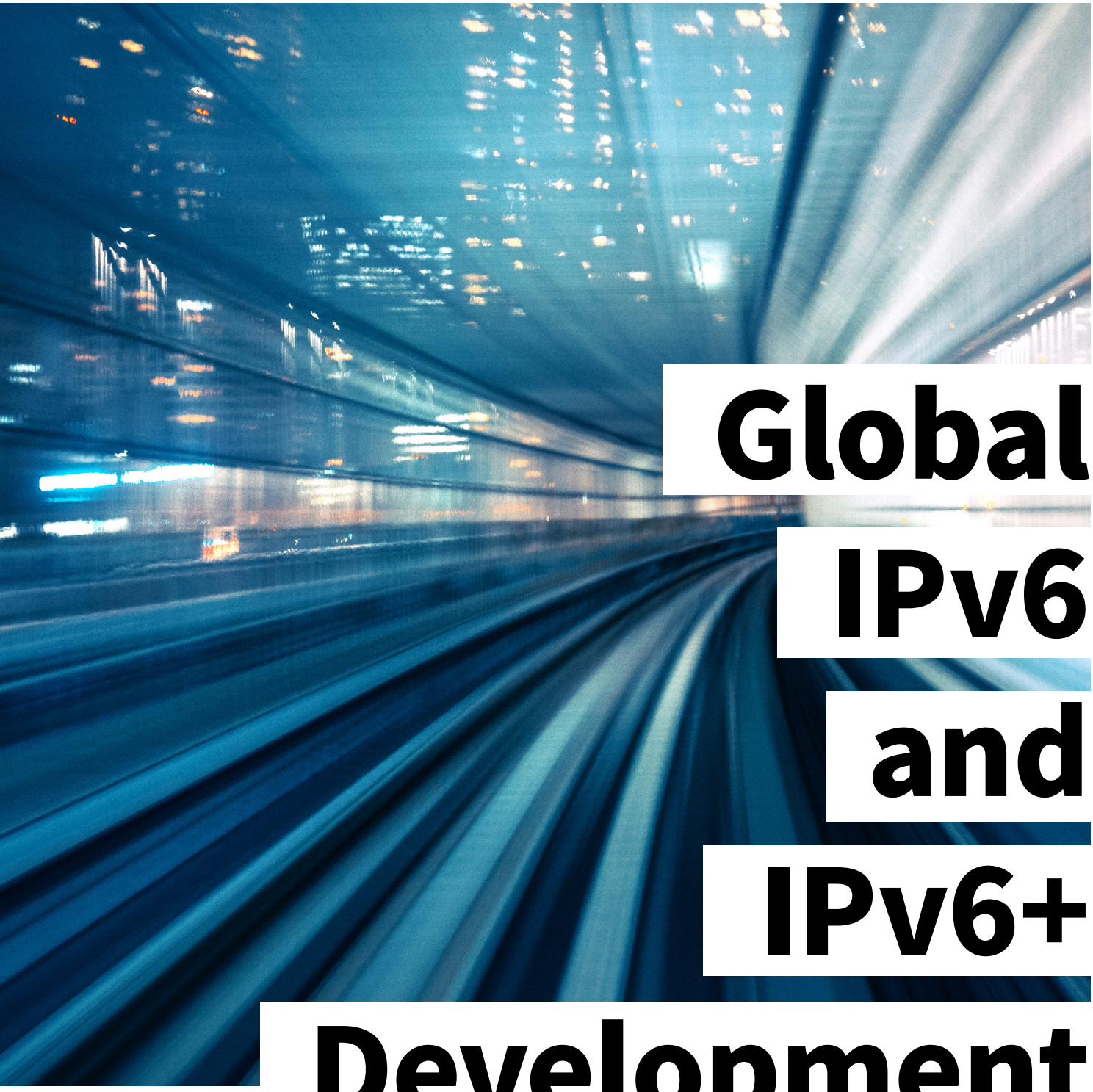


Global IPv6 and IPv6+ Development

Measurement and Analysis on Social and Economic Impact

October 2021

em lyon business school

Roland Berger

Executive Summary

With the advent of new communication and information technologies, the world has entered into a new era. We are witnessing an unprecedented historical moment where future-shaping technologies such as AI, 5G, cloud, IoT are emerging simultaneously.

A fundamental enabler lies at the core of all these technologies: IP address. It provides a "key" for devices to connect to the network, without which no communication can be carried out.

The previous protocol used for IP addressing was IPv4. It was designed in the early 1980s with a maximum total of only 4.3 billion addresses. The explosive growth of intelligent devices has exhausted the available IPv4 address resources, and IPv6 was introduced to solve this problem once and for all. With 3.8*10^38 total addresses available, IPv6 would be able to assign every grain of sand on earth an IP address.

However, IPv6 did not stop there. Related protocol innovations such as SRv6 are being currently standardized in IETF. They are denoted as IPv6+ in this whitepaper. Combined with AI, IPv6+ protocols go beyond enabling numerous connections to deliver high quality and smart connections.

IPv6 and IPv6+ enhance the deployment of advanced business applications like 5G, Cloud and Industrial IoT. They also provide the basis for the digitalization of all industries.

On a grander scheme, IPv6 and IPv6+ empower digital economy transformation, drive innovation and entrepreneurship, enhance social governance, and support digital equality. The ultimate transition to IPv6 and IPv6+, and the associated long-term benefits of the new technologies are beyond any doubt. Over the past decade, multiple initiatives at both global and regional levels have been implemented, to facilitate a coordinated transition to IPv6 for the entire internet ecosystem. At this moment, we find it necessary to reflect on how the world has progressed in this transition and summarize the concrete socio-economic value IPv6 and IPv6+ have created.

We indexed each country's IPv6 deployment level and analyzed how government policies helped to shape the current IPv6 landscape. We performed quantitative analysis of the relationship between IPv6 deployment and national GDP. We estimated the economic impacts of IP v6 and IPv6+ on various industries.

Although our analyses and estimates may be subject to limitations in sample scope and size, the results are still strongly in favor of IPv6 deployment: Every 10% increase in IPv6 deployment index would bring about 0.4% GDP growth. Total industry value enabled by IPv6 and IPv6+ is estimated at $10.8 trillion in 2030.

In conclusion, now is the perfect time for IPv6 deployment. Industry-wide adoption of IPv6 has taken off. Major telecom operators, internet content providers, equipment manufacturers have all participated in the rush into a new digital world through IPv6 and IPv6+ adoption. Policy makers may encourage 'long-tail' actors in the industry ecosystem to follow. With a combination of polices targeting the public sector, private sector, skills development, awareness enhancing and overall strategy, governments will be able to drive country-wide IPv6 and IPv6+ adoption.

