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A Set of Possible Requirements for a Future Routing Architecture
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Status of this Memo

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Abstract

The requirements for routing architectures described in this document were produced by two sub-groups under the IRTF Routing Research Group in 2001, with some editorial updates up to 2006. The two sub-groups worked independently, and the resulting requirements represent two separate views of the problem and of what is required to fix the problem. This document may usefully serve as part of the recommended

reading for anyone who works on routing architecture designs for the Internet in the future.
The document is published with the support of the IRTF RRG as a record of the work completed at that time, but with the understanding that it does not necessarily represent either the latest technical understanding or the technical consensus of the research group at the date of publication.

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1. Background

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In 2001, the IRTF Routing Research Group (IRTF RRG) chairs, Abha Ahuja and Sean Doran, decided to establish a sub-group to look at requirements for inter-domain routing (IDR). A group of well known routing experts was assembled to develop requirements for a new routing architecture. Their mandate was to approach the problem starting from a blank sheet. This group was free to take any approach, including a revolutionary approach, in developing requirements for solving the problems they saw in inter-domain routing.

Simultaneously, an independent effort was started in Sweden with a similar goal. A team, calling itself Babylon, with participation from vendors, service providers, and academia, assembled to understand the history of inter-domain routing, to research the problems seen by the service providers, and to develop a proposal of requirements for a follow-on to the current routing architecture. This group's remit required an evolutionary approach starting from current routing architecture and practice. In other words the group limited itself to developing an evolutionary strategy. The Babylon group was later folded into the IRTF RRG as Sub-Group B to distinguish it from the original RRG Sub-group A.

One of the questions that arose while the groups were working in isolation was whether there would be many similarities between their sets of requirements. That is, would the requirements that grew from a blank sheet of paper resemble those that started with the evolutionary approach? As can be seen from reading the two sets of requirements, there were many areas of fundamental agreement but some areas of disagreement.

There were suggestions within the RRG that the two teams should work together to create a single set of requirements. Since these requirements are only guidelines to future work, however, some felt that doing so would risk losing content without gaining any particular advantage. It is not as if any group, for example the IRTF RRG or the IETF Routing Area, was expected to use these requirements as written and to create an architecture that met these requirements. Rather, the requirements were in practice strong recommendations for a way to proceed in creating a new routing architecture. In the end the decision was made to include the results of both efforts, side by side, in one document.

This document contains the two requirement sets produced by the teams. The text has received only editorial modifications; the requirements

themselves have been left unaltered. Whenever the editors felt that conditions had changed in the few years since the text was written, an editors' note has been added to the text.
In reading this document it is important to keep in mind that all of these requirements are suggestions, which are laid out to assist those interested in developing new routing architectures. It is also important to remember that, while the people working on these suggestions have done their best to make intelligent suggestions, there are no guarantees. So a reader of this document should not treat what it says as absolute, nor treat every suggestion as necessary. No architecture is expected to fulfill every 'requirement.' Hopefully, though, future architectures will consider what is offered in this document.
The IRTF RRG supported publication of this document as a historical record of the work completed on the understanding that it does not necessarily represent either the latest technical understanding or the technical consensus of the research group at the time of publication. The document has had substantial review by members of the two teams, other members of the IRTF RRG and additional experts over the years. Finally, this document does not make any claims that it is possible to have a practical solution that meets all the listed requirements.

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2. Results from Group A

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This section presents the results of the work done by Sub-Group A of the IRTF-RRG during 2001- 2002. The work originally appeared under the title: "Requirements For a Next Generation Routing and Addressing Architecture" and was edited by Frank Kastenholz.

2.1. Group A - Requirements For a Next Generation Routing and Addressing Architecture

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The requirements presented in this section are not presented in any particular order.

2.1.1. Architecture

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The new routing and addressing protocols, data structures, and algorithms need to be developed from a clear, well thought out, documented, architecture.

The new routing and addressing system must have an architectural specification which describes all of the routing and addressing elements, their interactions, what functions the system performs, and how it goes about performing them. The architectural specification does not go into issues such as protocol and data structure design.
The architecture should be agnostic with regard to specific algorithms and protocols.
Doing architecture before doing detailed protocol design is good engineering practice. This allows the architecture to be reviewed and commented upon, with changes made as necessary, when it is still easy to do so. Also, by producing an architecture, the eventual users of the protocols (the operations community) will have a better understanding of how the designers of the protocols meant them to be used.

2.1.2. Separable Components

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The architecture must place different functions into separate components.
Separating functions, capabilities, and so forth, into individual components and making each component "stand alone" is generally considered by system architects to be "A Good Thing". It allows individual elements of the system to be designed and tuned to do their jobs "very well". It also allows for piecemeal replacement and upgrading of elements as new technologies and algorithms become available.
The architecture must have the ability to replace or upgrade existing components and to add new ones, without disrupting the remaining parts of the system. Operators must be able to roll out these changes and additions incrementally (i.e., no "flag days"). These abilities are needed to allow the architecture to evolve as the Internet changes.
The architecture specification shall define each of these components, their jobs, and their interactions.
Some thoughts to consider along these lines are

- Making topology and addressing separate subsystems. This may allow highly optimized topology management and discovery without constraining the addressing structure or physical topology in unacceptable ways.

- Separate "fault detection and healing" from basic topology. From Mike O'Dell:

  > "Historically the same machinery is used for both. While attractive for many reasons, the availability of exogenous topology information (i.e., the intended topology) should, it seems, make some tasks easier than the general case of starting with zero knowledge. It certainly helps with

> recovery in the case of constraint satisfaction. In fact, the intended topology is a powerful way to state certain kinds of policy." [ODell01] (O'Dell, M., “Private Communication,” 2001.)

- Making policy definition and application a separate subsystem, layered over the others.

The architecture should also separate topology, routing, and addressing from the application that uses those components. This implies that applications such as policy definition, forwarding, and circuit and tunnel management are separate subsystems layered on top of the basic topology, routing, and addressing systems.

2.1.3. Scalable

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Scaling is the primary problem facing the routing and addressing architecture today. This problem must be solved and it must be solved for the long term.
The architecture must support a large and complex network. Ideally, it will serve our needs for the next 20 years. Unfortunately:

1. we do not know how big the Internet will grow over that time, and

2. the architecture developed from these requirements may change the fundamental structure of the Internet and therefore its growth patterns. This change makes it difficult to predict future growth patterns of the Internet.

As a result, we can't quantify the requirement in any meaningful way. Using today's architectural elements as a mechanism for describing things, we believe that the network could grow to:

1. tens of thousands of AS's

   > Editors' Note: As of 2005, this level had already been reached.

2. tens to hundreds of millions of prefixes, during the lifetime of this architecture.

These sizes are given as a 'flavor' for how we expect the Internet to grow. We fully believe that any new architecture may eliminate some current architectural elements and introduce new ones.
A new routing and addressing architecture designed for a specific network size would be inappropriate. First, the cost of routing

calculations is based only in part on the number of AS's or prefixes in the network. The number and locations of the links in the network are also significant factors. Second, past predictions of Internet growth and topology patterns have proven to be wildly inaccurate so developing an architecture to a specific size goal would at best be shortsighted.

> Editors' note: At the time of these meetings, the BGP statistics kept at sites such as www.routeviews.org either did not exist or had been running for only a few months. After 5 years of recording public Internet data trends in AS growth, routing table growth can be observed (past) with some short term prediction. As each year of data collection continues the ability to observe and predict trends improves. This architecture work pointed out the need for such statistics to improve future routing designs.

Therefore we will not make the scaling requirement based on a specific network size. Instead, the new routing and addressing architecture should have the ability to constrain the increase in load (CPU, memory space and bandwidth, and network bandwidth) on ANY SINGLE ROUTER to be less than these specific functions:

1. The computational power and memory sizes required to execute the routing protocol software and to contain the tables must grow more slowly than hardware capabilities described by Moore's Law, doubling every 18 months. Other observations indicate that memory sizes double every 2 years or so.

2. Network bandwidth and latency are some key constraints on how fast routing protocol updates can be disseminated (and therefore how fast the routing system can adapt to changes). Raw network bandwidth seems to quadruple every 3 years or so. However, it seems that there are some serious physics problems in going faster than 40Gbit/s (OC768); we should not expect raw network link speed to grow much beyond OC768. On the other hand, for economic reasons, large swathes of the core of the Internet will still operate at lower speeds, possibly as slow as DS3.

   > Editors' Note: Technology is running ahead of imagination and higher speeds are already common.

   Furthermore, in some sections of the Internet even lower speed links are found. Corporate access links are often T1, or slower. Low-speed radio links exist. Intra-domain links may be T1 or fractional-T1 (or slower).

   Therefore, the architecture must not make assumptions about the bandwidth available.

3. The speeds of high-speed RAMs (SRAMs, used for caches and the like) are growing, though slowly. Because of their use in caches and other very specific applications, these RAMs tend to be small, a few megabits, and the size of these RAMs is not increasing very rapidly.

   On the other hand, the speed of "large" memories (DRAMs) is increasing even slower than that for the high speed RAMs. This is because the development of these RAMs is driven by the PC market, where size is very important, and low speed can be made up for by better caches.

   Memory access rates should not be expected to increase significantly.

   > Editors' Note: Various techniques have significantly increased memory bandwidth. 800MHz is now possible, compared with less than 100MHz in year 2000. This does not, however, contradict the next paragraph, but rather just extends the timescales somewhat.

The growth in resources available to any one router will eventually slow down. It may even stop. Even so, the network will continue to grow. The routing and addressing architecture must continue to scale in even this extreme condition. We cannot continue to add more computing power to routers forever. Other strategies must be available. Some possible strategies are hierarchy, abstraction, and aggregation of topology information.

2.1.4. Lots of Interconnectivity

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The new routing and addressing architecture must be able to cope with a high degree of interconnectivity in the Internet. That is, there are large numbers of alternate paths and routes among the various elements. Mechanisms are required to prevent this interconnectivity (and continued growth in interconnectivity) from causing tables, compute time, and routing protocol traffic to grow without bound. The "cost" to the routing system of an increase in complexity must be limited in scope; sections of the network that do not see, or do not care about, the complexity ought not pay the cost of that complexity.
Over the past several years, the Internet has seen an increase in interconnectivity. Individual end sites (companies, customers, etc.), ISPs, exchange points, and so on, all are connecting to more "other things". Companies multi-home to multiple ISPs, ISPs peer with more ISPs, and so on. These connections are made for many reasons, such as getting more bandwidth, increased reliability and availability, policy, and so on. However, this increased interconnectivity has a price. It

leads to more scaling problems as it increases the number of AS paths in the networks.
Any new architecture must assume that the Internet will become a denser mesh. It must not assume, nor can it dictate, certain patterns or limits on how various elements of the network interconnect.
Another facet of this requirement is that there may be multiple valid, loop free, paths available to a destination. See Section 2.1.7 (Multi-path) for a further discussion.
We wryly note that one of the original design goals of IP was to support a large, heavily interconnected, network, which would be highly survivable (such as in the face of a nuclear war).

2.1.5. Random Structure

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The routing and addressing architecture must not place any constraints on or make assumptions about the topology or connectedness of the elements comprising the Internet. The routing and addressing architecture must not presume any particular network structure. The network does not have a "nice" structure. In the past we used to believe that there was this nice "backbone/tier-1/tier-2/end-site" sort of hierarchy. This is not so. Therefore, any new architecture must not presume any such structure.
Some have proposed that a geographic addressing scheme be used, requiring exchange points to be situated within each geographic 'region'. There are many reasons why we believe this to be a bad approach, but those arguments are irrelevant. The main issue is that the routing architecture should not presume a specific network structure.

2.1.6. Multi-homing

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The architecture must provide multi-homing for all elements of the Internet. That is, multi-homing of hosts, subnetworks, end- sites, "low-level" ISPs, and backbones (i.e., lots of redundant interconnections) must be supported. Among the reasons to multi-home are reliability, load sharing, and performance tuning.
The term "multi-homing" may be interpreted in its broadest sense -- one "place" has multiple connections or links to another "place".
The architecture must not limit the number of alternate paths to a multi-homed site.
When multi-homing is used, it must be possible to use one, some (more than one but less than all), or all of the available paths to the multi-homed site. The multi-homed site must have the ability to declare which path(s) are used and under what conditions (for example, one path

may be declared "primary" and the other "backup" and to be used only when the primary fails).
A current problem in the Internet is that multi-homing leads to undue increases in the size of the BGP routing tables. The new architecture must support multi-homing without undue routing table growth.

