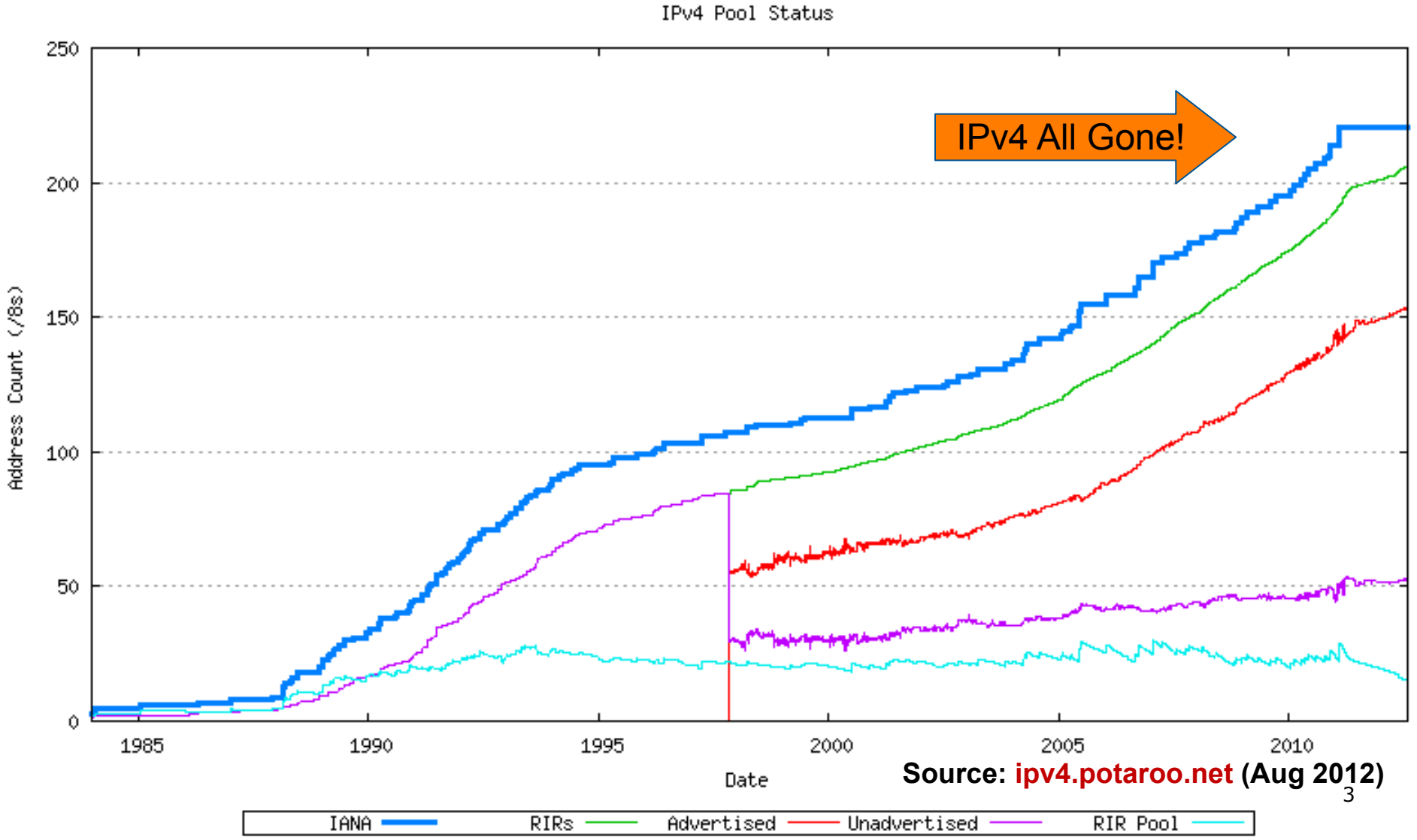
How can Network Operators face IPv4-Address Exhaustion?

A Review of IPv4-IPv6 Co-Existence Techniques

Introduction

Why should we care?

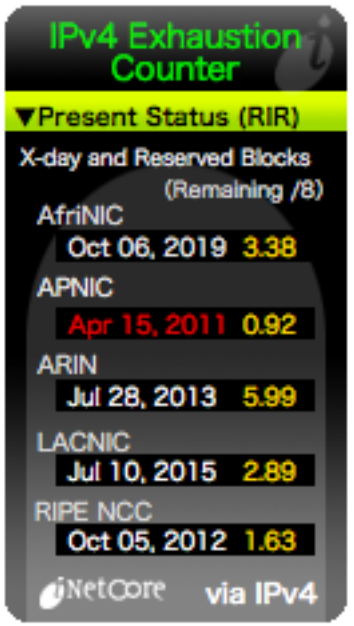
"The times, They are a' changin'"



Source: ipv4.potaroo.net (Aug 2012)

Is IPv4 really running out?

- Yes!
  - IANA IPv4 free pool ran out on 3rd February 2011
  - RIR IPv4 free pool will run out soon after
  - www.potaroo.net/tools/ipv4/
    - (depends on RIR soft-landing policies)
- The runout gadgets and widgets are now watching when the RIR pools will run out:
  - inetcore.com/project/ipv4ec/index_en.html
  - ipv6.he.net/statistics/



Strategies available for Service Providers

- Do nothing
  - Wait and see what competitors do
  - Business not growing, so don't care what happens
- Extend life of IPv4
  - Force customers to NAT
  - Buy IPv4 address space on the marketplace
- Deploy IPv6
  - Dual-stack infrastructure
  - IPv6 and NATed IPv4 for customers
  - 6rd (Rapid Deploy) with native or NATed IPv4 for customers
  - Or various other combinations of IPv6, IPv4 and NAT

Definition of Terms

Dual-Stack Networks

- Both IPv4 and IPv6 have been fully deployed across all the infrastructure
  - Routing protocols handle IPv4 and IPv6
  - Content, application, and services available on IPv4 and IPv6
- End-users use dual-stack network transparently:
  - If DNS returns IPv6 address for domain name query, IPv6 transport is used
  - If no IPv6 address returned, DNS is queried for IPv4 address, and IPv4 transport is used instead
- It is envisaged that the Internet will operate dual-stack for many years to come

IP in IP Tunnels

- A mechanism whereby an IP packet from one address family is encapsulated in an IP packet from another address family
  - Enables the original packet to be transported over network of another address family
- Allows ISP to provide dual-stack service prior to completing infrastructure deployment
- Tunnelling techniques include:
  - IPinIP, GRE, 6to4, Teredo, ISATAP, 6rd, MPLS

Address Family Translation (AFT)

- Refers to translation of an IP address from one address family into another address family
  - e.g. IPv6 to IPv4 translation (sometimes called NAT64)
  - Or IPv4 to IPv6 translation (sometimes called NAT46)

Network Address Translation (NAT)

- NAT is translation of one IP address into another IP address
- NAPT (Network Address & Port Translation) translates multiple IP addresses into one other IP address
  - TCP/UDP port distinguishes different packet flows
- NAT-PT (NAT – Protocol Translation) is a particular technology which does protocol translation in addition to address translation
  - NAT-PT is has now been made obsolete by the IETF