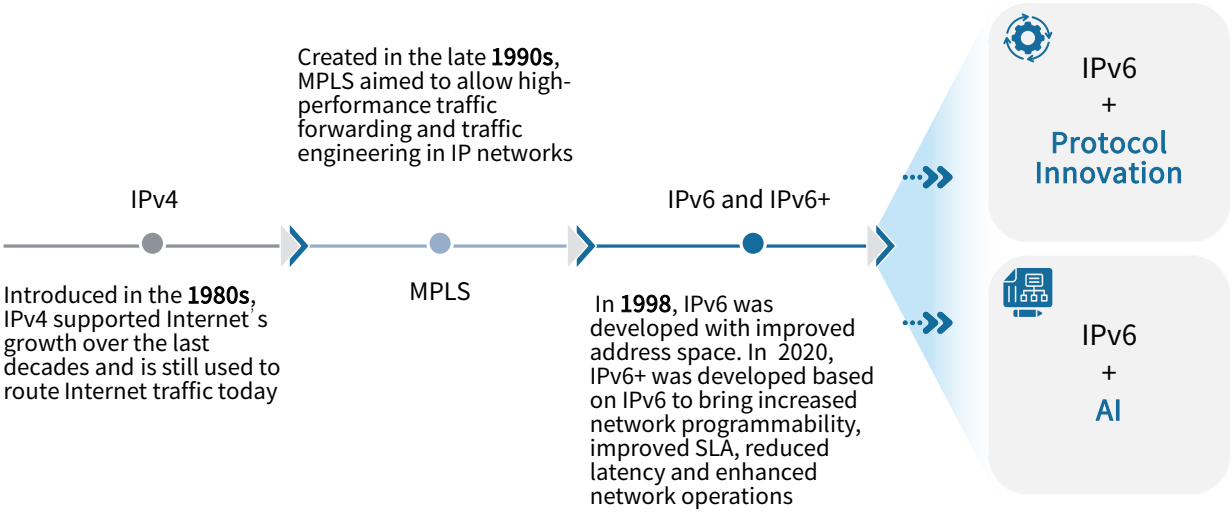
Introduction

Overview of IP address, IPv6 and IPv6+

An IP address is a unique address that identifies a device on the Internet or a local network. The IP protocol has evolved from IPv4, MPLS, to IPv6 and IPv6+. → 1

IPv6 technology brings enlarged address space, reduced subnet administration costs, and auto configuration[1] capabilities. Based on IPv6, IPv6+ further brings increased network programmability[2], improved SLA[3], reduced latency[4] and enhanced network operations[5][6]. → 2

1 Development of IP technology



Source: Desktop research; Roland Berger

[1] U.S. DEPARTMENT OF COMMERCE. IPv6 task force. Technical and Economic Assessment of Internet Protocol Version 6

[2] SRv6-PM: A Cloud-Native Architecture for Performance Monitoring of SRv6 Networks IEEE Transactions on Network and Service Management

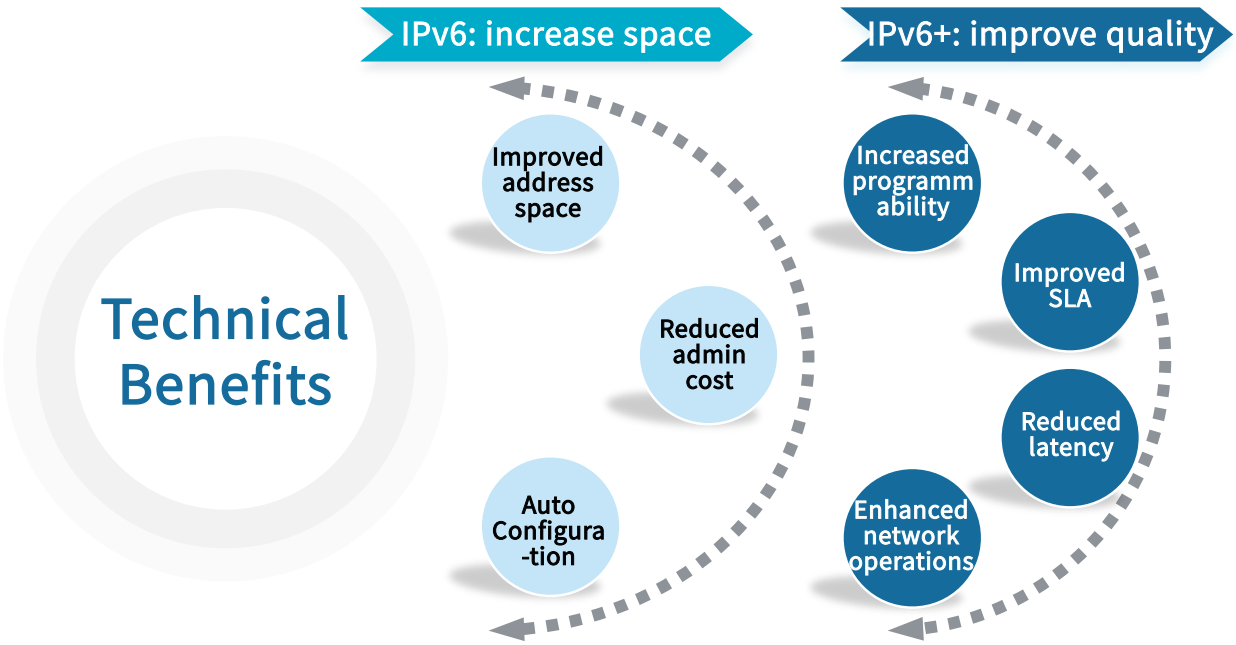
[3] Ruoyu Su, R. Venkatesan. Resource Allocation for Network Slicing in 5G Telecommunication Networks, IEEE Network

[4] U.S. DEPARTMENT OF COMMERCE. IPv6 task force. Technical and Economic Assessment of Internet Protocol Version 6

[5] S. Peng, Jim Guichard. Application-aware IPv6 Networking (APN6) Framework, Computer Science

[6] ETSI GR IPE 001 V1.1.1 (2021-08). IPv6 Enhanced Innovation (IPE) Gap Analysis

2 IPv6 and IPv6+ Technical Characteristics



Source: Desktop research; Roland Berger

Through its increased address pool size, IPv6 lays the foundation for the Internet to develop. IPv6+ greatly improves the quality of connections. It provides operators and enterprises of all industries with a highly automated and intelligent network that carries multiple services, and massive connections.

The Necessity of transition to IPv6 and IPv6+

The foremost reason to make the IPv6 transition is that IPv4 resources have nearly been depleted. Of the five Regional Internet Registries, all have reached exhaustion of the general address allocation function for IPv4 addresses over the past 10 years. By 2021, over 99% of all IPv4 addresses(/8s) have already been allocated.

The lack of IPv4 resources will put significant constraints on 5G/Cloud/IoT use cases as they require massive number of connections. Furthermore, rising acquisition costs and transactional costs of IPv4 addresses will have a negative impact on entrepreneurship and innovation. The scarcity of IPv4 addresses is also a potential factor that can lead to digital power concentration and demotes free access for all.

