Telecommunications @ Crossroads: The Transition from a Voice-Centric to a Data-Centric Communication Network

by

Philip Kyalo Mutooni
B.S., Electrical Engineering, University of Rochester (1995)

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Signature of Author_____
Department of Electrical Engineering and Computer Science
May 23, 1997

Certified by_____
Dr. David L. Tennenhouse
Principal Research Scientist, Dept. of Electrical Engineering and Computer Science
Thesis Supervisor

Certified by_____
Dr. Lee W. McKnight
Lecturer, Technology and Policy Program
Thesis Reader

Accepted by_____
Professor Richard de Neufville
Chairman, Technology and Policy Program

Accepted by_____
Frederic R. Morgenthaler
Chairman, Department Committee on Graduate Theses

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Abstract

Packet based, e.g., Internet, traffic will soon surpass conventional forms of wired communication, e.g., circuit-switched voice traffic. Moreover, the growth in packet traffic is so pronounced that by 2007, telephony may constitute only 10% of overall backbone traffic. In this thesis, I investigate this transition of the communication network from a "voice-centric" to a "data-centric" model. In particular, I examine the speed with which data traffic will eclipse voice traffic, and the significance of the shift's suddenness to the final outcome. While a prediction concerning the precise timing of the circuit-to-packet crossover is of some interest, this thesis' focus is on addressing the fundamental issues relevant to the rapid evolution of a data dominated communication network. To aid in understanding the shift, I present and characterize a traffic transition model. Based on this model, I determine that the window in which data traffic increases to contribute 90% of overall backbone traffic is 10 years from today, and find that the crossover (50%) point occurs in 1998. I argue that the suddenness of the change, as opposed to the change itself, will be a key issue in determining the post "crossover" telecommunication industry structure, and discuss the implications of this finding for ISPs, RBOCs, switch equipment vendors, Internet telephony, and Universal Access. In the appendix, this model is extended to investigate the revenue crossover that accompanies the traffic crossover and the relationship between the two events is characterized.

Thesis Supervisor: Dr. David L. Tennenhouse
Title: Principal Research Scientist
Department of Electrical Engineering and Computer Science

Thesis Reader: Dr. Lee W. McKnight
Title: Lecturer
Technology and Policy Program

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Introduction

On March 22, 1961, Fredrick R. Kappel, the President of the then American Telephone and Telegraph Company (AT&T), while giving a speech to the North Carolina Citizen's Association, made a controversial statement that would be misconstrued for years to follow. It was on the subject of trends in communication, of which he said,

"[W]e in the Bell System have such a strong feeling that in the foreseeable future, perhaps within 15 years or so, the volume of information communicated between machines may be even greater than the amount of communication between people."

Based on this, numerous studies were performed all concluding that this statement's prediction could not happen in this century. Recently, however, a second speech made by another industry executive, David Dorman, President of Pacific Bell, validated the essence of Mr. Kappel's statement. Mr. Dorman stated that in the middle of 1995, business data traffic (which includes fax and computer) constituted more than 50% of all business network traffic, exceeding business voice traffic.[1] No evidence as yet has surfaced to argue the contrary.

The importance of data traffic and its impact on the network is clearly an important topic to address. While various efforts have been made to prove or disprove

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[1] Mr. Dorman repeats this statement in his paper, "Mr. Jones Jacks in To Data Dial Tone" in the 1996 Annual review of Communications.

different claims of network traffic trends, little has been said on the factors that influence this transition and the resulting industry structure. This is the main contribution of this report: not to predict when a data-voice crossover will occur, but rather to focus on the suddenness with which it will occur and on the issues pertinent to this, nonetheless, very monumental event.

The increasing proliferation of data communication in the last two decades has gradually unveiled a new paradigm in communications.[2] While telecommunications technology has largely been associated with telephony and the public switched telephone network (PSTN) for the better part of this century, an examination of recent developments and trends suggests that we are in the process of a shift - from a voice-centric to a data-centric communication network.[3] In general terms, the demand for voice services has been increasing at 5% to 10% per year while that of data services has been expanding at 75% to 300% annually.[4] Granted that these two rates are applied to different base values, it is not surprising that, should this pattern continue, aggregate data traffic will surpass aggregate voice traffic. A less certain but much more interesting consideration involves the timing of this transformation. Further, such a crossover in traffic would be accompanied by a similar crossover in service revenues. Another issue worth exploring then is the concurrency of both these transitions.

This report examines the circuit-to-packet crossover event by examining two fundamental questions:

1) How rapidly will voice traffic be eclipsed by data traffic

2) How will the rate of the transition impact the final outcome

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[2] (Harassim, 1993)p. 35-56.

[3] (Bradley, Hausman, and Nolan, 1993).

[4] The growth rate of voice traffic is calculated in section 2.5 by considering volume increase for the RBOCs and IXCs. For the rate of data growth, see (Wallace, 1995), p.1, however, as I show in Chapter 3, data traffic has been growing at lower rates than some studies suggest.

To address these questions, this report presents a traffic transition model that is used to analyze trends in capacity growth. Using this model, the transition is characterized by defining three key milestones, the "lead-user" point, the "crossover" point, and the "eclipse" point. By serving as reference points in the network's shift, these three points provide an understanding of the rate of the crossover and the speed of data dominance in the network.

A parallel analysis is performed to analyze the companions trends in telecommunications revenue growth. Lead-user, crossover, and eclipse points are defined and used to characterize the voice-data revenue transition. This revenue transition model is integrated with the traffic transition model to present a unified Traffic-Revenue transition model. This unified model is characterized and provides further insight into the differences in the economics of the voice and data industries. Most importantly, it validates the hypothesis that the suddenness of the shift may have a significant impact on the outcome by demonstrating a lag in the traffic and revenue crossover events.

The thesis considers industry structure and telecommunication policy ramifications that accompany the problems it sets out to address. In understanding industry structure, the discussion focuses on: switching, bundling, and substitute technologies. The policy discussion is centered around the topic of universal service.

This report concludes that Packet based traffic will eclipse voice traffic by the year 2007 and that the crossover is in 1998. However, the emphasis of this work is not on predicting the exact timing of the lead-user, crossover, and eclipse events, but rather on understanding the issues that influence the post crossover industry structure. It argues that due to the suddenness in which packet-data traffic becomes the dominant mode of traffic, a period of close to a decade from now, the suddenness of the change as opposed to the change itself will be a significant determinant of the outcome of the crossover itself.

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The data used in this report was collected from various sources: InterExchange Carriers (IXCs), Regional Bell Operating Companies (RBOCs), switch vendors, and two selected MCI and AT&T Points of Presence. This data is used to calibrate the model, estimate the times when we expect these three checkpoints to occur, and make growth projections.

1.1 Contributions

This thesis makes original contributions to further the understanding of network traffic trends and their influence on the future telecommunications policy and business environments. Novel research aspects of this work are:

- The development of a model to characterize the transition of telecommunications traffic mix. This model is extended to characterize the transition of telecommunications revenue.

- A calibration of the change in network voice and data traffic composition. A parallel calibration is also performed for the accompanying change in network voice and data revenues.

- The observation that a lag exists between the traffic and revenue crossover events.

- The suggestion that the rapidity of the transition, as opposed to the change itself, is a primary determinant of the post "crossover" telecommunication industry structure.

- Specific observations concerning the consequences of the sudden shift with respect to Internet voice substitution effects, market economics, and Universal service.

1.2 Organization of this Report

This report seeks to present the reader with a clear and logical methodology for understanding the nature of data and voice traffic trends; develops a methodology for examining traffic trends; and, based on the analysis, identifies and addresses relevant economic and policy issues.

Specifically, Chapter 2 develops and presents a Traffic Transition Model. This model is used in characterizing the traffic trends in Chapter 3. In Chapter 4, the industry and telecommunications policy implications of the crossover rate and the crossover itself are considered. The appendix sections of the thesis introduce further analysis that can be expanded as future work. Appendix A extends the traffic model to characterize the revenue crossover that accompanies the traffic crossover, and proceeds to present an integrated traffic and revenue transition model. A mismatch between the traffic and revenue crossover events is identified and briefly discussed. In Appendix B, the characteristics, growth and trends of telecommunications traffic are examined while Appendix C considers the economic issues associated with the diffusion of telecommunication networks and proposes an alternative modeling approach to that presented in Chapter 2. Appendix D provides supporting data gathered from switch vendors.

1.2 Literature Review

This report explores the question of data traffic growth started in (Hough, 1970) and followed up in (Noll, 1991). Both of these works held that voice traffic will continue to dominate overall network traffic, an opposing view to what is argued here. (Noll, 1996) briefly discusses transmission, switching, and traffic issues coming to the same conclusion as before. (Noll, 1996) refers to the Internet as a "hyped phenomenon, whose transmission requirements are outstripped by voice communications." This report differs

from these prior works, not only in conclusion but also in methodology. The methodology used here is based on a model that uses parameterized capacity inputs obtained from service providers to develop an aggregate industry analysis, whereas previous works have relied on extrapolation of traffic from an average estimate of traffic sources that includes airline reservation systems, "information-age labor force", "people data", "moving images", "paper based media", data file transfer, and "video telephone." Prior research in this area occurred before the rapid growth and establishment of the Internet. While I have had the benefit of conducting research in a post Internet era, the basic analytical methodology and results do not depend on this. The key issue is the maturation of packet based traffic, be it Internet-based or not.

This research explores and develops some of the critical voice-data Switching issues discussed in (O'Shea ed., 1996) and (Wilson ed., 1992). While both these papers consider how the Local Exchange Carrier (LEC) and traditional switch vendor voice network offerings need to evolve as voice and data traffic intersect for broadband ISDN and ATM respectively, this report examines this evolutions impact at the backbone traffic level, choosing not to focus on any specific network platform. Both these papers also qualitatively consider the traffic mix change at the Central Office level, while the thesis examines the changing nature of network traffic quantitatively at the Point of Presence (POP) level, a larger traffic aggregation point. This research differs significantly from these earlier works by observing and arguing that the switching function of the Local Exchange Carriers (LECs) and traditional switch vendors is decreasing in importance as the composition of network traffic increasingly becomes dominated by packet-data, discussing the implications of this change in traffic composition for either of these players.

It contributes to the subject of network planning for local access telecommunication networks developed in (Park, 1994) and (Balakrishnan et al., 1989) by presenting a modeling methodology that addresses the capacity expansion projections in the MCI and AT&T POPs. In characterizing the shift in network traffic, this report

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contributes to telecommunication traffic modeling techniques extensively discussed in (Labetoulle ed., 1994). By examining the growth of Internet driven data traffic from a service provider point of view and exploring capacity growth considerations in a rapidly evolving public data network, this thesis builds on the Internet traffic work of (Claffy, Braun, and Polyzos, 1993.) Claffy et al (1993) develop a technical analysis and discussion about difficulties with long term traffic planning and forecasting aspects of an Internetwork in transition to commercialization, while in this thesis certain growth assumptions are made in developing the traffic model's projections, making it less technically oriented research. The focus of this work is to provide a thorough analysis with regard to voice and data capacity deployment without delving into the network level details which are covered well elsewhere.

This report extends the Internet economics work of (Bailey and McKnight, 1995) by addressing several relevant strategic and economic issues in a data dominated communication network. Specifically, it highlights the economic consequences of the post crossover industry structure. It discusses the usage pricing issues covered in Bailey and McKnight for the Internet, for a data dominated network, specifically in voice-data bundle pricing strategies and Universal data service policy.

This research extends the public Internet access work in (Kahin ed., 1995) by suggesting the use of data traffic as an alternative universal service subsidization mechanism. In reaching this conclusion it draws on (Vietor and Davidson, 1984). It also proposes the evolution of the Universal service concept to a Universal data network access policy.

In Appendix C of this thesis, an alternative modeling methodology is proposed that draws on the rich body of econometric modeling of the diffusion and saturation effects of new technologies discussed generally in (Chow, 1957) and (Bain, 1964), and more specifically for telecommunications in (Antonelli, 1989).

2

Traffic Transition Model

In this chapter, I develop a model that is used to characterize the circuit-to-packet crossover. The goal of the model is to analyze the transition of backbone traffic from predominantly voice to predominantly packet-data. I first lay out the assumptions of the model in section 2.1, then develop the model itself in section 2.2. The traffic transition model is then calibrated in chapter 3.

