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The Recommendation for the IP Next Generation Protocol

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Abstract

This document presents the recommendation of the IPng Area Directors on what should be used to replace the current version of the Internet Protocol. This recommendation was accepted by the Internet Engineering Steering Group (IESG).

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1. Summary

The IETF started its effort to select a successor to IPv4 in late 1990 when projections indicated that the Internet address space would become an increasingly limiting resource. Several parallel efforts then started exploring ways to resolve these address limitations while at the same time providing additional functionality. The IETF formed the IPng Area in late 1993 to investigate the various proposals and recommend how to proceed. We developed an IPng technical criteria document and evaluated the various proposals against it. All were found wanting to some degree. After this evaluation, a revised proposal was offered by one of the working

groups that resolved many of the problems in the previous proposals. The IPng Area Directors recommend that the IETF designate this revised proposal as the IPng and focus its energy on bringing a set of documents defining the IPng to Proposed Standard status with all deliberate speed.

This protocol recommendation includes a simplified header with a hierarchical address structure that permits rigorous route aggregation and is also large enough to meet the needs of the Internet for the foreseeable future. The protocol also includes packet-level authentication and encryption along with plug and play autoconfiguration. The design changes the way IP header options are encoded to increase the flexibility of introducing new options in the future while improving performance. It also includes the ability to label traffic flows.

Specific recommendations include:

* current address assignment policies are adequate
* there is no current need to reclaim underutilized assigned network numbers
* there is no current need to renumber major portions of the Internet
* CIDR-style assignments of parts of unassigned Class A address space should be considered
* "Simple Internet Protocol Plus (SIPP) Spec. (128 bit ver)" [Deering94b] be adopted as the basis for IPng
* the documents listed in Appendix C be the foundation of the IPng effort
* an IPng Working Group be formed, chaired by Steve Deering and Ross Callon
* Robert Hinden be the document editor for the IPng effort
* an IPng Reviewer be appointed and that Dave Clark be the reviewer
* an Address Autoconfiguration Working Group be formed, chaired by Dave Katz and Sue Thomson
* an IPng Transition Working Group be formed, chaired by Bob Gilligan and TBA
* the Transition and Coexistence Including Testing Working Group be chartered
* recommendations about the use of non-IPv6 addresses in IPv6 environments and IPv6 addresses in non-IPv6 environments be developed
* the IESG commission a review of all IETF standards documents for IPng implications
* the IESG task current IETF working groups to take IPng into account
* the IESG charter new working groups where needed to revise old standards documents
* Informational RFCs be solicited or developed describing a few specific IPng APIs

* the IPng Area and Area Directorate continue until main documents are offered as Proposed Standards in late 1994
* support for the Authentication Header be required
* support for a specific authentication algorithm be required
* support for the Privacy Header be required
* support for a specific privacy algorithm be required
* an "IPng framework for firewalls" be developed

2. Background

Even the most farseeing of the developers of TCP/IP in the early 1980s did not imagine the dilemma of scale that the Internet faces today. 1987 estimates projected a need to address as many as 100,000 networks at some vague point in the future. [Callon87] We will reach that mark by 1996. There are many realistic projections of many millions of interconnected networks in the not too distant future. [Vecchi94, Taylor94]

Further, even though the current 32 bit IPv4 address structure can enumerate over 4 billion hosts on as many as 16.7 million networks, the actual address assignment efficiency is far less than that, even on a theoretical basis. [Huitema94] This inefficiency is exacerbated by the granularity of assignments using Class A, B and C addresses.

In August 1990 during the Vancouver IETF meeting, Frank Solensky, Phill Gross and Sue Hares projected that the current rate of assignment would exhaust the Class B space by March of 1994.

The then obvious remedy of assigning multiple Class C addresses in place of Class B addresses introduced its own problem by further expanding the size of the routing tables in the backbone routers already growing at an alarming rate.

We faced the dilemma of choosing between accepting either limiting the rate of growth and ultimate size of the Internet, or disrupting the network by changing to new techniques or technologies.

The IETF formed the Routing and Addressing (ROAD) group in November 1991 at the Santa Fe IETF meeting to explore this dilemma and guide the IETF on the issues. The ROAD group reported their work in March 1992 at the San Diego IETF meeting. [Gross92] The impact of the recommendations ranged from "immediate" to "long term" and included adopting the CIDR route aggregation proposal [Fuller93] for reducing the rate of routing table growth and recommending a call for proposals "to form working groups to explore separate approaches for bigger Internet addresses."

In the late spring of 1992 the IAB issued "IP version 7" [IAB92], concurring in the ROAD group's endorsement of CIDR and also recommending "an immediate IETF effort to prepare a detailed and organizational plan for using CLNP as the basis for IPv7." After spirited discussion, the IETF decided to reject the IAB's recommendation and issue the call for proposals recommended by the ROAD group. This call was issued in July 1992 at the Boston IETF meeting and a number of working groups were formed in response

During the July 1993 Amsterdam IETF meeting an IPng (IP Next Generation) Decision Process (ipdecide) BOF was held. This BOF "was intended to help re-focus attention on the very important topic of making a decision between the candidates for IPng. The BOF focused on the issues of who should take the lead in making the recommendation to the community and what criteria should be used to reach the recommendation." [Carpen93]

3. A Direction for IPng

In September 1993 Phill Gross, chair of the IESG issued "A Direction for IPng". [Gross94] In this memo he summarized the results of the ipdecide BOF and open IESG plenary in Amsterdam.

* The IETF needs to move toward closure on IPng.
* The IESG has the responsibility for developing an IPng recommendation for the Internet community.
* The procedures of the recommendation-making process should be open and published well in advance by the IESG.
* As part of this process, the IPng WGs may be given new milestones and other guidance to aid the IESG.
* There should be ample opportunity for community comment prior to final IESG recommendation.

The memo also announced "a temporary, ad hoc, 'area' to deal specifically with IPng issues." Phill asked two of the current IESG members, Allison Mankin (Transport Services Area) and Scott Bradner (Operational Requirements Area), to act as Directors for the new area. The Area Directors were given a specific charge on how to investigate the various IPng proposals and how to base their recommendation to the IETF. It was also requested that a specific recommendation be made.

* Establish an IPng directorate.
* Ensure that a completely open process is followed.
* Develop an understanding of the level of urgency and the time constraints imposed by the rate of address assignment and rate of growth in the routing tables.
* Recommend the adoption of assignment policy changes if warranted.

* Define the scope of the IPng effort based on the understanding of the time constraints.
* Develop a clear and concise set of technical requirements and decision criteria for IPng.
* Develop a recommendation about which of the current IPng candidates to accept, if any.

4. IPng Area

After the IPng Area was formed, we recruited a directorate. (Appendix B) The members of the directorate were chosen both for their general and specific technical expertise. The individuals were then asked to have their management authorize this participation in the process and confirm that they understood the IETF process.

We took great care to ensure the inclusion of a wide spectrum of knowledge. The directors are experts in security, routing, the needs of large users, end system manufacturers, Unix and non-Unix platforms, router manufacturers, theoretical researchers, protocol architecture, and the operating regional, national, and international networks. Additionally, several members of the directorate were deeply involved in each of the IPng proposal working groups.

The directorate functions as a direction-setting and preliminary review body as requested by the charge to the area. The directorate engages in biweekly conference calls, participates in an internal mailing list and corresponds actively on the Big-Internet mailing list. The directorate held open meetings during the March 1994 Seattle and July 1994 Toronto IETF meetings as well as two additional multi-day retreats. To ensure that the IPng process was as open as possible, we took minutes during these meetings and then published them. Additionally, we placed the archives of the internal IPng mailing list on an anonymous ftp site. (Hsdndev.harvard.edu: pub/ipng.)

5. ALE Working Group

We needed a reasonable estimate of the time remaining before we exhausted the IPv4 address space in order to determine the scope of the IPng effort. If the time remaining was about the same needed to deploy a replacement, then we would have select the IPng which would only fix the address limitations since we would not have enough time to develop any other features. If more time seemed available, we could consider additional improvements.

The IETF formed an Address Lifetime Expectations (ALE) Working Group in 1993 "to develop an estimate for the remaining lifetime of the IPv4 address space based on currently known and available

technologies." [Solens93a] Tony Li of Cisco Systems and Frank Solensky of FTP Software are the co-chairs. The IETF also charged the working group to consider if developing more stringent address allocation and utilization policies might provide more time for the transition.

5.1 ALE Projections

The ALE Working Group met during the November 1993 Houston, [Solens93b] March 1994 Seattle [Bos93] and July 1994 Toronto [Solens94] IETF meetings. They projected at the Seattle meeting, later confirmed at the Toronto meeting that, using the current allocation statistics, the Internet would exhaust the IPv4 address space between 2005 and 2011.

Some members of the ipv4-ale and big-internet mailing lists called into question the reliability of this projection. It has been criticized as both too optimistic and as too pessimistic.

Some people pointed out that this type of projection makes an assumption of no paradigm shifts in IP usage. If someone were to develop a new 'killer application', (for example cable-TV set top boxes.) The resultant rise in the demand for IP addresses could make this an over-estimate of the time available.

There may also be a problem with the data used to make the projection. The InterNIC allocates IP addresses in large chunks to regional Network Information Centers (NICs) and network providers. The NICs and the providers then re-allocate addresses to their customers. The ALE projections used the InterNIC assignments without regard to the actual rate of assignment of addresses to the end users. They did the projection this way since the accuracy of the data seems quite a bit higher. While using this once-removed data may add a level of over-estimation since it assumes the rate of large block allocation will continue, this may not be the case.

These factors reduce the reliability of the ALE estimates but, in general, they seem to indicate enough time remaining in the IPv4 address space to consider adding features in an IPng besides just expanding the address size even when considering time required for development, testing, and deployment.

