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Router Renumbering Guide

Status of this Memo

This memo provides information for the Internet community. This memo does not specify an Internet standard of any kind. Distribution of this memo is unlimited.

Abstract

IP addresses currently used by organizations are likely to undergo changes in the near to moderate term. Change can become necessary for a variety of reasons, including enterprise reorganization, physical moves of equipment, new strategic relationships, changes in Internet Service Providers (ISP), new applications, and the needs of global Internet connectivity. Good IP address management may in general simplify continuing system administration; a good renumbering plan is also a good numbering plan. Most actions taken to ease future renumbering will ease routine network administration.

Routers are the components that interconnect parts of the IP address space identified by unique prefixes. Obviously, they will be impacted by renumbering. Other interconnection devices, such as bridges, layer 2 switches (i.e., specialized bridges), and ATM switches may be affected by renumbering. The interactions of these lower-layer interconnection devices with routers must be considered as part of a renumbering effort.

Routers interact with numerous network infrastructure servers, including DNS and SNMP. These interactions, not just the pure addressing and routing structure, must be considered as part of router renumbering.

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1. Introduction

Organizations can decide to renumber part or all of their IP address space for a variety of reasons. Overall motivations for renumbering are discussed in [RFC2071]. This document deals with the router-related aspects of a renumbering effort, once the decision to renumber has been made.

A renumbering effort must be well-planned if it is to be successful. This document deals with planning and implementation guidelines for the interconnection devices of an enterprise. Of these devices, routers have the clearest association with the IP numbering plan.

Planning begins with understanding the problem to be solved. Such understanding includes both the motivation for renumbering and the technical issues involved in renumbering.

1. Begin with a short and clear statement of the reason to renumber. Section 3 of this document discusses common reasons.

2. Understand the principles of numbering in the present and planned environments. Section 4 reviews numbering and suggests a method for describing the scope of renumbering.

3. Before the actual renumbering, it can be useful to evolve the current environment and current numbering to a more "renumbering-friendly" system. Section 5 discusses ways to introduce renumbering friendliness into current systems.

4. Be aware of potential pitfalls. These are discussed in Section 6.

5. Identify potential requirements for tools, discussed in Section 7.

6. Evaluate the specific router mechanisms that will be affected by renumbering. See Sections 8 through 13.

7. Set up a specific transition plan framework. Guidelines for such planning are in Section 15.

When trying to understand the interactions of renumbering on routers, remember there different aspects to the problem, depending on the scope of the renumbering involved. Remember that even an enterprise-wide renumbering probably will not affect all IP addresses visible within the enterprise, since some addresses (e.g., Internet service providers, external business partners) are outside the address space under the control of the enterprise.

2. Disclaimer

The main part of this document is intended to be vendor-independent. Not all features discussed, of course, have been implemented on all routers. This document should not be used as a general comparison of the richness of features of different implementations. References here are only to those features affected by renumbering. Some illustrative examples may be used that cite vendor-specific characteristics. These examples do not necessarily reflect the current status of products.

3. Motivations for Renumbering

Reasons to renumber can be technological, organizational, or both. Technological reasons fall into several broad categories discussed below. Just as there can be both technological and organizational motivations for renumbering [RFC2071], there can be multiple technological reasons.

There may not be a clear line between organizational and technical reasons for renumbering. While networks have a charm and beauty all their own, the organizational reasons should be defined first in order to justify the budget for the technical renumbering. There

also may be pure technnical reasons to renumber, such as changes in technology (e.g., from bridging to routing).

While this document is titled "Router Renumbering Guide," it recognizes that renumbering may be required due to the initial installation of routers in a bridged legacy network. Organizations may have had an adequate bridging solution that did not scale with growth. Some organizations could not able to move to routers until router forwarding performance improved [Carpenter] to be comparable to bridges.

Other considerations include compliance with routing outside the organization. Routing issues here are primarily those of the global Internet, but may also involve bilateral private links to other enterprises.

Certain new transmission technologies have tended to redefine the basic notion of an IP subnet. The numbering plan needs to work with these new ideas. Legacy bridged networks and leading-edge workgroup switched networks may very well need changes in the subnetting structure. Renumbering needs may also develop with the introduction of new WAN technologies, especially nonbroadcast multiaccess (NBMA) services such as frame relay. Other WAN technologies, dialup media using modems or ISDN, also may have new routing and numbering requirements. Switched virtual circuit services such as ATM, X.25, or switched frame relay also interact with routing and addressing.

3.1 Internet Global Routing

Many discussions of renumbering emphasize interactions among organizations' numbering plans and those of the global Internet [RFC1900]. There can be equally strong motivations for renumbering in organizations that never connect to the global Internet.

According to RFC1900, "Unless and until viable alternatives are developed, extended deployment of Classless Inter-Domain Routing (CIDR) is vital to keep the Internet routing system alive and to maintain continuous uninterrupted growth of the Internet....To contain the growth of routing information, whenever such an organization changes to a new service provider, the organization's addresses will have to change.

Occasionally, service providers themselves may have to change to a new and larger block of address space. In either of these cases, to contain the growth of routing information, the organizations concerned would need to renumber.... If the organization does not renumber, then some of the potential consequences may include (a) limited (less than Internet-wide) IP connectivity, or (b) extra cost

to offset the overhead associated with the organization's routing information that Internet Service Providers have to maintain, or both."

3.2 Bridge Limitations; Internal Use of LAN Switching

Introducing workgroup switches may introduce subtle renumbering needs. Fundamentally, workgroup switches are specialized, high-performance bridges, which make their main forwarding decisions based on Layer 2 (MAC) address information. Even so, they rarely are independent of Layer 3 (IP) address structure. Pure Layer 2 switching has a "flat" address space that will need to be renumbered into a hierarchical, subnetted space consistent with routing. Traditional bridged networks share many of the problems of workgroup switches, but have additional performance problems when bridged connectivity extends across slow WAN links.

Introducting single switches or stacks of switches may not have significant impact on addressing, as long as it is remembered that each system of switches is a single broadcast domain. Each broadcast domain should map to a single IP subnet.

Virtual LANs (VLAN) further extend the complexity of the role of workgroup switches. It is generally true that moving an end station from one switch port to another within the same "color" VLAN will not cause major changes in addressing. Many discussions of this technology do not make it clear that moving the same end station between different colors will move the end station into another IP subnet, requiring a significant address change.

Switches are commonly managed by SNMP applications. These network management applications communicate with managed devices using IP. Even if the switch does not do IP forwarding, it will itself need IP addresses if it is to be managed. Also, if the clients and servers in the workgroup are managed by SNMP, they will need IP addresses. The workgroup, therefore, will need to appear as one or more IP subnets.

Increasingly, internetworking products are not purely Layer 2 or Layer 3 devices. A workgroup switch product often includes a router function, so the numbering plan must support both flat Layer 2 and hierarchical Layer 3 addresses.

3.3 Internal Use of NBMA Cloud Services

"Cloud" services such as frame relay often are more economical than traditional services. At first glance, when converting existing enterprise networks to NBMA, it might appear that the existing subnet structure should be preserved, but this is often not the case.

Many organizations often began by treating the "cloud" as a single subnet, but experience has shown it is often better to treat the individual virtual circuits as separate subnets. When the individual point-to-point VCs become separate subnets, efficient address utilization requires the use of /30 prefixes for these subnets. This typically means the addressing and routing plan must support multiple prefix lengths, establishing one or more prefix lengths for LAN media with more than two hosts, and subdividing one or more of these shorter prefixes into longer /30 prefixes that minimize address loss.

There are alternative ways to configure routing over NBMA, using special mechanisms to exploit or simulate point-to-multipoint VCs. These often have a significant performance impact on the router, and may be less reliable because a single point of failure is created. Mechanics of these alternatives are discussed later in this section, but the motivations for such alternatives tend to include:

1. A desire not to use VLSM. This is often founded in fear rather than technology.
2. Router implementation issues that limit the number of subnets or interfaces a given router can support.
3. An inherently point-to-multipoint application (e.g., remote hosts to a data center). In such cases, some of the limitations are due to the dynamic routing protocol in use. In such "star" applications, static routing may actually be preferable from performance and flexibility standpoints, since it does not produce routing traffic and is unaffected by split horizon.

To understand how use of NBMA services affects the addressing structure and routers, it is worth reviewing what would appear to be very basic concepts of IP subnets. The traditional view is that a single subnet is associated with a single physical medium. All hosts physically connected to this medium are assumed to be able to reach all other hosts on the same medium, using data link level services. These services are medium specific: hosts connected to a LAN medium can broadcast to one another, while hosts connected to a point-to-point line simply need to transmit to the other end.

When one host desires to transmit to another, it first determines if the destination is local or remote. A local destination is on the same subnet and assumed to be reachable through data link services. A remote destination is on a different subnet, and it is assumed that router intervention is needed to reach it.

The first NBMA problem comes up when a single subnet is implemented over an NBMA service. Frame Relay provides single virtual circuits between hosts that have connectivity. It is quite common to design Frame Relay services as partial meshes, where not all hosts have VCs to all others. When the set of hosts in a partial mesh is in a single IP subnet, partial mesh violates the local model of full connectivity. Even when there is full meshing, a pessimistic but reasonable operational model must consider that individual VCs do fail, and full connectivity may be lost transiently.

There are several ways to deal with this violation, each with their own limitations. If a specific "central" host has connectivity to N all other hosts, that central host can replicate all frames it receives from one host onto outgoing VCs connecting it with the (N-1) other hosts in the subnet. Such replication usually causes an appreciable CPU load in the replicating router. The replicating router also is a single point of failure for the subnet. This method does not scale well when extended to fuller meshes within the subnet.

In a routing protocol, such as OSPF, that has a concept of designated routers, explicit configuration usually is needed. Other problems in using a meshed subnet is that all VCs may not have the same performance, but the router cannot prefer individual paths within the subnet.

