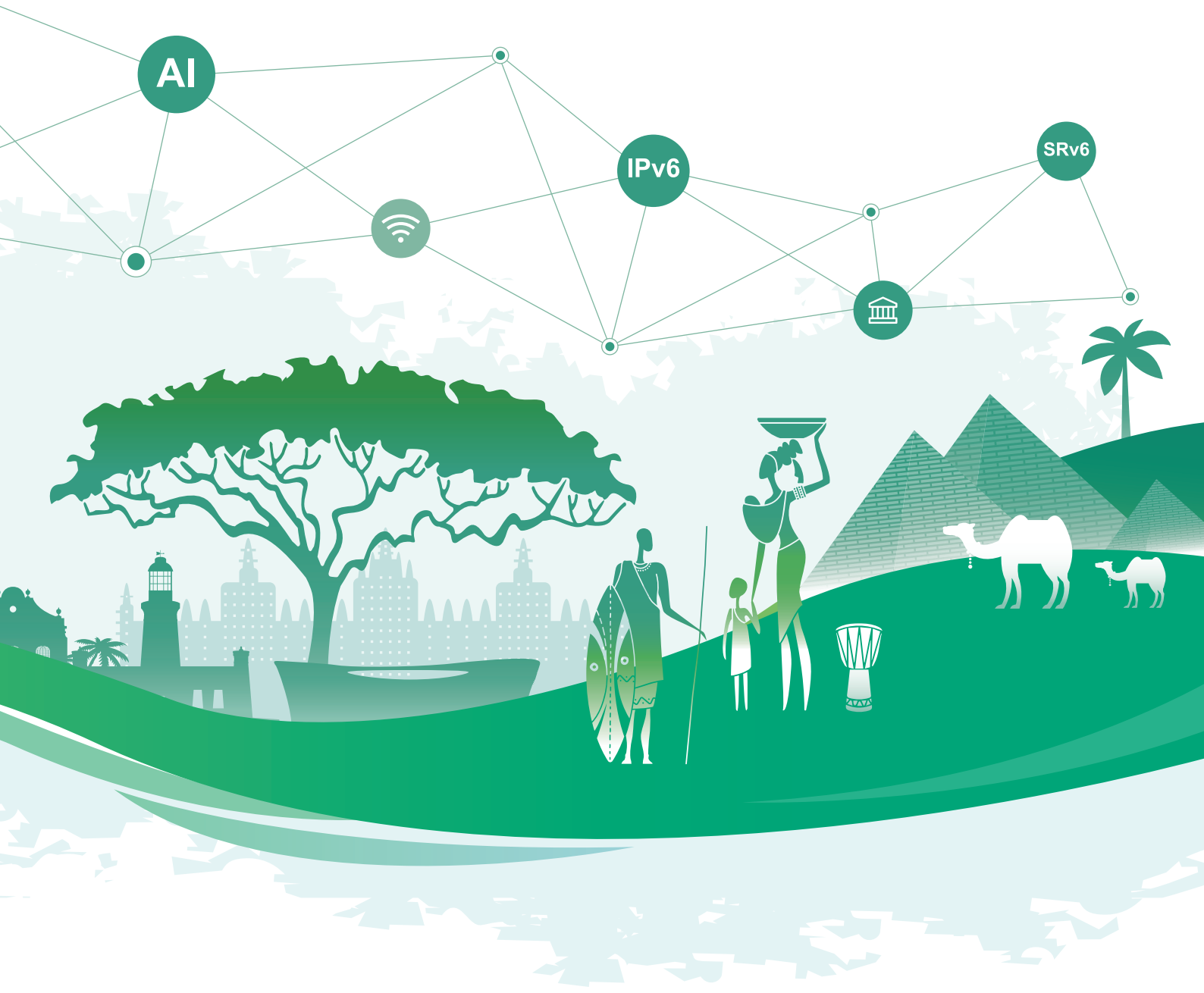
Africa IPv6 Development White Paper

IPv6: The Way Forward For Africa's Digital Future



››› Preface

The Internet has changed the world over the past 30 years. With the advent of new network innovations, one in particular stands out for having contributed to making the world more connected: the Internet Protocol (IP).

The previous version of IP, version 4 (IPv4), was designed in the 1980s to handle a maximum number of only 4.3 billion addresses at a time when no one could imagine the rapid growth of the Internet today. 40 years ago, this number was seen as a large number, but is far from enough to connect every person on the planet today (8 billion), not to mention everyone that we might want to connect in the future (50 billion or more). Therefore, it was important that IP version 6 (IPv6) is introduced to solve the problem of address shortages: with 3.4 x 10^{38} addresses provided, IPv6 can assign every grain of sand on the earth with an IP address. The vast address space makes IPv6 the ultimate choice for the Internet of Things (IoT) and 5G era.

Providing more addresses is not the only advantage of IPv6. It is also the basis for innovation and security of the Internet. In 2016, the Internet Architecture Board (IAB) stopped requiring IPv4 compatibility in new or extended Internet protocols. In other words, new protocols for the Internet will be optimized for and depend on IPv6. This means that the IPv4 networks will stop evolving and updating. It also means that the IPv4 networks will be more vulnerable to new security threats.

To guarantee the sustainability of the Internet, which is the foundation of our digital economy today, governments and operators have initiated the transition to IPv6. A number of developed and emerging economies have released policies to accelerate IPv6 deployment. Not only because IPv6 provides vast address space, but more importantly, its scalability and functionality to enable many enhanced features. With protocol innovations, we can provide differentiated high-quality services compared to traditional best efforts; with Artificial Intelligence, we have swift provisioning and greater customer satisfaction. In the 5G and cloud era, IPv6 Enhanced is fundamental to improve service experience.

This white paper is in this sense exciting as it first introduces the importance of IPv6 and IPv6 Enhanced for the future Internet. It then reviews the development of IPv6 globally and in the African region. Government policies play a critical role in the IPv6 deployment, as demonstrated by the analysis of the experiences from different countries, such as France, the US, China, India, Kenya and Nigeria show. Based on those successful experiences, the White Paper provides a policy toolbox to help policymakers adapt their IPv6 migration strategy. In the Appendix, there are technical recommendations for IPv6 transition which introduces the main technologies and migration roadmap.

I encourage everyone to interact with the White Paper closely and engage in conversations with colleagues and other stakeholders from the industry so that they can understand the importance and approaches for IPv6 migration and adoption. This is critical to the continued success of the internet in transforming the lives of Africans. If we can achieve the migration to IPv6, it will unlock new opportunities to do even more with the internet and have even greater impact in Africa. It is important that we act fast together!