2.1 Model Assumptions

I first introduce two important assumptions used in the formulation of the model. These pertain to the relation between traffic and capacity in the report and the nature of the growth rates used in the model.

2.1.1 Capacity and Peak Traffic

Throughout this report, the term "capacity" is used with reference to installed capacity. This term is also used interchangeably with peak traffic. In the investigation, I have found that installed capacity and peak traffic are closely matched.

2.1.2 Average Compounded Annual Growth Rates

To simplify the model, I have assumed that the capacity is growing at a relatively constant compounded annual rate.[5] While past growth is not indicative of future growth, this is a reasonable assumption provided that the interval under projection is of limited duration. I, therefore, maintain that if the transition interval is "sufficiently" small, errors due to this assumption are not consequential to the conclusions. In section 3.2 I explore the sensitivity of my calculations to the precise growth rates and find that the basic premise of rapid crossover holds over a wide range of growth values.

2.2 Model Formulation

Consider a backbone network supporting voice services based on traditional circuit switching, growing in their capacity demand at a constant annual rate r_v, and a suite of data services based on packet switching, growing at a different constant rate r_d. The capacity required to support either category of service is given by the function:

$$C(\tau) = C_o(1 + r_x)^\tau \dots\dots\dots (1),$$ where C_o is a base capacity, r_x is a voice or data growth rate, and τ is a time duration.

For some reference point in time, t_o, the base capacities in voice and data, C_{ov} and C_{od}, are related by[6]:

$$C_{ov} = \alpha\, C_{od} \dots\dots\dots\dots (2)$$

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[5] The growth is described as compounded rather than exponential. The term "exponential" is often used to describe high growth rates such as those in the Internet and PC markets. Strictly speaking, all compounded growth e.g., population growth, voice traffic growth, and gross national product, is exponential. The characteristic that distinguishes the traffic types is their compounded rates. To avoid confusion, 'exponential' is not used to describe any growth.

[6] The value of the constant α will be determined during the calibration of the model in Chapter 3.

GROWTH OF DATA AND VOICE CAPACITIES
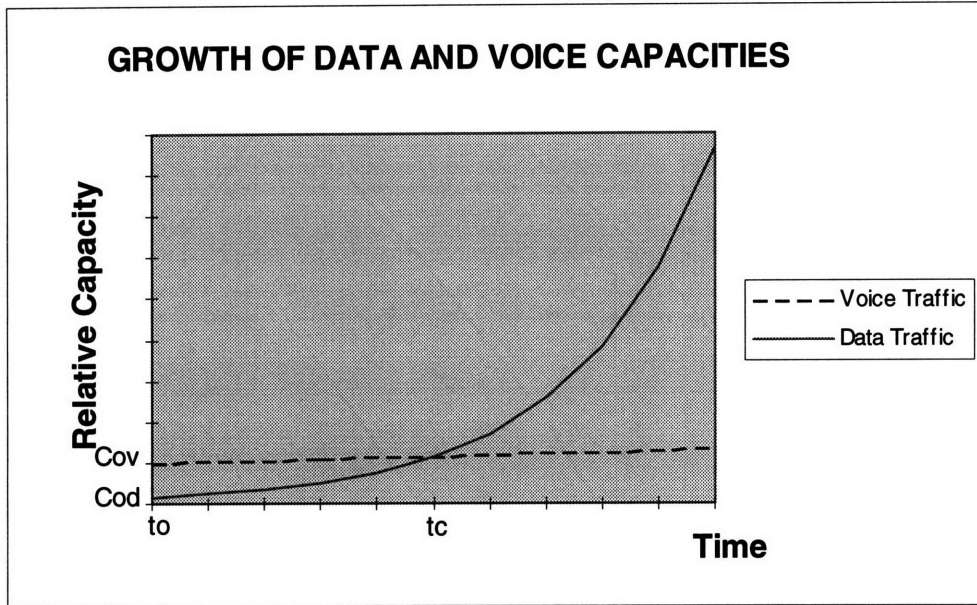
Figure 1[7]: A time series plot of the relative growth of voice and data capacities.

LOG (VOICE CAPACITY + DATA CAPACITY)
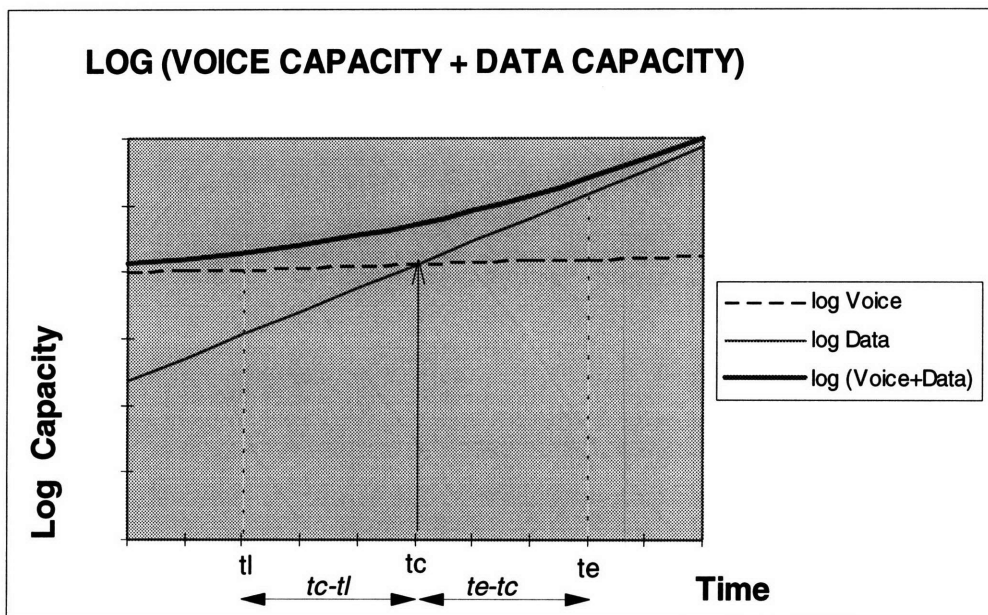
Figure 2: A log(Capacity)-time series plot of the relative growth of voice and data capacities.

A plot of these relative capacities is shown in Figure 1. Figure 2 shows the equivalent base 10 logarithm plot, and includes the curve representing the aggregate capacity i.e., the sum of the voice and data capacity requirements.

I define the following quantities as the results I wish to obtain from the model:

1) t_l or the lead-user point: The point at which packet-data traffic required 10% of the total capacity.

2) t_c or the crossover point: The point where both types of service require the same capacity.

3) t_e or the eclipse point. The point at which packet-data traffic consumes 90% of the overall backbone capacity.

4) t_c- t_l :The time interval from the lead-user point to the crossover point.

5) t_e- t_c :The time interval from the crossover point to the eclipse point.

The quantities t_l and t_e are arbitrarily chosen at ± 10% from the crossover point. However, they serve as convenient reference points that aid in understanding the rate of transit through the crossover point.

Through this parameterization of the capacity values, r_v, r_d, and α can be calculated. The value of r_x, the average annual rate of growth of data or voice, is calculated by fitting known or derived capacity quantities $\{C_{t1}, C_{t2},.., C_{tn}\}$, to the curve defined by equation (1).

Microsoft Excel's GROWTH and LOGEST functions are convenient tools for performing compounded growth curve fitting calculations.[8] These have been used in the MCI, AT&T, and aggregate Industry model calibrations.

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[7] The general function used to plot these graphs was $k(1+x)^t$. A different value of x was used in both the voice and data cases with x(voice)<x(data).

[8] The LOGEST function is useful in interpolating data between known quantities, while the GROWTH function is used to make projections given a compounded growth assumption..

2.3 Summary

In this chapter, a Traffic Transition model has been developed. The development was based on two key assumptions on the traffic-capacity relationship and on the nature of growth rates assumed in the model. It identified and defined several quantities of interest that will enable us characterize the traffic transition. Having parameterized the model and identified the relevant inputs and outputs, the next chapter of this report applies this traffic transition model to research data.

3

Traffic Transition Model Results

In this chapter, the traffic transition model is calibrated and applied. The calibration is done in section 3.1 using data obtained from MCI and AT&T. Following this, the main (industry-wide) results are developed and presented in section 3.1.3. Section 3.2 performs a sensitivity analysis on the industry-wide results of the model. In section 3.3, two alternative growth rate scenarios are modeled, while in 3.4 the traffic transition model is applied to estimate current Internet backbone traffic. Section 3.5 concludes this chapter with a summary of the findings.

3.1 Calibrating the Traffic Transition Model

In order to apply this model, I have performed a calibration through which I will both ascertain the growth rates of data, r_d and voice traffic, r_v, and determine α, the proportionality constant of the capacities at a specific time t_0. This calibration is done in four steps:

1) Obtain the overall capacity at known points in time.

2) Decompose this capacity into voice and data components.

3) From the results of (2), obtain the growth rates for voice capacity (r_v), data capacity (r_d), and total capacity (r_{total}).

4) Determine t_1, t_c, and t_e.

This procedure will be applied to two data sets: in 3.1.1 for a selected MCI POP, and for a selected AT&T POP in 3.1.2.[9] Section 3.1.3 uses both these data sets and FCC market-share information to obtain the industry-wide model results.

3.1.1 Analyzing growth at a selected MCI POP

I consider IXC carrier capacity as a metric of both voice and data capacity growth. Table 1 shows the growth of aggregate capacity deployed at a specific MCI point-of-presence (POP) for the period between 1991 and 1996.[10]

Table 1: The growth of capacity at a selected MCI POP (1991-1998).

Year	Total Number of DS1s	Equivalent Capacity[11] (Mbps)
1991	900	1386
1994	3696	5691.84
1996	11424	17592.96
Est 1997	18424	28372.96
Est 1998	25424	39152.96

In table 2, I decompose the capacity growth from table 1 into voice and data components. The plot of figure 3 shows the relative growth trends.

Table 2: Breaking down the capacity in table 1 into voice and data components.

Year	Voice Capacity (Mbps)	Data Capacity (Mbps)
1991	1247	139
1994	4553.47	1138.37
1996	12315.07	5277.89

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[9] In this context, POP stands for Point-Of-Presence, referring to an IXC facility used to obtain access to a Local Exchange Carrier's network within a particular LATA. It should be noted that the selected MCI and AT&T POPs may not be "representative" POPs and any interpretation of the overall results of the model needs to take this into account.

[10] The data presented in tables 1 and 2 was obtained from interviews with personnel at an MCI POP in late 1996. Table 1 also shows their estimates for capacity to be deployed in 1997 and 1998. The estimation equates to the addition of one DS3 per week. Note that the table reports interoffice trunk capacity.

[11] I assume that one DS1 has a capacity of 1.54 Mbps.

Now equation (1) can be used to obtain r_v, r_d and r_{total}, and equation (2) to obtain α.[12] The following table summarizes the results obtained for MCI's case for r_{total}, r_v, r_d, and α:

Table3: Results of the MCI data analysis.