5.2 Routing Table Size

Another issue in Internet scaling is the increasing size of the routing tables required in the backbone routers. Adopting the CIDR block address assignment and aggregating routes reduced the size of the tables for awhile but they are now expanding again. Providers now

need to more aggressively advertise their routes only in aggregates. Providers must also advise their new customers to renumber their networks in the best interest of the entire Internet community.

The problem of exhausting the IPv4 address space may be moot if this issue is ignored and if routers cannot be found that can keep up with the table size growth. Before implementing CIDR the backbone routing table was growing at a rate about 1.5 times as fast as memory technology.

We should also note that even though IPng addresses are designed with aggregation in mind switching to IPng will not solve the routing table size problem unless the addresses are assigned rigorously to maximize the affect of such aggregation. This efficient advertising of routes can be maintained since IPng includes address autoconfiguration mechanisms to allow easy renumbering if a customer decides to switch providers. Customers who receive service from more than one provider may limit the ultimate efficiency of any route aggregation. [Rekhter94]

5.3 Address Assignment Policy Recommendations

The IESG Chair charged the IPng Area to consider recommending more stringent assignment policies, reclaiming some addresses already assigned, or making a serious effort to renumber significant portions of the Internet. [Gross94]

The IPng Area Directors endorse the current address assignment policies in view of the ALE projections. We do not feel that anyone should take specific efforts to reclaim underutilized addresses already assigned or to renumber forcefully major portions of the Internet. We do however feel that we should all encourage network service providers to assist new customers in renumbering their networks to conform to the provider’s CIDR assignments.

The ALE Working Group recommends that we consider assigning CIDR-type address blocks out of the unassigned Class A address space. The IPng Area Directors concur with this recommendation.

6. IPng Technical Requirements

The IESG provided an outline in RFC 1380 [Gross92] of the type of criteria we should use to determine the suitability of an IPng proposal. The IETF further refined this understanding of the appropriate criteria with the recommendations of a Selection Criteria BOF held during the November 1992 IETF meeting in Washington D.C. [Almqu92] We felt we needed to get additional input for determining the requirements and issued a call for white papers. [Bradner93] This

call, issued as RFC 1550, intended to reach both inside and outside the traditional IETF constituency to get the broadest possible understanding of the requirements for a data networking protocol with the broadest possible application.

We received twenty one white papers in response to the RFC 1550 solicitation. (Appendix E) We received responses from the industries that many feel will be the major providers of data networking services in the future; the cable TV industry [Vecchi94], the cellular industry [Taylor94], and the electric power industry [Skelton94]. In addition, we received papers that dealt with military applications [Adam94, Syming94, Green94], ATM [Brazd94], mobility [Simpson94], accounting [Brown94], routing [Estrin94a, Chiappa94], security [Adam94, Bell94b, Brit94, Green94, Vecchi94, Flei94], large corporate networking [Britt94, Fleisch94], transition [Carpen94a, Heager94], market acceptance [Curran94, Britt94], host implementations [Bound94], as well as a number of other issues. [Bello94a, Clark94, Ghisel94]

These white papers, a Next Generation Requirements (ngreq) BOF (chaired by Jon Crowcroft and Frank Kastenholz) held during the March 1994 Seattle IETF meeting, discussions within the IPng Area Directorate and considerable discussion on the big-internet mailing list were all used by Frank Kastenholz and Craig Partridge in revising their earlier criteria draft [Kasten92] to produce "Technical Criteria for Choosing IP The Next Generation (IPng)." [Kasten94] This document is the "clear and concise set of technical requirements and decision criteria for IPng" called for in the charge from the IESG Chair. We used this document as the basic guideline while evaluating the IPng proposals.

6.1 The IPng Technical Criteria document

The criteria described in this document include: (from Kasten94)

* complete specification - The proposal must completely describe the proposed protocol. We must select an IPng by referencing specific documents, not to future work.
* architectural simplicity - The IP-layer protocol should be as simple as possible with functions located elsewhere that are more appropriately performed at protocol layers other than the IP layer.
* scale - The IPng Protocol must allow identifying and addressing at least 10**9 leaf-networks (and preferably much more)
* topological flexibility - The routing architecture and protocols ofIPng must allow for many different network topologies. They must not assume that the network’s physical structure is a tree.
* performance - A state of the art, commercial grade router must be able to process and forward IPng traffic at speeds capable of fully

utilizing common, commercially available, high-speed media at the time.

* robust service - The network service and its associated routing and control protocols must be robust.
* transition - The protocol must have a straightforward transition plan from IPv4.
* media independence - The protocol must work across an internetwork of many different LAN, MAN, and WAN media, with individual link speeds ranging from a ones-of-bits per second to hundreds of gigabits per second.
* datagram service - The protocol must support an unreliable datagram delivery service.
* configuration ease - The protocol must permit easy and largely distributed configuration and operation. Automatic configuration of hosts and routers is required.
* security - IPng must provide a secure network layer.
* unique names - IPng must assign unique names to all IP-Layer objects in the global, ubiquitous, Internet. These names may or may not have any location, topology, or routing significance.
* access to standards - The protocols that define IPng and its associated protocols should be as freely available and redistributable as the IPv4 and related RFCs. There must be no specification-related licensing fees for implementing or selling IPng software.
* multicast support - The protocol must support both unicast and multicast packet transmission. Dynamic and automatic routing of multicasts is also required.
* extensibility - The protocol must be extensible; it must be able to evolve to meet the future service needs of the Internet. This evolution must be achievable without requiring network-wide software upgrades.
* service classes - The protocol must allow network devices to associate packets with particular service classes and provide them with the services specified by those classes.
* mobility - The protocol must support mobile hosts, networks and internetworks.
* control protocol - The protocol must include elementary support for testing and debugging networks. (e.g., ping and traceroute)
* tunneling support - IPng must allow users to build private internetworks on top of the basic Internet Infrastructure. Both private IP-based internetworks and private non-IP-based (e.g., CLNP or AppleTalk) internetworks must be supported.

7. IPng Proposals

By the time that the IPng Area was formed, the IETF had already aimed a considerable amount of IETF effort at solving the addressing and routing problems of the Internet. Several proposals had been made and some of these reached the level of having a working group chartered. A number of these groups subsequently merged forming groups with a larger consensus. These efforts represented different views on the issues which confront us and sought to optimize different aspects of the possible solutions.

By February 1992 the Internet community developed four separate proposals for IPng [Gross92], "CNAT" [Callon92a], "IP Encaps" [Hinden92a], "Nimrod" [Chiappa91], and "Simple CLNP" [Callon92b]. By December 1992 three more proposals followed; "The P Internet Protocol" (PIP) [Tsuchiya92], "The Simple Internet Protocol" (SIP) [Deering92] and "TP/IX" [Ullmann93]. After the March 1992 San Diego IETF meeting "Simple CLNP" evolved into "TCP and UDP with Bigger Addresses" (TUBA) [Callon92c] and "IP Encaps" evolved into "IP Address Encapsulation" (IPAE) [Hinden92b].

By November 1993, IPAE merged with SIP while still maintaining the name SIP. This group then merged with PIP and the resulting working group called themselves "Simple Internet Protocol Plus" (SIPP). At the same time the TP/IX Working Group changed its name to "Common Architecture for the Internet" (CATNIP).

None of these proposals were wrong nor were others right. All of the proposals would work in some ways providing a path to overcome the obstacles we face as the Internet expands. The task of the IPng Area was to ensure that the IETF understand the offered proposals, learn from the proposals and provide a recommendation on what path best resolves the basic issues while providing the best foundation upon which to build for the future.

The IPng Area evaluated three IPng proposals as they were described in their RFC 1550 white papers: CATNIP [McGovern94] , SIPP [Hinden94a] and TUBA. [Ford94a]. The IESG viewed Nimrod as too much of a research project for consideration as an IPng candidate. Since Nimrod represents one possible future Internet routing strategy we solicited a paper describing any requirements Nimrod would put on an IPng to add to the requirements process. [Chiappa94]

7.1 CATNIP

"Common Architecture for the Internet (CATNIP) was conceived as a convergence protocol. CATNIP integrates CLNP, IP, and IPX. The CATNIP design provides for any of the transport layer protocols in use, for

example TP4, CLTP, TCP, UDP, IPX and SPX, to run over any of the network layer protocol formats: CLNP, IP (version 4), IPX, and CATNIP. With some attention paid to details, it is possible for a transport layer protocol (such as TCP) to operate properly with one end system using one network layer (e.g., IP version 4) and the other using some other network protocol, such as CLNP." [McGovern94]

"The objective is to provide common ground between the Internet, OSI, and the Novell protocols, as well as to advance the Internet technology to the scale and performance of the next generation of internetwork technology."

"CATNIP supports OSI Network Service Access Point (NSAP) format addresses. It also uses cache handles to provide both rapid identification of the next hop in high performance routing as well as abbreviation of the network header by permitting the addresses to be omitted when a valid cache handle is available. The fixed part of the network layer header carries the cache handles." [Sukonnik94]

7.2 SIPP

"Simple Internet Protocol Plus (SIPP) is a new version of IP which is designed to be an evolutionary step from IPv4. It is a natural increment to IPv4. It was not a design goal to take a radical step away from IPv4. Functions which work in IPv4 were kept in SIPP. Functions which didn't work were removed. It can be installed as a normal software upgrade in internet devices and is interoperable with the current IPv4. Its deployment strategy was designed to not have any 'flag' days. SIPP is designed to run well on high performance networks (e.g., ATM) and at the same time is still efficient for low bandwidth networks (e.g., wireless). In addition, it provides a platform for new internet functionality that will be required in the near future." [Hinden94b]

"SIPP increases the IP address size from 32 bits to 64 bits, to support more levels of addressing hierarchy and a much greater number of addressable nodes. SIPP addressing can be further extended, in units of 64 bits, by a facility equivalent to IPv4's Loose Source and Record Route option, in combination with a new address type called 'cluster addresses' which identify topological regions rather than individual nodes."

