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Global Diffusion of the Internet V - The Changing Dynamic of the Internet: Early and Late Adopters of the IPv6 Standard

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GLOBAL DIFFUSION OF THE INTERNET V - THE CHANGING DYNAMIC OF THE INTERNET: EARLY AND LATE ADOPTERS OF THE IPv6 STANDARD

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ABSTRACT

The introduction of a new network level protocol called Internet Protocol version 6 (IPv6) represents a significant step forward in the development of the Internet. While IPv6 offers a number of advantages over the current standard (IPv4), its adoption has been inconsistent, often varying by geographic and political region. Through an investigation of early and late adopters of IPv6, this paper seeks to understand the factors that influence the time of adoption decision. The study was conducted in two stages. In the first stage, we interviewed Internet thought leaders. Based on previous literature about the characteristics of early and late adopters, and characteristics specific to IPv6 derived from the interviews, we developed a set of initial notions describing the conditions that are likely to encourage early adoption of IPv6. In stage two we tested those conditions through interviews with eight ISPs in six countries. We found that relative advantage, uncertainty and risk, crisis, and power relationships influence an organization's time of adoption while organizational age does not impact the time of adoption. In addition, we found that sponsorship and availability of information indirectly affect time of adoption by mitigating the perceived risk of early adoption.

Keywords: Internet standards adoption, standards, IPv6, case study, Internet service providers

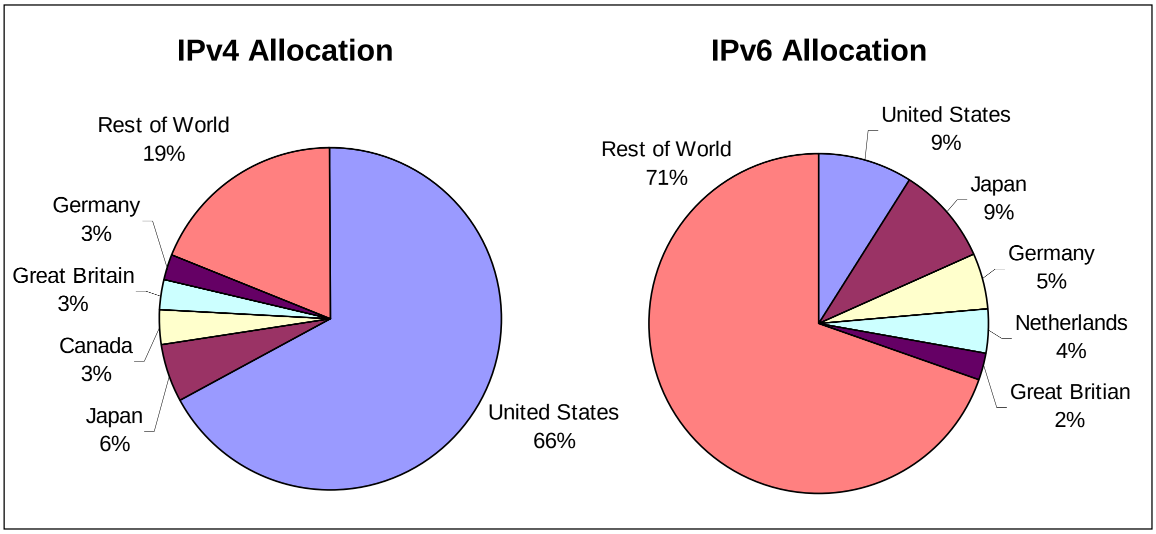
I. INTRODUCTION

The basic protocols used for communication over the Internet were developed by scientists in the United States and the U.S. Department of Defense over 40 years ago. Their adoption as a global standard was in part the result of the widespread adoption of local area networks and personal computers, the use of TCP/IP[1] with these platforms, and the incorporation of TCP/IP into the UC

[1] Transport Control Protocol/Internet Protocol. This is the basic communication protocol used for the Internet.

Berkeley Unix Operating System [Leiner et al. 1997]. With the exception of some complementary software solutions that provide additional functionality, these protocols have remained basically unchanged since their initial implementation.

The most fundamental change to the Internet to date is the introduction of a new network level protocol called Internet Protocol version 6 (IPv6). IPv6 (also known as IPng, for "next generation") offers a number of advantages over the current standard, IPv4. These advantages include increased address space, mobility, auto-configuration, multicasting, and quality of service capabilities[2]. Despite IPv6's superiority, its adoption has been inconsistent, often varying by geographic and political region. IPv6 is being adopted extensively by Internet Service Providers (ISPs) in Japan and China, with other Asian countries such as Singapore following closely behind. The European Union Commission (EU) mandated a timeline for the implementation of IPv6, leading to a slow but consistent adoption of the new standard by ISPs in Western Europe. In contrast, the adoption of IPv6 in the United States is minimal. Evidence of this disparity can be seen in the shift in address allocation between IPv4 and IPv6 (Figure 1) – the United States currently has 66% of the IPv4 addresses, but only 9% of the IPv6 addresses.



Source: IPv6style.com [2004]; Palet [2004]

Figure 1: Allocation of IPv4 and IPv6 Addresses: Top Five Countries

Since it would appear that the adoption of IPv6 would yield clear advantages over IPv4, this disparity in adoption becomes a phenomenon to study. In addition, adoption of standards in the context of the Internet introduces new challenges [Hovav, Patnayakuni, and Schuff, 2004). These challenges result from the tension created by two forces:

1. the distributed nature of the Internet and its lack of central governance, resulting in a set of autonomous entities and
2. the strong interrelatedness required to maintain communication among these entities.

While each organization makes its own decision whether or not to adopt, an emerging community of early adopters can influence the overall adoption and use of the standard significantly.

Therefore, the goals of this paper are

[2] For additional details regarding the key technical aspects of IPv6, refer to Appendix I.

1. to investigate the unique characteristics of IPv6 as an emerging Internet standard, and

2. to determine the primary influences that prompt certain ISPs to be early adopters of that standard while others either do not take an active role in adopting IPv6, or resist it entirely.

Understanding these influences will lead to a deeper understanding of the social and structural conditions that must exist in order to encourage the adoption of emerging Internet standards such as IPv6.

To address this question, we conducted a two-phase study:

- In the first phase, we examined the relevant adoption literature and interviewed several industry experts to arrive at a list of candidate factors that we believe will influence the time of adoption of IPv6.

- In the second phase, we test these candidate factors, by conducting a series of interviews with eight Internet Service Providers in six countries.