Quantity	r_{total}	r_v	r_d	$\alpha(1996)$
Value	0.66	0.58	1.07	2.33

Based on these rates, we can project MCI's capacity deployment for voice, data, and total capacity.
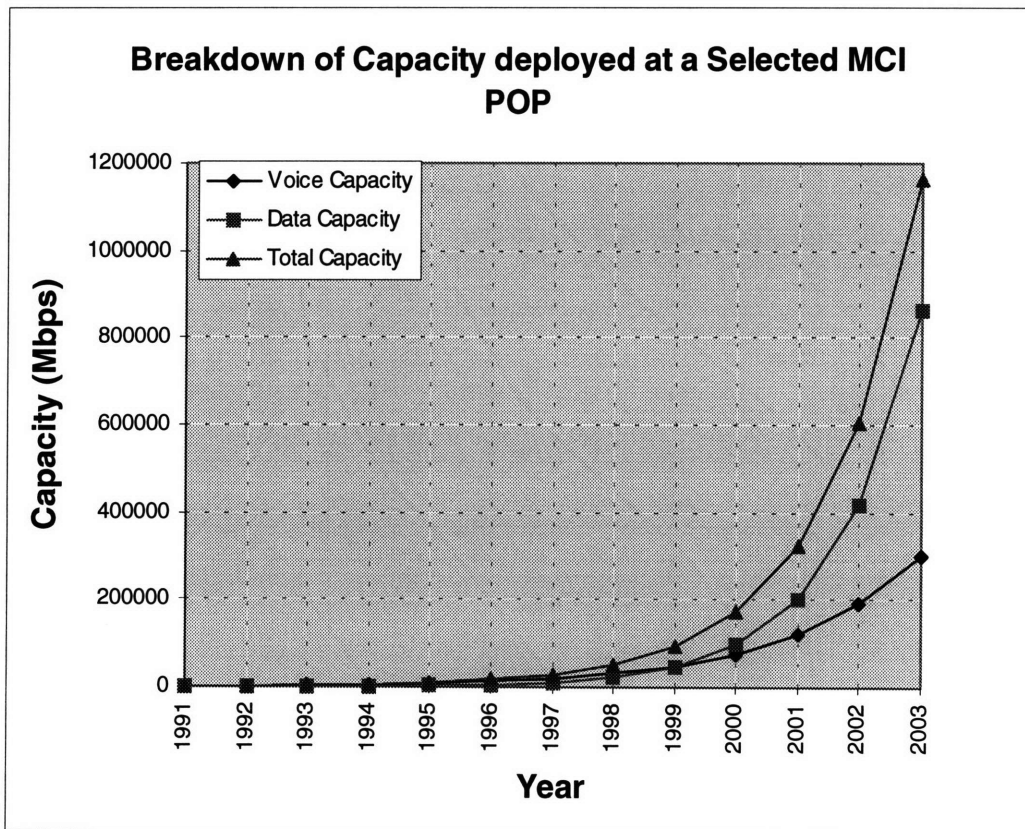
Figure 3: A graph resolving MCI Capacity growth into interpolated values for voice and data.

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[12] Here, the LOGEST and GROWTH functions in Microsoft Excel were used to interpolate the data and obtain projections respectively.

Having obtained the r_x growth rates, we can apply the traffic transition model to obtain the relevant MCI quantities which are plotted in figure 4 and summarized in table 4.

Figure 4: Graph showing MCI's estimated capacity.

Table 4: A table summarizing the quantities of interest for MCI's case.

t_i	t_c	t_e	t_c-t_i	t_e-t_c	α (1996)	r_v	r_d	r_{total}
1991	Jan 1999	2007	8 yrs	8 yrs	2.33	0.58	1.07	0.66

3.1.2 Analyzing growth at a selected AT&T POP

The interview data points summarized in table 5 provide insight into the growth of aggregate capacity deployed at a selected AT&T point-of-presence (POP) for the period between 1991 and 1996.[13] The voice and data capacity components of this total were deduced as discussed in table 6.

Table 5: Capacity growth data Points for a selected AT&T POP (1991-1999).

Data Points	
1.	Aggregate Capacity in 1996: 10.2 Gbps. (6 routes operating at 1.7 Gbps each)
2a.	Voice/Data Traffic Mix in 1996: 60%/40%
2b.	Voice/Data Traffic Mix in 1988-89: 90%/10%
3a	Year-over-Year Voice Traffic Compounded growth during 1988-93: 4% - 8%
3b	Annual Data growth during 1988-93: 2% - 3% of previous year's Aggregate capacity.
4a	Voice/Data Mix of all New Capacity Installed during 1994-96: 50%/50%
4b	Voice/Data Mix of all New Capacity Installed during 1997-99: 20%/80%
5	Year-over-Year Data traffic Compounded growth during 1994-97: 12%-15%
6	Newly Installed Capacity in 1997 is more than the Aggregate Capacity in 1991.[14]

Although the above data points do not directly address the quantities of interest, the five step process described in table 6 was used to deduce the AT&T POP's capacity growth from 1988-1997. A summary of the results of the spreadsheet analysis of this procedure are shown in table 7.

Table 6: Procedural steps used to obtain the rates and capacity values for AT&T (1988-1997).

Step	Procedure
1	Refer to data points 1 and 2a. Calculate the values of $C_{v(1996)}$ and $C_{d(1996)}$
2	Use the result of step 1, and data points 5 and 4a to reconstruct C_v and C_d for 1994-1996.[15]
3	Work from values of $C_{v(1994)}$ and $C_{d(1994)}$ and data point 4a to obtain $C_{v(1993)}$ and $C_{d(1993)}$.[16]
4	Apply data points 3a and 3b to the result of step 2 to obtain C_v and C_d for 1988-1993.[17]
5	Use the result of step 1, and data points 6 and 4b to obtain C_v and C_d for 1997.

[13] The data presented in this section was obtained from interviews with personnel at a corresponding AT&T POP in early 1997. This information was used to reconstruct capacity growth at the POP for the period 1988-1997. Table 5 also shows their estimates for capacity to be deployed in 1997-1999.

[14] This statement was made by Mr. Frank Ianna, AT&T's Executive VP of Networks and Computing Services, in a meeting with Wall Street analysts on a March 3, 1997. See http://www.att.com/speeches/

[15] The voice capacity quantities for 1994-1996 are obtained by working backwards from the 1996 values. The data capacity quantities for this period are then obtained using data point 5.

[16] Here the 1993 values are obtained iteratively from the 1994 quantities subject to the data point 4a constraint. A convenient tool for this sort of analysis is 'the goal seek' function in Microsoft Excel which is generally used for scenario modeling and 'what-if' analysis.

[17] Verify that the results of this step are consistent with data point 2b (i.e., voice/data ratio in 1988 is close to 90%/10%.)

Equation (1) is used to obtain r_v, r_d, and r_{total} and equation (2) to obtain α.[18] Based on these rates, we can project AT&T's capacity deployment for voice, data, and total capacity. I, therefore, apply the traffic transition model to obtain the desired, t_l, t_c, and t_e quantities. The results of applying the traffic transition model to obtain the relevant quantities for AT&T are plotted in figure 5 and summarized in table 8.[19]
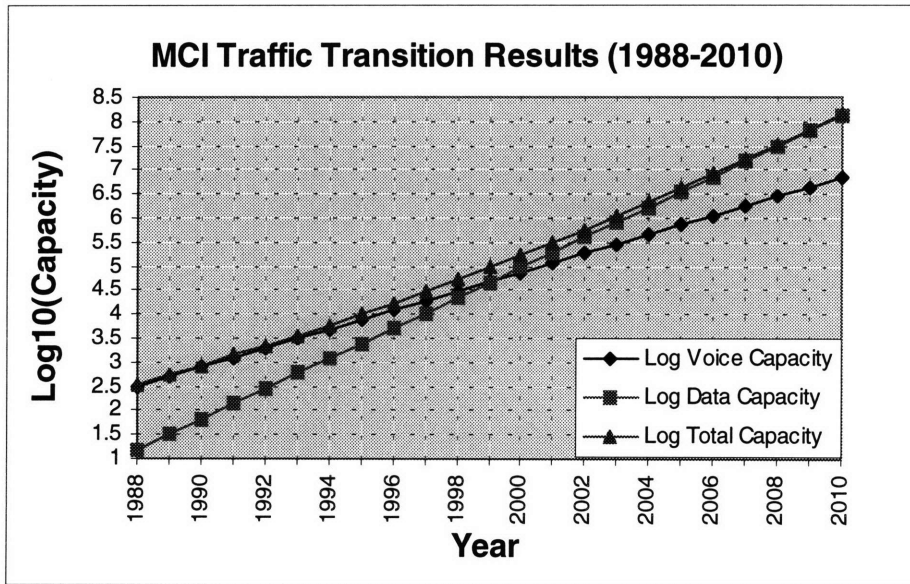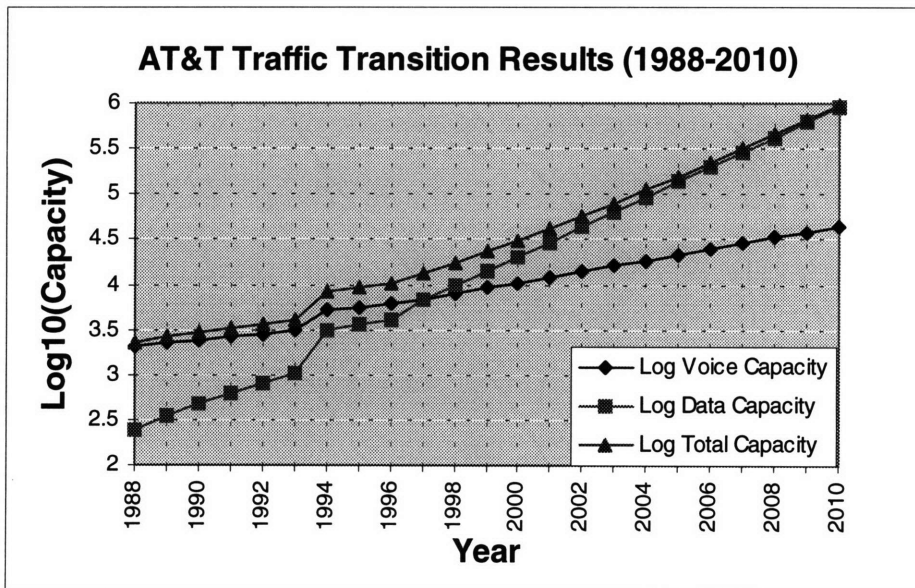

Figure 5: Graph showing AT&T's estimated capacity.

[18] Again, the LOGEST and GROWTH functions in Microsoft Excel were used to interpolate the data and obtain projections respectively. The reader may note that data points 3b and 5 use difference metrics for describing the data growth, leading to a discontinuity in C_d growth between 1993 and 1994. This may have also coincided with the replacement of older 565Mbps equipment by the 1.7 Gbps FT series. Accordingly, in deriving r_d I have fitted a compounded growth curve to the C_d values over the entire period in accordance with the model's constant compounded growth rate assumption.

[19] Note that MCI's value for r_v is larger than AT&T's. This may be attributed to an increase in MCI market share during this period.

Table 7: Table Summarizing Results of five step Spreadsheet Analysis procedure to obtain AT&T capacity values and growth rates.

Year n	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
voice cap. (Gbps)	2.10	2.25	2.44	2.64	2.85	3.08	5.12	5.58	6.12	6.77
data cap. (Gbps)	0.23	0.35	0.48	0.63	0.82	1.05	3.09	3.54	4.08	6.70
Total cap., T(n) (Gbps)	2.33	2.60	2.92	3.27	3.67	4.13	8.21	9.12	10.20	13.47
T(n)-T(n-1)			0.32	0.35	0.40	0.46	4.08	0.91	1.08	3.27
%Newvoice							0.5	0.5	0.5	0.2
%Newdata							0.5	0.5	0.5	0.8
voice fraction	0.90	0.87	0.84	0.81	0.78	0.75	0.62	0.61	0.6	0.50
data fraction	0.10	0.13	0.16	0.19	0.22	0.25	0.38	0.39	0.4	0.50
Checks	90/10								60/40	

Table 8: A table summarizing the quantities of interest for AT&T's case.

t_l	t_c	t_e	t_c-t_l	t_e-t_c	$\alpha(1996)$	r_v	r_d	r_{total}
1988	Apr 1997	2006	9 yrs	9 yrs	1.5	0.16	0.46	0.23

3.1.3 Aggregate Industry Model

Before applying the model and using the results of AT&T and MCI from 2.3.1 and 2.3.2 to obtain industry-wide growth, it is necessary to understand how the market share for both these IXCs has varied over this period. To do this, I use FCC data describing long distance market share for both AT&T and MCI between 1991 and 1996.[20]

Table 9[21]: Prescribed Line Market shares of AT&T and MCI (1990-1996).

Year	1991	1992	1993	1994	1995	1996
ATT	75.0%	73.0%	71.2%	70.0%	66.4%	64%
MCI	13.5%	14.5%	15.3%	14.8%	15.7%	15.6%
Total	88.5%	87.5%	86.5%	84.8%	82.1%	79.6%

Table 9 provides this information and shows that together, these two carriers accounted for about of 85% ($\pm$ 5%) of the total voice market over this period.[22] Given their combined dominance of the market, we should obtain reasonably accurate industry-wide growth rate estimates based on the MCI and AT&T data sets. The aggregate capacities were obtained by fitting a curve through the sum of the derived AT&T quantities of table 7 and the yearly interpolated MCI quantities calculated from table 2.[23] Equation (1) was used to obtain r_v, r_d, and r_{total} and equation (2) used to calculate α.