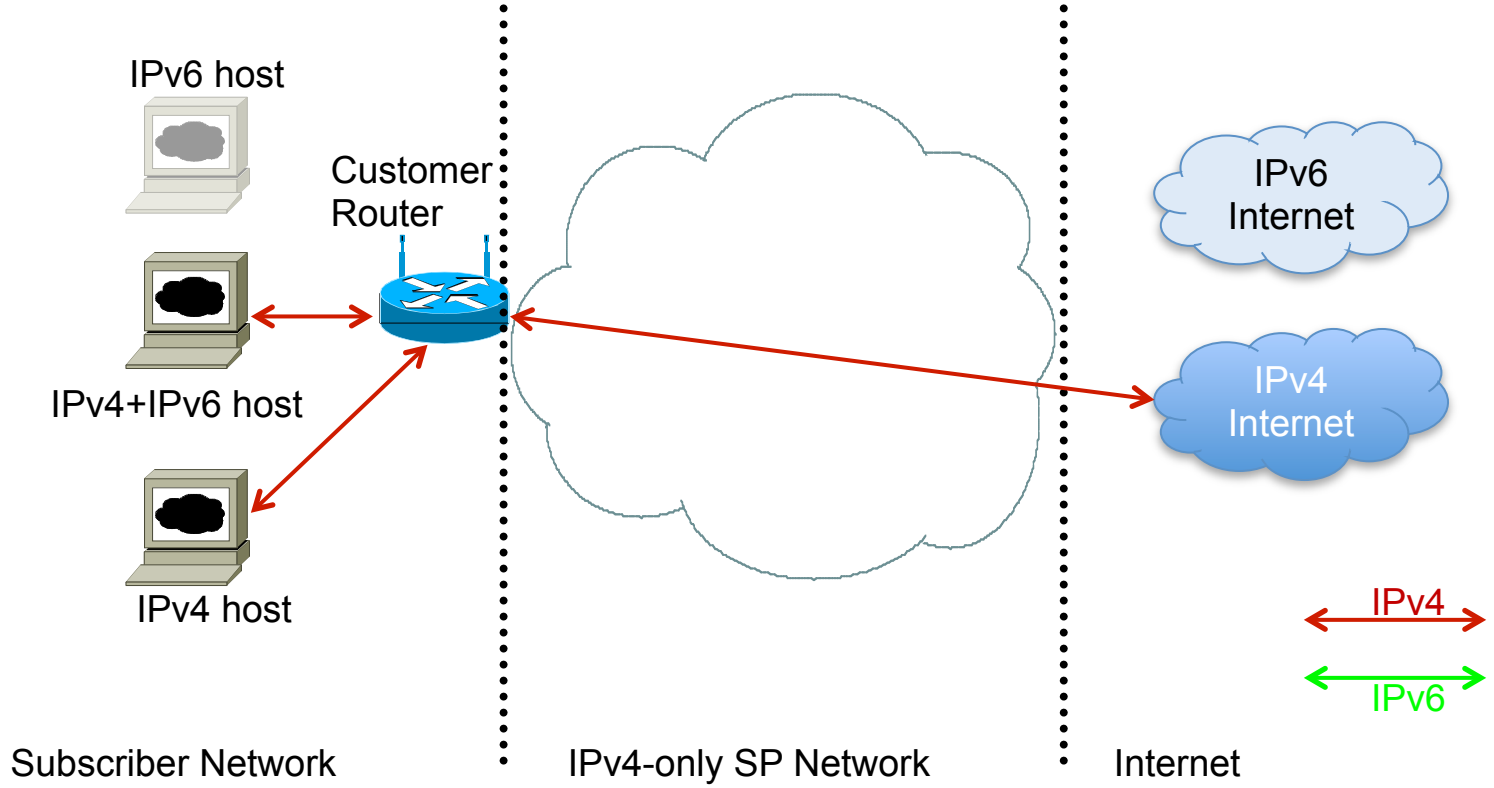
Carrier Grade NAT (CGN)

- ISP version of subscriber NAT
  - Subscriber NAT can handle only hundreds of translations
  - ISP NAT can handle millions of translations
- Not limited to just translation within one address family, but does address family translation as well
- Often referred to as Large Scale NAT (LSN)

Strategy One

Do Nothing

IPv4 only Network



- The situation for many SPs today:
  - No IPv6 for consumer
  - IPv4 scaling lasts as long as IPv4 addresses are available

IPv4 only: Issues

- Advantages
  - Easiest and most cost effective short term strategy
- Disadvantages
  - Limited to IPv4 address availability (RIRs or marketplace)
  - No access to IPv6
  - Negative public perception of SP as a laggard
  - Strategy will have to be reconsidered once IPv4 address space is no longer available

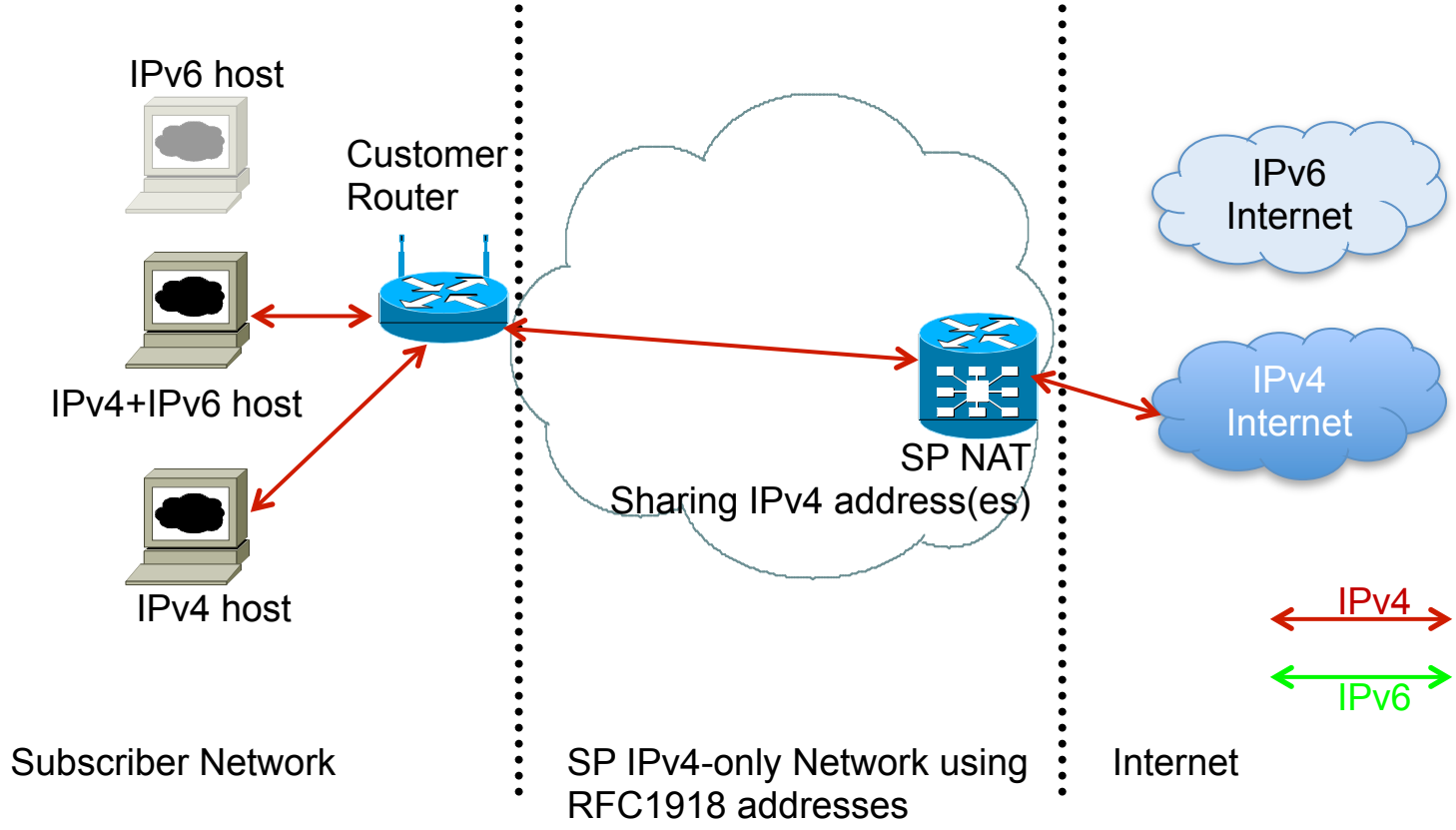
Strategy Two

Extend life of IPv4 network

Extending life of IPv4 Network

- Two ways of extending IPv4 network
  - Next step along from "Strategy One: Do nothing"
- Force customers to use NAT
  - Customers moved to RFC1918 address space
  - SP infrastructure moved to RFC6598 address space (or use RFC1918 where feasible)
- Acquire IPv4 address space from another organisation
  - IPv4 subnet trading

SP NAT in IPv4-only network



- Next step on from "doing nothing":
  - SP introduces NAT in core when IPv4 addresses run out
  - No access to IPv6 Internet for IPv6 enabled hosts

SP NAT in IPv4-only network: Issues

- Advantages
  - ISPs can reclaim global IPv4 addresses from their customers, replacing with non-routable private addresses and NAT
  - Allows continued IPv4 subscriber growth
- Disadvantages
  - SP needs a large NAT device in the aggregation or core layers
  - Has every well known technical drawback of NAT, including prevention of service deployment by customers
  - Double NAT highly likely (customer NAT as well as SP NAT)
  - Sharing IPv4 addresses could have behavioural, security and liability implications
  - Tracking association of port/address and subscriber, not to mention Lawful Intercept issues, are still under study
  - May postpone IPv6 deployment for a couple of years
  - Prevents subscribers from using IPv6 content, services and applications

IPv4 Subnet Trading

- Today the cost of getting IPv4 address space is low:
  - Service Provider:
    - RIR membership fee
    - Registration service fee (varies according to RIR service region)
  - End-sites usually receive IPv4 address block from SP as part of service
  - Many SPs already charge end-site for privilege of public IPv4 address
- In future when RIRs have no more IPv4 address space to distribute:
  - Cost of IPv4 addresses will be higher (today it's close to 0)
  - SPs may "purchase" IPv4 address space from other organisations

IPv4 Subnet Trading: Issues

- Advantages
  - Valuation of IPv4 addresses may hasten IPv6 adoption by encouraging sellers, perhaps more than offsetting costs to move some or all of their network to v6
  - Receivers of transferred IPv4 address space can prolong their IPv4 networks
- Disadvantages
  - Market may not materialise, so organisations hoping to benefit may not
  - Depending on region, if RIR doesn't register transfer, there may be no routability
  - Risk to integrity of routing system, as RIRs no longer authoritative for address records
  - Even more rapid growth of routing system
  - Financial pressure on ISPs to dispose of IPv4 addresses they still need