"SIPP changes in the way IP header options are encoded allows for more efficient forwarding, less stringent limits on the length of options, and greater flexibility for introducing new options in the future. A new capability is added to enable the labeling of packets belonging to particular traffic 'flows' for which the sender requests special handling, such as non-default quality of service or 'real-

time' service." [Hinden94a]

7.3 TUBA

"The TCP/UDP Over CLNP-Addressed Networks (TUBA) proposal seeks to minimize the risk associated with migration to a new IP address space. In addition, this proposal is motivated by the requirement to allow the Internet to scale, which implies use of Internet applications in a very large ubiquitous worldwide Internet. It is therefore proposed that existing Internet transport and application protocols continue to operate unchanged, except for the replacement of 32-bit IP addresses with larger addresses. TUBA does not mean having to move over to OSI completely. It would mean only replacing IP with CLNP. TCP, UDP, and the traditional TCP/IP applications would run on top of CLNP." [Callon92c]

"The TUBA effort will expand the ability to route Internet packets by using addresses which support more hierarchy than the current Internet Protocol (IP) address space. TUBA specifies the continued use of Internet transport protocols, in particular TCP and UDP, but specifies their encapsulation in ISO 8473 (CLNP) packets. This will allow the continued use of Internet application protocols such as FTP, SMTP, TELNET, etc. TUBA seeks to upgrade the current system by a transition from the use of IPv4 to ISO/IEC 8473 (CLNP) and the corresponding large Network Service Access Point (NSAP) address space." [Knopper94]

"The TUBA proposal makes use of a simple long-term migration proposal based on a gradual update of Internet Hosts (to run Internet applications over CLNP) and DNS servers (to return larger addresses). This proposal requires routers to be updated to support forwarding of CLNP (in addition to IP). However, this proposal does not require encapsulation nor translation of packets nor address mapping. IP addresses and NSAP addresses may be assigned and used independently during the migration period. Routing and forwarding of IP and CLNP packets may be done independently." ([Callon92c]

8. IPng Proposal Reviews

The IPng Directorate discussed and reviewed the candidate proposals during its biweekly teleconferences and through its mailing list. In addition, members of the Big-Internet mailing list discussed many of the aspects of the proposals, particularly when the Area Directors posted several specific questions to stimulate discussion. [Big]

The directorate members were requested to each evaluate the proposals in preparation for a two day retreat held near Chicago on May 19th and 20th 1994. The retreat opened with a roundtable airing of the

views of each of the participants, including the Area Directors, the Directorate and a number of guests invited by the working group chairs for each for the proposals. [Knopper94b] We will publish these reviews as well as a more detailed compendium review of each of the proposals as companion memos.

The following table summarizes each of the three proposals reviewed against the requirements in the IPng Criteria document. They do not necessarily reflect the views of the Area Directors. "Yes" means the reviewers mainly felt the proposal met the specific criterion. "No" means the reviewers mainly felt the proposal did not meet the criterion. "Mixed" means that the reviewers had mixed reviews with none dominating. "Unknown" means that the reviewers mainly felt the documentation did not address the criterion.

	CATNIP	SIPP	TUBA
complete spec	no	yes	mostly
simplicity	no	no	no
scale	yes	yes	yes
topological flex	yes	yes	yes
performance	mixed	mixed	mixed
robust service	mixed	mixed	yes
transition	mixed	no	mixed
media indepdnt	yes	yes	yes
datagram	yes	yes	yes
config. ease	unknown	mixed	mixed
security	unknown	mixed	mixed
unique names	mixed	mixed	mixed
access to stds	yes	yes	mixed
multicast	unknown	yes	mixed
extensibility	unknown	mixed	mixed
service classes	unknown	yes	mixed
mobility	unknown	mixed	mixed
control proto	unknown	yes	mixed
tunneling	unknown	yes	mixed

8.1 CATNIP Reviews

All the reviewers felt that CATNIP is not completely specified. However, many of the ideas in CATNIP are innovative and a number of reviewers felt CATNIP shows the best vision of all of the proposals. The use of Network Service Attachment Point Addresses (NSAPs) is well thought out and the routing handles are innovative.

While the goal of uniting three major protocol families, IP, ISO-CLNP and Novell IPX is laudable our consensus was that the developers had not developed detailed enough plans to support realizing that goal.

The plans they do describe suffer from the complexity of trying to be the union of a number of existing network protocols. Some reviewers felt that CATNIP is basically maps IPv4, IPX, and SIPP addresses into NSAPs and, as such, does not deal with the routing problems of the current and future Internet.

Additionally the reviewers felt that CATNIP has poor support for multicasting and mobility and does not specifically deal with such important topics as security and autoconfiguration.

8.2 SIPP Reviews

Most of the reviewers, including those predisposed to other proposals, felt as one reviewer put it, that SIPP is an "aesthetically beautiful protocol well tailored to compactly satisfy today's known network requirements." The SIPP Working Group has been the most dynamic over the last year, producing a myriad of documentation detailing almost all of the aspects necessary to produce a complete protocol description.

The biggest problem the reviewers had with SIPP was with IPAE, SIPP's transition plan. The overwhelming feeling was that IPAE is fatally flawed and could not be made to work reliably in an operational Internet.

There was significant disagreement about the adequacy of the SIPP 64 bit address size. Although you can enumerate 10**15 end nodes in 64 bits people have different views about how much inefficiency real-world routing plans introduce. [Huitema94] The majority felt that 64 bit addresses do not provide adequate space for the hierarchy required to meet the needs of the future Internet. In addition since no one has any experience with extended addressing and routing concepts of the type proposed in SIPP, the reviewers generally felt quite uncomfortable with this methodology. The reviewers also felt that the design introduces some significant security issues.

A number of reviewers felt that SIPP did not address the routing issue in any useful way. In particular, there has been no serious attempt made at developing ways to abstract topology information or to aggregate information about areas of the network.

Finally, most of the reviewers questioned the level of complexity in the SIPP autoconfiguration plans as well as in SIPP in general, other than the header itself.

8.3 TUBA Reviews

The reviewers generally felt that the most important thing that TUBA has offers is that it is based on CLNP and there is significant deployment of CLNP-capable routers throughout the Internet. There was considerably less agreement that there was significant deployment of CLNP-capable hosts or actual networks running CLNP. Another strong positive for TUBA is the potential for convergence of ISO and IETF networking standards. A number of reviewers pointed out that, if TUBA were to be based on a changed CLNP then the advantage of an existing deployed infrastructure would be lost and that the convergence potential would be reduced.

A number of aspects of CLNP were felt to be a problem by the reviewers including the inefficiencies introduced by the lack of any particular word alignment of the header fields, CLNP source route, the lack of a flow ID field, the lack of a protocol ID field, and the use of CLNP error messages in TUBA. The CLNP packet format or procedures would have to be modified to resolve at least some of these issues.

There seems to be a profound disagreement within the TUBA community over the question of the ability of the IETF to modify the CLNP standards. In our presentation in Houston we said that we felt that "clone and run" was a legitimate process. This is also what the IAB proposed in "IP version 7". [IAB92] The TUBA community has not reached consensus that this view is reasonable. While many, including a number of the CLNP document authors, are adamant that this is not an issue and the IETF can make modifications to the base standards, many others are just as adamant that the standards can only be changed through the ISO standards process. Since the overwhelming feeling within the IETF is that the IETF must ’own’ the standards on which it is basing its future, this disagreement within the TUBA community was disquieting.

For a number of reasons, unfortunately including prejudice in a few cases, the reviews of the TUBA proposals were much more mixed than for SIPP or CATNIP. Clearly TUBA meets the requirements for the ability to scale to large numbers of hosts, supports flexible topologies, is media independent and is a datagram protocol. To the reviewers, it was less clear that TUBA met the other IPng requirements and these views varied widely.

There was also disagreement over the advisability of using NSAPs for routing given the wide variety of NSAP allocation plans. The Internet would have to restrict the use of NSAPs to those which are allocated with the actual underlying network topology in mind if the required degree of aggregation of routing information is to be

achieved.

8.4 Summary of Proposal Reviews

To summarize, significant problems were seen in all three of the proposals. The feeling was that, to one degree or another, both SIPP and TUBA would work in the Internet context but each exhibited its own problems. Some of these problems would have to be rectified before either one would be ready to replace IPv4, much less be the vehicle to carry the Internet into the future. Other problems could be addressed over time. CATNIP was felt to be too incomplete to be considered.

9. A Revised Proposal

As mentioned above, there was considerable discussion of the strengths and weaknesses of the various IPng proposals during the IPng 'BigTen' retreat on May 19th and 20th 1994. [Knopper94b] After this retreat Steve Deering and Paul Francis, two of the co-chairs of the SIPP Working Group, sent a message to the sipp mailing list detailing the discussions at the retreat and proposing some changes in SIPP. [Deering94a]

The message noted "The recurring (and unsurprising) concerns about SIPP were:

(1) complexity/manageability/feasibility of IPAE, and

(2) adequacy/correctness/limitations of SIPP's addressing and routing model, especially the use of loose source routing to accomplish 'extended addressing'".

They "proposed to address these concerns by changing SIPP as follows:

* Change address size from 8 bytes to 16 bytes (fixed-length).

* Specify optional use of serverless autoconfiguration of the 16-byte address by using IEEE 802 address as the low-order ("node ID") part.

* For higher-layer protocols that use internet-layer addresses as part of connection identifiers (e.g., TCP), require that they use the entire 16-byte addresses.

* Do *not* use Route Header for extended addressing."

After considerable discussion on the sipp and big-internet mailing lists about these proposed changes, the SIPP working group published a revised version of SIPP [Deering94b], a new addressing architecture [Francis94], and a simplified transition mechanism [Gillig94a]. These were submitted to the IPng Directorate for their consideration.

This proposal represents a synthesis of multiple IETF efforts with much of the basic protocol coming from the SIPP effort, the autoconfiguration and transition portions influenced by TUBA, the addressing structure is based on the CIDR work and the routing header evolving out of the SDRP deliberations.