John OMO

Secretary-General
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Preface

In the 1980s, IPv4 became the basic protocol of the Internet and promoted the development of IP networks. In the 2000s, the MPLS technology was born, which enhanced the comprehensive bearing capability of voice and video services. In the 2020s the 5G and cloud era will drive next-generation IP networks, IPv6 Enhanced is based on massive IPv6 addresses and based on protocol innovation and network intelligence technology innovation.

IPv6 Enhanced is a comprehensive technical system that comprehensively improves IP network capabilities in six dimensions: ultra-high bandwidth, ubiquitous connectivity, security, automation, deterministic quality, and low latency. It meets requirements for fast service provisioning, user experience optimization, differentiated assurance, and network O&M. The IPv6 Enhanced technology system has the following capabilities:

• Innovation of network technology systems, such as SRv6 (Segment Routing over IPv6), network programming, network slicing, deterministic forwarding, In-situ flow detection, new multicast, application awareness, and lossless networks.

• Innovation of the intelligent O&M system is represented by real-time health awareness, proactive network fault detection, fast fault identification, intelligent network self-healing, and automatic system optimization.

• Innovation in network business models is represented by 5G 2B, multi-cloud interconnection, business migration to the cloud, and network security linkage.

Currently, the IPv6 adoption rate in African countries is relatively low, and development of IPv6 Enhanced has broad and far-reaching prospects. Operators are pioneers in IPv6 innovation, over the past two years, Africa's top operators have actively carried out IPv6 innovation practices and achieved fruitful results.

This white paper analyzes typical cases of IPv6 Enhanced for African operators in detail. This paper describes the application innovation and technical achievements of IPv6 technology systems such as SRv6, slicing, and IFIT (In-situ Flow Information Telemetry), aiming to provide guidance and reference for IPv6 technology innovation in the African continent.

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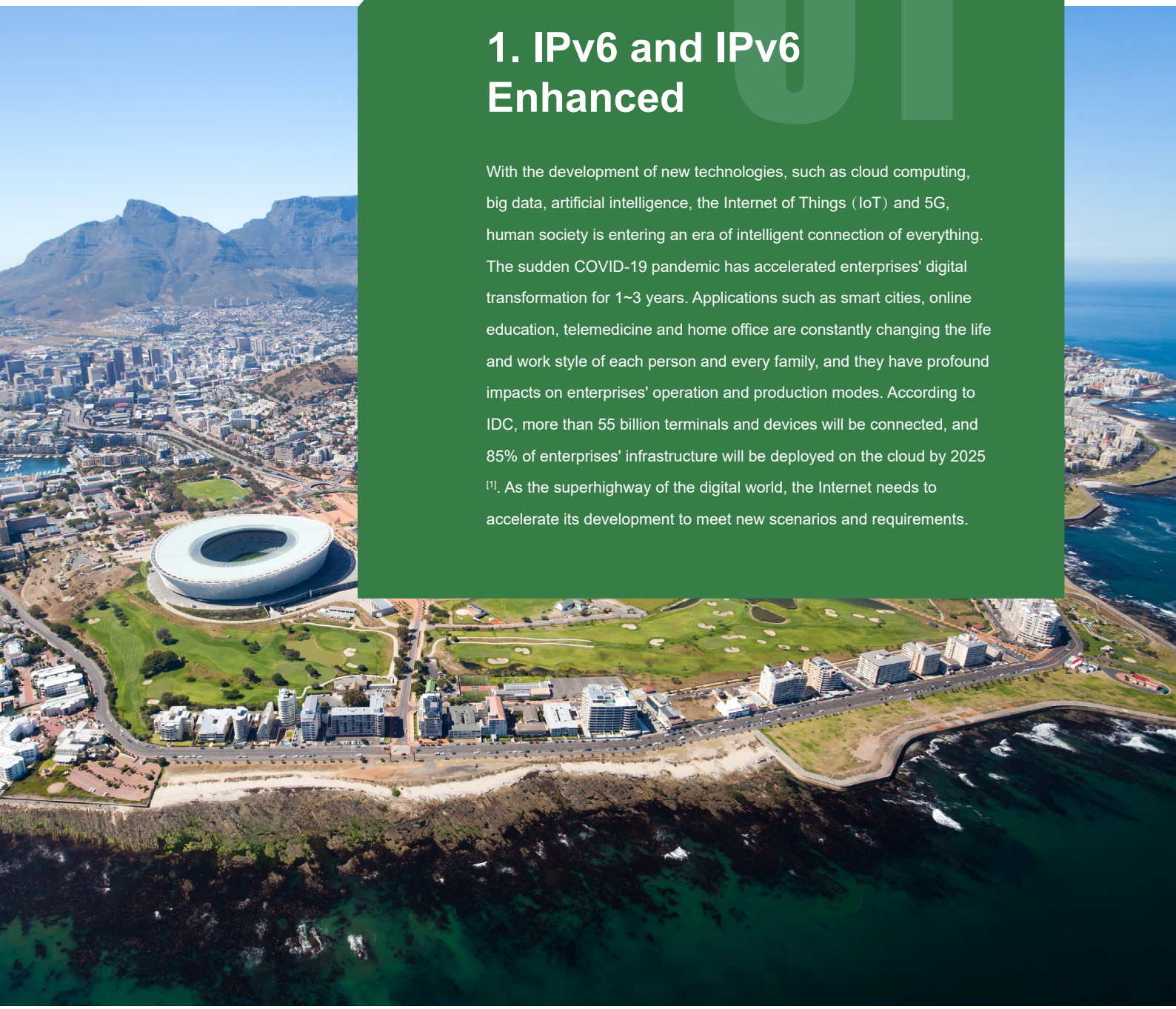
Table of Contents ‹‹

01

1. IPv6 and IPv6 Enhanced

With the development of new technologies, such as cloud computing, big data, artificial intelligence, the Internet of Things（IoT）and 5G, human society is entering an era of intelligent connection of everything. The sudden COVID-19 pandemic has accelerated enterprises' digital transformation for 1~3 years. Applications such as smart cities, online education, telemedicine and home office are constantly changing the life and work style of each person and every family, and they have profound impacts on enterprises' operation and production modes. According to IDC, more than 55 billion terminals and devices will be connected, and 85% of enterprises' infrastructure will be deployed on the cloud by 2025 [1]. As the superhighway of the digital world, the Internet needs to accelerate its development to meet new scenarios and requirements.



[1] IDC, Worldwide Global DataSphere IoT Device and Data Forecast 2021-2025, July 2021

1.1 IP, IPv4 and IPv6

The IP (Internet Protocol) and IP address are fundamental underlying elements of Internet technology. The device cannot access the network without an IP address. Data cannot be transmitted between devices without the IP protocol. It has been more than 40 years since the birth of the last generation of IP protocol, IPv4, and it is difficult to adapt to the new digital era. Today, countries and economies have proposed digital strategies and IPv6 promotion plans to promote industrial upgrading and inject new impetus into social development. For example, the US launched a digital infrastructure plan to upgrade at least 80% of IPv6-only networks by 2025; the EU renaissance plan and set up a dedicated IPv6 promotion team; China plans to build an advanced and secure digital infrastructure based on IPv6 technology by 2025.