2.1.7. Multi-path

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As a corollary to multi-homing, the architecture must allow for multiple paths from a source to a destination to be active at the same time. These paths need not have the same attributes. Policies are to be used to disseminate the attributes and to classify traffic for the different paths.
There must be a rich "language" for specifying the rules for classifying the traffic and assigning classes of traffic to different paths (or prohibiting it from certain paths). The rules should allow traffic to be classified based upon at least the following:

- IPv6 FlowIDs,
- DSCP values,
- source and/or destination prefixes, or
- random selections at some probability.

A mechanism is needed that allows operators to plan and manage the traffic load on the various paths. To start, this mechanism can be semi-automatic or even manual. Eventually it ought to become fully automatic.
When multi-path forwarding is used, options must be available to preserve packet ordering where appropriate (such as for individual TCP connections).
Please refer to Section 2.2.7 (Dynamic Load Balancing) for a discussion of dynamic load-balancing and management over multiple paths.

2.1.8. Convergence

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The speed of convergence (also called the "stabilization time") is the time it takes for a router's routing processes to reach a new, stable, "solution" (i.e., forwarding information base) after a change someplace in the network. In effect, what happens is that the output of the routing calculations stabilizes -- the Nth iteration of the software produces the same results as the N-1th iteration.

The speed of convergence is generally considered to be a function of the number of subnetworks in the network and the amount of connections between those networks. As either number grows, the time it takes to converge increases.
In addition, a change can "ripple" back and forth through the system. One change can go through the system, causing some other router to change its advertised connectivity, causing a new change to ripple through. These oscillations can take a while to work their way out of the network. It is also possible that these ripples never die out. In this situation the routing and addressing system is unstable; it never converges.
Finally, it is more than likely that the routers comprising the Internet never converge simply because the Internet is so large and complex. Assume it takes S seconds for the routers to stabilize on a solution for any one change to the network. Also assume that changes occur, on average, every C seconds. Because of the size and complexity of the Internet, C is now less than S. Therefore, if a change, C1, occurs at time T, the routing system would stabilize at time T+S, but a new change, C2, will occur at time T+C, which is before T+S. The system will start processing the new change before it's done with the old.
This is not to say that all routers are constantly processing changes. The effects of changes are like ripples in a pond. They spread outward from where they occur. Some routers will be processing just C1, others C2, others both C1 and C2, and others neither.
We have two separate scopes over which we can set requirements with respect to convergence:

1. Single Change
   In this requirement a single change of any type (link addition or deletion, router failure or restart, etc.) is introduced into a stabilized system. No additional changes are introduced. The system must re-stabilize within some measure of bounded time. This requirement is a fairly abstract one as it would be impossible to test in a real network. Definition of the time constraints remains an open research issue.

2. System-wide
   Defining a single target for maximum convergence time for the real Internet is absurd. As we mentioned earlier, the Internet is large enough and diverse enough so that it is quite likely that new changes are introduced somewhere before the system fully digests old ones.

So, the first requirement here is that there must be mechanisms to limit the scope of any one change's visibility and effects. The number of routers that have to perform calculations in response to a change is kept small, as is the settling time.
The second requirement is based on the following assumptions:

-

  the scope of a change's visibility and impact can be limited. That is, routers within that scope know of the change and recalculate their tables based on the change. Routers outside of the scope don't see it at all.

- Within any scope, S, network changes are constantly occurring and the average inter-change interval is Tc seconds.

- There are Rs routers within scope S.

- A subset of the destinations known to the routers in S, Ds, are impacted by a given change.

- We can state that for Z% of the changes, within Y% of Tc seconds after a change, C, X% of the Rs routers have their routes to Ds settled to a useful answer (useful meaning that packets can get to Ds, though perhaps not by the optimal path -- this allows some 'hunting' for the optimal solution)
  X, Y, and Z are yet to be defined. Their definition remains a research issue.

This requirement implies that the scopes can be kept relatively small in order to minimize Rs and maximize Tc.
The growth rate of the convergence time must not be related to the growth rate of the Internet as a whole. This implies that the convergence time either

1. not be a function of basic network elements (such as prefixes and links/paths), and/or

2. that the Internet be continuously divisible into chunks that limit the scope and effect of a change, thereby limiting the number of routers, prefixes, links, and so on, involved in the new calculations.

2.1.9. Routing System Security

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The security of the Internet's routing system is paramount. If the routing system is compromised or attacked, the entire Internet can fail. This is unacceptable. Any new architecture must be secure. Architectures by themselves are not secure. It is the implementation of an architecture; its protocols, algorithms, and data structures, that are secure. These requirements apply primarily to the implementation. The architecture must provide the elements that the implementation

needs to meet these security requirements. Also, the architecture must not prevent these security requirements from being met.
Security means different things to different people. In order for this requirement to be useful, we must define what we mean by security. We do this by identifying the attackers and threats we wish to protect against. They are:

Masquerading The system, including its protocols, must be secure against intruders adopting the identity of other known, trusted, elements of the routing system and then using that position of trust for carrying out other attacks. Protocols must use cryptographically strong authentication.

Denial of Service (DoS) Attacks The architecture and protocols should be secure against DoS attacks directed at the routers.

The new architecture and protocols should provide as much information as it can to allow administrators to track down sources of DoS and Distributed DOS (DDoS) attacks.

No Bad Data Any new architecture and protocols must provide protection against the introduction of bad, erroneous, or misleading, data by attackers. Of particular importance, an attacker must not be able to redirect traffic flows, with the intent of

- directing legitimate traffic away from a target, causing a denial-of-service attack by preventing legitimate data from reaching its destination,
- directing additional traffic (going to other destinations which are 'innocent bystanders') to a target, causing the target to be overloaded, or
- directing traffic addressed to the target to a place where the attacker can copy, snoop, alter, or otherwise affect the traffic.

Topology Hiding Any new architecture and protocols must provide mechanisms to allow network owners to hide the details of their internal topologies, while maintaining the desired levels of service connectivity and reachability.

Privacy By "privacy" we mean privacy of the routing protocol exchanges between routers.

When the routers are on point-to-point links, with routers at each end, there may not be any need to encrypt the routing protocol traffic as the possibility of a third party intercepting the traffic is limited though not impossible. We do believe,

> however, that it is important to have the ability to protect routing protocol traffic in two cases:
>
> 1. When the routers are on a shared network, it is possible that there are hosts on the network that have been compromised. These hosts could surreptitiously monitor the protocol traffic.
>
> 2. When two routers are exchanging information "at a distance" (over intervening routers and, possibly, across administrative domain boundaries). In this case, the security of the intervening routers, links, and so on, cannot be assured. Thus, the ability to encrypt this traffic is important.
>
> Therefore, we believe that the option to encrypt routing protocol traffic is required.
>
> **Data Consistency** A router should be able to detect and recover from any data that is received from other routers which is inconsistent. That is, it must not be possible for data from multiple routers, none of which is malicious, to "break" another router.

Where security mechanisms are provided, they must use methods that are considered to be cryptographically secure (e.g., using cryptographically strong encryption and signatures -- no clear text passwords!).
Use of security features should not be optional (except as required above). This may be "social engineering" on our part, but we believe it to be necessary. If a security feature is optional, the implementation of the feature must default to the "secure" setting.

2.1.10. End Host Security

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The architecture must not prevent individual host-to-host communications sessions from being secured (i.e., it cannot interfere with things like IPsec).

2.1.11. Rich Policy

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Before setting out Policy requirements, we need to define the term. Like "security", "policy" means many things to many people. For our

purposes, policy is the set of administrative influences that alter the path determination and next-hop selection procedures of the routing software.
The main motivators for influencing path and next-hop selection seem to be transit rules, business decisions, and load management.
The new architecture must support rich policy mechanisms. Furthermore, the policy definition and dissemination mechanisms should be separated from the network topology and connectivity dissemination mechanisms.
Policy provides input to and controls the generation of the forwarding table and the abstraction, filtering, aggregation, and dissemination of topology information.
Note that if the architecture is properly divided into subsystems then at a later time, new policy subsystems that include new features and capabilities could be developed and installed as needed.
We divide the general area of policy into two sub-categories, routing information and traffic control. Routing Information Policies control what routing information is disseminated or accepted, how it is disseminated, and how routers determine paths and next-hops from the received information. Traffic Control Policies determine how traffic is classified and assigned to routes.

2.1.11.1. Routing Information Policies

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There must be mechanisms to allow network administrators, operators, and designers to control receipt and dissemination of routing information. These controls include, but are not limited to:

- Selecting to which other routers routing information will be transmitted.
- Specifying the "granularity" and type of transmitted information. The length of IPv4 prefixes is an example of "granularity".
- Selection and filtering of topology and service information that is transmitted. This gives different 'views' of internal structure and topology to different peers.
- Selecting the level of security and authenticity for transmitted information.
- Being able to cause the level of detail that is visible for some portion of the network to reduce the farther you get from that part of the network.
- Selecting from whom routing information will be accepted. This control should be "provisional" in the sense of "accept routes from "foo" only if there are no others available".

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  Accepting or rejecting routing information based on the path the information traveled (using the current system as an example, this would be filtering routes based on an AS appearing anywhere in the AS path). This control should be "use only if there are no other paths available".

- Selecting the desired level of "granularity" for received routing information (this would include, but is not limited to, things similar in nature to the prefix-length filters widely used in the current routing and addressing system).

- Selecting the level of security and authenticity of received information in order for that information to be accepted.

- Determining the treatment of received routing information based on attributes supplied with the information.

- Applying attributes to routing information that is to be transmitted and then determining treatment of information (e.g., sending it "here" but not "there") based on those tags.

- Selection and filtering of topology and service information that is received.

2.1.11.2. Traffic Control Policies

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The architecture should provide mechanisms that allow network operators to manage and control the flow of traffic. The traffic controls should include, but are not limited to:
- The ability to detect and eliminate congestion points in the network (by re-directing traffic around those points)
- The ability to develop multiple paths through the network with different attributes and then assign traffic to those paths based on some discriminators within the packets (discriminators include, but are not limited to, IP Addresses or prefixes, IPv6 flow ID, DSCP values, and MPLS labels)
- The ability to find and use multiple, equivalent, paths through the network (i.e., they would have the "same" attributes) and allocate traffic across the paths.
- The ability to accept or refuse traffic based on some traffic classification (providing, in effect, transit policies).
Traffic classification must at least include the source and destination IP addresses (prefixes) and the DSCP value. Other fields may be supported, such as

- Protocol and port based functions,
- DSCP/QoS tuple (such as ports)
- Per-host operations (i.e., /32s for IPv4 and /128s for IPv6),
- Traffic matrices (e.g., traffic from prefix X and to prefix Y).

2.1.12. Incremental Deployment

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The reality of the Internet is that there can be no Internet wide cut over from one architecture and protocol to another. This means that any new architecture and protocol must be incrementally deployable; ISPs must be able to set up small sections of the new architecture, check it out, and then slowly grow the sections. Eventually, these sections will "touch" and "squeeze out" the old architecture.
The protocols that implement the architecture must be able to interoperate at "production levels" with currently existing routing protocols. Furthermore, the protocol specifications must define how the interoperability is done.
We also believe that sections of the Internet will never convert over to the new architecture. Thus, it is important that the new architecture and its protocols be able to interoperate with "old architecture" regions of the network indefinitely.
The architecture's addressing system must not force existing address allocations to be redone: no renumbering!

2.1.13. Mobility

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There are two kinds of mobility; host mobility and network mobility. Host mobility is when an individual host moves from where it was to where it is. Network mobility is when an entire network (or subnetwork) moves.
The architecture must support network level mobility. Please refer to Section 2.2.9 (Host Mobility) for a discussion of Host Mobility.

> Editor's Note: Since the time of this work, the NEMO extensions to Mobile IP [RFC3963] (Devarapalli, V., Wakikawa, R., Petrescu, A., and P. Thubert, “Network Mobility (NEMO) Basic Support Protocol,” January 2005.) to accommodate mobile networks have been developed.

