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Yet Another Double Address and Translation Technique
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Abstract

This document provides a stepwise migration between IPv4 and IPv6 with baby steps from an IPv4-only stack/gateway/ISP to an IPv6-only version, that allows portions of the nodes and of the networks to remain IPv4, and reduces the need for dual stack and CG NATs between participating nodes. A first mechanism named YADA to augment the capacity of the current IPv4 Internet by interconnecting IPv4 realms via a common footprint called the shaft. YADA extends RFC 1122 with the support of an IP-in-IP format used to forward the packet between parallel IPv4 realms. This document also provides a stateless address and IP header translation between YADA and IPv6 called YATT and extends RFC 4291 for the YATT format. The YADA and YATT formats are interchangeable, and the stateless translation can take place as a bump in the stack at either end, or within the network at any router. This enables an IPv6-only stack to dialog with an IPv4-only stack across a network that can be IPv6, IPv4, or mixed. YATT requires that the IPv6 stack owns a prefix that derives from a YADA address and that the IPv4 stack in a different realm is capable of YADA, so it does not replace a generic 4 to 6 translation mechanism for any v6 to any v4.

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1. Introduction and Motivation

At the time of this writing, the transition to IPv6 started 20 years

ago and large amounts of networks, hosts, and programs, are still IPv4-only. The IPv4 and IPv6 camps are quite entrenched, and there's no indication that things will change any time soon.

During that endless transition, stacks must implement both protocols (aka dual stack) and a mechanism to use either based on the responsiveness (Happy Eyeballs). Service Providers must implement heavy weaponry called Carrier-Grade Network Address Translators (CG-NATs) to translate between protocols between legacy IPv4-only and IPv6-only stacks, and tunneling techniques such as DS-Lite [RFC7333] and 464XLAT [RFC6877] to traverse portions of the network that support only one of the IP versions. This means both CAPEX to install dual stack infrastructures and NAT devices and OPEX to maintain them. The current situation is often qualified as the worst of both worlds and any indications is that it's here to stay, till each side suffered enough and is ready for a compromise.

This document prepares for that time where the players will effectively be ready for a compromise. An acceptable compromise must provide both sides with way to remain as long as desired, while eliminating the need for dual stack and CG-NATs between participating nodes. Certainly, an effort must be asked on each side to reduce the chasm, and that effort must come with enough benefits to effectively encourage a majority of interested parties to make the step.

Yet Another Double Address (YADA) refers to effort that is asked from the IPv4 side to support a new IP-in-IP model. YADA extends [INT-ARCHI] with the support of an IP-in-IP format used to forward the packet between parallel IPv4 realms. The proposed benefit is a thousandfold increase of the IPv4-addressable domain by building parallel realms each potentially the size of the current Internet. Only the stacks that need to talk to a parallel realm need to evolve. Routing and forwarding can remain IPv4-only with the same operations as today, though new routers with YADA capabilities must be deployed to route between realms.

Yet Another Translation Technique (YATT) refers to an effort to be made by the IPv6 side to support a new IPv6 Prefix with special properties, which impacts in particular source address selection (SAS). YATT extends [IPv6-ADDRESSING] for the YATT format. The

proposed benefit is a prefix (say /32) per realm and a prefix (say /64) per host in the realm. This address space may for instance become handy for load balancing between physical servers / VMs / pods that operate a service associated with the virtual server that owns the host prefix.

The YADA and YATT formats are interchangeable, which means that the translation is stateless and can take place as a bump-in-the-stack at either end or can be operated at line rate anywhere in the network by an upgraded hardware. The routers that connect the shaft also perform a stateless operation that can be achieved at line rate by upgraded hardware. This is how the chasm between IPv4 and IPv6 can be reduced, removing the need to deploy dual stack and CG-NATs between participating nodes.

This document provides a stepwise migration between IPv4 and IPv6 with baby steps from an IPv4-only stack/gateway/ISP to YADA to YATT to an IPv6-only version. The migration strategy allows portions of the nodes and of the networks to remain IPv4.

YATT requires that the IPv6 stack owns a prefix that derives from a YADA address associated to a realm, even if there's absolutely no IPv4 operation taking place in that realm. The resulting connectivity without dual stack and CG-NAT is as follows:

* A legacy IPv4-only node can only talk within its realm. It can talk to an IPv4 legacy node, a YADA IPv4-only node, and even a YATT IPv6-only node, e.g., leveraging a bump-in-the-stack in the YATT node if the access network is IPv4-only.

* In addition, a YADA IPv4-only node can talk across realms to a YADA IPv4-only node and to any YATT IPv6-only node, e.g., leveraging a bump-in-the-stack in the YADA node if the network is IPv6-only.

* In addition, a YATT IPv6-only node can talk to any other IPv6-only node.

Connectivity between an IPv4-only node and an IPv6-only node, or between an IPv4-only node and a YADA node in different realm, still requires a CG-NATs as of today, e.g., using the YATT format for the IPv6 side in an unmodified CG-NAT.

2. Terminology

2.1. Glossary

This document often uses the following acronyms:

YADA: Yet Another Double Address
YATT: Yet Another Translation Technique
NAT: Network address Translation
IID: Interface ID
CG-NAT: Carrier Grade NAT

2.2. New Terms

This document often uses the following new terms:

IPv4 realm: A full IPv4 network like the current Internet. YADA does not affect the traditional IPv4 operations within a realm.
The shaft: The shaft refers to a collection of IPv4 unicast and multicast prefixes that are assigned to Inter-realm communications and cannot be assigned to hosts or multicast groups within a realm.
Realm address: An IPv4 address that derives from a shaft prefix.
Uni-realm address: A realm address that is unicast or anycast. A realm may have more than one Uni-realm add ress.
Multi-realm address: A realm address that is multicast and denotes a collection of realms.
YADA realm prefix: A prefix assigned to the shaft and from which realm addresses can be derived.
YADA NAT prefix: A prefix assigned to the YADA bump-in-the-stack NAT operation.
Double-A or YADA address: A YADA address is a tuple (realm address, IPv4 address) where the IPv4 address is only significant within the realm denoted by the realm address.