Strategy Three

IPv4/v6 Coexistence/Transition techniques

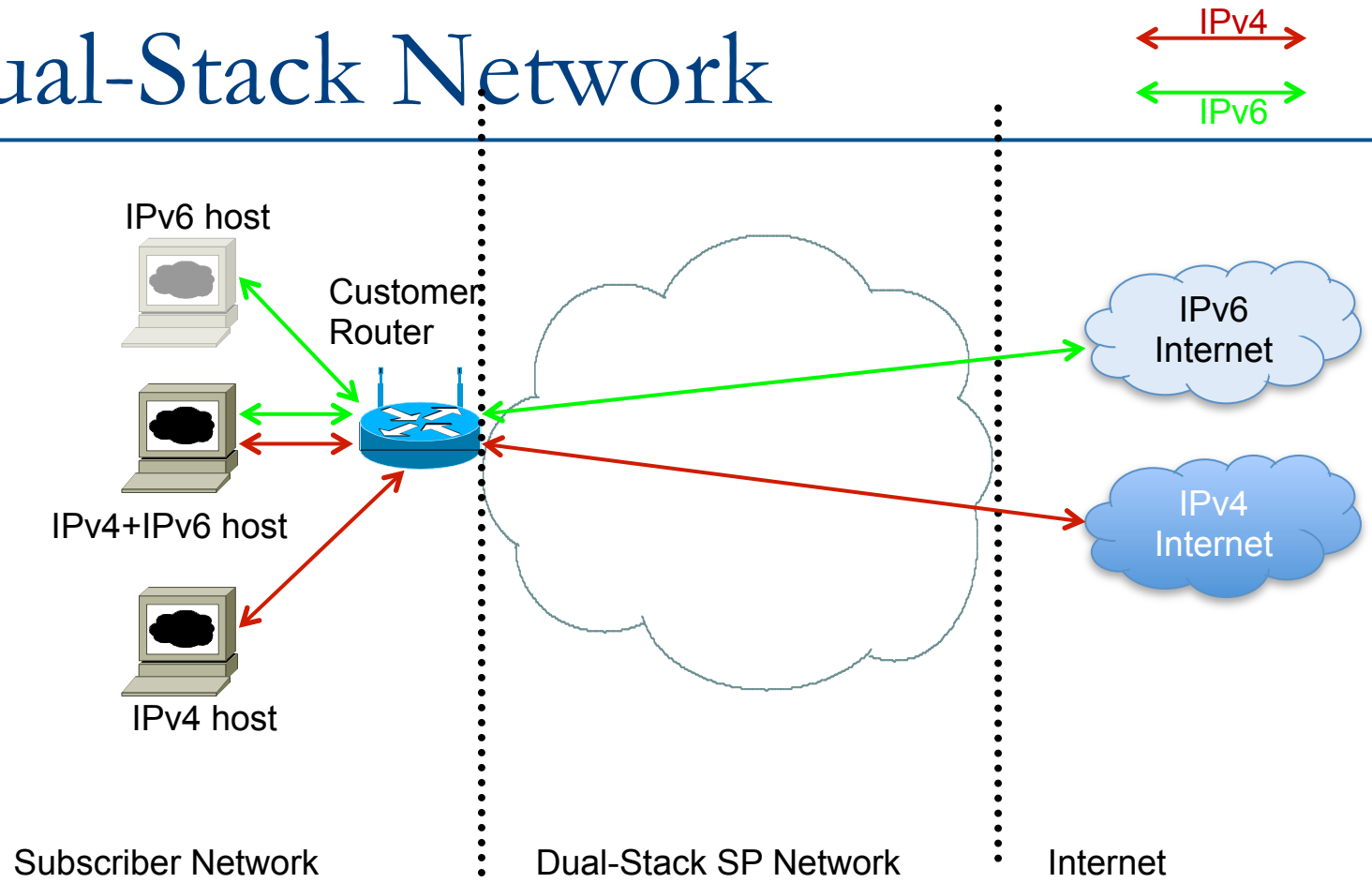
IPv4/IPv6 coexistence & transition

- Three strategies for IPv6 transition:
  - Dual Stack Network
    - The original strategy
    - Depends on sufficient IPv4 being available
  - 6rd (Rapid Deploy)
    - Improvement on 6to4 for SP customer deployment
    - Activity of IETF Softwires Working Group
  - Large Scale NAT (LSN)
    - SP deploys large NAT boxes to do address and/or protocol translation

IPv4/IPv6 coexistence & transition

- Large Scale NAT (LSN)
  - NAT444/SP NAT
    - NAT to customer, optionally NAT'ed core.
  - Dual-Stack Lite
    - Private IPv4 to IPv6 to Public IPv4
    - Activity of IETF Softwires Working Group
  - NAT64 & IVI
    - Translation between IPv6 and IPv4
    - Activity of IETF Behave Working Group

Dual-Stack Network

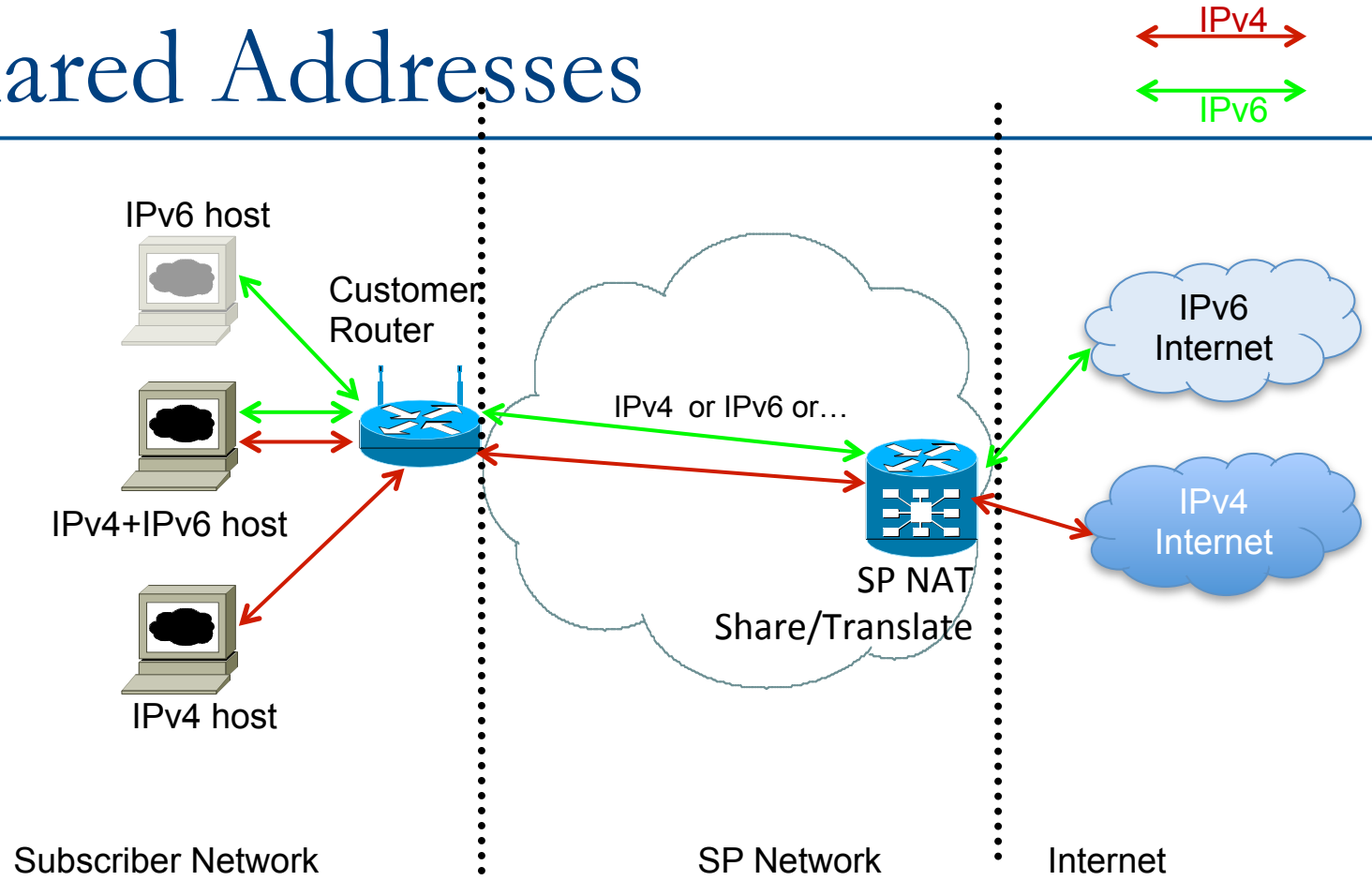


- The original transition scenario, but dependent on:
  - IPv6 being available all the way to the consumer
  - Sufficient IPv4 address space for the consumer and SP core