10. Assumptions

10.1 Criteria Document and Timing of Recommendation

In making the following recommendations we are making two assumptions of community consensus; that the IPng criteria document represents the reasonable set of requirements for an IPng, and that a specific recommendation should be made now and that from this point on the IETF should proceed with a single IPng effort.

As described above, the IPng Technical Criteria document [Kasten94] was developed in a open manner and was the topic of extensive discussions on a number of mailing lists. We believe that there is a strong consensus that this document accurately reflects the community's set of technical requirements which an IPng should be able to meet.

A prime topic of discussion on the big-internet mailing list this spring as well as during the open IPng directorate meeting in Seattle, was the need to make a specific IPng recommendation at this time. Some people felt that additional research would help resolve some of the issues that are currently unresolved. While others argued that selecting a single protocol to work on would clarify the picture for the community, focus the resources of the IETF on finalizing its details, and, since the argument that there were open research items could be made at any point in history, there might never be a 'right' time.

Our reading of the community is that there is a consensus that a specific recommendation should be made now. This is consistent with the views expressed during the ipdecide BOF in Amsterdam [Gross94] and in some of the RFC 1550 white papers [Carpen94a].

There is no particular reason to think that the basic recommendation would be significantly different if we waited for another six months or a year. Clearly some details which are currently unresolved could

be filled in if the recommendation were to be delayed, but the current fragmentation of the IETF's energies limits the efficiency of this type of detail resolution. Concentrating the resources of the IETF behind a single effort seems to us to be a more efficient way to proceed.

10.2 Address Length

One of the most hotly discussed aspects of the IPng design possibilities was address size and format. During the IPng process four distinct views were expressed about these issues:

1. The view that 8 bytes of address are enough to meet the current and future needs of the Internet (squaring the size of the IP address space). More would waste bandwidth, promote inefficient assignment, and cause problems in some networks (such as mobiles and other low speed links).

2. The view that 16 bytes is about right. That length supports easy auto-configuration as well as organizations with complex internal routing topologies in conjunction with the global routing topology now and well into the future.

3. The view that 20 byte OSI NSAPs should be used in the interests of global harmonization.

4. The view that variable length addresses which might be smaller or larger than 16 bytes should be used to embrace all the above options and more, so that the size of the address could be adjusted to the demands of the particular environment, and to ensure the ability to meet any future networking requirements.

Good technical and engineering arguments were made for and against all of these views. Unanimity was not achieved, but we feel that a clear majority view emerged that the use of 16 byte fixed length addresses was the best compromise between efficiency, functionality, flexibility, and global applicability. [Mankin94]

11. IPng Recommendation

After a great deal of discussion in many forums and with the consensus of the IPng Directorate, we recommend that the protocol described in "Simple Internet Protocol Plus (SIPP) Spec. (128 bit ver)" [Deering94b] be adopted as the basis for IPng, the next generation of the Internet Protocol. We also recommend that the other documents listed in Appendix C be adopted as the basis of specific features of this protocol.

This proposal resolves most of the perceived problems, particularly in the areas of addressing, routing, transition and address autoconfiguration. It includes the broad base of the SIPP proposal effort, flexible address autoconfiguration features, and a merged transition strategy. We believe that it meets the requirements outlined in the IPng Criteria document and provides the framework to fully meet the needs of the greater Internet community for the foreseeable future.

11.1 IPng Criteria Document and IPng

A detailed review of how IPng meets the requirements set down in the IPng Criteria document [Kasten94] will soon be published. Following is our feelings about the extent to which IPng is responsive to the criteria.

* complete specification - the base specifications for IPng are complete but transition and address autoconfiguration do remain to be finalized
* architectural simplicity - the protocol is simple, easy to explain and uses well established paradigms
* scale - an address size of 128 bits easily meets the need to address 10**9 networks even in the face of the inherent inefficiency of address allocation for efficient routing
* topological flexibility - the IPng design places no constraints on network topology except for the limit of 255 hops
* performance - the simplicity of processing, the alignment of the fields in the headers, and the elimination of the header checksum will allow for high performance handling of IPng data streams
* robust service - IPng includes no inhibitors to robust service and the addition of packet-level authentication allows the securing of control and routing protocols without having to have separate procedures
* transition - the IPng transition plan is simple and realistically covers the transition methods that will be present in the marketplace
* media independence - IPng retains IPv4’s media independence, it may be possible to make use of IPng’s Flow Label in some connection-oriented media such as ATM
* datagram service - IPng preserves datagram service as its basic operational mode, it is possible that the use of path MTU discovery will complicate the use of datagrams in some cases
* configuration ease - IPng will have easy and flexible address autoconfiguration which will support a wide variety of environments from nodes on an isolated network to nodes deep in a complex internet
* security - IPng includes specific mechanisms for authentication and encryption at the internetwork layer; the security features do rely

on the presence of a yet to be defined key management system
* unique names - IPng addresses may be used as globally unique names although they do have topological significance
* access to standards - all of the IPng standards will be published as RFCs with unlimited distribution
* multicast support - IPng specifically includes multicast support
* extensibility - the use of extension headers and an expandable header option feature will allow the introduction of new features into IPng when needed in a way that minimizes the disruption of the existing network
* service classes - the IPng header includes a Flow Label which may be used to differentiate requested service classes
* mobility - the proposed IPv4 mobility functions will work with IPng
* control protocol - IPng includes the familiar IPv4 control protocol features
* tunneling support - encapsulation of IPng or other protocols within IPng is a basic capability described in the IPng specifications

11.2 IPv6

The IANA has assigned version number 6 to IPng. The protocol itself will be called IPv6.

The remainder of this memo is used to describe IPv6 and its features. This description is an overview snapshot. The standards documents themselves should be referenced for definitive specifications. We also make a number of specific recommendations concerning the details of the proposed protocol, the procedures required to complete the definition of the protocol, and the IETF working groups we feel are necessary to accomplish the task.

12. IPv6 Overview

IPv6 is a new version of the Internet Protocol, it has been designed as an evolutionary, rather than revolutionary, step from IPv4. Functions which are generally seen as working in IPv4 were kept in IPv6. Functions which don’t work or are infrequently used were removed or made optional. A few new features were added where the functionality was felt to be necessary.

The important features of IPv6 include: [Hinden94c]

* expanded addressing and routing capabilities - The IP address size is increased from 32 bits to 128 bits providing support for a much greater number of addressable nodes, more levels of addressing hierarchy, and simpler auto-configuration of addresses.

The scaleability of multicast routing is improved by adding a "scope" field to multicast addresses.

A new type of address, called a "cluster address" is defined to identify topological regions rather than individual nodes. The use of cluster addresses in conjunction with the IPv6 source route capability allows nodes additional control over the path their traffic takes.

* simplified header format - Some IPv4 header fields have been dropped or made optional to reduce the common-case processing cost of packet handling and to keep the bandwidth overhead of the IPv6 header as low as possible in spite of the increased size of the addresses. Even though the IPv6 addresses are four time longer than the IPv4 addresses, the IPv6 header is only twice the size of the IPv4 header.

* support for extension headers and options - IPv6 options are placed in separate headers that are located in the packet between the IPv6 header and the transport-layer header. Since most IPv6 option headers are not examined or processed by any router along a packet's delivery path until it arrives at its final destination, this organization facilitates a major improvement in router performance for packets containing options. Another improvement is that unlike IPv4, IPv6 options can be of arbitrary length and not limited to 40 bytes. This feature plus the manner in which they are processed, permits IPv6 options to be used for functions which were not practical in IPv4.

  A key extensibility feature of IPv6 is the ability to encode, within an option, the action which a router or host should perform if the option is unknown. This permits the incremental deployment of additional functionality into an operational network with a minimal danger of disruption.

* support for authentication and privacy - IPv6 includes the definition of an extension which provides support for authentication and data integrity. This extension is included as a basic element of IPv6 and support for it will be required in all implementations.

  IPv6 also includes the definition of an extension to support confidentiality by means of encryption. Support for this extension will be strongly encouraged in all implementations.

* support for autoconfiguration - IPv6 supports multiple forms of autoconfiguration, from "plug and play" configuration of node addresses on an isolated network to the full-featured facilities offered by DHCP.

* support for source routes - IPv6 includes an extended function source routing header designed to support the Source Demand Routing Protocol (SDRP). The purpose of SDRP is to support source-initiated selection of routes to complement the route selection provided by existing routing protocols for both inter-domain and intra-domain routes. [Estrin94b]