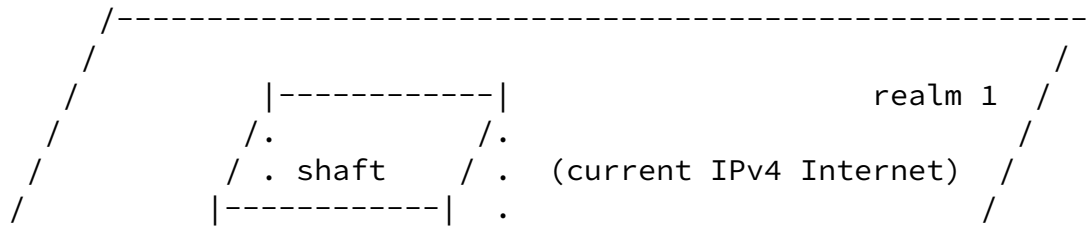
YATT Space: An IPv6 range that is assigned for YATT operation.
YATT prefix: An IPv6 prefix that is derived from a YADA address by appending the YATT space prefix, the (truncated) realm address and the IPv4 address.
YATT-IID: A 64-bit assigned constant that is used in YATT to statelessly form an IPv6 address from a YATT prefix.
Multinternet: A collection of IPv4 realms interconnected using a common shaft.

3. Overview

This document provides a stepwise migration between IPv4 and IPv6 with baby steps from an IPv4-only stack/gateway/ISP to an IPv6-only version. The baby steps reduce the gap between the only versions and the associated need for dual stack and CG-NATs.

This first mechanism called YADA allows to grow the Internet beyond the current IPv4 [IPv4] realm that limits its capacity to form public addresses. Depending on the assignments to be made, the model allows to reuse all IP addresses and all Autonomous System Number (ASN) currently available in the internet hundreds to millions of times. This is achieved by interconnecting IPv4 realms via a common footprint called the shaft.

In the analogy of a building, the ground floor would be the Internet, and each additional floor would be another IPv4 realm. The same surface of floor is available in each level, analog to the full IPv4 addressing that is available in each realm. The same footprint is dedicated across the building levels for the elevator shaft. The elevator shaft enables a third dimension that spans across the levels and allows to traverse from any level to any other level. The elevator shaft cannot be used for living or office space.



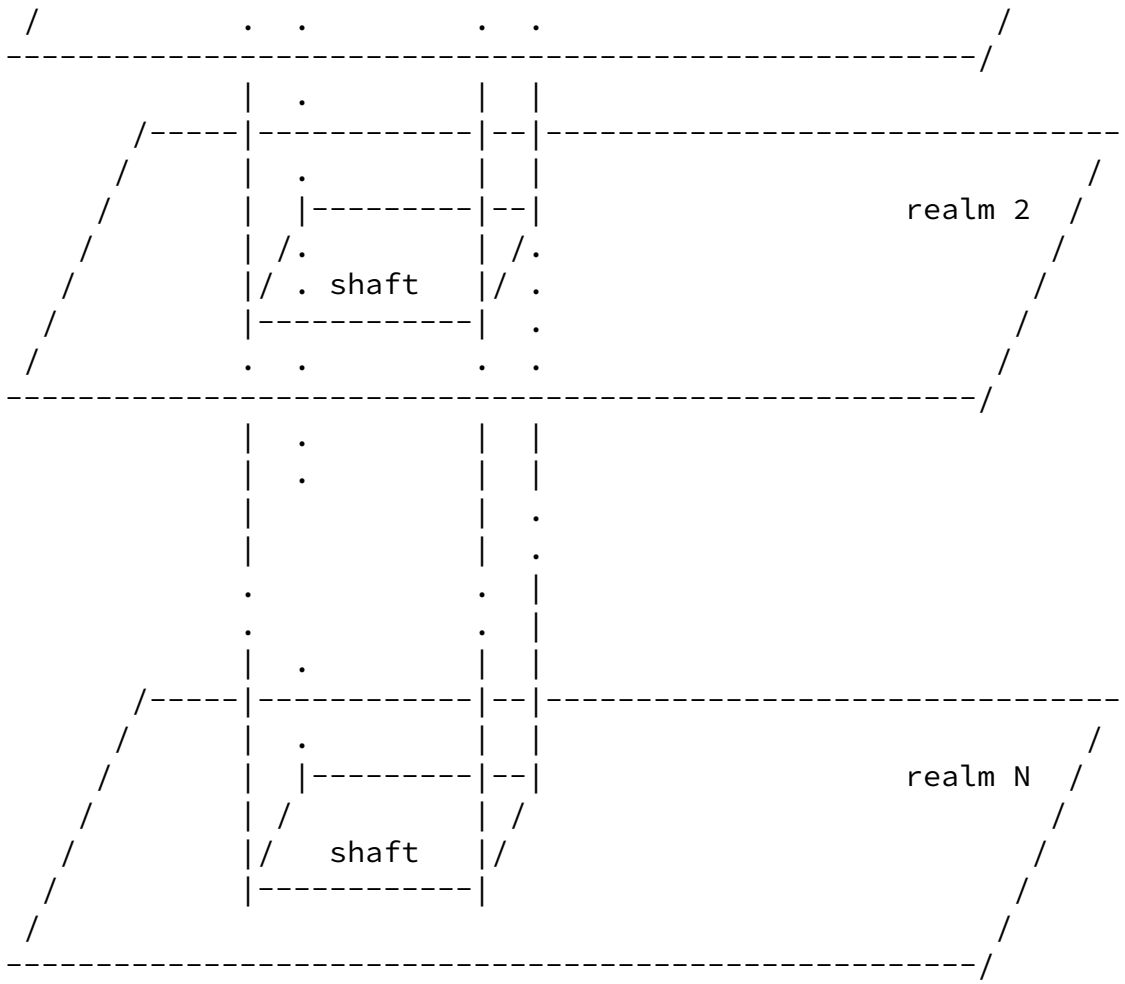


Figure 1: The shaft

By analogy, YADA assigns IPv4 prefixes to a multinternet shaft; those prefixes are common across the realms that are interconnected by the shaft. A single /24 IPv4 prefix assigned allows for > 250 times the capacity of the Internet as we know it at the time of this writing.

Multiple prefixes can be assigned to the shaft for unicast and multicast communications, and each realm needs at least one unicast address in the shaft called its realm address. A YADA address is formed by the tuple (realm address, IPv4 address) and is advertised in DNS as a new double-A record.