Dual-Stack Network: Issues

- Advantages
  - Most cost effective long term model
  - Once services are on IPv6, IPv4 can simply be discontinued
- Disadvantages
  - IPv4 growth limited to available IPv4 address space
  - Running dual-stack network requires extra staff training
  - IPv6 on existing IPv4 infrastructure might cost extra in terms of hardware changes (RIB and FIB memories)
  - IPv6-only end-points cannot access IPv4, but given most IPv6 end-points are dual-stack, require IPv4 address too

Shared Addresses



- SP shares globally routable IPv4 addresses amongst customers:
  - Customer could have IPv6, or IPv4, or a mixture
  - SP NAT device does necessary sharing and translation to access IPv4 and IPv6 Internets

Shared Addresses: Issues

- Advantages
  - ISPs can reclaim global IPv4 addresses from their customers, replacing with non-routable private addresses and NAT
  - Allows continued IPv4 subscriber growth
- Disadvantages
  - SP needs a large NAT device in the aggregation or core layers
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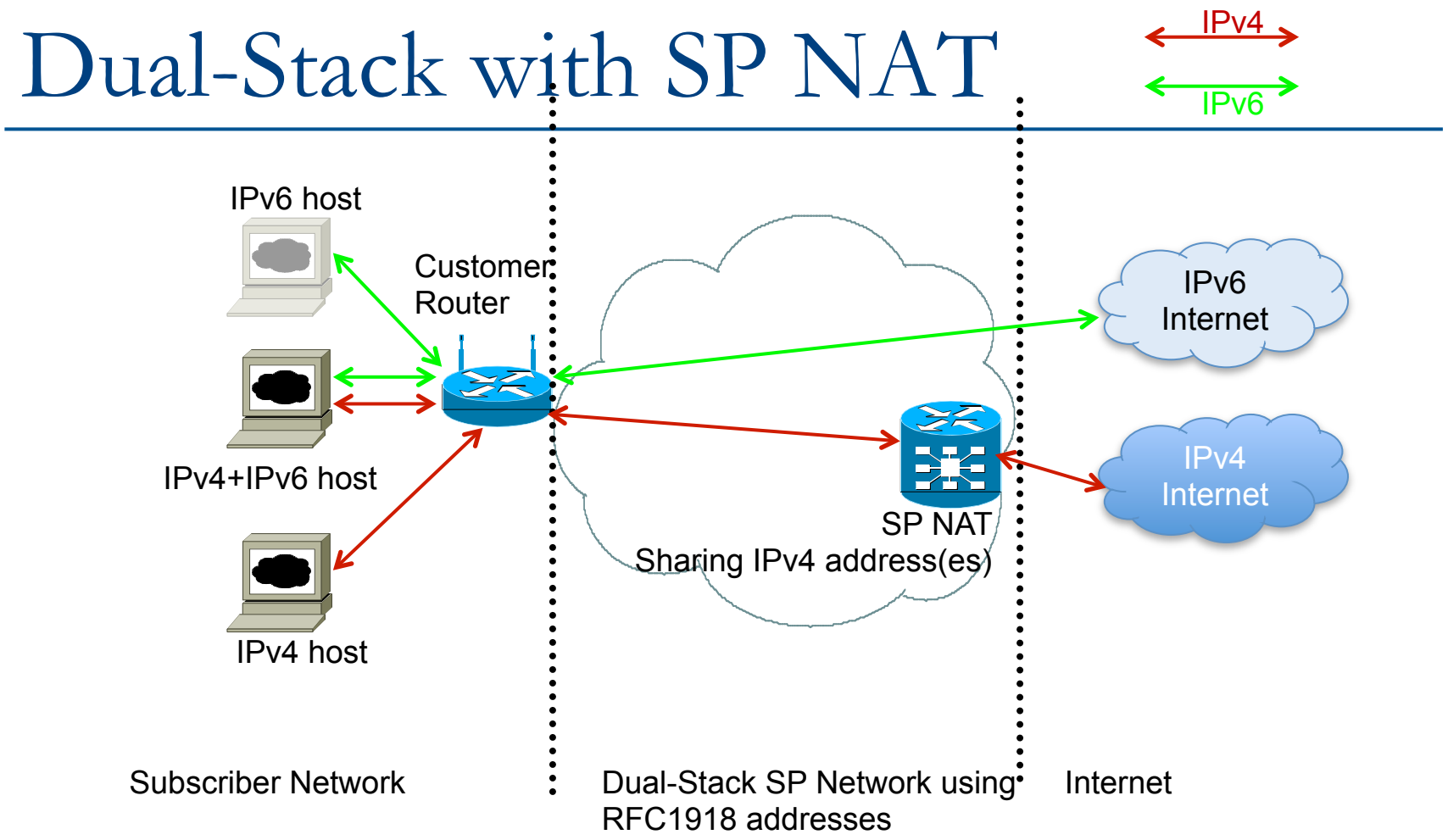
Dual-Stack with SP NAT

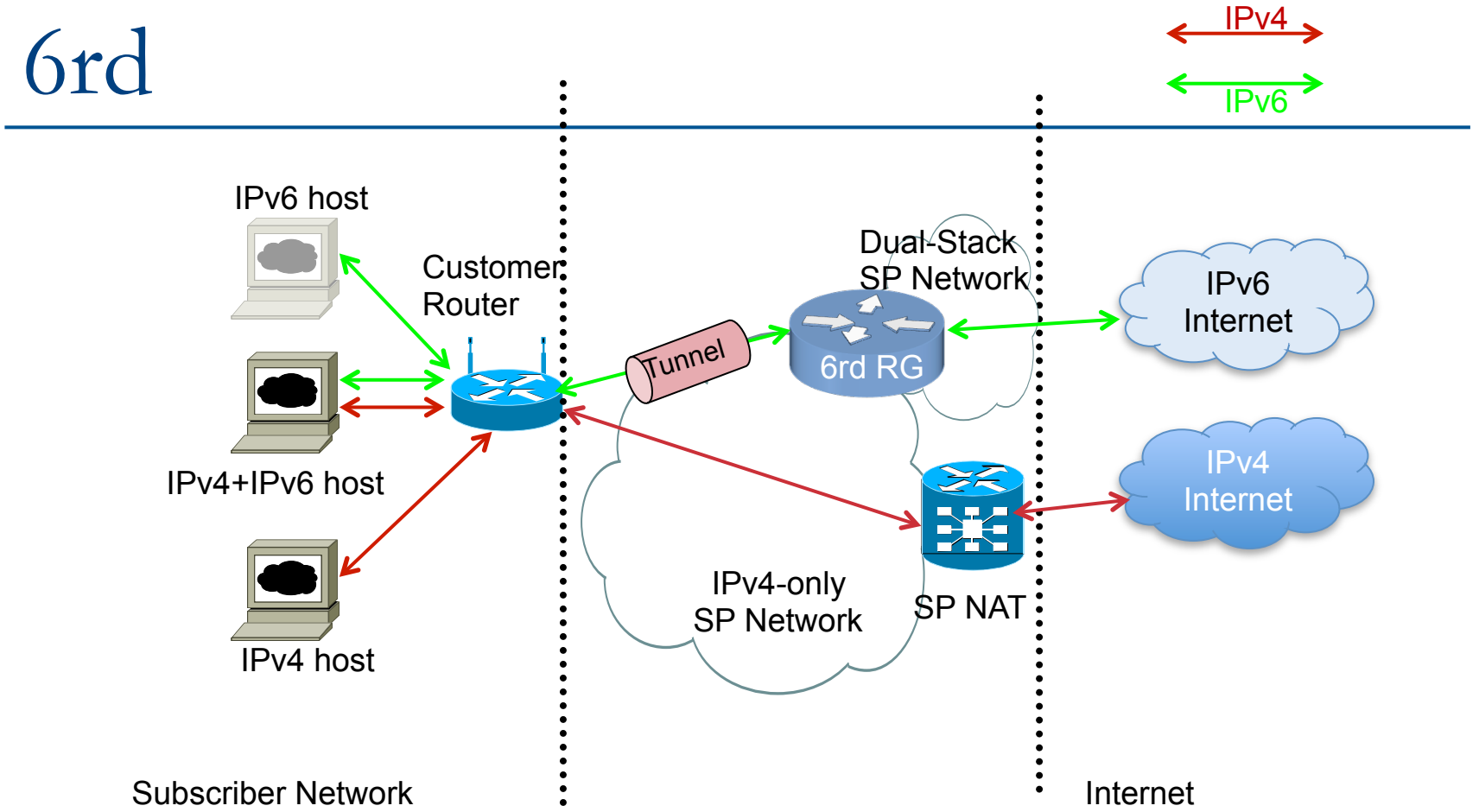


- More likely scenario:
  - IPv6 being available all the way to the consumer
  - SP core and customer has to use IPv4 NAT due to v4 depletion