2.1.14. Address Portability

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One of the big "hot items" in the current Internet political climate is portability of IP addresses (both v4 and v6). The short explanation is that people do not like to renumber when changing connection point or provider and do not trust automated renumbering tools.
The architecture must provide complete address portability.

2.1.15. Multi-Protocol

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The Internet is expected to be "multi-protocol" for at least the next several years. IPv4 and IPv6 will co-exist in many different ways during a transition period. The architecture must be able to handle both IPv4 and IPv6 addresses. Furthermore, protocols that supplant IPv4 and IPv6 may be developed and deployed during the lifetime of the architecture. The architecture must be flexible and extensible enough to handle new protocols as they arise.
Furthermore, the architecture must not assume any given relationships between a topological element's IPv4 address and its IPv6 address. The architecture must not assume that all topological elements have IPv4 addresses/prefixes, nor can it assume that they have IPv6 addresses/prefixes.
The architecture should allow different paths to the same destination to be used for different protocols, even if all paths can carry all protocols.
In addition to the addressing technology, the architecture need not be restricted to only packet based multiplexing/demultiplexing technology (such as IP); support for other multiplexing/ demultiplexing technologies may be added.

2.1.16. Abstraction

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The architecture must provide mechanisms for network designers and operators to:

- Group elements together for administrative control purposes,
- Hide the internal structure and topology of those groupings for administrative and security reasons,
- Limit the amount of topology information that is exported from the groupings in order to control the load placed on external routers,
- Define rules for traffic transiting or terminating in the grouping.

The architecture must allow the current Autonomous System structure to be mapped into any new abstraction schemes.
Mapping mechanisms, algorithms, and techniques must be specified.

2.1.17. Simplicity

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The architecture must be simple enough so that someone who is extremely knowledgeable in routing and who is skilled at creating straightforward and simple explanations can explain all the important concepts in less than an hour.
This criterion has been chosen since developing an objective measure of complexity for an architecture can be very difficult and is out of scope for this document.
The requirement is that the routing architecture be kept as simple as possible. This requires careful evaluation of possible features and functions with a merciless weeding out of those that "might be nice" but are not necessary.
By keeping the architecture simple, the protocols and software used to implement the architecture are simpler. This simplicity in turn leads to:

1. Faster implementation of the protocols. If there are fewer bells and whistles, then there are fewer things that need to be implemented.
2. More reliable implementations. With fewer components, there is less code, reducing bug counts, and fewer interactions between components that could lead to unforeseen and incorrect behavior.

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2.1.18. Robustness

The architecture, and the protocols implementing it, should be robust. Robustness comes in many different flavors. Some considerations with regard to robustness include (but are not limited to):

- Continued correct operation in the face of:
  - *Defective (even malicious) trusted routers.
  - *Network failures. Whenever possible, valid alternate paths are to be found and used.
- Failures must be localized. That is, the architecture must limit the "spread" of any adverse effects of a misconfiguration or failure. Badness must not spread.

Of course, the general robustness principle of being liberal in what's accepted and conservative in what's sent must also be applied.

> **Original Editor's note:** Some of the contributors to this section have argued that robustness is an aspect of Security. I have exercised editor's discretion by making it a separate section. The reason for this is that to too many people "security" means "protection from break-ins" and "authenticating and encrypting data". This requirement goes beyond those views.

2.1.19. Media Independence

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While it is an article of faith that IP operates over a wide variety of media (such as Ethernet, X.25, ATM, and so on), IP routing must take an agnostic view toward any "routing" or "topology" services that are offered by the medium over which IP is operating. That is, the new architecture must not be designed to integrate with any media-specific topology management or routing scheme.
The routing architecture must assume, and must work over, the simplest possible media.
The routing and addressing architecture can certainly make use of lower-layer information and services, when and where available, and to the extent that IP routing wishes.

TOC

2.1.20. Stand-alone

The routing architecture and protocols must not rely on other components of the Internet (such as DNS) for their correct operation. Routing is the fundamental process by which data "finds its way around the Internet" and most, if not all, of those other components rely on routing to properly forward their data. Thus, Routing cannot rely on any Internet systems, services or capabilities that in turn rely on Routing. If it did, a dependency loop would result.

2.1.21. Safety of Configuration

TOC

The architecture, protocols, and standard implementation defaults must be such that a router installed "out of the box" with no configuration, etc., by the operators will not cause "bad things" to happen to the rest of the routing system (e.g., no dial-up customers advertising routes to 18/8!)

2.1.22. Renumbering

TOC

The routing system must allow topological entities to be renumbered.

2.1.23. Multi-prefix

TOC

The architecture must allow topological entities to have multiple prefixes (or the equivalent under the new architecture).

2.1.24. Cooperative Anarchy

TOC

> **As** RFC1726[RFC1726] (Partridge, C. and F. Kastenholz, “Technical Criteria for Choosing IP The Next Generation (IPng),” Dec 1994.) said: "A major contributor to the Internet's success is the fact that there is no single, centralized, point of control or promulgator of policy for the entire network. This allows individual constituents of the network to tailor their own networks, environments, and policies to suit their own needs. The individual constituents must cooperate only to the degree necessary to ensure that they interoperate."

This decentralization, called "cooperative anarchy", is still a key feature of the Internet today. The new routing architecture must retain this feature. There can be no centralized point of control or promulgator of policy for the entire Internet.

2.1.25. Network Layer Protocols and Forwarding Model

TOC

For the purposes of backward compatibility, any new routing and addressing architecture and protocols must work with IPv4 and IPv6 using the traditional "hop by hop" forwarding and packet-based multiplex/demultiplex models. However, the architecture need not be restricted to these models. Additional forwarding and multiplex/ demultiplex models may be added.

2.1.26. Routing Algorithm

TOC

The architecture should not require a particular routing algorithm family. That is to say, the architecture should be agnostic about link-state, distance-vector, or path-vector routing algorithms.

2.1.27. Positive Benefit

TOC

Finally, the architecture must show benefits in terms of increased stability, decreased operational costs, and increased functionality and lifetime, over the current schemes. This benefit must remain even after the inevitable costs of developing and debugging the new protocols, enduring the inevitable instabilities as things get shaken out, and so on.

2.1.28. Administrative Entities and the IGP/EGP Split

TOC

We explicitly recognize that the Internet consists of resources under control of multiple administrative entities. Each entity must be able to manage its own portion of the Internet as it sees fit. Moreover, the constraints that can be imposed on routing and addressing on the portion of the Internet under the control of one administration may not be feasibly extended to cover multiple administrations. Therefore, we recognize a natural and inevitable split between routing and addressing that is under a single administrative control and routing and

addressing that involves multiple administrative entities. Moreover, while there may be multiple administrative authorities, the administrative authority boundaries may be complex and overlapping, rather than being a strict hierarchy.
Furthermore, there may be multiple levels of administration, each with its own level of policy and control. For example, a large network might have "continental-level" administrations covering its European and Asian operations, respectively. There would also be that network's "inter-continental" administration covering the Europe-to-Asia links. Finally, there would be the "Internet" level in the administrative structure (analogous to the "exterior" concept in the current routing architecture).
Thus, we believe that the administrative structure of the Internet must be extensible to many levels (more than the two provided by the current IGP/EGP split). The interior/exterior property is not absolute. The interior/exterior property of any point in the network is relative; a point on the network is interior with respect to some points on the network and exterior with respect to others.
Administrative entities may not trust each other; some may be almost actively hostile toward each other. The architecture must accommodate these models. Furthermore, the architecture must not require any particular level of trust among administrative entities.

2.2. Non-Requirements

TOC

The following are not required or are non-goals. This should not be taken to mean that these issues must not be addressed by a new architecture. Rather, addressing these issues or not is purely an optional matter for the architects.

2.2.1. Forwarding Table Optimization

TOC

We believe that it is not necessary for the architecture to minimize the size of the forwarding tables (FIBs). Current memory sizes, speeds, and prices, along with processor and ASIC capabilities allow forwarding tables to be very large, O(E6), and allow fast (100M lookups/second) tables to be built with little difficulty.

TOC

2.2.2. Traffic Engineering

Traffic Engineering is one of those terms that has become terribly overloaded. If one asks N people what traffic engineering is, one would get something like N! disjoint answers. Therefore, we elect not to require "traffic engineering", per se. Instead, we have endeavored to determine what the ultimate intent is when operators "traffic engineer" their networks and then make those capabilities an inherent part of the system.

2.2.3. Multicast

TOC

The new architecture is not designed explicitly to be an inter-domain multicast routing architecture. However, given the notable lack of a viable, robust, and widely deployed inter-domain multicast routing architecture, the architecture should not hinder the development and deployment of inter-domain multicast routing without adverse effect on meeting the other requirements.
We do note however that one respected network sage [Clark91] (Clark, D., “Quote reportedly from IETF Plenary discussion,” 1991.) has said (roughly)

> "When you see a bunch of engineers standing around congratulating themselves for solving some particularly ugly problem in networking, go up to them, whisper "multicast", jump back, and watch the fun begin..."

2.2.4. Quality of Service (QoS)

TOC

The architecture concerns itself primarily with disseminating network topology information so that routers may select paths to destinations and build appropriate forwarding tables. Quality of Service (QoS) is not a part of this function and we make no requirements with respect to QoS.
However, QoS is an area of great and evolving interest. It is reasonable to expect that in the not too distant future, sophisticated QoS facilities will be deployed in the Internet. Any new architecture and protocols should be developed with an eye toward these future evolutions. Extensibility mechanisms, allowing future QoS routing and signaling protocols to "piggy-back" on top of the basic routing system are desired.

We do require the ability to assign attributes to entities and then do path generation and selection based on those attributes. Some may call this QoS.

2.2.5. IP Prefix Aggregation

TOC

There is no specific requirement that CIDR-style IP Prefix aggregation be done by the new architecture. Address allocation policies, societal pressure, and the random growth and structure of the Internet have all conspired to make prefix aggregation extraordinarily difficult, if not impossible. This means that large numbers of prefixes will be sloshing about in the routing system and that forwarding tables will grow quite big. This is a cost that we believe must be borne.
Nothing in this non-requirement should be interpreted as saying that prefix aggregation is explicitly prohibited. CIDR-style IP Prefix aggregation might be used as a mechanism to meet other requirements, such as scaling.

2.2.6. Perfect Safety

TOC

Making the system impossible to mis-configure is, we believe, not required. The checking, constraints, and controls necessary to achieve this could, we believe, prevent operators from performing necessary tasks in the face of unforeseen circumstances.
However, safety is always a "good thing", and any results from research in this area should certainly be taken into consideration and, where practical, incorporated into the new routing architecture.

2.2.7. Dynamic Load Balancing

TOC

Past history has shown that using the routing system to perform highly dynamic load balancing among multiple more-or-less-equal paths usually ends up causing all kinds of instability, etc., in the network. Thus, we do not require such a capability.
However, this is an area that is ripe for additional research, and some believe that the capability will be necessary in the future. Thus, the architecture and protocols should be "malleable" enough to allow development and deployment of dynamic load balancing capabilities, should we ever figure out how to do it.

2.2.8. Renumbering of Hosts and Routers

TOC

We believe that the routing system is not required to "do renumbering" of hosts and routers. That's an IP issue.
Of course, the routing and addressing architecture must be able to deal with renumbering when it happens.

2.2.9. Host Mobility

TOC

In the Internet architecture, host-mobility is handled on a per-host basis by a dedicated, Mobile-IP protocol [RFC3344] (Perkins, C., “IP Mobility Support.,” August 2002.). Traffic destined for a mobile-host is explicitly forwarded by dedicated relay agents. Mobile-IP [RFC3344] (Perkins, C., “IP Mobility Support.,” August 2002.) adequately solves the host-mobility problem and we do not see a need for any additional requirements in this area. Of course, the new architecture must not impede or conflict with Mobile-IP.

2.2.10. Backward Compatibility

TOC

For the purposes of development of the architecture, we assume that there is a 'clean slate'. Unless specified in Section 2.1 (Group A - Requirements For a Next Generation Routing and Addressing Architecture), there are no explicit requirements that elements, concepts, or mechanisms of the current routing architecture be carried forward into the new one.

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3. Requirements from Group B

TOC

The following is the result of the work done by Sub-Group B of the IRTF-RRG in 2001-2002. It was originally released under the title: "Future Domain Routing Requirements" and was edited by Avri Doria and Elwyn Davies.