YADA leverages IP-in-IP encapsulation to tunnel packets across the shaft while normal IPv4 operations happen within a realm. YADA

requires a change in the stack in the YADA endpoints that communicate with other realms to support the IP-in-IP YADA encapsulation. YADA also provides a bump in the stack method for legacy applications. More in Section 9.

A second mechanism called YATT translates the YADA format into flat IPv6 [IPv6]. While a YADA address pair can be seen as some foot print in one level, the YATT prefix encompasses that same foot print plus all the air above it. For unicast addresses, YATT forms an IPv6 prefix by collating an well-known assigned short prefix, the realm address (in the shaft), and the host IPv4 address (locally significant within the realm). The resulting IPv6 prefix is automatically owned by the host that owns the IPv4 address in the realm. YATT then forms an IPv6 address for that host by collating a well-known Interface ID, so there's a one-to-one relationship between the YADA and the IPv6 address derived from it. More in Section 10.

A key concept for this specification is that YADA (the IPv4 formulation) and YATT (the IPv6 formulation) are alternative representations of the same abstract object (a double address), which can serve as an intermediate step across the IPv4-IPv6 chasm. The IPv4 formulation (YADA) is a plain IP-in-IP with no new extension. The IPv6 formulation (YATT) uses a standard IPv6 header with a special encoding of the addresses. The formulations are interchangeable; if a link supports both IP versions then the next hop is valid for both formulations, whichever of the 2 Address Families (AFs) was used to learn it; else any node can convert one formulation to the other to accomodate the IP version that is available on the next hop link.

4. Extending RFC 1122

YADA extends [INT-ARCHI] to add the capability for an IPv4 host to recognize an special IP-in-IP format as an inter-realm IPv4 packet and process it accordingly. It also adds a new DNS double-A record format that denotes a YADA address.

5. Extending RFC 2131

The Dynamic Host Configuration Protocol [RFC2131] (DHCP) is extended to pass information to the host about its current realm. When this information is present, the host is free to use YADA using that realms as source realm.

If a host obtains a public address from DHCP, and for the duration of the lease, the host automatically owns the YATT prefix associated to a owned YADA address. In this manner, DHCPv4 becomes an alternate method for delegating an IPv6 prefix from which the host may provision an IPv6 stack.

6. Extending RFC 4291

YATT extends the IPv6 Addressing Architecture [IPv6-ADDRESSING] to add the capability for a host to recognize an special IPv6 format as an YATT address embedding a YADA address and process it accordingly. This is achieved in particular by the allocation of a YATT space that is a short prefix for all YATT prefixes, and a YATT-IID.

7. Extending RFC 8415

The DHCPv6 prefix delegation mechanism in Dynamic Host Configuration Protocol for IPv6 [RFC8415] is extended to delegate YATT prefixes to the hosts by enforcing that a delegated YATT prefix is provided in the form defined by Section 6.

8. YADA

YADA assigns IPv4 prefixes to a multinternet shaft; those prefixes must be the same across all the realms that are interconnected by the shaft. Multiple prefixes can be assigned to the shaft for unicast and multicast communications, and each realm needs at least one unicast address in the shaft called its realm address. A YADA address is formed by the tuple (realm address, IPv4 address) and is advertised in DNS as a new double-A record. Because the YADA prefixes are assigned for YADA, a packet that has either source or destination IPV4 address derived from a shaft prefix is a YADA packet.

YADA leverages IP-in-IP encapsulation to tunnel packets across the shaft for inter-realm communications, while the IPv4 operations within a realm are unaffected. The YADA address is found by using both inner and outer header and combining that information. The pair of IP headers is seen by a YADA stack as a single larger header though a non-YADA forwarder only needs the outer header and plain IPv4 operations on the outer IPv4 header to forward.

YADA requires a change in the stack in the YADA endpoints that communicate with other realms to support the YADA encapsulation. A stack that resolve a DNS name with a double-A record indicating a different realm generates an IP-in-IP packet to signal both the source and destination realms and the source and destination IPv4 addresses within the respective realms.

Inside the source realm, the outer IPv4 header indicates the node's IPv4 address as source, to remain topologically correct, and the local realm address as source in the inner header, as shown in Figure 2

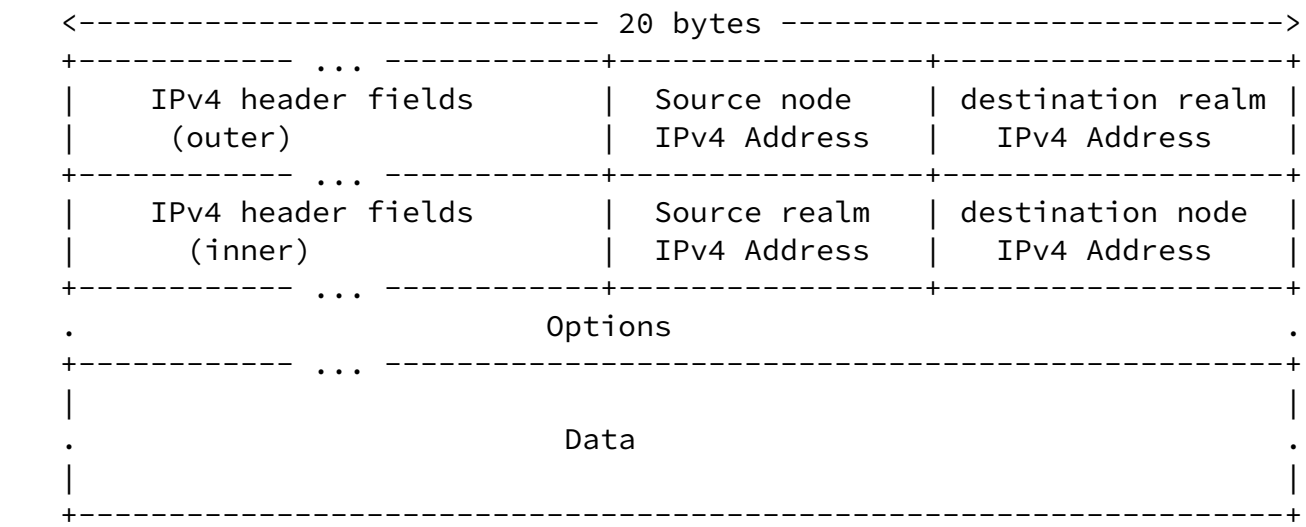


Figure 2: YADA format in the source realm

YADA also requires a change for the routers that serve the shaft. Those routers play a special role for packets that are delivered from the shaft to the destination realm, and for ICMP errors across realms. All other IPv4 nodes in the realm continue to operate routing and forwarding as before.

