The Internet Way of Networking

A Foundation for Success

EXECUTIVE SUMMARY

To sustain the Internet's value for our future, we need to recognize and protect what makes it unique.

What makes the Internet 'the Internet'? Other computer networks existed before the Internet, but none of them have been embraced by so many people on a global scale and integrated into day-to-day life. What is it about the Internet as a 'network of networks' that has evolved into an essential global tool, and a whole new space for innovation, growth, and transformation?

The Internet owes its success not only to the technology, but to the way it operates and evolves. The Internet provides unprecedented opportunities for advancing social and cultural understanding. The online environment empowers individuals to connect, speak, innovate, share, learn, and organize. There are virtually infinite opportunities in which we can use the Internet as a force for good. To make sure we can keep using it this way, we need to recognize and protect its critical properties.

The Internet Society has identified the critical properties that define the Internet Way of Networking and underpin the growth and adaptability of the Internet. The benefits of these properties have enabled the economic and technological development the Internet has brought around the globe.

Specific technologies and business models may come and go, but the Internet Way of Networking has been a constant foundation for the success of the Internet from the beginning. For the Internet of the future to be as innovative and sustainable as it has been so far, the critical properties need to guide its evolution.

Using the Internet Way of Networking as a lens through which we view technology and policy developments will help us ensure tomorrow's Internet is open and vibrant for everyone.

While the critical properties are the foundational pillars of the Internet Way of Networking, they manifest themselves through the benefits they provide to anyone who uses, builds, develops, and operates various components of the Internet ecosystem.

Critical Property	**Benefits**
An Accessible Infrastructure with a Common Protocol that is open and has low barriers to entry	Unrestricted access and common protocols deliver global connectivity and encourage the network to grow. As more and more participants connect, the value of the Internet increases for everyone.
Open Architecture of Interoperable and Reusable Building Blocks based on open standards development processes voluntarily adopted by a user community	Open architecture creates common interoperable services, which deliver fast and permissionless innovation everywhere. The inclusive standardization process and demand-driven adoption ensures that useful changes are adopted, while unnecessary ones disappear.
Decentralized Management and a Single Distributed Routing System which is scalable and agile	Distributed routing delivers a resilient and adaptable network of autonomous networks, allowing for local optimizations while maintaining worldwide connectivity.

Common Global Identifiers which are unambiguous and universal	A common identifier set delivers consistent addressability and a coherent view of the entire network, without fragmentation or fractures.
A General-purpose Network which is simple and adaptable	Generality delivers flexibility. The Internet continuously serves a diverse and constantly evolving community of users and applications. It does not require significant changes to support this dynamic environment.

Critical Property 1: An Accessible Infrastructure with a Common Protocol

You don't need permission to connect to the Internet. You find a point nearby, make arrangements to connect, and you're on the Internet. The network is extended by the many different kinds of organizations that connect to it. There is no international policy on who can connect or what they should pay; these factors are largely driven by the market, not a centralized authority. Individual nodes connect to the Internet using different physical attachments (e.g., wireless LAN, Ethernet, DSL) and using a variety of underlying networking technologies. However, every hardware connection presents itself, eventually, as a packet-switched interface, and every node has a common, open, network layer protocol available: the Internet Protocol (IP).

<u>This open and accessible infrastructure delivers several key benefits: the first is global connectivity, bringing participants from around the world together and allowing them to reach each other. The second is growth: the network continues to grow because participants find value in connecting, which continues to create even more value for everyone connected.</u> An Internet user trying to use a new application doesn't have to ask questions like "Are they running the same protocol I am?" or "Can I reach their part of the Internet from my part of the Internet?" In fact, most Internet users may not even know to ask these questions, because the Internet's open model means they don't have to think about such things. The network is open to anyone willing to participate, as a consumer, an information provider, an infrastructure builder, or an academic who wants to study how it all fits together.[1] Without a central authority dictating who, how, and where connections are made, the network can grow organically to support the needs of its users.[2] Once the network has surmounted the basic task of connecting to the Internet, they are part of the entire global Internet.

