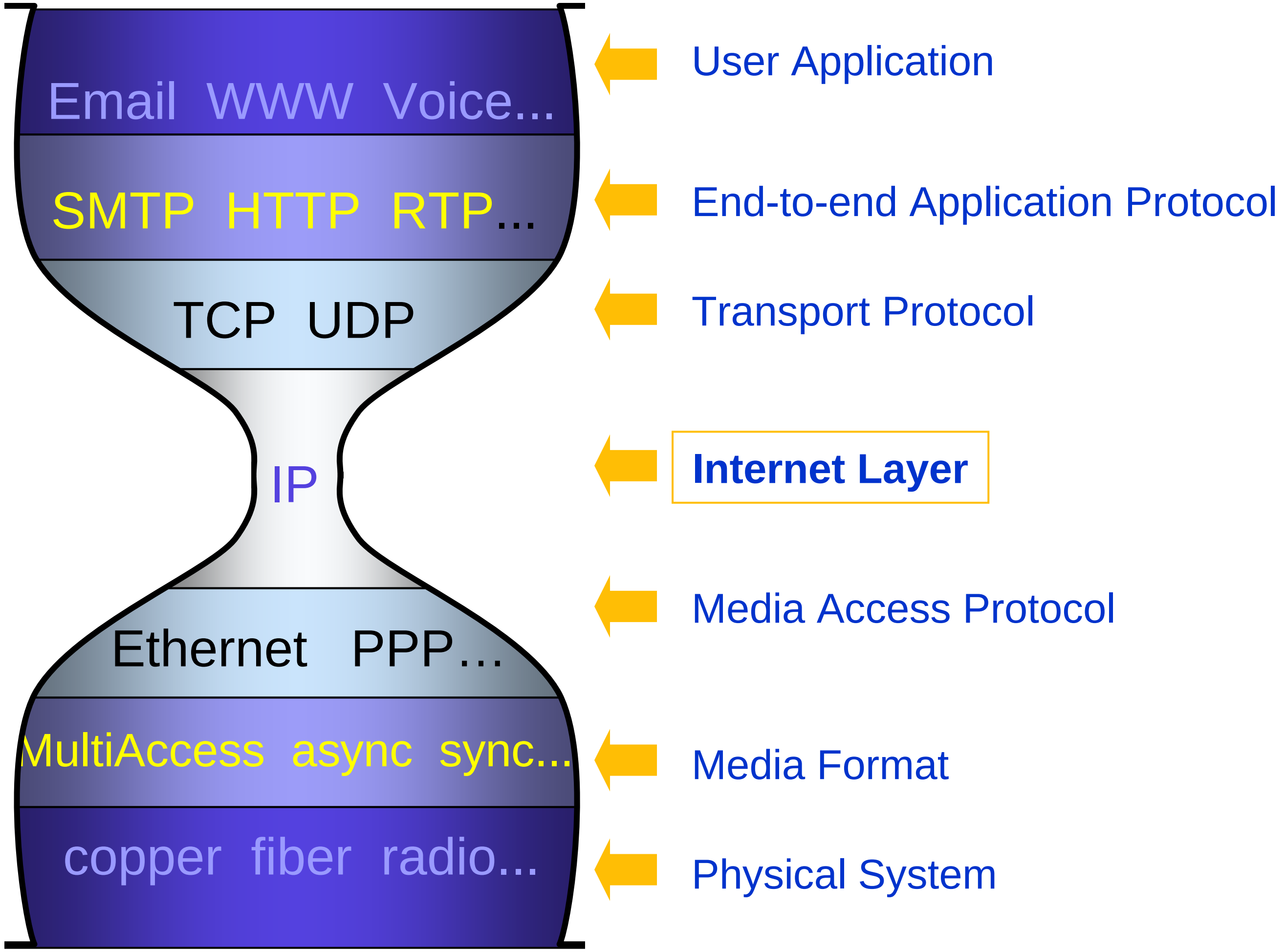
Another view is that IP is **a universal adaptation layer**