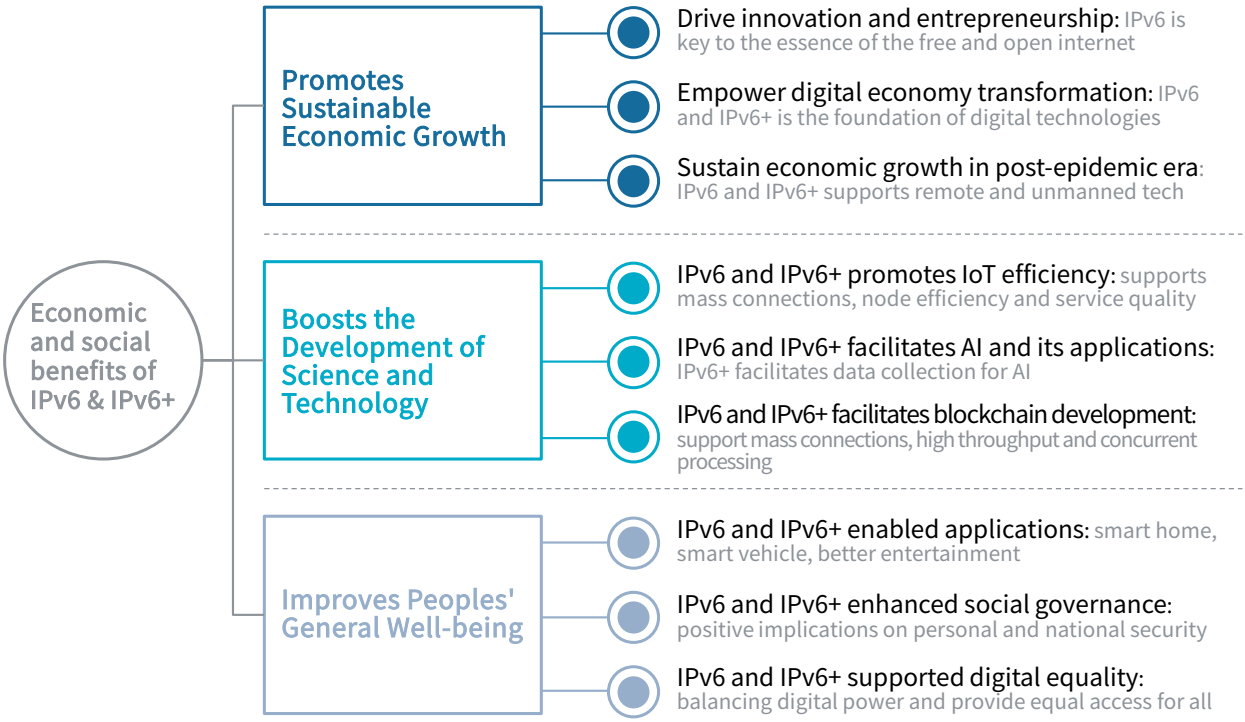
Although work-around technologies such as Network Address Translation (NAT) and Carrier Grade Network

Address Translation (CGNAT) have been introduced, they have limited scalability to large number of connections, and do not support applications requiring end-to-end connections. The massive, smart and high-quality connections needed in the era of 5G and cloud calls for the transition to IPv6 and IPv6+.

Economic and social benefits of IPv6 and IPv6+

IPv6 and IPv6+ technologies promote sustainable economic growth, boost the development of science and technology, and improve peoples' general well-being[7]. → 3

3 Economic and social benefits of IPv6 and IPv6+



Source: Roland Berger

[7] OECD. Economic Considerations in the Management of IPv4 and in the deployment of IPv6.

IPv6 and IPv6+ Industry Sector Impact

We estimate the industry sector impact of IPv6 and IPv6+ in 2030 by examining the cost reduction derived from preventing data security issues of different types, the impact of improved efficiency[8] enabled by IPv6 and IPv6+, and the value created by innovative technologies and their application scenarios. We mainly focus on 5G/IoT/cloud, empowered by IPv6 and IPv6+.

IPv6 and IPv6+ Economic Impact 2030 Estimate

IPv6 and IPv6+ deployments will positively affect virtually every industry sector. Since industries have differing economic and regulatory structures that will affect the timing of IPv6 and IPv6+ adoption, we focused on a longer time horizon and chose 2030 as the analysis timeframe.

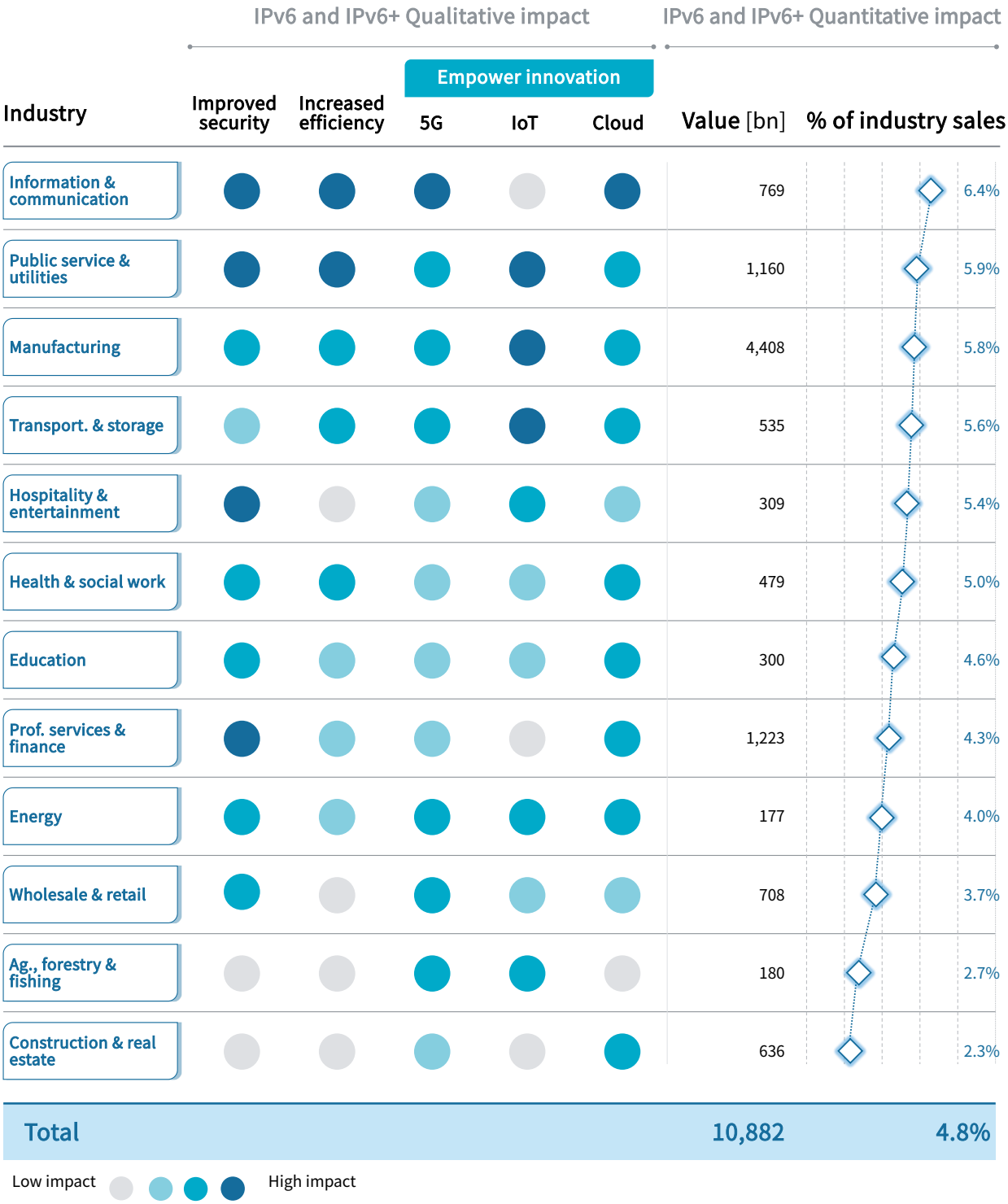
Based on our model and expert input, we estimate that potential global value created across multiple industry sectors enabled by IPv6 and IPv6+ could reach $10.8 trillion in 2030. This represents about 4.8% of the total real output of the industries analyzed in 2030. → 4