Dual-Stack with SP NAT: Issues

- Advantages
  - Inherits benefits of the shared IPv4 address model
  - SP can offer IPv6 connectivity too
  - Does not postpone IPv6 deployment
- Disadvantages
  - Inherits all the drawbacks of the shared IPv4 address model
  - SP incurs additional investment and operational expenditure by deploying an IPv6 infrastructure

6rd

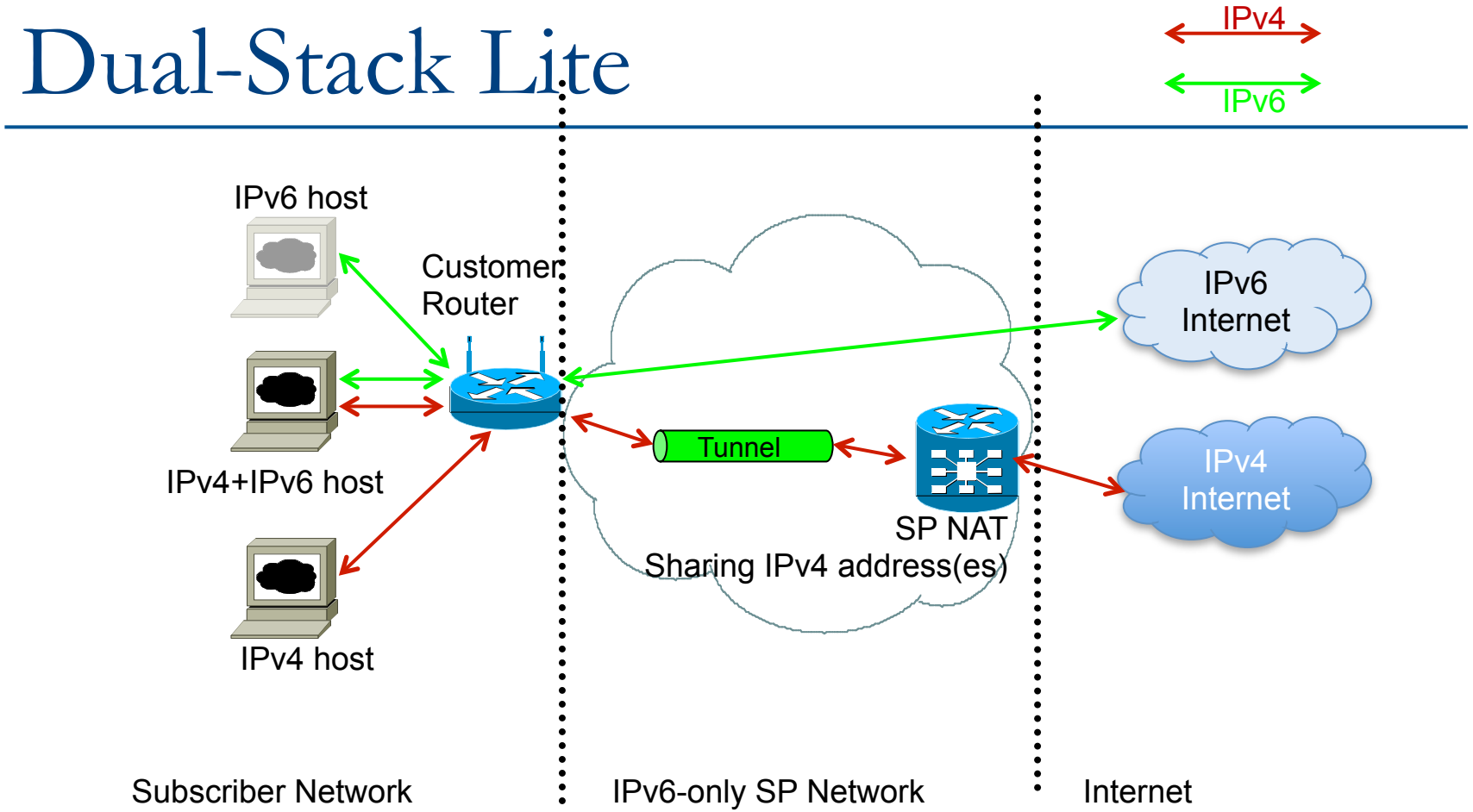


- 6rd (Rapid Deploy) used where ISP infrastructure to customer is not IPv6 capable (eg IPv4-only BRAS)
  - Customer has IPv4 Internet access either natively or via NAT
  - Customer IPv6 address space based on ISP IPv4 block

6rd: Issues

- Advantages
  - The service provider has a relatively quick way of providing IPv6 to their customer without deploying IPv6 across their infrastructure
  - Subscribers can readily get access to IPv6
  - 6rd relay and CPE are becoming available from vendors
  - 6rd operation is completely stateless, does not have the operational drawbacks of 6to4, and does not postpone IPv6 deployment
- Disadvantages
  - 6rd is not a long-term solution for transitioning to IPv6 – one further transition step to remove the tunnels
  - CPE needs to be upgraded to support 6rd
  - The ISP has to deploy one or several 6rd termination devices
  - If customer or SP uses NAT for IPv4, all NAT disadvantages are inherited

Dual-Stack Lite

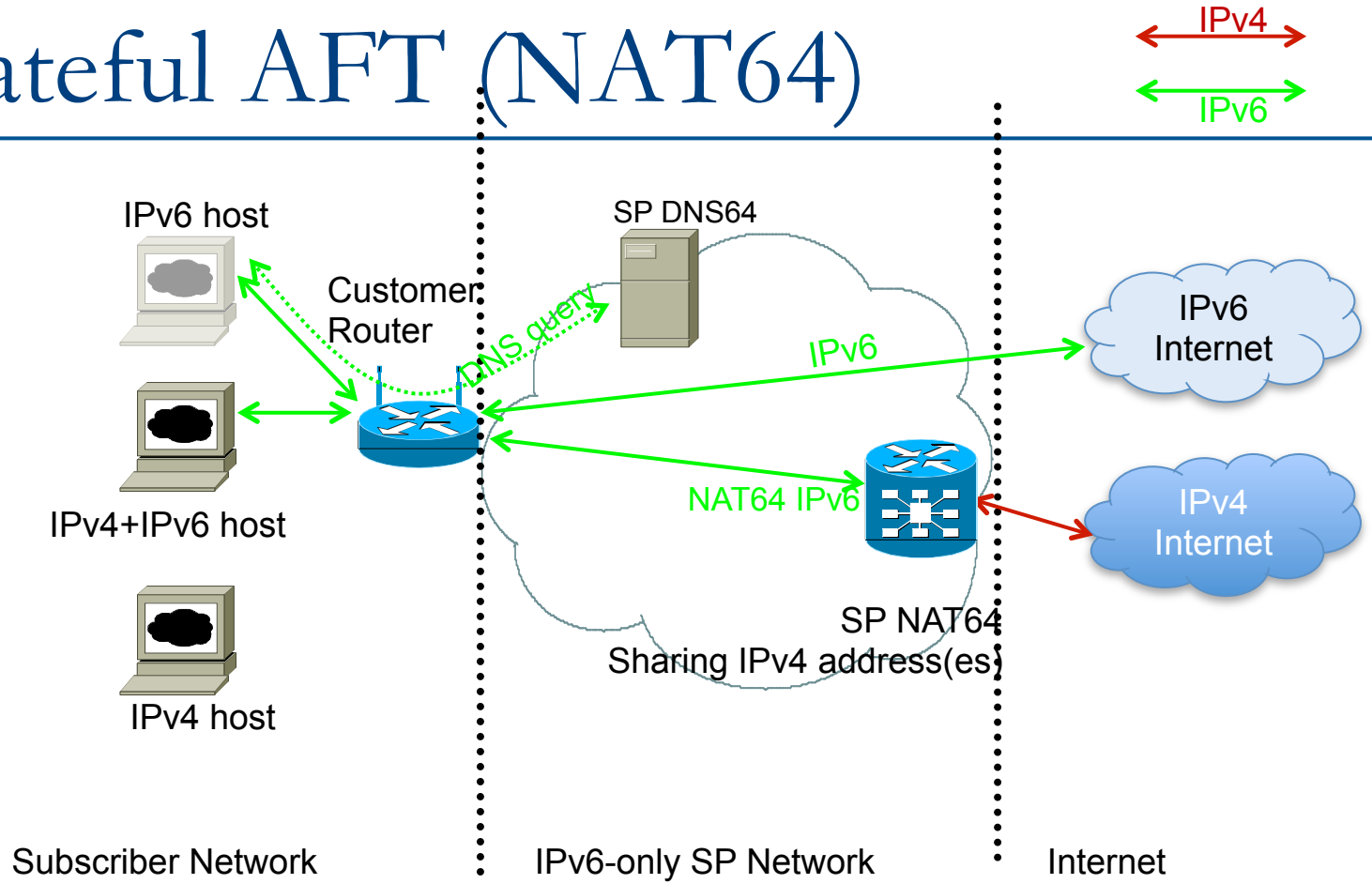


- Service Provider deploys IPv6-only infrastructure:
  - IPv6 being available all the way to the consumer
  - IPv4 is tunnelled through IPv6 core to Internet via SP NAT device