Our analysis shows that several factors, including the existence of “killer applications” that provide a clear advantage to adopting the new technology, levels of uncertainty and risk, disparities in resource allocation leading to crisis, and power issues resulting from control over these resources impact the time of adoption of IPv6 significantly. Contrary to prior literature, we found that organizational age only impacts the time of adoption marginally. We also found that sponsorship and the availability of information affect the time of adoption indirectly in that they can reduce the levels of uncertainty and risk associated with early adoption.

In Section II we define what constitutes an “early” or “late” organizational adopter. These definitions are derived from the literature on early and late individual and organizational adoption. We then describe IPv6 and its distinctive attributes, proposing a set of potential influences on the time of adoption of that standard (Section III). Section IV describes our methodology and the eight cases studied. Section V details our analysis of the cases. The findings and a proposed framework for predicting time of adoption for IPv6 are discussed in Section VI. We conclude with the study’s limitations and future research directions.

II. ROGER’S CHARACTERISTICS OF EARLY AND LATE ADOPTERS

Most current research on the adoption of innovations in an organizational context describes the innovation and its features (e.g., Rogers [1962, 1983]; Eveland and Tornatzky [1990]; Van de Ven [1993]: Fichman and Kemerer [1993]). For example, Rogers [1962, 1983] proposed five fundamental characteristics of the innovation:

1. relative advantage,

2. compatibility,

3. complexity,

4. trialability, and

5. observability.

Environmental characteristics (e.g., Farrell and Saloner [1985]; Katz and Shapiro [1986]; Farrell and Saloner [1987]; Fichman and Kemerer [1993]; Arthur [1996]) were also found to influence the adoption decision. For example, Katz and Shapiro [1986] and Van de Ven [1993] discussed the positive influence of sponsorship on the adoption decision. Generally, the outcome is considered to be dichotomous – either the organization adopts the technology, or it does not.

An issue that is rarely addressed in an organizational context is the timing of the adoption decision. Rogers' Adoption/Innovation Curve [1995] places potential individual adopters into five categories (Figure 2) on a continuum of: (1) innovators, (2) early adopters, (3) early majority, (4) late majority, and (5) laggards.

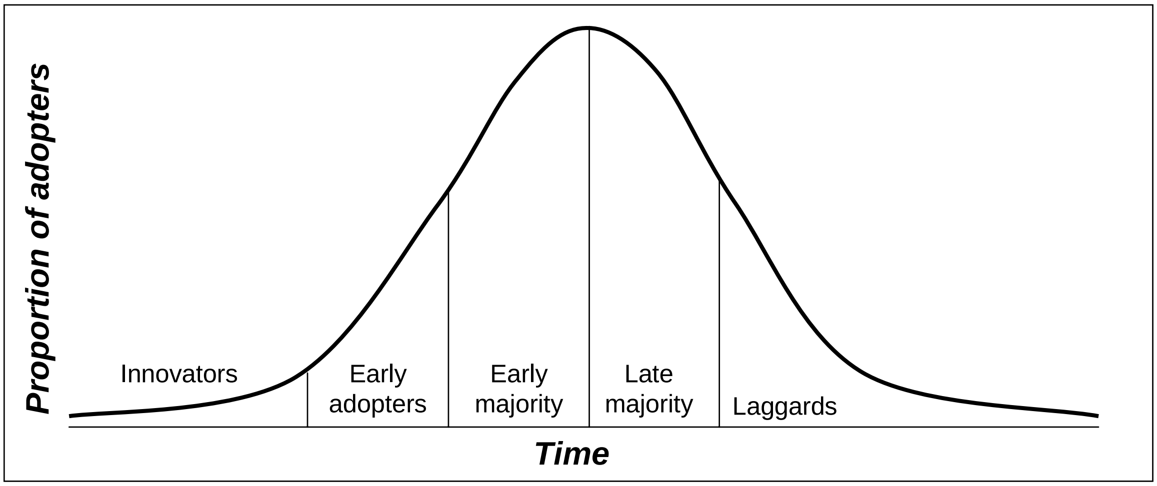


Figure 2: Adoption/Innovation Curve *(Adapted from Rogers, 1995)*

Those who adopt early (innovators, early adopters, and the early majority) are characterized as being more "venturesome," [Rogers 1995, p. 263], having access to capital, being more able to assimilate technical information, and being less risk averse. Early adopters can act as opinion leaders, disseminating information regarding the innovation to those who have not yet adopted. The later adopters (late majority and laggards) are more "skeptical and cautious," [Rogers 1995, p. 265) waiting for the innovation to become pervasive in order to take advantage of the network externalities. They are more risk averse and less able to withstand a failure financially because they adopted something new.

We used Rogers [1995) definitions to investigate the time of adoption of IPv6. It should be noted that the categories "early" and "late" as described by Rogers [1995) are two ends of a continuum. An organization that is neither an early nor a late adopter could fall within the "early majority" or "late majority" categories of Rogers' adoption curve (Figure 2). This assignment could occur if the organization shows some characteristics of an early adopter and some of a late adopter. For the purposes of this study, we cluster adopters into three categories – "early adopter," "majority adopter," and "late adopter." "Early adopters" are characterized as those who implemented (or are in the process of implementing) IPv6. "Majority adopters" are organizations in the planning stages of an IPv6 implementation, or organizations that already set up a test environment for IPv6. Organizations classified as "late adopters" do not plan to implement IPv6 in the near future.

Section III, which follows, describes the unique features of IPv6 and discusses why it is an important standard to study. We begin by explaining how we collected the information about the state of adoption of IPv6. We continue by detailing topics such as the nature of IPv6 as an infrastructure standard, the Internet's lack of central governance, the lack of significant sponsorship or a champion for the new standard, the minimal amount of information available about IPv6, and the disparity in the allocation of IPv4 addresses.

III. PHASE ONE - THE CASE OF IPV6

To understand better the unique issues involved in the time of adoption of IPv6, we collected information from two main sources:

1. We studied the web sites of the regional IP address allocation agencies such as Réseaux IP Européens (RIPE), the Asia Pacific Network Information Centre (APNIC), and the American Registry for Internet Numbers (ARIN)[3]. These agencies are responsible for the allocation of Internet resources around the world. In addition, we studied the Web sites of several related organizations such as the Internet Engineering Task Force (IETF[4]), the IPv6 task force and the European Union Commission (EU).
2. We conducted interviews with several thought leaders regarding the deployment of IPv6:
   - A senior networking engineer (from a leading networking company) that was part of the initial design of IPv6.
   - The president of the IPv6 forum and the chair of the EU Commission IPv6 Task Force.
   - The main designer of Euro6IX.
   - Marketing Director of the North America IPv6 Task Force.
   - A member of Japan's IPv6 Council
   - The chair of the RIPE IPv6 workgroup of 6BONE registry.