One of the simplest methods is not to attempt to emulate a broadcast medium, but simply to treat each VC as a separate subnet. This will cause a need for renumbering. Efficient use of the address space dictates a /30 prefix be used for the per-VC subnets. Such a prefix often needs VLSM support in the routers.

3.4 Expansion of Dialup Services

Dialup services, especially public Internet access providers, are undergoing explosive growth. This success represents a particular drain on the available address space, especially with a commonly used practice of assigning unique addresses to each customer.

In this practice, individual users announce their address to the access server using PPP's IP configuration option [RFC1332]. The server may validate the proposed address against some user identifier, or simply make the address active in a subnet to which the access server (or set of bridged access servers) belongs.

These access server functions may be part of the software of a "router" and thus are within the scope of this Guide.

The preferred technique [Hubbard] is to allocate dynamic addresses to the user from a pool of addresses available to the access server. Various mechanisms are used actually to do this assignment, and are discussed in Section 5.5.

3.5 Internal Use of Switched Virtual Circuit Services

Services such as ATM virtual circuits, switched frame relay, etc., present challenges not considered in the original IP design. The basic IP decision in forwarding a packet is whether the destination is local or remote, in relation to the source host's subnet. Address resolution mechanisms are used to find the medium address of the destination in the case of local destinations, or to find the medium address of the router in the case of remote routers.

In these new services, there are cases where it is far more effective to "cut-through" a new virtual circuit to the destination. If the destination is on a different subnet than the source, the cut-through typically is to the egress router that serves the destination subnet.

The advantage of cut-through in such a case is that it avoids the latency of multiple router hops, and reduces load on "backbone" routers. The cut-through decision is usually made by an entry router that is aware of both the routed and switched environments.

This entry router communicates with a address resolution server using the Next Hop Resolution Protocol (NHRP) [Cansever] [Katz]. This server maps the destination network address to either a next-hop router (where cut-through is not appropriate) or to an egress router reached over the switched service. Obviously, the data base in such a server may be affected by renumbering. Clients may have a hard-coded address of the server, which again may need to change.

While the NHRP work is in progress at the time of this writing, commercial implementations based on drafts of the protocol standard are in use.

4. Numbering and Renumbering

What is the role of any numbering plan? To understand the general problem, it can be worthwhile to review the basic principles of routers. While most readers will have a good intuitive sense of this, the principles have refined in the current usage of IP.

A router receives an inbound IP datagram on one of its interfaces, and examines some number of bits of the destination address. The sequence of bits examined by the router always begin at the left of the address (i.e., the most significant bit). We call this sequence a "prefix."

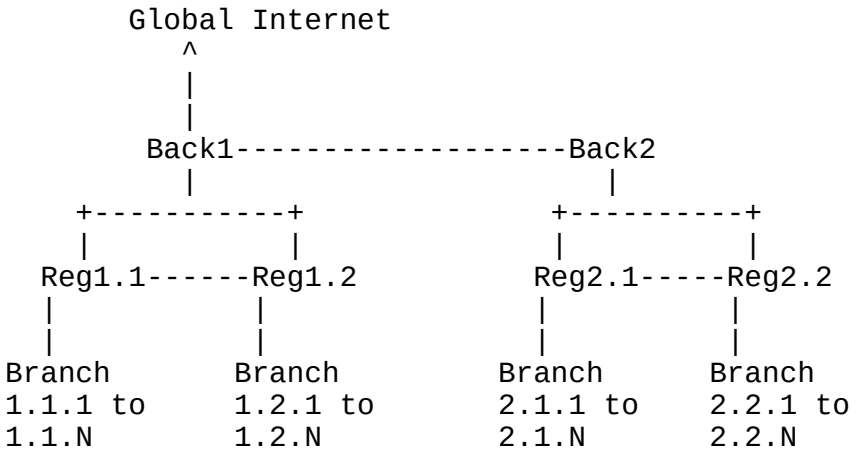
Routing decisions are made on totalPrefix bits, which start at the leftmost (i.e., most significant) bit position of the IP address. Those totalPrefix bits may be completely under the control of the enterprise (e.g., if they are in the private address space), or the enterprise may control the lowOrderPrefix bits while the highOrderPrefix bits are assigned by an outside organization.

The router looks up the prefix in its routing table (formally called a Forwarding Information Base). If the prefix is in the routing table, the router then selects an outgoing interface that will take the routed packet to the next hop IP address in the end-to-end route. If the prefix cannot be found in the routing table, the router returns an ICMP Destination Unreachable message to the source address in the received datagram.

Assuming the prefix is found in the routing table, the router then transmits the datagram through the indicated outgoing interface. If multicast routing is in effect, the datagram may be copied and sent out multiple outgoing interfaces.

4.1 Categorizing the topology

From the router renumbering perspective, renumbering impact is apt to be greatest in highly connected parts of "backbones," and least in "stub" parts of the routing domain that have a single route to the backbone.

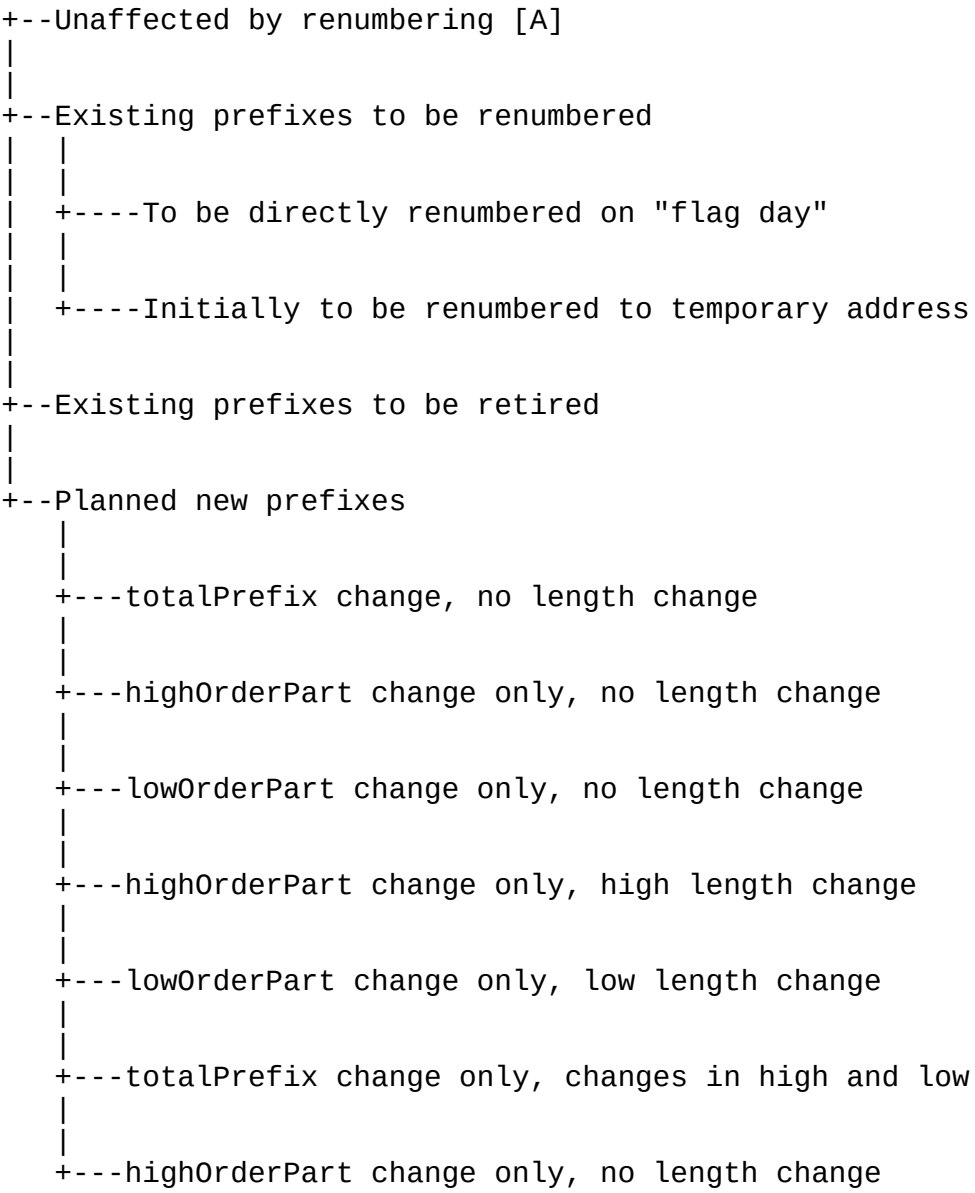


In this drawing, assume Back1 and Back2 exchange full routes; Back1 is also the exterior router. Regional routers (Reg) exchange full routes with one another and aggregate addresses to the backbone routers. Branch routers default to regional routers.

From a pure topological standpoint, the higher in the hierarchy, the greater are apt to be the effects of renumbering. This is a first approximation to scoping the task, assuming addresses have been assigned systematically. Systematic address space is rarely the case in legacy networks.

4.2 Categorizing the address space

An inventory of present and planned address space is a prerequisite to successful renumbering. Begin by identifying the prefixes in or planned into your network, and whether they have been assigned in a systematic and hierarchical manner.



Ideally, a given prefix should either be "unchanged," "old," or "new." Renumbering will be easiest when each "old" prefix can be mapped to a single "new" prefix.

Unfortunately, the ideal often will not be attainable. It may be necessary to run parts of the new and old address spaces in parallel.

Renumbering applies first to prefixes and then to host numbers to the right of the prefix. To understand the scope of renumbering, it is essential to:

1. Identify the prefixes (and possibly host fields) potentially affected by the renumbering operation.

2. Identify the authority that controls the values of the prefix, or part of the prefix, affected by renumbering.

In a given enterprise, prefixes may be present that will be under the complete or partial control of the enterprise, as well as totally outside the control of the enterprise. Let us review the principles of control over address space.