Major impacts and Industry use cases of IPv6 and IPv6+

IPv6 and IPv6+ as a fundamental enabler for other technologies have a wide range of impact on different industries. A detailed introduction of IPv6 and IPv6+ enabled industry use-cases can be found in the full report. → 5

[8] Technical and Economic Assessment of Internet Protocol, Version 6 (IPv6), U.S. department of commerce, National Telecommunications and Information Administration, National Institute of Standards and Technology

4 2030 IPv6 and IPv6+ enabled economic impact result, by industry (USD bn, %)



Source: Expert interview; desktop research; Roland Berger analysis

5 IPv6 and IPv6+ enabled scenarios in each industry

Industry	Application (some examples)	Improved security	Increased efficiency	Innovation
Manufacturing	**Smart manufacturing**: production visualization, remote operation			
Info. & communication	**Intelligent operations**: predictive maintenance, intelligent detection			
Wholesale & retail	**Smart shelves**: environment monitoring, automatic warning			
Public service &utilities	**Smart water system:** real-time monitoring of pipe network operation			
Prof. services & finance	**Risk control platform**: warning, identification and prevention			
Transport. & storage	**Driverless**: responsive navigation and operation with low latency			
Health & social work	**Telemedicine**: remote physician coaching operations			
Ag., forestry & fishing	**Smart agriculture**: remote monitoring, real-time data analysis			
Construction& real estate	**Operations security**: wearable devices monitor workers' moving line			
Energy	**Smart drilling system**: soil detection, automatic adjustment of drilling			
Education	**Smart classroom**: interactive distance learning, AR classroom			
Hospitality & entertainment	**Mobile games**: real-time interaction and enhanced experience			

Source: Expert interview, desktop research; Roland Berger analysis

IPv6 and IPv6+ Index

Referencing previous methods adopted by LACNIC, OECD and Cisco, we measure IPv6 deployment by four stages: IPv6 planning, IPv6 deployment at communication network, IPv6 deployment at content providers and IPv6 user capability. A detailed methodology can be found in the Appendix of the full report.

The index ranges from 0 to 1. A higher value means more advanced progress in IPv6 deployment.

We selected 79 countries across the globe, and calculated their IPv6 index for 2020 using data from APNIC and other relevant sources. → 6

We segmented the countries into front-runners, adopters and starters. Front-runners are countries with index value in the top 25 percentile. Starters are the bottom 25 percentile and the rest are adopters.

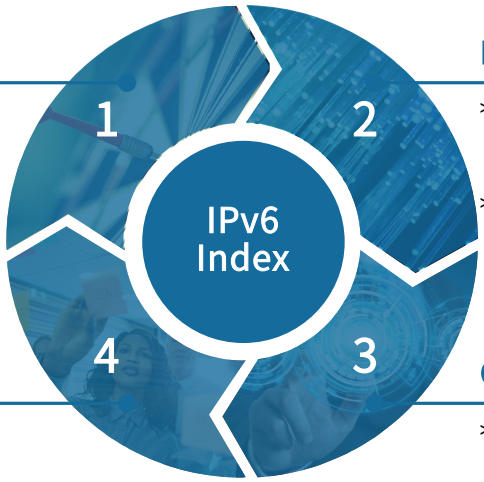
6 IPv6 Index Methodology

Planning

- Measure the growth of **IPv6 prefix allocation**, which is an **indicator of future IPv6 deployment**
- Ranges from 0 to 1, higher value means more IPv6 resources planned

Network

- Measure IPv6 readiness at **the core of the internet** which is the network **of telecom operators** and **cloud service providers**
- Ranges from 0 to 1, higher value means more ISPs support IPv6



Users

- Measure **end-user's capability** to access the internet through IPv6
- Ranges from 0 to 1, higher value means better user accessibility to IPv6

Content

- Measure IPv6 readiness of **websites and applications** of **content providers**
- Ranges from 0 to 1, higher value means more content are offered in IPv6

Source: LACNIC; Roland Berger

IPv6 Index Result

As the index construction method focus more on the development of IPv6 relative to that of IPv4, countries such the Unites States and China which have high absolute numbers in IPv6 deployment statistics are not among the top countries of IPv6 index. → 7,8

We also constructed the index for 2015 and calculated index growth for each country. Overall, China is showing the fastest growth, followed by Vietnam and India. → 9

7 IPv6 Index 2020 Ranking List

Front-runners

Rank	Country
1	Belgium
2	Germany
3	Finland
4	India
5	Brazil
6	Switzerland
7	Malaysia
8	Greece
9	Portugal
10	Thailand
11	Uruguay
12	Netherlands
13	Luxembourg
14	France
15	Paraguay
16	Japan
17	Vietnam
18	United Kingdom
19	United States