We conducted these interviews in person using a scripted questionnaire designed to capture the subject's attitudes toward the deployment and adoption of IPv6 among ISPs. The questions were based on the constructs commonly found in the adoption literature, including issues such as relative advantage, compatibility, drag (the cost of upgrading), and the existence of sponsorship. A similar scripted questionnaire was later used to interview the ISPs themselves in phase two of our study (Section IV). The questionnaire is described in more detail in Section IV on methodology.

As a result of phase one of the study we established four conditions of IPv6 that augment the more traditional adoption factors;

1. IPv6 was developed by a consortium with minimal available funding and no infrastructure to conduct intensive marketing,
2. IPv6 is not owned by any given company,
3. the Internet governance structure cannot mandate or support the implementation of standards, and
4. the historical development of IPv4 and the disproportionate allocation of IPv4 addresses across global geopolitical regions.

Based on these conditions we derived five characteristics that we hypothesize are pertinent to the IPv6 adoption decision. These characteristics drove our investigation:

1. IPv6 is an infrastructure technology
2. IPv6 lacks a champion and strong sponsorship
3. Relatively little information exists regarding IPv6

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[3] RIPE's web site is http://www.ripe.net, APNIC's web site is http://www.apnic.org, and ARIN's site is available at http://www.arin.net.

[4] More information about the IETF is available through its website at http://www.ietf.org.

4. IPv6 provides an expanded address space
5. The impact of organizational age directly relates to address availability and cost to upgrade

IPV6 IS AN INFRASTRUCTURE TECHNOLOGY

The adoption of infrastructure technologies, intermediate technologies, and advanced technologies differs [Goncalves, 1999]. Because infrastructure technologies (also called “architecture technologies”) are the most removed from the user, their value is difficult to convey clearly [Gawer and Cusumano 2002]. IPv6 is an example of an infrastructure technology – it underlies other technologies that take advantage of its features. However, on its own its value is difficult to communicate to the user. The user often does not know whether their ISP is using IPv4 or IPv6. Instead, users look for applications that require the features afforded by the infrastructure technology available to them.

Vendors providing the value-added applications depend on the market structure of a given industry. In general, successfully driving the adoption of an infrastructure technology requires either vertically integrated companies to create complementary technologies (e.g., IBM’s mainframe architecture) or third party vendors (e.g., Microsoft and Intel) to collaborate and develop “killer applications.” For example, in the case of the “Wintel” standard, new versions of Windows (the application) take advantage of the advances in Intel processors (the infrastructure). In the case of the mainframe, IBM introduced applications that took advantage of their own new hardware. In both cases the technology was championed by the vendor (i.e., Intel and IBM).

In contrast, IPv6 is not owned by anyone. IPv6 was proposed and developed by an independent, voluntary group (IETF), and so far no vendor chose to act as a champion for that standard. As of early 2005, IPv6 is being promoted by the IPv6 forum and regional and national task groups.

> *“There is no one entity that is out to make money off the introduction and the adoption of IPv6.”* Marketing Director of the North American IPv6 task force

Instead, profit can only be made from the introduction of complementary technologies that will take advantage of the new standard. Therefore, to drive its adoption, ISPs or other technology companies (e.g., hardware, software, or consumer electronics vendors) must develop Internet-based applications that will

1. take advantage of specific capabilities of IPv6, and therefore
2. cannot be implemented using IPv4.

The implication is that the existence of a “killer application” for IPv6 is an essential component in driving the early adoption of the standard. The advantage of early adoption does not result from the adoption of IPv6 itself. Instead, vendors will profit from the integration of IPv6 into their own products that are specifically designed to exploit the standard’s new features.

IPV6’S LACK OF A CHAMPION AND SPONSORSHIP

At the beginning of 2005, IPv6 is not privately sponsored. None of the major Information Communication Technology (ICT) companies adopted IPv6 as its platform or advocated its adoption as the next Internet Protocol. For example, telecommunication equipment providers such as Cisco, telecommunications companies and Internet Service Providers such as MCI and Sprint, and Internet software providers such as Microsoft are not taking a leadership role in encouraging IPv6’s adoption. Also, government sponsorship for IPv6 is generally limited, varying by region. In Asia, the level of sponsorship depends on the country. Japan, for example, provides tax incentives and invested over eight million yen (~ US$76,000) in the promotion of IPv6. In Pakistan, the government provides some training. The European Union Commission (EU) mandated the implementation of IPv6 as a long-term goal to increase the competitive position of the European community. The EU provided over 180 million Euros for research and development. However, the mandate is not accompanied by financial incentives for the commercial sector (i.e., ISPs). North America does not offer financial or regulatory incentives for the adoption of IPv6. This lack of sponsorship can result in limited marketing efforts and a lack of information about IPv6.

RELATIVELY LITTLE INFORMATION EXISTS REGARDING IPV6

One of the issues facing early adopters is the risk associated with the adoption of a new standard. The risk is partially the result of uncertainty as to that standard's future. An adopting organization can reduce its risk if it can leverage its knowledge about the new standard to encourage its adoption. This knowledge can be obtained in a number of ways, such as from vendor-supported marketing campaigns, trade magazines, and consortia.

In many cases, the vendor developing new products supplies early adopters with information about the features of the technology, technical specifications, and training [Gawer and Cusumano 2002). This information enables adopters to evaluate the value of the new technology, its implementation requirements, and its associated risks. In the case of IPv6, adopters are forced to rely more heavily on independently produced information such as their own testing efforts (which require significant investment), internal training, trade publications, or support from consortia.

In addition, because IPv6 was developed by the IETF, a voluntary consortium with limited funds, no significant marketing effort encourages IPv6 adoption. For example, IPv6 is already integrated into Cisco routers, Microsoft's Windows XP operating system, and some Nokia phones. However, unlike Intel, which used the "Intel Inside" campaign to promote its brand name, most companies do not publicize this support for IPv6[5].

Lack of marketing also results in limited information available in trade publications. For example, a survey of four top trade magazines[6] showed that the number of articles about IPv6 between 1998 and 2004 totaled 97, compared to 743 articles about Windows XP and approximately 1500 articles about XML (both championed by Microsoft). Although the number of articles increased from between five and nine per year in the years 2000 through 2003 to about 40 in 2004, it is still a fraction of the number of articles published about other standards, further limiting the availability of information about IPv6 to potential early adopters.