Routers serving the shaft advertise the shaft prefix(es) in their respective realms, and their realm addresses within the shaft, as host routes for unicast and anycast addresses.

Inside the source realm, the IPv4 destination in the outer header is an address is the shaft and it is attracted by a router that serves the shaft in the source realm. The packet source in the outer header is the address of the source node in the local realm, so the packet does not defeat BCP 38 rules in the ISP network, as shown in

Figure 3.

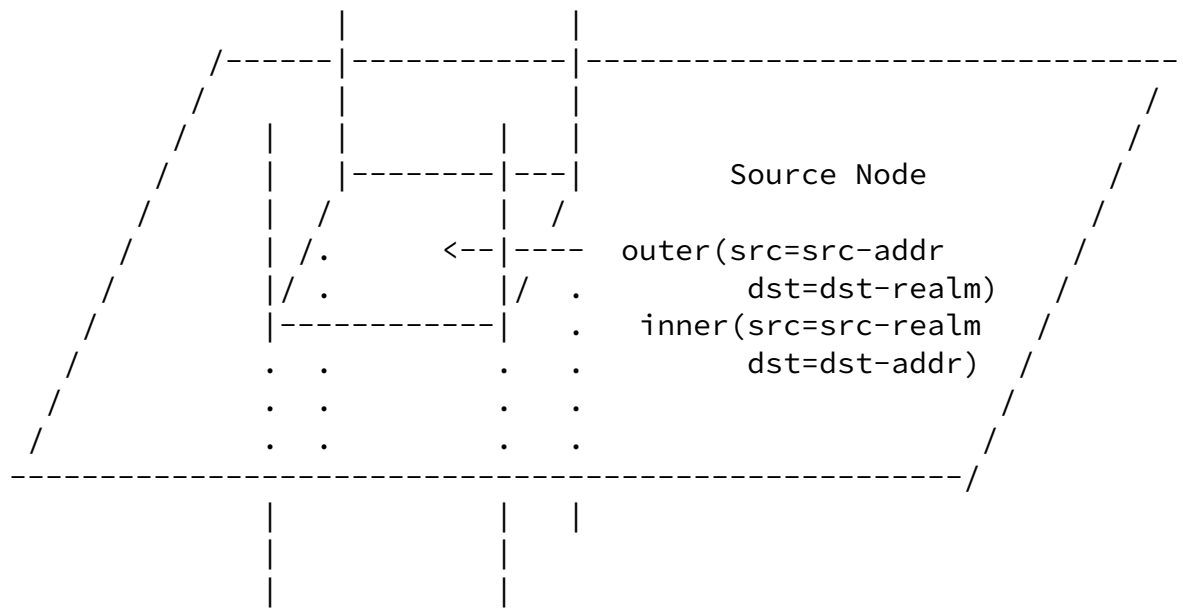


Figure 3: Packets Entering the shaft

When the packet reaches the shaft, the router that serves the shaft in this realm checks that packet source in the inner header is an address of this realm, and if so, it swaps the inner and outer source IPv4 address, and forwards the packet down the shaft. this way, the the packet remains topologically correct inside the shaft, as shown in Figure 4.

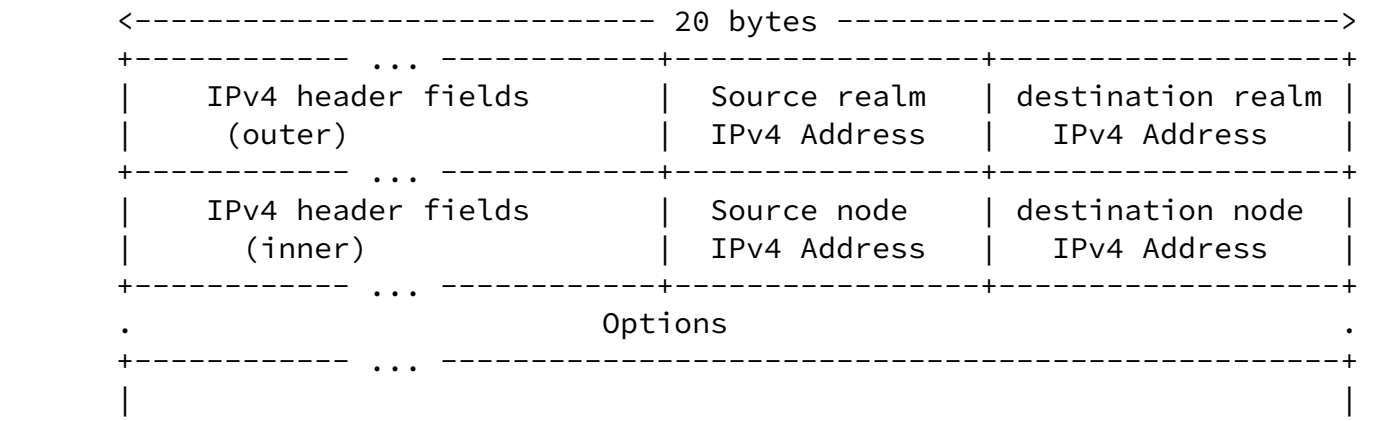


Figure 4: YADA format inside the shaft

Based on longest match, the router forwards the packet inside the shaft following the host route to a router that serves the destination realm, as shown in Figure 5.