- IP sits above a large number of network media
  - SDN, SDH, Ethernet, DSL, Wireless, even carrier pigeon
- IP provides a consistent addressing and transport service for a variety of application requirements
  - Unicast and Multicast modes
  - Reliable data transfer
  - Semi-Real time streams
  - High volume streams
  - Reliable Transactions
  - multi-level Referrals

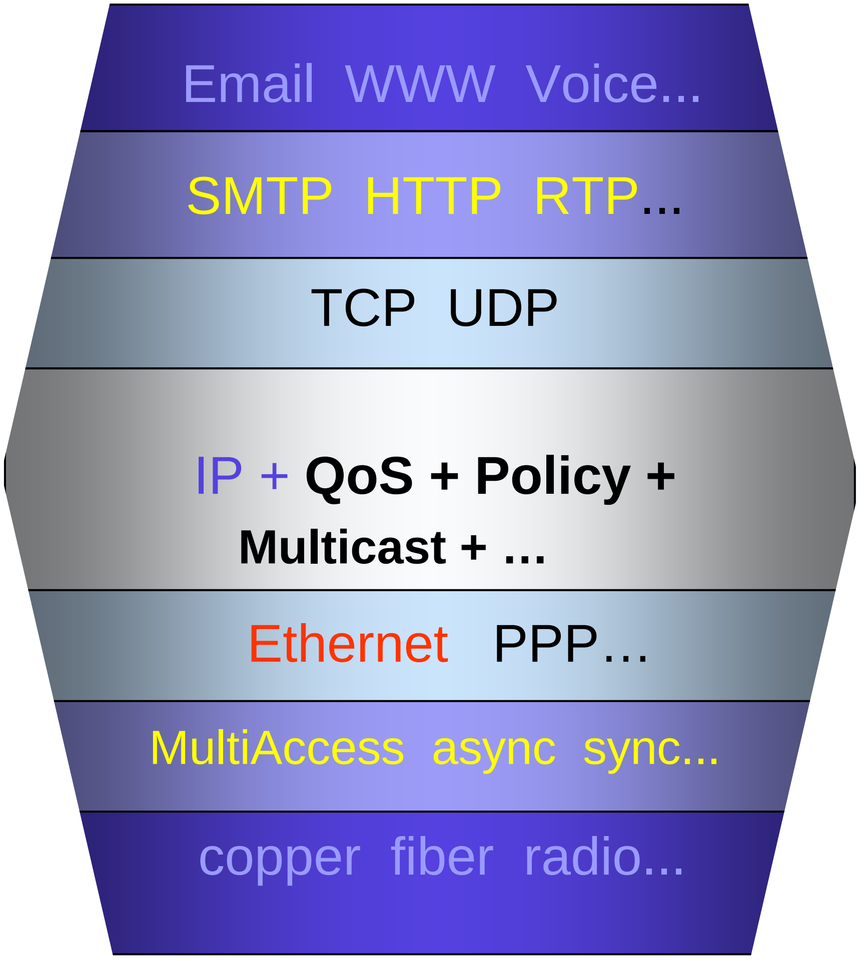
Why use an IP adaptation layer?

- Simple to **adapt to new media**
  - IP Address to MAC address resolution protocol
  - IP packet framing definition
  - And its done!
- Simple to create **composite networks**
  - Ethernet - ATM – SDH – Ethernet – wireless
- Simple to **scale**
  - IP networks are composite networks
  - No single coordinated effort required
  - Minimal interdependencies between component networks
  - Very simple network-to-network interface
- Simple to **create applications** in IP
  - Applications do not need to understand or adapt to varying transport characteristics