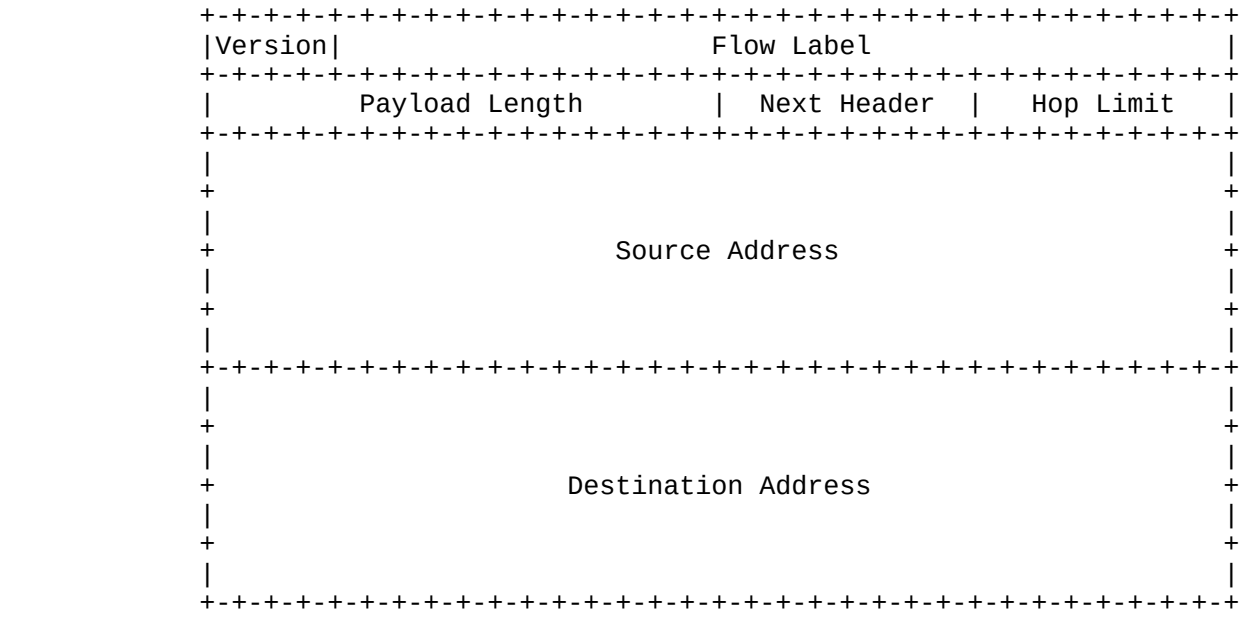
* simple and flexible transition from IPv4 - The IPv6 transition plan is aimed at meeting four basic requirements: [Gillig94a]

  - Incremental upgrade. Existing installed IPv4 hosts and routers may be upgraded to IPv6 at any time without being dependent on any other hosts or routers being upgraded.
  - Incremental deployment. New IPv6 hosts and routers can be installed at any time without any prerequisites.
  - Easy Addressing. When existing installed IPv4 hosts or routers are upgraded to IPv6, they may continue to use their existing address. They do not need to be assigned new addresses.
  - Low start-up costs. Little or no preparation work is needed in order to upgrade existing IPv4 systems to IPv6, or to deploy new IPv6 systems.

* quality of service capabilities - A new capability is added to enable the labeling of packets belonging to particular traffic "flows" for which the sender has requested special handling, such as non-default quality of service or "real-time" service.

12.1 IPv6 Header Format

The IPv6 header, although longer than the IPv4 header, is considerably simplified. A number of functions that were in the IPv4 header have been relocated in extension headers or dropped. [Deering94b]



* Version - Internet Protocol version number. IPng has been assigned version number 6. (4-bit field)

* Flow Label - This field may be used by a host to label those packets for which it is requesting special handling by routers within a network, such as non-default quality of service or "real-time" service. (28-bit field)

* Payload Length - Length of the remainder of the packet following the IPv6 header, in octets. To permit payloads of greater than 64K bytes, if the value in this field is 0 the actual packet length will be found in an Hop-by-Hop option. (16-bit unsigned integer)

* Next Header - Identifies the type of header immediately following the IPv6 header. The Next Header field uses the same values as the IPv4 Protocol field (8-bit selector field)

* Hop Limit - Used to limit the impact of routing loops. The Hop Limit field is decremented by 1 by each node that forwards the packet. The packet is discarded if Hop Limit is decremented to zero. (8-bit unsigned integer)

* Source Address - An address of the initial sender of the packet. (128 bit field)

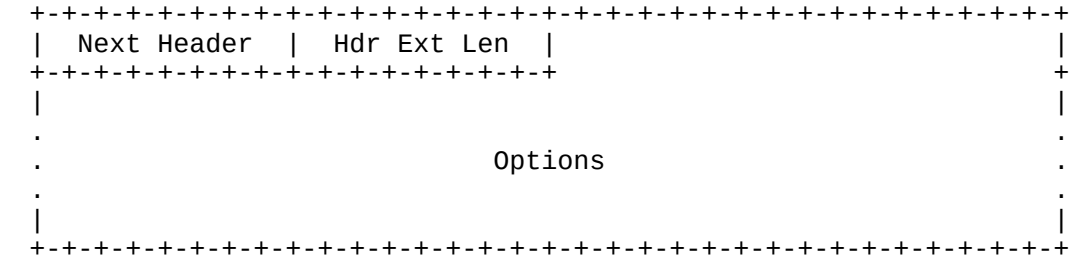
* Destination Address - An address of the intended recipient of the packet (possibly not the ultimate recipient, if an optional Routing Header is present). (128 bit field)

12.2 Extension Headers

In IPv6, optional internet-layer information is encoded in separate headers that may be placed between the IPv6 header and the transport-layer header in a packet. There are a small number of such extension headers, each identified by a distinct Next Header value. [From a number of the documents listed in Appendix C.]

12.2.1 Hop-by-Hop Option Header

The Hop-by-Hop Options header is used to carry optional information that must be examined by every node along a packet's delivery path. The Hop-by-Hop Options header is identified by a Next Header value of 0 in the IPv6 header, and has the following format:



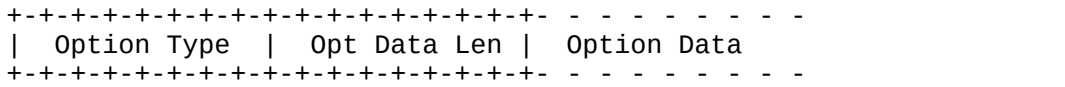
* Next Header - Identifies the type of header immediately following the Hop-by-Hop Options header. Uses the same values as the IPv4 Protocol field. (8-bit selector)

* Hdr Ext Len - Length of the Hop-by-Hop Options header in 8-octet units, not including the first 8 octets. (8-bit unsigned integer)

* Options - Contains one or more TLV-encoded options. (Variable-length field, of length such that the complete Hop-by-Hop Options header is an integer multiple of 8 octets long.)

12.2.2 IPv6 Header Options

Two of the currently-defined extension headers -- the Hop-by-Hop Options header and the End-to-End Options header -- may carry a variable number of Type-Length-Value (TLV) encoded "options", of the following format:



* Option Type - identifier of the type of option (8-bit field)

* Opt Data Len - Length of the Option Data field of this option, in octets. (8-bit unsigned integer)

* Option Data - Option-Type-specific data. (Variable-length field)

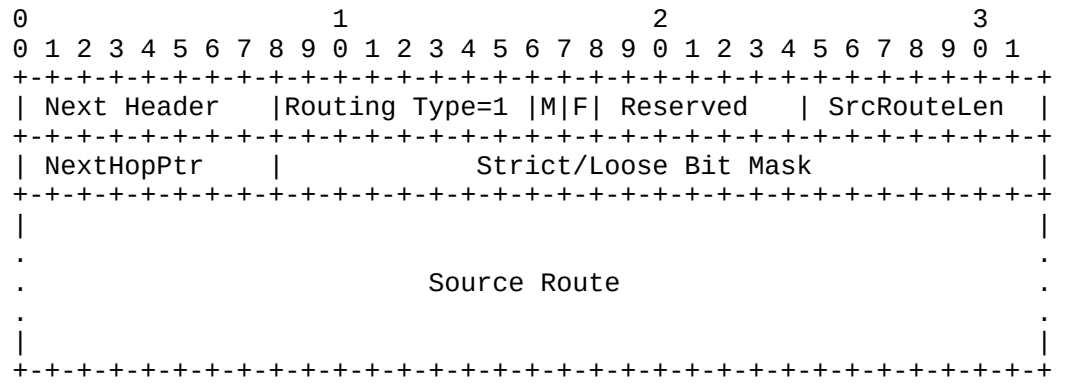
The Option Type identifiers are internally encoded such that their highest-order two bits specify the action that must be taken if the processing IPv6 node does not recognize the Option Type:

00 - skip over this option and continue processing the header
01 - discard the packet
10 - discard the packet and send an ICMP Unrecognized Type message to the packet's Source Address, pointing to the unrecognized Option Type
11 - undefined.

In the case of Hop-by-Hop options only, the third-highest-order bit of the Option Type specifies whether or not the Option Data of this option shall be included in the integrity assurance computation performed when an Authentication header is present. Option data that changes en route must be excluded from that computation.

12.2.3 Routing Header

The Routing header is used by an IPv6 source to list one or more intermediate nodes (or topological clusters) to be "visited" on the way to a packet's destination. This particular form of the Routing Header is designed to support SDRP. [Estrin94b]



* Next Header - Identifies the type of header immediately following the Routing Header. Uses the same values as the IPv4 Protocol field. (8-bit selector)

* Routing Type - Indicates the type of routing supported by this header. Value must be 1.

* MRE flag - Must Report Errors. If this bit is set to 1, and a router can not further forward a packet (with an incompletely traversed source route), as specified in the Source Route, the router must generate an ICMP error message. If this bit is set to 0, and a router can not further forward a packet (with an incompletely traversed source route), as specified in the Source Route, the router should not generate an ICMP error message.

* F flag - Failure of Source Route Behavior. If this bit it set to 1, it indicates that if a router can not further forward a packet (with an incompletely traversed source route), as specified in the Source Route, the router must set the value of the Next Hop Pointer field to the value of the Source Route Length field, so that the subsequent forwarding will be based solely on the destination address. If this bit is set to 0, it indicates that if a router can not further forward a packet (with an incompletely traversed source route), as specified in the Source Route, the router must discard the packet.

* Reserved - Initialized to zero for transmission; ignored on reception.