More commonly, the most significant bits of the prefix are assigned to the enterprise by an address registry (e.g., InterNIC, RIPE, or APNIC) or by an Internet Service Provider (ISP). This assignment of a value in the most significant bit positions historically has been called a "network number," when the assigned high-order part is 8, 16, or 24 bits long. More recent usage does not limit the assigned part to a byte boundary. The preferred term for the assigned part is a "CIDR block" of a certain number of bits [RFC1518].

The enterprise then extends the prefix to the right, creating "subnets." It is critical to realize that routers make routing decisions based on the total prefix of interest, regardless of who controls which bits. In other words, the router really doesn’t know or care about subnet boundaries.

The way to think about subnetting is that it creates a longer prefix. Even before CIDR, we collapsed multiple subnets into a single network number advertisement sent to external routers. In a more general way, we now think of extending the prefix to the right as subnetting and collapsing it to the left as supernetting, aggregating, or summarizing. Depending on the usage of subnetting or aggregation, different prefix lengths are significant at different router interfaces.

4.3 Renumbering Scope

Prefixes may be taken from the private address space [RFC1918] that is not routable on the global Internet. Since these addresses are not routable on the global Internet, changing parts of private address space prefixes is an enterprise-local decision.

If a prefix is totally outside the control of the enterprise, it is external, and will be minimally affected by routing. Potential interactions of external prefixes with enterprise renumbering include:

1) Inadvertent alteration or deletion of external addresses as part of router reconfiguration.
2) Loss of connectivity to application servers inside the enterprise, because the external client no longer knows the internal address of the server.
3) DNS/BGP
4) Security

Prefixes partially under the control of the enterprise may change. The scope of this will vary depending on whether only the externally controlled part of the prefix changes, or if part of the internally controlled part is to be renumbered. If the length of either the high-order or low-order parts change, the process becomes more complex.

High-order-part-only renumbering is most common when an organization changes ISPs, and needs to renumber into the new provider's space. The old prefix may have been assigned to the enterprise but will no longer be used for global routing, or the old prefix may have been assigned to the previous provider. Note that administrative procedures may be necessary to return the previous prefix, although this usually will be done by the previous provider. There often will need to be a period of coexistence between the old and new prefixes.

Low-order-part-only renumbering can occur when an enterprise modifies its internal routing structure, and the changes only affect the internal subnet structure of the enterprise network. This is typical of efforts involved in increasing the number of available subnets (e.g., for more point-to-point media) or increasing the number of hosts on a medium (e.g., in greater use of workgroup switches).

Both the high-order and low-order parts may change. This might happen when the enterprise changes to a new ISP, who assigns address space from a CIDR block rather than a classful network previously used. With a different high-order prefix length, the enterprise might be forced to change its subnet structure.

5. Moving toward a Renumbering-Friendly Enterprise

Renumbering affects both the configuration of specific router "boxes," and the overall system of routers in a routing domain. The emphasis of this section is on making the current enterprise more renumbering-friendly, before any prefixes are actually changed.

Renumbering will have the least impact when the minimum number of reconfiguration options are needed. When planning renumbering on routers, consider that many existing configurations may contain hard-coded IP addresses that may not be necessary, even if renumbering were not to occur. Part of a router renumbering effort should include, wherever possible, replacing router mechanisms based on hard-coded addresses with more flexible mechanisms.

Renumbering will also generally be easier if the configuration changes can be made offline on appropriate servers, and then downloaded to the router if the router implementation permits.

5.1 Default Routes

A well-known method for reducing the amount of reference by one router to other routers is to use a default route to a higher-level, better-connected router. This assumes a hierarchical network design, which is generally desirable in the interest of scaling.

Default routes are most appropriate for stub routers inside a routing domain, and for boundary routers that connect the domain to a single ISP.

5.2 Route Summarization and CIDR

When routes need to be advertised, summarize as much as is practical. Summarization is most effective when address prefixes have been assigned in a consistent and contiguous manner, which is often not the case in legacy networks. Nevertheless, there is less to change when we can refer to blocks of prefixes.

Not all routing mechanisms support general summarization. Interior routing mechanisms that do include RIPv2, OSPF, EIGRP, IS-IS, and systems of static routes. RIPv1 and IGRP do support classful summarization (i.e., at Class A/B/C network boundaries only).

If existing addresses have been assigned hierarchically, it may be possible to renumber below the level of summarization, while hiding the summarization to the rest of the network. In other words, if all the address bits being renumbered are to the right of the summarized prefix length, the change can be transparent to the overall routing system.

Even when effective summarization is possible to hide the details of routing, DNS, filters, and other services may be affected by any renumbering.

5.3 Server References in Routers

Routers commonly communicate with an assortment of network management and other infrastructural servers. Examples of these servers are given in the "Network Management" section below. DNS itself, however, may be an important exception.

Wherever possible, servers should be referenced by DNS name rather than by IP address. If a specific router implementation only supports explicit address references, this should be documented as part of the renumbering plan.

Routers may also need to forward end host broadcasts to other infrastructure services (e.g., DNS, DHCP/BOOTP). Configurations that do this are likely to contain hard-coded IP addresses of the destination hosts or their subnets, which will need to be changed as part of renumbering.

5.4 DNS and Router Renumbering

The Domain Name Service is a powerful tool in any renumbering effort, and can help routers as well as end hosts. If traceroute displays DNS names rather than IP addresses, certain debugging options can be transparent through the address transition.

Be aware that dynamically learned names and addresses may be cached in router tables. For a router to learn changes in address to name correspondence, it may be necessary to restart the router or explicitly clear the cache.

Alternatively, router configuration files may contain hard-coded address/name correspondences that will not be affected by a change in the DNS server.

Different DNS databases are affected by renumbering. For example, the enterprise usually controls its own "forward" data base, but the reverse mapping data base may be maintained by its ISP. This can require coordination when changing providers.

Commonly, router renumbering goes through a transition period. During this transition, old and new addresses may coexist in the routing system. Coexistence over a significant period of time is especially likely for DNS references to addresses that are known in the global Internet [deGroot]. Various DNS servers throughout the world may cache addresses for periods of days.

If, for example, a given router interface may have a coexisting new and old address, it can be appropriate to introduce the new address as an additional A record for the new address.

DNS RR statements can end with a semicolon, indicating the rest of the line is a comment. This can be used as the basis of tools to renumber DNS names for router addresses, by putting a comment (e.g., ";newaddr") at the end of the A statements for the new addresses. At an appropriate time, a script could generate a new zone file in which the new addresses become the primary definitions on A records, and the old addresses could become appropriately commented A records. At a later time, these commented entries could be removed.

Care should be taken to assure that PTR reverse mapping entries are defined for new addresses, because some router vendor tools depend on reverse mapping.

5.5 Dynamic Addressing

Renumbering is easiest when addresses need to be changed in the least possible number of places. Dynamic address assignment is especially attractive for end hosts, and routers may play a key role in this process. Routers may act as servers and actually assign addresses, or may be responsible for forwarding end host address assignment requests to address assignment servers.

The most common use of dynamic address assignment is to provide IP addresses to end systems. Dynamic address assignment, however, is also used to assign IP addresses to router interfaces. An address assignment server may assign an IP address to a router either in the usual DHCP way, based on a MAC address in the router, or simply based on the physical connectivity of the new router. In other words, any router connected on a specific interface of the configuring router would be assigned the same IP address.

5.5.1 Router Roles in LAN-based DHCP Address Assignment

End hosts attached to LANs often obtain address assignments from BOOTP or DHCP servers. If the server is not on the same medium as the end hosts, routers may need to play a role in establishing connectivity between the end host and the address server.

If the client is not on the same medium as the address assignment server, routers either must act as address assignment services, or forward limited broadcasts to the location of appropriate servers.

If the router acts as an address assignment server, its database of addresses that it can assign may change during renumbering. If the router forwards to a DHCP or BOOTP server, it must know the address of that server. That server address can itself change as a result of renumbering.

While the usual perception of DHCP is that it assigns addresses from a pool, such that assignments to a given host at a given time is random within the pool, DHCP can also return a constant IP address for a specific MAC address. This may be much easier to manage and troubleshoot, especially during renumbering.

Clearly, if the DHCP server identifies end hosts based on their MAC address, consideration must be given to making that address unique, and changing the DHCP database if either the MAC address or the IP address changes. One way to reduce such reconfiguration is to use Locally-Administered Addresses (LAA) on end hosts, rather than globally unique addresses stored in read-only memory (ROM). Using LAAs solves the problem of MAC addresses changing when a network interface card changes, but LAAs have their own management problems of configuration into end systems and maintaining uniqueness within the enterprise.

5.5.2 Router Roles in Dialup Address Assignment

There are several possible ways in which an dialup end host interacts with address assignment. Routers/access servers can play critical roles in this process, either to provide connectivity between client and server, or directly to assign addresses.

Different vendors handle address assignment in different ways. Methods include:

1. The access server forwards the request to a DHCP server, using a unique 48-bit identifier associated with the client. Note that this usually should not be the MAC address of the access server, since the same MAC address would then be associated with different hosts.

2. The server forwards the request to an authentication server, which in turn gets a dynamic address either from:

   a. internal pools
   b. a DHCP server to which it forwards

3. The server selects an address from locally configured pools and provides it to the dialing host without the intervention of other services.

When the router contains assignable addresses, these may need to change as part of renumbering. Alternatively, hard-coded references to address assignment or authentication servers may need to change.

5.5.3 Router Autoonfiguration

This initial address assignment may provide an address only for a single connection (i.e., between the new and configuring routers). The newly assigned address may then be used to "bootstrap" a full configuration into the new router.

Dynamic address assignment to routers is probably most common at outlying "stub" or "edge" routers that connect via WAN links to a central location with a configuration server. Such edge devices may be shipped to a remote site, plugged in to a WAN line, and use proprietary methods to acquire part or all of their address configuration.

When such autoconfiguration is used on edge routers, it may be necessary to force a restart of the edge router after renumbering. Restarting may be the only way to force the autoconfigured router to learn its new address. Other out-of-band methods may be available to change the edge router addresses.