In some regions major efforts are underway to create test beds and distribute information on IPv6 (such as the 6BONE and the Euro6IX). These efforts are mostly concentrated in Europe. In addition, the IPv6 forum conducts information sessions in various regions of the world. In an interview with the authors in 2004, the President of the IPv6 forum mentioned that the attendance of these formal information sessions in Asia is overwhelming. In the United States, however, attendance is quite low. Overall, he reports little interest in seeking out information about IPv6 in North America. Thus, the levels of available information about IPv6 (just as the current allocation of IPv4 addresses) vary by region.

IPV6'S EXPANDED ADDRESS SPACE

The concept of "crisis" is not new to Information and Communication Technologies. Microsoft consistently forces upgrades by discontinuing support and maintenance of older products. We term this practice "forced crisis." Such crises also force complementary technology upgrades (i.e., faster processors to run the newest version of Windows). In the case of IPv6, if all major networking component providers announce they plan to discontinue support of IPv4, they could create this type of forced crisis, thereby triggering ISPs to upgrade their networking equipment to

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[5] Although an IPv6 ready logo program was initiated in 2003, it is limited in scope and low in funding.
[6] The search methodology used is described in Appendix II

be IPv6-compatible. However, this type of vendor-induced “forced crisis” did not occur as of early 2005.

Another form of crisis is created by the limitations of the current IPv4 standard. Specifically, IPv6 solves an intractable problem of the current IPv4 standard – the allocation and availability of network addresses. The number of IP addresses currently available under IPv4 is limited and fixed. The result is that IPv4 addresses are a scarce resource with limited growth capabilities. Further, the class structure of current IP addresses and the allocation scheme used to distribute IPv4 addresses, created an uneven distribution of addresses. A “class A” address, when allocated to an organization, can support approximately two million unique IP addresses. An organization that receives a “class A” address controls these addresses, whether they use them or not.

IPv4 addresses were allocated on a “first come-first serve” basis, and not on the basis of need. Organizations in the United States and Canada, who were early users of the Internet, were allocated over 70% of all IPv4 addresses. Europe, a second mover, owns a little over 20%. The rest of the world owns less than 10%. For example, Xerox (which was allocated a “class A” address in 1991) currently owns more IPv4 addresses than the entire country of China (PRC) (about 31,000 addresses). The result is a major concentration of a scarce and limited resource over a relatively small population. An urgent need for additional address space that cannot be fulfilled would most likely lead to early adoption regardless of other mitigating factors such as value added, availability of information, and lack of sponsorship.

THE IMPACT OF ORGANIZATIONAL AGE

The effect of organizational age on time of adoption is unclear. Traditionally, the investment in existing infrastructure is greater for older organizations. Thus, they are less likely to be early adopters. At the same time, older organizations usually have more funding, skills, and experience and are thus better positioned to absorb the risk involved in early adoption. In the case of IPv6, two additional important attributes of organizational age need to be considered.

1. Newer firms’ equipment is already compatible with IPv6, making the upgrade less costly and less complex.

2. Since IPv4 addresses were allocated based on a “first come, first served” basis, newer organizations are more likely to be resource deficient.

Age is not independent from the other characteristics discussed in this section: instead it is tied closely to the cost to upgrade, available funds, and crisis. Table 1 describes the five hypothesized factors that impact the time of adoption of IPv6 and their association to the unique characteristics of that protocol.

IV. METHODOLOGY

Yin [1994) suggests that exploratory studies that try to answer questions about “how” something is done should use case methodology. Eisenhardt [1989) suggests that case studies may be used when little is known about a phenomenon, or if in the early stages of research on a topic. Although adoption research is not new, examining standards adoption is a relatively unexplored research area [Lyytinen et al. 1998]. These factors are especially true in the context of the Internet and therefore warrant the type of rich analysis case research can provide. For this study, we selected a multiple case design with a single unit of analysis for each case (also called “type 3” case study methodology [Yin 1994]). This design can provide more compelling evidence by supplying multiple data points by which to test theory.

Table 1. Factors that Impact Time of Adoption of IPv6

Ipv6 Characteristics	Impact on Time of Adoption
IPv6 is an infrastructure technology	The existence of *Killer Application* or integrated services will induce adoption
IPv6 lacks a champion and strong sponsorship	Regions that enjoy strong *sponsorship* are more likely to adopt
Relatively little information exists regarding IPv6	The existence of test beds and the dissemination of *information* through consortia and workshops is vital to the adoption of IPv6
IPv6 has an expanded address space	Organizations facing an address *crisis* are most likely to adopt IPv6
The impact of organizational age	*Organizational age* is a factor because older organizations are more likely to have enough IPv4 addresses, reducing their need for adoption. Further, a well-developed IPv4 infrastructure raises their cost to upgrade.

Note: Hypothesized factor is shown in italics under the Impact of Time of Adoption

Eight Internet Service Providers from six countries were used in our study. The cases varied in size and age, serving to reduce these characteristics' potential as sources of bias. The subjects represent distinct regions of the world such as North America (United States and Canada), Western Europe, the Middle East, and Asia. We chose countries that varied in their level of economic development, existing Internet infrastructure, and access to communities involved in IPv6.

Within each ISP, one or more senior technical managers were selected as interview subjects. These managers are directly responsible for infrastructure implementation decisions within their respective organizations and therefore reasonably represent both a managerial and technical perspective view regarding the adoption of IPv6. In cases where more than one manager was interviewed, they were interviewed as a group. Upon agreement to participate in the study, either face-to-face or telephone interviews were conducted with the managers. The interviews followed a scripted set of open-ended questions. Follow-up questions were asked when clarifications were needed. The set of questions (Appendix III) were developed from the list of factors derived from the literature. The questions were phrased in such a way as to be "neutral" so that the interviewee would not be led to answer in a particular way. In each case at least two interviewers were present. One interviewer asked the questions and recorded the responses. The second interviewer also wrote down the interviewee's responses to ensure that the responses were being recorded correctly. After the interview was complete, each interview was summarized. The summaries were compared for consistency and accuracy. Inconsistencies were resolved by follow up e-mails or phone conversations with each interviewee. The final summaries were sent to each subject for their review and comments. If necessary, further phone calls or e-mails were used to clarify answers. Table 2 lists the ISPs studied, their location, size, and age.

V. ANALYSIS

The eight cases presented in Table 2 include two early adopters, three majority adopters, and three late adopters. The following analysis examines each factor listed in Table 1 (Section III) and how that factor effect the time of adoption decisions of the ISPs.