Dual-Stack Lite: Issues

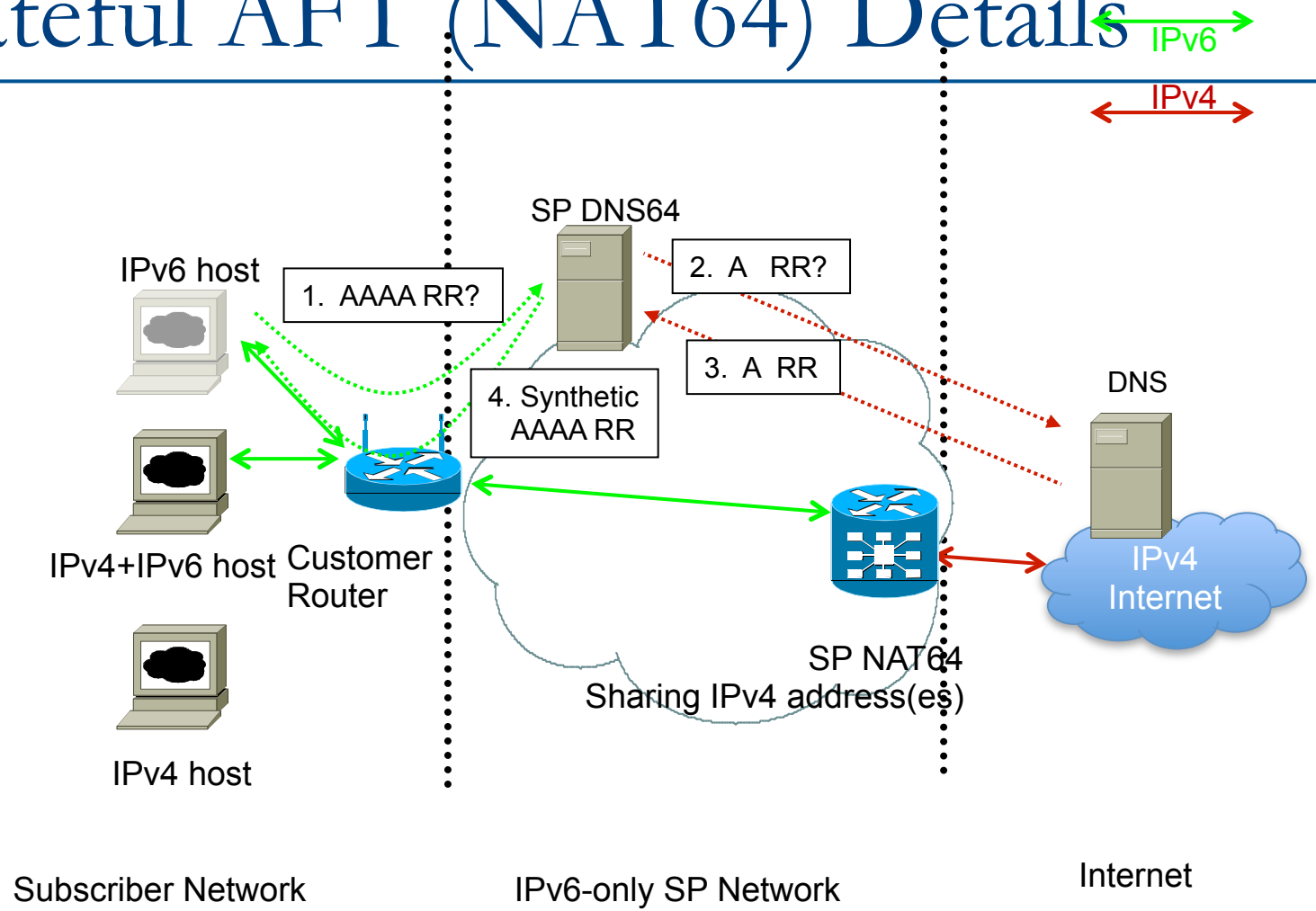
- Advantages
  - The SP is using IPv6 across their entire infrastructure, avoiding the IPv4 address pool depletion issue totally
  - The SP can scale their infrastructure without any IPv4 dependencies
  - Consumers can transition from IPv4 to IPv6 without being aware of any differences in the protocols
  - IPv6 packets routed natively
- Disadvantages
  - SP requires NAT device in core supporting DS-Lite
  - Subscriber router needs to be IPv6 capable
  - Model has all drawbacks of IPv4 address sharing model

Stateful AFT (NAT64)



- Service Provider deploys IPv6-only infrastructure:
  - Only IPv6 is available to the consumer
  - IPv4 Internet available via Address Family Translation on SP NAT device