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[20] Industry-wide data from the FCC is used for this purpose of providing an approximation for the average trends in market share. This data was obtained from the FCC's State link web site found at http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/fcc-link.html.

[21] The FCC defines "Prescribed Lines" as: Lines are prescribed to a carrier that receives a long distance call placed on their line.

[22] Their combined share did decrease by 8.9%, presumably due to losses to second tier carriers. Sprint has consistently held about 6.5% market share over this period.

[23] As in the MCI and AT&T cases, the LOGEST and GROWTH functions were used here.

Table 10 summarizes the quantities of interest for the industry-wide model which are plotted in figure 6.
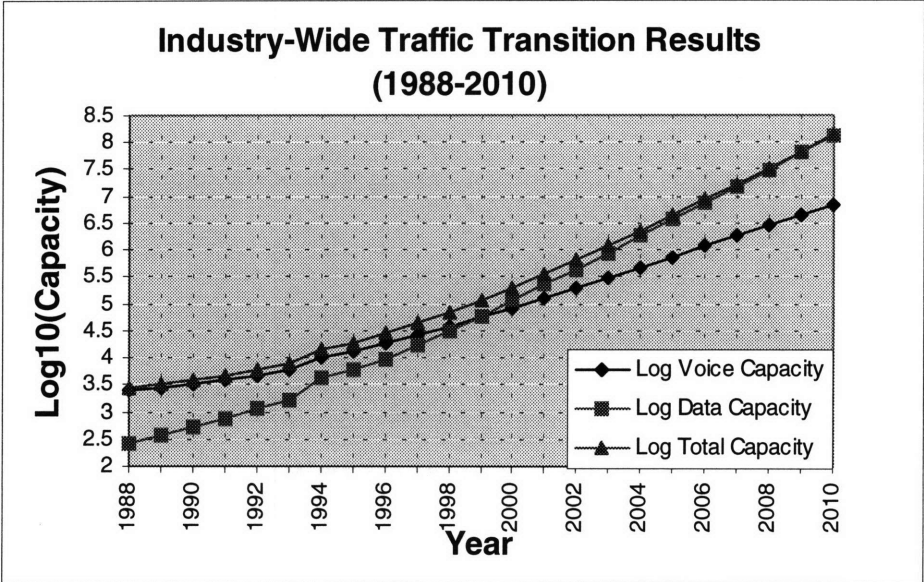
Figure 6: Graph showing Industry-wide estimated capacity.

Table 10: Summary of Industry-wide model results.

t_l	t_c	t_e	t_c-t_l	t_e-t_c	r_v	r_d	α (1996)
1988	Nov 1998	2007	10 years	9 years	0.38	0.69	1.97

3.2 Sensitivity Analysis

The objective of this section is to investigate how the key quantities that I have obtained vary with changes in r_v and r_d. A key outcome of this sensitivity section is that the crossover transition is relatively independent of the precise growth rates (table 11.)

Table 11: Sensitivity analysis results on transition period.

r_v	r_d	t_e-t_{NOW}	t_e-t_l	t_e-t_c
10%	40%	1 yr	10 yrs	9 yrs
10%	100%	-4 yrs	5 yrs	4 yrs
20%	50%	1 yr	10 yrs	10 yrs
20%	90%	-3 yrs	6 yrs	4 yrs
30%	60%	2 yrs	11 yrs	9 yrs
30%	80%	-1 yrs	8 yrs	4 yrs
38%	69%	1 yrs	10 yrs	9 yrs
40%	80%	0 yrs	9 yrs	5 yrs
60%	90%	3 yrs	12 yrs	9 yrs

As will be discussed in Chapter 4, a key determinant of post-industry structure is the transition interval t_e-t_{NOW} i.e., t_e-t_{1997}. Table 11 summarizes the results of a sensitivity analysis performed to assess how this interval changes with changes in the growth rates. Based on this information, I conclude that the transition period occurs relatively fast over a wide range of growth rates.

3.3 Alternate Voice Growth Rate Assumption

It is important to note that the value of r_v from table 10 is much higher than the commonly accepted industry average of 5%-10%. Given that these carriers are serving the same market, this high growth raises several questions about their market's characteristics. Such a high growth rate seems to indicate that there may be an over supply of voice capacity at both these facilities.[24] If there is a high surplus of voice capacity then this would imply that a 'price war' is imminent. Alternatively, this build up

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[24] It is conceivable that the geographic region covered by these POPs is experiencing anomalous growth.

of excess capacity can be used to further stimulate and absorb the growth of data transmission.[25]

Estimates of the traffic transition model's voice growth rate parameter (r_v) can be derived from alternative industry sources. Assuming this new r_v, in this section I investigate how the circuit-to-packet transition differs from section 3.1. This alternative derivation involves the following steps:

1. Derive $r_{v'}$ based on published IXC and RBOC telephone traffic volumes.
2. Project the voice capacity $C_{v'}(t)$ based on this $r_{v'}$.
3. Determine the parameters of interest.

To derive the industry-wide growth rate of voice traffic, data from the Regional Bell Operating Companies (RBOCs) and InterExchange Carriers (IXCs) was used. Table 12 below summarizes the data obtained.

Table 12[26]:Annual rates of Network Traffic Volume Increase for the RBOCs and IXCs.

Company	1991	1992	1993	1994	1995	1996	Traffic Metric
ATT			162945	171907	184800	195888	Billed Minutes
MCI	36567	42735	49452	58233	70095		Overall Network Traffic
USWest	35144	37413	40594	43768	47801		Interstate Access minutes
PacTel	43872	46800	49674	53486	59193		Carrier Access minutes
SBC		41235	44203	48430	53681	58668	Access minutes

A weighted average calculation was performed to obtain a voice traffic growth rate, r_v, of 8.8%.

Using this alternative voice growth rate, two cases were modeled: an "idle voice capacity" scenario and an "accelerated data growth" scenario.

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[25] Especially if Internet "market share" becomes a strategic objective of the IXCs.
[26] This data was obtained from the 1991-1996 annual reports of each of these service providers.

3.3.1 Idle Voice Capacity Scenario

In this scenario, it is assumed that voice capacity is growing at 8.8% and that the "excess" voice capacity reported by AT&T and MCI remains unused. It is also assumed that data capacity is growing at 69%. Based on these assumptions, estimates for the annual values of total capacity were obtained as: $C_{total'}(t) = C_{total}(t) - (C_v(t) - C_{v'}(t))$. Using the resulting total capacities, equation (1) gave an estimate for r_{total} of 0.27. Finally, the traffic transition model was applied using these alternative r_v and r_{total} rates and the 1996 aggregate capacities, as base capacities, to obtain the parameters of interest. The results of this scenario are summarized in table 13.

Table 13:Summary of results for the idle voice scenario.

t_l	t_c	t_e	t_c-t_l	t_e-t_c	r_v	r_d	r_{total}
1988	Sep 1997	2008	9 years	11 years	0.088	0.69	0.27

3.3.2 Accelerated Data Growth Scenario

In this scenario, it was assumed that voice capacity is growing at 8.8% and total capacity growing at 45%. The "excess" voice capacity was apportioned to data capacity yielding an accelerated data growth. Based on this optimistic data assumption, estimates for the annual values of data capacity were obtained as: $C_{data'}(t) = C_{total}(t) - C_{v'}(t)$. Using the resulting data capacities, equation (1) gave an estimate for r_d of 0.98. Again, the traffic transition model was applied using these alternative r_v and r_d rates and the 1996 aggregate capacities as base capacities, to obtain the parameters of interest. The results of this scenario are summarized in table 14.

Table 14:Summary of results for the accelerated data growth scenario.

t_l	t_c	t_e	t_c-t_l	t_e-t_c	r_v	r_d	r_{total}
1988	Feb 1997	2001	9 years	4 years	0.088	0.988	0.45

3.4 Applying the Traffic Transition Model to Estimate Internet Growth

Since the introduction of Internet competition, it has been difficult to determine aggregate Internet backbone traffic levels. In this section, we combine 1993 NSFnet data that put average monthly internet traffic at 7.8 E+13 bytes per year[27] with the growth rates determined in section 2.3 and 2.5 to extrapolate an Internet traffic estimate, $C_{d(1997)}$. The growth of the capacity is projected using the 69% r_d rate determined from the aggregate industry model and the 98% r_d rate calculated for the accelerated data growth assumption. Applying these rates as annual compounded growth rates to the 1993 traffic quantities gives estimates of $C_{d(1997)}$ of 6.4 E+14 bytes per year and 12 E+14 bytes per year respectively.[28]

3.5 Summary

This chapter calibrated and applied the traffic transition model to obtain industry-wide traffic growth trends. It relied upon data from selected MCI and AT&T POPs and a sensitivity analysis was performed on the overall results. It was found that the industry-wide growth rates of voice and data are 38% and 69% respectively giving values for the lead-user, crossover, and eclipse points of 1988, November 1998, and 2007. A sensitivity analysis was performed on these results finding that the crossover interval does not vary significantly over a wide range of values around the precise growth estimates. Assuming that the high growth rate of voice traffic found earlier was higher than widely held, the model was applied to find new estimates for the quantities of interest, using a calculated voice traffic growth of 8.8%. The chapter concluded with applying the model's results to estimate today's Internet traffic level. The following chapter discusses the strategy and policy implications of the analysis.

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[27] This data is available from http://www.merit.edu/.

[28] By comparison, FCC market data placed 1993 and 1994 voice traffic at 6.7 E+14 bytes per year and 7 E+14 bytes per year respectively.

4

Conclusions:

Implications for Industry Structure and

Telecommunications Policy

A key result of this report's model is a characterization of the interval between the lead-user and eclipse points from the traffic perspective. As previously discussed, this interval defines the rate at which the crossover event transpires. In this chapter of the report, I highlight and address some key questions that arise from the results of chapters 3. In section 4.1, I discuss the importance of the crossover interval in determining post crossover industry structure while 4.2 and 4.3 discusses several relevant economic and policy issues that arise from a data dominated communication network; in particular, I address the basic question of the nature and existence of a voice market in the post crossover era. Then I proceed to discuss three important considerations: Internet voice substitution effects, market economics, and universal service. Section 4.4, concludes this section, and the thesis, with a summary of the key findings of this research.

4.1 Industry Structure: Who Will Supply The Switching?

From the analysis presented in section 3.2, we observe that the entire interval t_e-t_c is likely to be about 10 years in length. Closer examination of this interval shows:

1) In the space of a decade or less, the communication network will migrate from a predominantly voice service oriented network to a predominantly data service oriented network.[29]

2) The process accelerates, so progress towards a scenario where voice traffic is only 10% of total traffic, occurs faster once the crossover point is reached.

This rapid change in the network environment influences the market competitiveness of telco players - switch vendors or service providers - directly correlating their competitive position after the crossover to how well they adapt to the rapid change in the network. Therefore, the ability for such a telecommunication market player to compete in the post-crossover industry structure will, arguably, be constrained by a "window of opportunity" described by, $\pi = t_e - t_{NOW}$. The smaller π becomes, the more constraining the window. Following this reasoning, there exists a critical value of π below which it becomes inconsequential for the player to act. The question then becomes what this critical vale of π is. In fact, it may already be too late for "badly" positioned market players to act. The key point here is that the faster π shrinks, the less significant technical or strategic choices become in influencing the final outcome.[30] Therefore, the ability for a market player to compete is constrained by the rate of this transition, as much or more than by any other factors. I now briefly discuss two of these potentially constrained players: the Regional Bell Operating Companies (RBOCs) and TDM switch vendors.

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[29] By dominant I mean contributing 90% or more of the overall back bone traffic.

[30] Three issues which determine the competitiveness of a firm in the marketplace are the strategy, the technology, and the policy (internal and external). See (Bradley, Hausman, and Nolan, 1993) p. 17-22. The ability to gain a reasonable competitive advantage is, however, constrained by a window of opportunity, beyond which it is lost.

Case 1: The RBOCs vs ISPs

Two key roles of the RBOC were defined at divestiture: providing the last mile and central office serving the customer's premise, and providing regional switching and inter-office transmission within a LATA.[31] This discussion focuses on the second function.