Table 2 ISPs Studied

SUB-JECT	Location	Size	Age	Time to adoption	Information and Sponsorship	Comments
CA	North America	Small	Originally connected to the “core Internet”	In the process of adopting – 20% of their client base was using IPv6 as of 2002(early)	No sponsorship. Part of 6NETand CANARIE	Provides Internet connectivity for a major university and eight other research institutes
BI	Middle East	Large	Oldest in its market	No plans to adopt in the near future (late)	No sponsorship. Not involved with any IPv6 related consortia. Follows USA opinion leaders	Subsidiary of the national telecommunication company – control over the infrastructure
GL	Middle East	Small	2-3 years. Low drag	No plans to adopt in the near future (late)	No sponsorship. Not involved with any IPv6 related consortia Follows USA opinion leaders	Vision: to become market leader by providing innovative services
BG	North America	Large	An original Internet providers – High drag	In the testing stage and running pilot sites – rollout schedule is in place (majority)	Part of the IPv6 task force. Act as opinion leader. Can act as a pseudo champion	An ISP servicing a government agency – large client base and abundant funding
CL	Europe	Small	New in Internet connectivity services (leapfrogged to IPv6)	Leading in the adoption of IPv6 services (80% of client base by 2006)(early)	Working under the EU mandate. Part of the IPv6 forum and Euro6IX. Act as opinion leaders	This company provides end-to-end solutions using IPv6. IPv6 is a core business and is vital for survival
GN	Middle East	Largest in its niche market	Relatively new to the market – low drag	Will adopt only if 3G standard prevails (late)	No sponsorship. Not involved with any IPv6 related consortia. Follows USA opinion leaders	Provides mobile Internet access
NX	Europe	Small (3,000 custo-mers)	3rd oldest in its market (founded in 1992)	Running test beds. Full implementation depends on available funding (majority)	Working under the EU mandate. Requested financial support from their government and 6BONE	Their mission is to become opinion leaders and leverage their advanced IPv6 knowledge
ST	Asia	Small but fast growing	Relatively new (3-4 years) – low drag	Implementing test beds (majority)	Limited sponsorship (free training). Not involved with any IPv6 related consortia	Facing a major address shortage

Note: Size refers to the relative size of the ISP within its market and not an absolute size: Age refers to the age of the ISP at the time of the study

THE EXISTENCE OF A KILLER APPLICATION

IPv6 is an infrastructure technology (Section III), removed from the user, and thereby requiring a "killer application" to drive adoption. Our case analyses indicate that the relative advantage gained from the introduction of such an application can influence the time of adoption positively. Therefore, we expect that IPv6 is more likely to be adopted early in one of the following two situations:

1. When an ISP is vertically integrated and provides end-to-end Internet solutions. In this case the ISP is likely to benefit from the IPv6-related applications it offers. For example, BG provides end-to-end solutions. The development of new, state-of-the-art applications such as remote control and remote sensing heavily relies on the availability of IPv6 mobile, structured addressing, multicasting and security capabilities. Similarly, CL is providing new services such as ambient intelligent applications which rely on IPv6's auto-configuration. Thus, CL which did not provide IPv4 based connectivity is becoming an ISP for IPv6 as a way to support services they want to offer their clients.

2. Where there are "killer applications" being developed by external entities. For example, subject CA in Table 2 serves academic and research institutes that are getting ready to implement Internet II. The implementation of Internet II relies on the availability of IPv6, leading CA to become an early adopter. Similarly, European telecommunications companies recently introduced 3G phones, which rely on IPv6[7]. Subject GN stated that if the 3G wireless standard prevails, they will adopt IPv6 because GN's wireless services depend upon the European wireless standards. Thus, their existing infrastructure is IPv6-compatible and their technical staff is literate in the standard. Conversely, BI and GN do not envision a major application that will necessitate adopting IPv6 and therefore they are not adopting the new standard.

THE IMPACT OF SPONSORSHIP

As discussed in Section IV, IPv6 lacks private sponsorship or a product champion. Given the limited sponsorship for IPv6 it is difficult to ascertain its impact. BG, BI, GL, GN and CA operate in environments with no sponsorship. ST, NX, and CL operate in environments with partial sponsorship.

Although the managers surveyed stated that sponsorship in the form of regulation is undesirable, mandates do appear to aid in the adoption process accelerating the time of adoption. By guaranteeing that IPv6 will become the prevalent network protocol in that region, the levels of uncertainty associated with being an early adopter is reduced.

For example, CL and NX operate in Europe where the EU established a timeline for the mandatory implementation of IPv6. Those mandates impact time of adoption decisions since they appear to reduce the levels of uncertainty associated with being an early adopter by guaranteeing that IPv6 will become the prevalent network protocol in that region. NX is relying on the EU mandate to force increased adoption of the new protocol in the next few years (thus reducing uncertainty and risk) and is working to position themselves as an opinion leader and an early implementer. CL is also relying on the EU mandate in promoting IPv6 as the prevailing infrastructure of the future.

The impacts of other forms of sponsorships are unclear. Based on the analysis of the cases, it appears that most ISPs prefer sponsorship in the form of financial incentives and tax relief. For example, ST received government-subsidized IPv6 training. This subsidy encouraged their

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[7] 3G phones rely on the availability of a large pool of addresses, the mobile capabilities and auto-configuration available in IPv6.

adoption somewhat, leading them to be a majority (but not an early) adopter. However, BG and CA who operate in an environment without any sponsorship are adopting IPv6 relatively early, leading us to the conclusion that sponsorship may not affect early adoption directly.

THE IMPACT OF INFORMATION SCARCITY

IPv6's lack of a champion, combined with the limited marketing capabilities of the IETF and the IPv6 forum, resulted in a limited amount of information available to early adopters. Our analysis of the cases indicates that the availability of information does not directly affect time of adoption of IPv6. It does, however, indirectly impact ISPs' perceptions of the risk involved in being an early adopter and can reduce the uncertainty involved in the future of the new standard.

ISPs that are involved in private consortia such as 6BONE, Euro6IX and CANARIE (for example, CA, BG, and NX and CL) have greater access to information. Others (for example, BI and GL, GN and ST) have less access to information leading to uncertainty about the technology. For example, BI and GL have very little knowledge of the advantages of IPv6, implementation needs, cost to upgrade or IPv6 compatibility with IPv4. This lack of knowledge increases their perceived risk and their uncertainty about the new standard. These ISPs receive most of their information from US-based trade magazines, which contain little on IPv6 (Section III). GN's understanding of the technical features of IPv6 is better, but its understanding of its market potential for the company is insufficient. As a result, GN is a late adopter and will adopt IPv6 only if they can gain competitive advantage from the introduction of 3G wireless phones in their market. All three ISPs feel uncertain as to the future of the standard. ST, which is also in an environment with little available information, is in the process of implementing IPv6. The special case of ST is discussed in the next section.

