Diffusion of Network Innovation: Implications for Adoption of Internet Services

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by
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ABSTRACT

The Internet and network applications have achieved significant growth. This thesis reviews the historical development of the Internet and projects future expansion of network application usage. Observed data points for Internet hosts, World Wide Web servers, the Multicasting Backbone, USENET, and Internet telephony were fit to an s-shaped logistic curve. The results of the model predict the applications' growth rate, halfway points of growth, and saturation limits. The number of Internet hosts is expected saturate at about 39 million hosts by the early part of the next century, while the number of Web servers will saturate at about 40% of responding Internet hosts.

The adoption rate of Internet Telephony was estimated by analogy to adoption patterns of more established applications. The factors necessary for successful deployment of Internet telephony were addressed in terms of network architecture and user interface. Internet telephony and multicast applications that require reserved network resources were concluded to be in very early stages of development. At the time of this writing, only a small fraction of the users who have knowledge and have tried telephony applications are willing to adopt and actively use the technology. This indicates that augmentations to Internet services are necessary to improve the usability of realtime applications, such as Internet telephony.

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ACKNOWLEDGEMENTS

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1. Introduction

Forecasts concerning the use of the Internet and technology, in general, are difficult to make. The Internet is fundamentally unpredictable. It functions as a decentralized network of networks, has no central point of control or planning and is continuously changing. Without any central authority, technology and the demands of users on the network's periphery drive adoption patterns. In contrast, the telephone network consists of switches that serve as central points of control. Regional telephone companies, Post, Telegraph and Telephone (PTT) organizations, and regulators act as planners. This article examines the diffusion of new technologies and considers the challenges to enabling voice communications on the net.

User behavior will be the most crucial factor in technology adoption. The consumer's willingness to try and exploit new technologies will determine the future direction of communications networks. [42] The design of modern networks allows user needs to be accommodated by configuring end-node equipment instead of the network itself. [1] With end-users gaining greater control of network usage, analysis of network traffic trends is becoming an important tool. 'Basic' voice telephony is regulated and 'enhanced' data services are unregulated, providing the opportunity for unlimited entry and innovation. [33] But the distinction between voice and data is beginning to blur as voice transmissions are digitized and are treated identically to data. Mutooni concludes that by the year 2007, at the latest, packet based data traffic will exceed voice traffic. [37] This use of data networks for voice applications may have a significant impact on the revenue of traditional carriers. [48] However, analyses of traffic trends alone are likely to be inadequate in predicting the future use of networks and the demand of applications. The technologies themselves and the rapidly the needs of users are rapidly evolving. The most important issue is clearly defining the uses of network applications and understanding what they will become.

1.1 Communication Networks and Convergence

Traditionally, communications services have been tightly coupled to their transportation medium. [56] Radio, television, and telephone service have all been bound to a dedicated network. The Internet, however, has demonstrated that a diverse set of content and

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[1] For example, the World Wide Web emerged as a result of the demand for easy-to-use information retrieval software and the widespread adoption of browser software by Internet users.

applications may be provided across heterogeneous networks. The Internet Protocol (IP) allows a spanning layer between the network substrate and applications.[22] The capabilities of the Internet can be extended without modifying the underlying structure of the network. The union of computers and communication systems has enabled this unbundling of network elements.[2] By disassembling content into atomic computable units a universal, interoperable, and ubiquitous network of interconnected devices can theoretically be obtained. The challenge to realizing the ideal of convergence will be interconnecting a diverse set of networks and devices and overcoming the limitations of cost and capacity.

Although convergence appears to be a modern development sparked by the incorporation of computing power with communications and the digitization of information, the concept dates back to the early days of the telephone network.[3] Paradoxically, the creation of a truly universal network through the interconnection of foreign networks and devices increases the value of the network to its users while eroding the power of the incumbent network service provider. Interconnected networks serve as both complements and competitors.[36] Historically, AT&T fought vigorously against the interconnection of independent phone companies and the attachment of third party devices. The merger of the Internet and telephony is likely to create a similar scenario of providing new features and benefits to users and competition for established players.

1.2 Network Architecture

The independence of applications from the underlying transport is transforming the architecture of communications systems and shifting business models to focus on opportunities stemming from vertical rather than horizontal integration. The horizontally integrated network can be described as a four layered interoperating architecture, consisting of the bearer service, transport, middleware services, and applications, see figure 1.2. [39] At the lowest level the bearer service incorporates lines, switches and other networking components. The transport level transforms the bearer service into the proper infrastructure

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[2] In theory, the computation performed by one computer can be emulated by any other computer. British mathematician Alan Turing proved that any mathematical operation that could be performed on one machine could be accomplished on a single universal machine.[54]

[3] Theodore Vail, president of AT&T, envisioned the Bell System in 1910 as based upon "a common policy, common purpose, and common action; comprehensive, universal, interdependent, intercommunicating like the highway system of the country."[12]

for higher level applications with protocols and coding formats. Middleware provides commonly used features and services to applications. At the highest level exist the applications with which the user directly interacts.

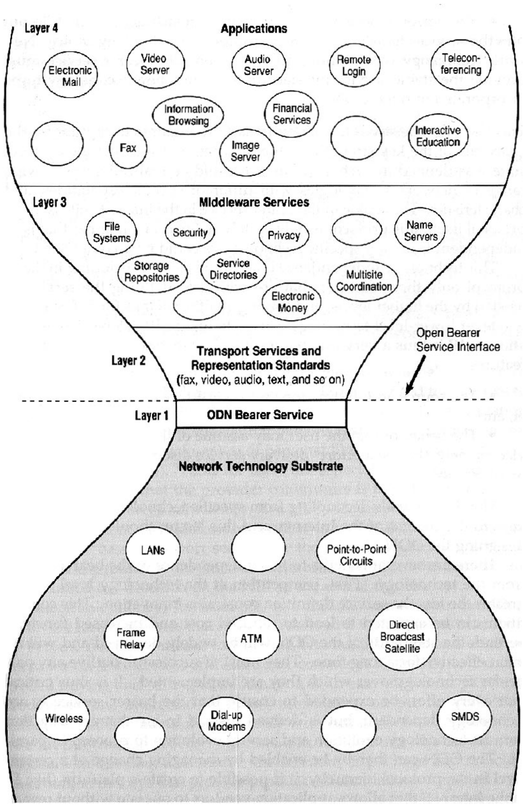

Figure 1.2: NRC Open Data Network Architecture [59]