As other types of service providers, namely, Internet Service Providers (ISPs), have gradually established themselves as the premier provider of packet switching services within the LATAs, a 'turf war' has developed between them and the RBOCs. While the RBOCs provides access and connectivity between the end customer and the ISP, the ISP serves as an alternative provider of onwards traffic switching and transmission (see figure 7).[32]
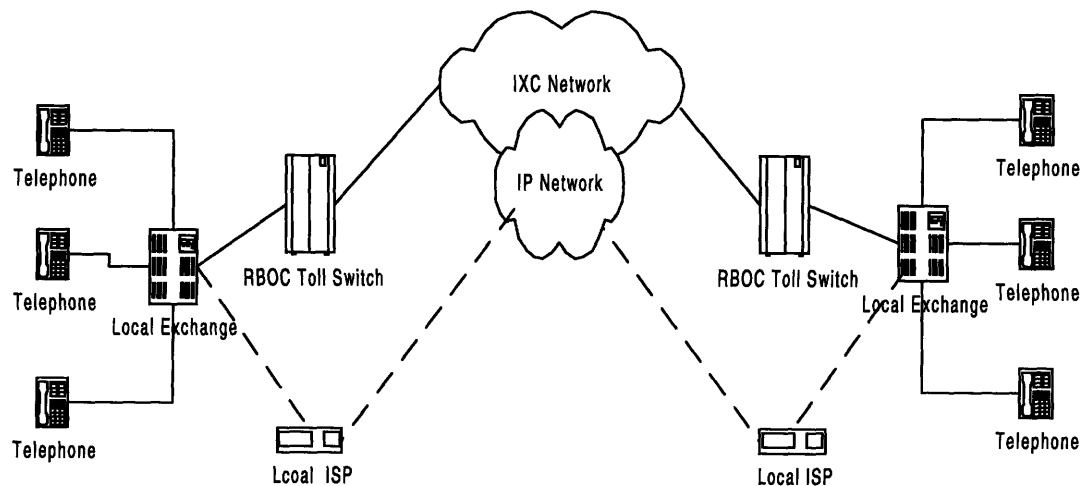

Figure 7: Topological representation of network connectivity.

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[31] A Local Access and Transport Area (LATA) is a geographic market service area served by an RBOC.
[32] The second RBOC role, of providing a two to three tier switching service within and to points outside the LATA, is under threat as both the number of ISPs and the amount of traffic they switch continues to grow.

It is likely that at time t_c, the bulk of the packet-switching "assets" will be in the hands of the Internet Service Providers and that, beyond t_c, ISPs would switch more traffic than RBOCs. Further, the RBOCs are unlikely to ramp up switch installation fast enough to forestall market share erosion by ISPs and will quickly find their switch base eclipsed by that of the ISPs. Finally, once the ISPs are switching 80%-90% of all traffic (t_e), it will be difficult for the RBOCs to displace them from this role. The effect of this will be to "hollow-out" the RBOCs before they can place orders and take delivery of the necessary equipment.[33]

Case 2: Traditional Circuit-Switch Vendors

I have identified "traditional" switch vendors as a second market player whose focus, based on the combination of market segment served and business model used, may lead to sudden demise.[34] The business model used here is based on a stream of regular payments from the customer, as contracts usually spanning a period of several years.[35] Generally, the sale of the switch system is bundled as a total solution that includes installation, network management, switch maintenance, and system integration. These latter services and products serve as a key revenue stream for the vendor and are usually contracted for a period of several years. I observe that beyond t_c, as data begins to becomes the predominant component of traffic, new sales not only drop off quickly, but

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[33] While some may argue that the RBOCs provide the last mile, this is becoming a less important consideration as the local markets continue to open up and bypass technologies such as wireless begin to establish themselves as alternative last mile technologies.

[34] By "traditional" it is meant that the switch is a TDM based legacy switch, largely designed for wireline circuit switching. The key players in this market are Lucent, Northern Telecom (Nortel), Alcatel, Siemens, and NEC. While GDC is a key player in this market too, it primarily serves international markets. Its strategy has been to migrate to providing ATM based WAN and telco solutions. Ericsson which is a leading provider of public network switching, has also carved out a profitable niche in the cellular telephony market - at the beginning of 1997 Ericsson had about 40% of the global market share of mobile telephone systems. Nortel also recently moved aggressively into the wireless arena, and thus far this area alone accounts for between 30% and 40% of it's revenues. However, it is unlikely that all of the existing players can be accommodated in niche markets.

[35] The main advantage for the vendor is that they have effectively achieved customer "tying" due to the length of these contracts- five to ten years. See (Pindyck and Rubinfeld, 1995) p. 392 for a discussion on "tying." Conversely, the economic model for the "non-traditional" switch vendor market is largely based on capacity, therefore, its key advantage is performance in a high growth market The cost recovery model here is a price-discrimination strategy, where the buyer is charged "per module", "per port", etc, based on capacity. Examples of these vendors include Newbridge Networks, Bay Networks, 3Com, and Cabletron.

so does the upgrade and maintenance revenue stream. Moreover, the large labor force that currently captures this down-stream revenue becomes very costly to maintain or even dismantle.[36]

4.2 Industry Structure: Consequences

As we have seen from the model, voice traffic becomes a minority contributor to overall backbone traffic beyond the crossover point. I now consider some economic and policy consequences of this transition.

A separate revenue transition model has been developed and is included in appendix A. This additional model is based on a similar methodology to the traffic transition model and provides further insight into economic issues, in particular it finds that there exists a "lag" between the capacity crossover and the revenue crossover. During this lag, data traffic exceeds voice traffic yet voice revenues are higher than data revenues, further aggravating the likelihood that the RBOCs and traditional switch vendors will act in a decisive and timely manner. Possible reasons for the existence of this lag are given, and it's implications on the post crossover industry structure is discussed.

In addressing industry structure consequences, I first consider how significant the "voice market" will be after the crossover point. The economic definition of a market, as a congregation and interaction of buyers and sellers of a good or service, would suggest that a "voice market" would exist as long as there was demand for voice services. A more difficult notion is ascertaining the relevance of this market relative to the data market.[37] From the traffic transition model, we can deduce that the fraction of resources (capacity) used to effect voice communication, becomes negligible as we move onward from the

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[36] In 1996-97, Nortel, Ericsson, Lucent, and Alcatel each had 68,000, 90,000, 124,000, and 185,000 employees respectively.

[37] From an economics stand point, circuit and packet switching may be treated as two different goods. Hence, I talk about two different markets: the voice market and data market.

crossover point, t_c. Consequently, the marginal cost of providing capacity to carry voice in the overall communication network also becomes negligible.

Based on this argument, I begin an exploration of three important issues that impact telecommunication policy and business strategy: Internet voice substitution effects, market economics, and universal service.

4.2.1 Internet Voice Substitution Effects

The role of substitute technologies, such as Internet telephony, in the post crossover world, is interesting.[38] The plot of figure 6 suggests that the fraction of voice traffic in the network is rapidly diminished, becoming a small part of the overall traffic in a relatively short time. Therefore, contrary to contemporary thinking, packet voice technologies (in and of themselves) cannot "power" the growth of IP or data traffic.[39] Nonetheless, their success may be very significant and very sudden, driven by the arbitrage opportunity they present. As we move away from t_c, it will become increasingly expensive to maintain a resource intensive worldwide circuit switched voice network, whose traffic requirements represents a small fraction of overall capacity - a factor which will become suddenly apparent to service providers and their customers. As t_e approaches, these players will decisively migrate to technologies, such as Internet telephony, so that they may dismantle their circuit switched networks, and rid themselves of the costs these networks represent. Because of migration to one packet-based network, technologies such as Internet voice will be immensely successful. However, I suggest it is the potential for infrastructure sharing, and not bandwidth savings as commonly held, that will drive the growth of these technologies.

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[38] In this context, Internet telephony is defined as the transmission of voice and fax over the Internet.
[39] IP here stands for Internet Protocol. For references on Internet telephony see (Sears, A. L., 1995)

4.2.2 Market Economics: the Voice-Data Bundle

I now consider the dynamics of the post eclipse industry structure. I note that currently, the long distance transmission market is dominated by AT&T, MCI, and Sprint.[40] At the same time, the ISP market is dominated by UUNET, MCI, BBN, and PSI.[41] An economic argument may be made that both these markets are oligopolies and that these firms can exercise their market power by adapting a bundling strategy.[42]

Beyond t_e, since the incremental cost of transporting voice over a packet infrastructure is close to zero, and a customer's demand for data service is more easily stimulated, bundling is a feasible strategy for the service provider. Indeed, the bundling of voice and data goods is practiced today.[43] What is important here is that this bundle may evolve to suit a data-centric market. Whereas, today your long distance carrier may offer you say 5 free hours of Internet access per month if you sign up for their telephone service, after t_e you are likely to get a bundle that includes close to free long distance telephone service if you sign up for a suite of data services.

4.3 Universal Service

Universal service has been a key component of telecommunications policy in the United States since the communications act of 1934. To understand the role of Universal service in the post crossover era, I consider one of the primary ways through which it has been implemented to date: subsidization.

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[40] According to 1996 FCC market share data, these three long distance carriers in total held over 87% market share of prescribed lines.

[41] Over 80% of the ISP market is currently dominated by UUNET, MCI, PSI, AT&T, and BBN. For a discussion of the ISP market see (Meeker, M. and DePuy, C.,1996).

[42] From an economic perspective, bundling is advantageous if a customer's demands for some goods is heterogeneous, and the firm is unable to price discriminate. Considering these goods to be data and voice, the bundling strategy here is applicable.

[43] MCI has recently introduced "MCI one" which is a bundle that consists of cellular, wireline, and pager access. AT&T in its Worldnet™ service offers AT&T telephone customers 5 free hours of online access.

One case where this has been applied with great success is the local access subsidy that long distance carriers pay local telephone companies (RBOCs) to access their subscriber loop.[44] A consideration in setting up such a subsidization policy is the demand for the service. An argument could be made suggesting that because local residential service is priced to support saturated demand, then growth in long distance residential service could subsidize local service. Similarly, in a data-centric market, voice traffic imposes minimal demands on the overall network and could leverage data traffic growth through subsidization. We can make two observations: first, the potential new role of data as a subsidization mechanism for voice: Because of the high growth nature of the data network, it is capable of being an effective subsidization mechanism supplementing and even substituting the present mechanisms; and second, the evolution of the Universal [telephone] service concept to a Universal [data] service concept, ensuring equitable data access and services.

4.4 Summary

In this thesis, a model was presented and used to characterize the circuit-to-packet transition. The overall transition was characterized using three key milestones: the "lead-user" point (t_l), the "crossover" point(t_c), and the "eclipse" point (t_e). Through these points, the model's key outputs were defined and discussed with the most significant result being the time interval between now and the eclipse points, t_e-t_{NOW}. The methodology that was developed focused on obtaining projections based on assumptions about the capacity-traffic interrelation and average compounded capacity growth. As an abstraction it allowed us to ignore the physical topology of the networks being analyzed and focus on the variable of interest i.e., traffic growth.

Using data from MCI and AT&T, the model was used to analyze the growth of these IXCs and to calibrate industry-wide growth. The model's industry-wide results

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[44] The asymmetric pricing in local residential and business telecommunication services has also served as a subsidization mechanism of the former by the latter.

suggest that the times for t_i, t_c, and t_e are 1988, November 1998, and 2007 respectively. A sensitivity analysis was then done on the model to gain an understanding of how the three points mentioned above are affected by growth rate changes. Most importantly, this sensitivity analysis section showed that the t_e-t_{NOW} interval period was not as sensitive to precise growth rates as expected *a priori*, and that it's occurrence is sudden across a range of values.[45]

I have also considered the telecommunication's business and policy implications of the suddenness of the crossover event. I found that the ability for market players to compete in the post crossover industry structure may largely be determined by the rate of the transition rather than by technical, economic, or other external factors. Two cases were discussed to highlight this implication: RBOC vs ISPs, and traditional circuit-switched vendors. I found that the RBOCs will quickly have their switch base eclipsed by that of the ISPs who would be switching over 50% of the traffic at t_c and 80%-90% of all traffic by t_e. Consequently, in a decade the RBOCs will be displaced from their switching role by ISPs. In considering the impact the shift will have on the makeup of tomorrow's switching industry structure, I observed that beyond t_c traditional switch vendors like Lucent and Alcatel may see revenues from new sales, equipment upgrade and maintenance contracts drop off quickly.