3.1. Group B - Future Domain Routing Requirements

TOC

It is generally accepted that there are major shortcomings in the inter-domain routing of the Internet today and that these may result in

meltdown within an unspecified period of time. Remedying these shortcomings will require extensive research to tie down the exact failure modes that lead to these shortcomings and identify the best techniques to remedy the situation.

> Reviewer's Note: Even in 2001, there was a wide difference of opinion across the community regarding the shortcomings of interdomain routing. In the years between writing and publication, further analysis, changes in operational practice, alterations to the demands made on inter-domain routing, modifications made to BGP and a recognition of the difficulty of finding a replacement may have altered the views of some members of the community.

Changes in the nature and quality of the services that users want from the Internet are difficult to provide within the current framework, as they impose requirements never foreseen by the original architects of the Internet routing system.
The kind of radical changes that have to be accommodated are epitomized by the advent of IPv6 and the application of IP mechanisms to private commercial networks that offer specific service guarantees beyond the best-effort services of the public Internet. Major changes to the inter-domain routing system are inevitable to provide an efficient underpinning for the radically changed and increasingly commercially-based networks that rely on the IP protocol suite.

3.2. Underlying Principles

TOC

Although inter-domain routing is seen as the major source of problems, the interactions with intra-domain routing, and the constraints that confining changes to the inter-domain arena would impose, mean that we should consider the whole area of routing as an integrated system. This is done for two reasons:

- Requirements should not presuppose the solution. A continued commitment to the current definitions and split between inter-domain and intra-domain routing would constitute such a presupposition. Therefore this part of the document uses the name Future Domain Routing (FDR).

- It is necessary to understand the degree to which inter-domain and intra-domain routing are related within today's routing architecture.

We are aware that using the term "domain routing" is already fraught with danger because of possible misinterpretation due to prior usage. The meaning of "domain routing" will be developed implicitly throughout the document, but a little advance explicit definition of the word

'domain' is required, as well as some explanation on the scope of 'routing'.
This document uses "domain" in a very broad sense, to mean any collection of systems or domains that come under a common authority that determines the attributes defining, and the policies controlling, that collection. The use of domain in this manner is very similar to the concept of region that was put forth by John Wroclawski in his Metanet model [Wroclawski95] (Wroclowski, J., “The Metanet White Paper - Workshop on Research Directions for the Next Generation Internet,” 1995.). The idea includes the notion that certain attributes will characterize the behavior of the systems within a domain and that there will be borders between domains. The idea of domain presented here does not presuppose that two domains will have the same behavior. Nor does it presuppose anything about the hierarchical nature of domains. Finally, it does not place restrictions on the nature of the attributes that might be used to determine membership in a domain. Since today's routing domains are an example of the concept of domains in this document, there has been no attempt to create a new term.
Current practice in routing system design stresses the need to separate the concerns of the control plane and the forwarding plane in a router. This document will follow this practice, but we still use the term "routing" as a global portmanteau to cover all aspects of the system. Specifically, however, routing will be used to mean the process of discovering, interpreting, and distributing information about the logical and topological structure of the network.

3.2.1. Inter-domain and Intra-domain

TOC

Throughout this section the terms intra-domain and inter-domain will be used. These should be understood as relative terms. In all cases of domains, there will be a set of network systems that are within that domain; routing between these systems will be termed intra-domain. In some cases there will be routing between domains, which will be termed inter-domain. It is possible that the routing exchange between two network systems can be viewed as intra-domain from one perspective and as inter-domain from another perspective.

3.2.2. Influences on a Changing Network

TOC

The development of the Internet is likely to be driven by a number of changes that will affect the organization and the usage of the network, including:

-

Ongoing evolution of the commercial relationships between (connectivity) service providers, leading to changes in the way in which peering between providers is organized and the way in which transit traffic is routed.

- Requirements for traffic engineering within and between domains including coping with multiple paths between domains.

- Addition of a second IP addressing technique, in the form of IPv6.

- The use of VPNs and private address space with IPv4 and IPv6.

- Evolution of the end-to-end principle to deal with the expanded role of the Internet, as discussed in [Blumenthal01] (Blumenthal, M. and D. Clark, “Rethinking the design of the Internet: The end to end arguments vs. the brave new world,” May 2001.): This paper discusses the possibility that the range of new requirements, especially the social and techno-political ones that are being placed on the future, may compromise the Internet's original design principles. This might cause the Internet to lose some of its key features, in particular its ability to support new and unanticipated applications. This discussion is linked to the rise of new stakeholders in the Internet, especially ISPs; new government interests; the changing motivations of the ever growing user base; and the tension between the demand for trustworthy overall operation and the inability to trust the behaviour of individual users.

- Incorporation of alternative forwarding techniques such as the explicit routing (pipes) supplied by the MPLS [RFC3031] (Rosen, E., Viswanathan, A., and R. Callon, “Multiprotocol Label Switching Architecture,” January 2001.) and GMPLS [RFC3471] (Berger, L., “Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description,” January 2003.) environments.

- Integration of additional constraints into route determination from interactions with other layers (e.g., Shared Risk Link Groups [I-D.many-inference-srlg] (Papadimitriou, D. and others, “Inference of Shared Risk Link Groups,” February 2002.)). This includes the concern that redundant routes should not fate-share, e.g., because they physically run in the same trench.

- Support for alternative and multiple routing techniques that are better suited to delivering types of content organised in ways other than into IP addressed packets.

Philosophically, the Internet has the mission of transferring information from one place to another. Conceptually, this information is rarely organised into conveniently sized, IP-addressed packets, and

the FDR needs to consider how the information (content) to be carried is identified, named and addressed. Routing techniques can then be adapted to handle the expected types of content.

3.2.3. High Level Goals

TOC

This section attempts to answer two questions:

- What are we trying to achieve in a new architecture?
- Why should the Internet community care?

There is a third question that needs to be answered as well, but that has seldom been explicitly discussed:

- How will we know when we have succeeded?

3.2.3.1. Providing a Routing System Matched to Domain Organization

TOC

Many of today's routing problems are caused by a routing system that is not well matched to the organization and policies that it is trying to support. Our goal is to develop a routing architecture where even a domain organization that is not envisioned today can be served by a routing architecture that matches its requirements. We will know when this goal is achieved when the desired policies, rules, and organization can be mapped into the routing system in a natural, consistent, and simply understood way.

3.2.3.2. Supporting a Range of Different Communication Services

TOC

Today's routing protocols only support a single data forwarding service that is typically used to deliver a best-effort service in the public Internet. On the other hand, DiffServ for example, can construct a number of different bit transport services within the network. Using some of the per-domain behaviors (PDB)s that have been discussed in the IETF, it is possible to construct services such as Virtual Wire [I-D.ietf-diffserv-pdb-vw] (Jacobson, V., Nichols, K., and K. Poduri, “The 'Virtual Wire' Behavior Aggregate,” July 2000.) and Assured Rate [I-D.ietf-diffserv-pdb-ar] (Seddigh, N., Nandy, B., and J. Heinanen,

“An Assured Rate Per-Domain Behaviour for Differentiated Services,” February 2001.).
Providers today offer rudimentary promises about traffic handling in the network, for example delay and long-term packet loss guarantees. As time goes on, this becomes even more relevant. Communicating the service characteristics of paths in routing protocols will be necessary in the near future, and it will be necessary to be able to route packets according to their service requirements.
Thus, a goal of this architecture is to allow adequate information about path service characteristics to be passed between domains and consequently, to allow the delivery of bit transport services other than the best-effort datagram connectivity service that is the current common denominator.

3.2.3.3. Scalable Well Beyond Current Predictable Needs

TOC

Any proposed FDR system should scale beyond the size and performance we can foresee for the next ten years. The previous IDR proposal as implemented by BGP, has, with some massaging, held up for over ten years. In that time the Internet has grown far beyond the predictions that were implied by the original requirements.
Unfortunately, we will only know if we have succeeded in this goal if the FDR system survives beyond its design lifetime without serious massaging. Failure will be much easier to spot!

3.2.3.4. Alternative Forwarding Mechanisms

TOC

With the advent of circuit-based technologies (e.g., MPLS [RFC3031] (Rosen, E., Viswanathan, A., and R. Callon, “Multiprotocol Label Switching Architecture,” January 2001.) and GMPLS [RFC3471] (Berger, L., “Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description,” January 2003.)) managed by IP routers there are forwarding mechanisms other than the datagram service that need to be supported by the routing architecture.
An explicit goal of this architecture is to add support for forwarding mechanisms other then the current hop-by-hop datagram forwarding service driven by globally unique IP addresses.

TOC

3.2.3.5. Separation of Topology Map from Connectivity Service

It is envisioned that an organization can support multiple services within a single network. These services can, for example, be of different quality, of different connectivity type, or of different protocols (e.g., IPv4 and IPv6). For all these services there may be common domain topology, even though the policies controlling the routing of information might differ from service to service. Thus, a goal with this architecture is to support separation between creation of a domain (or organization) topology map and service creation.

3.2.3.6. Separation Between Routing and Forwarding

TOC

The architecture of a router is composed of two main separable parts, control and forwarding. These components, while inter-dependent, perform functions that are largely independent of each other. Control (routing, signaling, and management) is typically done in software while forwarding typically is done with specialized ASICs or network processors.
The nature of an IP-based network today is that control and data protocols share the same network and forwarding regime. This may not always be the case in future networks, and we should be careful to avoid building in this sharing as an assumption in the FDR.
A goal of this architecture is to support full separation of control and forwarding, and to consider what additional concerns might be properly considered separately (e.g., adjacency management).

3.2.3.7. Different Routing Paradigms in Different Areas of the Same Network

TOC

A number of routing paradigms have been used or researched, in addition to the conventional shortest path by hop count paradigm that is the current mainstay of the Internet. In particular, differences in underlying transport networks may mean that other kinds of routing are more relevant, and the perceived need for traffic engineering will certainly alter the routing chosen in various domains.
Explicitly, one of these routing paradigms should be the current routing paradigm, so that the new paradigms will inter-operate in a backward-compatible way with today's system. This will facilitate a migration strategy that avoids flag days.

TOC

3.2.3.8. Protection Against Denial of Service and Other Security Attacks

Currently, existence of a route to a destination effectively implies that anybody who can get a packet onto the network is entitled to use that route. Whilst there are limitations to this generalization, this is a clear invitation to denial of service attacks. A goal of the FDR system should be to allow traffic to be specifically linked to whole or partial routes so that a destination or link resources can be protected from unauthorized use.

> Editors' note: When sections like this one and the previous ones on quality differentiation were written, the idea of separating traffic for security or quality was considered an unqualified advantage. Today, however, in the midst of active discussions on Network Neutrality, it is clear that such issues have a crucial policy component that also needs to be understood. These, and other similar issues are open to further research.

3.2.3.9. Provable Convergence with Verifiable Policy Interaction

TOC

It has been shown both analytically by Griffin et al (see [Griffin99] (Griffin, T. and G. Wilfong, “An Analysis of BGP Convergence Properties,” 1999.)) and practically (see [RFC3345] (McPherson, D., Gill, V., Walton, D., and A. Retana, “Border Gateway Protocol (BGP) Persistent Route Oscillation Condition,” August 2002.)) that BGP will not converge stably or is only meta-stable (i.e., will not re-converge in the face of a single failure) when certain types of policy constraint are applied to categories of network topology. The addition of policy to the basic distance vector algorithm invalidates the proofs of convergence that could be applied to a policy free implementation. It has also been argued that global convergence may no longer be a necessary goal and that local convergence may be all that is required. A goal of the FDR should be to achieve provable convergence of the protocols used which may involve constraining the topologies and domains subject to convergence. This will also require vetting the policies imposed to ensure that they are compatible across domain boundaries and result in a consistent policy set.

> Editors' note: This requirement is very optimistic in that it implies that it is possible to get operators to cooperate even it is seen by them to be against their business practices. Though perhaps Utopian, this is a good goal.

3.2.3.10. Robustness Despite Errors and Failures

TOC

From time to time in the history of the Internet there have been occurrences where mis-configured routers have destroyed global connectivity.
A goal of the FDR is to be more robust to configuration errors and failures. This should probably involve ensuring that the effects of misconfiguration and failure can be confined to some suitable locality of the failure or misconfiguration.