The single best effort quality of service afforded by the Internet can create problems at times for almost all applications, and yet it has been essential for expansion of the Internet as a low cost communications medium. For example, to ensure the integrity of a conversation, voice traffic must be delivered reliably, with a minimum delay. Voice applications can tolerate some packet loss due to the redundancy of the human language. Data packets can tolerate longer and variable delays but no loss. [3]

The Real-time Protocol (RTP) and Reservation Setup Protocols (RSVP) were designed to alleviate some of the difficulties of implementing real-time applications on IP networks. RTP works by attaching packet timing information and a sequence number to UDP packets. This ensures that packets reach their destination on time and in the proper order, which is essential for IP telephony. RSVP allows bandwidth to be allocated along different levels of QoS. An RSVP session involve two processes: admission control and policy control. Admission control determines whether the router has sufficient resources to accommodate the requested QoS. Policy control determines whether the user has permission to make the reservation. [6][4]

1.3 Applications

Application's architectures can be described as either peer-to-peer or client-server. Peer-to-peer applications involve two or more users interacting directly through end-node terminals or computers. In client-server applications the user interacts with a server to store information or to retrieve previously recorded information.[34] Real-time peer-to-peer voice applications, such as telephony, are sensitive to delay and require immediate QoS guarantees if the network is over-provisioned. Table 1.1 summarizes characteristics of various network applications. Immediate QoS ensures that little delay occurs in transmission between peers.

Application	Architecture	QoS Requirements	Content
Telephony	Peer-to-peer	Immediate	Voice
Email, news, messaging	Client-server	Deferred	Data
Web browsing	Client-server	Delay tolerant	Data
Fax	Peer-to-peer	Delay tolerant	Data
Fax over IP	Client-server	Deferred	Data
Voice mail	Client-server	Deferred / delay tolerant	Voice
Video/audio broadcast	Multicast	Immediate	Data

Table 1.1: Comparison of network applications

Delay has much less of an effect on the usability of information in a client-server environment. Electronic mail (email) requires only a deferred level of QoS. That is, application messages could be temporarily stored at intermediate points in the network without noticeably affecting the performance of the application. Thus, applications in which data can be stored and forwarded at a later time, such as fax, are amenable to networks with low immediacy QoS transport. On the other hand, transmission errors have a greater effect on data applications than voice or video applications. A voice message can still be understood with some amount of noise. However, a small change in a sequence of computer code will cause the information to be unusable. Client-server applications that involve user interaction

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[4] However, before applications may take advantage of these protocols, deployment problems must be addressed and pricing models must be developed to produce incentives to not overburden the network. [9]

such as Web browsing are delay tolerant. Delay does not affect the usability of information but may cause frustration if users must wait an excessive amount time to receive a response from the server.

Inefficiencies arise when applications are implemented on unsuitable network systems. The PSTN system's switched connections maintain a high degree of synchronism and symmetry.[46] Such connections are unnecessary and expensive for many data based applications. The Internet, however, provides an efficient mechanism for asynchronous data transmission and replication, but is unreliable for video broadcast and real-time voice applications, see table 1.2. An ideal network would provide an adaptive and flexible model to accommodate the distinct technical characteristics of each application. An IP network, such as the Internet, that exploits asymmetries, provides suitable capacity, and is augmented with the means to reserve resources may approach such a model.

	High Delay Tolerance	**Low Delay Tolerance**
High Error Tolerance	Client-Server Voice/Video Ex: Voice mail	Peer-To-Peer Voice/Video Transmission Ex: Telephony, Broadcast
Low Error Tolerance	Data Replication Ex: Backup	Data Retrieval Ex: WWW browsing

Table 1.2: Delay and Error properties of Network Applications

2. Adoption of Technology

2.1 Modeling Adoption Behavior

The two curves in Figure 2.1 below can be used to characterize in general terms the process involved in the diffusion and adoption of technology. The normal Gaussian distribution curve describes the rate of adoption at time t. The bottom s-shaped logistic curve describes the cumulative number of users of the technology at time t. Adoption behavior can be divided into three stages: growth, maturity, and saturation. During the growth stage, the rate of diffusion and number of users grow as communication increases the knowledge and acceptability of the innovation. The earliest period of the growth stage may be approximated by the exponential curve, $N(t) = ae^{bt}$, where N quantifies the users at time, t. The rate of diffusion reaches a maximum at the halfway point indicated by the vertical line in Figure 2.1. The maturity stage surrounds the maximum point of the curve. The curve begins to level off during the saturation stage as all potential users have adopted the technology. The saturation stage often coincides with the growth stage of a competing technology. An additional stage of decline occurs often as users substitute one technology for another. In some cases, a new diffusion wave for each technology may build as additional uses are identified and current users replace or upgrade their existing equipment. Some technologies do not experience a significant decline with the introduction of newer technologies.

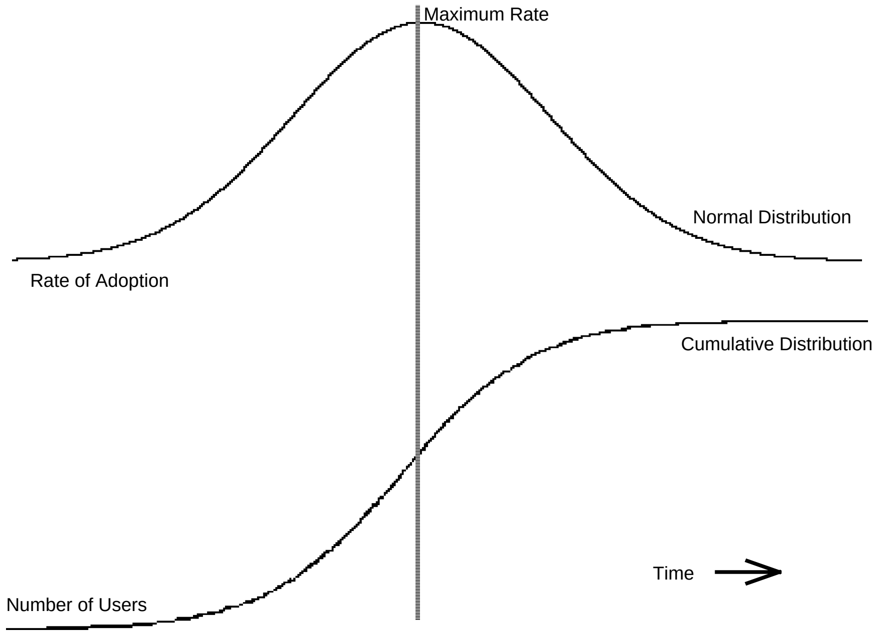

Figure 2.1: Diffusion and Adoption Curves

The rate of adoption can be described by the differential equation,

$$\frac{dN}{dt} \propto N(M-N) \qquad (1)$$

where M is the saturation point of the diffusion process. Thus, diffusion is proportional to the amount of the innovation adopted and the amount remaining to be adopted. The solution to this differential equation is

$$N(t)=\frac{M}{1+e^{-(at+b)}} \qquad (2)$$

where a describes the rate of adoption and b is the constant of integration. The halfway point of the process is identified by the relation,

$$t_{1/2} = -\frac{b}{a} \qquad (3)$$

The halfway point is also the point of inflection of equation (2),

$$\frac{d^2N}{dt^2}(t_{1/2}) = 0 \qquad (4)$$

A useful relation to compare the diffusion of different technologies is Δt, the time, in years, required for diffusion to proceed from 10% to 90% of M, or the takeover time.