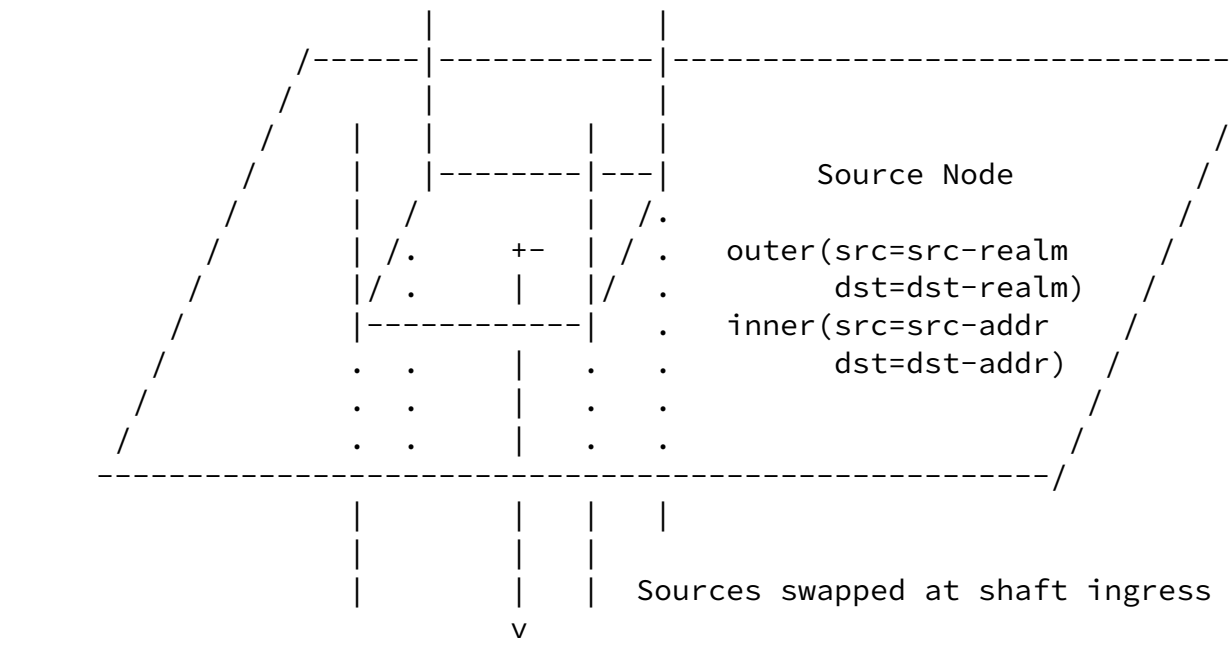
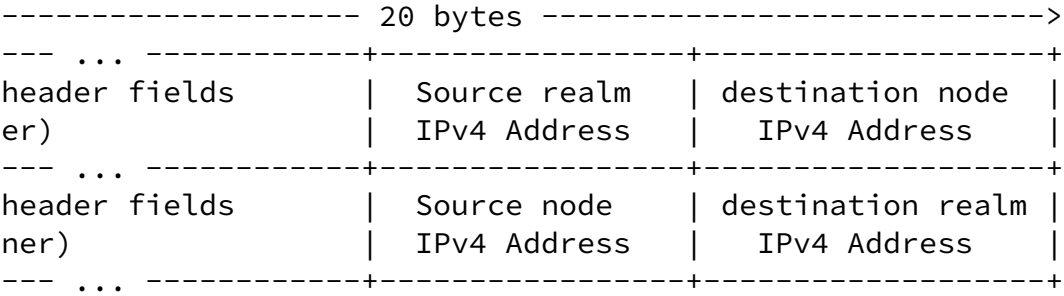


Figure 5: Packets Entering the shaft

That router swaps the destination address in the inner and outer headers and forwards within its realm to the final destination, as shown in Figure 6.



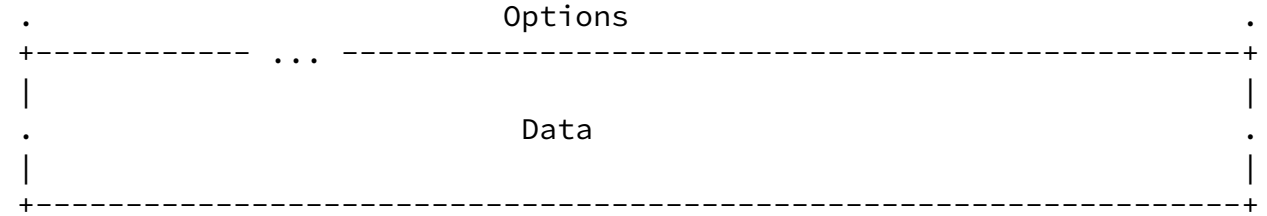


Figure 6: YADA format in the destination realm

In normal conditions, the stack of the destination node recognizes the YADA format and replies accordingly.

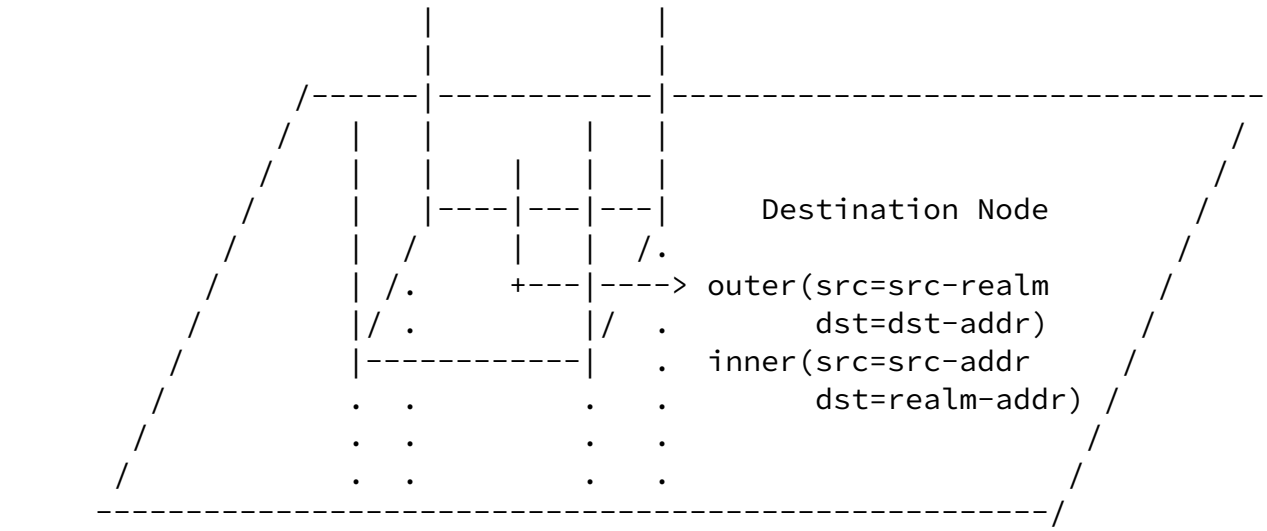


Figure 7: Packets Outgoing the shaft

In case of an error down the shaft or in the destination realm, if an ICMP message is generated by a node that is not YADA-aware, the message reaches the router that serves the shaft in the source realm. If the inner header is present in the ICMP payload, then the Router extracts it and forwards to the packet source. If the destination stack does not support YADA and decapsulates, the message reaches the