The accessible Internet assumes a market-based approach to growth, which has the effect of disenfranchising those without the means to fund connectivity and services. If you don't have any money to pay for it, there may be no business reason for someone to extend the Internet to your home or business. The Internet is open, but this does not mean that everyone will have access in an organic market. In areas where Internet users have few choices in service providers

[1] Of course, local conditions must also create a basic infrastructure to bring users and technology together to connect, which can be a challenge in some environments. However, the value of the Internet is high enough that it creates a demand pull which can lead to changes in local infrastructure that help connect more users. The open and accessible model works worldwide.

[2] While there is no need for a gatekeeper, national policy occasionally steps in to blunt the accessibility of the Internet. The result, almost universally, is that end users work around these policies to connect and use the services of the Internet. This, by itself, is strong evidence of the value of an accessible and open network.

and connections, the benefits of this critical property may be diminished: the Internet user may see a less accessible Internet.

When the property of a common protocol is missing, then users do not experience the full value of the Internet. For example, the Internet is undergoing a transition from IPv4 to IPv6. During that transition period, some users may be "on the Internet," yet unable to connect to some applications because one is on IPv4 and the other on IPv6. The danger of losing connectivity and, therefore, fragmenting the Internet is one of the reasons that the transition has taken so long and been so expensive: no one wants to violate this critical property and isolate themselves from the rest of the network.

Critical Property 2: An Open Architecture of Interoperable and Reusable Building Blocks

The Internet provides well-defined and well-understood services to applications using a simple open architecture. Technology building blocks are assembled in a layered fashion, working together to provide services to applications and end-users. Each building block delivers a specific function, like supporting different network types, ensuring reliable transport, enabling security, or providing name resolution[3]. Anyone can add innovation at any point[4]—and Internet users can adopt (or reject) those building blocks that bring value without re-engineering the entire network. When building blocks for new common services are easy to build and install, this speeds deployment and innovation.

<u>This open architecture delivers a key benefit: the common interoperable services and reusable building blocks allow for fast, permissionless innovation everywhere</u>. An application designer does not have to start from first principles and wonder about the architecture and technology of the underlying network. Instead, the Internet's architecture offers a well-understood menu of choices that allow for fast deployment and innovation. Even uncertainties such as whether the underlying network is IPv4 or IPv6 are minimized from the application designer's perspective, because the building blocks responsible for transport functions hide these differences.[5]

The structure of the Internet building blocks tends to push innovation upwards, as developers build on top of what exists, delivering better and more creative services — without requiring changes to the underlying technology.

The process of standardization is open to all interested and informed parties, and the results of this process are deployed on a voluntary basis. Changes are adopted when they serve a purpose, and unnecessary ones die. Even when some of the building blocks are proprietary (the Google Maps API, for example) their definitions are open enough to allow decentralized development and deployment, preventing ossification.

The importance of these open and interoperable building blocks can be seen when we find parts of the network closed. For example, Internet firewalls operate at a level where they "manage"

[3] Examples of the building blocks include protocols for wireless networks IEEE 802.11, or TCP ensuring reliable data transport between two end-systems.

4 To have a chance of being adopted, the innovation has to meet certain requirements, such as interoperate with other relevant building blocks. Standardization can be essential for adoption, especially for the foundational building blocks.

[5] An influential 1984 paper, "End-to-End Arguments in System Design" by Saltzer, *et al.*, offered a detailed argument for why the Internet should retain this layered architecture and push services such as connection-oriented and connection-less transport layer protocols to the edges of the network, and influenced early Internet designers to adhere rigidly to this model. [J. H. Saltzer *et al.*, End-to-End Arguments in Systems Design, ACM Transactions on Computer Systems, Vol 2, No. 4, November 1984, pages 277-288. https://doi.org/10.1145/357401.357402

transport layer TCP and UDP connections in between end nodes.[6] These devices have a much more static view of the Internet. This means that even if two end systems agree to run a new transport protocol, it may be difficult to deploy this protocol across the Internet because many Internet firewalls would not have the capability to control it, and thus would block it.

Fast innovation on the Internet is underpinned by an application designer's ability to take advantage of well-defined layered services. This is a great benefit to both the application and its users. For example, the well-known TLS protocol provides a defined security service to any application, eliminating the need to invent this mechanism from scratch. Experience has shown that trying to reinvent security rather than use standard building blocks, like TLS, often results in security compromises and breaches. Although the Internet is not free of breaches, the ability of security designers to re-use building blocks such as TLS delivers greater security at lower costs.