The IP is designed for computers to communicate with each other in a network. It defines the rules that computers should follow when communicating. It unifies the "frame" data of various network systems and devices into the IP packet format. With the IP, the Internet has rapidly developed into the world's largest and most open computer communication network.

The previous generation of IP, IPv4, was released in 1981 and used 32-bit (4-byte) addresses to provide 4.3 billion addresses. But with the explosion of computer devices, IPv4 addresses have been allotted. Therefore, the Internet standardization organization, IETF (Internet Engineering Task Force), began to plan the next generation of IPv4 protocols in 1990. In addition to addressing the shortage of IP addresses, the new protocol needs to develop more extensions. In 1994, the IETF formally proposed an IPv6 development plan. In 1998, IPv6 was officially released by the IETF.

An IPv6 address consists of 128 bits. In order of magnitude, the capacity of IPv6 addresses is about 8×10^{28} times that of IPv4 addresses, reaching 2^{128} addresses. This not only solves the problem of the number of network address resources, but also provides a foundation for the development of the Internet of Things.

1.2 The Benefits of IPv6

IPv6 not only solves the problem of IPv4 address shortage. By providing more objects connected to the Internet and protocol extensibility, IPv6 can further release the potential of the Internet, bringing significant social and economic values, especially in technology innovations and network security.

• Technology Innovations

On November 2016, the Internet Architecture Board (IAB) released a statement on IPv6, announcing that "*The IAB expects that the IETF will stop requiring IPv4 compatibility in new or extended protocols. Future IETF protocol work will then optimize for and depend on IPv6.*"[2] This means that all Internet innovations will be based on IPv6 while IPv4 will gradually stale.

Besides the protocol innovations, IPv6 brings an equal chance to players in the market. In the early days of the Internet, the IPv4 address was free of charge. This brings extreme imbalance in the address allocation: the developed countries and large enterprises can easily obtain large address blocks at no cost. In contrast, emerging countries and new companies have very limited resources. For example, the United States have 4911 IPv4 addresses per 1000 population, and most of the African countries have only tens of IPv4 addresses per

[2] IAB, IAB Statement on IPv6, November 2017.

1000 population[3]. With the rapid development of the Internet, the IPv4 address becomes a scarce resource and the price increases significantly: the cost of each IPv4 address doubled in 2021 and passed $50[4]. This brings a high barrier for newcomers and hinders competition.

• **Network Security**

To resolve the address shortage, IPv4 also has alternatives by having multiple users share an IPv4 address. But this brings two critical security issues: 1) it is hard to identify cyber crimes hiding behind shared addresses; 2) it is challenging to provide data protection because the Internet was split into pieces.

IPv6 is the ultimate solution: by providing unique addresses to every object connected to the Internet, it is much easier for law enforcement agencies to trace cyber crimes and provide data encryption in data transmission.

By releasing the full potential of connectivity and providing better network security, it is estimated that the total industry value enabled by IPv6 and its innovations can reach $10.8 trillion in 2030[5].

From a more technical perspective, IPv6 has the following advantages:

1) Larger address space: IPv6 has sufficient address space and hierarchical structure. IPv6 increases the length of an existing IPv4 address by four times, from 32 bits to 128 bits, to support a large number of network nodes. The maximum number of IP addresses is 2^{128}. IPv6 supports more levels of address hierarchy. The IPv6 designer divides the IPv6 address space according to different prefixes and adopts a hierarchical address structure to facilitate the fast-forwarding of data packets by routers.

2) Enhanced multicast: IPv6 provides enhanced multicast support and flow control, which can promote the development of Internet multimedia applications and provide a good network platform for quality of service (QoS) control. The format of an IPv6 data packet includes an 8-bit class and a 20-bit flow label. The source node that sends the service flow and the router that forwards the service flow can add labels to the data packet and perform different processing in addition to the default processing.

3) More efficient routing: IPv6 provides flexible routing mechanisms and uses smaller routing tables. IPv6 address allocation follows the clustering principle at the beginning. This enables a router to use an entry to represent a subnet in the routing table. This dramatically reduces the length of the routing table in the router and improves the speed of forwarding data packets.

4) Auto-configuration: IPv6 implements stateless address auto-configuration. IPv6 defines both stateless and stateful address auto-configuration mechanisms. Stateful auto-configuration uses DHCPv6 to dynamically allocate IPv6 addresses to hosts, and stateless auto-configuration uses NDP to implement stateless auto-configuration.

5) Improved security: IPv6 supports authentication and encryption at the network layer, providing higher protection. Encryption and authentication options in IPv6 provide confidentiality and integrity of packets. This dramatically enhances network security.

6) Network simplification: IPv6 simplifies headers, reduces processor overhead, and saves network bandwidth. This makes it easier for routers to handle IPv6 headers. IPv6 uses a new header format with options separate from the base header, which can be inserted between the base header and the upper layer data if needed. This simplifies and speeds up the routing process.

7) Extensibility: IPv6 facilitates flexible expansion. IPv6 allows extensions to protocols as needed by new technologies or applications. IPv6 defines multiple extension headers, which makes IPv6 extremely flexible, provides strong support for multiple applications, and makes it possible to support new applications in the future.

8) Mobility support: IPv6 can better support mobile communications. Mobile communication is closely connected with the Internet at present. Mobile IPv6 design draws on the experience of mobile IPv4 design and makes use of many new features of IPv6, so it provides more and better features than mobile IPv4.

[3] IP Address by Country 2022, https://worldpopulationreview.com/country-rankings/ip-address-by-country

[4] IPv4 Prior Sales, https://auctions.ipv4.global/prior-sales

[5] Roland Berger, Global IPv6 and IPv6+ Development Measurement and Analysis on Social and Economic Impact, October 2021

1.3 IPv6 Enhanced

1.3.1 What is IPv6 Enhanced

Besides larger address space, IPv6 brings extensibility to the Internet. Based on IPv6, IPv6 Enhanced improves IP network capabilities in six aspects: ultra-high bandwidth, ubiquitous connectivity, security, automation, deterministic quality, and low latency.

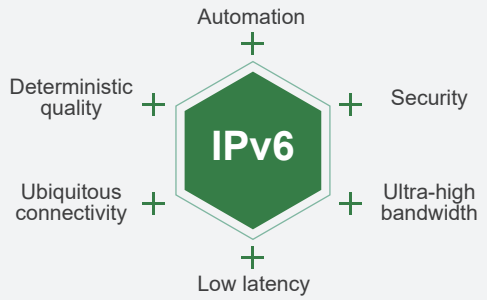


Figure 1 Six key features of IPv6 Enhanced [Source: ETSI IPE Gap Analysis, August 2021]

Ultra-high bandwidth: continuously release ultra-high bandwidth to meet the challenges of future service uncertainty.