$$\Delta t = \frac{1}{83.06 \cdot a} \qquad (5)$$

Equation (2) can be manipulated to produce a form in which the parameters a and b can be calculated with linear regression methods,

$$\ln\left(\frac{\mathrm{N}(t)}{\mathrm{M} - \mathrm{N}(t)}\right) = at + b \qquad (6)$$

The variable, N, can be expressed either in terms of the percentage of the total market or the absolute number of users adopting the technology. The saturation level, M, can be expressed in terms of the total percentage of the market or the absolute number of users that the technology will reach. When an innovation acts as a simple substitute, substitutions have been observed to almost completely replace older technologies if substitution progresses a few percent. [14] In this case, M may be approximated as 100%. If M is not known beforehand, an M may be calculated that results in the best statistical fit of the model with existing data points. [18] [5]

The diffusion model describes the transfer of knowledge and experience from early adopters to the rest of the population. The innovation decision process consists of four steps: knowledge, persuasion, decision and implementation and confirmation. [47] Individuals obtain knowledge of the innovation and evaluate it in terms of perceived characteristics. The validity and reliability of the information is assessed during persuasion and then the decision to adopt or reject the innovation is made. This decision is reassessed and confirmed based on the actions of other individuals. The adoption rate increases as uncertainty decreases with a

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[5] The mathematical equations of adoption processes make assumptions that do not necessarily reflect actual adoption behavior. Specifically, the adoption curve is symmetric about the halfway point, an asymptote exists which diffusion can not proceed beyond, and adoption begins in the infinite past and goes to completion in the

larger community to gather information concerning the innovation. Members of the community learn from the experiences of others and imitate the behavior of innovators. There may be a significant time lag between the point at which one learns and tries a technological innovation and actually adopts the technology by making some commitment and including the innovation as part of routine usage.

2.2 Factors Affecting the Adoption of Network Applications

As a communications medium, the Internet naturally facilitates rapid diffusion of novel network applications through the transmission of both information about applications and the applications software itself. In this section, the perceived characteristics of innovations are discussed according to a framework defined by Rogers. The most important attributes of innovations are relative advantage, compatibility, complexity, trialability, and observability. [47]

Innovation Attribute	**Web**	**IP Telephony Software**
Relative Advantage	Multimedia, hypertext information format	Cost savings call management features
Compatibility	Compatible with ftp, gopher	can interconnect with PSTN through gateways
Complexity	Easy-to-use graphical interface	varies by implementation
Trialability	Free client software requiring no commitment	Many implementations are free to download Some applications require service commitments
Observability	Highly observable URL's	Limited

Table 2.1: Summary of Innovation Attributes of the Web and IP telephony

Relative advantage is the degree to which an innovation is perceived as superior to its predecessor. Users migrate to applications that provide benefits over existing applications. Figure 2.2 illustrates the percentage of traffic originating from three popular applications on the NSFNET backbone. Note that on April 30, 1995, NSFNET was transitioned to a new architecture in which traffic is exchanged at four network access points and, therefore, comparable traffic data does not exist after this date. Traffic from World Wide Web browsers surpassed both ftp and gopher traffic. The advantages provided by the Web resulted in users substituting the Web for gopher and ftp.

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infinite future. The model is intended only to be a descriptive tool and provides no insight into driving forces or causality.

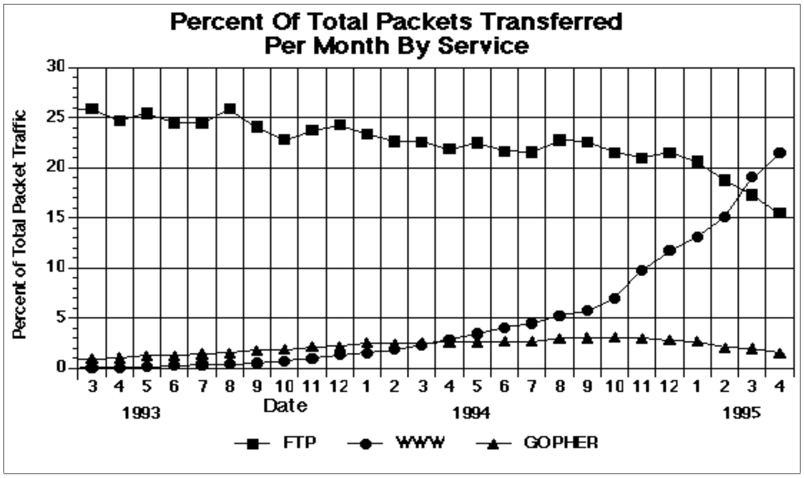

Figure 2.2: Traffic on the NSFnet backbone, Sources: Merit NIC, James Pitkow, GVU

IP telephony applications must present some benefit over traditional forms of telephony. Cost savings have attracted early adopters of these applications. Although cost savings do exist, quality tends to be much lower due to latency and other factors. Lower quality tends to be a result of network connectivity, or bitways, and not the application layer. However, the perception of overall poor quality may hamper future adoption even as bandwidth improves.

Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experience and needs of potential adopters. Interfaces that are compatible with familiar applications will positively affect the rate of adoption. Web browsers provided a similar interface and compatibility with ftp and gopher browsers. Users could continue to access ftp and gopher services as well as Web services. Computer based telephony applications appear to be incompatible with methods of interacting with existing technology. Connecting with another party may require different directory lookup procedures, such as locating an IP address, and similar system platforms or software. Improved gateway services may help achieve more compatible telephony applications.

Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Complexity impedes the adoption of innovations. For example, the Web achieved widespread acceptance due to the easy-to-use interface of browsers. For users unfamiliar with computers these telephony applications have a more complex interface and are more difficult to setup than POTS equipment.