3.2.3.11. Simplicity in Management

TOC

The policy work ([rap-charter02] (Internet Engineering Task Force, “IETF Resource Allocation Protocol working group,” 2002.), [snmpconf-charter02] (Internet Engineering Task Force, “IETF Configuration management with SNMP working group,” 2002.) and [policy-charter02] (Internet Engineering Task Force, “IETF Policy working group,” 2002.)) that has been done at IETF provides an architecture that standardizes and simplifies management of QoS. This kind of simplicity is needed in a Future Domain Routing architecture and its protocols.
A goal of this architecture is to make configuration and management of inter-domain routing as simple as possible.

> Editors' Note: Snmpconf and rap are the hopes of the past. Today configuration and policy hope is focused on netconf [netconf-charter] (Internet Engineering Task Force, “IETF Network Configuration working group,” 2005.).

3.2.3.12. The Legacy of RFC1126

TOC

RFC1126 outlined a set of requirements that were used to guide the development of BGP. While the network has changed in the years since 1989, many of the same requirements remain. A future domain routing solution has to support, as its base requirement, the level of function that is available today. A detailed discussion of RFC1126 and its requirements can be found in [I-D.irtf-routing-history] (Davies, E., “Analysis of IDR requirements and History,” August 2006.). Those requirements, while specifically spelled out in that document, are subsumed by the requirements in this document.

3.3. High Level User Requirements

TOC

This section considers the requirements imposed by the target audience of the FDR both in terms of organizations that might own networks that would use FDR, and the human users who will have to interact with the FDR.

3.3.1. Organisational Users

TOC

The organizations that own networks connected to the Internet have become much more diverse since RFC1126 [RFC1126] (Little, M., “Goals and functional requirements for inter-autonomous system routing,” October 1989.) was published. In particular, major parts of the network are now owned by commercial service provider organizations in the business of making profits from carrying data traffic.

3.3.1.1. Commercial Service providers

TOC

The routing system must take into account the commercial service provider's need for secrecy and security, as well as allowing them to organize their business as flexibly as possible.
Service providers will often wish to conceal the details of the network from other connected networks. So far as is possible, the routing system should not require the service providers to expose more details of the topology and capability of their networks than is strictly necessary.
Many service providers will offer contracts to their customers in the form of Service Level Agreements (SLAs). The routing system must allow the providers to support these SLAs through traffic engineering and load balancing as well as multi-homing, providing the degree of resilience and robustness that is needed.
Service providers can be categorized as:

- Global Service Providers (GSPs) whose networks have a global reach. GSPs may, and usually will, wish to constrain traffic between their customers to run entirely on their networks. GSPs will interchange traffic at multiple peering points with other GSPs, and they will need extensive policy-based controls to control the interchange of traffic. Peering may be through the use of dedicated private lines between the partners or, increasingly, through Internet Exchange Points.

-

  National, or regional, Service Providers (NSPs) that are similar to GSPs but typically cover one country. NSPs may operate as a federation that provides similar reach to a GSP and may wish to be able to steer traffic preferentially to other federation members to achieve global reach.

- Local Internet Service Providers (ISPs) operate regionally. They will typically purchase transit capacity from NSPs or GSPs to provide global connectivity, but they may also peer with neighbouring, and sometimes distant, ISPs.

The routing system should be sufficiently flexible to accommodate the continually changing business relationships of the providers and the various levels of trustworthiness that they apply to customers and partners.
Service providers will need to be involved in accounting for Internet usage and monitoring the traffic. They may be involved in government action to tax the usage of the Internet, enforce social mores and intellectual property rules, or apply surveillance to the traffic to detect or prevent crime.

3.3.1.2. Enterprises

TOC

The leaves of the network domain graph are in many cases networks supporting a single enterprise. Such networks cover an enormous range of complexity. Some multi-national companies own networks that rival the complexity and reach of a GSP, whereas many fall into the Small Office-Home Office (SOHO) category. The routing system should allow simple and robust configuration and operation for the SOHO category, while effectively supporting the larger enterprise.
Enterprises are particularly likely to lack the capability to configure and manage a complex routing system, and every effort should be made to provide simple configuration and operation for such networks.
Enterprises will also need to be able to change their service provider with ease. While this is predominantly a naming and addressing issue, the routing system must be able to support seamless changeover, for example, if the changeover requires a change of address prefix, the routing system must be able to cope with a period when both sets of addresses are in use.
Enterprises will wish to be able to multi-home to one or more providers as one possible means of enhancing the resilience of their network.
Enterprises will also frequently need to control the trust that they place both in workers and external connections through firewalls and similar mid-boxes placed at their external connections.

3.3.1.3. Domestic Networks

TOC

Increasingly domestic, i.e., non-business home, networks are likely to be 'always on' and will resemble SOHO enterprises networks with no special requirements on the routing system.
The routing system must also continue to support dial-up users.

3.3.1.4. Internet Exchange Points

TOC

Peering of service providers, academic networks, and larger enterprises is increasingly happening at specific Internet Exchange Points where many networks are linked together in a relatively small physical area. The resources of the exchange may be owned by a trusted third party or owned jointly by the connecting networks. The routing systems should support such exchange points without requiring the exchange point to either operate as a superior entity with every connected network logically inferior to it or by requiring the exchange point to be a member of one (or all) connected networks. The connecting networks have to delegate a certain amount of trust to the exchange point operator.

3.3.1.5. Content Providers

TOC

Content providers are at one level a special class of enterprise, but the desire to deliver content efficiently means that a content provider may provide multiple replicated origin servers or caches across a network. These may also be provided by a separate content delivery service. The routing system should facilitate delivering content from the most efficient location.

3.3.2. Individual Users

TOC

This section covers the most important human users of the FDR and their expected interactions with the system.

3.3.2.1. All End Users

TOC

The routing system must continue to deliver the current global connectivity service (i.e., any unique address to any other unique

address, subject to policy constraints) that has always been the basic aim of the Internet.
End user applications should be able to request, or have requested on their behalf by agents and policy mechanisms, end-to-end communication services with QoS characteristics different from the best-effort service that is the foundation of today's Internet. It should be possible to request both a single service channel and a bundle of service channels delivered as a single entity.

3.3.2.2. Network Planners

TOC

The routing system should allow network planners to plan and implement a network that can be proved to be stable and will meet their traffic engineering requirements.

3.3.2.3. Network Operators

TOC

The routing system should, so far as is possible, be simple to configure, operate and troubleshoot, behave in a predictable and stable fashion, and deliver appropriate statistics and events to allow the network to be managed and upgraded in an efficient and timely fashion.

3.3.2.4. Mobile End Users

TOC

The routing system must support mobile end users. It is clear that mobility is becoming a predominant mode for network access.

3.4. Mandated Constraints

TOC

While many of the requirements to which the protocol must respond are technical, some aren't. These mandated constraints are those that are determined by conditions of the world around us. Understanding these requirements requires an analysis of the world in which these systems will be deployed. The constraints include those that are determined by:

- environmental factors,
- geography,

- political boundaries and considerations, and

- technological factors such as the prevalence of different levels of technology in the developed world compared to those in the developing or undeveloped world.

3.4.1. The Federated Environment

TOC

The graph of the Internet network, with routers and other control boxes as the nodes and communication links as the edges, is today partitioned administratively into a large number of disjoint domains.
A common administration may have responsibility for one or more domains that may or may not be adjacent in the graph.
Commercial and policy constraints affecting the routing system will typically be exercised at the boundaries of these domains where traffic is exchanged between the domains.
The perceived need for commercial confidentiality will seek to minimise the control information transferred across these boundaries, leading to requirements for aggregated information, abstracted maps of connectivity exported from domains, and mistrust of supplied information.
The perceived desire for anonymity may require the use of zero-knowledge security protocols to allow users to access resources without exposing their identity.
The requirements should provide the ability for groups of peering domains to be treated as a complex domain. These complex domains could have a common administrative policy.

3.4.2. Working with Different Sorts of Networks

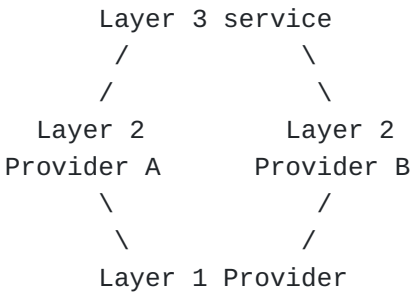
TOC

The diverse Layer 2 networks over which the layer 3 routing system is implemented have typically been operated totally independently from the layer 3 network and often with their own routing mechanisms.
Consideration needs to be given to the desirable degree and nature of interchange of information between the layers. In particular, the need for guaranteed robustness through diverse routing layers implies knowledge of the underlying networks.
Mobile access networks may also impose extra requirements on Layer 3 routing.

3.4.3. Delivering Resilient Service

TOC

The routing system operates at Layer 3 in the network. To achieve robustness and resilience at this layer requires that, where multiple diverse routes are employed as part of delivering the resilience, the routing system at Layer 3 needs to be assured that the Layer 2 and lower routes are really diverse. The 'diamond problem' is the simplest form of this problem - a layer 3 provider attempting to provide diversity buys layer 2 services from two separate providers who in turn buy layer 1 services from the same provider:



Now when the backhoe cuts the trench, the Layer 3 provider has no resilience unless he had taken special steps to verify that the trench wasn't common. The routing system should facilitate avoidance of this kind of trap.
Some work is going on to understand the sort of problems that stem from this requirement, such as the work on Shared Risk Link Groups [I-D.many-inference-srlg] (Papadimitriou, D. and others, “Inference of Shared Risk Link Groups,” February 2002.). Unfortunately, the full generality of the problem requires diversity be maintained over time between an arbitrarily large set of mutually distrustful providers. For some cases, it may be sufficient for diversity to be checked at provisioning or route instantiation time, but this remains a hard problem requiring research work.

3.4.4. When Will the New Solution Be Required?

TOC

There is a full range of opinion on this subject. An informal survey indicates that the range varies from 2 years to 6 years. And while there are those, possibly outliers, who think there is no need for a new routing architecture as well as those who think a new architecture was needed years ago, the median seems to lie at around 4 years. As in all projections of the future, this is not provable at this time.

> Editors' note: The paragraph above was written in 2002, yet could be written without change in 2006. As with many technical predictions and schedules, the horizon has remained fixed through this interval.

3.5. Assumptions

TOC

In projecting the requirements for the Future Domain Routing a number of assumptions have been made. The requirements set out should be consistent with these assumptions, but there are doubtless a number of other assumptions that are not explicitly articulated here:

1. The number of hosts today is somewhere in the area of 100 million. With dial-in, NATs and the universal deployment of IPv6, this is likely to become up to 500 million users (see [CIDR] (Telcordia Technologies, “CIDR Report,” .)). In a number of years, with wireless accesses and different appliances attaching to the Internet, we are likely to see a couple of billion (10^9) 'users' on the Internet. The number of globally addressable hosts is very much dependent on how common NATs will be in the future.

2. NATs, firewalls, and other middle-boxes exist, and we cannot assume that they will cease being a presence in the networks.

3. The number of operators in the Internet will probably not grow very much, as there is a likelihood that operators will tend to merge. However, as Internet-connectivity expands to new countries, new operators will emerge and then merge again.

4. At the beginning of 2002, there are around 12000 registered AS's. With current use of AS's (for e.g., multi-homing) the number of AS's could be expected to grow to 25000 in about 10 years.[Broido02] (Broido, A., Nemeth, E., Claffy, K., and C. Elves, “Internet Expansion, Refinement and Churn,” February 2002.) This is down from a previously reported growth rate of 51% per year.[RFC3221] (Huston, G., “Commentary on Inter-Domain Routing in the Internet,” December 2001.). Future growth rates are difficult to predict.

   > Editors' Note: In the routing report table of August 2006, the total number of AS's present in the Internet Routing Table was 23000. In 4 years this is substantial progress on the prediction of 25000 AS's. Also, there are significantly more AS's registered then are visibly active, i.e., in excess of 42000 in mid-2006. It is possible, however, that many are being used internally.

5. In contrast to the number of operators, the number of domains is likely to grow significantly. Today, each operator has different domains within an AS, but this also shows in SLAs and

policies internal to the operator. Making this globally visible would create a number of domains 10-100 times the number of AS's, i.e., between 100,000 and 1,000,000.

6. With more and more capacity at the edge of the network the IP network will expand. Today there are operators with several thousands of routers, but this is likely to be increased. Some domains will probably contain tens of thousands of routers.

