REQUEST FOR COMMENT: NTIA invites comment on the following questions, in whole or in part:

Benefits:

1. What are the benefits of implementing IPv6? For example, what are the direct performance benefits of implementing IPv6 for end users, or for enhanced network security, as compared to IPv4?

IPv6 increases the amount of available address space, such that any Internet host can have one or more than one address. This enables deployments which do not require network address translation. Since NATs may introduce delay, connection failures, or unexpected behavior on an end-to-end flow, IPv6 flows may be more robust than flows which traverse NATs and may have better latency. Because the scarcity of IPv4 addresses has gotten worse over time, both NAT and CGN ("Carrier Grade NAT" or double NAT) are increasingly prevalent, which has also increased the importance of IPv6 implementation and deployment.

As part of its efforts, Google has implemented IPv6 in its server systems, network elements, and host stacks like Android OS. We believe that this benefits Google and our customers by making sure that we have the broadest possible connectivity. Google also maintains an open interconnect policy for IPv6, supporting both public and private peering; for public peering, Google has no minimum traffic requirement. As of October 1 2016, approximately 14.11% of Google's users reach our services over IPv6.

2. What are the expected or unexpected benefits of implementing IPv6?

The primary benefit, as noted above, is enhanced connectivity.

As laid out in RFC 7934, there are benefits to privacy when IPv6 is used. The size of the address space allows a host to use multiple addresses for a single interface or to change addresses periodically. This behavior can increase the privacy of flows, by reducing the ability of an observer to cross-correlate flows using the source address. While CGN or even NAT may also reduce traceability somewhat, they are not under the control of the user. This means that the end system cannot be certain that they effectively limit traceability. CGN and NAT also have the performance and reliability issues noted above.

An additional benefit is that address constraints do not limit the number of systems which might use IP. The sensors, actuators, and hubs that are common to the Internet of Things, for example, would exacerbate address space exhaustion enormously were they deployed using IPv4. Cellular deployments faced this prior to the common deployment of IoT systems, and many were early adopters of IPv6 as a result.

Obstacles:

1. What are the biggest obstacles related to IPv6 implementation? For example, is it difficult to access adequate vendor support for IPv6 hardware and/or software? Does successful implementation depend directly on another service provider?

For implementation of networking software, there are occasionally hardware limitations in the underlying chipsets initially designed for IPv4. The larger size of the IPv6 address space may, for example, caused some network chipsets to limit IPv6 table entries to a quarter of the number available in IPv4. As IPv6 has increased in deployment and velocity, these issues have become rarer, and they do not pose a problem on general-purpose hardware, though memory requirements generally increase.

A larger obstacle is that many common networking calls are, in effect, twinned by the addition of support for IPv6. These calls may add support for IPv6 concepts, like network scope or flow identifier, but they mean each software system that uses these calls must be explicitly updated to support IPv6. As a result, deployment of an IPv6-capable service may be held up by the slow software update cycle of a single constituent component. Where the service's implementation has been done in house or within the context of an open-source project, Google has some control over the effort. Outside of those contexts, we may depend on an external party.

For deployment, the largest obstacle is that peers' networks may not support IPv6 or may access Google via transit networks that do not provide IPv6 transit. Many networks have very long refresh cycles for their networking gear, and this means that older routers and switches may stay in service until support for them is ended by the manufacturer. Backporting IPv6 to these is rarely a priority for the network equipment vendor, and what support can be created may be significantly less performant than the IPv4 equivalent.

2. How does an organization overcome those obstacles?

For implementation, an organization must either develop or select its implementations with IPv6 requirements in mind, so that constraints based on an assumption of IPv4 do not arise.

For deployment, overcoming the obstacle is largely an effort in helping peers understand the value generated by deploying IPv6. A willingness to peer any amount of traffic over IPv6 is particularly important here, as traffic-based evaluation of suitability for peering would generally frustrate the early phases of the peer's efforts. That negative cycle can look like this: If a network has no one to peer with using IPv6, they will have no IPv6 traffic; if they have no IPv6 traffic, they cannot meet a traffic-based evaluation and will have no one to peer with over IPv6. Breaking that cycle is critical.