Trialability is the degree to which an innovation may be experimented with on a limited basis. Many successful network applications have been very trialable. Web and gopher clients could be downloaded for free and experimented without any commitment Most telephony applications, as well, do not require any commitment of the user and do not present any difficulties in discontinuing use. Users can simply install the software experiment without modifying their primary telephone system. Some Internet telephony applications permit users to try Internet based services without switching their primary telephony service provider.[6]

Observability is the degree to which the results of an innovation are visible to others. Innovations that have observable benefits are adopted more quickly. Roger notes that software based innovations are less observable than hardware based innovations. Some software innovations such as the World Wide Web had certain aspects that were highly observable such as widely advertised URL’s. New telephony applications may use existing addresses such as telephone number or host names that will not differentiate them. However, the peer-to-peer nature of telephony applications may cause early adopters to encourage others to try the applications.

2.3 Growth of the Internet

There are several factors that will drive and constrain the growth of the Internet. Communications systems are characterized by both positive and negative externalities.[2] Positive externalities arise when the total number of users affects the value of the network for individual users. New adopters derive more value from the network than early adopters because of the greater availability of information and number of users with which to communication. However, as the size of the network’s knowledge base grows, information becomes more difficult to locate and organize. Such negative externalities arise when the performance or usability of the network degrades due to increased usage and traffic. Heightened costs, congestion, and complexity often occur in expanding networks. Each additional user produces a network with different qualities. New applications also change the nature of the network. For example, the demand for Web access created the need for direct connection to the Internet instead of simple access methods such as mail gateways.

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[6] Trialability is more important to early adopters who have less assurances of the viability of the applications.

2.3.1 Internet Hosts

Figure 2.3 describes the growth of hosts on the Internet from 1969 to 1998. The data was obtained from several sources and may not be consistent throughout the entire time-series because of different host count methods. From 1969 to about 1988 all Internet hosts were registered in host tables with the Network Information Center. In 1988, the Domain Name System (DNS) was implemented and deployed and host counts were performed by querying the DNS system. [27] Beginning in January 1998, the survey mechanism was modified to account for organizations restricting access to domain data. The new survey counts hosts by querying the domain systems to discover IP addresses assigned names. From 1969 to 1998 Internet host expansion exhibits an exponential growth pattern but growth rates during different periods are inconsistent due to different host count methods. The solid line in figure 2.3 illustrates the exponential regression curve for the data.

The host count only describes the number of visible machines connected to the Internet and does not provide information on usage. There exists no accurate calculation of Internet users. Multiple users accessing the network through the same machine obscure the actual size of the Internet community. For example, many individuals may read electronic mail through a single machine acting as a mail server or access the Internet using public terminals. Internet hosts that act as public file servers may have an unlimited number of

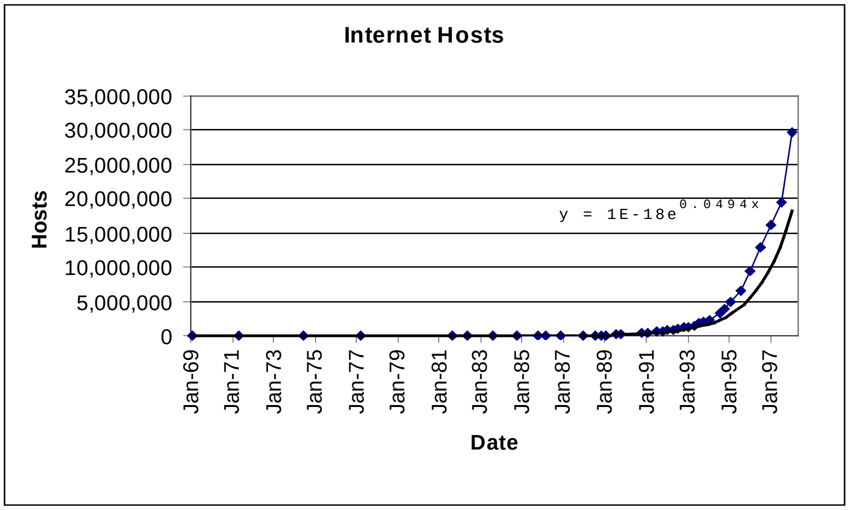

Figure 2.3: Growth of Internet Hosts, Source: Network Wizards

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Late adoptions are assured of the applications success through observation of previous adopters.

potential users. The ratio of users to machines has been decreasing as network services are being accessed with personal computers instead of timeshared mainframes. Despite the fact that hosts may be private terminals or public servers, the Internet host count currently provides the most reliable measure of the size of the Internet.

Figure 2.4 projects the growth of Internet hosts by fitting data to equation (2). The upper limit of hosts, 39 million, was calculated by finding the best statistical fit. The logarithmic scale more clearly distinguishes several waves of Internet host growth in which hosts counts do not fit the predicted curve. The host count observations begin to converge on the predicted curve around 1989. This period of growth may represent the commercialization of the Internet or the implementation of the DNS. Although the growth of Internet hosts is predicted to saturate in the early part of the next century, this does not imply that expansion of the Internet will discontinue. The stabilization of the number of hosts may be coincidental with the growth of private networks, often called Intranets. [21] Hosts within these private networks are hidden from the surveying devices described earlier. Organizations that create Intranets isolate internal users from the rest of the Internet through firewalls, proxy servers, and gateways. These organizations decide what content and services from the external network to allow users to access and provide internal content on private servers. The rise of an Intranet based Internet may be a response to the need for improved security, filtering of content, or differentiated levels of service. Another trend that might also cause a slowdown in

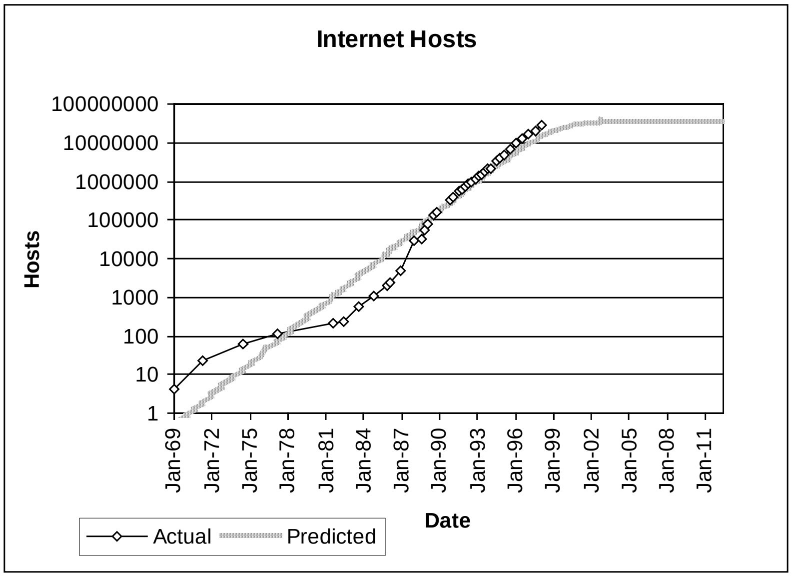

Figure 2.4: Predicted Growth of Internet Hosts

the growth of the number of hosts is the use of the Internet as a transport mechanism. Users can access a gateway device that utilizes the Internet for transport through terminals that are not Internet hosts, such as POTS equipment.