5.6 Network Address Translation

Network address translation (NAT) is a valuable technique for renumbering, or even for avoiding the need to renumber significant parts of an enterprise [RFC1631]. It is not always transparent to network layer protocols, upper layer protocols, and network management tools, and must not be regarded as a panacea.

In the classic definition of NAT, certain parts of the routing system are designated as stub domains, and connect to the global domain only through NAT functions. The NAT contains a translation mechanism that maps a stub address to a global address. This mechanism may map statically or dynamically.

A more general NAT mechanism often is implemented in firewall bastion hosts, which isolate "inside" and "outside" addresses through transport- or application-level authenticated gateways. Mappings from a "local" or "inside" address to a global address often is not one-to-one, because an inside address is dynamically mapped to a TCP or UDP port on an outside interface address.

In general, if there are multiple NATs, their translation mechanisms should be synchronized. There are specialized cases when a given stub address appears in more than one stub domain, and ambiguity

develops if one wishes to map, say, from 10.1.0.1/16 in stub domain A to 10.1.0.1/16 in stub domain B. In this case, both 10.1.0.1 addresses identify different hosts. Special mechanisms would have to exist to map the domain A local address into one global address, and to map the domain B local address into a different global address.

NAT can have a valuable role in renumbering. Its intelligent use can greatly minimize the amount of renumbering that needs to be done. NAT, however, is not completely transparent.

Specifically, it can interfere with the proper operation of any protocol that carries an IP address as data, since NAT does not understand passenger fields and is unaware numbers need to change.

Examples of protocols affected are:

- --TCP and UDP checksums that are in part based on the IP header. This includes end-to-end encryption schemes that include the TCP/UDP checksum
- --ICMP messages containing IP addresses
- --DNS queries that return addresses or send addresses
- --FTP interactions that use an ASCII-encoded IP address as part of the PORT command

It may be possible to avoid conflict if only certain hosts use affected protocols. Such hosts could be assigned only global addresses, if the network topology and routing plan permit.

Early NAT experiments suggested that it needs a sparse end-to-end traffic mapping database for reasonable performance. This may or may not be an issue in more hardware-based NAT implementations.

Another concern with NAT is that unique host addresses are hidden outside the local stub domains. This may in fact be desirable for security, but may present network management problems. One possibility would be to develop a NAT MIB that could be queried by SNMP to find the specific local-to-global mappings in effect.

There are also issues for DNS, DHCP, and other address management services. There presumably would need to be local servers within stub domains, so address requests would be resolved uniquely in each stub (or would return appropriate global addresses).

6. Potential Pitfalls in Router Renumbering

One way to categorize potential pitfalls is to look at those associated with the overall numbering plan itself and routing advertisement, and those associated with protocol behavior. In general, the former case is static and the latter is dynamic.

6.1 Static

Problems can be implicit to the address/routing structure itself. These can include failures of components to understand arbitrary prefix addressing (i.e., classless routing), reachability due to inappropriate default or aggregated routes, etc.

6.1.1 Classless Routing Considerations

Among the major reasons to renumber is to gain globally routable address space. In the global Internet, routable address space is based on arbitrary-length prefixes rather than traditional address classes. Classless Inter-Domain Routing (CIDR) is the administrative realization of prefix addressing in the global Internet. Inside enterprises, arbitrary prefix length addressing often is called Variable Length Subnet Masking (VLSM) or "subnetting a subnet."

The general rules of prefix addressing must be followed in CIDR. Among these are permitting use of the all-zeroes and all-one subnets [RFC1812], and not assuming that a route to a "Class A/B/C network number" implies routes to all subnets of that network. Assumptions also should not be made that a prefix length is implied by the structure of the high-order bits of the IP address (i.e., the "First Octet Rule").

This ideal, unfortunately, is not understood by a significant number of routers (and terminal access servers that participate in routing), and an even more significant number of host IP implementations.

When planning renumbering, network designers must know if the new address has been allocated using CIDR rules rather than traditional classful addressing. If CIDR rules have been followed in address assignment, then steps need to be taken to assure the router understands them, or appropriate steps need to be taken to interface the existing environment to the CIDR environment.

Current experience suggests that it is best, when renumbering, to maintain future compatibility by moving to a CIDR-supportive routing environment. While this is usually thought to mean introducing a classless dynamic routing protocol, this need not mean that routing become much more complex. In a RIPv1 environment, moving to RIPv2

may be a relatively simple change. Alternative simple methods include establishing a default route from a non-CIDR-compliant routing domain to a CIDR-compliant service provider, or making use of static routes that are CIDR-compliant.

Some routers support classless routing without further configuration, other routers support classless routing but require specific configuration steps to enable it, while other routers only understand classful routing. In general, most renumbering will eventually require classless routing support. It is essential to know if a given router can support classless routing. If it does not, workarounds may be possible. Workarounds are likely to be necessary.

6.1.1.1 Aggregation Problems

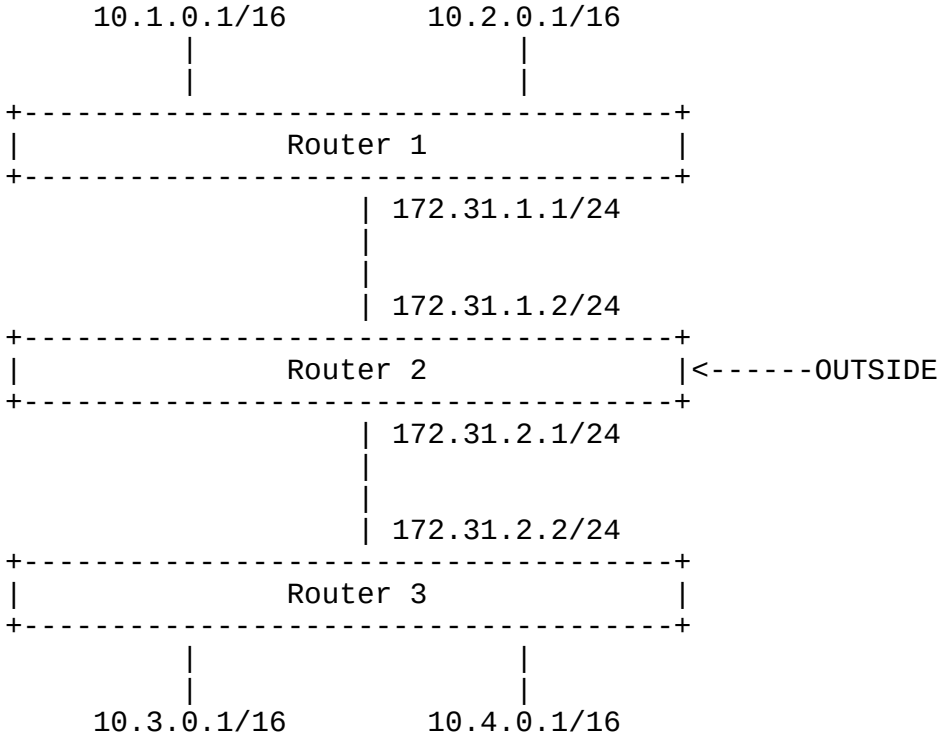
In experimenting with the CIDR use of a former Class A network number, it was shown in RFC1879 that CIDR compliance rules must be enabled explicitly in some routers, while other routers do not understand CIDR rules.

RFC 1897 demonstrated problems with some existing equipment, especially "equipment that depends on use of a classful routing protocol, such as RIPv1 are prone to misconfiguration. Tested examples are current Ascend and Livingston gear, which continue to use RIPv1 as the default/only routing protocol. RIPv1 use will create an aggregate announcement.... The Ascend was told to announce 39.1.28/24, but since RIPv1 can’t do this, the Ascend instead sent 39/8." RIPv1, like all classful interior protocols, is obsolescent.

6.1.1.2 Discontiguous Networks

Another problem that can occur with routers or routing mechanisms that do not understand arbitrary length prefix addressing is that of discontiguous networks. This problem is easy to create inadvertently when renumbering. In the example below, assume the enterprise has been using 10.0.0.0/8 as its primary prefix, but has introduced an ISP whose registered addresses were in 172.31.0.0/16.

Assume a RIPv1 system of three routers:



Router 1 can reach its two locally connected subnets, 10.1.0.0/16 and 10.2.0.0/16. It will aggregate them into a single announcement of 10.0.0.0/8 when it advertises out the 172.31.1.1 interface.

In like manner, Router 3 can reach its two locally connected subnets, 0.3.0.0/16 and 10.4.0.0/16. It will aggregate them into a single announcement of 10.0.0.0/8 when it advertises out the 172.31.2.2 interface.

When Router 2 receives a packet from its "outside" interface destined, say, to 10.1.1.56/16, where does it send it? Router 2 has received two advertisements of 10.0.0.0 on different interfaces, without any detail of subnets inside 10.0.0.0. Router 2 has an ambiguous routing table in terms of the next hop to a subnet of 10.0.0.0. We call this problem, when parts of the same classful network are separated by different networks, discontigous subnets.

Two problems occur in this configuration. Router 2 does not know where to send outside packets destined for a subnet of 10.0.0.0. Connectivity, however, also will break between Routers 1 and 3, because Router 2 does not know the next hop for any subnet of 10.0.0.0.

There are several workarounds to this problem. Obviously, one would be to change to a routing mechanism that does advertise subnets. An alternative would be to establish an IP-over-IP tunnel through Router 2, and give this a subnet in 10.0.0.0. This additional subnet would be visible only in Routers 1 and 3. It would solve the connectivity problem between Routers 1 and 3, but Router 2 would still not be able to forward outside packets. This might be a perfectly acceptable solution if Router 2 is simply being used to connect two parts of 10.0.0.0.

Another way to deal with the discontiguous network problem is to assign secondary addresses in 10.0.0.0 to the R1-R2 and R2-R3 interfaces, which would allow the 10.0.0.0 subnets to be advertised to R2. This would work as long as there is no problem in advertising the 10.0.0.0 subnets into the R2 routing system. There would be a problem, for example, if the 10.0.0.0 address were in the private address space but the R2 primary addresses were registered, and R2 advertised the 10.0.0.0 addresses to the outside.