Adopters

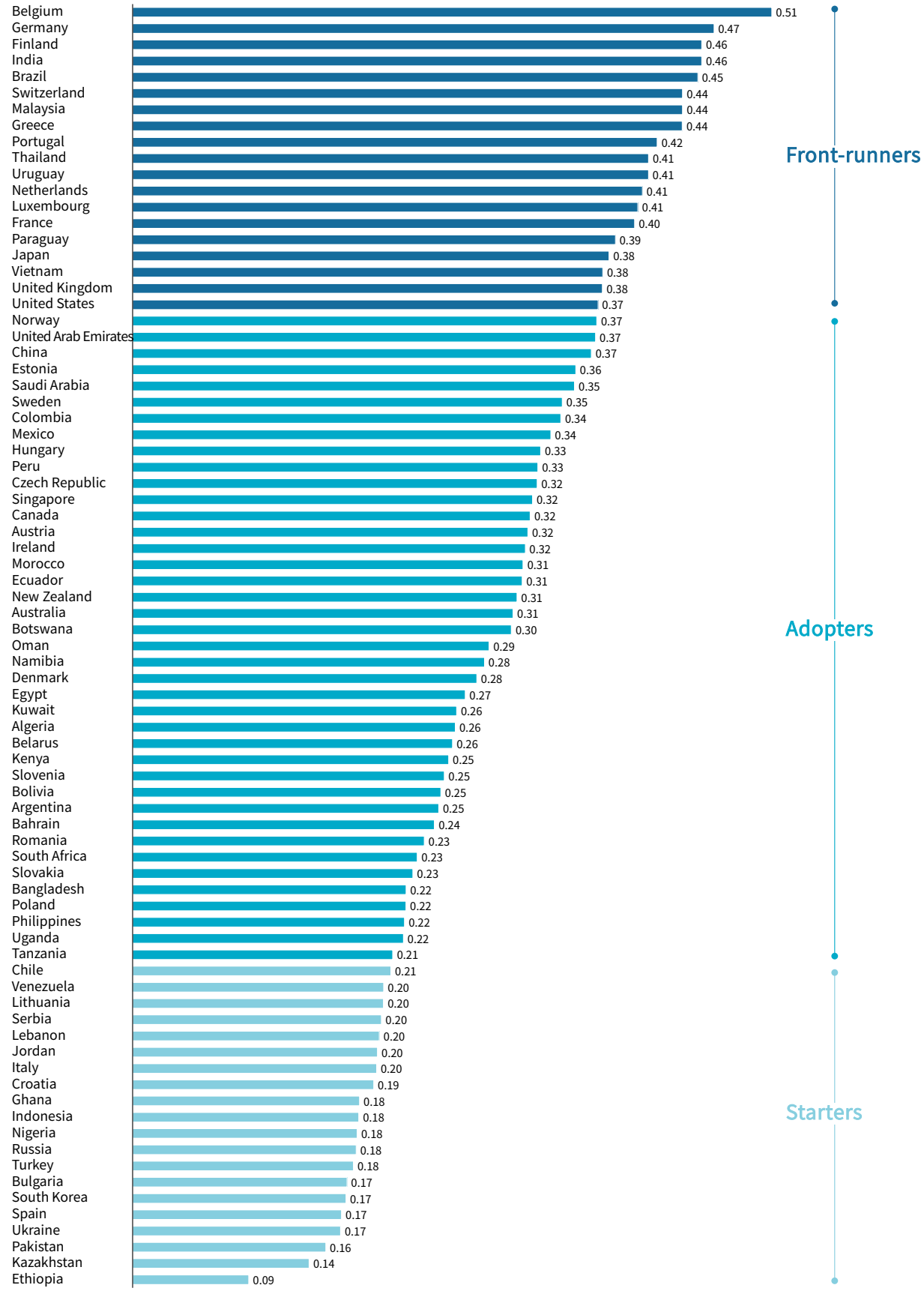
Rank	Country
20	Norway
21	United Arab Emirates
22	China
23	Estonia
24	Saudi Arabia
25	Sweden
26	Colombia
27	Mexico
28	Hungary
29	Peru
30	Czech Republic
31	Singapore
32	Canada
33	Austria
34	Ireland
35	Morocco
36	Ecuador
37	New Zealand
38	Australia
39	Botswana
40	Oman
41	Namibia
42	Denmark
43	Egypt
44	Kuwait
45	Algeria
46	Belarus
47	Kenya
48	Slovenia
49	Bolivia
50	Argentina
51	Bahrain
52	Romania
53	South Africa
54	Slovakia
55	Bangladesh
56	Poland
57	Philippines
58	Uganda
59	Tanzania

Starters

Rank	Country
60	Chile
61	Venezuela
62	Lithuania
63	Serbia
64	Lebanon
65	Jordan
66	Italy
67	Croatia
68	Ghana
69	Indonesia
70	Nigeria
71	Russia
72	Turkey
73	Bulgaria
74	South Korea
75	Spain
76	Ukraine
77	Pakistan
78	Kazakhstan
79	Ethiopia