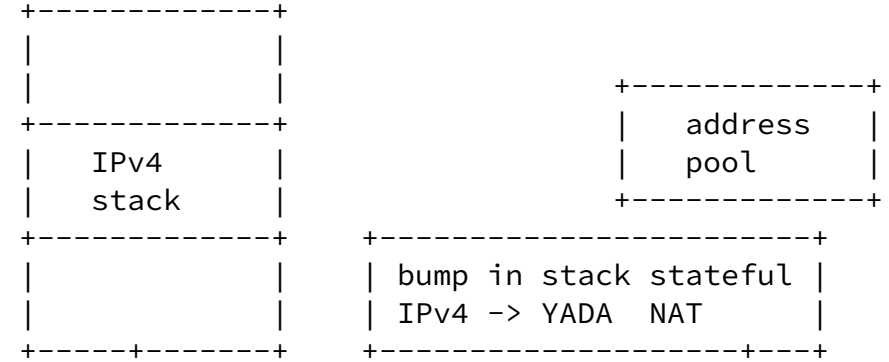
router that serves the destination realm which logs and drops. based on the log, the node may be updated, or the DNS records may be fixed to avoid pointing on a node that does not support YADA.

YADA was initially published as USPTO 7,356,031, filed in February 2002.

9. YADA Stateful NAT

Inside a realm, a YADA stack falls back to classical IPv4 operations and will natively connects to any legacy IPv4 peers. To reach YADA nodes in alternate realms, YADA also provides a stateful NAT operation that performs an IPv4-to-YADA translation below the legacy stack. The translation reuses some prefix space allocated for either [RFC1918] or [RFC6598] for a local NAT pool that is used to present a single address to the legacy stack.

The YADA formulation couples a realm address with a public IPv4 address. A host that owns a public address may perform the YADA stateful NAT operation as a bump-in-the-stack below the legacy stack. In a private network, the operation is preferably done in the private gateway, outside the existing private-public NAT so it operates on the resulting public address, to keep the classical NAT operation as is.



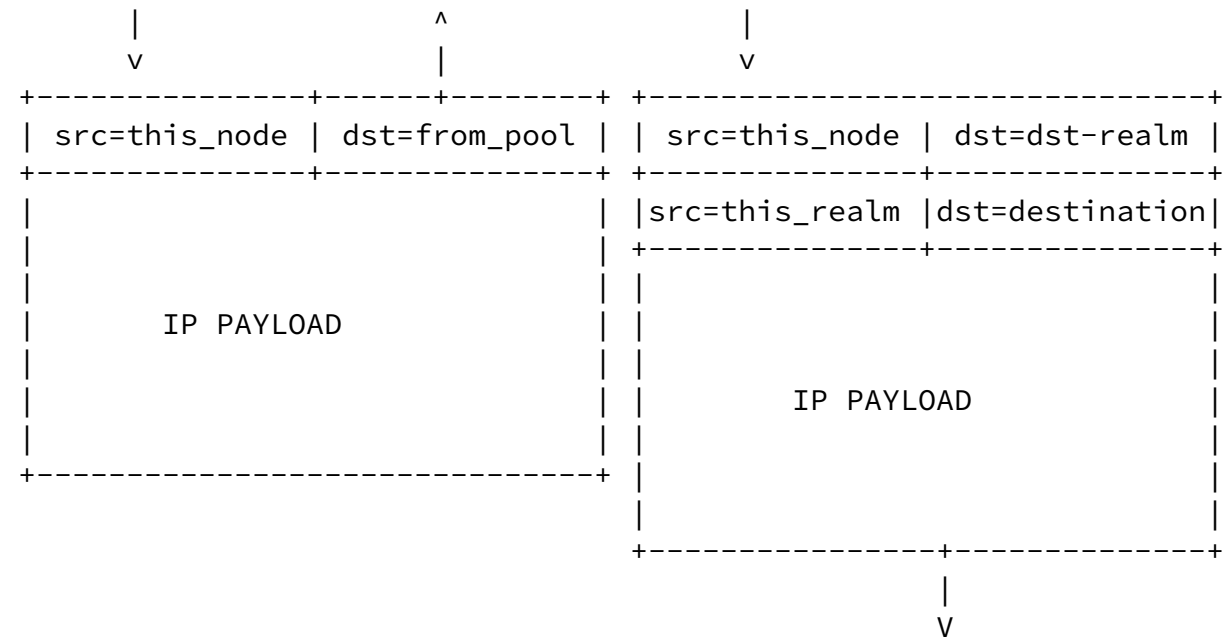


Figure 8: YADA Stateful NAT

The stateful NAT intercepts the DNS lookups. If the response contains an A record, then the address is reachable in the local realm and the NAT ignores that destination, letting the legacy operations take place transparently.

When the response yields a double-A record with a foreign realm, the stateful NAT allocates an IPv4 address from the local NAT pool and adds it in an A record to the DNS response. A local NAT state is built, indexed by the double-A outside and the allocated single-A inside.

When the legacy stack pushes a packet to that particular address, the stateful NAT translates to the YADA format, using the information in the double-A record for the destination, and the local realm as source realm.

The other way around, if a packet arrives in the YADA formulation from a different realm, the stateful NAT allocates an address from the pool, and NATs to classical IPv4 using that address as source.

As an optimization, a NAT in a private gateway may learn which nodes inside support YADA and bypass the YADA stateful NAT operation

completely for those nodes.

As long at the bump-in-the-stack (or the gateway) generates YADA packets, the packets can be translated statelessly to YATT as a last bump-in-the-stack operation before transmission to be pushed on an IPv6-only link.

The YATT and YADA formulations refer to the same object. A node that is configured with a YATT address is de facto owner of the embedded IPv4 address within the embedded IPv4 realm, and that address can be used to install a legacy IPv4 stack even if the attachement link is pure IPv6. As long at the stack generates YADA packets, the packets can be translated statelessly to YATT as a next bump-in-the-stack operation before transmission and placed on the IPv6-only network.