Ubiquitous connectivity: provides flexible multi-service bearer and service-oriented network capabilities. Uses technologies such as SRv6 to implement end-to-end traffic scheduling, protocol simplification, network programmability, and user experience assurance, meeting multi-service convergent experience requirements.

Security: IPv6 overcomes the defects of IPv4 and effectively defends against broadcast storms, fragment attacks, and scanning attacks. Each device can be assigned a globally unique IP address, implementing traceability of network attacks. In addition, IPv6 Enhanced provides a new platform. New technologies, such as SRv6 and APN6, provide innovative solutions to network security problems.

Automation: The automation enables automatic, self-healing, self-optimization, and autonomous driving networks. With key technologies such as artificial intelligence, on-demand detection, and knowledge graph, the fault recovery time is shortened from hours to minutes, and anomalies can be intelligently predicted.

Deterministic quality: The deterministic quality creates a predictable, deterministic experience for the IP network. The slicing technology is used to provide a secure, reliable, and predictable network environment and achieve jitter from *ms to us/ns.* The intelligent lossless network technology is used to achieve zero packet loss in the data center.

Low latency: Low latency creates an immersive experience for real-time interaction between people and the virtual world. The end-to-end latency of the MAN reaches 10 ms. In a data center network, the static latency of device-network coordination is reduced from us to ns, and the single-hop dynamic latency is reduced from 10 to 100 *us* to 1 *us*, providing efficient data channels.

As shown in Figure 2, the Internet technologies have developed from IPv4 for traditional services like web and voice call to MPLS (Multi-Protocol Label Switch) for multimedia services. Today, the Internet is embracing the IPv6 and IPv6 Enhanced technologies for applications like the Internet of Things, industrial automation, satellite communication, autonomous driving, etc.

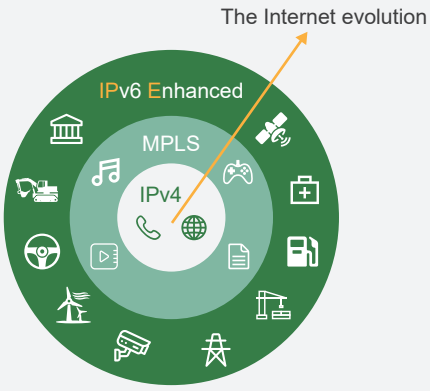


Figure 2 The direction of the Internet evolution: from IPv4 to IPv6 Enhanced

1.3.2 ETSI IPE Introduction

In October 2020, ETSI (European Telecommunications Standards Institute) established the IPE (IPv6 Enhanced Innovation) Workgroup to address IPv6 deployment problems in emerging scenarios such as 5G transport networks, industrial Internet, and cloud-network synergy. IPE aims to identify and describe IPv6 based solutions, look into the derived requirements and reference architectures that are needed to enable the deployment of IPv6 across the new and evolving technology domains. The focus is also on the automated IPv6 end-to-end reference architecture by introducing a horizontal approach that complements the activities of other SDOs. The IPE Alliance aims to build a global IPv6 Enhanced industry platform, promote healthy industry development, expand industry space, expand consensus, and facilitate business success. The alliance has more than 100 members worldwide in 2022, including operators, vendors, and academia. The alliance is dedicated to improving the IPv6 Enhanced industry ecosystem and accelerating innovation.

02

2. Global IPv6 Development

With the rapid growth of the Internet and emerging applications like IoT, smart home, industry automation, etc., the deployment of IPv6 is growly significantly during the past ten years. As the IP is the fundamental protocol of the Internet, the governments have to take the lead in bringing together all the stakeholders: from user equipment vendors, network device vendors to ISPs and content providers. Therefore, both developed countries and emerging countries released industry policies to promote the development of IPv6 and IPv6 Enhanced.

This chapter firstly introduces IPv6 as the global trend of Internet development. Then the IPv6 industry policies of some examples countries, including France, the US, China and regional countries like Nigeria, Kenya, etc., are analyzed. The goal is to illustrate what a policymaker could do to accelerate the IPv6 migration and make the country ready for the digital transition.

2.1 IPv6: the Global Trend of Internet

2.1.1 Global IPv6 deployment status

Since the event of World IPv6 Day on June 8, 2011, the IPv6 deployment rate has grown from almost 0 to close to 40% of the Internet in October 2022, covering nearly half of the Internet (Figure 3).

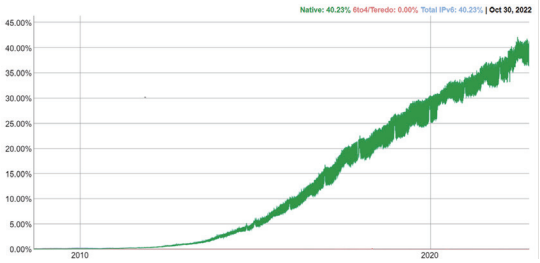


Figure 3 IPv6 Adoption Rate [Source: Google IPv6 Statistics, October 2022]

This is due to the joint efforts of equipment vendors, application developers, standardization organizations, content providers and governments. Some of the significant moves in the industry include:

• **2012:** Akamai, Facebook and Netflix started IPv6 services;

• **2016:** Apple requires iOS App Store apps to support IPv6-only networks;

• **2016:** The Internet Architecture Board (IAB) announced that it "*expects that the IETF will stop requiring IPv4 compatibility in new or extended protocols. Future IETF protocol work will then optimize for and depend on IPv6.*"

• **2017:** Facebook announces that all new data center clusters would be IPv6-only;

• **2021:** AWS announced the ability to create an IPv6-only architecture on AWS. All GitHub pages support IPv6.

As of October 2022, 80% of user equipments, 42% of metro/backbone networks and 50% of the clouds support IPv6. There is no doubt that the value chain of IPv6 is ready, and the Internet is embracing its new generation of protocols. The IPv6 Enhanced development is also growing rapidly: by April 2022, there are 140+ SRv6 deployments and 30+ IP network slicing deployments.

However, it is also noticed that the development among the countries is extremely unbalanced, as shown in Figure 4: while some of the countries like India (70%), Belgium (66%), the US (53%) and France (55%) have high IPv6 adoption rate, lots of countries, especially those in Africa have very limited IPv6 deployment. It could be easily observed that the countries with developed ICT industries tend to have higher IPv6 adoption rates.