The consequences of the resulting industry structure were then discussed for three cases: The substitution effect of packet voice technologies for circuit-switched voice was the first outcome of traffic migration to a predominantly data dominated network. Here, it was found that although the success of packet voice technologies will be very significant and very sudden, they will be driven by the potential for infrastructure sharing, and not bandwidth savings as commonly held; The consequences for the voice-data bundle were also briefly discussed, arguing that the composition of the voice-data bundle is likely to change to reflect overall traffic composition and that because the incremental cost of

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[45] The results obtained are based on data from selected AT&T and MCI POPs and any interpretation of these results needs to take into account that the capacity deployment at these facilities may not be representative of either IXC's network as a whole.

transporting voice over a packet infrastructure will be close to zero after t_e, the bundle will evolve to suit a data-centric market, conceivably incorporating close to free voice service; Finally, the consequences to Universal service were addressed. I suggested that data traffic could be used as a potential subsidization mechanism and that the Universal service concept may evolve to a Universal data policy as data traffic dominates the network.

This thesis has identified several areas for future research. The most immediate are partially developed in the appendix sections; in Appendix A, a Revenue transition model is discussed and developed based on the Traffic Transition Model's methodology. By integrating both these models, it is found that a mismatch exists between both the traffic and revenue crossover events. Further investigation is warranted to understand this phenomena. In Appendix C, I suggest the use of econometric modeling techniques as an alternative methodology to investigate the evolving composition of network traffic. Exploring the circuit-to-packet transition this way could stimulate new insights into the event.

A

A Unified Traffic-Revenue Transition Model

The crossover in network traffic is directly linked to a change in the revenue mix, and therefore, would be accompanied by a similar crossover in service revenues. Another issue worth exploring, then, is the relationship between these transitions. This appendix develops a unified traffic-revenue transition analysis. In the first section, a revenue transition model is developed on the basis of the traffic transition model. In the second section, both models are integrated to present industry-wide results of the unified model. This appendix seeks to provide the framework and examine the key issues in the analysis, presenting the discussion as areas for future research.

A.1 Revenue Transition Model: Formulation and Results

In this section, the methodology in chapter 2 is used to present a revenue transition model. The resulting model is used to characterize the revenue crossover associated with the circuit-to-packet traffic crossover. Later in section A.2, both of these models are used to establish a relationship between the traffic and revenue crossover events. The organization of this section is as follows: In section A.1.1, I present the relevant assumptions and introduce model; and, in A.1.2, I calibrate and develop the model's results. Finally, the revenue model and the traffic model are combined in A.2.

A.1.1 Introduction

The fundamental methodology assumptions stated in Chapter 3.1 still hold in the revenue case i.e.:

- Peak traffic and capacity are used interchangeably.
- Constant and compounded average annual growth rates for voice and data.

Again, I consider that the revenue derived from either service category is an independent function $R_o(1+ i)^\tau$, where R_o is a base revenue and τ is an arbitrary year. Further, I observe that i in this case refers to revenue growth and corresponds to r in the traffic case.[46]

I consider five quantities which correspond to those obtained earlier in the traffic case: the three points e_c (at the crossover point), e_e (at the eclipse point), e_l (at the lead-user point), and the two intervals e_e- e_c and e_c- e_l. These are defined as follows:

1) e_l or the lead-user point: The point at which packet-data revenue constitutes 10% of the total traffic revenues.

2) e_c or the crossover point: The point where both types of service earn the same revenue.

3) e_e or the eclipse point. The point at which packet-data traffic accounts for 90% of the overall traffic revenues.

4) e_c- e_l :The time interval from the lead-user point to the crossover point.

5) e_e- e_c :The time interval from the crossover point to the eclipse point.

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[46] Note, however, unlike in the traffic case where C(t) is monotonically increasing due to an always positive r, R(t) can increase or decrease depending on whether i is positive or negative.

These are plotted in figure A-1 to illustrate the parallel derivation with the traffic transition model of chapter 2.
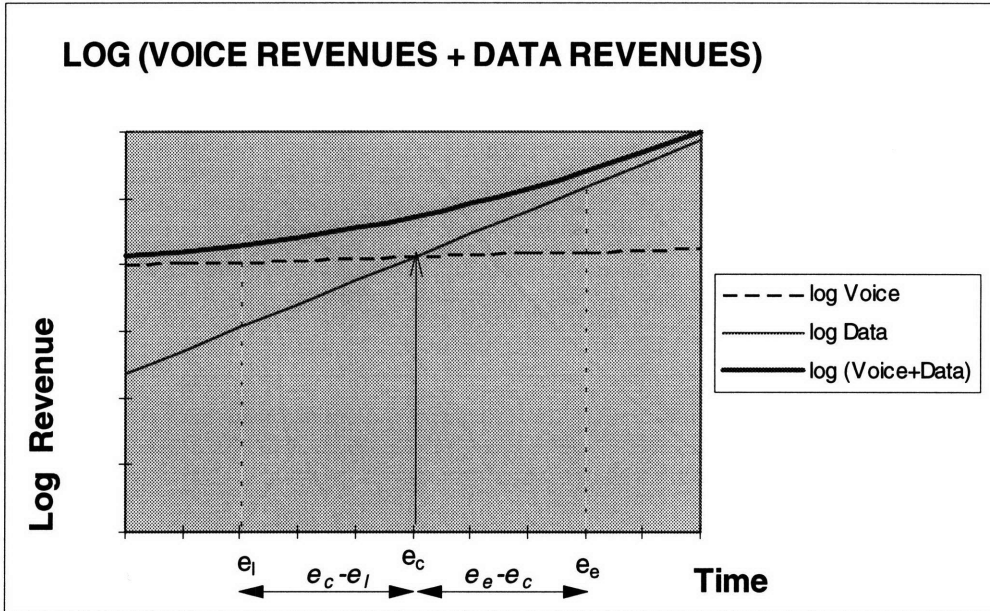

LOG (VOICE REVENUES + DATA REVENUES)

Legend:
- – – – – log Voice
- ———— log Data
- ———— log (Voice+Data)

Y-axis: **Log Revenue**
X-axis: **Time**

X-axis labels: e_l, $e_c - e_l$, e_c, $e_e - e_c$, e_e

Figure A-1: A log(Revenues)-time series plot of the relative growth of voice and data revenues.

Again, the quantities e_l and e_e are arbitrarily chosen at ± 10% from the crossover point. This choice also follows from the report's objective to determine whether a revenue-traffic crossover relationship exists.

A.1.2 Results

I first consider the growth of voice revenues. Figure A-2 presents data obtained from the FCC showing industry-wide voice service revenues growing at an average compounded rate of 2.7%.
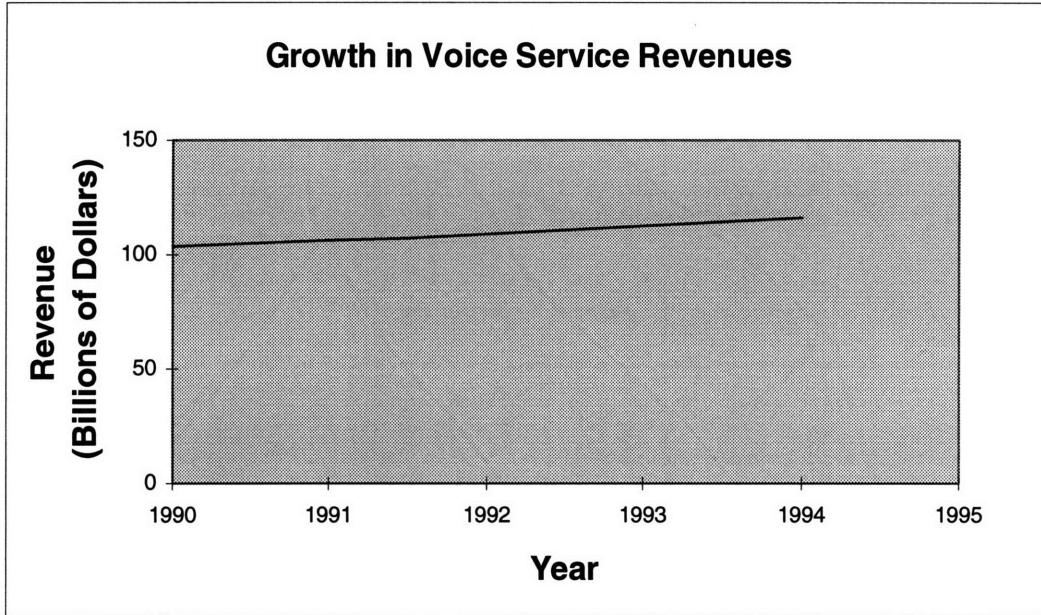
Growth in Voice Service Revenues

Figure A-2[47]: Aggregate Operating Revenues for the Telcos (1990- 1994)

To calibrate the data revenue growth rate, I consider three scenarios based on the data traffic results of chapter 3: annual revenue growth at 35%, 69%, and 98%. It is difficult to assess the specific growth rate of Internet based service revenues, therefore, these rates have been chosen to frame revenue growth in the context of traffic growth. It is expected that the price per bit will be falling each year, meaning that the data revenue growth rates cannot exceed data traffic growth rates. Further, I assume that during the base year, 1993, Internet revenues were about US $33 million.[48] The voice-data revenue graph of figure A-3 shows these three scenarios and the results of the quantities of interest are summarized in table A-1.

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[47] This data is available from http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/fcc-link.html.

[48] I base this figure on the earnings of the US market share leader, UUNET, which in 1993 earned $10 million from Commercial Internet services and accounted for approximately 30% of this market's revenues.

Table A-1: A summary of the quantities of interest for three data revenue growth scenarios.

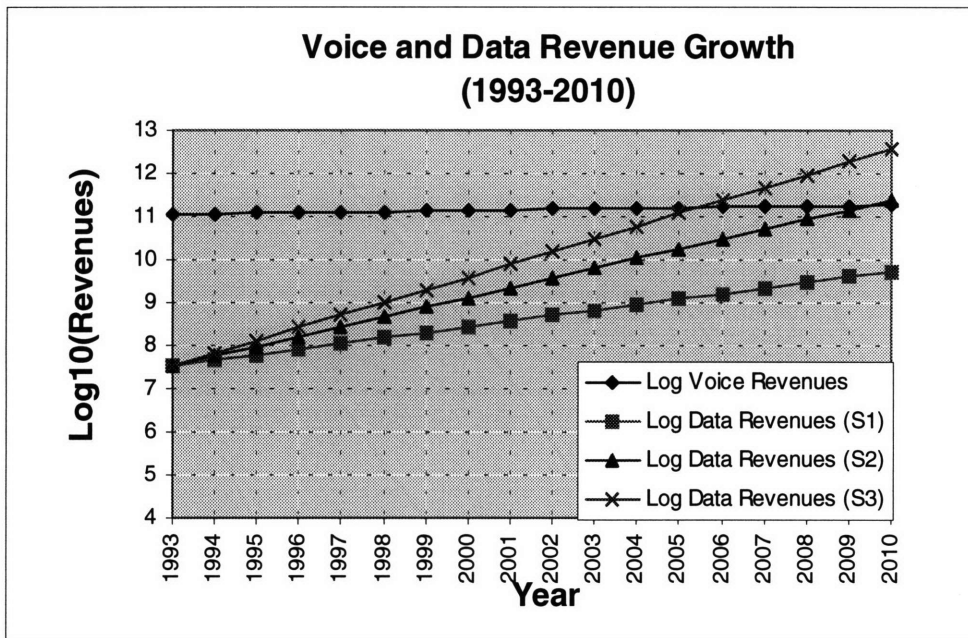|	i_v	i_d	e_l	e_c	e_e	e_c-e_l	e_e-e_c
Scenario 1 (S1)	0.03	0.35	2015	2022	2029	7 yrs	7 yrs
Scenario 2 (S2)	0.03	0.69	2005	2009	2013	4 yrs	4 yrs
Scenario 3 (S3)	0.03	0.98	2002	2005	2008	3 yrs	3 yrs

Figure A-3: A graph showing the relative growth of voice and data revenues.