The Hourglass IP Model



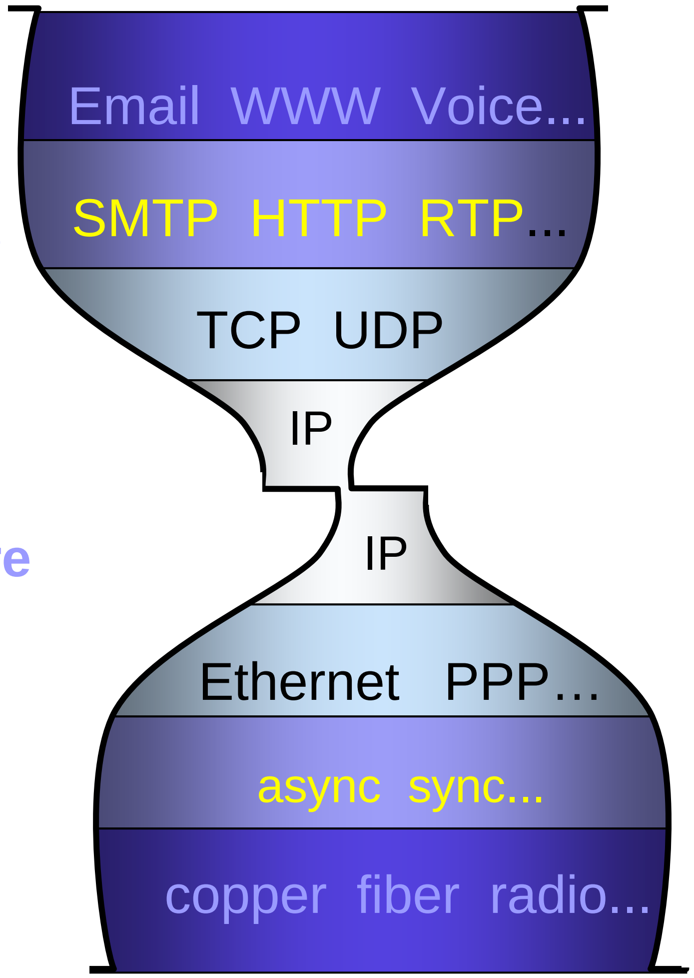
But:
IP is changing shape!



Additional functionality within the IP layer requires greater levels of application complexity

Additional functionality within the IP layer requires more functionality and greater levels of coupling from underlying transmission networks

IP is snapping apart!

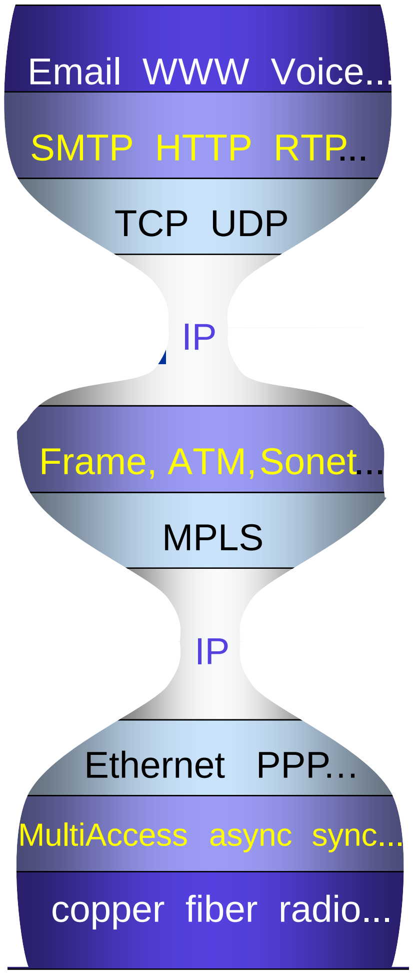


You can't take the falls any more without breaking something!

And the repairs are now costly and complex!