THE IMPACT OF CRISIS

A fourth factor that may affect organizational time of adoption is crisis (Section III). Crisis could be externally induced (such as a vendor discontinuing product support or a government mandate) or inherent in the technology (such as the limited number of possible IPv4 addresses). From our analysis, we conclude that the existence (or, seemingly as important, the perception) of crisis will outweigh other considerations. ISPs might adopt a new standard, even if there is uncertainty as to its success, because they face a sufficiently severe crisis. Although forced crisis is a common occurrence in information technology, it has not yet occurred in the case of IPv6. The EU mandate involves a long-term transitional plan, and therefore does not introduce a crisis. In addition, none of the major networking component providers discontinued (or announced plans to discontinue) IPv4 support.

In our study, only ST (a relatively small ISP with limited financial resources) faces an inherent crisis. Although ST doesn't consider itself an adoption leader, they are in the process of adopting IPv6. They cite their lack of IPv4 addresses and the related sharp increase in the cost of those addresses as the main reason for their early adoption. In 2000, the cost of a "class C" address was between $1,050 and $1,275 per year. In 2002, the cost was between $1,900 and $2,300 a year. These rising costs outweigh the financial risk involved in the adoption of IPv6. Similarly, CL which is also a relatively small company with limited financial resources acknowledged that the cost of IPv4 addresses is prohibitively expensive and is an incentive for the adoption of IPv6 but did not refer to it as a crisis.

ISPs in the Middle East (especially GL and GN), which rely on the European address pool, do not perceive a crisis at this point. They acknowledge that obtaining addresses is becoming more difficult (and somewhat more costly) but they do not consider their lack of addresses to be at a crisis level. However, GL and GN are in a country that, in the short term, has a sufficient supply of IPv4 addresses (one IPv4 address for every two people). This status is in strong contrast to ST, where addresses are in short supply (only has one IPv4 address for every 730 people). Thus, it appears that difficulty in obtaining new IP addresses by itself does not always lead to perception of a crisis.

THE IMPACT OF ORGANIZATIONAL AGE

We expect younger ISPs to implement IPv6 more readily since the cost to upgrade for young ISPs is lower (newer equipment is IPv6 compatible) and since young ISPs are more likely to suffer from lack of IP addresses. However, our analysis indicates that organizational age correlates little with the time of adoption of IPv6. For example, BG which is an old organization is adopting IPv6. BG is one of the original organizations to connect to the "core Internet." Its large base of customized applications are written specifically for IPv4 (i.e., high drag) which will have to be converted. BG also owns an ample supply of IPv4 addresses. Yet, it is in the process of adopting IPv6. Conversely, ISPs such as GN and GL which are young, own IPv6 ready equipment and are facing IPv4 address shortage (although not at a crisis level) are not adopting. We therefore conclude that age by itself is not a factor.

Table 3 summarizes the analysis detailed in this section.

Table 3. Influences on the Time of Adoption of IPv6

SUBJECT	Time to Adoption	Killer application	Sponsorship	Availability of Information	Crisis	Age[8]
CA	Early	N/A	N/A	Yes	No	Yes
BI	Late	Yes	N/A	Yes	Yes	Yes
GL	Late	Yes	N/A	Yes	Yes	No
BG	Majority	Yes	N/A	Yes	Yes	No
CL	Early	Yes	Yes	Yes	Yes	Yes
GN[9]	Late	Yes	N/A	Yes	Yes	No
NX	Majority	N/A	Yes	Yes	No	Yes
ST	Majority	Yes	No	No	Yes	Yes
"Yes" indicates that we found that factor influenced the ISP's adoption decision "No" indicates that we did not find that factor influenced the ISP's adoption decisions "N/A" indicates that the factor did not exist for that ISP.						

VI. DISCUSSION

From the above analysis we conclude that our hypothesized effect of age on time of adoption is not supported by the data. We also observed that sponsorship and the pervasiveness of information affect the time of adoption indirectly. In both cases, they affect adoption through their impact on the perceived levels of risk. In addition, we found that resource concentration and power also impact the time of adoption of IPv6. This influence is the result of an uneven allocation of IPv4 addresses and most likely cannot be extended to other Internet standards. These two new factors, the impact of uncertainty and risk and resource concentration and power, are explained in this section.

THE IMPACT OF UNCERTAINTY AND RISK

The risk involved in the adoption of IPv6 is exacerbated by the lack of central governance or a private champion. This risk is associated with the levels of uncertainty surrounding the new standard. Under these circumstances, IPv6 is more likely to be adopted if:

1. ISPs financial resources are ample and the investment in the new technology is minimal compared to the potential gains, making the risk of early adoption economically justified. This

[8] Refers to the age of the ISP at the time of the study
[9] GN is the largest in its niche market but relatively small compared to the general ISP market

situation is exemplified by CA and BG which operate in an environment lacking sponsorship, government subsidies, or mandates. However, slack funding is available to both ISPs that mitigate the risk associated with the early adoption of IPv6.

2. Government sponsorship offsets the costs and the uncertainty associated with early adoption. Government support can reduce the economic risk involved in early adoption. None of the cases we studied received direct financial incentives from their respective governments. However, ST received subsidies in employee training. NX and CL, through the EU, received financial backing in the form of information, test environments, and technical support.
3. Government regulations reduce the level of risk and uncertainty about the future of a new standard. In cases where a government mandates the implementation of a new standard, that standard will become dominant (at least in that country or region), ensuring some market for related products. For example NX, an ISP that lacks slack funding, is adopting IPv6 relatively early. NX believes that the European Union mandate will force the widespread adoption of IPv6 – in this environment, by adopting early they are positioning themselves to be opinion leaders. NX intends to leverage their knowledge in providing service and support for late adopters.
4. ISPs obtain better access to information regarding IPv6, reducing the levels of uncertainty. For example, within the same region, GN was better informed about IPv6 (such as the cost to upgrade, implementation risks and training needs) and thus was more prepared for an upgrade than BI and GL.