Critical Property 3: Decentralized Management and a Single Distributed Routing System

As a network of networks, the Internet's infrastructure is based on nearly 70,000[7] independent networks choosing to collaborate and connect together. Each of these networks runs a common, open, protocol (Border Gateway Protocol, BGP) that allows it to exchange routing information with its neighbors. And each of these networks makes independent decisions on how to route traffic to its neighbors, based on its own needs and local requirements. There is no central direction, or a controller dictating how and where connections are made, so the network grows organically, driven by local interests.

<u>The distributed routing system delivers several key benefits: global reach, resilience, and optimized connectivity</u>. Each organization that joins the Internet selects how they connect and how they route their data based on local requirements. They are able to optimize how their Internet connection works to match their needs: price, services available, connection bandwidth, reliability, or quality, and so on. No central coordination is required because all agreements and policy decisions are between the connecting organization and their neighbors; you don't need to request permission to join the Internet from some central authority.[8] The ability to make independent decisions on a regional, local, or hyper-local basis allows the Internet to be more agile, scalable, and adaptable to the needs of its users.

The lack of a central routing authority within the Internet, however, does come with disadvantages as well. Without enforcement of a common policy, both human error and deliberate malice can result in interruptions to connectivity and security issues such as spying on Internet traffic or impersonating an organization. By taking a collaborative approach to

[6] Firewalls and similar devices, such as load balancers, address translators, and security scanners, are often called "middleboxes" because they sit "in the middle" between two end-nodes, changing the layered model so that the two end-nodes are not really directly communicating over an underlying network layer. Well-designed middleboxes minimize the interruption to the Internet's layered model by helping preserve end-to-end communications. To the extent that middleboxes disrupt the layered model, this critical property is compromised. For this reason, middleboxes are one of the technologies Internet engineers love to hate.

[7] These are "Autonomous Systems," each of which represents a separate administrative entity, every one of which may have hundreds of internal networks. On Tuesday, June 23, 2020, there were 68,577 Autonomous Systems advertising routes into the global Internet.

[8] To take full advantage of distributed routing, an organization connecting to the Internet does need to request an Autonomous System Number (AS number) as well as a block of IP addresses which are assigned by Regional Internet Registries and usually have ongoing maintenance fees. However, the Registries have no input, influence, or knowledge of how the requesting organization connects to the Internet or routes their traffic.

routing, the Internet relies on peer pressure and community action to resolve issues — and resolution usually occurs very quickly once the community has identified the problem.[9]

In the absence of a common distributed routing system, the Internet would lose both agility and scalability. Local decisions and requirements would be impossible to accommodate without updating the central controller. Enforcing centralized routing – or even regional routing – eliminates the ability for end users to choose the best connectivity for their needs, creates scalability problems, brings economic disadvantages, and inevitably degrades the resilience and performance of a network as large as the Internet.

Critical Property 4: Common Global Identifiers

The Internet is an infrastructure that supports complex applications, some of them so large that they spread across continents and have millions of cooperating servers behind them. Internet users see elegant interfaces hiding behind a single name: Google, Facebook, Microsoft, and others. But there's an essential glue that allows every user to connect to the applications they use: IP addresses. Every bit of data flowing between a user's computer and the applications being used is in an IP packet, and every single IP packet has an address that says where it is going. These IP addresses allow any two systems on the Internet to find each other, without ambiguity.

Having common global identifiers delivers a key benefit: consistent addressability. The common identifier space, underneath all of the various levels of application, delivers a coherent view of the entire network. From any point on the Internet, a tiny packet of information can be passed from computer to computer, each one examining the same few bits — the address — to clearly identify a destination. When used as designed, the IP address isn't subject to abbreviation or interpretation; IP addresses can't be confused or ambiguous. The common identifier space seems like such a small thing, but the consistency it delivers to the Internet is a critical property.[10]

Closely tied to IP addresses is another identifier space: the Internet's Domain Name System (DNS). The DNS has many uses, but the most common is the creation of a consistent mapping between names and IP addresses. The consistency of the DNS is an important part of delivering a predictable and reliable service to every Internet user.