- Network Address Translators (NATs) & Application Level Gateways (ALGs) used to glue together network domains
- lots of kinds of new glue being invented—ruins predictability and makes applications more complex
- some applications remain broken, since the NAT glue does not provide fully transparent connectivity

Layered complexity takes over



The addition of MPLS to the protocol model has caused some surprising outcomes in terms of using MPLS and IP as a substrate for emulated wire services

It is not obvious this this form of complexity is a reliable foundation for a scaleable network architecture. Indeed its becoming clear that MPLS and NGN approaches are good examples of complex cripple-ware, rather than clear scaleable architecture

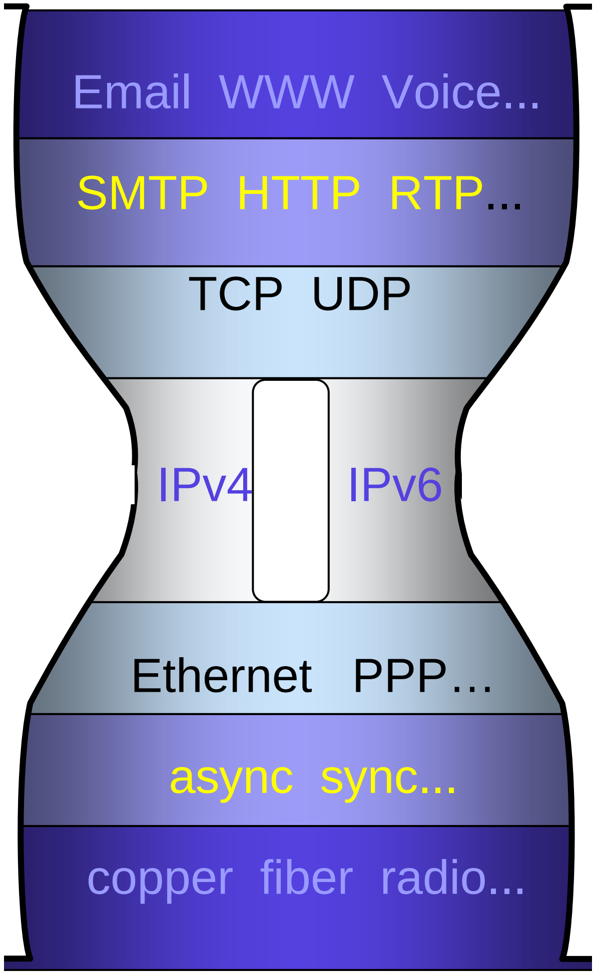
Insecurities and Anxieties

- IP networks today are plagued with hostile and annoying forms of traffic
- The end-to-end model of applications operating above the IP layer is causing a multitude of problems for end users, operators and IP itself
  - Firewalls, Application Level Gateways, Network mediation of traffic
  - Application servers are being embedded into the service provider's architectures
- Requirement for "robust" IP services

And IP has its weaknesses…

- IP has some serious weaknesses in large scale environments that support high volume real time synchronous communications
- IP does not readily support large scale mobility environments
- IP has some problems with wide area coverage radio environments
- IP has challenges in supporting provider-based VPNs with address and service quality partitioning
- IP routing does not scale
- IP address renumbering without NATs is horrendous

And now we have an Identity Crisis!



The introduction of a V6 transition into IP:

- Doubles the number of service interfaces
- Requires changes above and below the IP layer
- Creates subtle (and not so subtle) interoperability problems

IPv6 - Entropy or Evolution?

- The Internet as an evolving lifeform or ecosystem
  - If IPv6 can offer clearly superior value propositions to the industry then it will be deployed
    - The “invisible hand” of competitive market forces will lead the industry to adopt IPv6 naturally
  - Inferior technologies will wither away as they cease to offer any utility or lasting value

- Just let nature (the market) take its course!
  - though result is undesigned and unpredictable, should not be viewed as decay. Its adaptation.

Is IPv6 really evolutionary?

Or, to use a multi-choice variant of this question: Is an industry-wide IPv6 transition going to proceed as:

- **extinction** - acting as a catalyst to take a step to some other entirely different technology platform that may have little in common with the Internet architecture as we understood it?
- **evolution** - by migrating existing IPv4 networks and their associated service market into IPv6 in a piecemeal fashion?
- **revolution** - by opening up new service markets with IPv6 that directly compete with IPv4 for overall market share?

Extinction?