THE IMPACT OF RESOURCE CONCENTRATION AND POWER

Power relationships can impact organizational adoption decisions [Hart and Saunders, 1997]. Organizations in the United States control a majority of the available IPv4 addresses, a finite resource. As the need for new addresses escalates, their price will rise, increasing their value to the companies that currently own them. From a resource allocation perspective, the incentives for organizations in the United States to promote the early adoption of IPv6 are small. This lack of incentives introduces a new factor to be considered: power. In this case, ISPs in Europe and the Far East might drive the adoption of IPv6 in an attempt to equalize control over the Internet. To quote the European Union commission report: “The risk of IPv4 addresses becoming increasingly scarce by 2005, coupled with the uneven distribution of address space between North America and the rest of the world, is sufficiently serious for action to be taken now and swiftly...” [Communications of the European Communities 2002, page 7]. ISPs in the United States, however, will resist the dissemination of IPv6.

Figure 3 presents a framework that includes the four predictors we found that influence the time of adoption of IPv6 by Internet Service Providers. These predictors were derived from the original five hypothesized factors, and are the result of our analysis of the case data. The figure reflects the removal of the factor “age,” the creation of “uncertainty and risk” as a meta factor describing “sponsorship” and “pervasiveness of information,” and the addition of the new factor “power relationships.”

VII. LIMITATIONS AND FUTURE RESEARCH

One limitation of our study is the distinctiveness of IPv6. The factors that we found relevant to its time of adoption may not apply to other standards. For example, the limited number of IPv4 addresses is a unique problem although crisis (especially a forced one) is common to the ICT industry. The second, attempting to predict the time of adoption of IPv6 by ISPs involves a combination of several factors. Each ISP indicated the factors that were most dominant in their time of adoption decision. However, the interaction between the various factors and their relative magnitude are unclear. For example, CL is an early adopter because it expects to benefit from innovative applications and services. However, it would be useful to investigate the point at which the added value will be offset by the increased risk. In addition, the existence of sponsorship might mitigate the balance between risk and value added. Therefore, an ISP in Europe might be willing to take more risk as a result of the European Union's sponsorship.

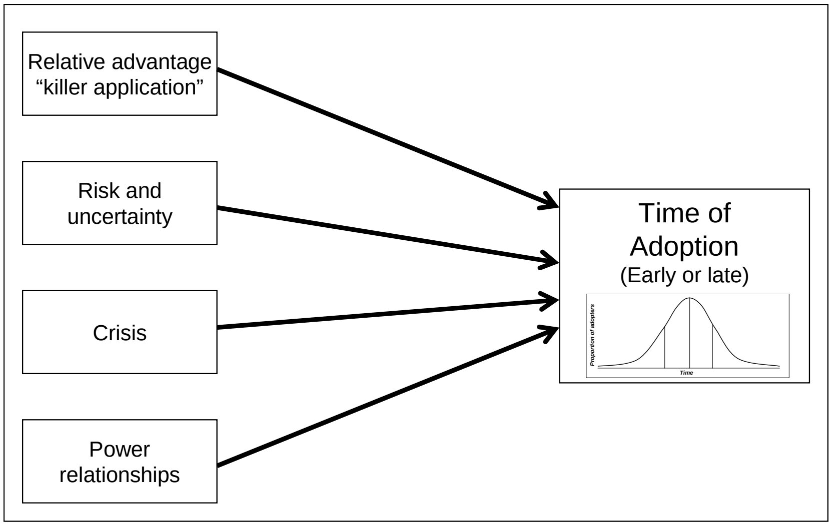

Figure 3: Framework for Predicting Time of Adoption for IPv6

Future research should focus on addressing these limitations to determine if the factors we derived from our analysis could be applied to other standards. Also, it should

1. determine the relative weight that should be given to each of these factors to increase our level of understanding of the relative importance of each factor, and

2. consider the issues from varying perspectives, such as vendors (of infrastructure technologies and advanced technologies), the development community, the end user, and regulators and policy makers, rather than only the perspective of the adopting organization (in our case, the ISP).

Another lens through which to study the timing of Internet standards adoption is to investigate more fully the role of power and control over resources. This analysis is especially important in the case of IPv6 because of the scarcity of IPv4 addresses. However, power affects all Internet standards because of the widely varying levels of sponsorship, combined with the Internet's overall lack of central governance.

VIII. CONCLUSIONS

As the use of the Internet becomes increasingly pervasive, the dissemination of Internet-based standards will become increasingly important. Given the lack of central governance, understanding the process in which the Internet community adopts these new standards is imperative. One such standard is the communications protocol IPv6. The purpose of this study was to understand more clearly the adoption patterns of IPv6 by investigating its early and late adopters. To that end, a two phase, interview-based study was conducted.

We found that the following factors impact organizational time of adoption of a new standard:

1. the relative advantage (brought on by a "killer application") associated with the new standard,

2. the levels of uncertainty and risk involved with being an early adopter,

3. the existence of a crisis, and

4. the power relationships resulting from control over the existing standard.

Notably, power relationships provide some insight into the apparent “late adopter” behavior for IPv6 of many ISPs in the United States. The evidence we found indicates that the majority of ISPs in the United States are not acting as early adopters from a strategic and power position. Given their considerable control over the current pool of IPv4 address, it is to the advantage of these organizations to maintain the status quo.

If that trend continues, the possibility exists for two “Internets” to emerge, one based on IPv4 and the other based on IPv6. This outcome is most likely to happen if strong forces in Europe and Japan drive an absolute implementation of IPv6 (also known as native IPv6), while ISPs in the United States retain their IPv4-based networks. The existence of two Internets will require the implementation and maintenance of transitional technologies (networking components that translate between the two protocols) and conversion points where the two networks are connected. The need for these transitional technologies will result in

- increasing cost to maintain a global Internet and
- highly concentrated points of failure resulting in communications failures between the two networks.

If maintenance costs[10] become prohibitive, the global information superhighway may break down completely.

An understanding of all four factors, taken together, can create a more complete picture of how the adoption of Internet-based standards can be encouraged. The fundamental problem is one of conflicting risks – the risk of moving too early versus moving too late. Adopting early is expensive and may not pay off for the adopter if the standard is not widely accepted. Adopting late can lead to incompatibility between the late adopter and the rest of the community.

Many ISPs, both in the United States and elsewhere, currently seem content to risk late adoption, perhaps because they estimate the cost of upgrading to IPv6 to be higher than the potential costs of incompatibility. Based on the interview data, the late adopters are more likely to be in a position of power because they control a limited and depleting supply of IPv4 addresses. Late adopters may also lack the necessary information, making the upgrade to IPv6 seem more risky than it actually is. One solution to these problems is increasing governmental, vendor, and organizational sponsorship, which can reduce IPv6 adoption risk. Evidence of this trend can be found in the mandate published by the EU [Commission of the European Communities, 2002].