2.3.2 The Web

In 1989, the World Wide Web (WWW or Web) was conceived at CERN as a distributed hypertext system to manage information about the lab's accelerators and experiments. The first multimedia browsers were introduced in 1992 and 1993. Although no accurate count of Web users exists, the number of Web servers or sites has been recorded and is displayed in figure 2.5. The Web has experienced tremendous growth but interception of the data with the exponential curve indicates that this growth is beginning to slow. To more accurately predict an upper limit on Web growth, web servers were plotted as a percentage of the total number of responding Internet hosts in figure 2.6. Responding Internet hosts were estimated by Network Wizards by querying a statistical sampling of the Internet. All public Web servers are responding Internet hosts. Other types of responding hosts include other forms of servers and networked machines that are always on and are outside of a firewall. The number of Web servers should not exceed the number of responding hosts. An upper limit of 40% of responding hosts functioning as Web servers was obtained. This is equivalent

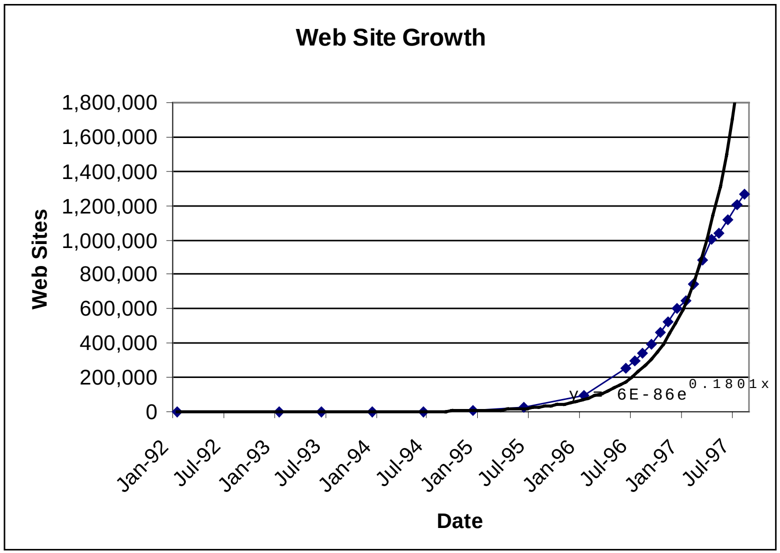

Figure 2.5: Growth of Web Sites. Sources: W3 Consortium, Matt Gray, MIT

to approximately 8.6 million Web servers by the middle of year 2000. The halfway point of Web growth occurred in December 1996. These results are consistent with the fact that many organizations have already created a presence on the Web. A new wave of growth may occur if individuals were to setup private Web servers as personal computers gain the ability to be continuously connected to the network. Such a capability would enable the transition from web content hosted on a single server to content hosted on local personal computers. However, this would not necessarily increase the total information base of the Web.

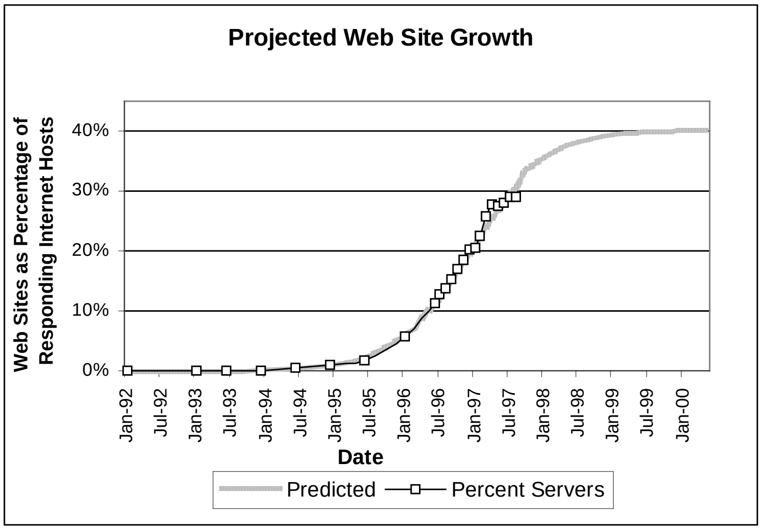

Figure 2.6: Predicted Web Site Growth as Percentage of Responding Internet Hosts

2.3.3 Multicast Applications

The IP Multicast Backbone (MBone) is an early Internet based real-time video and voice application. The first multicast session was established between BBN and Stanford University in 1988. The MBone distributes information in a one-to-many fashion rather than a one-to-one fashion, as is the case with peer-to-peer IP telephony. Information about hosts participating in the MBone was collected using the *mlisten* tool that continuously monitors multicast addresses used to advertise MBone sessions. [1] The data may not reflect the actual size the MBone user community. As described previously more than one user may use a computer with an assigned IP address. Problems in the collection method may also distort the results. Unreliable transmissions that cause packet loss may result in group members appearing to leave a session, but not actually doing so. In addition, abnormal MBone behavior may occur as a result of software bugs and performance experiments. Unique IP addresses were counted from the *mlisten* tool log files. Figure 2.7 describes the usage of the MBone from 1995 to 1998 in terms of the cumulative number of distinct IP addresses identified. The MBone has experienced rapid exponential expansion, but this growth is beginning to slow based on the intersecting of the data with the fitted exponential curve.