7. The speed of connections in the (fixed) access will technically be (almost) unconstrained. However, the cost for the links will not be negligible so that the apparent speed will be effectively bounded. Within a number of years some will have multi-gigabit speed in the access.

8. At the same time, the bandwidth of wireless access still has a strict upper-bound. Within the foreseeable future each user will have only a tiny amount of resources available compared to fixed accesses (10kbps to 2Mbps for UMTS with only a few achieving the higher figure as the bandwidth is shared between the active users in a cell and only small cells can actually reach this speed, but 11Mbps or more for wireless LAN connections). There may also be requirements for effective use of bandwidth as low as 2.4 Kbps or lower, in some applications.

9. Assumptions 7 and 8 taken together suggest a minimum span of bandwidth between 2.4 kbps to 10 Gbps.

10. The speed in the backbone has grown rapidly, and there is no evidence that the growth will stop in the coming years. Terabit-speed is likely to be the minimum backbone speed in a couple of years. The range of bandwidths that need to be represented will require consideration on how to represent the values in the protocols.

11. There have been discussions as to whether Moore's law will continue to hold for processor speed. If Moore's law does not hold, then communication circuits might play a more important role in the future. Also, optical routing is based on circuit technology, which is the main reason for taking 'circuits' into account when designing an FDR.

12. However, the datagram model still remains the fundamental model for the Internet.

13. The number of peering points in the network is likely to grow, as multi-homing becomes important. Also traffic will become more locally distributed, which will drive the demand for local peering.

> Editors' note: On the other hand peer to peer networking may shift the balance in demand for local peering.

14. The FDR will achieve the same degree of ubiquity as the current Internet and IP routing.

3.6. Functional Requirements

TOC

This section includes a detailed discussion of new requirements for a Future Domain Routing architecture. The nth requirement carries the label "R(n)". As discussed in section 3.2.3.12 a new architecture must build upon the requirements of the past routing framework and must not reduce the functionality of the network. A discussion and analysis of the RFC1126 requirements can be found in [I-D.irtf-routing-history] (Davies, E., “Analysis of IDR requirements and History,” August 2006.).

3.6.1. Topology

TOC

3.6.1.1. Routers Should Be Able To Learn and To Exploit the Domain Topology

TOC

> **R(1)** Routers must be able to acquire and hold sufficient information on the underlying topology of the domain to allow the establishment of routes on that topology.
>
> **R(2)** Routers must have the ability to control the establishment of routes on the underlying topology.
>
> **R(3)** Routers must be able, where appropriate, to control Sub-IP mechanisms to support the establishment of routes.

The OSI Inter-Domain Routing Protocol (IDRP)[ISO10747] (ISO/IEC, “Protocol for Exchange of Inter-Domain Routeing Information among Intermediate Systems to Support Forwarding of ISO 8473 PDUs,” 1993.) allowed a collection of topologically related domains to be replaced by an aggregate domain object, in a similar way to the Nimrod[Chiappa02] (Chiappa, N., “A New IP Routing and Addressing Architecture,” July 1991.) domain hierarchies. This allowed a route to be more compactly represented by a single collection instead of a sequence of individual domains.

R(4)

> Routers must, where appropriate, be able to construct abstractions of the topology that represent an aggregation of the topological features of some area of the topology.

3.6.1.2. The Same Topology Information Should Support Different Path Selection Ideas

TOC

The same topology information needs to provide the more flexible spectrum of path selection methods that we might expect to find in a future Internet, including distributed techniques such as hop-by-hop, shortest path, local optimization constraint-based, class of service, source address routing, and destination address routing, as well as the centralized, global optimization constraint-based 'traffic engineering' type. Allowing different path selection techniques will produce a much more predictable and comprehensible result than the 'clever tricks' that are currently needed to achieve the same results. Traffic engineering functions need to be combined.

> **R(5)** Routers must be capable of supporting a small number of different path selection algorithms

---

3.6.1.3. Separation of the Routing Information Topology from the Data transport topology.

TOC

> **R(6)** The controlling network may be logically separate from the controlled network.

The two functional 'planes' may physically reside in the same nodes and share the same links, but this is not the only possibility, and other options may sometimes be necessary. An example is a pure circuit switch (that cannot see individual IP packets) combined with an external controller. Another example may be multiple links between two routers, where all the links are used for data forwarding but only one is used for carrying the routing session.

3.6.2. Distribution

TOC

3.6.2.1. Distribution Mechanisms

TOC

> **R(7)** Relevant changes in the state of the network, including modifications to the topology and changes in the values of dynamic capabilities, must be distributed to every entity in the network that needs them, in a reliable and trusted way, at the earliest appropriate time after the changes have occurred.
>
> **R(8)** Information must not be distributed outside areas where it is needed, or believed to be needed, for the operation of the routing system.
>
> **R(9)** Information must be distributed in such a way that it minimizes the load on the network, consistent with the required response time of the network to changes.

3.6.2.2. Path Advertisement

TOC

> **R(10)** The router must be able to acquire and store additional static and dynamic information that relates to the capabilities of the topology and its component nodes and links and that can subsequently be used by path selection methods.

The inter-domain routing system must be able to advertise more kinds of information than just connectivity and domain paths.

> **R(11)** The Routing System must support service specifications, e.g., the Service Level Specifications (SLSs) developed by the Differentiated Services working group [RFC3260] (Grossman, D., “New Terminology and Clarifications for Diffserv,” April 2002.).

Careful attention should be paid to ensuring that the distribution of additional information with path advertisements remains scalable as domains and the Internet get larger, more numerous, and more diversified.

> **R(12)** The distribution mechanism used for distributing network state information must be scalable with respect to the expected size of domains and the volume and rate of change of dynamic state that can be expected.

The combination of R(9) and R(12) may result in a compromise between the responsiveness of the network to change and the overhead of distributing change notifications. Attempts to respond to very rapid changes may damage the stability of the routing system.

Possible examples of additional capability information that might be carried include:

- QoS information
  To allow an ISP to sell predictable end-to-end QoS service to any destination, the routing system should have information about the end-to-end QoS. This means that:

R(13) The routing system must be able to support different paths for different services.

R(14) The routing system must be able to forward traffic on the path appropriate for the service selected for the traffic, either according to an explicit marking in each packet (e.g., MPLS labels, DiffServ PHB's or DSCP values) or implicitly (e.g., the physical or logical port on which the traffic arrives).

R(15) The routing system should also be able to carry information about the expected (or actually, promised) characteristics of the entire path and the price for the service.

  (If such information is exchanged at all between network operators today, it is through bilateral management interfaces, and not through the routing protocols.) This would allow for the operator to optimise the choice of path based on a price/ performance trade-off.
  In addition to providing dynamic QoS information the system should be able to use static class-of-service information.

- Security information
  Security characteristics of other domains referred to by advertisements can allow the routing entity to make routing decisions based on political concerns. The information itself is assumed to be secure so that it can be trusted.

- Usage and cost information
  Usage and cost information can be used for billing and traffic engineering. In order to support cost-based routing policies for customers (i.e., peer ISPs), information such as "traffic on this link or path costs XXX per Gigabyte" needs to be advertised, so that the customer can choose a more or a less expensive route.

- Monitored performance
  Performance information such as delay and drop frequency can be carried. (This may only be suitable inside a domain because of trust considerations). This should support at least the kind of delay bound contractual terms that are currently being offered by service providers. Note that these values refer to the outcome of carrying bits on the path, whereas the QoS information refers to the proposed behaviour that results in this outcome.

- Multicast information

R(16) The routing system must provide information needed to create multicast distribution trees. This information must be provided for one-to-many distribution trees and should be provided for many-to-many distribution trees.

The actual construction of distribution trees is not necessarily done by the routing system.

3.6.2.3. Stability of Routing Information

TOC

R(17) The new network architecture must be stable without needing global convergence, i.e., convergence is a local property.

The degree to which this is possible and the definition of "local" remain research topics. Restricting the requirement for convergence to localities will have an effect on all of the other requirements in this section.

R(18) The distribution and the rate of distribution of changes must not affect the stability of the routing information. For example, commencing redistribution of a change before the previous one has settled must not cause instability.

3.6.2.3.1. Avoiding Routing Oscillations

TOC

R(19) The routing system must minimize oscillations in route advertisements.

3.6.2.3.2. Providing Loop-free Routing and Forwarding

TOC

In line with the separation of routing and forwarding concerns:

R(20)

The distribution of routing information must be, so far as is possible, loop-free.

R(21) The forwarding information created from this routing information must seek to minimize persistent loops in the data forwarding paths.

It is accepted that transient loops may occur during convergence of the protocol and that there are trade-offs between loop avoidance and global scalability.

3.6.2.3.3. Detection, Notification and Repair of Failures

TOC

R(22) The routing system must provide means for detecting failures of node equipment or communication links.

R(23) The routing system should be able to coordinate failure indications from layer 3 mechanisms, from nodal mechanisms built into the routing system, and from lower-layer mechanisms that propagate up to Layer 3 in order to determine the root cause of the failure. This will allow the routing system to react correctly to the failure by activating appropriate mitigation and repair mechanisms if required, whilst ensuring that it does not react if lower layer repair mechanisms are able to repair or mitigate the fault.

Most layer 3 routing protocols have utilized keepalives or 'hello' protocols as a means of detecting failures at Layer 3. The keepalive mechanisms are often complemented by analog mechanisms (e.g., laser light detection) and hardware mechanisms (e.g., hardware/software watchdogs) that are built into routing nodes and communication links. Great care must be taken to make best possible use of the various failure repair methods available whilst ensuring that only one repair mechanism at a time is allowed to repair any given fault. Interactions between, for example, fast reroute mechanisms at layer 3 and SONET/SDH repair at Layer 1 are highly undesirable and are likely to cause problems in the network.

R(24) Where a network topology and routing system contains multiple fault repair mechanisms, the responses of these systems to a detected failure should be coordinated so that the fault is repaired by the most appropriate means, and no extra repairs are initiated.

R(25) Where specialized packet exchange mechanisms (e.g., layer 3 keepalive or 'hello' protocol mechanisms) are used to detect

> failures, the routing system must allow the configuration of the rate of transmission of these keepalives. This must include the capability to turn them off altogether for links that are deliberately broken when no real user or control traffic is present (e.g., ISDN links).

This will allow the operator to compromise between the speed of failure detection and the proportion of link bandwidth dedicated to failure detection.

3.6.3. Addressing

TOC

3.6.3.1. Support Mix of IPv4, IPv6 and Other Types of Addresses

TOC

> **R(26)** The routing system must support a mix of different kinds of addresses.

This mix will include at least IPv4 and IPv6 addresses, and preferably various types of non-IP addresses too. For instance networks like SDH/SONET and WDM may prefer to use non-IP addresses. It may also be necessary to support multiple sets of 'private' (e.g., RFC1918) addresses when dealing with multiple customer VPNs.

> **R(27)** The routing system should support the use of a single topology representation to generate routing and forwarding tables for multiple address families on the same network.

This capability would minimise the protocol overhead when exchanging routes.

3.6.3.2. Support for Domain Renumbering/Readdressing

TOC

> **R(28)** If a domain is subject to address reassignment that would cause forwarding interruption, then the routing system should support readdressing (e.g., when a new prefix is given to an old network, and the change is known in advance) by maintaining routing during the changeover period [RFC2071] (Ferguson, P. and H. Berkowitz, “Network Renumbering Overview: Why would I want it and what is it anyway?,” January 1997.),[RFC2072] (Berkowitz, H., “Router Renumbering Guide,” January 1997.).

3.6.3.3. Multicast and Anycast

TOC

> **R(29)** The routing system must support multicast addressing, both within a domain and across multiple domains.
>
> **R(30)** The routing system should support anycast addressing within a domain. The routing system may support anycast addressing across domains.

An open question is whether it is possible or useful to support anycast addressing between cooperating domains.

3.6.3.4. Address Scoping

TOC

> **R(31)** The routing system must support scoping of unicast addresses, and it should support scoping of multicast and anycast address types.

The unicast address scoping that is being designed for IPv6 does not seem to cause any special problems for routing. IPv6 inter-domain routing handles only IPv6 global addresses, while intra-domain routing also needs to be aware of the scope of private addresses.