* SrcRouteLen - Source Route Length - Number of source route elements/hops in the SDRP Routing header. Length of SDRP routing header can be calculated from this value (length = SrcRouteLen * 16 + 8) This field may not exceed a value of 24. (8 bit unsigned integer)

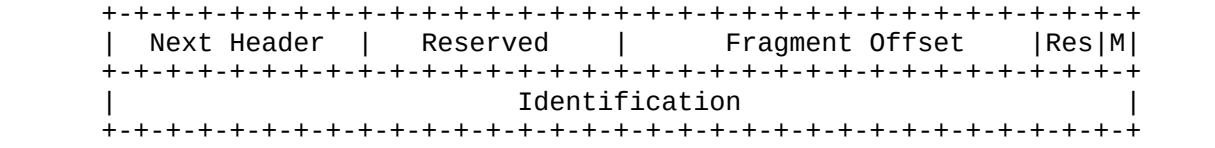
* NextHopPtr - Next Hop Pointer- Index of next element/hop to be processed; initialized to 0 to point to first element/hop in the source route. When Next Hop Pointer is equal to Source Route Length then the Source Route is completed. (8 bit unsigned integer)

* Strict/Loose Bit Mask - The Strict/Loose Bit Mask is used when making a forwarding decision. If the value of the Next Hop Pointer field is N, and the N-th bit in the Strict/Loose Bit Mask field is set to 1, it indicates that the next hop is a Strict Source Route Hop. If this bit is set to 0, it indicates that the next hop is a Loose Source Route Hop. (24 bit bitpattern)

* Source Route - A list of IPv6 addresses indicating the path that this packet should follow. A Source Route can contain an arbitrary intermix of unicast and cluster addresses. (integral multiple of 128 bits)

12.2.4 Fragment Header

The Fragment header is used by an IPv6 source to send payloads larger than would fit in the path MTU to their destinations. (Note: unlike IPv4, fragmentation in IPv6 is performed only by source nodes, not by routers along a packet's delivery path) The Fragment header is identified by a Next Header value of 44 in the immediately preceding header, and has the following format:



* Next Header - Identifies the type of header immediately following the Fragment header. Uses the same values as the IPv4 Protocol field. (8 bit selector)

* Reserved, Res - Initialized to zero for transmission; ignored on reception.

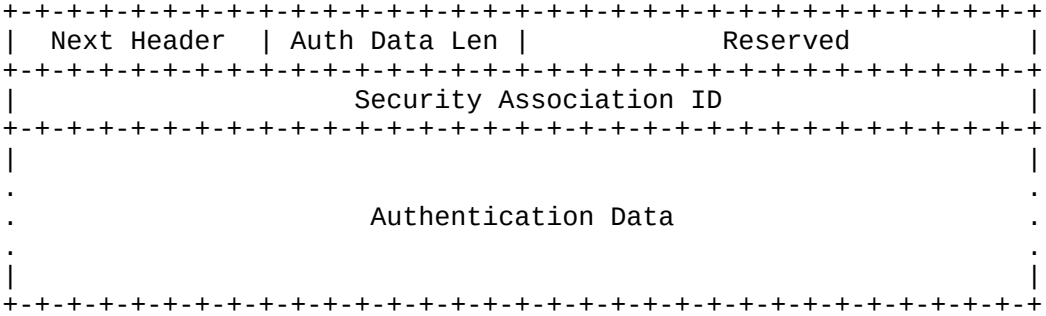
* Fragment Offset - The offset, in 8-octet units, of the following payload, relative to the start of the original, unfragmented payload. (13-bit unsigned integer)

* M flag - 1 = more fragments; 0 = last fragment.

* Identification - A value assigned to the original payload that is different than that of any other fragmented payload sent recently with the same IPv6 Source Address, IPv6 Destination Address, and Fragment Next Header value. (If a Routing header is present, the IPv6 Destination Address is that of the final destination.) The Identification value is carried in the Fragment header of all of the original payload's fragments, and is used by the destination to identify all fragments belonging to the same original payload. (32 bit field)

12.2.5 Authentication Header

The Authentication header is used to provide authentication and integrity assurance for IPv6 packets. Non-repudiation may be provided by an authentication algorithm used with the Authentication header, but it is not provided with all authentication algorithms that might be used with this header. The Authentication header is identified by a Next Header value of 51 in the immediately preceding header, and has the following format:



* Next Header - Identifies the type of header immediately following the Authentication header. Uses the same values as the IPv4 Protocol field. (8-bit selector)

* Auth Data Len - Length of the Authentication Data field in 8-octet units. (8-bit unsigned integer)

* Reserved - Initialized to zero for transmission; ignored on reception.

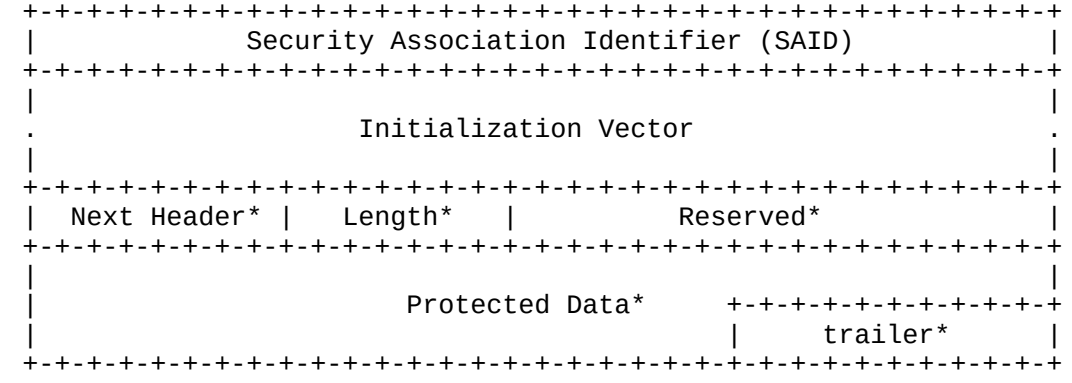
* Security Assoc. ID - When combined with the IPv6 Source Address, identifies to the receiver(s) the pre-established security association to which this packet belongs. (32 bit field)

* Authentication Data - Algorithm-specific information required to authenticate the source of the packet and assure its integrity, as specified for the pre-established security association. (Variable-length field, an integer multiple of 8 octets long.)

12.2.6 Privacy Header

The Privacy Header seeks to provide confidentiality and integrity by encrypting data to be protected and placing the encrypted data in the data portion of the Privacy Header. Either a transport-layer (e.g., UDP or TCP) frame may be encrypted or an entire IPv6 datagram may be encrypted, depending on the user's security requirements. This encapsulating approach is necessary to provide confidentiality for the entire original datagram. If present, the Privacy Header is always the last non-encrypted field in a packet.

The Privacy Header works between hosts, between a host and a security gateway, or between security gateways. This support for security gateways permits trustworthy networks to exist without the performance and monetary costs of security, while providing security for traffic transiting untrustworthy network segments.



*encrypted

* Security Association Identifier (SAID) - Identifies the security association for this datagram. If no security association has been established, the value of this field shall be 0x0000. A security association is normally one-way. An authenticated communications session between two hosts will normally have two SAIDs in use (one in each direction). The receiving host uses the combination of SAID value and originating address to distinguish the correct association. (32 bit value)

* Initialization Vector - This field is optional and its value depends on the SAID in use. For example, the field may contain cryptographic synchronization data for a block oriented encryption algorithm. It may also be used to contain a cryptographic initialization vector. A Privacy Header implementation will normally use the SAID value to determine whether this field is present and, if it is, the field's size and use. (presence and length dependent on SAID)

* Next Header - encrypted - Identifies the type of header immediately following the Privacy header. Uses the same values as the IPv4 Protocol field. (8 bit selector)

* Reserved - encrypted - Ignored on reception.

* Length - encrypted - Length of the Privacy Header in 8-octet units, not including the first 8 octets. (8-bit unsigned integer)

* Protected Data - encrypted - This field may contain an entire encapsulated IPv6 datagram, including the IPv6 header, a sequence of zero or more IPv6 options, and a transport-layer payload, or it may just be a sequence of zero or more IPv6 options followed by a transport-layer payload. (variable length)

* trailer (Algorithm-dependent Trailer) - encrypted - A field present to support some algorithms which need to have padding (e.g., to a full cryptographic block size for block-oriented encryption algorithms) or for storage of authentication data for use with a encryption algorithm that provides confidentiality without authentication. It is present only when the algorithm in use requires such a field. (presence and length dependent on SAID)

12.2.7 End-to-End Option Header

The End-to-End Options header is used to carry optional information that needs to be examined only by a packet's destination node(s). The End-to-End Options header is identified by a Next Header value of TBD in the immediately preceding header, and has the same format as the Hop-by-Hop Option Header except for the ability to exclude an option from the authentication integrity assurance computation.

13. IPng Working Group

We recommend that a new IPng Working Group be formed to produce specifications for the core functionality of the IPv6 protocol suite. The working group will carry out the recommendations of the IPng Area Directors as outlined at the July 1994 IETF and in this memo. We recommend that this working group be chaired by Steve Deering of Xerox PARC and Ross Callon of Wellfleet.

The primary task of the working group is to produce a set of documents that define the basic functions, interactions, assumptions, and packet formats for IPv6. We recommend that Robert Hinden of Sun Microsystems be the editor for these documents. The documents listed in Appendix C will be used by the working group to form the basis of the final document set.

The work of the IPng Working Group includes:

* complete the IPv6 overview document
* complete the IPv6 detailed operational specification
* complete the IPv6 Addressing Architecture specification
* produce specifications for IPv6 encapsulations over various media
* complete specifications for the support of packets larger than 64KB
* complete specifications of the DNS enhancements required to support IPv6
* complete specification of ICMP, IGMP and router discovery for support of IPv6.
* complete specification of path MTU discovery for IPv6
* complete specifications of IPv6 in IPv6 tunneling
* complete the suggested address format and assignment plan
* coordinate with the Address Autoconfiguration Working Group
* coordinate with the NGTRANS and TACIT Working Groups
* complete specifications of authentication and privacy support headers

The working group should also consider a few selected enhancements including:

* consider ways to compress the IPv6 header in the contexts of native IPv6, multiple IPv6 packets in a flow, and encapsulated IPv6
* consider specifying support for a larger minimum MTU

14. IPng Reviewer

Currently it is the task of the IPng Area Directors, the IPng Directorate and the chairs of the proposed ipng working group to coordinate the activities of the many parallel efforts currently directed towards different aspects of IPng. While this is possible and currently seems to be working well it can not be maintained over the long run because, among other reasons, the IPng Area will be dissolved eventually and its Directorate disbanded. It will also become much more difficult as IPng related activities start up in other IETF areas.