Source: Roland Berger analysis

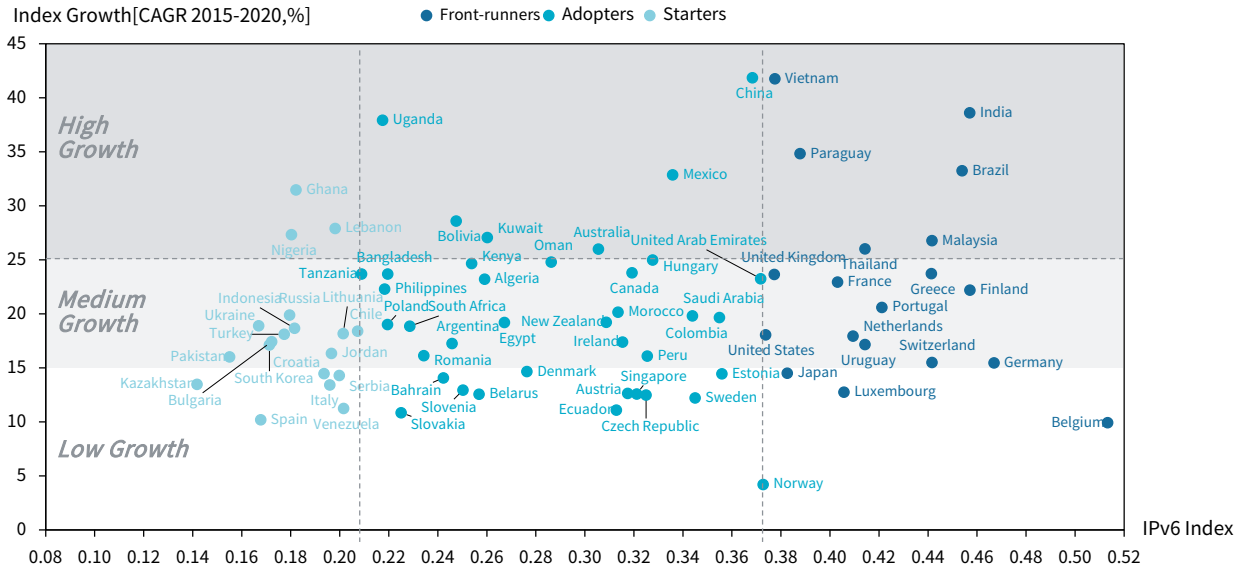
8 IPv6 Index 2020 Ranking



Data as of December 2020

Source: APNIC; Roland Berger analysis

9 IPv6 Index Growth 2015-2020



Source: APNIC; Roland Berger analysis

IPv6 Index Interpretation

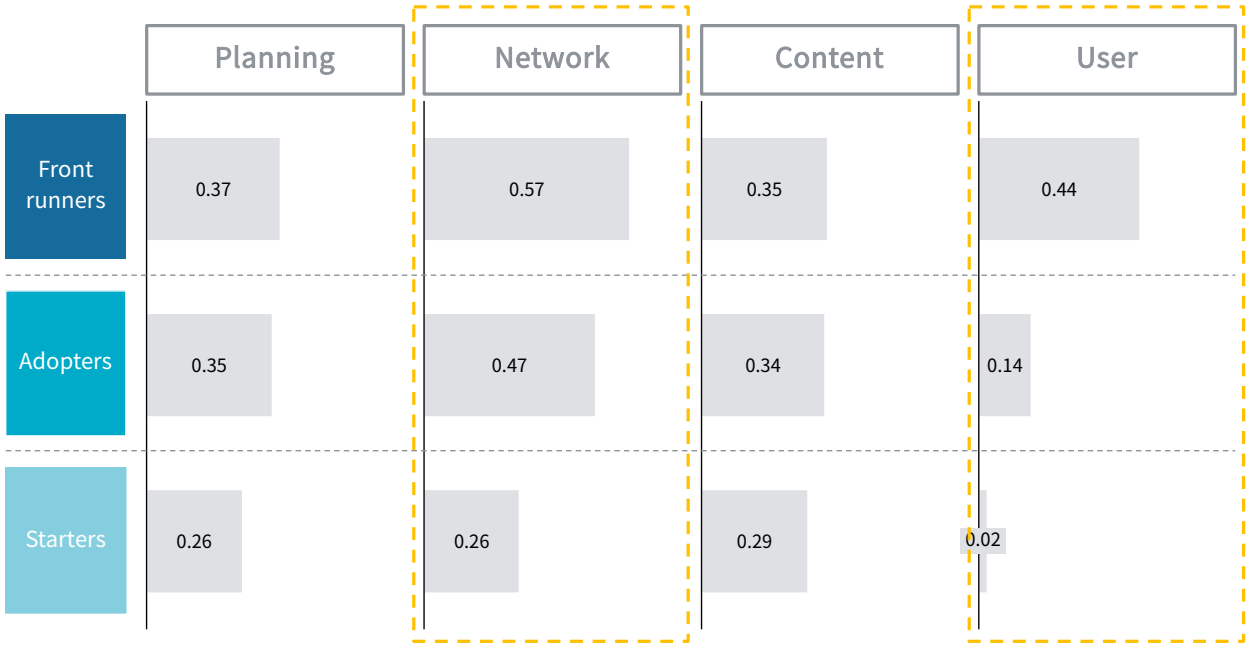
At the sub-indicator level, differences between countries are mainly driven by discrepancies at network and user level. This depicts the importance of IPv6 deployment in communication networks and user capability to access the internet through IPv6. → 10

IPv6 and economic performance are highly correlated (Figure 3-5. GDP per capita by IPv6 Index segment). IPv6 front-runner countries display a much higher level of GDP per capita compared to adopter and starters. → 11

In order to have a more quantitative analysis on the cause-and-effect relationship between IPv6 deployment and GDP growth, we ran a linear regression model with the growth of IPv6 index from 2015-2020 as the input variable and GDP growth from 2015-2020 as the output variable. The result is presented in Figure 3-6. Given the results of the regression, for every 10% increase in IPv6 index, GDP will have a 50% probability to increase by 0.08*10%, resulting in an expected 0.4% increase in GDP. → 12

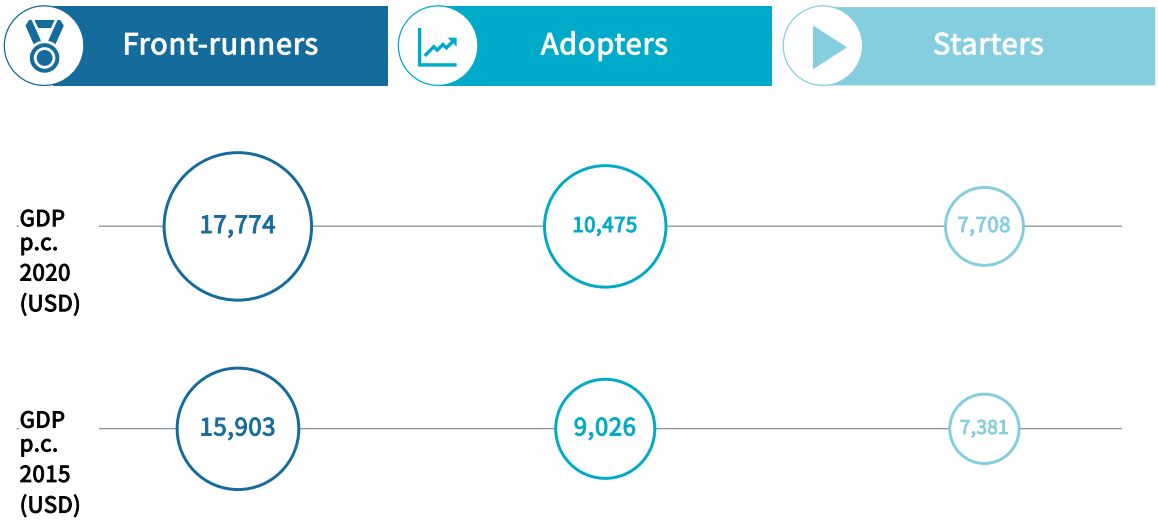
Although this result may be subject to sample limitations in terms of both countries and time-frame, and thus need to be interpreted with caution, it at least provides a basic idea about the huge economic benefits that IPv6 and IPv6+ technology could bring.