10. YATT

A second mechanism called YATT translates the YADA format into flat IPv6.

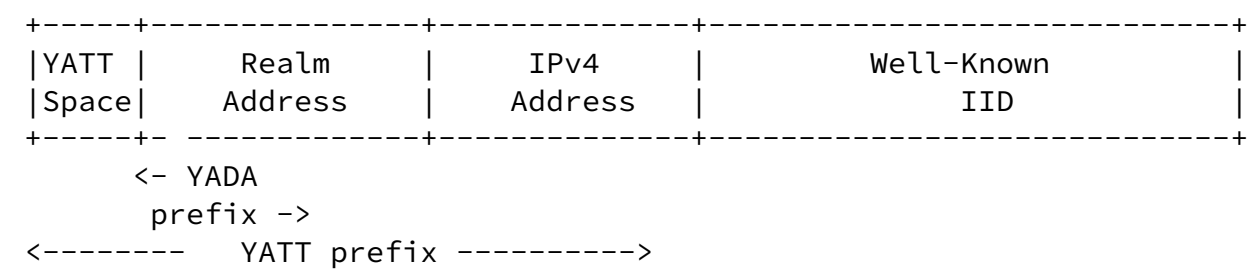


Figure 9: YATT format

For unicast addresses, YATT forms an IPv6 prefix by collating an well-known assigned short prefix called the YATT space, the realm address, and the host IPv4 address (locally significant within the realm). The resulting IPv6 prefix is automatically owned by the host that owns the IPv4 address in the realm.

Depending on assignment, the leftmost piece realm prefix may be truncated if it is well-known, to allow the YATT space and the realm address to fit in a 32-bit DWORD. This way, the YATT prefix can be a full /64 prefix that is entirely owned by the host that owns the

associated YADA address.

YATT then forms an IPv6 address for that host by collating a well-known Interface ID, so there's a one-to-one relationship.

The formats can not be strictly provided till the YATT space and YADA prefix are assigned. But say that the YATT Space is F000::/6 and the YADA prefix is 240.0.0.0/6. In that case the values perfectly overlap and the YATT format becomes as follows:

```
+-----+----------+----------------+----------------------------------+
| Realm Address  |    IPv4 Host   |            Well-Known            |
| in 240.0.0.0/6 | Public Address |                IID               |
+-----+- --------+----+-----------+----------------------------------+
<--- 32 bits ---><--- 32 bits ---><------------ 64 bits ------------>
<------   YATT IPv6 prefix ------->
```

Figure 10: YATT format using 240.0.0.0/6

In that case, the NAT operation is a plain insertion. Depending on the assignment, it might be that the Realm address must be placed in full after YATT space. In that case, the length of the YATT prefix will be more than 64 bits.

Also, since 240.0.0.0/6 is currently unassigned, using it for the shaft would allow literally to reuse every ASN and every IPv4 address currently available in the Internet in each and every other realm and reallocate them in any fashion desirable in that realm.

If the network supports IPv6 to the shaft, it makes sense for the YADA host or the bump-in-the-stack to generate the packets in the YATT form natively. The shaft router must then attract the shaft YADA realm prefix in both IPv4 and YATT forms.

If the network is IPv4 only, the packets are still generated using IP-in-IP, and the YATT NAT operation may happen at the router that delivers the packet in the destination realm, if it is v6-only, or in the destination host, if its stack is v6-only.

YATT was initially published as USPTO 7,764,686, filed in December 2002.

11. YATT Stateful PAT

The YATT and YADA formulations refer to the same object. A node that is the owner of a public address in a realm is de facto owner of the matching YATT prefix, and is de facto assigned the IPv6 address derived with the YATT-IID. The other way around, a node that is delegated a YATT prefix is de facto owner of the embedded IPv4 address within the embedded IPv4 realm.

In an IPv4-only environment, a YATT stack may obtain a YADA address pair from DHCPv4 (see Section 5), derive a YATT prefix, and use it to configure the local IPv6 stack. As long at the stack generates YATT packets, the packets can be translated statelessly to YADA as a last bump-in-the-stack operation before transmission. In that model, lower-layer protocols such as ARP and DHCP must be supported, but the IP stack can be IPv6-only.

In that case, the node shows as a YADA node, and may talk to a legacy IPv4 stack in a remote realm if the legacy that supports the YADA stateful translation. This combination of stateful PAT after the IPv6 stack and stateful NAT after the IPv4 stack allow the 2 stacks to communicate in the YADA/YATT formulations, and traverse IPv4-only and IPv6-only links using the appropriate formulation.

The YATT node may use the YATT prefix to autoconfigure addresses, or it may offer it on an IPv6 stub (tethered) network for address autoconfiguration by attached nodes, protecting the addresses that it keeps for itself using in the DAD procedure. Addresses that are not derived from the YATT-IID will be reachable from IPv6 nodes over an IPv6 network, but not from YADA node, and not over IPv4-only links.

To reach YADA nodes and traverse IPv4, the YATT node may leverage a stateful Port Address Translation (PAT) to transform the original IID in the YATT-IID outside. The stateful PAT operation can happen as a bump-in-the-stack before the YATT-to-YADA stateless translation.