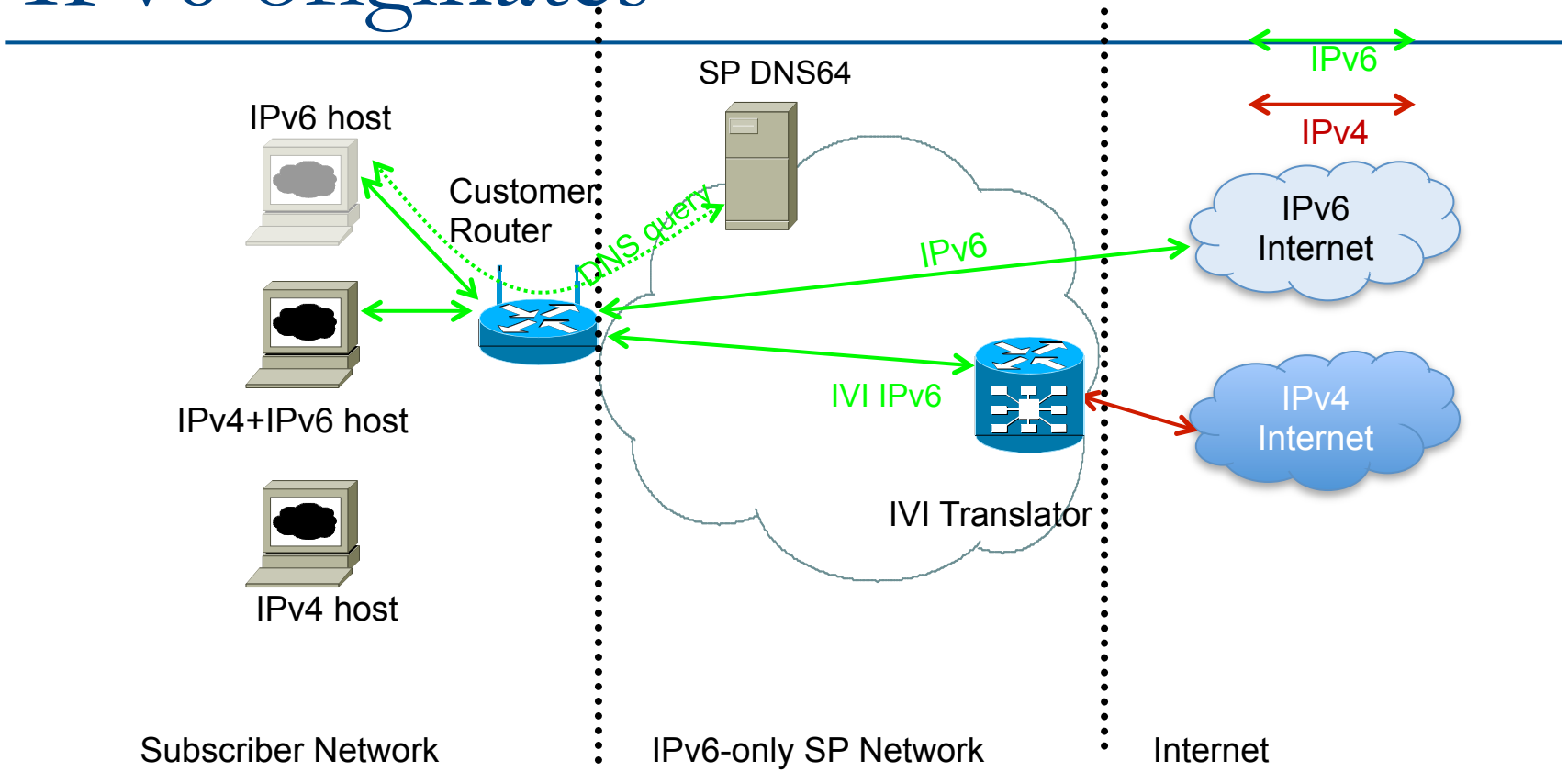
Stateful AFT (NAT64) Details



Stateful AFT: Issues

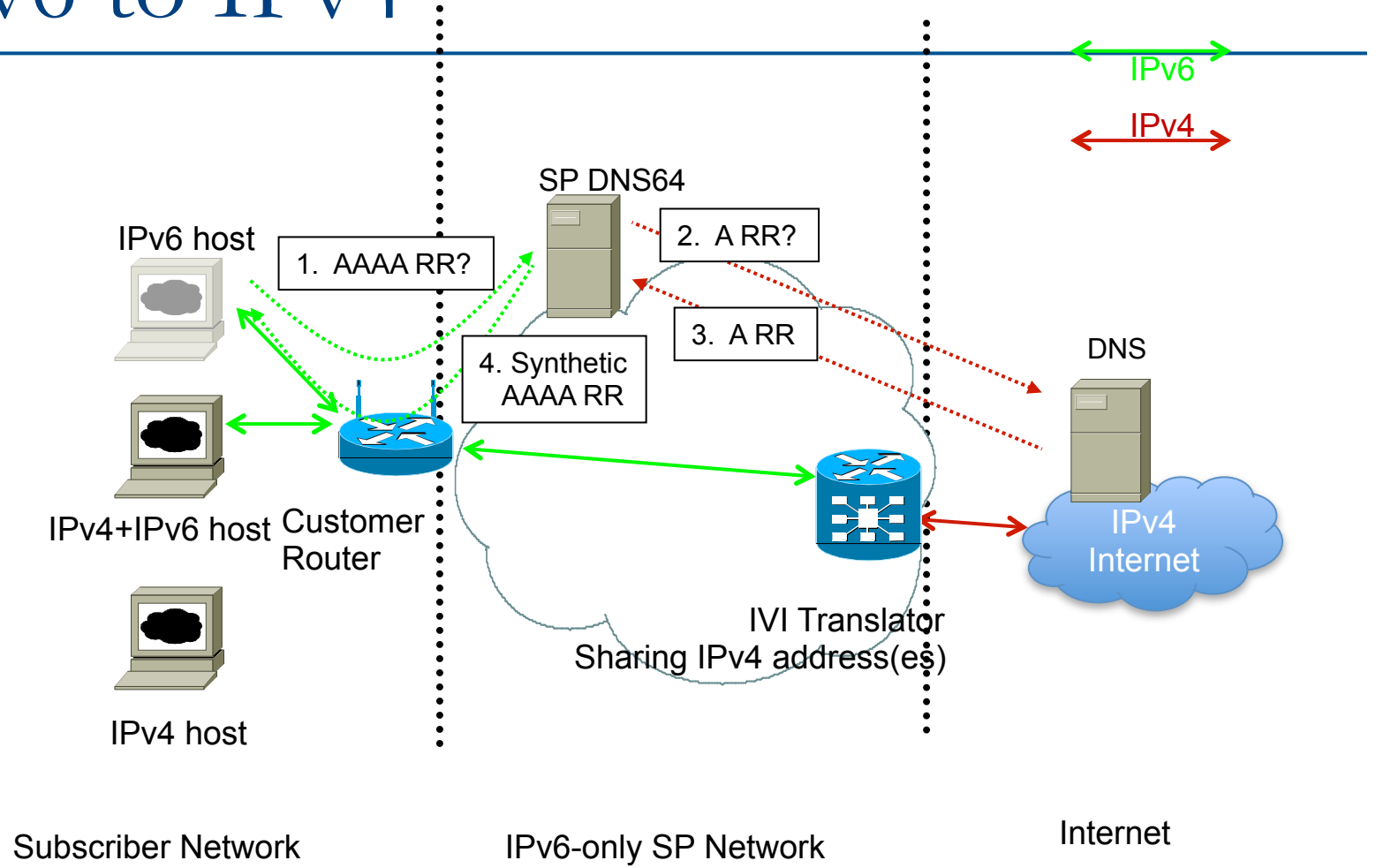
- Advantages
  - Allows IPv6 only consumers access to IPv4 based content without giving them IPv4 address resources
  - IPv6 services and applications offered natively to consumers
  - SP network runs IPv6 only, avoiding IPv4 dependencies
- Disadvantages
  - SP requires NAT device in core
  - SP's DNS infrastructure needs to be modified to support NAT64
  - Subscriber router needs to be IPv6 capable
  - Subscriber devices need to be IPv6 capable (no legacy support)
  - Model has all drawbacks of IPv4 address sharing model for IPv4 traffic

Stateless AFT (IVI): IPv6 originates

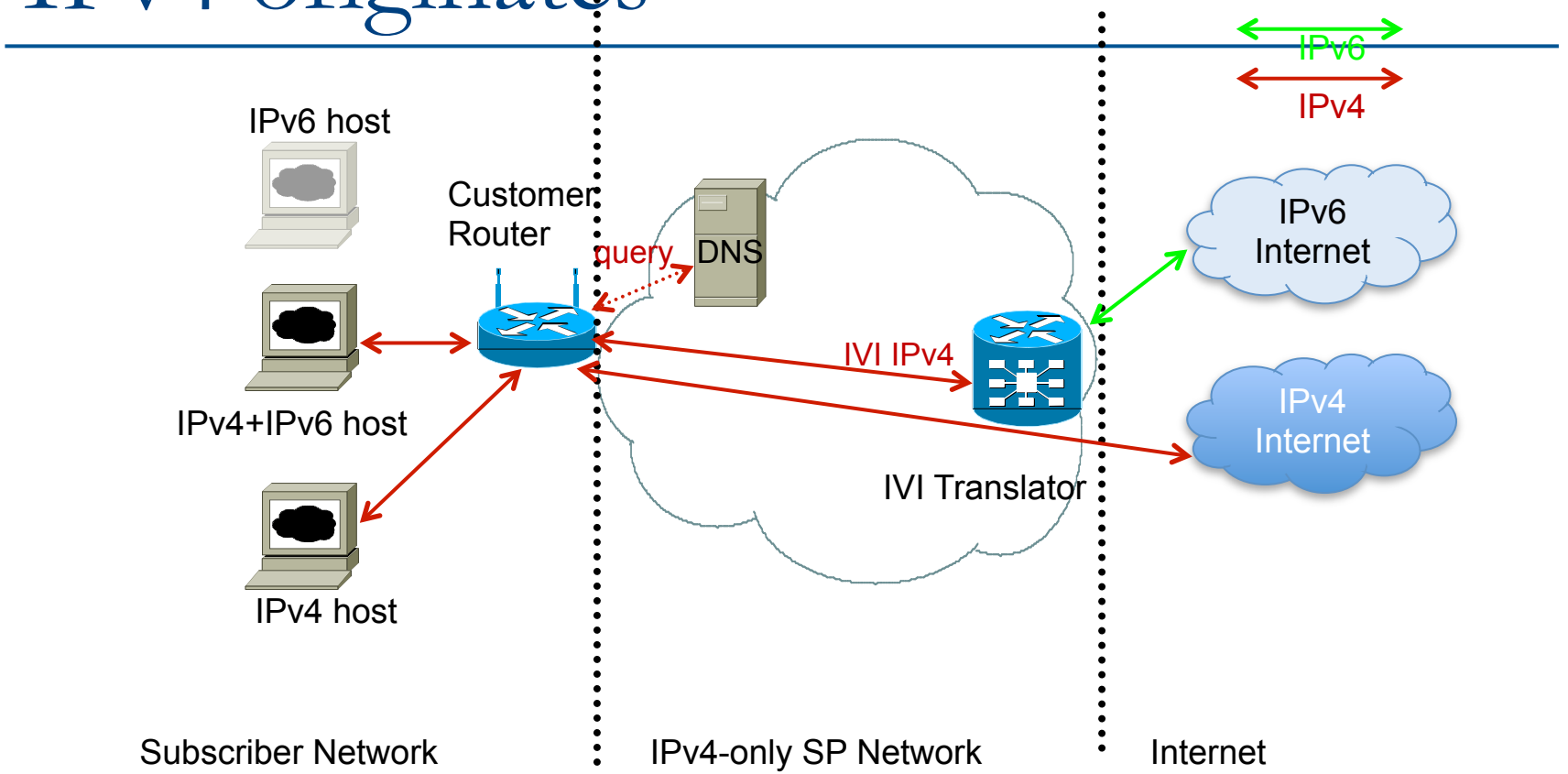


- Service Provider deploys IPv6-only infrastructure:
  - Only IPv6 is available to the consumer
  - IPv4 Internet available via IVI Translator (SP sets aside portion of existing IPv6 and IPv4 blocks to facilitate stateless translator)