We recommend that an IPng Reviewer be appointed to be specifically responsible for ensuring that a consistent view of IPv6 is maintained across the related working groups. We feel that this function is required due to the complex nature of the interactions between the parts of the IPng effort and due to the distribution of the IPng related work amongst a number of IETF areas. We recommend that Dave Clark of MIT be offered this appointment.

This would be a long-term task involving the review of on-going activities. The aim is not for the IPng Reviewer to make architectural decisions since that is the work of the various working groups, the IAB, and the IETF as a whole.. The aim is to spot gaps or misunderstandings before they reach the point where functionality or interworkability is threatened.

15. Address Autoconfiguration

As data networks become more complex the need to be able to bypass at least some of the complexity and move towards "plug and play" becomes ever more acute. The user can not be expected to be able to understand the details of the network architecture or know how to configure the network software in their host. In the ideal case, a user should be able to unpack a new computer, plug it into the local network and "just" have it work without requiring the entering of any special information. Security concerns may restrict the ability to offer this level of transparent address autoconfiguration in some environments but the mechanisms must be in place to support whatever level of automation which the local environment feels comfortable with.

The basic requirement of "plug and play" operation is that a host must be able to acquire an address dynamically, either when attaching to a network for the first time or when the host needs to be readdressed because the host moved or because the identity of the network has changed. There are many other functions required to support a full "plug and play" environment. [Berk94] Most of these must be addressed outside of the IPv6 Area but a focused effort to define a host address autoconfiguration protocol is part of the IPv6 process.

We recommend that a new Address Autoconfiguration Working Group (addrconf) be formed with Dave Katz of Cisco Systems and Sue Thomson of Bellcore as co-chairs. The purpose of this working group is to design and specify a protocol for allocating addresses dynamically to IPv6 hosts. The address configuration protocol must be suitable for a wide range of network topologies, from a simple isolated network to a sophisticated globally connected network. It should also allow for varying levels of administrative control, from completely automated operation to very tight oversight.

The scope of this working group is to propose a host address autoconfiguration protocol which supports the full range of topological and administrative environments in which IPv6 will be used. It is the intention that, together with IPv6 system discovery, the address autoconfiguration protocol will provide the minimal bootstrapping information necessary to enable hosts to acquire further configuration information (such as that provided by DHCP in IPv4). The scope does not include router configuration or any other host configuration functions. However, it is within the scope of the working group to investigate and document the interactions between this work and related functions including system discovery, DNS autoregistration, service discovery, and broader host configuration issues, to facilitate the smooth integration of these functions. [Katz94a]

The working group is expected to complete its work around the end of 1994 and disband at that time. The group will use "IPv6 Address Autoconfiguration Architecture" [Katz94b] draft document as the basis of their work.

16. Transition

The transition of the Internet from IPv4 to IPv6 has to meet two separate needs. There is a short term need to define specific technologies and methods to transition IPv4 networks, including the Internet, into IPv6 networks and an IPv6 Internet. There is also a long term need to do broad-based operational planning for transition, including developing methods to allow decentralized migration

strategies, understanding the ramifications of a long period of coexistence when both protocols are part of the basic infrastructure, developing an understanding of the type and scope of architectural and interoperability testing that will be required to ensure a reliable and manageable Internet in the future.

16.1 Transition - Short Term

Any IPng transition plan must take into account the realities of what types of devices vendors will build and network managers will deploy. The IPng transition plan must define the procedures required to successfully implement the functions which vendors will be likely to include in their devices. This is the case even if there are good arguments to recommend against a particular function, header translation for example. If products will exist it is better to have them interoperate than not.

We recommend that a new IPng Transition (NGTRANS) Working Group be formed with Bob Gilligan of Sun Microsystems and xxx of yyy as co-chairs to design the mechanisms and procedures to support the transition of the Internet from IPv4 to IPv6 and to give advice on what procedures and techniques are preferred.

The work of the group will fall into three areas:

* Define the processes by which the Internet will make the transition from IPv4 to IPv6. As part of this effort, the group will produce a document explaining to the general Internet community what mechanisms will be employed in the transition, how the transition will work, the assumptions about infrastructure deployment inherent in the operation of these mechanisms, and the types of functionality that applications developers will be able to assume as the protocol mix changes over time.
* Define and specify the mandatory and optional mechanisms that vendors should implement in hosts, routers, and other components of the Internet in order for the transition to be carried out. Dual-stack, encapsulation and header translation mechanisms must all be defined, as well as the interaction between hosts using different combinations of these mechanisms. The specifications produced will be used by people implementing these IPv6 systems.
* Articulate a concrete operational plan for the Internet to make the transition from IPv4 to IPv6. The result of this work will be a transition plan for the Internet that network operators and Internet subscribers can execute.

[Gillig94c]

The working group is expected to complete its work around the end of 1994 and disband at that time. The group will use the "Simple SIPP Transition (SST)" [Gilig94a] overview document as the starting point for its work.

16.2 Transition - Long Term

There are a number of transition related topics in addition to defining the specific IPv4 to IPv6 mechanisms and their deployment, operation and interaction. The ramifications and procedures of migrating to a new technology or to a new version of an existing technology must be fully understood.

We recommend that the Transition and Coexistence Including Testing (TACIT) Working Group, which was started a few months ago, explore some of the basic issues associated with the deployment of new technology into an established Internet. The TACIT Working Group will focus on the generic issues of transition and will not limit itself to the upcoming transition to IPv6 because, over time, enhancements to IPv6 (IPv6ng) will be developed and accepted. At that point they will need to be deployed into the then existing Internet. The TACIT Working Group will be more operationally oriented than the NGTRANS Working Group and will continue well into the actual IPv6 transition.

The main areas of exploration are:

* Make the transition from a currently deployed protocol to a new protocol while accommodating heterogeneity and decentralized management.
* Since it is often difficult or impossible to replace all legacy systems or software, it is important to understand the characteristics and operation of a long period of coexistence between a new protocol and the existing protocol.
* The Internet must now be considered a utility. We are far removed from a time when a new technology could be deployed to see if it would work in large scale situations. Rigorous architectural and interoperability testing must be part of the predeployment phase of any proposed software for the Internet. Testing the scaling up behaviors and robustness of a new protocol will offer particular challenges. The WG should determine if there are lessons to be learned from: OSPF, BGP4 and CIDR Deployment, the AppleTalk 1 to 2 transition, DECnet Phase 4 to Phase 5 planning and transition, among others.

The TACIT Working Group will explore each of these facets of the deployment of new technology and develop a number of documents to help guide users and managers of affected data networks and provide to the IETF:

* Detailed descriptions of problem areas in transition and coexistence, both predicted, based on lessons learned, and observed as the IPv6 process progresses.
* Recommendations for specific testing procedures.
* Recommendations for coexistence operations procedures
* Recommendations for the smoothing of decentralized transition planning.

[Huston94]

17. Other Address Families

There are many environments in which there are one or more network protocols already deployed or where a significant planning effort has been undertaken to create a comprehensive network addressing plan. In such cases there may be a temptation to integrate IPv6 into the environment by making use of an existing addressing plan to define all or part of the IPv6 addresses. The advantage of doing this is that it permits unified management of address space among multiple protocol families. The use of common addresses can help facilitate transition from other protocols to IPv6.

If the existing addresses are globally unique and assigned with regard to network topology this may be a reasonable idea. The IETF should work with other organizations to develop algorithms that could be used to map addresses between IPv6 and other environments. The goal for any such mapping must be to provide an unambiguous 1 to 1 map between individual addresses.

Suggestions have been made to develop mapping algorithms for Novell IPX addresses, some types of OSI NSAPs, E164 addresses and SNA addresses. Each of these possibilities should be carefully examined to ensure that use of such an algorithm solves more problems than it creates. In some cases it may be better to recommend either that a native IPng addressing plan be developed instead, or that an IPv6 address be used within the non-IP environment. [Carpen94b]

We recommend that, in conjunction with other organizations, recommendations about the use of non-IPv6 addresses in IPv6 environments and IPv6 addresses in non-IPv6 environments be developed.

18. Impact on Other IETF Standards

Many current IETF standards are affected by IPv6. At least 27 of the current 51 full Internet Standards must be revised for IPv6, along with at least 6 of the 20 Draft Standards and at least 25 of the 130 Proposed Standards. [Postel94]

In some cases the revisions consist of simple changes to the text, for example, in a number of RFCs an IP address is referred to in passing as a "32 bit IP address" even though IP addresses are not directly used in the protocol being defined. All of the standards track documents will have to be checked to see if they contain such references.

In most of the rest of the cases revisions to the protocols, including packet formats, will be required. In many of these cases the address is just being carried as a data element and a revised format with a larger field for the address will have no effect on the functional paradigm.

In the remaining cases some facet of the operation of the protocol will be changed as a result of IPv6. For example, the security and source route mechanisms are fundamentally changed from IPv4 with IPv6. Protocols and applications that relied on the IPv4 functionality will have to be redesigned or rethought to use the equivalent function in IPv6.

In a few cases this opportunity should be used to determine if some of the RFCs should be moved to historic, for example EGP [Mills84] and IP over ARCNET. [Provan91]

The base IPng Working Group will address some of these, existing IETF working groups can work on others, while new working groups must be formed to deal with a few of them. The IPng Working Group will be responsible for defining new versions of ICMP, ARP/RARP, and UDP. It will also review RFC 1639, "FTP Operation Over Big Address Records (FOOBAR)" [Piscit94] and RFC 1191 "Path MTU Discovery" [Mogul90]

Existing working groups will examine revisions for some of the routing protocols: RIPv2, IS-IS, IDRP and SDRP. A new working group may be required for OSPF.