The histogram in figure 2.8 describes the number of days between a user's first and last MBone connection. Each unique IP address appearing in the *mlisten* log files was considered to be an MBone user. The first bar in the figure represents the number of users having zero days between connection. Therefore, about 10% of the total number of users participated in the MBone only once. About 54% of the users used the MBone again within a

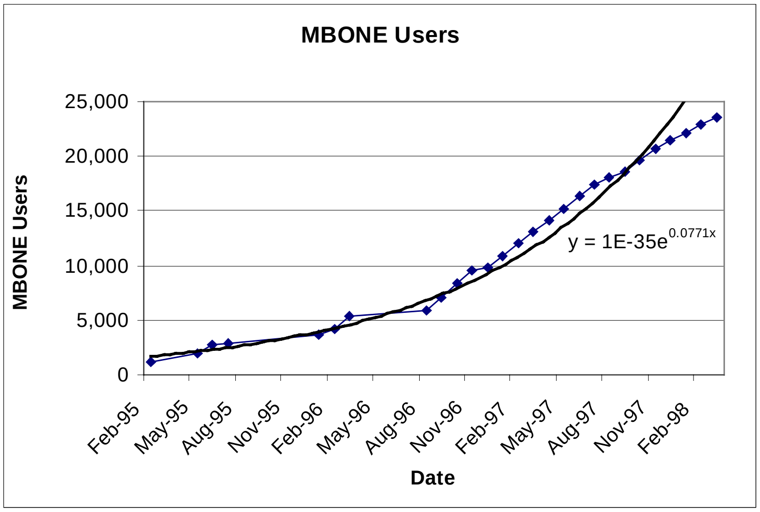

Figure 2.7: MBone Growth, Source: Kevin Almeroth, UCSB

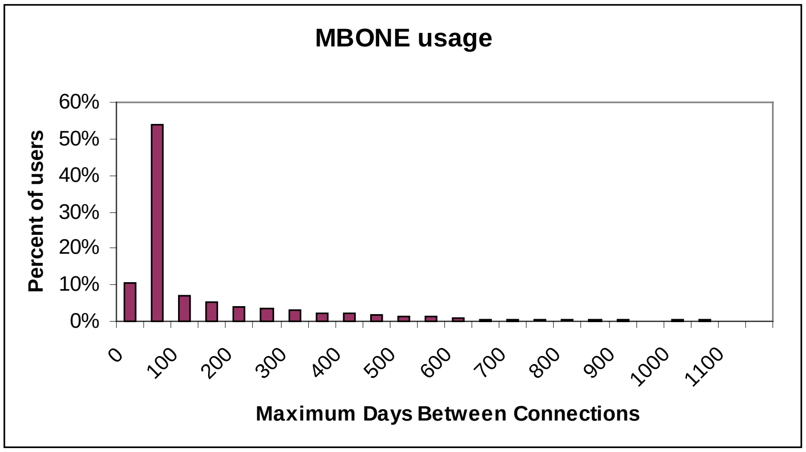

Figure 2.8: Histogram of maximum days between MBone connections

50 day or less period of time. These results suggest that most users tried the application a few times and then discontinued use. The remaining 36% of the total user population made use of the MBone within 50-day or more period of time. Of the users observed in figure 2.7, only a small percentage decided to actually adopt the technology. Most users experimented with the MBone over several days and then discontinued use.

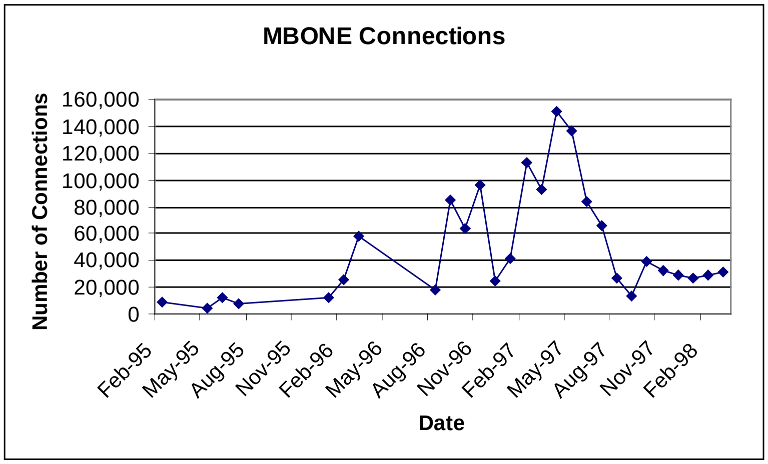

Figure 2.9: Number of MBone connections made each month

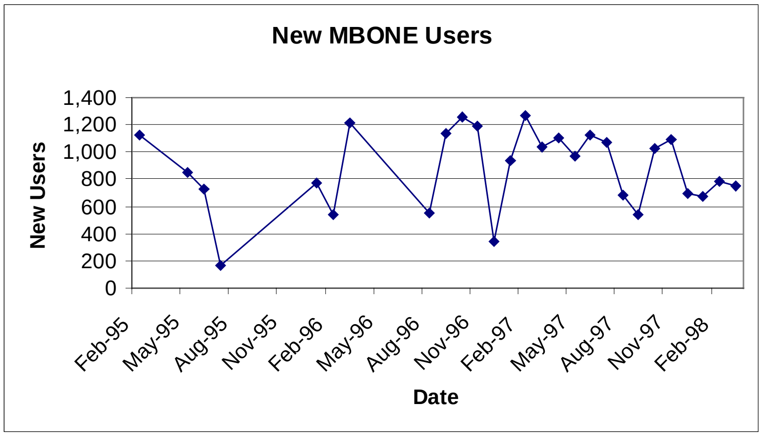

Figure 2.10: New MBone users by month

The number of connections made by MBone receivers per month is displayed in figure 2.9. Instead of increasing in a regular manner, connections fluctuated and exhibited several peaks in usage. These peaks coincide with the presentation of events on the MBone such as IETF meetings or space shuttle or Mars exploration audio and video provided by NASA. The number of new users joining the MBone, in figure 2.10, fluctuates in a similar manner and peeks also coincide with the availability of certain content. This suggests to date that new users join the MBone to participate in special sessions and find little reason to participate in subsequent sessions. Thus, the number of MBone adopters is very small compared to the number of users observed.

The number of MBone users is only expected to reach 36,500, see figure 2.11. The small size of the MBone user community can be attributed to the adoption patterns described above and competition from newer multicast and telephony applications. The MBone may also experience a decline in usage as users migrate to these newer applications.