> Editors' note: the original reference was to site-local addresses but these have been deprecated by the IETF. Link-local addresses are never routed at all.

More study may be needed to identify the requirements and solutions for scoping in a more general sense and for scoping of multicast and anycast addresses.

3.6.3.5. Mobility Support

TOC

> **R(32)** The routing system must support system mobility. The term "system" includes anything from an end system to an entire domain.

We observe that the existing solutions based on re-numbering and/or tunneling are designed to work with the current routing, so they do not add any new requirements to future routing. But the requirement is

general, and future solutions may not be restricted to the ones we have today.

3.6.4. Statistics Support

TOC

> **R(33)** Both the routing and forwarding parts of the routing system must maintain statistical information about the performance of their functions.

3.6.5. Management Requirements

TOC

While the tools of management are outside the scope of routing, the mechanisms to support the routing architecture and protocols are within scope.

> **R(34)** Mechanisms to support Operational, Administrative and Management control of the routing architecture and protocols must be designed into the original fabric of the architecture.

3.6.5.1. Simple Policy Management

TOC

The basic aims of this specification are:

- to require less manual configuration than today and
- to satisfy the requirements for both easy handling and maximum control. That is:
    - All the information should be available,
    - but should not be visible except for when necessary.
    - Policies themselves should be advertised and not only the result of policy, and
    - policy conflict resolution must be provided.

> **R(35)** The routing system must provide management of the system by means of policies. For example, policies that can be expressed in terms of the business and services implemented on the network and

reflect the operation of the network in terms of the services affected.

> Editors' note: This requirement is optimistic in that it implies that it is possible to get operators to cooperate even it is seen by them to be against their business practices.

R(36) The distribution of policies must be amenable to scoping to protect proprietary policies that are not relevant beyond the local set of domains.

3.6.5.2. Startup and Maintenance of Routers

TOC

A major problem in today's networks is the need to perform initial configuration on routers from a local interface before a remote management system can take over. It is not clear that this imposes any requirements on the routing architecture beyond what is needed for a ZeroConf host.
Similarly, maintenance and upgrade of routers can cause major disruptions to the network routing because the routing system and management of routers is not organized to minimize such disruption. Some improvements have been made, such as graceful restart mechanisms in protocols, but more needs to be done.

R(37) The routing system and routers should provide mechanisms that minimize the disruption to the network caused by maintenance and upgrades of software and hardware. This requirement recognizes that some of the capabilities needed are outside the scope of the routing architecture (e.g., minimum impact software upgrade).

3.6.6. Provability

TOC

R(38) The routing system and its component protocols must be demonstrated to be locally convergent under the permitted range of parameter settings and policy options that the operator(s) can select.

There are various methods for demonstration and proof that include, but are not limited to: mathematical proof, heuristic, and pattern recognition. No requirement is made on the method used for demonstrating local convergence properties.

R(39)

> Routing protocols employed by the routing system and the overall routing system should be resistant to bad routing policy decisions made by operators.

Tools are needed to check compatibility of routing policies. While these tools are not part of the routing architecture, the mechanisms to support such tools are.
Routing policies are compatible if their interaction does not cause instability. A domain or group of domains in a system is defined as being convergent, either locally or globally, if and only if, after an exchange of routing information, routing tables reach a stable state that does not change until the routing policies or the topology changes again.
To achieve the above-mentioned goals:

R(40) The routing system must provide a mechanism to publish and communicate policies so that operational coordination and fault isolation are possible.

Tools are required that verify the stability characteristics of the routing system in specified parts of the Internet. The tools should be efficient (fast) and have a broad scope of operation (check large portions of Internet). While these tools are not part of the architecture, developing them is in the interest of the architecture and should be defined as a Routing Research Group activity while research on the architecture is in progress.
Tools analyzing routing policies can be applied statically or (preferably) dynamically. Dynamic solution requires tools that can be used for run time checking for oscillations that arise from policy conflicts. Research is needed to find an efficient solution to the dynamic checking of oscillations.

3.6.7. Traffic Engineering

TOC

The ability to do traffic engineering and to get the feedback from the network to enable traffic engineering should be included in the future domain architecture. Though traffic engineering has many definitions, it is, at base, another alternative or extension for the path selection mechanisms of the routing system. No fundamental changes to the requirements are needed, but the iterative processes involved in traffic engineering may require some additional capabilities and state in the network.
Traffic engineering typically involves a combination of off-line network planning and administrative control functions in which the expected and measured traffic flows are examined, resulting in changes to static configurations and policies in the routing system. During

operations, these configurations control the actual flow of traffic and affect the dynamic path selection mechanisms; the results are measured and fed back into further rounds of network planning.

3.6.7.1. Support for, and Provision of, Traffic Engineering Tools

TOC

At present there is an almost total lack of effective traffic engineering tools, whether in real time for network control or off-line for network planning. The routing system should encourage the provision of such tools.

> **R(41)** The routing system must generate statistical and accounting information in such a way that traffic engineering and network planning tools can be used in both real time and off-line planning and management.

3.6.7.2. Support of Multiple Parallel Paths

TOC

> **R(42)** The routing system must support the controlled distribution over multiple links or paths of traffic toward the same destination. This applies to domains with two or more connections to the same neighbor domain, and to domains with connections to more than one neighbor domain. The paths need not have the same metric.
>
> **R(43)** The routing system must support forwarding over multiple parallel paths when available. This support should extend to cases where the offered traffic is known to exceed the available capacity of a single link, and to the cases where load is to be shared over paths for cost or resiliency reasons.
>
> **R(44)** Where traffic is forwarded over multiple parallel paths, the routing system must, so far as is possible, avoid reordering of packets in individual micro-flows.
>
> **R(45)** The routing system must have mechanisms to allow the traffic to be reallocated back onto a single path when multiple paths are not needed.

3.6.7.3. Peering Support

TOC

> **R(46)** The routing system must support peer-level connectivity as well as hierarchical connections between domains.

The network is becoming increasingly complex, with private peering arrangements set up between providers at every level of the hierarchy of service providers and even by certain large enterprises, in the form of dedicated extranets.

> **R(47)** The routing system must facilitate traffic engineering of peer routes so that traffic can be readily constrained to travel as the network operators desire, allowing optimal use of the available connectivity.

3.6.8. Support for Middleboxes

TOC

One of our assumptions is that NATs and other middle-boxes such as firewalls, web proxies and address family translators (e.g., IPv4 to IPv6) are here to stay.

> **R(48)** The routing system should work in conjunction with middle-boxes, e.g., NAT, to aid in bi-directional connectivity without compromising the additional opacity and privacy that the middle-boxes offer.

This problem is closely analogous to the abstraction problem, which is already under discussion for the interchange of routing information between domains.

3.7. Performance Requirements

TOC

Over the past several years, the performance of the routing system has frequently been discussed. The requirements that derive from those discussions are listed below. The specific values for these performance requirements are left for further discussion.

> **R(49)** The routing system must support domains of at least N systems. A system is taken to mean either an individual router or a domain.
>
> **R(50)** Local convergence should occur within T units of time.

R(51)

The routing system must be measurably reliable. The measure of reliability remains a research question.

R(52) The routing system must be locally stable to a measured degree. The degree of measurabilty remains a research issue.

R(53) The routing system must be globally stable to a measured degree. The degree of measurabilty remains a research issue.

R(54) The routing system should scale to an indefinitely large number of domains.

There has been very little data or statistical evidence for many of the performance claims made in the past. In recent years, several efforts have been initiated to gather data and do the analyses required to make scientific assessments of performance issues and requirements. In order to complete this section of the requirements analysis, the data and analyses from these studies needs to be gathered and collated into this document. This work has been started but has yet to be completed.

3.8. Backwards Compatibility (Cutover) and Maintainability

TOC

This area poses a dilemma. On one hand it is an absolute requirement that:

R(55) The introduction of the routing system must not require any flag days.

R(56) The network currently in place must continue to run at least as well as it does now while the new network is being installed around it.

However, at the same time, it is also an requirement that:

R(57) The new architecture must not be limited by the restrictions that plague today's network.

It has to be admitted that R(57) is not a well defined requirement, because we have not fully articulated what the restrictions might be. Some of these restrictions can be derived by reading the discussions for the positive requirements above. It would be a useful exercise to explicitly list all the restrictions and irritations that we wish to do away with. It would be further useful to determine if these restrictions can currently be removed at reasonable cost or whether we are actually condemned to live with them.

Those restrictions cannot be allowed to become permanent baggage on the new architecture. If they do, the effort to create a new system will come to naught. It may, however, be necessary to live with some of them temporarily for practical reasons while providing an architecture which will eventually allow them to be removed. The last three requirements have significance not only for the transition strategy, but also for the architecture itself. They imply that it must be possible for an internet such as today's BGP-controlled network, or one of its AS's, to exist as a domain within the new FDR.

3.9. Security Requirements

TOC

As previously discussed, one of the major changes that has overtaken the Internet since its inception is the erosion of trust between end users making use of the net, between those users and the suppliers of services, and between the multiplicity of providers. Hence security, in all its aspects, will be much more important in the FDR.
It must be possible to secure the routing communication.

> **R(58)** The communicating entities must be able to identify who sent and who received the information (authentication).
>
> **R(59)** The communicating entities must be able to verify that the information has not been changed on the way (integrity).

Security is more important in inter-domain routing where the operator has no control over the other domains, than in intra-domain routing where all the links and the nodes are under the administration of the operator and can be expected to share a trust relationship. This property of intra-domain trust, however, should not be taken for granted:

> **R(60)** Routing communications must be secured by default, but an operator must have the option to relax this requirement within a domain where analysis indicates that other means (such as physical security) provide an acceptable alternative.
>
> **R(61)** The routing communication mechanism must be robust against denial-of-service attacks.
>
> **R(62)** It should be possible to verify that the originator of the information was authorized to generate the information.

Further considerations that may impose further requirements include:

> - whether no one else but the intended recipient is able to access (privacy) or understand (confidentiality) the information,

-

  whether it is possible to verify that all the information has been received and that the two parties agree on what was sent (validation and non-repudiation),

- whether there is a need to separate security of routing from security of forwarding, and

- whether traffic flow security is needed (i.e., whether there is value in concealing who can connect to whom, and what volumes of data are exchanged).

Securing the BGP session, as done today, only secures the exchange of messages from the peering domain, not the content of the information. In other words, we can confirm that the information we got is what our neighbor really sent us, but we do not know whether this information (that originated in some remote domain) is true or not.
A decision has to be made on whether to rely on chains of trust (we trust our peers who trust their peers who..), or whether we also need authentication and integrity of the information end-to-end. This information includes both routes and addresses. There has been interest in having digital signatures on originated routes as well as countersignatures by address authorities to confirm that the originator has authority to advertise the prefix. Even understanding who can confirm the authority is non-trivial, as it might be the provider who delegated the prefix (with a whole chain of authority back to ICANN) or it may be an address registry. Where a prefix delegated by a provider is being advertised through another provider as in multi-homing, both may have to be involved to confirm that the prefix may be advertised through the provider who doesn't have any interest in the prefix!

R(63) The routing system must cooperate with the security policies of middle-boxes whenever possible.

This is likely to involve further requirements for abstraction of information. For example, a firewall that is seeking to minimize interchange of information that could lead to a security breach. The effect of such changes on the end-to-end principle should be carefully considered as discussed in [Blumenthal01] (Blumenthal, M. and D. Clark, “Rethinking the design of the Internet: The end to end arguments vs. the brave new world,” May 2001.).

R(64) The routing system must be capable of complying with local legal requirements for interception of communication.

TOC

3.10. Debatable Issues

This section covers issues that need to be considered and resolved in deciding on a Future Domain Routing architecture. While they can't be described as requirements, they do affect the types of solution that are acceptable. The discussions included below are very open- ended.

3.10.1. Network Modeling

TOC

The mathematical model that underlies today's routing system uses a graph representation of the network. Hosts, routers and other processing boxes are represented by nodes and communications links by arcs. This is a topological model in that routing does not need to directly model the physical length of the links or the position of the nodes; the model can be transformed to provide a convenient picture of the network by adjusting the lengths of the arcs and the layout of the nodes. The connectivity is preserved and routing is unaffected by this transformation.
The routing algorithms in traditional routing protocols utilize a small number of results from graph theory. It is only recently that additional results have been employed to support constraint-based routing for traffic engineering.
The naturalness of this network model and the 'fit' of the graph theoretical methods may have tended to blind us to alternative representations and inhibited us from seeking alternative strands of theoretical thinking that might provide improved results.
We should not allow this habitual behavior to stop us looking for alternative representations and algorithms; topological revolutions are possible and allowed, at least in theory.