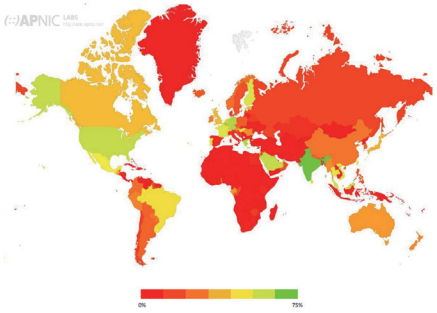


Figure 4 IPv6 Adoption Rate by country [Source: APNIC Labs, October 2022]

2.1.2 Africa Regional IPv6 deployment status

In 2021, 40% of the population has Internet access, and 60% of them access the Internet via mobile phones[6] in Africa. While the network coverage grows rapidly in those regions, there is still great potential compared to other parts of the world. This will also bring significant social and economic values: IFC (The International Finance Corporation) estimated that improving internet access to reach 75% of the population could create a further 44 million jobs.

The rapid growth of the Internet requires not only access technologies like 4G/5G, fiber, etc. but also IP as the basic protocol. As the IPv4 address pool is already exhausted and the standards around IPv4

[6] Investment Monitor, African e-Connectivity Index 2021, November 2021

gradually stop evolving, IPv6 has become the only choice for sustainable development of the Internet. However, not every country is aware of the trend. Figure 5 illustrates the African countries with less than 5% IPv6 adoption rate. The deployment in the majority of the countries is still low, and the regional development is well below the world average (13.92% in western Asia and 1.36% in Africa).

It is worth noting that some countries in the regions have noticed the importance of IPv6 development and started the migration progress. The industry policies will be introduced in the rest of this chapter.

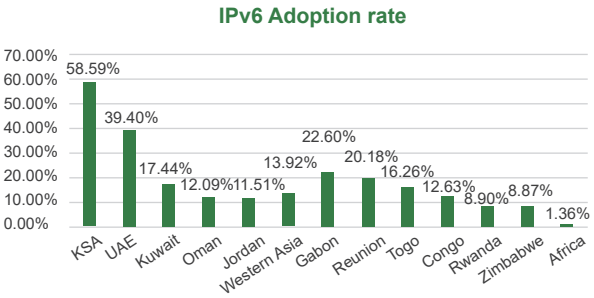


Figure 5 Arab and African countries with more than 5% IPv6 adoption rate [source: APNIC Labs, April 2022]

2.2 Global IPv6 Industry Policies

This section introduces some typical policies released by different countries around the world: binding the wireless spectrum with IPv6 (France), promoting IPv6 in the government networks (the US), setting up a national commission for IPv6 promotion (China), engagement from both government and private section (India) and embedding IPv6 in the national ICT plan (Vietnam).

2.2.1 France: Regulator released IPv6-5G binding policy

The French telecommunication regulator, ARCEP (Autorité de régulation des communications électroniques, des postes et de la distribution de la presse), confirms that the transition to IPv6 is a major issue for competitiveness and innovation. Major operators in France (Bouygues Telecom, Orange and SFR) had already assigned between 93% and 98% of their IPv4 addresses. Sharing IPv4 addresses brings issues like blocking new Internet services and increasing difficulty in identifying cybercrimes.

In November 2019, ARCPE released the regulation on 5G spectrum distribution[7], requiring that:

• An obligation of IPv6 support to guarantee the service interoperability and not block services only available in IPv6

• The 3.4-3.8GHz 5G spectrum holders must have their network compatible with IPv6 protocol from December 31 2020.

In addition to the IPv6-5G binding policy, ARCEP publishes Annual IPv6 Barometers[8] every year to follow the deployment of IPv6 in the country and provide suggestions. ARCEP also set up the national IPv6 Task Force[9] to promote the IPv6 deployment in the country. In March 2022, the Task Force published "Enterprises: How to Deploy IPv6" to guide the enterprises' IPv6 migration.

The actions from both the regulator and operators are boosting the IPv6 deployment in France, as shown in Figure 6. By the middle of 2024, the IPv6-enabled deployment is expected to be close to 100% for major operators like Orange, Bouygues Telecom and Free. Although SFR is lagged, it is also catching up.

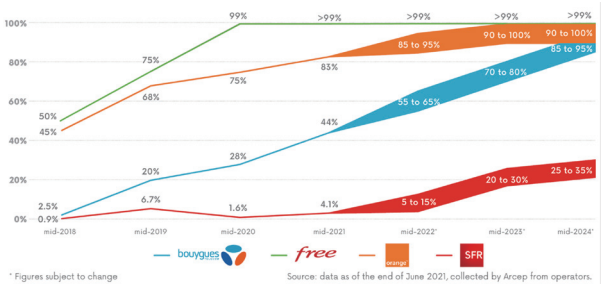


Figure 6 IPv6-enabled customers evolution in fixed networks of major operators in France [Source: 2021 Annual Barometer of the Transition to IPv6 in France]

[7] ARCEP, Décision n° 2019-1386, November 2019.
[8] ARCEP, ANNUAL BAROMETER OF THE TRANSITION TO IPv6 IN FRANCE, 2019-2022
[9] ARCEP, France IPv6 Task Force https://en.arcep.fr/publications/task-force-ipv6.html

2.2.2 The United States: Released multiple policies since 2009 and set up an agenda for IPv6-only transition in federal networks

As the leading country in Internet technologies, the US is the most active country in IPv6 promotion. The US federal government also released multiple policies to accelerate IPv6 deployment in the public sector. Some key actions include:

• **2009, the Federal Chief Information Officers Council (CIO) published the "Planning Guide/Roadmap Toward IPv6 Adoption within the US Government"**, clearing the position of IPv6 as an integrating framework and organizing principle for the next generation of Federal IT Infrastructure.

• **2012, the CIO Council released the 2nd version of the road map**, summarizing the Federal transition components, business rationale, 'to-be' states and transition steps within the process.

• **2020, the Office of Management and Budget (OMB) published OMB-M21-07 (2020)**, which defines a specific glide path for agencies' transition to IPv6:

- ➤ At least 20% of IP-enabled assets on Federal networks should be operating in IPv6-only by the end of 2023.
- ➤ At least 50% of IP-enabled assets on Federal networks should be operating in IPv6-only by the end of 2024.
- ➤ At least 80% of IP-enabled assets on Federal networks should be operating in IPv6-only by the end of 2025.

Besides the actions mentioned above, the OMB, CIO Council and the National Institute of Standards and Technology (NIST) also released multiple guidelines and technical standards. The industry leaders like Cisco, Google, Facebook, and Microsoft from the private sector have also played a significant role in IPv6 adoption to guarantee the competitiveness of the enterprises. More details of the policy actions could be found in Axon Partners Groups whitepaper "IPv6: Benefits and best practices of public policies"[10].