We also note that dual-stack deployments are an effective deployment approach, as they ensure that the connectivity improvement created by adopting IPv6 is not hampered by the loss of connectivity to IPv4 peers that have not yet implemented IPv6.

Incentives:
1. What factors contribute to an organization's decision to implement IPv6?

Positive incentives derive from an increased set of customers or partners enabled by native IPv6. The increased connectivity noted above may provide new or improved access for customers with limited IPv4 connectivity.

Negative incentives are driven by the exhaustion of the IPv4 address space. While there is a secondary market for IPv4 addresses, buying IPv4 addresses is a stopgap measure. The secondary market can only redistribute the connectivity; it cannot increase it. For very large internal deployments, it is also possible to deplete the IPv4 private address space, so that adoption of IPv6 is needed to maintain connectivity among internal devices.

2. What additional incentives would be helpful in a decision to implement IPv6?

The network effect of IPv4 has been stronger than that of IPv6 for a lot of IPv6's deployment history, in part because most resources made available on IPv6 were already available via IPv4 connectivity, reducing the incentive to adopt IPv6. The "Happy Eyeballs" approach to dual-stack deployment has improved the situation to some degree, because it provides an additional incentive to deploy IPv6-enabled paths when the host stacks use the method.

To go beyond that incentive would require the connectivity graph for IPv6 to include some hosts or resources that were either not reachable via IPv4 or whose connectivity via IPv4 is significantly impaired by the techniques to manage address space exhaustion.

3. If one factor made the crucial difference in deciding to implement IPv6, as opposed to not implementing IPv6, what is that factor?

For implementing IPv6 in networking hardware or software, customers' needs for the increased connectivity graph of IPv6 is critical.

For a network to be interested in deploying IPv6, the crucial requirement is better connectivity, either through making new nodes reachable or eliminating the pain of address translation. As noted above, NATs may introduce delay, connection failures, or unexpected behavior on an end-to-end flow so IPv6 flows may be more robust than flows which traverse NATs and may have better latency.

Motivation:
1. What is typically the driving motivation behind an organization's decision to implement IPv6?

Our motivation is to enable future growth in the Internet by removing a constraint on connectivity. As company built around services offered over the Internet, ensuring its long-term growth is a core concern.

2. What are the job titles and/or roles of the people within an organization typically involved in a decision to implement IPv6? What are those individuals' primary motivations when it comes to implementing IPv6?

For implementing in software: product managers, software engineering managers, directors, and executives. For deployment: network architects and engineers, peering managers, and operations managers and directors. For selection of IPv6-capable hosts and software systems, CIOs or their teams. Even when there is no management directive, engineers may choose to add support for IPv6 based on their own understanding of its importance. In those cases, management must approve, but does not drive the implementation.

Return on Investment:
1. What is the anticipated return on an IPv6-related investment? How quickly is a return on investment expected?

Because IPv6 supports increased or improved connectivity, the return on investment will depend on the connectivity requirements and opportunities specific to a particular organization.

2. Is return on investment a reason to implement IPv6, or is implementation considered a cost of doing business?

For any organization that benefits from the increased or improved connectivity, then the return on investment from that can provide a reason to implement IPv6.

Implementation:
1. How long does the planning process for IPv6 implementation take?

Greenfield deployments of IPv6 have planning processes similar to those for IPv4. Very few deployments are, however, pure greenfield deployments. As a result, the IPv6 planning process often starts by reexamining existing code or deployments to see what IPv4-only assumptions have been made that need to be addressed prior to implementation. For example, a software effort to add IPv6 capabilities to an existing application will require a review of the application's code base to ensure that it contains no IPv4 literals or related system calls (e.g. a DNS request for the IPv4 address of a specific host or service), confirmation that it allocates and manages memory sufficient for IPv6, and verification that the underlying operating system supports the appropriate IPv6 networking calls, including transitional technologies like DNS64. The time taken for the tasks will vary depending on the application's complexity, and the planning cycle will be similarly variable.

For a network deployment, the planning process for the addition of IPv6 to an existing network similarly starts with a confirmation that the deployed routers, switches, and firewalls are capable of supporting IPv6 and can do so without an impact on the speed or capacity of the relevant links. Where there are issues, a network may have to schedule software or hardware upgrades prior to building out the IPv6 paths; this necessarily lengthens the deployment cycle.