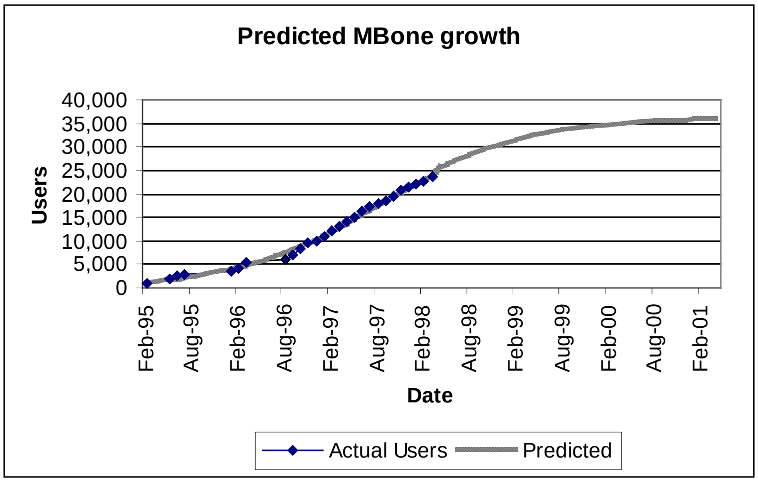

Figure 2.11: Predicted Mbone growth

2.3.4 IP telephony Applications

Clark identifies three general classes of Internet Protocol (IP) telephony applications. [8] Although these applications are often referred to as Internet telephony applications, they may be implemented on any Internet Protocol based network, not just the public Internet. Class 1 connects Plain Old Telephone Service (POTS) equipment, with the Internet serving only as a conduit. Class 3 utilizes computers attached to the Internet for voice communications and other advanced applications. This class does not involve any interaction with the Public Switched Telephone Network (PSTN) or equipment with the possible exception of a telephone line and modem for dialup access. Class 2 is a hybrid of classes 1 and 3. Class 2 allows communication between computer based telephony systems and POTS equipment. Thus, a computer telephony application resides on one end-node and a PSTN phone resides on the other end-node. Some applications provide both class 2 and 3 capabilities.

The number of IP telephony software users over a three-year period is displayed in figure 2.12. In this section, IP telephony software refers to class 2 and 3 applications. The data was approximated from software sales of Vocaltec's Internet Phone product that has an estimated 90% market share. IP telephony like the MBone appears to still be in an early exponential growth phase based on the close fit of the data in figure 2.12. Projections for IP telephony are likely to be very unreliable based on the limited availability of data.

A model for the growth of IP telephony was developed by analogy to other applications discussed. An upper limit was chosen as identical to the upper limit of Internet hosts. The saturation of telephony clients was approximated as not exceeding the total number of Internet hosts. A growth constant was then derived that best fit observed data points. IP telephony adoption was predicted to reach its halfway point in January 2002 and had a Δt value of 5.5 years. The growth of telephony software users displayed in figure 2.13 is not as dramatic as some other predictions. For example, International Data Corporation predicted there would be 16 million IP telephony users by 2000, whereas this model suggests telephony applications will still be in an early stage of growth at this point. The more conservative results of this model may reflect the exclusion of class 1 applications in which the Internet is used solely for transport and accounting only for active users of the software. According to Vocaltec, 3 million individuals have tried telephony software, but only .5 million are active users and make frequent calls. As is the case of the MBone, there are many

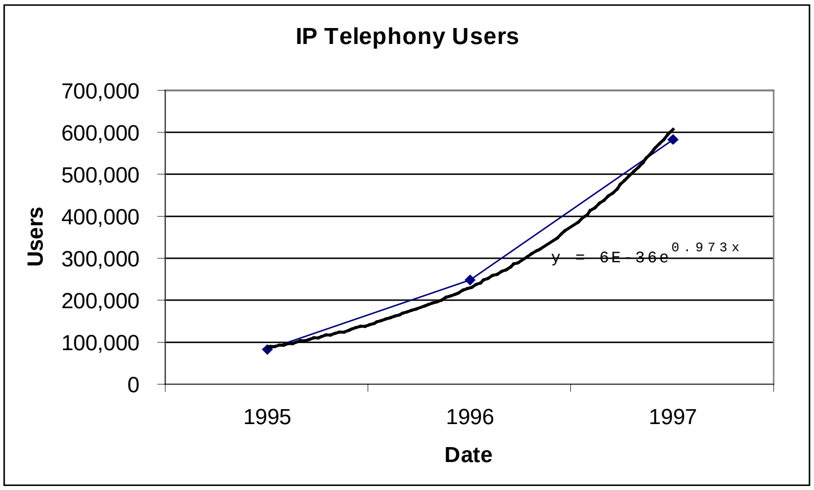

Figure 2.12: Growth of IP Telephony Users, Source: Scott

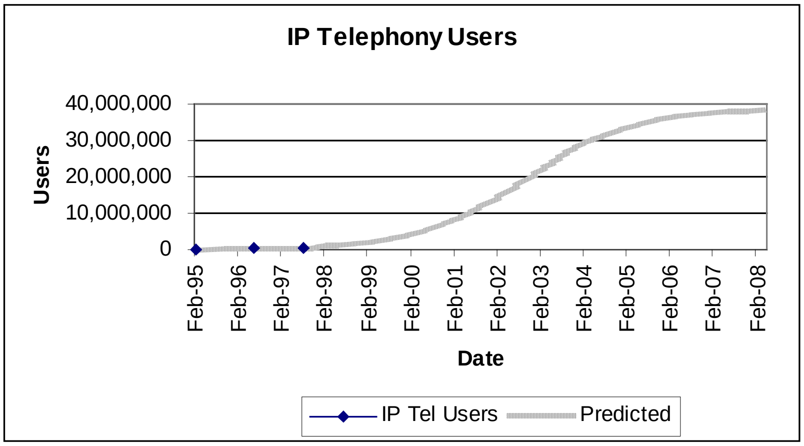

Figure 2.13: Predicted Growth of IP Telephony

users in the knowledge or trial stage of the adoption process who are not yet willing to adopt the technology.

3. Conclusions

The growth rates for the Internet itself, based on host counts, were slower than for most applications. The expansion of the Internet was delayed by the arrival of easy-to-use software, such as Mosaic, and the commercialization of Internet backbones. For many years the Internet was restricted to academia and scientific research networks. The Web experienced the most rapid growth of the applications studied with a takeover time of 2.4 years. As discussed in chapter 2, the takeover time describes the time required for adoption to proceed from 10% to 90% of the saturation point. Information placed on Web was immediately accessible to all Internet users. The value of the Web to users was related to available content and the suitability and organization of information. The longer takeover time for IP telephony and network news can be attributed to the application's limited value during early stages of development. The MBone was determined to have a takeover value of

Technology	Growth Constant	Halfway point	Δt in years
Internet Hosts	0.00162	October 1998	7.2
Web Servers	0.00501	December 1996	2.4
MBone users	0.00344	August 1997	3.5
IP telephony software users	0.00218	January 2004	5.5

Table 3.1: Growth Rates of Network Applications

3.5 years. Although, MBone growth occurred quickly, the MBone was only attractive to a limited number of users. This growth rate reflects diffusion through a much smaller user community than other applications. There are several reasons that explain the MBone's failure to attract more users. Unlike the Web, limited content was available to MBone users. MBone sessions also tend to suffer from poor transmission quality. In a study performed by Handley, 80% of sites observed reported intervals with packet loss rates greater than 20%, which is regarded as the threshold above which audio without redundancy becomes unintelligible. [20] If problems related to poor transmission continue, the growth of IP telephony applications may slow as future users may be less tolerant to inferior performance than early adopters.