This problem can be handled if R2 has filtering mechanisms that can selectively block 10.0.0.0 advertisements to the outside world. The configuration, however, will become more and more complicated.

6.1.1.3 Router-Host Interactions

The situation may not be as bleak if hosts do not understand prefix addressing but routers do. Methods exist for hiding a VLSM structure from end hosts that do not understand it. These do involve protocol mechanisms as workarounds, but the fundamental problem is hosts' understanding of arbitrary prefix lengths.

A key mechanism is proxy ARP [Carpenter]. The basic mechanism of using proxy ARP in prefix-based renumbering is to have the hosts issue an ARP whenever they want to communicate with a destination. If the destination is actually on the same subnet, it will respond directly to the ARP. If the destination is not, the router will respond as if it were the destination, and the originating host will send the datagram to the router. Once the datagram is in the router, the VLSM-aware router can forward it.

Many end hosts, however, will only issue an ARP if they conclude the destination is on their own subnet. All other traffic is sent to a hard-coded default router address. In such cases, workarounds may be needed to force the host to ARP for all destinations.

One workaround involves a deliberate misconfiguration of hosts. Hosts that only understand default routers also are apt only to understand classful addressing. If the host is told its major (i.e.,

classful) network is not subnetted, even though the address plan actually is subnetted, this will often persuade it to ARP to all destinations.

This also works for hosts that do not understand subnetting at all. An example will serve for both levels of host understanding. Assume the enterprise uses 172.31.0.0/16 as its major address, which is in the Class B format. This is actually subnetted with eight bits of subnetting -- 172.31.0.0/24. Individual hosts unaware of VLSM, however, either infer Class B from the address value, or are told that the subnet mask in effect is 255.255.0.0.

Yet another approach that helps hosts find routers is to run passive RIP on the hosts, so that they hear routing updates. They assume any host that issues routing updates must be a router, so traffic for non- local destinations can be forwarded there. While RIPv1 does not support arbitrary prefixes, the router(s) issuing the routing updates may have additional capabilities that let them correctly forward such traffic. The priority, therefore, is to get the non-local routers to a router that understands the overall routing structure, and passive RIP may be a viable way to do this.

It may be appropriate to cut over on a site-by-site basis [Lear]. In such an approach, some sites have VLSM-aware hosts but others do not. As long as the routing structure supports VLSM, workarounds can be applied where needed.

6.1.2 MAC Address Interactions

While it is uncommon now for a router to acquire any of its interface addresses as a DHCP client, this may become more common. When a router so acquires addresses, care must be taken that the MAC address presented to the DHCP server is in fact unique.

Modern routers usually support protocol architectures besides IP. Some of these architectures, notably DECnet, Banyan VINES, Xerox Network Services, and IPX, may modify MAC addresses of routers such that a given MAC address appears on more than one interface. While this is normally not a problem, it could cause difficulties when the MAC address is assumed to be unique.

Other situations occur when the same MAC address can appear on more than one interface. There are high-availability IBM options which establish primary and backup instances of the same MAC address on different physical interfaces of 37x5 communications controllers.

Some end hosts running protocol stacks other than IP, notably DECnet, may change their MAC address from the globally assigned built-in address.

6.2 Dynamic

Dynamic protocol mechanisms that to some extent depend on IP addresses may be affected by router renumbering. These include mechanisms that assign or resolve addresses (e.g., DHCP, DNS), mechanisms that use IP addresses for identification (e.g., SNMP), security and authentication mechanisms, etc. The listed mechanisms are apt to have configuration files that will be affected by renumbering.

Another area of dynamic behavior that can be affected is caching. Application servers, directory functions such as DNS, etc., may cache IP addresses. When the router is renumbered, these servers may point to old addresses. Certain proxy server functions may reside on routers, and the router may need to be restarted to reset the cache.

The endpoints of TCP tunnels terminating on routers may be internally identified by address/port pairs at each end. If the address changes, even if the port remains the same, the tunnel is likely to need to be reestablished.

7. Tools and Methods for Renumbering

The function of a renumbering tool can be realized either as manual procedures as well as software. This section deals with functionality of hypothetical yet general renumbering tools rather than their implementation.

General caveat: tools should know whether the environment supports classless addressing. If it does not, newly generated addresses should be checked to see they do not fall into the all-zeroes or all-ones subnet values.

7.1 Search Mechanisms

Tools will be needed to search configuration files and other databases to identify addresses and names that will be affected by reorganization. This search should be based on the address inventory described above.

Especially when searching for names, common search tools using regular expressions (e.g., grep) may be very useful. Some additional search tools may be needed. One would convert dotted decimal search arguments to binary and only then makes the comparison.

The comparison may need to be done under the constraint of a mask. Such a comparator would also be relevant as the second phase that looks for ipAddress and other relevant strings in MIBs.

7.2 Address Modification

The general mechanism for address modification is substitution of an arbitrary number of bits in an address. In the simplest cases, there is a one-to-one correspondence between old and new bit positions.

Especially when address modification is manual, it should be remembered that the affected bits can be obscured by dotted decimal notation. Work in, or at least consider, binary notation to assure accuracy.

Several basic functions can be defined:

```
zerobits(position,length):
   clear <length> bits starting at <position>
orbits(position,length,newbits)
   OR the bit string <newbits> of <length> starting at <position>
```

In these examples, the index [j] is used to identify entries in the address inventory database for existing addresses, while [k] identifies new addresses.

Remember that these tools operate at a bit level, so the new address will have to be converted back into dotted decimal, MIB ASN.1, or other notation before it can be replaced into configuration files.

7.2.1 Prefix Change, No Change in Length

If the entire new prefix has the same number of bits as the old external part, requiring no change to subnetting, the router part of renumbering may be fairly simple. If the router configurations are available in machine-readable form, as text files or parsable SNMP data, it is a relatively simple task to define a tool to examine IP addresses in the configuration, identify those beginning with the old prefix, and substitute the new prefix bit-by-bit.

```
for each address[j],
   zerobits(0,PrefixLength[j])
   orbits(0,PrefixLength[j],NewPrefix[j])
```

Note that the host part is unaffected. Both subnet specifications (e.g., for route advertisements) and specific host references will be changed correctly in this simple case.

7.2.2 highOrderPart change

Matters are slightly more complex when the change applies only to the externally-controlled part of the prefix, as might be the case when an organization changes ISPs and renumbers into the ISP's address space, without changing the internal subnet structure.

The substitution process is much as the previous case, except only the high-order bits change:

```
for each address,
   zerobits(0,highOrderPartLength[j])
   orbits(0,highOrderPartLength,newHighOrderPart[k])
```

7.2.3 lowOrderPart change

Organizations might renumber only the lowOrderPart (i.e., the subnet field) of their address space. This might be done to clean up an address space into contiguous blocks prior to introducing a routing system that aggregates addresses, such as OSPF.

```
for each address[j],
   zerobits(highOrderPartLength[j],lowOrderPartLength[j])
   orbits(highOrderPartLength[j],
         lowOrderPartLength[j],newLowOrderPart[k])
```

7.2.4 lowOrderPart change, Change in lowOrderPart length

When the length of the subnet field changes in all or part of the address space, things become significantly more complex. A fairly simple case arises when the host field is consistently too long, at least in the affected subnets. This is common, for example, when address space is being recovered in an existing Class B network with 8 bits of subnetting. Certain /24 bit prefixes are being extended to /30 and reallocated to point-to-point real or virtual (e.g., DLCI) media.

```
for each address [j]
 if address is affected by renumbering
  if newLowOrderPartLength[k] > oldLowOrderPartLength[j]
   then
    zerobits(highOrderPartLength[k],newLowOrderPartLength[k])
    orbits(highOrderPartLength[k],newLowOrderPart[k])
   end
```

7.2.5 highOrderPart change, Change in highOrderPart length

When the length of the high-order part changes, but it is desired to keep the existing subnet structure, constraints apply. The situation is fairly simple if the new high-order part is shorter than the existing high order part.

If the new high-order part is longer than the old high order part, constraints are more complex. The key is to see if any of the <k> most significant bits of the oldHighOrderPart, which overlap the <k> least significant bits of the newHighOrderPart, are nonzero. If no bits are nonzero, it may be simply to overlay the new prefix bits.

7.3 Naming

It is worthwhile to distinguish that a router's use of a DNS name does not necessarily mean that name is defined in a name server. Routers often contain static address to name mappings local to the router, so both the DNS zone files and the router configurations will need to be checked.

What we first want to do is generate a list of name/address mappings, the mapping mechanism for each instance (e.g., static entry in configuration file, RR in our zone's DNS, RR in a zone file outside ours), the definition statement (or equivalent if the routers are configured with SNMP), and current IP address. We then want to compare the addresses in this list to the list defined earlier of prefixes affected by renumbering. The intersection of these lists define where we need to make changes.

Note that the explicit definition statement, or at leasts its variables, should be kept. In the real world, static IP address mappings in hosts may not have been maintained as systematically as are RR records in a DNS server. It is entirely possible that different host mapping entries for the same name point to different addresses.

7.3.1 DNS Tools

The DNS itself can both delay and and speed router renumbering. Caches in DNS servers both inside and outside the organization may have sufficient persistence that a "flag day" cutover is not practical if worldwide connectivity is to be kept. DNS can help, however, make a period of old and new address coexistence work.

If, for example, a given router interface may have a coexisting new and old address, it can be appropriate to introduce the new address as a CNAME alias for the new address.

DNS RR statements can end with a semicolon, indicating the rest of the line is a comment. This can be used as the basis of tools to renumber DNS names for router addresses, by putting a comment (e.g., ";newaddr") at the end of the CNAME statements for the new addresses. At an appropriate time, a script could generate a new zone file in which the new addresses become the primary definitions on A records, and the old addresses could become appropriately commented CNAME records. At a later time, these commented CNAME entries could be removed.