2. How long does actual implementation of IPv6 typically take? Is implementation a single event or evolutionary?

Implementation of IPv6 is evolutionary. An organization may, for example, initially prioritize providing its public services or content over IPv6 and thus focus development efforts on the external interfaces of those systems. Once that it is done, it may choose to enable IPv6 on the back end systems that provide the constituent elements of that service or content, to minimize the amount of translation required between the externally facing service and the internal systems. Enabling IPv6 on the systems which monitor and manage the various systems elements should be done in concert with the first phases or as soon as possible afterwards. Given the evolutionary nature of implementation, it is not really possible to provide a time estimate for IPv6 implementation; it is variable both with the complexity of the systems being enabled and the priority for IPv6 support among the constituent elements.

Cost of Implementation:
1. What are the different types of costs involved in implementing IPv6? What are the typical magnitudes of each type of cost?
2. How does an organization cover those costs?
3. How does an organization justify those costs?
4. What considerations are there for cost-saving?
5. What implication does the size of an organization implementing IPv6 have on cost?

The types of costs involved in implementing an IPv6-enabled application or network node are not different from those for an IPv4 implementation: development, testing, and deployment are required for each. Similarly, deploying IPv6 networks involves the same costs as deploying an IPv4 network: networking equipment, network engineering, peering space, circuits, and potentially transit costs. The magnitude of each cost will depend on the scale and complexity of each project. Because these costs are of the same type as those related to IPv4, an organization would typically cover and justify those costs in the same way it does for IPv4-related costs. Similarly, the implications of organizational size and cost-saving are the same for both address families.

Promotional Efforts:
1. What promotional efforts, if any, should NTIA take? What would have the most impact?

The U.S. Government should clearly and unambiguously demonstrate the importance of IPv6 adoption by rebooting nascent interagency efforts to encourage IPv6 adoption throughout the federal government's internal and externally-facing networks. Those efforts could include, among other things, government procurement guidelines to ensure that devices and services acquired under contract are IPv6-capable. It may be helpful in this regard for the Federal CIO Council to revisit and update as necessary its May 2012 “Planning Guide/Roadmap Toward IPv6 Adoption within the U.S. Government.”

In addition, as discussed below, NTIA should continue to support the Internet technical community in its efforts to deploy IPv6 around the world.

2. What promotional efforts, if any, are being led by the private sector? Have they been effective?

There are a number of groups dedicated specifically to IPv6 advocacy, both internationally and regionally. The IPv6 Forum is commonly recognized in this space, as are the regional efforts like Rocky Mountain IPv6 Task Force and California IPv6 Task Force. They provide educational materials and outreach. Other organizations related to numbering policy, like the American Registry for Internet Numbers (ARIN) also provide resources. The Internet Society has also organized multiple IPv6 efforts, including material under its Deploy360 program and events like World IPv6 Day and World IPv6 Launch Day. We believe that the Internet Society’s events have been particularly effective, as the growth since them has been effectively exponential. We also note that involvement of mobile carriers in IPv6 efforts has had a major impact on IPv6 traffic.

Overall, the tutorials and training material available can provide effective information for those who have decided to implement IPv6 and are useful efforts that do not presume a single vendor’s set of solutions or approaches. The events are also useful in raising awareness of IPv6 resources; these are, however, necessarily episodic.

3. Which additional stakeholders should NTIA target? What is the most effective forum?

As noted above, NTIA should focus on two principal goals: (1) reinvigorating interagency efforts to ensure that the federal government leads by example with robust adoption of IPv6, and (2) to continue to support the efforts of the Internet technical community, especially the Regional Internet Registries, as they work to deploy IPv6 around the world.

4. Should NTIA partner with any particular stakeholder group?

See above.

Additional Issues: NTIA invites commenters to provide any additional information on other issues not identified in this RFC that could contribute to NTIA’s understanding of the considerations that organizations take into account when deciding to proceed with IPv6 implementation, as well as future IPv6 promotional efforts that NTIA may undertake.

The use of the term “implementation” in the Request for Comments could relate to the deployment of IPv6 on internal and peering links, the development of networking software and hardware, or enabling applications to use the IPv6 address family. While the NTIA may be interested in commentary on all of these matter, it may be useful in future promotional efforts to distinguish among them.