3.10.2. System Modeling

TOC

The assumption that object modeling of a system is an essential first step to creating a new system is still novel in this context.
Frequently the object modeling effort becomes an end in itself and does not lead to system creation. But there is a balance, and a lot that can be discovered in an ongoing effort to model a system such as the Future Domain Routing system. It is recommended that this process be included in the requirements. It should not, however, be a gating event to all other work.
Some of the most important realizations will occur during the process of determining the following:

- Object classification

- Relationships and containment

- Roles and Rules

3.10.3. One, Two or Many Protocols

TOC

There has been a lot of discussion of whether the FDR protocol solution should consist of one (probably new) protocol, two (intra- and inter-domain) protocols, or many protocols. While it might be best to have one protocol that handles all situations, this seems improbable. On the other hand, maintaining the 'strict' division evident in the network today between the IGP and EGP may be too restrictive an approach. Given this, and the fact that there are already many routing protocols in use, the only possible answer seems to be that the architecture should support many protocols. It remains an open issue, one for the solution, to determine if a new protocol needs to be designed in order to support the highest goals of this architecture. The expectation is that a new protocol will be needed.

3.10.4. Class of Protocol

TOC

If a new protocol is required to support the FDR architecture, the question remains open as to what kind of protocol this ought to be. It is our expectation that a map distribution protocol will be required to augment the current path-vector protocol and shortest path first protocols.

3.10.5. Map Abstraction

TOC

Assuming that a map distribution protocol, as defined in [RFC1992] (Castineyra, I., Chiappa, N., and M. Steenstrup, “The Nimrod Routing Architecture,” August 1996.) is required, what are the requirements on this protocol? If every detail is advertised throughout the Internet, there will be a lot of information. Scalable solutions require abstraction.

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  If we summarise too much, some information will be lost on the way.

- If we summarise too little, then more information than required is available, contributing to scaling limitations.

- One can allow more summarisation, if there also is a mechanism to query for more details within policy limits.

- The basic requirement is not that the information shall be advertised, but rather that the information shall be available to those who need it. We should not presuppose a solution where advertising is the only possible mechanism.

3.10.6. Clear Identification for All Entities

TOC

As in all other fields, the words used to refer to concepts and to describe operations about routing are important. Rather than describe concepts using terms that are inaccurate or rarely used in the real world of networking, it is necessary to make an effort to use the correct words. Many networking terms are used casually, and the result is a partial or incorrect understanding of the underlying concept. Entities such as nodes, interfaces, sub-networks, tunnels, and the grouping concepts such as AS's, domains, areas, and regions, need to be clearly identified and defined to avoid confusion.
There is also a need to separate identifiers (what or who) from locators (where) from routes (how to reach).

> Editors' Note: Work was undertaken in the shim6 working group of the IETF on this sort of separation. This work needs to be taken into account in any new routing architecture.

3.10.7. Robustness and Redundancy

TOC

The routing association between two domains should survive even if some individual connection between two routers goes down.
The "session" should operate between logical "routing entities" on each domain side, and not necessarily be bound to individual routers or addresses. Such a logical entity can be physically distributed over multiple network elements. Or it can reside in a single router, which would default to the current situation.

3.10.8. Hierarchy

TOC

A more flexible hierarchy with more levels and recursive groupings in both upward and downward directions allows more structured routing. The consequence is that no single level will get too big for routers to handle.
On the other hand, it appears that the real world Internet is becoming less hierarchical, so that it will be increasingly difficult to use hierarchy to control scaling.
Note that groupings can look different depending on which aspect we use to define them. A DiffServ area, an MPLS domain, a trusted domain, a QoS area, a multicast domain, etc., do not always coincide. But neither are they strict hierarchical subsets of each other. The basic distinction at each level is "this grouping versus everything outside".

3.10.9. Control Theory

TOC

Is it possible to apply a control theory framework to analyze the stability of the control system of the whole network domain, with regards to e.g., convergence speed and the frequency response, and then use the results from that analysis to set the timers and other protocol parameters?
Control theory could also play a part in QoS Routing, by modifying current link state protocols with link costs dependent on load and feedback. Control theory is often used to increase the stability of dynamic systems.
It might be possible to construct a new, totally dynamic routing protocol solely on a control theoretic basis, as opposed to the current protocols that are based in graph theory and static in nature.

3.10.10. Byzantium

TOC

Is solving the Byzantine Generals problem a requirement? This is the problem of reaching a consensus among distributed units if some of them give misleading answers. The current intra-domain routing system is, at one level, totally intolerant of misleading information. However, the effect of different sorts of misleading or incorrect information has vastly varying results, from total collapse to purely local disconnection of a single domain. This sort of behavior is not very desirable.

There are, possibly, other network robustness issues that must be researched and resolved.

3.10.11. VPN Support

TOC

Today BGP is also used for VPNs, for example as described in RFC4364 [RFC4364] (Rosen, E. and Y. Rekhter, “BGP/MPLS IP Virtual Private Networks (VPNs),” February 2006.).
Internet routing and VPN routing have different purposes and most often exchange different information between different devices. Most Internet routers do not need to know VPN-specific information. The concepts should be clearly separated.
But when it comes to the mechanisms, VPN routing can share the same protocol as ordinary Internet routing; it can use a separate instance of the same protocol or it can use a different protocol. All variants are possible and have their own merits. These requirements are silent on this issue.

3.10.12. End-to-End Reliability

TOC

The existing Internet architecture neither requires nor provides end-to-end reliability of control information dissemination. There is, however, already a requirement for end-to-end reliability of control information distribution, i.e., the ends of the VPN established need to have an acknowledgment of the success in setting up the VPN. While it is not necessarily the function of a routing architecture to provide end-to-end reliability for this kind of purpose, we must be clear that end-to-end reliability becomes a requirement if the network has to support such reliable control signaling. There may be other requirements that derive from requiring the FDR to support reliable control signaling.

3.10.13. End-to-End Transparency

TOC

The introduction of private addressing schemes, Network Address Translators, and firewalls has significantly reduced the end-to-end transparency of the network. In many cases the network is also no longer symmetric, so that communication between two addresses is possible if the communication session originates from one end but not from the other. This impedes the deployment of new peer-to-peer services and some 'push' services where the server in a client- server

arrangement originates the communication session. Whether a new routing system either can or should seek to restore this transparency is an open issue.
A related issue is the extent to which end user applications should seek to control the routing of communications to the rest of the network.

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4. Security Considerations

TOC

We address security issues in the individual requirements. We do require that the architecture and protocols developed against this set of requirements be "secure". Discussion of specific security issues can be found in the following sections:

*Group A: Routing System Security - Section 2.1.9 (Routing System Security)

*Group A: End Host Security - Section 2.1.10 (End Host Security)

*Group A: Routing Information Policies - Section 2.1.11.1 (Routing Information Policies)

*Group A: Abstraction - Section 2.1.16 (Abstraction)

*Group A: Robustness - Section 2.1.18 (Robustness)

*Group B: Protection against denial of service and other security attacks - Section 3.2.3.8 (Protection Against Denial of Service and Other Security Attacks)

*Group B: Commercial service providers - Section 3.3.1.1 (Commercial Service providers)

*Group B: The Federated Environment - Section 3.4.1 (The Federated Environment)

*Group B: Path advertisement - Section 3.6.2.2 (Path Advertisement)

*Group B: Security Requirements - Section 3.9 (Security Requirements)

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5. IANA Considerations

This document is a set of requirements from which a new routing and addressing architecture may be developed. From that architecture, a new protocol, or set of protocols, may be developed.
While this note poses no new tasks for IANA, the architecture and protocols developed from this document probably will have issues to be dealt with by IANA.

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TOC

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7. Informative References

TOC

[Blumenthal01]	Blumenthal, M. and D. Clark, “Rethinking the design of the Internet: The end to end arguments vs. the brave new world,” May 2001.
[Broido02]	Broido, A., Nemeth, E., Claffy, K., and C. Elves, “Internet Expansion, Refinement and Churn,” February 2002.
[CIDR]	Telcordia Technologies, “CIDR Report.”
[Chiappa02]	Chiappa, N., “A New IP Routing and Addressing Architecture,” July 1991.
[Clark91]	Clark, D., “Quote reportedly from IETF Plenary discussion,” 1991.
[Griffin99]	Griffin, T. and G. Wilfong, “An Analysis of BGP Convergence Properties,” SIGCOMM , 1999.
[I-D.ietf-diffserv-pdb-ar]	Seddigh, N., Nandy, B., and J. Heinanen, “An Assured Rate Per-Domain Behaviour for Differentiated Services,” draft-ietf-diffserv-pdb-ar-01 (work in progress), February 2001.
[I-D.ietf-diffserv-pdb-vw]	Jacobson, V., Nichols, K., and K. Poduri, “The 'Virtual Wire' Behavior Aggregate,” draft-ietf-diffserv-pdb-vw-00 (work in progress), July 2000.
[I-D.irtf-routing-history]	

	Davies, E., “Analysis of IDR requirements and History,” draft-irtf-routing-history-06 (work in progress), August 2006.
[I-D.many-inference-srlg]	Papadimitriou, D. and others, “Inference of Shared Risk Link Groups,” draft-many-inference-srlg-02 (work in progress), February 2002.
[ISO10747]	ISO/IEC, “Protocol for Exchange of Inter-Domain Routeing Information among Intermediate Systems to Support Forwarding of ISO 8473 PDUs,” International Standard 10747 ISO/IEC JTC 1, Switzerland, 1993.
[ODell01]	O'Dell, M., “Private Communication,” 2001.
[RFC1126]	Little, M., “Goals and functional requirements for inter-autonomous system routing,” RFC 1126, October 1989 (TXT).
[RFC1726]	Partridge, C. and F. Kastenholz, “Technical Criteria for Choosing IP The Next Generation (IPng),” RFC 1726, Dec 1994.
[RFC1992]	Castineyra, I., Chiappa, N., and M. Steenstrup, “The Nimrod Routing Architecture,” RFC 1992, August 1996 (TXT).
[RFC2071]	Ferguson, P. and H. Berkowitz, “Network Renumbering Overview: Why would I want it and what is it anyway?,” RFC 2071, January 1997 (TXT).
[RFC2072]	Berkowitz, H., “Router Renumbering Guide,” RFC 2072, January 1997 (TXT).
[RFC3031]	Rosen, E., Viswanathan, A., and R. Callon, “Multiprotocol Label Switching Architecture,” RFC 3031, January 2001 (TXT).
[RFC3221]	Huston, G., “Commentary on Inter-Domain Routing in the Internet,” RFC 3221, December 2001 (TXT).
[RFC3260]	Grossman, D., “New Terminology and Clarifications for Diffserv,” RFC 3260, April 2002.
[RFC3344]	Perkins, C., “IP Mobility Support.,” RFC 3344, August 2002.
[RFC3345]	McPherson, D., Gill, V., Walton, D., and A. Retana, “Border Gateway Protocol (BGP) Persistent Route Oscillation Condition,” RFC 3345, August 2002 (TXT).
[RFC3471]	Berger, L., “Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description,” RFC 3471, January 2003 (TXT).
[RFC3963]	Devarapalli, V., Wakikawa, R., Petrescu, A., and P. Thubert, “Network Mobility (NEMO) Basic Support Protocol,” RFC 3963, January 2005 (TXT).
[RFC4364]	Rosen, E. and Y. Rekhter, “BGP/MPLS IP Virtual Private Networks (VPNs),” RFC 4364, February 2006 (TXT).

[Wroclawski95]	Wroclowski, J., “The Metanet White Paper - Workshop on Research Directions for the Next Generation Internet,” 1995.
[netconf-charter]	Internet Engineering Task Force, “IETF Network Configuration working group,” 2005.
[policy-charter02]	Internet Engineering Task Force, “IETF Policy working group,” 2002.
[rap-charter02]	Internet Engineering Task Force, “IETF Resource Allocation Protocol working group,” 2002.
[snmpconf-charter02]	Internet Engineering Task Force, “IETF Configuration management with SNMP working group,” 2002.

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