2.2.3 China: Set up national IPv6 Promotion and Deployment Commission to release policies, and formulate a development strategy

As a country with a large population and in lack of IPv4 addresses, the Chinese government set IPv6 migration as a national strategy and established *the National IPv6 Promotion and Deployment Commission* to release IPv6 policies and formulate the development strategy. The most recent one is in July 2021, the government published the "Special Action Plan of IPv6 Traffic Promotion (2021-2023)", setting up goals for different phases. The final goals of phase 3 include:

• IPv6 Traffic ratio in mobile networks is over 50%, the traffic volume of fixed networks is more than three times of that of December 2020.

• IPv6 concentration in TOP 100 commercial websites is over 70%

• The ratio of Fixed terminal which obtains IPv6 address is over 80%.

2.2.4 Kenya: Publication of national IPv6 migration strategy

In July 2022, the Communications Authority of Kenya (CA) released the National IPv6 Migration Strategy[11], aiming at bringing impetus to the current IPv6 adoption rate in Kenya. The strategy includes:

• **Regulatory Intervention**

- ➤ Only devices with IPv6 capability will be type-approved in Kenya effective July 2023.
- ➤ Further assignments of resources, namely, numbering resources, frequency assignments and Top-level Domain Name assignment documents will contain in them a regulatory requirement for the adoption IPv6 addresses.
- ➤ Inspection and Certification of Operator systems and networks will involve a check on the transition to IPv6 component, and those found not to have adopted IPv6 would be deemed non-complaint.

[10] Axon Partners Group, IPv6: Benefits and best practices of public policies, December 2021

[11] Kenya CA, IPV6 Migration Strategy https://www.ca.go.ke/wp-content/uploads/2022/06/IPv4-to-IPv6-Migration-Strategy-.pdf , July 2022.

➤ Network Readiness Assessment report will be established.

• Awareness

Develop an awareness campaign plan targeting the operators, vendors and consumers as appropriate.

• Training

Organize hands-on physical training on IPv6 migration and related technologies.

• Report Submissions

Define reporting templates, and the service providers will be required to report on the steps taken to adopt IPv6.

A set of milestones are also established to measure the progress. The service providers are also encouraged to adopt emerging IPv6 Enhanced technologies to create additional values based on IPv6.

2.3 Africa Regional IPv6 Application Cases

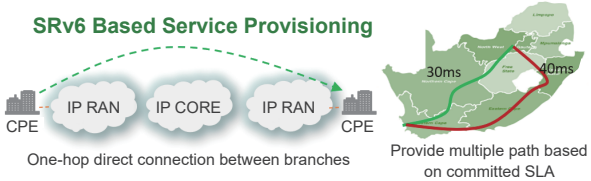
Countries in the African regions have relatively low IPv6 adoption rates. However, in some of these African countries, the industrial application of IPv6 is being gradually explored.

2.3.1 South Africa Operator C: As a result of the SRv6+IFIT feature, the TTM is shortened, SLAs can be committed and the overall competitiveness of private lines are improved.

There are three operators A, B, and C in the 2B market in South Africa. Intensive competition exists among operators. In addition, due to the high homogeneity of products, the main source of competition is price war. Operator C, as a traditional leader in the 2B market, needs to strengthen the overall competitiveness of private lines and avoid price war, which will adversely affect its return on investment.

Operator C uses SRv6+IFIT to improve private line competitiveness:

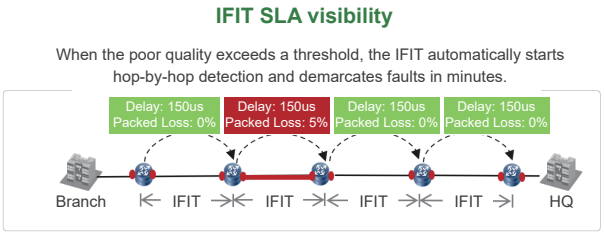
• With SRv6, cross-department and hop-by-hop service configuration can be reduced that simplifies service provisioning procedures, and shortens private line TTM. With SRv6 and SDN Controller, before service provisioning, service paths can be calculated based on different required SLAs, which in turn makes the SLA viable.



Description:
• Path computation based on multiple factors, such as delay and bandwidth.
• Services are only configured on the CPE. The network does not need to be changed (SRv6 Enable).
Benefit:
• SLA visibility and commitment before service provisioning.
• Shorter TTM.

Figure 7 Benefit of SRv6 Based Service Provisioning

• The IFIT technology is used to accurately measure and display the SLA of private line services. In addition, the automatic hop-by-hop detection function is used to greatly shorten the fault locating time.



Benefit:
• Proactively identify problems before customers complain
• Shorten the poor-QoE recovery time.

Description:
• Hop by hop in-band detection of poor-quality private lines quickly identify fault points.
• 7x24 historical performance snapshot

Figure 8 Benefit of IFIT

By 2022 Q4, Operator C had upgraded the traditional MPLS private line to SRv6 private line at one mining project. Summarizing this project's experience, Operator C will launch new value-added products for the 2B market to improve the overall competitiveness of the products.

2.3.2 South Africa Operator M: Use SRv6+Automatic Network Optimization feature to release suppressed traffic and increase service revenue during the load-shedding period.

Operator M is an important mobile operator in South Africa, and mobile data is its main source of revenue.

Load shedding is increasing in South Africa in 2022 (2 to 3 times, 6 hours/per day). The network traffic changes frequently,

the daily O&M workload increases by 2 or 3 times. If traditional manual O&M is used, OPEX will increase accordingly. Meanwhile, manual O&M takes a long time, highly relies on expert experience and the O&M effect cannot be guaranteed.

As a result, Operator M was facing the risk of lower revenues, higher OPEX, and finally lower profits.

Operator M decided to use SRv6+Automatic Network Optimization features to address these challenges.

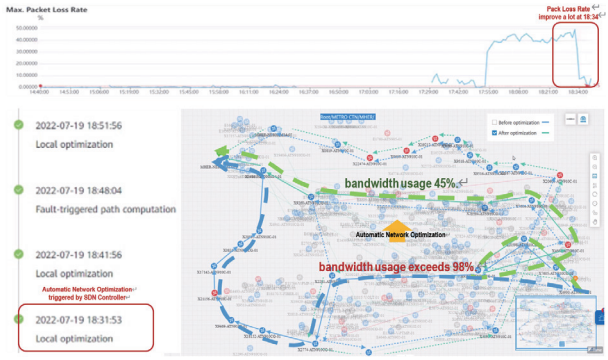


Figure 9 Automatic Network Optimization Example in Operator M

As shown in the picture above, IFIT detects that the packet loss rate significantly improves at 18:34. Check the network optimization history. It is found that the SDN controller performs automatic network optimization at 18:31, and traffic is automatically adjusted from the link whose bandwidth usage is 98% to the link whose load is light. In this way, the bandwidth utilization is more balanced and the service quality is guaranteed.