- The original IP architecture is dying – if not already terminally dead
  - Coherent transparent end-to-end is disappearing
  - Any popular application today has to be able to negotiate through NATs, ALGs and other middleware
  - Peer-to-peer networks now require mediators and agents (SpeakFreely vs Skype), plus stun, ice,…
  - Efforts to impose overlay topologies, tunnels, virtual circuits, traffic engineering, fast reroutes, protection switches, selective QoS, policy-based switching on IP networks appear to have simply added to the cost and detracted from the end user utility
- It was a neat idea, but we killed it!

Today

- We are engineering applications and services in an environment where NATs, firewalls and ALGs are assumed to be part of the IP plumbing
  - Client-initiated transactions
  - Application-layer identities
  - Agents to orchestrate multi-party rendezvous and NAT identification and traversal
  - Multi-party shared NAT state

- All this complexity just results in more fragile applications and lower operational margins

IPv6?

- We’ve all heard views that:
  - IPv6 was rushed through the standards process
  - It represents a very marginal change in terms of design decisions from IPv4
  - It did not manage to tackle the larger issues of overloaded address semantics
  - It did nothing to address routing scaling issues
  - And the address architecture is so broken that it yields just 48 useful bits out of 128 *

(* same as V4 + NAT!)

IPv6 or something else?

- Is there anything else around today that takes a different view how to multiplex a common communications bearer?
- How long would a new design effort take?
- Would an new design effort end up looking at an entirely different architecture?
- Or would it be taking a slightly different set of design trade-offs within a common set of constraints?

Alternate Worlds?

- Is there anything else around?

  Nope - not in the near term

- How long would a new design effort take?

  Tough – At least a decade or longer

  (we're not getting any smarter!)

- Would an entirely new design effort end up as a marginal outcome effort – would we be looking at no more than a slightly different set of design trade-offs within a common set of constraints?

  Probably

  (all that effort to get nowhere different!)

So “extinction” is not very likely – there is simply no other viable option on our technology horizon

What about “evolution”?

So should we evolve?

- The general answer appears to be "**yes**" for most values of "**we**"
- The possible motivations differ for each player:
  - Allow for networks with more directly addressed end points
  - Reduce per-address cost
  - Reduce application complexity
  - Increase application diversity and capability
  - Allow direct peer-to-peer networking
  - Allow utility device deployment
  - Leverage further efficiencies in communications

Pressure for Change?

- The pain of deployment complexity is not shared uniformly:
  - ISPs are not application authors -- thank god!
  - ISPs are not device manufacturers -- also a good thing!

- There appear to be no clear “early adopter” rewards for IPv6
  - Existing players have strong motivations to defer expenditure decisions -– because their share price is plummeting
  - New players have no compelling motivations to leap too far ahead of their seed capital
  - All players see no incremental benefit in early adoption
  - And many players short term interests lie in deferral of additional expenditure
  - The return on investment in the IPv6 business case is simply not evident in today’s ISP industry

When?

- So the industry response to IPv6 deployment appears to be:

“yes, of course, but **later**”

What is the trigger for change?

- At what point, and under what conditions, does a common position of "**later**" become a common position of "**now**"?

- So far we have no clear answer from industry on this question

The Case for IPv6

- IPv4 address scarcity is already driving network service provision.
  - Network designs are based on address scarcity
  - Application designs are based on address scarcity
- We can probably support cheaper networks and more capable applications in networks that support clear and coherent end-to-end packet transit
- IPv6 is a conservative, well-tested technology
- IPv6 has already achieved network deployment, end host deployment, and fielded application support

- For the Internet industry this should be a **<u>when</u>** not **<u>if</u>** question

But….