The existing DHCP Working Group may be able to revise DHCP and examine BOOTP.

A TCPng Working Group will be formed soon, and new working groups will have to be formed to deal with standards such as SNMP, DNS, NTP, NETbios, OSI over TCP, Host Requirements, and Kerberos as well as reviewing most of the RFCs that define IP usage over various media.

In addition to the standards track RFCs mentioned above there are many Informational and Experimental RFCs which would be affected as well as numerous Internet Drafts (and those standards track RFCs that we missed).

We recommend that the IESG commission a review of all standards track RFCs to ensure that a full list of affected documents is compiled. We recommend that the IESG charge current IETF working groups with the task of understanding the impact of IPv6 on their proposals and, where appropriate, revise the documents to include support for IPv6.

We recommend that the IESG charter new working groups where required to revise other standards RFCs.

19. Impact on non-IETF standards and on products

Many products and user applications which rely on the size or structure of IPv4 addresses will need to be modified to work with IPv6. While the IETF can facilitate an investigation of the impacts of IPv6 on non-IETF standards and products, the primary responsibility for doing so resides in the other standards bodies and the vendors.

Examples of non-IETF standards that are effected by IPv6 include the POSIX standards, Open Software Foundation's DCE and DME, X-Open, Sun ONC, the Andrew File System and MIT's Kerberos. Most products that provide specialized network security including firewall-type devices are among those that must be extended to support IPv6.

20. APIs

It is traditional to state that the IETF does not "do" APIs. While there are many reasons for this, the one most commonly referenced is that there are too many environments where TCP/IP is used, too many different operating systems, programming languages, and platforms. The feeling is that the IETF should not get involved in attempting to define a language and operating system independent interface in the face of such complexity.

We feel that this historical tendency for the IETF to avoid dealing with APIs should be reexamined in the case of IPv6. We feel that in a few specific cases the prevalence of a particular type of API is such that a single common solution for the modifications made

necessary by IPv6 should be documented.

We recommend that Informational RFCs be solicited or developed for these few cases. In particular, the Berkeley-style sockets interface, the UNIX TLI and XTI interfaces, and the WINSOCK interfaces should be targeted. A draft document exists which could be developed into the sockets API description. [Gillig94b]

21. Future of the IPng Area and Working Groups

In our presentation at the Houston IETF meeting we stated that the existing IPng proposal working groups would not be forced to close down after the recommendation was made. Each of them has been working on technologies that may have applications in addition to their IPng proposal and these technologies should not be lost.

Since the Toronto IETF meeting the existing IPng working groups have been returned to the Internet Area. The group members may decide to close down the working groups or to continue some of their efforts. The charters of the working groups must be revised if they choose to continue since they would no longer be proposing an IPng candidate.

In Toronto the chairs of the SIPP Working Group requested that the SIPP Working Group be concluded. The chairs of the TUBA Working Group requested that the TUBA working group be understood to be in hiatus until a number of the documents in process were completed, at which time they would request that the working group be concluded.

We recommend that the IPng Area and its Directorate continue until the basic documents have entered the standards track in late 1994 or early 1995 and that after such time the area be dissolved and those IPng Area working groups still active be moved to their normal IETF areas.

22. Security Considerations

The security of the Internet has long been questioned. It has been the topic of much press coverage, many conferences and workshops. Almost all of this attention has been negative, pointing out the many places where the level of possible security is far less than that deemed necessary for the current and future uses of the Internet. A number of the RFC 1550 White Papers specifically pointed out the requirement to improve the level of security available [Adam94, Bell94b, Brit94, Green94, Vecchi94, Flei94] as does "Realizing the Information Future". [Nat94]

In February of 1994, the IAB convened a workshop on security in the Internet architecture. The report of this workshop [IAB94] includes an exploration of many of the security problem areas and makes a number of recommendations to improve the level of security that the Internet offers its users.

We feel that an improvement in the basic level of security in the Internet is vital to its continued success. Users must be able to assume that their exchanges are safe from tampering, diversion and exposure. Organizations that wish to use the Internet to conduct business must be able to have a high level of confidence in the identity of their correspondents and in the security of their communications. The goal is to provide strong protection as a matter of course throughout the Internet.

As the IAB report points out, many of the necessary tools are not a function of the internetworking layer of the protocol. These higher level tools could make use of strong security features in the internetworking layer if they were present. While we expect that there will be a number of special high-level security packages available for specific Internet constituencies, support for basic packet-level authentication will provide for the adoption of a much needed, widespread, security infrastructure throughout the Internet.

It is best to separate the support for authentication from the support for encryption. One should be able to use the two functions independently. There are some applications in which authentication of a corespondent is sufficient and others where the data exchanged must be kept private.

It is our recommendation that IPv6 support packet authentication as a basic and required function. Applications should be able to rely on support for this feature in every IPv6 implementation. Support for a specific authentication algorithm should also be mandated while support for additional algorithms should be optional.

Thus we recommend that support for the Authentication Header be required in all compliant IPv6 implementations.

We recommend that support for a specific authentication algorithm be required. The specific algorithm should be determined by the time the IPv6 documents are offered as Proposed Standards.

We recommend that support for the Privacy Header be required in IPv6 implementations.

We recommend that support for a privacy authentication algorithm be required. The specific algorithm should be determined by the time the IPv6 documents are offered as Proposed Standards.

Clearly, a key management infrastructure will be required in order to enable the use of the authentication and encryption headers. However, defining such an infrastructure is outside the scope of the IPv6 effort. We do note that there are on-going IETF activities in this area. The IPv6 transition working groups must coordinate with these activities.

Just as clearly, the use of authentication and encryption may add to the cost and impact the performance of systems but the more secure infrastructure is worth the penalty. Whatever penalty there is should also decrease in time with improved software and hardware assistance.

The use of firewalls is increasing on the Internet. We hope that the presence of the authentication and privacy features in IPv6 will reduce the need for firewalls, but we do understand that they will continue to be used for the foreseeable future. In this light, we feel that clear guidance should be given to the developers of firewalls on the best ways to design and configure them when working in an IPv6 environment.

We recommend that an "IPv6 framework for firewalls" be developed. This framework should explore the ways in which the Authentication Header can be used to strengthen firewall technology and detail how the IPv6 packet should be analyzed by a firewall.

Some aspects of security require additional study. For example, it has been pointed out [Vecchi94] that, even in non-military situations, there are places where procedures to thwart traffic analysis will be required. This could be done by the use of encrypted encapsulation, but this and other similar requirements must be addressed on an on-going basis by the Security Area of the IETF. The design of IPv6 must be flexible enough to support the later addition of such security features.

We believe that IPv6 with its inherent security features will provide the foundation upon which the Internet can continue to expand its functionality and user base.

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Appendix A - Summary of Recommendations

5.3 Address Assignment Policy Recommendations
changes in address assignment policies are not recommended
reclamation of underutilized assigned addresses is not currently recommended
efforts to renumber significant portions of the Internet are not currently recommended
recommend consideration of assigning CIDR-type address blocks out of unassigned Class A addressees

11. IPng Recommendation
recommend that "Simple Internet Protocol Plus (SIPP) Spec. (128 bit ver)" [Deering94b] be adopted as the basis for IPng
recommend that the documents listed in Appendix C be the basis of IPng

13. IPng Working Group
recommend that an IPng Working Group be formed, chaired by Steve Deering and Ross Callon
recommend that Robert Hinden be the document editor for the IPng effort

14. IPng Reviewer
recommend that an IPng Reviewer be appointed and that Dave Clark be that reviewer

15. Address Autoconfiguration
recommend that an Address Autoconfiguration Working Group be formed, chaired by Dave Katz and Sue Thomson

16.1 Transition - Short Term
recommend that an IPng Transition Working Group be formed, chaired by Bob Gilligan and TBA

16.2 Transition - Long Term
recommend that the Transition and Coexistence Including Testing Working Group be chartered

17. Other Address Families
recommend that recommendations about the use of non-IPv6 addresses in IPv6 environments and IPv6 addresses in non-IPv6 environments be developed

18. Impact on Other IETF Standards
recommend the IESG commission a review of all standards track RFCs
recommend the IESG charge current IETF working groups with the task of understanding the impact of IPng on their proposals and, where appropriate, revise the documents to include support for IPng
recommend the IESG charter new working groups where required to revise other standards RFCs

20. APIs
recommend that Informational RFCs be developed or solicited for a few of the common APIs

21. Future of the IPng Area and Working Groups
    recommend that the IPng Area and Area Directorate continue until main documents are offered as Proposed Standards in late 1994
22. Security Considerations
    recommend that support for the Authentication Header be required
    recommend that support for a specific authentication algorithm be required
    recommend that support for the Privacy Header be required
    recommend that support for a specific privacy algorithm be required
    recommend that an "IPng framework for firewalls" be developed

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Daniel Karrenberg of RIPE joined the Directorate when it was formed but had to withdraw due to the demands of his day job.

Since the Toronto IETF meeting Paul Francis has resigned from the Directorate to pursue other interests. Robert Hinden of Sun Microsystems and Yakov Rekhter of IBM joined.

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Appendix G - Acknowledgments

Reaching this stage of the recommendation would not have been even vaguely possible without the efforts of many people. In particular, the work of IPng Directorate (listed in Appendix B), Frank Kastenholz and Craig Partridge (the authors of the Criteria document) along with Jon Crowcroft (who co-chaired the ngreq BOF) was critical. The work and cooperation of the chairs, members and document authors of the three IPng proposal working groups, the ALE working group and the TACIT working group laid the groundwork upon which this recommendation sits.

We would also like to thank the many people who took the time to respond to RFC1550 and who provided the broad understanding of the many requirements of data networking that any proposal for an IPng must address.

The members of the IESG, the IAB, and the always active participants in the various mailing lists provided us with many insights into the issues we faced.

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To all of the many people mentioned above and those we have skipped in our forgetfulness, thank you for making this task doable.