Care should be taken to assure that PTR reverse mapping entries are defined for new addresses, because some router vendor tools depend on reverse mapping.

7.3.2 Related name tools

Especially on UNIX and othe that do routing, there may be static name definitions. Such definitions are probably harder to keep maintained than entries in the DNS, simply because they are more widely distributed.

Several tools are available to generate more maintainable entries. A perl script called h2n converts host tables into zone data files that can be added to the DNS server. It is available as ftp://ftp.uu.net/published/oreilly/nutshell/dnsbind/dns.tar.Z. Another tool, makezones, is part of the current BIND distribution, and can also be obtained from ftp://ftp.cus.cam.ac.uk/pub/software/programs/DNS/makezones

See the DNS Resources Directory at http://www.dns.net/dnsrd.

8. Router Identifiers

Configuration commands in this category assign IP addresses to physical or virtual interfaces on a single router. They also include commands that assign IP-address-related information to the router "box" itself, and commands which involve the router’s interaction with neighbors below the full routing level (e.g., default gateways, ARP).

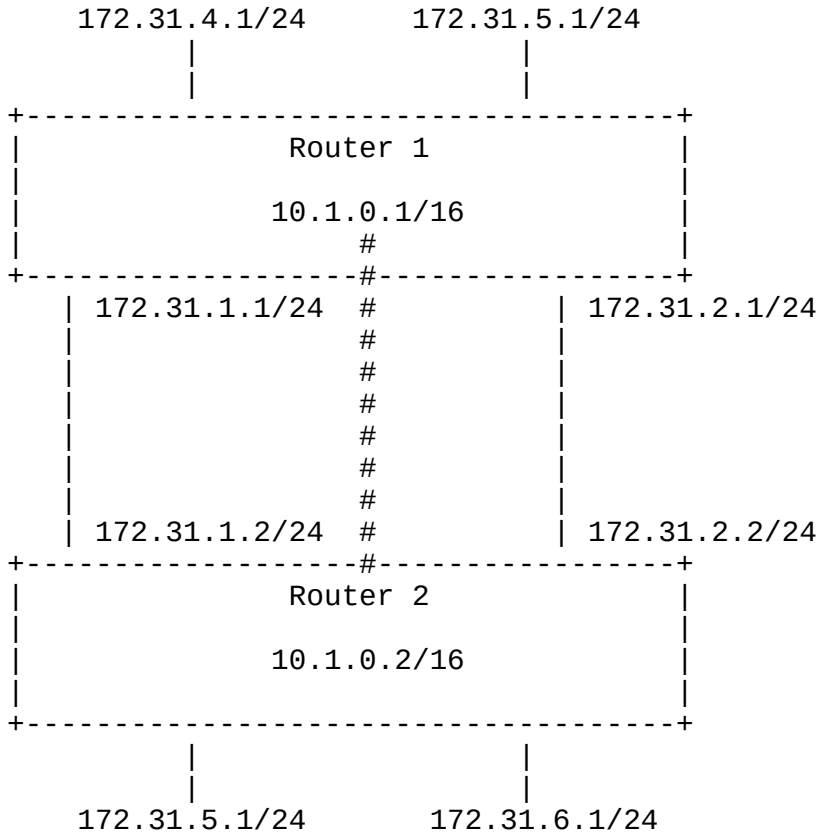
Routers may have other unique identifiers, such as DNS names used for the set of addresses on the "box," or SNMP systemID strings.

8.1. Global Router Identification

Traditional IP routers do not have unique identifiers, but rather are treated as collections of IP addresses associated with their interfaces. Some protocol mechanisms, notably OSPF and BGP, need an

address for the router itself, typically to establish tunnel endpoints between peer routers. Other applications include "unnumbered interfaces" used to conserve address space for serial media, a practice discussed further below.

In the illustration below, the 10.1.0.0/16 address space is used for global identifiers. A TCP tunnel runs from 10.1.0.1 to 10.1.0.2, but its traffic is load-shared among the two real links, 172.31.1.0 and 172.31.2.0.



A common practice to provide router identifiers is using the "highest IP address" on the router as an identifier for the "box." Many implementations have a default mechanism to establish the router ID, which may be the highest configured address, or the highest active address.

Typical applications of a global router ID may not require it be a "real" IP address that is advertised through the routing domain, but is simply a 32-bit identifier local to each router. When this is the case, this identifier can come from the RFC 1918 private address space rather than the enterprise's registered address space.

Allowing default selection of the router ID can be unstable and is not recommended. Most implementations have a means of declaring a pseudo-IP address for the router itself as opposed to any of its ports.

Changes to this pseudo-address may have implications for DNS. Even if this is not a real address, A and PTR resource records may have been set up for it, so diagnostics can display names rather than addresses.

Another potential DNS implication is that a CNAME may have been established for the entire set of interface addresses on a router. This allows testing, telnet, etc., to the router via any reachable path.

8.2 Interface Address

Interface addresses are perhaps the most basic place to begin router renumbering. Interface configuration will require an IP address, and usually a subnet mask or prefix length. Some implementations may not have a subnet mask in the existing configuration, because they use a "default mask" based on a classful assumption about the address. Be aware of possible needs for explicit specification of a subnet mask or other prefix length specification when none previously was specified. This will be especially common on older host-based routers.

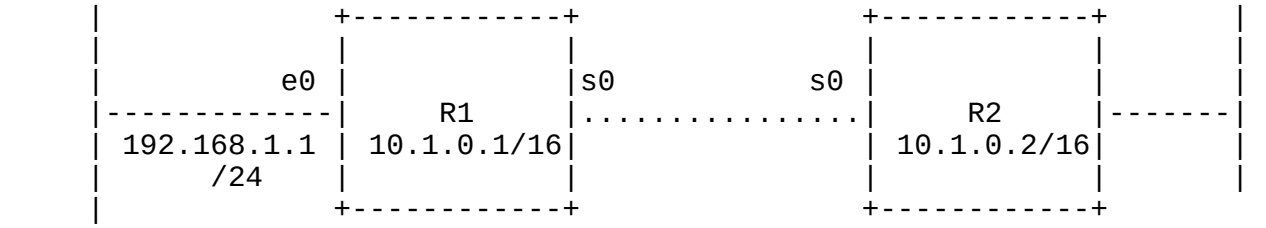
Multiple IP addresses, in different subnets, can be assigned to the same interface. This is often a valuable technique in renumbering, because the router interface can be configured to respond to both the new and old addresses.

Caution is necessary, however, in using multiple subnet addresses on the same interface. OSPF and IS-IS implementations may not advertise the additional addresses, or may constrain their advertisement so all must be in the same area.

When this method is used to make the interface respond to new and old addresses, and the renumbering process is complete, care must be taken in removing the old addresses. Some router implementations have special meaning to the order of address declarations on an interface. It is highly likely that routers, or at least the interface, must be restarted after an address is removed.

8.3 Unnumbered Interfaces

As mentioned previously, several conventions have been used to avoid wasting subnet space on serial links. One mechanism is to implement proprietary "half-router" schemes, in which the unnumbered link between router pairs is treated as an "internal bus" creating a "virtual router," such that the scope of the unnumbered interface is limited to the pair of routers.



In the above example, software in routers R1 and R2 automatically forward every packet received on serial interface S0 to Ethernet interface E0. They forward every packet on e0 to their local S0. Neither S0 has an IP address. R1 has the router ID 10.1.0.1/16 and R2 has 10.1.0.2/16.

It is thus impossible to send a specific ping to the S0 interfaces, making it difficult to test whether a connectivity problem is due to S0 or E0. Some management is possible as long as at least one IP address on the router (e.g., E0) is reachable, since this will permit SNMP connectivity to the router. Once the router is reachable with SNMP, the unnumbered interface can be queried through the MIB ifTable.

Another approach is to use the global router identifier as a pseudo-address for every unnumbered interface on a router. In the above example, R1 would use 10.1.0.1 as its identifier. This provides an address to be used for such functions as the IP Route Recording option, and for providing a next-hop-address for routes.

The second approach is cleaner, but still can create operational difficulties. If there are multiple unnumbered interfaces on a router, which one (if any) should/will respond to a ping? Other network management mechanisms do not work cleanly with unnumbered interface.

As part of a renumbering effort, the need for unnumbered interfaces should be examined. If the renumbering process moves the domain to classless addressing, then serial links can be given addresses with a /30 prefix, which will waste a minimum of address space.

For dedicated or virtual dedicated point-to-point links within an organization, another alternative to unnumbered operation is using RFC1918 private address space. Inter-router links rarely need to be accessed from the Internet unless explicitly used for exterior routing. External traceroutes will also fail reverse DNS lookup.

If unnumbered interfaces are kept, and the router-ID convention is used, it will probably be more stable to rely on an explicitly configured router ID rather than a default from a numbered interface address.

The situation becomes even more awkward if it is desired to use unnumbered interfaces over NBMA services such as Frame Relay. OSPF, for example, uses the IP address of numbered interfaces as a unique identifier for that interface. Since unnumbered interfaces do not have their own unique address, OSPF has not obvious way to identify these interfaces. A physical index (e.g., ifTable) could be used, but would have to be extended to have an entry for each logical entry (i.e., VC) multiplexed onto the physical interface.

8.4 Address Resolution

While mapping of IP addresses to LAN MAC addresses is usually done automatically by the router software, there will be cases where special mappings may be needed. For example, the MAC address used by router interfaces may be locally administered (i.e., set manually), rather than relying on the burnt-in hardware address. It may be part of a proprietary method that dynamically assigns MAC addresses to interfaces. In such cases, an IP address may be part of the MAC address configuration statements and will need to be changed.

Manual mapping to medium addresses will usually be needed for NBMA and switched media. When renumbering IP addresses, statements that map the IP address to frame relay DLCIs, X.121 addresses, SMDS and ATM addresses, telephone numbers, etc., will need to be changed to the new address. Local requirements may require a period of parallel operation, where the old and new IP addresses map to the same medium address.