10 IPv6 Index sub-indicators by segment



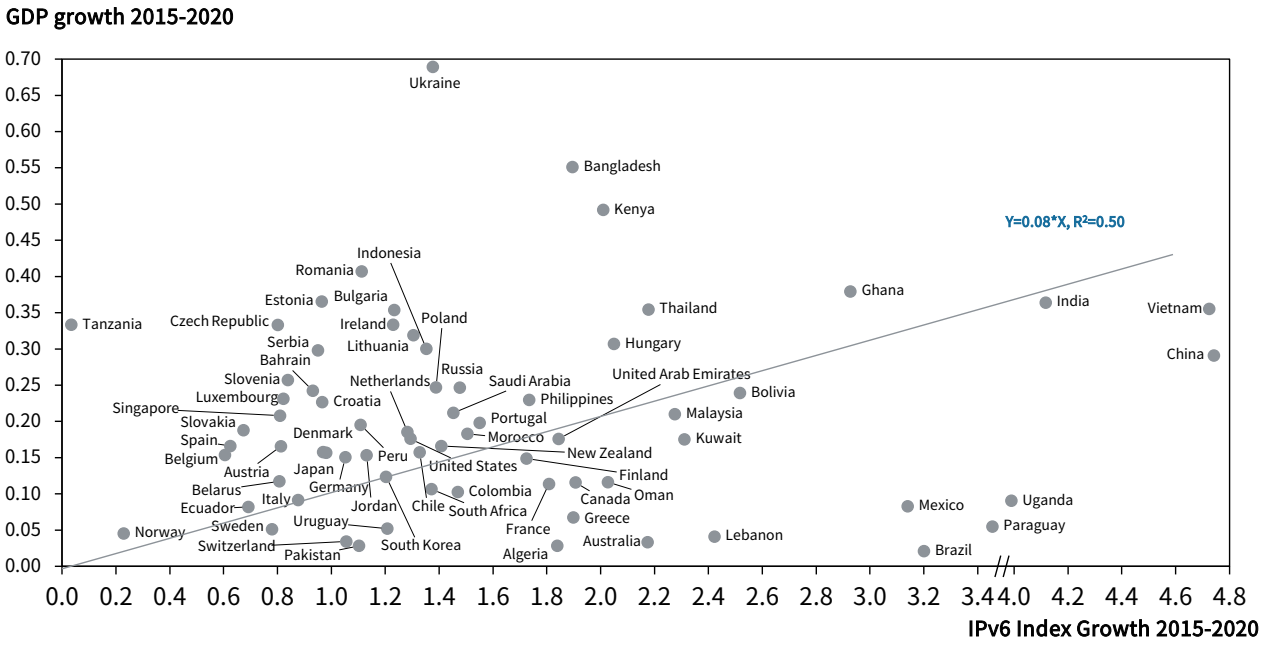
Source: APNIC; Roland Berger analysis

11 GDP per capita by IPv6 Index segment



Source: World bank; Roland Berger analysis

12 IPv6 Index growth and GDP growth regression result



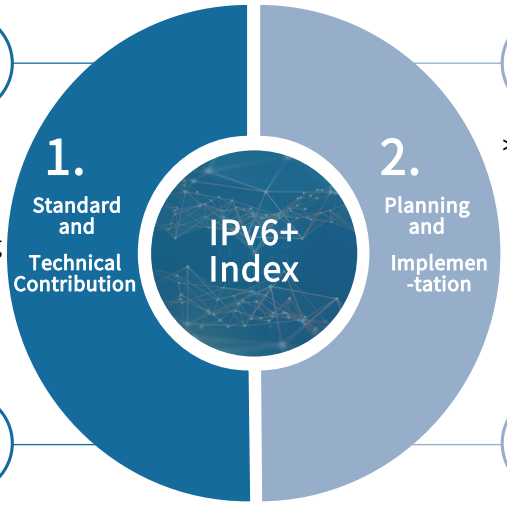
Source: World bank; Roland Berger analysis

IPv6+ Index

We also measured IPv6+ deployment for a sample of 25 countries around the world, by looking at their standard and academic contributions, as well as planning and implementation. → 13

China, United States, France, United Kingdom, Germany, Finland and Switzerland are the front-runners in IPv6+ adoption. While China is the front-runner of IPv6+ adoption, it still needs more policies to improve IPv6 adoption. The Unites States is leading in IPv6+ academic contributions and policy encouragement but with slower IPv6+ implementation. → 14

13 IPv6+ Index Methodology



International Standards Contribution

> Measures the number of membership companies, universities and other institutions in the IPv6 enhanced innovation working group of ETSI

IPv6+ Policy Encouragement

> The number of organizations established by the government to regulate the development of IPv6+ and the number of related policies

Academic Contribution

> Measures the number of academic papers on IPv6+ technology published in SCI-level publications

IPv6+ Implementation

> The number of operators and enterprises that have implemented an IPv6+ pilot or commercial use

Source: Roland Berger

14 IPv6+ Index Segments

	Countries	Situation and recommendations
Front-runners	> China, United States, France, United Kingdom, Germany, Finland, Switzerland	> China and the United States are leading IPv6+ international Standards. China is the front-runner of IPv6+ implementation but still needs more policy to encourage IPv6 adoption. The United States is leading in IPv6+ academic contribution and policy encouragement but with slower IPv6+ implementation. > Other front-runners should focus on policy encouragement and implementation to boost its IPv6+ adoption.
Adopters	> Greece, Luxembourg, Japan, UAE, Belgium, Malaysia, KSA, India, Portugal, Netherlands	> IPv6+ adopters have achieved certain level of implementation and have contributed to the standards development of IPv6+. Luxembourg, for example, have made some contributions to IPv6+ standards and achieved certain level of implementation. IPv6 and IPv6+ implementation is also gaining pace in KSA. > Different countries should evaluate their current standard and technical contribution status, as well as planning and implementation status and focus policy efforts accordingly.
Starters	> Norway, Brazil, Thailand, Vietnam, Uruguay, Paraguay, Italy, Spain	> IPv6+ starters have some pilot implementation but with limited technical contribution to IPv6+ standards. > Governments should focus policy efforts on following up with existing successful IPv6+ use cases in front-running countries.

Source: Desktop research; Roland Berger

Recommendation for Policy Makers

What drives IPv6 and IPv6+ adoption? We found that government actions have strong effects on the overall adoption of IPv6 and IPv6+ technologies. Frontrunner governments display stronger policy implementation capabilities, wider range of enacted policies and more frequent policy updates. → 15,16

15 Government action characteristics

	Front-runners United States, Germany etc.	Adopters China, Singapore etc.	Starters Russia, Turkey etc.
Policy Determination	Government has strong implementation for IPv6 deployment *The U.S. federal government is committed to IPv6 deployment and incorporating IPv6 requirements into IT acquisition standard. The German government required ISPs to implement only IPv6 enabled components in the future*	Government has moderate implementation of IPv6 deployment *UK government stated that procurements should include dual-stack software as a preparation for IPv4 to IPv6 migration* *Swedish government stated the importance of IPv6, but has not tasked the municipalities with actions.*	Government has weak implementation of IPv6 deployment *Ugandan government enacted policy on IPv6, but due to the lack of funding and expertise, IPv6 development remains low* *Some governments have yet to formulate clear policies for the IPv6 transition, such as Ethiopia and Chile.*
Policy Coverage	Policies enacted in multiple dimension *Multi-dimension policies enable stakeholders to effectively collaborate with IPv6 deployment. For instant, U.S. government provide consistently IPv6 policy for national layer, industry layer and end-user layer.*	Policies enacted in some dimension *The lack of some dimension in policy making can lead to inefficient IPv6 deployment. For instant, UK government argues that there is no need for public know the IPv6 progress. However, according to OECD, IPv6 education and public awareness is quite vital.*	Policies enacted in few dimensions *Most "starters countries" lack of investments and technology support. Therefore, the government IPv6 policy formulation is mainly oriented internally or only a few dimensions. Due to the low adaptability of other industries.*
Policy Frequency	Frequent policy updates *More government agencies are publishing authoritative IPv6 deployment reports and policies. Policies are issued in a long-time span and updated in a timely manner. For example, the United States has the latest IPv6 policy of 2021*	Moderate policy updates *Government agencies have issued IPv6 policies. But the quantity is relatively small and lack of up-to-date IPv6 policy. For example, United Kingdom, Singapore and Denmark.*	Few policy updates *The government has few policies regarding the development of IPv6*

Source: Desktop research; Roland Berger

16 Country Examples

Front-runners

India

> The Indian government released two important IPv6 policy documents. "National IPv6 Deployment Roadmap-I" in July 2010 and "National IPv6 Deployment Road-II" in March 2013. The India IPv6 Task Force regularly updates IPv6 transition timeline with two revisions published in 2016 and 2020.