By 2022 Q4, the commercial deployment of the SRv6+Automatic Network Optimization feature has been completed in the northern region of Operator M. After the deployment, 91% of base station service quality had significantly improved. The average daily traffic in the northern region increased from 370.4 GB to 427.6 GB, with a growth rate of 15.4%.

2.3.3 Mauritius Operator T: Use the SRv6+Slicing feature to provide deterministic experience for enterprise customers to expand its 2B market and continuously increase revenue.

Operator T is a leading operator in Mauritius. Due to the impact of the pandemic and currency devaluation, Operator T's profits have plummeted in recent years. To continuously increase revenue, Operator T decided to focus on how to increase 2B service revenue.

Operator T planned to increase 2B service revenue through differentiated competition. The way is mainly focus on optimizing the enterprise private line package, which is not only based on bandwidth, but also includes value-added products such as latency guarantee.

Operator T decided to use the SRv6+slicing technology to provide hard isolation assurance and deterministic experience for enterprise customers.

As shown in the picture below, different services can be carried by different slices in one network, every service is hard isolated and has a private network-like experience.

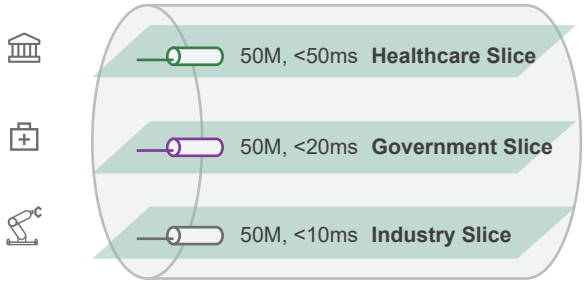


Figure 10 Benefit of Slicing

By the end of 2022 Q4, the POC test has been successfully completed. It is planned to be put into commercial use in 2023.

3. IPv6 Transition: Recommendations of Industry Policies

03

The experiences from different countries in the world have shown that the government's industry policy plays a critical position in the IPv6 transition. Pictures below lists a set of policy actions and tools that the government could apply to accelerate the IPv6 migration process from policy preparation to policy enforcement.

Policy Preparation (1st year)	➤ Set up IPv6 industry organizations ➤ Join international industry alliances ➤ Build the IPv6 awareness campaign and training ➤ Include IPv6 training in university curriculum
Policy Design (2nd year)	➤ Create high level national strategy with ICT planning ➤ Set up compliance goals for operator and government networks ➤ Encourage IPv6 Enhanced pilots in operator and government networks
Policy Enforcement	➤ Impose an IPv6 adoption progress reporting obligation for operators ➤ Enforce IPv6 support on newly-built networks ➤ Bind national fund for broadband/mobile coverage projects with IPv6 support ➤ Enforce IPv6 requirements for new devices in the market ➤ Tax/limit the use of IPv4 address sharing ➤ Bind Frequency and Number Resource Allocation with IPv6 support

Figure 11 IPv6 industry policy tools

3.1 Policy Preparation

• Set up IPv6 Industry Organizations

The IPv6 industry organizations, named IPv6 Council or IPv6 Task Force, could bring together stakeholders like government agencies, operators, vendors, consulting companies and research institutes to build and promote the IPv6 ecosystem. The initiative could be from the regulator, national network information center (NIC), ministry of communication or major operators in the country.

All the countries mentioned in chapter 2 have established similar organizations.

• Join International Industry Alliances

At the international level, ETSI IPE[12] (detailed introduction in section 1.2.3) plays an essential role in sharing experience in IPv6 deployment and enhanced innovations. By joining IPE, the participants could:

- ➤ Obtain the latest advancement in IPv6-related technologies;
- ➤ Learn and get help from industry partners working in IPv6;
- ➤ Share one's experience and solutions by participating in the discussion and co-authoring white papers;
- ➤ Join the proof-of-concept projects;
- ➤ Participate in the alliance workshops.

Therefore, it is encouraged that all the stakeholders of IPv6, including government agencies, operators, equipment vendors, research institutes, and verticals join the ETSI IPE.

Currently, there are almost 100 members in ETSI IPE, covering all the continents and domains related to IPv6. The participation is free of charge.

• Build the IPv6 Awareness Campaign and Training

Competent network architects, engineers and technicians are key to the adoption of IPv6 by the industry. Therefore, the government should develop an awareness campaign plan and training sessions through workshops, online platforms, hands-on sessions, etc.

• Including IPv6 training in the university curriculum

Computer Network courses are indispensable in any computer science and computer engineering curriculum. Unfortunately, the examples and hands-on in nowadays' network courses are mostly based on IPv4 rather than IPv6. It is important to have IPv6 in the network training, which is helpful for university students to get prepared for their future professional careers.

3.2 Policy Design

• Create high-level national strategy

The government should identify key public agencies such as regulators, the ministry of telecommunications, ministry of economy and ministry of education to create high-level IPv6 roll-out strategy. It could be an independent IPv6 migration strategy or be combined with other national ICT plans.

• Set up Compliance Goals for Service providers and Government networks

For service providers and big enterprises that run complex network infrastructures, migration to IPv6 is not a short-term task but a journey of several years. The regulators and governments could set up a compliance goal with clear milestones to urge the service providers and government networks to transfer to IPv6 with concrete steps. A reasonable goal is to increase the

[12] ETSI IPE https://www.etsi.org/committee/ipe

operators' or governments' IPv6 adoption rate by 20~30% every year. This approach has been applied by countries like the US, China, Kenya, etc.

• Encourage IPv6 Enhanced pilots in operator and government networks

IPv6 is more than a larger address space. One of the essential reasons of delayed IPv6 deployment is the lack of business cases, and alternative approaches such as IPv4 NAT could still be used. As the protocol development based on IPv4 becomes stale, the government can encourage the deployment of IPv6 Enhanced technologies such as SRv6, BIERv6, network slicing, IFIT etc. Those innovations could bring additional values to the operator, thus further motivating the IPv6 deployment.

3.3 Policy Enforcement

• Impose an IPv6 Adoption Progress Reporting Obligation for Service Providers

By imposing service providers to report the IPv6 adoption progress regularly, the government and regulators can follow the status of IPv6 deployment. This exercise has been adopted by countries like France and China. Based on the reports, the regulator could set KPIs for the service providers.

• Enforce IPv6 Support on Newly-Built Networks

Legacy networks need to deal with devices with inadequate IPv6 support, which may make the immediate migration challenging to achieve. However, for the newly -built networks, deploying IPv6 will be a much smoother task. The regulator and government should impose an obligation of IPv6 support to guarantee service interoperability, especially for those services only available in IPv6. This makes the new networks ready for future evolution. The government should even encourage IPv6-only networks, which is the case required by the US government for its federal networks.