8.5 Broadcast Handling

RFC1812 specifies that router interfaces MUST NOT forward limited broadcasts (i.e., to the all-ones destination address, 255.255.255.255). It is common, however, to have circumstances where a LAN segment is populated only by clients that communicate with key servers (e.g., DNS or DHCP) by sending limited broadcasts. Router interfaces can cope with this situation by translating the limited broadcast address to a directed broadcast address or a specific host address, which is legitimate to forward.

When limited address translation is done for serverless segments, and the new target address is renumbered, the translation rule must be reconfigured on every interface to a serverless segment. Be sure to recognize that a given segment might have a server from the perspective of one service (e.g., DHCP), but could be serverless for other services (e.g., NFS or DNS).

8.6 Dynamic Addressing Support

Routers can participate in dynamic addressing with RARP, DHCP, BOOTP, or PPP. In a renumbering effort, several kinds of changes may made to be made on routers participating in dynamic addressing.

If the router acts as a server for dynamic address assignment, the addresses it assigns will need to be renumbered. These might be specific addresses associated with MAC addresses or dialup ports, or could be a pool of addresses. Pools of addresses may be seen in pure IP environments, or in multiprotocol situations such as Apple MacIP.

If the router does not assign addresses, it may be responsible for forwarding address assignment requests to the appropriate server(s). If this is the case, there may be hard-coded references to the IP addresses of these servers, which may need to be changed as part of renumbering.

9. Filtering and Access Control

Routers may implement mechanisms to filter packets based on criteria other than next hop destination. Such mechanisms often are implemented differently for unicast packets (the most common case) or for multicast packets (including routing updates). Filtering rules may contain source and/or destination IP addresses that will need to change as part of a renumbering effort.

Filtering can be done to implement security policies or to control traffic. In either case, extreme care must be taken in changing the rules, to avoid leakage of sensitive information. denial of access to legitimate users, or network congestion.

Routers may implement logging of filtering events, typically denial of access. If logging is implemented, logging servers to which log events are sent preferably should be identified by DNS name. If the logging server is referenced by IP address, its address may need to change during renumbering. Care should be taken that critical auditing data is not lost during the address change.

9.1 Static Access Control Mechanisms

Router filters typically contain some number of include/exclude rules that define which packets to include in forwarding and which to exclude. These rules typically contain an address argument and some indication of the prefix length. This length indication could be a count, a subnet mask, or some other mask.

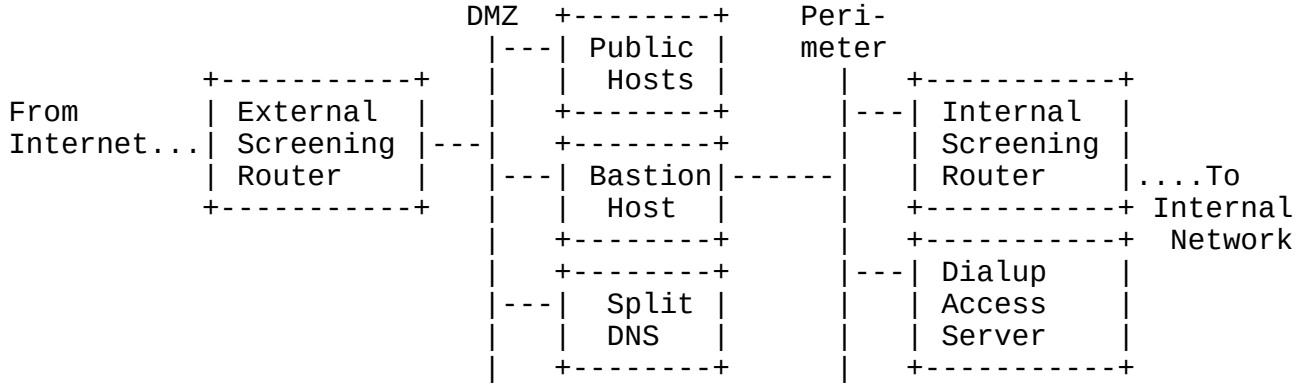
When renumbering, the address argument clearly has to change. It can be more subtle if the prefix length changes, because the length specification in the rule must change as well. Needs for such changes may be hard to recognize, because they apply to ranges of addresses that might be at a level of aggregation above the explicit renumbering operation.

RFC 1812 requires that address-based filtering allow arbitrary prefix lengths, but some hosts and routers might only allow classful prefixes.

9.2 Special Firewall Considerations

Routers are critical components of firewall systems. Architecturally, two router functions are described in firewall models, the external screening router between the outside and the "demilitarized zone (DMZ)," and the internal screening router between the inside and the "perimeter network." Between these two networks is the bastion host, in which reside various non-routing isolation and authentication functions, beyond the scope of this document.

One relevant aspect of the bastion host, however, is that it may do address translation or higher-layer mappings between differnt address spaces. If the "outside" address space (i.e., visible to the Internet) changes, this will mean that the outside screening router will need configuration changes. Since the outside screening router may be under the control of the ISP rather than the entrerprise, administrative coordination will be needed.



External screening routers typically have inbound access lists that block unauthorized traffic from the Internet, and outbound access lists that permit access only to DMZ servers and the bastion host. The inbound filters commonly block the Private Address Space, as well as address space from the enterprise’s internal network. If the internal network address changes, the inbound filters clearly will need to change.

If DMZ host addresses change, the corresponding outbound filters from the external screening host also will need to change. Internal screening routers permit access from the internal network to selected servers on the perimeter network, as well as to the bastion host itself. If the enterprise uses private address space internally, renumbering may not affect this router.

Another component of a firewall system is the "split DNS" server, which provides address mapping in relation to the globally visible parts of the

9.3 Dynamic Access Control Mechanisms

Certain access control services, such as RADIUS and TACACS+, may insert dynamically assigned access rules into router configurations. For example, a RADIUS database "contains a list of requirements which must be met to allow access for the user. This always includes verification of the password, but can also specify the client(s) or port(s) to which the user is allowed access. [Rigney]."

Configuration information dynamically communicated to the router may be in the form of filtering rules. Effectively, this authentication database becomes an extension of the router configuration database. Both these databases may need to change as part of a renumbering effort.

Another dynamic configuration issue arises when "stateful packet screening" on bastion hosts or routers is used to provide security for UDP-based services, or simply for IP. In such services, when an authorized packet leaves the local environment to go into an untrusted address space, a temporary filtering rule is established on the interface on which the response to this packet is expected. The rule typically has a lifetime of a single packet response. If these rules are defined in a database outside of the router, the rule database again is an extension of router configuration that must be part of the renumbering effort.

10. Interior Routing

This section deals with routing inside an enterprise, which generally follows, ignoring default routes, the rules:

1. Does a single potential route exist to a destination? If so, use it.
2. Is there more than one potential path to a destination? If so, use the path with the lowest end-to-end metric.
3. Are there multiple paths with equal lowest cost to the destination? If so, consider load balancing.

Most enterprises do not directly participate in global Internet routing mechanisms, the details of which are of concern to their service providers. The next section deals with those more complex exterior mechanisms.

10.1 Static Routes

During renumbering, the destination and/or next hop address of static routes may need to change. It may be necessary to restart routers or explicitly clear a routing table entry to force the changed static route to take effect.

10.2 RIP (Version 1 unless otherwise specified)

The Routing Information Protocol (RIP) has long been with us, as one of the first interior routing protocols. It still does that job in small networks, and also has been used for assorted functions that are not strictly part of interior routing. In this discussion, we will first deal with pure interior routing applications.

In a renumbering effort that involves classless addressing, RIPv1 may not be able to cope with the new addressing scheme. Officially, this protocol is Historic and should be avoided in new routing plans. Where legacy support requirements dictate it be retained, it is worthwhile to try to limit RIPv1 in "stub" parts of the network. Vendor-specific mechanisms may be available to interface RIPv1 to a classless environment.

As part of planning renumbering, strong consideration should be given to moving to RIPv2, OSPF, or other classless routing protocols as the primary means of interior routing. Doing so, however, may not remove the need to run RIP in certain parts of the enterprise.

RIP is widely implemented on hosts, where it may be used as a method of router discovery, or for load-balancing and fault tolerance when multiple routers are on a subnet. In these applications, RIP need not be the only routing protocol in the domain; RIP may be present only on stub subnets. Destination information from more capable routing protocols may be translated into RIP updates. While it is generally reasonable to minimize or remove RIP as part of a renumbering effort, be careful not to disable the ability of hosts to locate routers.

RIP is also used as a quasi-exterior routing mechanism between some customers and their ISPs, as a means simpler than BGP for the customer to announce routes to the provider.

10.3 OSPF

OSPF has several sensitivities to renumbering beyond those of simpler routing protocols. If router IDs are assigned to be part of the registered address space, they may need to be changed as part of the renumbering effort. It may be appropriate to use RFC 1918 private

address space for router IDs, as long as these can be looked up in a DNS server within the domain.

Summarization rules are likely to be affected by renumbering, especially if area boundaries change.

Special addressing techniques, such as unnumbered interfaces and physical interfaces with IP addresses in multiple subnets, may not be transparent to OSPF. Care should be exercised in their use, and their use definitely should be limited to intra-area scope.

If part of the renumbering motivation is the introduction of NBMA services, there can be numerous impacts on OSPF. Generally, the best way to minimize impact is to use separate subnets for each VC. By doing so, different OSPF costs can be assigned to different VCs, designated router configuration is not needed, etc.

10.4 IS-IS

IP prefixes are usually associated with IS-IS area definitions. If IP prefixes change, there may be a corresponding change in area definitions.

10.5 IGRP and Enhanced IGRP

When a change from IGRP to enhanced IGRP is part of a renumbering effort, the need to disable IGRP automatic route summarization needs to be considered. This is likely if classless addressing is being implemented.

Also be aware of the nuances of automatic redistribution between IGRP and EIGRP. The "autonomous system number," which need not be a true AS number but simply identifies a set of cooperating routers, must be the same on the IGRP and EIGRP processes for automatic redistribution to occur.