United States

> The Memorandum M-05-22 in 2005 initiated the Federal process of IPv6 transition. In December 2009, the FAR issued a rule that government purchases must be IPv6 compatible. Since 2009, a series of strategy and policy was introduced. In November 2020 memorandum M-21-07 was published to instruct federal agencies to achieve IPv6-only status.

Germany

> German IPv6 council established in 2007. National IPv6 action plan introduced in 2009. IPv6 Transition Guide for the Public Administration was introduced in 2013 to facilitate public procurement of IPv6-ready production. In addition, a series of guidelines has been published during 2010-2013 that promote IPv6 at both federal and state level.

Thailand

> In June 2013, the Thai cabinet approved the IPv6 Action Plan 2013-2015. An IPv6 coordination and operation center was then established. In December 2015, the Action Plan for the mobilization, promotion, acceleration, and follow up of IPv6 in Thailand: Phase 2 (2016-2018) was approved and MICT was appointed to oversee its implementation.

Malaysia

> National IPv6 council established in 2004. National IPv6 Strategic Roadmap and R&D Roadmap released in 2008. The government announced IPv6 implementation schedule in 2011 aiming for Native IPv6 mode by 2015. The" IPv6 adoption act" in 2015 provided the necessary push for ISPs to move to IPv6. By 2019, successful adoption was achieved.

France

> IPv6 task force established in 2002. Since 2016, Arcep has been producing IPv6 progress reports, IPv6 barometer result and suggesting multiple actions to accelerate the transition to IPv6. In 2020, Arcep decided to make the allocation of 5G frequencies conditional on the massive switch to IPv6, thus requiring 5G operators to be IPv6 compatible.

Adopters

China

> Office of the State Council released national strategy in 2017 <Promoting the large-scale deployment action plan of Internet Protocol Version 6 (IPv6). Multiple action plans was released afterward including <Notice on accelerating the deployment and application of the sixth edition (IPv6) of the Internet Protocol> published in July 2021.

United Arab Emirates

> The Telecommunications Regulatory Authority's (TRA) has signed a MoU with Ripe NCC in 2017 for the development of the IPv6. The UAE M-Government has developed future strategies for the implementation of IPv6, including standards of security, expansion and meeting the growing demand for communication in the era of big data and IoT.

Saudi Arabia

> The National IPv6 Task Force was formed by The Communications and Information Technology Commission (CITC) in 2008. In 2018, the task force brings in service providers as core participants with more regular meetings and IPv6 adoption progress reporting. Since 2019, regular KPI reporting has been adopted to track and maintain IPv6 deployment efforts.

Source: Desktop research; Roland Berger

The adoption of IPv6 is faced by granular as well as higher level challenges. Policy makers as the key driving factor for IPv6 deployment should be aware of and make efforts in tackling these challenges. At a granular level, there are concerns about IPv6's performance and security issues due to lack of understanding, concerns about IPv6's cost of implementation and unpromising short-term ROI, and lack of demand generated from end-users. At a higher level, IPv6 and IPv6+'s technology diffusion has network effects with a 'last-mover' advantage. Furthermore, the continual fixes on IPv4 technology have resulted in a strong competition of protocols due to IPv6's backward incompatibility with IPv4. Finally, there is a lack of societal awareness of the benefits of IPv6 and the acute consequences of IPv6's delayed transition.

To provide suggestions on how policies can help address these issues, we analyzed the policies introduced by leading countries in IPv6 deployment, and summarized the key areas and the specific content of their policies as a best-practice manual. → 17

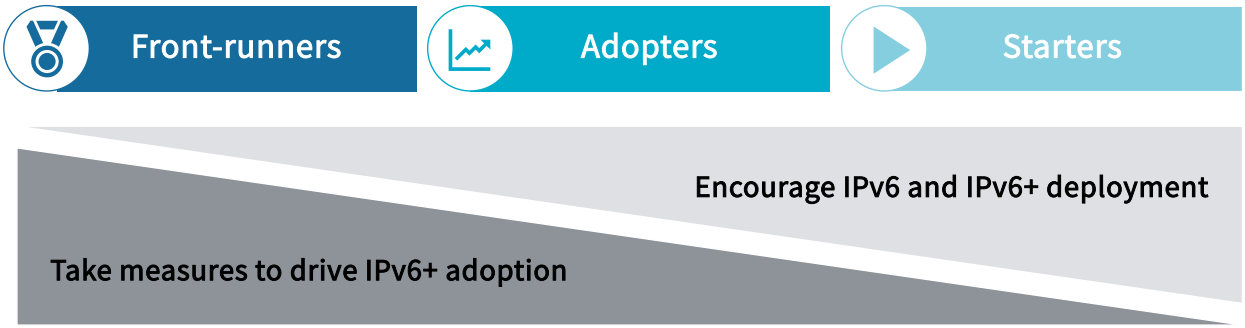
Overall, countries in the front-runner segment of IPv6 adoption should take the next step toward driving IPv6+ adoption, while countries in the adopters and starters segment should leverage the above-mentioned policy types to further encourage the deployment of IPv6. As IPv6 adoption at telecom operators is crucial to the overall development of country-wide deployment, we recommend countries in the starters segment to increase policy efforts toward the private sector, particularly targeting telecom operators. → 18

17 Policy suggestions to encourage IPv6 adoption

Overall Strategy	> Create high level IPv6 roll-out strategy and roadmap in line with other digital strategies > Create dedicated national task forces in coordinating and supporting roll-out plan > Encourage IPv6+ pilot in telecommunications and government networks > Enhance international collaboration on knowledge exchange
Public Sector	> Mandate IPv6-only readiness in government procurements and encourage IPv6+ technology adoption > Promote the use of IPv6 and IPv6+ by public agencies by mandating IPv6 and IPv6+ roll-out plan > Provide guidance on IPv6 and IPv6+ operational implementation for public agencies
Private Sector	> Tax/limit the use of NAT/CGNAT technologies and require telecom operators to be IPv6 compatible for 5G > Provide tax incentive and subsidization to encourage IPv6 and IPv6+ deployment > Provide funding for the private industry for IPv6 and IPv6+ related research and development > Mandate enterprise IPv6 and IPv6+ readiness in order to participate in government biddings
Skills enablement	> Include IPv6 and IPv6+ in higher education curriculum > Create public/private partnership organizations in offering IPv6 and IPv6+ implementation support > Promote initiatives that foster the exchange of information and best-practices for deployment
Awareness boost	> Organize workshops/seminars/conferences/marketing campaigns to boost awareness for industry end-users > Measure national IPv6 and IPv6+ deployment and publicize through dedicated website

Source: Desktop research; Roland Berger

18 Policy suggestions for different countries



> Countries in front-runner segment of IPv6 adoption should take the next step toward driving IPv6+ adoption
> Countries in adopters and starters segment should leverage the above-mentioned policies to further encourage the IPv6 and IPv6+ deployment

Source: Roland Berger

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