• Bind National Fund for Broadband/Mobile Coverage Projects with IPv6 support

Lots of countries have national or department funds to support broadband and mobile network deployment in the country. The governments and regulators could use the fund to leverage and motivate the application of IPv6 in those projects.

• Tax or Limit the Use of IPv4 Address Sharing

Although IPv4 address sharing relieved the address shortage in the short term, it is nowadays the worst barrier to the Internet's end-to-end connectivity and IPv6 deployment. The regulator should limit the sharing of one IPv4 address to subscribers. For example, in Belgium, the maximum number of subscribers behind 1 IPv4 address is 16.

• Enforce IPv6 Requirements for New Devices in the Market

The regulators can build IPv6 certification programs and standards requiring equipment compliance for IPv6. It could assist various stakeholders in ensuring that any products with Internet functionality to be used in the national market meets the minimum capabilities to support an IPv6 ecosystem. This approach has been applied by countries like Malaysia and Brazil.

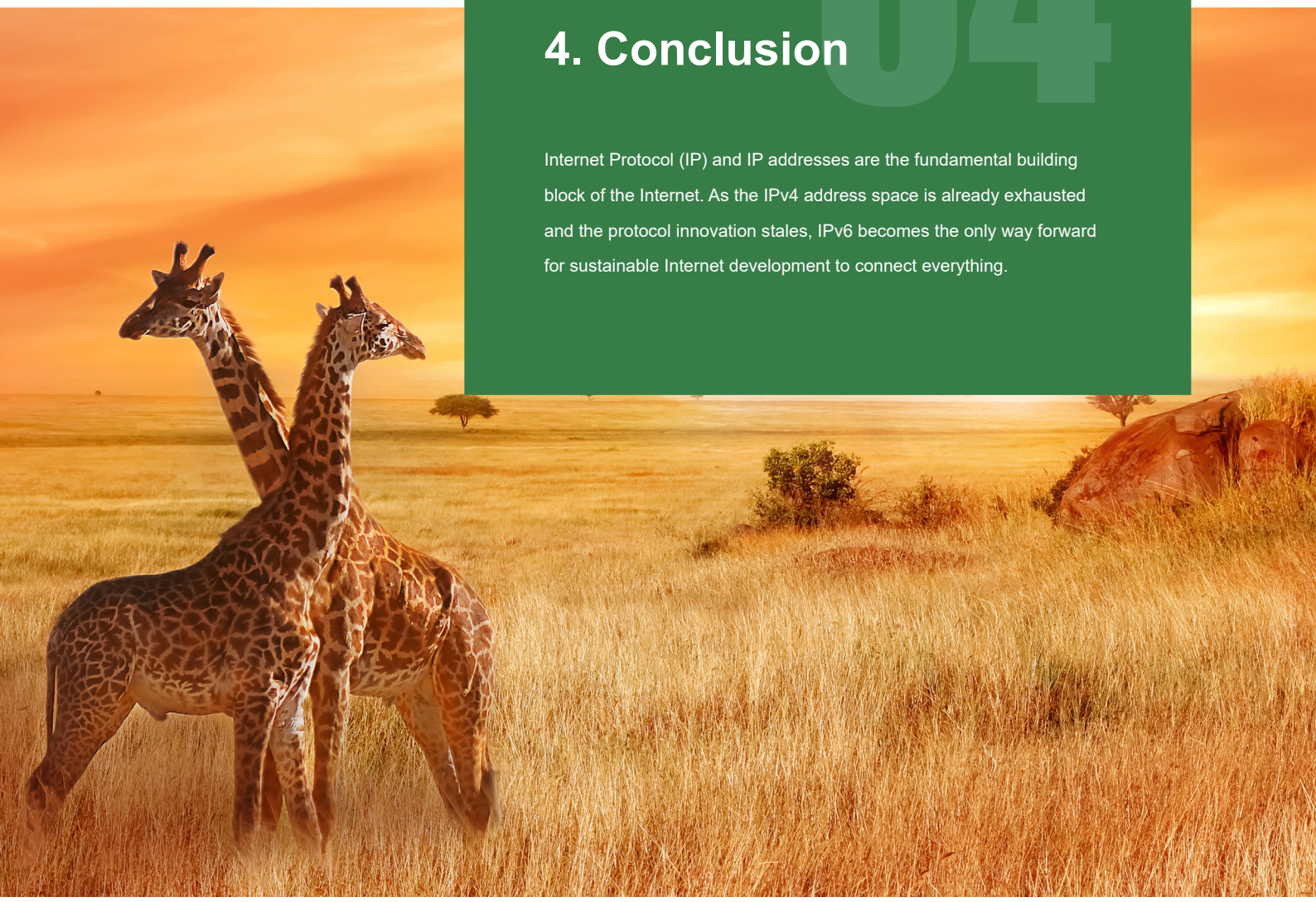
• Bind Frequency and Number Resource Allocation with IPv6 support

The regulators and NICs can add the IPv6 support requirement while allocating resources such as frequency, top-level domain names and numbering resources. The method is used by countries like France and Kenya.

04

4. Conclusion

Internet Protocol (IP) and IP addresses are the fundamental building block of the Internet. As the IPv4 address space is already exhausted and the protocol innovation stales, IPv6 becomes the only way forward for sustainable Internet development to connect everything.



The core values of IPv6 include:

• **Innovation.** From a technology point of view, all the new protocol designs are based on IPv6 rather than IPv4. This means that network innovations will be IPv6-based, and IPv4-based networks will gradually stop evolving. From a social point of view, the over-priced IPv4 address creates a high barrier for newcomers to the market – while the massive and free IPv6 address is much more welcoming for emerging enterprises.

• **Security.** By simplifying the network with end-to-end connectivity, IPv6 supports authentication and encryption during the data forwarding. Furthermore, by eliminating shared IPv4 addresses, every device is able to have its unique identity on the Internet, which facilitates tracing network attacks and crimes.

Because of the critical role that IPv6 plays in the digital transformation and the great potential of IPv6 Enhanced, the governments of different countries released various industry policies to accelerate the IPv6 deployment. The policies include but are not limited to: imposing IPv6 adoption progress reporting mechanisms, enforcing IPv6 support on newly-built networks, setting up compliance goals for operator/government networks and requiring IPv6 support in national broadband/mobile coverage projects and frequency allocation. Those policies have proven to be effective and raised not only the IPv6 adoption rate but also the efficiency of the digital society.

Migration to IPv6 concerns the digital competitiveness of a country in the 21st century. It is crucial for the government and private sectors to cooperate to push the next generation of the Internet forward together.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