Stateless AFT (IVI) Details: IPv6 to IPv4



Stateless AFT (IVI): IPv4 originates

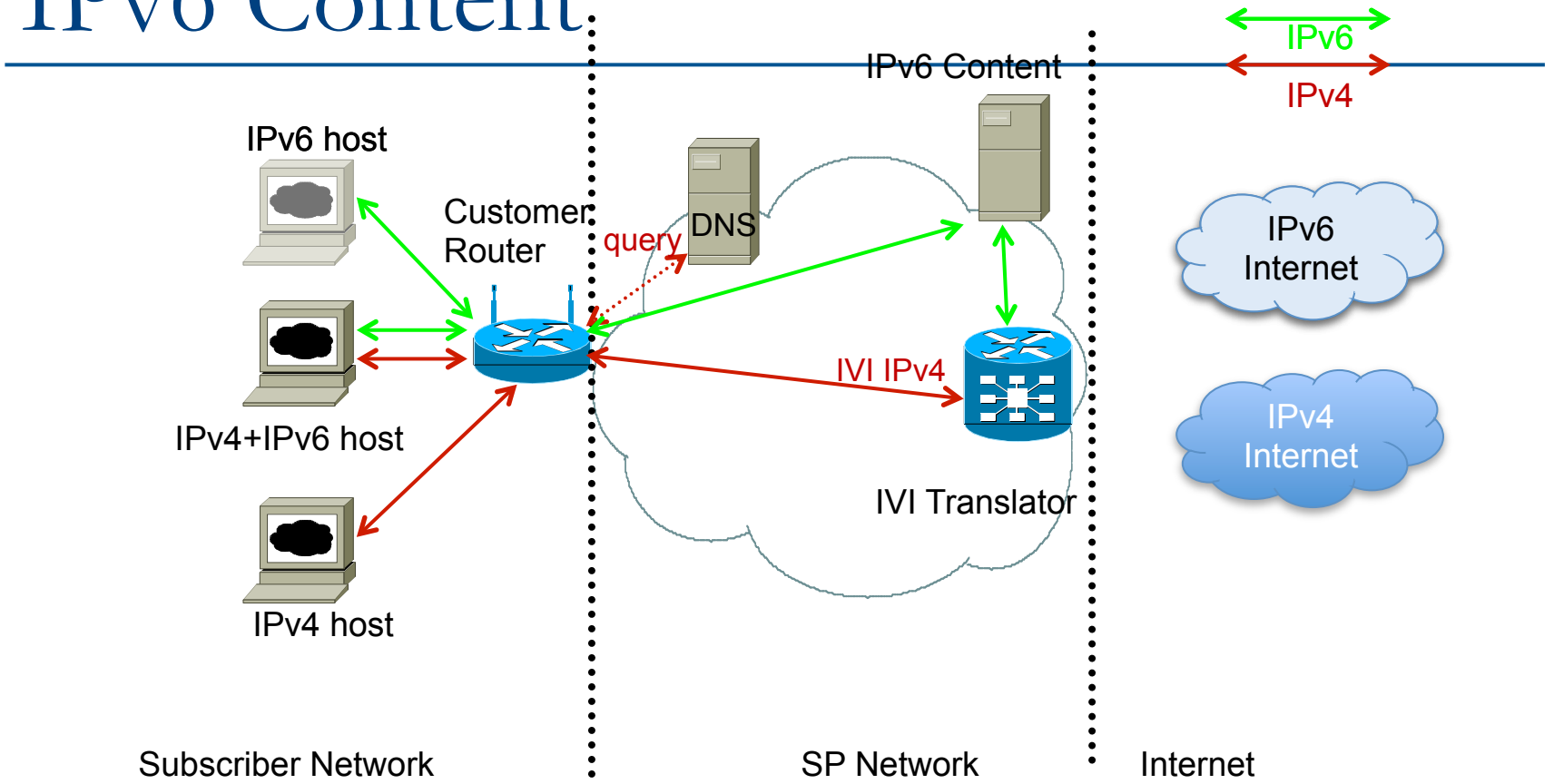


- Service Provider deploys IPv4-only infrastructure:
  - Only IPv4 is available to the consumer
  - IPv6 Internet available via IVI Translator (SP sets aside portion of existing IPv6 and IPv4 blocks to facilitate stateless translator)

Stateless AFT: Issues

- Common deployment is for SP to implement both IPv4 to IPv6 and IPv6 to IPv4 IVI translator
- Advantages
  - All the advantages of NAT64
  - Unlike NAT64, IVI is a stateless translator, therefore scaling better than NAT64
- Disadvantages
  - Addressing & troubleshooting needs care
  - One IP address consumed per mapping (doesn't solve IPv4 runout problem, just helps with transition)
  - SP requires NAT device in core
  - SP's DNS infrastructure needs to be modified to support IVI
  - Subscriber router needs to be IPv6 capable

IPv6 Content



- Service Provider deploys content on IPv6-only servers:
  - Servers are put in IVI IPv6 address space – accessible directly from IPv6 subscribers, and via IVI translator from IPv4 subscribers

IPv6 Content

- Stateless AFT is but one way of deploying IPv6-only content servers
  - Allows SP to move content over to IPv6 without loss of IPv4 accessibility for subscribers
- For content, another technique could be:
  - HTTP proxy converting traffic between IPv4 clients and IPv6 servers
- For telephony:
  - Session Border Controller could connect IPv6 IP phone to IPv4 IP phone

Conclusions & Recommendations

Functionalities and Operational Issues

	IPv4 only network	Dual-Stack, no SP NAT	SP IPv4-NAT & IPv4-only network	SP IPv4-NAT & Dual-Stack network	6rd	6rd with IPv4-NAT	DS-Lite	Stateful AFT	Stateless AFT
Prolongs IPv4	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Allows Business Growth	No	Limited to IPv4 address availability	Yes (scaling issues if content is mostly IPv6)	Yes (traffic to IPv4-only servers)	Limited to IPv4 address availability	Yes	Yes	Yes	Yes
Requires IPv6 Deployment	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Coexists with IPv6 Deployment	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Complexity of Operation	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Complexity of Troubleshooting	Low	Low	Moderate	High	Moderate	High	High	Moderate	Moderate
Breaks End-to-End IPv4	No	No	Yes	Yes	No	Yes	Yes	N/A	N/A
NAT Scalability issues to IPv4 services	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes
NAT Scalability issues to IPv6 services	N/A	No	No	No	No	No	No	No	No
DNSSEC issues	No	No	Yes	Yes for IPv4 No for IPv6	No	Yes for IPv6 No for IPv4	Yes for IPv4 No for IPv6	Yes for IPv4 No for IPv6	Yes for IPv4 No for IPv6
Lawful Intercept issues	No	No	Yes	Yes for IPv4	No	Yes for IPv4	Yes for IPv4	Yes for IPv4	No

Functionalities and Operational Issues

- Complexity of operation:
  - Moderate in the case of a single network with two address families
- Complexity of troubleshooting:
  - Running two address families and/or tunnels is assumed to be more complex
- Breaks end-to-end connectivity in IPv4:
  - Subscribers sharing a CGN will have little to no hurdles in their communication
  - Subscribers separated by one or several CGN will experience some application issues

Comparing where changes will occur

	IPv4 only network	Dual-Stack, no SP NAT	SP IPv4-NAT & IPv4-only network	SP IPv4-NAT & Dual-Stack network	6rd	6rd with IPv4-NAT	DS-Lite	Stateful AFT	Stateless AFT
Change CPE	No	Only if customer wants IPv6	No	Only if customer wants IPv6	Yes	Yes	Yes	Yes	Yes
CPE to do AFT to access IPv6	No	No	No	No	No	No	No	No	No
IPv4 NAT in core/ edge	No	No	Yes	Yes	No	Yes	Yes	No	No
AFT in core/edge to access IPv6	Yes	No	Yes	No	No	No	No	Yes	Yes

Conclusions
Potential Scenarios

- Most of the content and applications move to IPv6 only;
- Most of the content and applications are offered for IPv4 and IPv6;
- Most of the users move to IPv6 only
  - Especially mobile operators offering LTE handsets in emerging countries
- No change (the contents/applications stay IPv4 and absence of pro-IPv6 regulation), SP customer expectations devolve to double-NAT;
- No change (the contents/applications stay IPv4) but SP customer expectations do not devolve to double-NAT (or they are ready to pay for peer-to-peer connectivity).
  - Perhaps well established broadband markets like US or Europe

Conclusions
Potential Techniques

Scenario	Potential Techniques
Content and Applications move to IPv6	IPv6 only network; Dual-Stack, 6rd and DS-lite as migration techniques
Content and Applications on IPv4 and IPv6	Dual-Stack (if enough IPv4) or 6rd; SP IPv4-NAT; DS-lite (for greenfield) *
Users are IPv6 only	Stateful/Stateless AFT to get to IPv4 content *
No change (double NAT)	SP IPv4-NAT *
No change (no double NAT)	Do nothing *

* Transfer Market applicable

Recommendations

1. Start deploying IPv6 as long term strategy
2. Evaluate current addressing usage to understand if IPv4 to IPv4 NAT is sufficient for transition period
3. Prepare a translation mechanism from the IPv4 Internet to the IPv6 Internet
4. Educate your user base on IPv6 introduction, the use cases and troubleshooting

How can Network Operators face IPv4-Address Exhaustion?

A Review of IPv4-IPv6 Co-Existence Techniques