- But we are not sending the right signals that this is ‘cooked and ready’ - we are still playing with:
  - The Address Plan
  - Aspects of Stateless auto-configuration
  - Flow Label
  - QoS
  - Security
  - Mobility
  - Multi-addressing
  - Multi-homing
  - Routing capabilities
  - Revisiting endpoint identity and network locator semantics

The Business Obstacles for IPv6

- Deployment by regulation or fiat has not worked in the past – repeatedly
  - GOSIP anyone?
- There are no network effects that drive differentials at the edge
  - its still email and still the web
- There is today a robust supply industry based on network complexity, address scarcity, and insecurity
  - And they are not going to go away quietly or quickly
- There is the prospect of further revenue erosion from simpler cheaper network models
  - Further share price erosion in an already gutted industry

More Business Obstacles for IPv6

- Having already reinvested large sums in packet-based data communications over the past decade there is little investor interest in still further infrastructure investment at present
  - The only money around these days is to fund MPLS fantasies!
- There is no current incremental revenue model to match incremental costs
  - Oops! Customer won't pay more for IPv6
- IPv6 promotion may have been too much too early – these days IPv6 may be seen as tired not wired
  - Too much powerpoint animation!
- Short term individual interests do not match long term common imperatives
  - The market response is never an intelligent one
- "Everything over HTTP" has proved far more viable than it should have

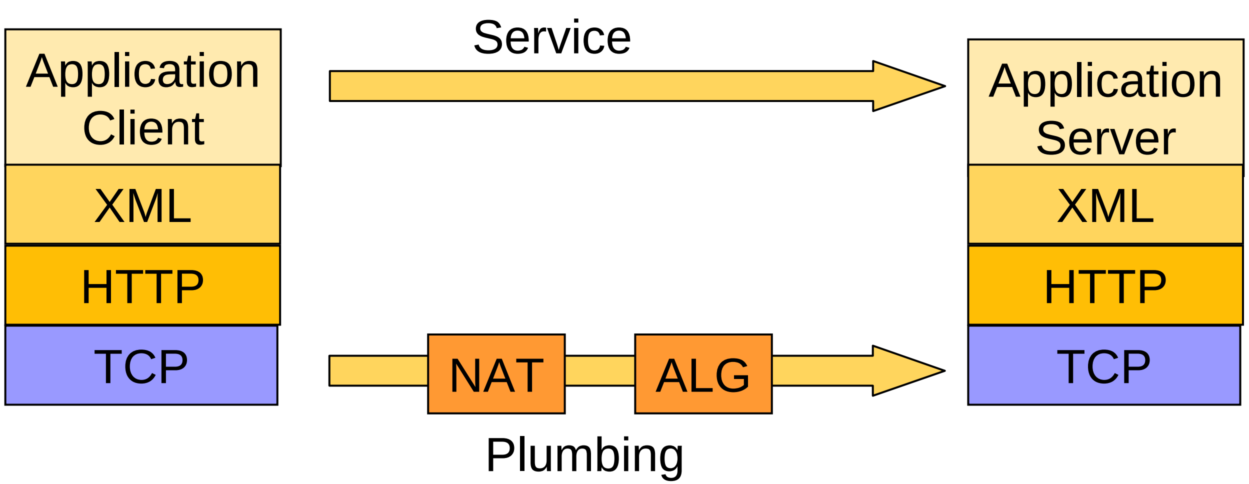
Meet the Enemy!

- "As easy as plugging in a NAT"
  - NATs are an excellent example of incremental deployment and incremental cost apportionment
- The search for perfection
  - Constant adjustment of the protocol specifications fuels a common level of perception that this is still immature technology
- The search for complexity
  - Pressure to include specific mechanisms for specific scenarios and functionality as a business survival model

The current situation

The entire Internet service portfolio appears to be collapsing into a small set of applications that are based on an even more limited set of HTTP transactions between servers and clients

This is independent of IPv4 or V6



Maybe it's just deregulation

- Near term business pressures simply support the case for further deferral of IPv6 infrastructure investment
- There is insufficient linkage between the added cost, complexity and fragility of NAT-based applications at the edge and the costs of infrastructure deployment of IPv6 in the middle
  - Deregulated markets are not perfect information markets – pain becomes isolated from potential remedy
  - Markets often cannot readily trade off short term cost against longer term benefit

So “evolution” does not look that likely either

What about “revolution”?