The lack of central Internet governance creates a context for the study of the time of adoption of IPv6. The uneven allocation of IPv4 addresses introduces the notions of crisis and power position. As a result, the tradeoffs between the risks of early adoption versus the benefits attained by early movers are mitigated by the existence of crisis and the power relationships between Internet Service Providers in various regions of the world. This disparity could result in a decline in the compatibility for Internet communications.

[10] As measured in funds available and coordination costs

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Appendix I. Comparison of IPv6 to IPv4

Category	Advantage of IPv6	Why it is Important
Addressing	The address space in IPv6 is much larger than IPv4 (16 bytes instead of 4 bytes). This means that IPv6 allows for 3.4 x 10^{38} addresses, compared with 4.2 x 10^{9} possible addresses with IPv4.	The number of unique IPv4 addresses is dwindling rapidly. This is mostly a problem in undeveloped countries.[11] It is also anticipated to become a problem if the 3G wireless standard replaces the current 2.5G and if smart homes proliferate.[12]
Configuration	A client running the IPv6 protocol can automatically configure itself with a unique address, eliminating the need for static addresses or previous methods of auto configuration such as DHCP (Dynamic Host Configuration Protocol).	The management of multiple IPv4 clients within an organization involves tracking the assignment of addresses either for each client, or for "pools" of clients.
Data Delivery	There are new header fields in IPv6, which indicate the type of information being sent within each packet. This information can be used to prioritize traffic and guarantee Quality of Service (QoS)[13]. However, it is important to note that the actual implementation of QoS is still in the "research and development" stage as IPv6 alone is not sufficient for implementing end-to-end QoS.	For the transmission of multimedia data over the Internet, the fast and reliable delivery of IP packets is critical. Prioritization is one method of increasing speed and interactivity within the existing network topologies.
Routing	IPv6 packets are moved from segment to segment using a simplified, hierarchical routing structure.	Routing under IPv4 is only partially hierarchical, relying also on large flat routing tables that can exceed 70,000 entries. Routing under IPv6, with its significantly smaller routing tables, requires less overhead at the router and is therefore more efficient and faster.
Security	IP security standards (IPSec), previously optional under IPv4, are now required under IPv6.	Standardized, layer 3 security reduces hacking activities.

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[11] In Pakistan, a class C address in 2000 cost between $1050 and $1275 a year . Due to a lack of addresses, the price of a class C address almost doubled. By 2002, a class C address cost between $1900 and $2300 a year.

[12] "'Smart' Homes for Smart People," *Wired News* [online], 1999, http://www.wired.com/news/business/0,1367,17676,00.html [accessed 3/27/2004].

[13] Suydam, M. "Blazing trails: By paving paths for packets, MPLS could clear the way for IP convergence,"– *CommVerge [online]*, 2002 http://www.reed-electronics.com/ednmag/index.asp?layout=article&articleid=CA214592&rid=0&rme=0&cfd=1 [accessed 3/27/2004].

Mobile	Current implementation of mobile IPv4 requires the use of a foreign agent (FA), a home agent (HA), and a care-of (CO) address. The FA has to communicate the CO address through a tunnel back to the HA on the user's home network. The packets from the corresponding node to the mobile unit always have to go through the HA. IPv6 uses similar but more efficient process. The auto-configuration feature of IPv6 enables the mobile nodes to configure its own address without the help of any servers other than a router. Route optimization signaling enables a mobile IPv6 node to inform its correspondent node about its new care-of address. This allows both mobile node and the correspondent node to send and receive packets using the shortest path between the two.	No special mechanism is necessary on organization's networks to support Mobile IPv6, other than home agent (embedded in IPv6 protocol). The large address space ensures that the auto-configured address on the mobile node does not conflict with the existing addresses of the network. Resulting in ubiquitous support for mobile Internet access and increase support of wireless devices such as PDAs and Pocket PCs by ISPs.
Multicasting	The built-in multicasting in IPv6 allows a server to send a single packet with multiple addresses. The ISP will do the final routing. This reduces the bandwidth required for multimedia applications and broadcasting.	Allows several levels of multicasting and the creation of routing trees. This is a more efficient routing mechanism for applications such as Jini, which depend upon the ability to "discover" compatible devices on the network. Similar mechanism is used in Universal Plug and Play. Also, improve the distribution of multimedia applications such as video steaming.

APPENDIX II. PROCEDURE USED TO SEARCH TRADE JOURNALS

To compare the amount of information about IPv6 that is available to managers, we compared the number of articles on that topic to the number of articles on two other standards that were introduced at approximately the same time. The search was restricted to 1998 through 2004. The following describes the procedure used in the search.

Four top trade publications:

1. InfoWorld
2. Information week
3. Computer world
4. CIO magazine

were searched for the number of articles published on three topics: IPv6, Windows XP, and XML.

The search was conducted by visiting the web sites of the four publications. However, the sites did not provide equivalent search facilities. For example, all sites featured an "advanced search," however the search engine of InfoWorld magazine behaved erratically and displayed different results every time a search was repeated, therefore the search was conducted six times for each technology and the results were then consolidated after eliminating duplicate entries. To triangulate the search results, the ProQuest and ABI/Inform bibliographic database were used

For keywords that returned excessive number of matches, the search was restricted to article titles only. The search results were then separated by year.

APPENDIX III. SAMPLE INTERVIEW QUESTIONS

- Would you consider your company's policy towards the adoption of new technologies to be a leader, a follower, or a laggard?
- What type of services does your company offer?
- Have you implemented IPv6?
    - If yes, when did you complete the implementation?
    - If no, do you intend to implement and when?
- If you do not intend to implement IPv6:
    - Why have you chosen not to adopt IPv6?
    - If you do not adopt IPv6, how do you deal with the limitations of IPv4?
- What are the risks of NOT implementing IPv6?
- Do you plan to roll out a suite of IPv6 client-side software to take advantage of its new capabilities?
- Do you anticipate significant legacy support efforts to maintain backwards compatibility with IPv4 clients?
- Should the government provide tax incentives to ISPs, telecomm companies etc. to defer the cost of upgrading to IPv6?
- Should there be some government involvement in mandating an implementation schedule?
- How serious do you perceive the lack of IP addresses to be?
- When do you estimate your allocation of IP addresses will run out?

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