A.2 Integrating the Traffic and Revenue Transition Models

In this section, I integrate the traffic model results developed in section 3.1.3 and the revenue model results developed in A.1.2. The objective is to investigate the relationship between the crossover quantities defined for traffic and their counterpart revenue quantities. In the characterization section the relationship between traffic and revenues is established. The discussion section briefly introduces some policy issues based on this characterization.

A.2.1 Model Characterization

To investigate the specific nature of this relationship, the time scales for both graphs are synchronized and the plots superimposed. The result is shown in figure A-4.[49] Observe that, while one expects an overlap in the crossover points, this is not the case. Some possible reasons for this are explored in the discussion section. Here, the lag between t_c and e_c is identified with the results for each scenario summarized in table A-2.
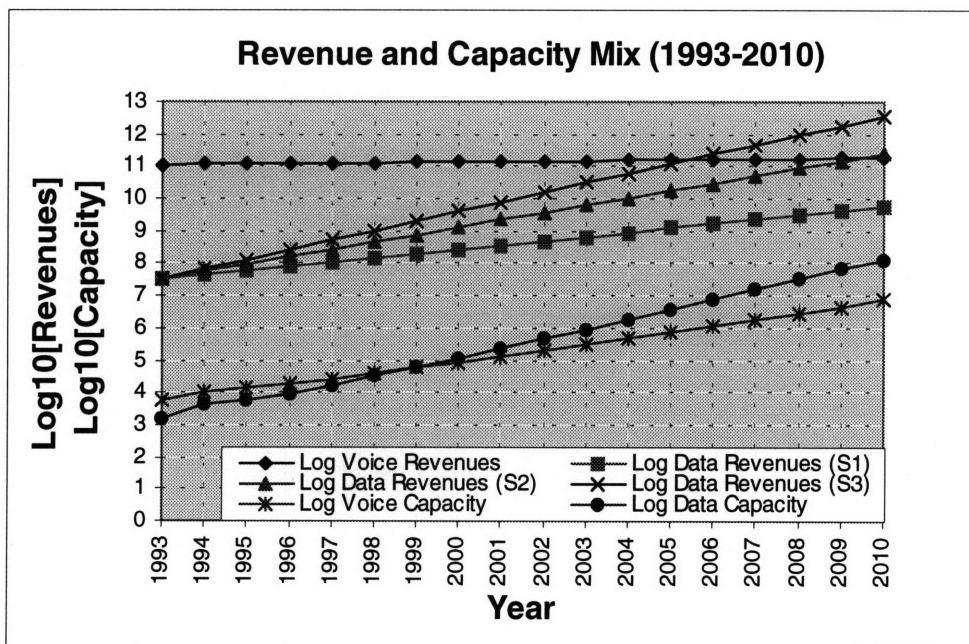

Figure A-4: Integrating the Traffic and Revenue Models

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[49] The reader may note that the 1993 estimates for data and voice revenues differ by a factor of 1000. Because the data revenues are derived from the Internet revenue projection based on UUNET

Table A-2: Comparing the crossover mismatch between network traffic and revenue mix.

	i_v	i_d	r_v	r_d	t_c-e_c
Scenario 1	0.03	0.35	0.38	0.69	7 yrs
Scenario 2	0.03	0.69	0.38	0.69	11 yrs
Scenario 3	0.03	0.98	0.38	0.69	24 yrs

A.2.2 Discussion

This section focuses on addressing the mismatch between the revenues and traffic crossover by considering reasons why this mismatch exists.

Observe from table A-4 that the t_c-e_c lag is at least 7 years in length, assuming that annual data revenues are growing as high as annual data traffic at 98%, and increases for lower revenue growth rates. This crossover mismatch may be attributable to the following:

1. The difference in the base year (1993) revenue points. In this analysis, it has been assumed that the 1993 data revenue figures were approximately US $33 Million. This estimate, which is based on industry wide Internet revenue projections, may be low, because at this time the commercial Internet market was at it's early stages. This artifact of the graph may exaggerate the length of the crossover mismatch.

2. Because the cost per unit of traffic is falling annually, it should be expected that the revenue curves are going to be shallower than the traffic curves. Therefore, mathematically the crossover points should not coincide, with the lag interval primarily determined by the base year revenue per unit traffic quantities and respective growth rates.

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earnings when the commercial Internet market was in it's infancy, the data revenue figure for 1993 may be understated.

3. Capacity upgrades are done in quantum units. Capacity is a "lumpy" quantity and increases cannot be performed incrementally. However, revenues do increase incrementally with usage based service pricing. This difference in the size of "increase steps" for capacity and revenues contributes to the lag.

4. While both revenue curves are shallower than their respective traffic curves, the revenue per unit capacity is lower for data.[50] The reason for this difference is due to the economics in both these industries - the long distance voice market must be *less* competitive than the data market for this to occur.[51] As the network transitions to a data-centric model (t_c to t_e), the pricing and cost structures are more likely to be driven by the increasingly more dominant data industry model.[52]

In conclusion, the lag is relevant in analyzing the relationship between capacity and revenue for both voice and data, and is insightful because it provides an understanding into the economics of capacity and those of revenue. Further, it highlights the differences between the economics of both the voice and data industries. In the overall crossover question, this mismatch's significance increases because it aggravates the possibility that constrained market players will act with decisiveness, and in time.

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[50] Although there is a difference in the robustness of service and interconnect charges.

[51] (Mackie-Mason and Varian, 1995) suggests that that the cost of packet switching has been falling at 30% per year since the mid 1980s.

[52] This assumes that a "unit" of data traffic is interchangeable with a "unit" of voice traffic.

B

Telecommunications Traffic

The inherent differences in voice and data traffic add a significant level of complexity to managing the circuit-to-packet transition. In this chapter, I present a synopsis of three important issues that provide a framework for a rational approach to understanding the traffic transition problem from a technology perspective. For both the voice and data cases, sections B.1 and B.2 examine traffic growth from a historical perspective, the characteristics of the traffic type, and practical forecasting techniques used in both networks. The objective here is to raise awareness of the technical issues particular to telecommunications traffic, rather than develop a detailed technical discussion. (Pecar, 1993), (Farr, 1988), (Labetoulle and Roberts ed., 1994), (Bertsekas and Gallager, 1992), and (Comer, 1995) provide a thorough coverage of pertinent technical topics. Section B.3 then compares the trend in network growth between the PSTN and the Internet. In this latter section of the appendix, the goal is to put the traffic growth problem into perspective by contrasting growth trends in network access terminals.

B.1 Voice Traffic

The anatomy of a voice call may be broken down into three stages: call set-up, the call itself, and call tear-down. This duration of this entire process is referred to as the call holding time. The statistical average of this length has been determined to be three

minutes.[53] When the parties are communicating, a permanent 64 Kbps full duplex channel is reserved for their session. Ordinarily, because of silence and one party speaking at a time, the bandwidth of the channel is utilized only 50% to 60% of the time. In Chapter 3 of this thesis, the volume of telephone traffic was calculated to be growing at 8.8%. Figure B-1 shows the historical growth of telephone instruments in the US.

Voice traffic is simply an aggregation of statistically similar voice calls. From that perspective, engineering for its growth is conventionally done by considering historical records. Where none of these are available, e.g., in the case of a new network, estimates may be used from similar markets.
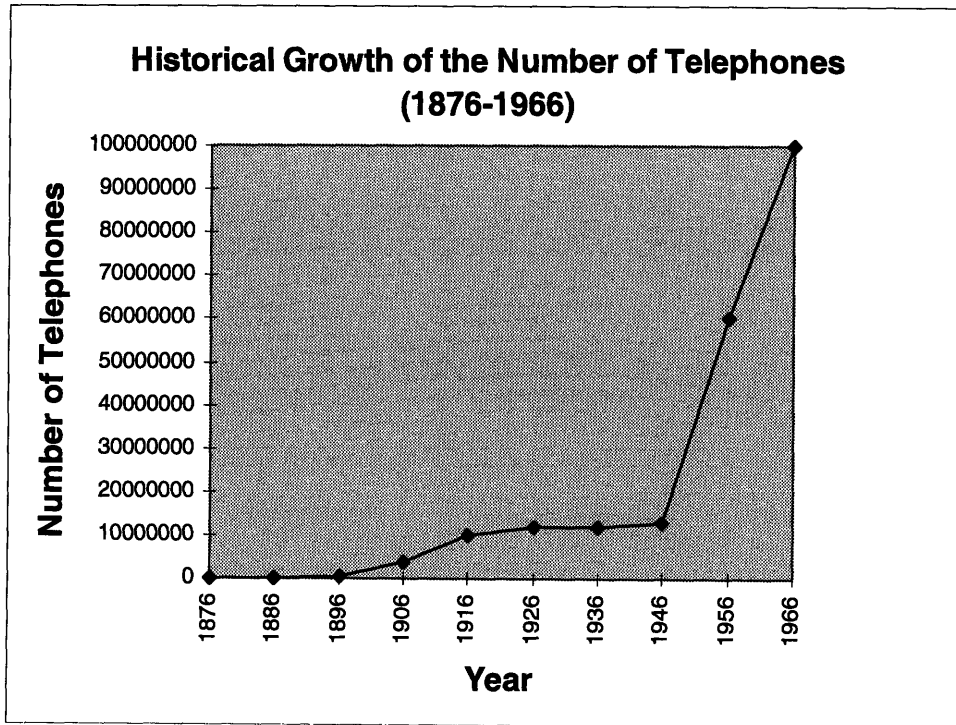

Figure B-1: The historical growth of the number of telephones. (Source: Hough, 1970)

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[53] This is derived from telephony's so called "3-3-3" rule i.e., the average voice call lasts three minutes, the user makes an average of three call attempts during a peak busy hour, and the call travels bidirectionally

B.1.1 Nature of Voice Traffic

Telephone traffic (and demand) varies on a temporal basis: by time of day and day of the week. The concepts of peak busy hour or peak busy day are used in voice traffic engineering to determine the number of circuits (i.e., the capacity) required to meet user demand. A busy hour call attempt (BHCA) rate is used to determine the loading on the circuits. Figure B-2 shows the typical daily pattern of voice traffic in the Public Switched Telephone Network (PSTN). The capacity deployed is, therefore, statistically based on historical trends of peak loads. To minimize excess capacity, tariffs are used to ensure that the network is effectively utilized even during off peak periods.
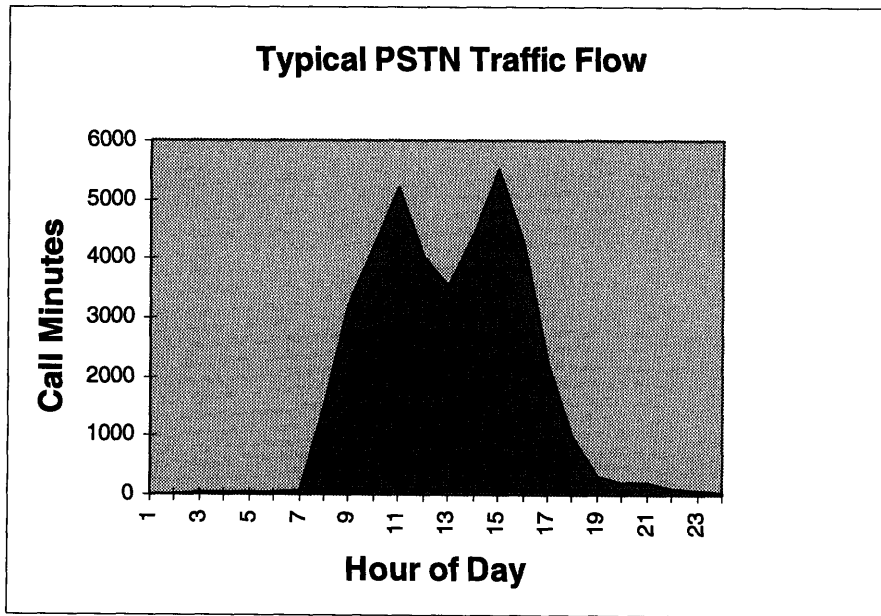

Figure B-2: Pattern Distribution of typical daily traffic flow in the PSTN. (Source: Pecar et al, 1993)

B.1.2 Forecasting Voice Traffic Growth

Voice traffic forecasting for a Central Office (CO) is based on a series of statistical measurements of various network parameters:

over a 3Khz channel

51

- The Busy-Hour Call Attempt (BHCA) rate.