Learning from IPv4

- IPv4 leveraged:
  - cheaper switching technologies
  - more efficient network use
  - lower operational costs
  - structural cost transferral

- IPv4 represented a compelling and revolutionary business case of stunningly cheaper and better services to end consumers, based on the silicon revolution

The IPv6 Condition

- There are no compelling technical feature levers in IPv6 that are will drive new investments in existing IP service platforms
- There are no compelling revenue levers in IPv6 that will drive new investments in existing IP service platforms

So why IPv6?

- IPv6 represents an opportunity to embrace the communications requirements of a device-dense world
  - Way much more than PCs
  - Device population that is at least some 2 – 3 orders of magnitude larger than today's Internet
- BUT - Only if we can further reduce IP service costs by a further 2 -3 orders of magnitude
  - Think about prices of the level of $1 per DSL service equivalent per year

IPv6 - From PC to iPOD to iPOT

If we are seriously looking towards a world of billions of chattering devices then we need to look at an evolved communications service industry that understands the full implications of the words "**<u>commodity</u>**" and "**<u>utility</u>**"

The IPv6 Revolutionary Manifesto

- **Volume over Value**
  - Supporting a network infrastructure that can push down unit cost of packet delivery by orders of magnitude
  - Commodity volume economics can push the industry into providing
    - even “thicker” transmission systems
    - simpler, faster switching systems
    - utility-based provider industry
    - Lightweight application transaction models

- So it looks like the IPv6 future may well be **revolution** where IPv6 is forced into direct customer competition with existing IPv4+NAT networks

- And the primary leverage here is one of **cheaper** and **bigger**, and not necessarily *better*

If all IPv6 can offer is just IPv4 with bigger header fields then the ‘transition’ into IPv6 has already stalled and its unclear how it will ever regain industry momentum

In such a world IPv4 plus NATs will be highly persistent

Maybe

- we need to regard IPv6 in different terms:
  - Perhaps we should look at IPv6 as the enabler for **vastly** larger networks
  - And stop looking for higher value propositions with IPv6 networks

But…is this realistic?

- Is it really possible that there are further cost economies to be realized in the carrier IP network industry?

Where is the margin to strip?

- Transmission infrastructure?
  - Fibre optics vs Physics
  - Spread spectrum wireless vs spectrum pollution
  - ?
- Switching?
  - Electrical vs power and speed
  - Optical vs physics
- O&M?
- Cost of Finance?
- Investor returns?

SO

- A vastly ‘cheaper’ network is unlikely in the near to medium term
  - Irrespective of volume drivers
- Which doesn’t look good for IPv6

- And it makes the “revolutionary” IPv6 approach of achieving vastly lower cost points though higher volumes for IPv6 look rather unsatisfactory as a viable outcome!

Then what's left?

- Making IPv4 + NATS work for <u>ever</u>?
  - Unlikely!
- Forced IPv6 conversion?
  - Unlikely?
- Something else?

End Stack Middleware!

- HIP and SHIM6 are good examples of this approach
  - externalizing the costs of additional addressing complexity out of the network and onto the hosts

Splitting Identity and Location

- Hosts care deeply about absolute identity
- Networks care deeply only about relative location
  - All a network really cares about is to associate incoming packets with the relative location of the network exit point
  - After that its SEP!
- Its actually the identity component of IPv4 addressing that's under stress, not the network address component
  - And HIP and SHIM6 are both decent experimental prototypes of how these differing semantic address components can be split at the endpoint rather than within the network infrastructure elements

So

- Its not really an IPv4 / IPv6 issue at all
  - Its actually about what element of end-to-end address semantics is essential at the transport level and what part is devolved to a mapping / translation problem at the network level

- Indeed it may even be the case that Ipv6 is never going to be needed as a network locator identity space at all!
  - We do need a deterministic, massive, cohesive persistent identity space that has more deterministic and more reliable properties than FQDN
  - But we don’t need 128 bits of routing locator space!

Maybe the issue we face with IP today is really all about the fundamentals of networking architectures after all!

Thank You