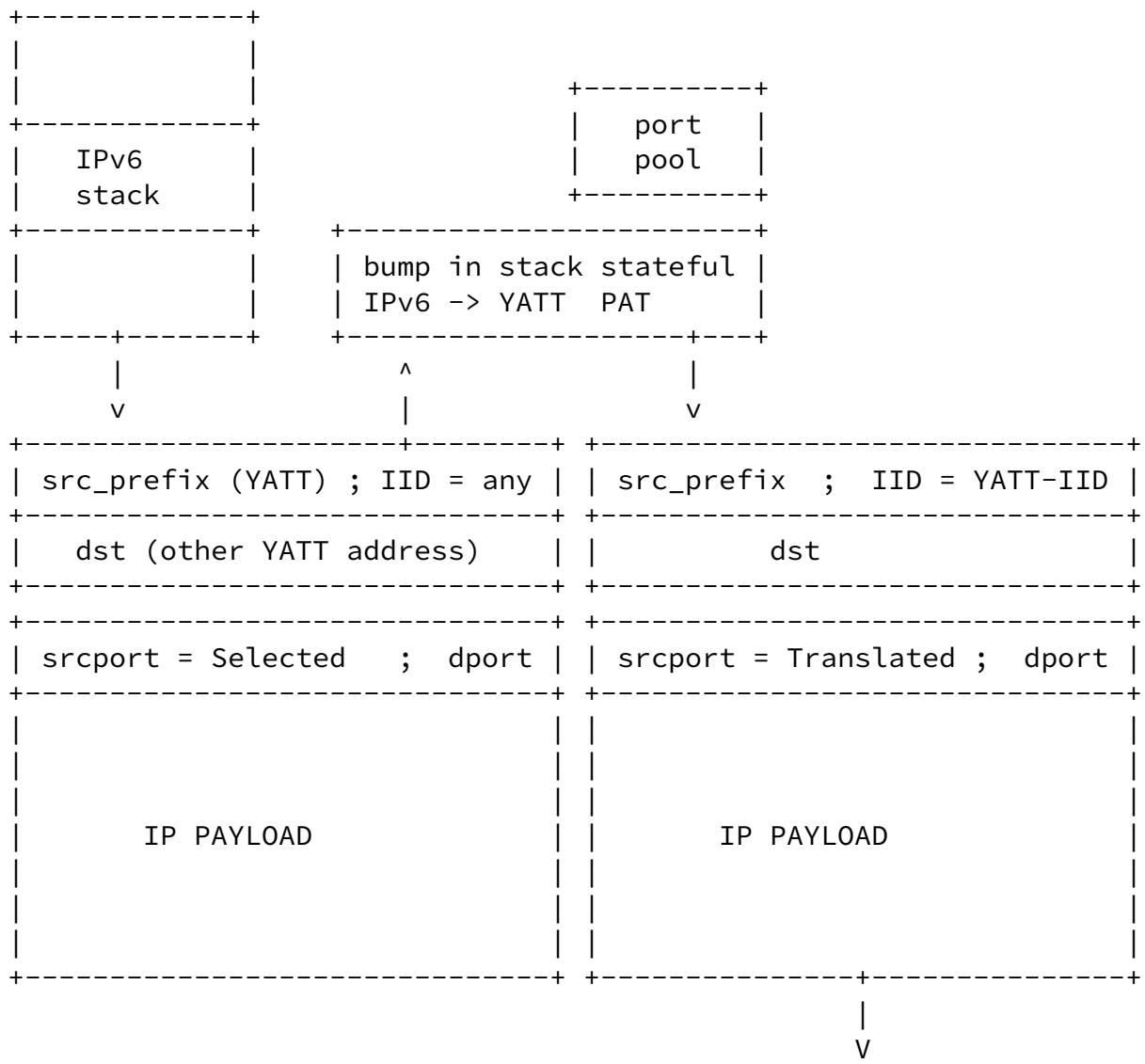


Figure 11: YATT Stateful PAT

12. The structure of the shaft

A 10 miles view of the shaft could be as follows: it is implemented in one IXP, spans all realms, and each realm has one address in the shaft, with one router serving that realm. The address of the realm is encoded in a loopback in the router, and advertised through an IGP inside the shaft, while BGP is used inside the realms but not inside

the shaft. The shaft has a single large prefix that is advertised in each realm by the router that serves the shaft, and that is disaggregated into host routes inside the shaft.

None of the above is expected to remain true for long. As YADA and YATT get deployed, the shaft will be implemented in different sites over the world. A realm may be multihomed to be reached from a different physical instance of the shaft, meaning that the shaft is

composed of either more prefixes or the shaft prefix is disaggregated. Multiple routers will serve the same realm with high availability and load balancing taking place inside the shaft to maintain connectivity. A private shaft may be deployed to interconnect a subset of the realms, in which case the shaft would use a specific prefix that would not be advertised outside the concerned realms.

13. Applicability

YADA And YATT enable communication between YADA-enabled IPv4 nodes across realms, and with IPv6 nodes that own a YADA address from which a YATT address can be derived. Communication from a legacy IPv4 application/stack that is not YADA-enabled, or to an IPv6 address that is not a YATT address, is not provided.

Since the YATT translation is stateless, the header translation can happen anywhere in the network, e.g., as a bump in the stack at either end, or within the network, e.g., at the routers that serve the realms on the shaft. The shaft itself is expected to be dual stack to forward packets in their native form, either v4 or v6.

For a legacy IPv4 node to communicate with YADA-enabled IPv4 node in another realm, a NAT operation similar to NAT46 [NAT-DEPLOY], but between IPv4 and YADA addresses, is required. The same would be required to allow an IPv4-only YADA node to communicate with an IPv6 node a non-YATT address.

In summary:

* this specification does not allow any IPv4 legacy node to talk to any pure IPv6 node, and recognizes that this Graal may actually be a non-goal.

* With YADA the current IPv4 Internet operations within a realm are not mostly unaffected, though additional provisionning is needed for routing and security purposes

* YADA extends the IPv4-reachable world by creating (millions of) parallel realms

* The stack on IPv4 hosts that require inter-realm communication must be upgraded at least with a bump, though the function may be deported to the private gateway

* A new functionality is needed in specific routers at the ingress of the realms and at the border to a single-version domain for NAT operation

* A YADA node can talk (using IPv4) to a YATT node (using IPv6) with a stateless translation. The translation can happen anywhere in the network or in the stack.

14. Backwards Compatibility

YADA operation does not affect the intra-realm communication. The only affected stacks are the endpoints that communicate between realms leveraging YADA.

15. Security Considerations

YADA introduces an IP-in-IP format that might be used to obfuscate an IP address impersonation performed in the inner header. A proper implemetation of BCP 38 should thus include the capability to recognize a YADA format and allow the source IP address in the inner header to be set to the local realm.

Before the router that serves the realm swaps the source address to place a YADA packet in the shaft, it MUST ensure that the realm address in the inner header matches this realm. Otherwise it MUST drop the packet and MAY generate and ICMP Error message back to the source, indicating the offset of the source IP address of the inner header.

16. IANA Considerations

This document requires the creation of a registry for IPv4 YADA realm prefixes, and the assignment of at least one YADA realm prefix.

This document requires the creation of a registry for IPv4 YADA NAT prefixes, and the assignment of at least one YADA NAT prefix.

This document requires the creation of a new record in the Resource Record (RR) TYPEs subregistry of the Domain Name System (DNS) Parameters. The new record would be of type AA meaning a YADA address.

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18. References

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