11. Exterior Routing

Exterior routes may be defined statically. If dynamic routing is involved, such routes are learned primarily from BGP. RIP is not infrequently used to allow ISPs to learn dynamically of new customer routes, although there are security concerns in such an approach. IGRP and EIGRP can be used to advertise external routes.

Renumbering that affects BGP-speaking routers can be complex, because it can require changes not only in the BGP routers of the local Autonomous System, but also require changes in routers of other AS and in routing registries. This will require careful administrative coordination.

If for no other reason than documentation, consider use of a routing policy notation [RIPE-181++] [RPSL] to describe exterior routing policies

11.1 Routing Registries/Routing Databases

Organizations who participate in exterior routing usually will have routing information not only in their routers, but in databases operated by registries or higher-level service providers (e.g., the Routing Arbiter).

If an ISP whose previous address space came from a different provider either renumbers into a different provider's address space, or gains a recognized block of its own, there may be administrative requirements to return the previously allocated addresses. These include changes in IN-ADDR.ARPA delegation, SWIP databases, etc., and need to be coordinated with the specific registries and providers involved. Not all registries and providers have the same policies.

If the enterprise is a registered Autonomous System and renumbers into a different address space, route objects with old prefixes in routing registries need to be deleted and route objects with new prefixes need to be added.

11.2 BGP--Own Organization

IP addressing information can be hard-coded in several aspects of a BGP speaker. These include:

1. Router ID
2. Peer router IP addresses
3. Advertised prefix lists
4. Route filtering rules

Some tools exist [RtConfig] for generating policy configuration part of BGP router configuration statements from the policies specified in RIPE-181 or RPSL.

11.3 BGP--Other AS

Other autonomous systems, including nonadjacent ones, can contain direct or indirect (e.g., aggregated) references to the above routing information. Tools exist that can do preliminary checking of connectivity to given external destinations [RADB].

12. Network Management

This section is intended to deal with those parts of network management that are intimately associated with routers, rather than a general discussion of renumbering and network management.

Methods used for managing routers include telnets to virtual console ports, SNMP, and TFTP. Network management scripts may contain hard-coded references to IP addresses supporting these services. In general, try to convert script references to IP addresses to DNS names.

A critical and complex problem will be converting SNMP databases, which are usually organized by IP address.

12.1 Configuration Management

Names and addresses of servers that participate in configuration management may need to change, as well as the contents of the configurations they provide. TFTP servers are commonly used here, as may be SNMP managers.

12.2 Name Resolution/Directory Services

During renumbering, it will probably be useful to assign DNS names to interfaces, virtual interfaces, and router IDs of routers. Remember that it is perfectly acceptable to identify internal interfaces with RFC1597/RFC1918 private addresses, as long as firewalling or other filtering prevent these addresses to be propagated outside the enterprise.

If dynamic addressing is used, dynamic DNS should be considered. Since this is under development, it may be appropriate to consider proprietary means to learn what addresses have been assigned dynamically, so they can be pinged or otherwise managed.

Also remember that some name resolution may be done by static tables that are part of router configurations. Changing the DNS entries, and even restarting the routers, will not change these.

12.3 Fault Management

Abnormal condition indications can be sent to several places that may have hard-coded IP addresses, such as SNMP trap servers, syslogd servers, etc.

It should be remembered that large bursts of transient errors may be caused as part of address cutover in renumbering. Be aware that these bursts might overrun the capacity of logging files, and conceivably cause loss of auditing information. Consider enlarging files or otherwise protecting them during cutover.

12.4 Performance Management

Performance information can be recorded in routers themselves, and retrieved by network management scripts. Other performance information may be sent to syslogd, or be kept in SNMP data bases.

Load-generating scripts used for performance testing may contain hard-coded IP addresses. Look carefully for scripts that contain executable code for generating ranges of test addresses. Such scripts may, at first examination, not appear to contain explicit IP addresses. They may, for example, contain a "seed" address used with an incrementing loop.

12.5 Accounting Management

Accounting records may be sent periodically to syslogd or as SNMP traps. Alternatively, the SNMP manager or other management applications may periodically poll accounting information in routers, and thus contain hard-coded IP addresses.

12.6 Security Management

Security management includes logging, authentication, filtering, and access control. Routers can have hard-coded references to servers for any of these functions.

In addition, routers commonly will contain filters containing security-related rules. These rules are apt to need explicit recoding, since they tend to operate on a bit level.

Some authentication servers and filtering mechanisms may dynamically update router filters.

12.7 Time Service

Hard-coded references to NTP servers should be changed to DNS when possible, and renumbered otherwise.

13. IP and Protocol Encapsulation

IP packets can be routed to provide connectivity for non-IP protocols, or for IP traffic with addresses not consistent with the active routing environment. Such encapsulating functions usually have a tunneling model, where an end-to-end connection between two "passenger" protocol addresses is mapped to a pair of endpoint IP addresses. Generic Route Encapsulation is a representative means of such tunneling [RFC1701, RFC1702].

13.1 Present

Renumbering of the primary IP environment often does not mean that passenger protocol addresses need to change. In fact, such protocol encapsulation for IP traffic may be a very viable method for handling legacy systems that cannot easily be renumbered. For this legacy case, the legacy IP addresses can be tunneled over the renumbered routing environment.

Also note that IP may be a passenger protocol over non-IP systems using IPX, AppleTalk, etc.

13.2 Future

Tunneling mechanisms are fundamental for the planned transition of IPv4 to IPv6. As part of an IPv4 renumbering effort, it may be worthwhile to reserve some address space for future IPv6 tunnels.

While there are clear and immediate needs for IPv4 renumbering, there may be cases where IPv4 renumbering can be deferred for some months or years. If the effort is deferred, it may be prudent at that time to consider if available IPv6 implementations or tunneling mechanisms form viable alternatives to IPv4 renumbering. It might be appropriate to renumber certain parts of the existing IPv4 space directly into the IPv6 space. Tools for this purpose are experimental at the time this document was written.

14. Security Considerations

Routers are critical parts of firewalls, and are otherwise used for security enforcement. Configuration errors made during renumbering can expose systems to malicious intruders, or deny service to authorized users. The most critical area of concern is that filters are configured properly for old and new address, but other numbers also can impact security, such as pointers to authentication, logging, and DNS servers.

During a renumbering operation, it may be appropriate to introduce authentication mechanisms for routing updates.

15. Planning and Implementing the Renumbering

Much of the effort in renumbering will be on platforms other than routers. Nevertheless, routers are a key part of any renumbering effort.

Step 1--Inventory of affected addresses and names.

Step 2--Design any needed topological changes. If temporary address space, network address translators, etc., are needed, obtain them.

Step 3--Install and test changes to make the network more renumbering-friendly. These include making maximum use of default routes and summarization, while minimizing address-based references to servers.

Step 4--Plan the actual renumbering. Should it be phased or total? Can it be done in a series of stub network renumberings, possibly with secondary addresses on core routers? Is NAT appropriate? If so, how is it to be used?

What is your plan of retreat if major problems develop? Make a distinction between problems in the routing system and unforeseen problems in hosts affected by renumbering.

Step 5--Take final backups.

Step 6--Cut over addresses and names, or begin coexistence.

Make needed DNS and firewall changes.
Restart routers and servers as appropriate.
Clear caches as appropriate.
Remember static name definitions in routers may not be affected by DNS changes.
Coordinate changes with affected external organizations (e.g., ISPs, business partners, routing registries)

Step 6--Document what isn't already documented. Make notes to help the person who next needs to renumber. Share experience with the PIER working group or other appropriate organizations.

15.1 Applying Changes

Renumbering changes should be introduced with care into operational networks. For changes to take effect, it is likely that at least interfaces and probably routers will have to be restarted. The sequence in which changes are applied must be carefully thought out, to avoid loss of connectivity, routing loops, etc., while the renumbering is in process.

See case studies presented to the PIER Working Group for examples of operational renumbering experience. Organizations that have undergone renumbering have had to pay careful attention to informing users of possible outages, coordinating changes among multiple sites, etc. It will be an organization-specific decision whether router renumbering can be implemented incrementally or must be done in a major "flag day" conversion.

Before making significant changes, TAKE BACKUPS FIRST of all router configuration files, DNS zone files, and other information that documents your present environment.

15.2 Configuration Control

Operationally, an important part of renumbering and continued numbering maintenance is not to rely on local router interfaces, either command language interpreter, menu-based, or graphic, for the more sophisticated aspects of configuration, but to do primary configuration (and changes) on an appropriate workstation. On a workstation or other general-purpose computer, configuration files can be edited, listed, processed with macro processors and other tools, etc. Source code control tools can be used on the router configuration files.

Once the configuration file is defined for a router, mechanisms for loading it vary with the specific router implementation. In general, these will include a file transfer using FTP or TFTP into a configuration file on the router, SNMP SET commands, or logging in to the router as a remote console and using a terminal emulator to upload the new configuration under the router's interactive configuration mode. Original acquisition of legacy configuration files is the inverse of this process.

15.3 Avoiding Instability

Routing processes tend towards instability when they suddenly need to handle very large numbers of updates, as might occur if a "flag day" cutover is not carefully planned. A general guideline is to make changes in only one part of a routing hierarchy at a time.

Routing system design should be hierarchical in all but the smallest domains. While OSPF and IS-IS have explicit area-based hierarchical models, hierarchical principles can be used with most implementations of modern routing protocols. Hierarchy can be imposed on a protocol such as RIPv2 or EIGRP by judicious use of route aggregation, routing advertisement filtering, etc.

Respecting a hierarchical model during renumbering means such things as renumbering a "stub" part of the routing domain and letting that part stabilize before changing other parts. Alternatively, it may be reasonable to add new numbers to the backbone, allowing it to converge, renumbering stubs, and then removing old numbers from the backbone. Obviously, these guidelines are most practical when there is a distinct old and new address space without overlaps. If a block of addresses must simply be reassigned, some loss of service must be expected.

16. Acknowledgments

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