3.1 Technological Substitutions

The adoption of technology can be understood as the substitution of old technologies for newer more efficient ones. Although the diffusion of network innovations has not been explicitly analyzed as such in this article, underlying substitutions are present with network applications. Electronic mail acts as a substitute for postal mail, content available through the Web serves as a substitute for paper-based magazines and journals, and IP packet routed telephony substitutes for conventional switched telephone services. The overall trend of media convergence is driven by the underlying substitution of general-purpose programmable systems for special-purpose devices. [16] Substitution itself is catalyzed by the need to improve efficiency due to the depletion of resources and competitive pressures. [26] General-purpose computing equipment and network architectures more efficiently perform the tasks

Substitution	**Half-way point**	**Δt in years**
Synthetic/Natural Rubber	1956	58
Synthetic/Natural Fibers	1969	58
Water-Based/Oil Based Paint	1967	43
Plastic/Hardwood Floors	1966	25
Plastics/Metal in Cars	1981	16
Organic/Inorganic Insecticides	1946	19
Synthetic/Natural Tire Fibers	1948	17.5
Detergent/Natural Soap (US)	1951	8.75

Table 3.2: Technological Substitution rates
Source: Fisher and Pry [14]

of separate dedicated infrastructures and specialized devices. Digitization permits more efficient delivery of information, increasing its availability in time and place. [5]

Based on the takeover times listed in table 3.1 and table 3.2, the Internet and network applications, on average, experienced much greater adoption rates than traditional technological substitutions. Advances in computing performance, rapid diffusion of information, standardization, and positive feedback, can explain the unusual rates of adoption for network applications. Positive feedback occurs as advances in networks and computing produce conditions that fuel further expansion. [56] The use of computers in the design and fabrication of semiconductor circuits sustains the current exponential evolution of computing performance. Such advances in computing have allowed higher-capacity networks to become available supporting the demand for bandwidth intensive applications. User participation also factors into positive feedback as users increase the value of the network and attract additional users. Users of the Internet have produced most of its content and developed many of its applications.

3.2 Standardization and the effect of gateway devices

The interconnection of incompatible systems has the affect of nullifying competition between contending variants. For example, the interconnection of alternating and direct current electric power distribution networks through the rotary converter neutralized the rivalry between these competing systems.[10] Interconnection of the IP network and PSTN through gateways allows elements of both systems to co-exist. Gateways achieve compatibility and integrate different modes even if undesired or unintended by the designers of the original network. The early Bell telephone system could technically be interconnected with independent companies but interconnection was usually refused in order to control the telephone business and induce operating companies into becoming Bell licensees. [36] In modern telecommunications systems, the presence of voice transmissions over IP networks and interconnections of the PSTN with IP network are difficult to detect. The PSTN system does not derive any advantage over IP based systems from having a larger user base because traffic originating from IP networks can not easily be eliminated or treated differently. From the user's perspective, an Internet based telephone connection could appear identical to a PSTN based telephone connection.

Gateway devices do impose costs as a result of achieving compatibility. These costs arise in the form of speed, accuracy, capacity and availability. Additionally, the limited deployment of gateways provides IP telephony applications access to a small number of PSTN exchanges. Gateways will become bottlenecks, as they are more widely deployed and their usage increases. When gateway inefficiencies become more apparent, incentives to transparently interconnect IP networks and the PSTN will arise. Telephony applications will evolve such that the distinctions between application classes will be eliminated. The earliest adopters of IP telephony applications, Internet users and hobbyists, were restricted to communicating with other Internet users (class 3 applications). Later adopters, including corporations and Intranet users, could communicate with PSTN telephone users (class 2 applications). Subsequent adopters of class 1 applications used the Internet as a transport mechanism only and make calls through PSTN equipment by service arrangements with certain long distance carriers. New generations of telephony systems will transparently incorporate elements of all applications. Thus, computers will seamlessly provide voice and data services and telephone calls will be routed over the most efficient network.

3.3 The Dynamic Nature of Network Applications

The forecasting and modeling of innovation diffusion in the article have relied on a narrow definition of each application. A model that is too broadly defined is likely to incorporate elements of unintended technologies. For this reason, the IP telephony model only included software products and Internet hosts were modeled instead of all Internet users, as it is not precisely understood what qualifies as an Internet user. However, the Internet's emphasis on end-node processing and user participation is resulting in dynamic applications. The design and implementation of applications are rapidly evolving according to user requirements and the constraints of technology. Telephony applications will quickly change as network capabilities are upgraded and user needs are realized.

In the absence of frameworks to understand innovation, this evolution is often envisioned in terms of existing processes. Concepts based on and defined in terms of old technologies tend to hinder the development of new technologies. [46] Most telephony systems are still based on the assumption of technology as a scarce and expensive resource. The Internet has the potential of transforming communications services as antiquated notions of technology are discarded. IP telephony application not only can reproduce existing telephony features, but also incorporate multicast and information retrieval features to form new types of applications. The differences in the capabilities of Internet enhanced telephony and conventional telephony imply the path of innovation diffusion may not strictly adhere to the linear model of simple technological substitution. New applications will emerge that are not incremental improvements over current communication systems.

Network services have become increasingly difficult to classify as they are changing and diversifying. The nature of modern networks renders the distinctions between types of content, transport, and applications irrelevant. The Internets transports and processes bits without regard to distance or intended use. The breakdown of the barriers between services is beginning to reveal the irrelevance of regulatory and policy models that distinguish different modes of communications. Along with the convergence of technologies, it is necessary for regulatory frameworks to also converge. [32] Isolated regulations will hinder innovation in affected regions. Specific regulations will be ineffective. An attempt to regulate or impose fees on Internet telephony service providers will simply cause more users to migrate to PC based telephony applications. [9]

This article has demonstrated that open flexible networks such as the Internet have the ability to achieve rapid growth and innovation. The pace of innovation diffusion will present challenges as technological change becomes more difficult to manage. Future research should attempt to further understand what technical, policy, and social factors are required to continue to sustain the current growth of network application innovation.

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