We can see how essential a single common global identifier space is by looking at what happens when this critical property is threatened. The perfect example is the continuing transition from the shorter IPv4 addresses to longer and more plentiful IPv6 addresses. IPv6 addresses are absolutely, increasingly required because there are simply not enough IPv4 addresses to accommodate the growth of the Internet. But with the introduction of IPv6 addresses, there now are two global identifier spaces, and if you have an address in one space, you may not be able to reach the other. The challenge is that both address families are incompatible, meaning that a device with an IPv4 address cannot exchange data, or 'talk', with an IPv6 device without the need for address translation. This creates fragmentation of the Internet, and the resistance to

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[9] See, for example, "Mutually Agreed Norms for Routing Security", at https://www.manrs.org/, where industry players demonstrate their commitment to routing security by voluntary adopting a set of practices and therefore creating a more secure environment.

[10] Compare IP addresses with another famous global identifier: telephone numbers. A number such as 867-5309 can confound an end user who want to dial it: Oh, that's too short, so they must have left off the city code, so I have to add that in, unless I'm inside the office when I have to dial 9 to get an outside line, but if I take my phone to the USA, I add 001 for the country code, while if I'm in Switzerland, I would just dial +1 to get to the USA and do I need to add a 0 before the city code if I'm dialing from across the border?" Compared to telephone numbers, IP addresses are an amazing, raging, success.

this fragmentation is one of the reasons that the transition from IPv4 addresses to IPv6 addresses is taking so long.

The common global identifier space of IP addresses means that individual users and network managers all have a single view of the network. Without these common global identifiers, we would have to construct special gateways, install translators, and create mapping tables to keep everything connected. Fracturing other name spaces, such as the DNS, also creates additional costs, overhead, and friction within the network. The utility of the Internet would be reduced and resources would be wasted. Instead, with common, consistent, and predictable global identifiers, the Internet, a huge 'network of networks', acts as one single connected network.

Critical Property 5: A General-purpose Network

The most popular uses of the Internet have changed dramatically from its first days: remote terminals and file transfer gave way to e-mail and simple collaborative communications systems, which evolved to Web browsing, social networks and media streaming. This was possible because the Internet was designed as a general-purpose network—not optimized for voice, particular usage patterns, or special traffic characteristics. The Internet is completely agnostic about the type of content that flows through it, guaranteeing neither quality nor connectivity, yet delivering enough of both to be a base layer for information services, commerce, communications, recreation, and more.

The benefit of a general-purpose network is its ability to continuously meet the requirements of a diverse, constantly evolving, environment. With no specific purpose in mind, the network serves data communications needs of billions of people, through an infinite number of applications, all doing different things, all at the same time. The Internet has been adapted for so many uses that it is displacing other types of networks: Dedicated voice telephone lines in the world peaked 15 years ago, replaced in part by Internet telephony. Streaming television and movie services are being delivered over the Internet, partially replacing programming delivered over cable TV and satellite networks. And because the Internet is not attached to any particular technology, it is able to re-use the cable TV and satellite infrastructure as data communications networks, incorporating them into the Internet as well. The building blocks of the Internet can be rearranged to achieve a desired result without the need for global coordination or fundamental changes to the design.

The Internet's general purpose comes with drawbacks: while the Internet can be used for many things, it is not designed to do any particular job especially well. For example, without widespread mechanisms for congestion control and quality of service, or the ability to centrally manage capacity and scalability of the network, streaming services have had to establish elaborate caching systems to serve their subscribers, i.e. ensuring they can watch high-definition videos or play virtual reality games without endless buffering. But this development also demonstrates the Internet's ability to adjust, adapt and build on top, or amend parts of it.

While the networks constituting the Internet may have been built for specific purposes, the general design was not. Otherwise, the Internet would not have been able to support other types of applications. For example, the first digital telephone networks were optimized for voice, delivering calls with higher quality and greater efficiency than the Internet can. Yet, these networks had to be completely renovated to deliver a new feature, say a video call, at great expense and considerable difficulty. A general-purpose network may not be perfectly optimized for every new application, but it can support most new applications. A long-lived general-purpose Internet design lets innovators pursue, without permission, their ideas knowing the network's benefits and drawbacks, enabling fast movement forward while in comparison the network changes are small and gradual.