- Average call holding times for all traffic routes connected to the CO.

- Daily Peak busy hour per traffic route.

- The number and type of users.

The standard industry practice is to forecast requirements out one year ahead, however, since additional equipment may need to be installed, longer forecasts are often used at the CO level.

B.2 Data Traffic

To examine data traffic I now consider one of its key constituents - the Internet. The Internet, generally described as a network of networks, is a public packet-data network that may be contrasted against a public circuit-switched voice network. Its origin is the ARPAnet which was established as a research network in 1969. This network evolved into the NSFnet in the mid 1980s becoming fully commercialized in the mid 1990s. Figure B-3 shows how the number of host computers connected to the Internet has increased as it's backbone capacity has increased from 56 Kbps in the early 1970s to a relatively high speed 622 Mbps backbone today.[54]

Data network traffic is packet based and each session is connectionless, with each packet individually routed at a network node. When two parties are communicating, individual packets from the same session are routed independently, with the complete message being reassembled at the receiver. Generally, each packet transmitted instantaneously occupies the channel's entire bandwidth, which is statistically shared among various sessions. In Chapter 3 of this thesis, data traffic was found to be growing at annual compounded growth estimate of 69%. This rapid growth followed the Internet's commercialization. Figure B-3 shows this aggressive growth from 1981 to 1995.[55]

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[54] This is NSF net data obtained from http://www.merit.edu/nsfnet/statistics/
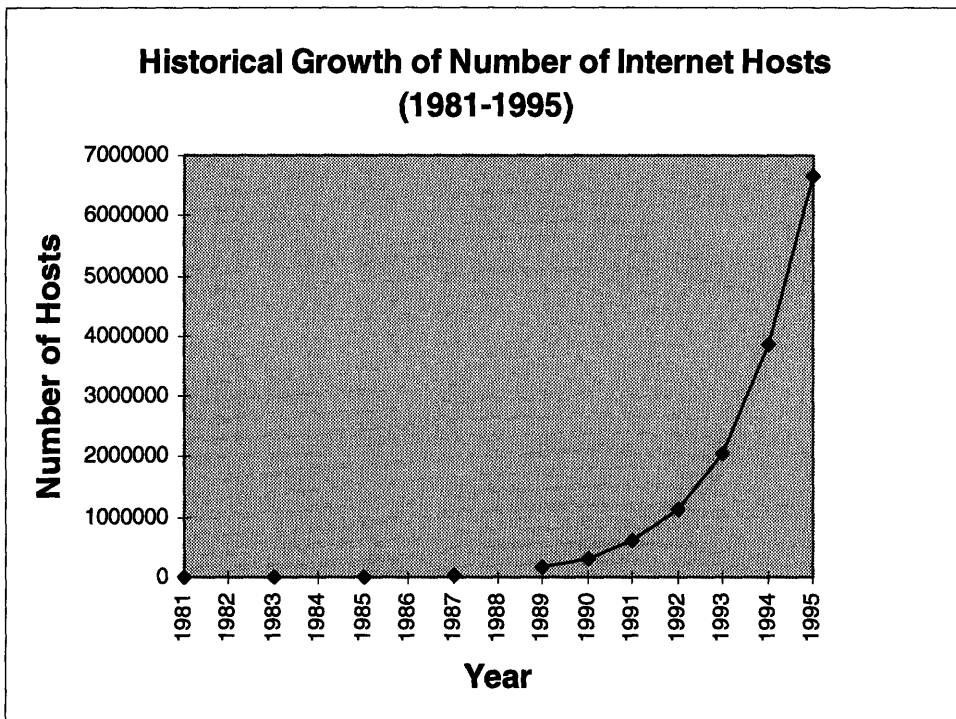
Figure B-3: The historical growth of the number of Internet hosts.

B.2.1 Nature of Data Traffic

Data traffic is inherently bursty i.e., unlike voice traffic, it exhibits large fluctuations in it's use of network resources, exhibiting unpredictable. Figure B-4 shows the typical pattern of packet-data traffic on the Internet. The concepts of packet handling time and throughput in packet-data traffic engineering are important in determining the number of circuits (i.e., the capacity) required to meet user demand.

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[55] This data was obtained from http://www.merit.edu/nsfnet/statistics/

Typical Pattern of Packet-Data Traffic
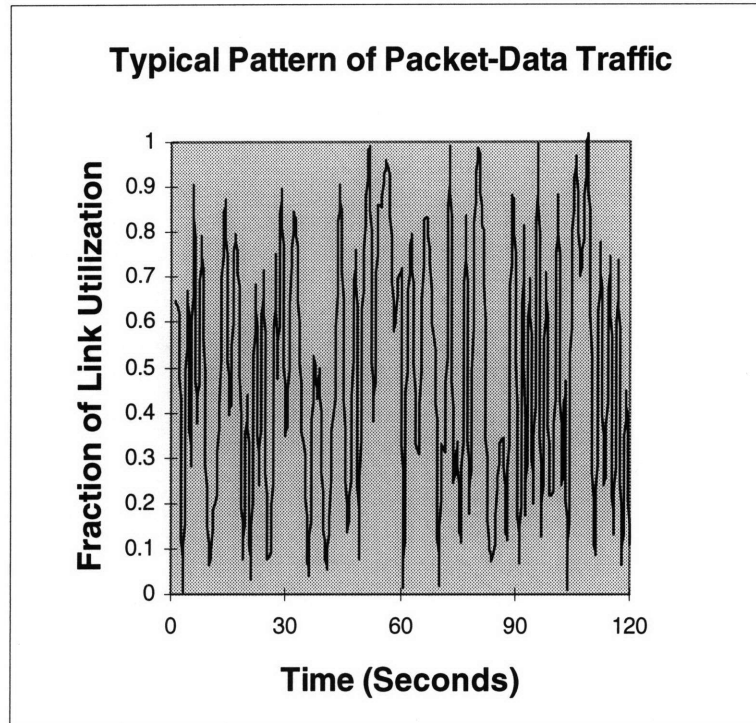
Figure B-4: Graph illustrating the bursty nature of packet-data traffic
(Source: Mackie-Mason and Varian, 1995)

B.2.2 Forecasting Data Traffic Growth

Data traffic forecasting, much like voice traffic forecasting has largely been based on historical trend analysis. The process in this case involves a comparison between measured packet handling times and a target handling time. However, because the packets can take multiple routes between the same origin-destination pair of nodes, it becomes far more difficult to forecast demand growth on individual routes than in the voice traffic case. Moreover, in a fast evolving network or in a new network, sample statistics will be atypical because of the packet nature of the traffic.

B.3 Comparing Trends in Voice and Data communications

Based on the growth metrics in B-1 and B-2, I contrast the evolution in both the voice and data networks by considering the average annual growth of PSTN network

access terminals (telephones) and Internet network access terminals (hosts).[56] Figure B-5 illustrates this comparison.[57] The growth rate of network access devices for the Internet has been at least double that of the telephone at every stage of the technologies' growth. This important observation demonstrates that the volume of data traffic such a rapidly growing installed base of users can generate will soon surpass that of the voice network.[58]
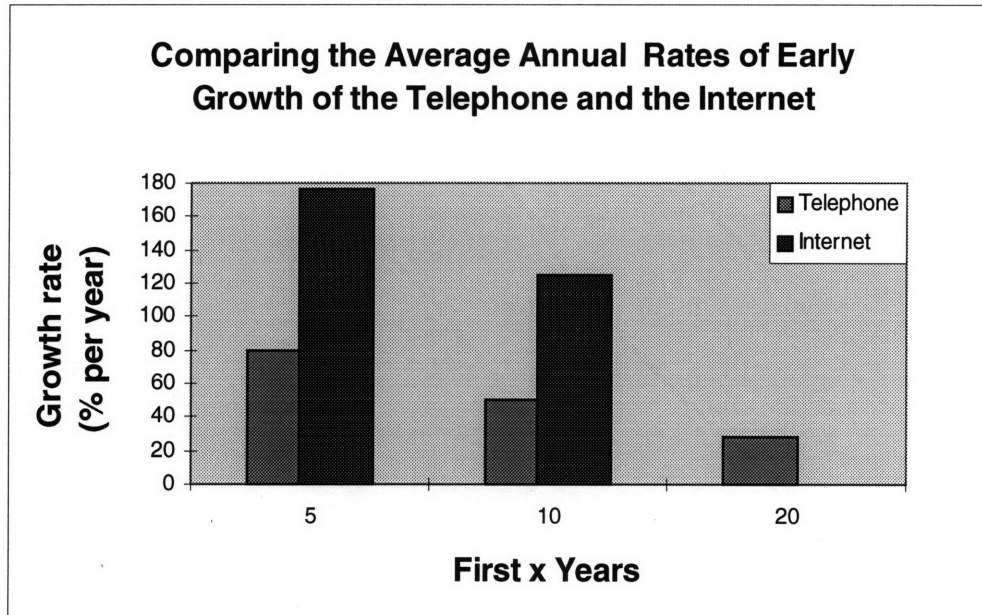

Figure B-5: Early Growth rate trends of terminals for telephone network and Internet access.

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[56] Strictly speaking Internet access terminals includes both clients and servers (hosts.) This comparison is therefore a lower bound on the diffusion of network access terminals between the two networks.

[57] This chart was derived from figures B-1 and B-3. It is assumed that the base year for telephones is 1876 while that for the Internet is 1981.

[58] Consider that the PSTN generates a volume of traffic that is proportional to the product of the average call holding time and the 64 Kbps channel capacity of a call. Contrast this to the Internet case, where the traffic volume is not subject to a 64 Kbps bandwidth cap and sessions last longer than the 3 minute average on the PSTN. Moreover, the data type transmitted in the packet network can range from video to ASCII text.

C

Economics of diffusion in Telecommunications Networks

The circuit-to-packet transition can be alternatively modeled as a saturation process. This is because modeling the demand of a resource, such as capacity, is fundamentally a saturation process problem. Moreover, the growth of both data and voice networks can be examined from the perspective of the economics of packet and circuit switching respectively. This appendix provides a survey of how such modeling may be done. This is an extensive subject and therefore no attempt is made to develop a detailed analysis. Rather, this section focuses on developing a framework for this alternative by examining the relevant demand driven economic issues that influence the diffusion of telecommunications in the marketplace, and that could be adapted in analyzing the circuit-to-packet crossover. The background section provides a brief introduction to demand modeling while the model section considers a possible methodology that may be used. The theory of both telecommunication network diffusion and demand modeling presented here draws on (Antonelli, 1989), (Bain, 1964), and (Chow, 1957.)

C.1 Background

A telephone or a computer may be considered a durable good whose diffusion in the marketplace can be modeled. By extension, the telecommunication service and hence traffic tied to these goods, i.e., voice and data, can also be modeled. Capacity growth can, therefore, be modeled using any one of a variety of economic demand modeling techniques.

Demand for telecommunication services and networks is subject to learning processes and externalities. Learning processes are present when a new good is introduced and when the learning duration, hence the speed of its adoption, depends on the good's characteristics. Externalities are present when the utility of a good depends upon the number of users. Telecommunication networks are subject to both positive externalities (i.e., band wagon effects) and negative externalities (i.e. snob effects.)[59] Capacity is a good that is subject to network externalities and its demand, and hence growth rate is also driven by these externalities. If we assume that voice and data capacity are goods subject to both learning and externalities, then the growth of these goods, can be modeled by growth curves.

With this assumption, the existing "stock" of bandwidth users of either good at time τ may be defined by a saturation curve.[60] The maximum stock possible is defined as the saturation level s, however, because it is dependent on the number of people, demographic, technological innovations, and economic factors, this saturation level is never fixed to one particular value. Rather, it changes slowly but monotonically with time reflecting effects from the above mentioned factors. Revenues, R, are proportional to an increase in existing stock and to any replacement stock, falling off as the saturation level is approached where they tend towards a steady state "replacement" level $\rho*s$. We, therefore, expect that:

1) The rate of change of stock is positively correlated to the existing stock i.e., it exhibits a bandwagon effect.

2) As the saturation level is approached, the rate of change of stock should go to zero.

3) Rate of sales/revenues, $q(t)=dy/dt+\rho y(t)$

---

[59] For example, the value derived by an individual from using e-mail or a telephone, increases with the number of people accessible by either one of these technologies- this is a positive externality. On the other hand, if the demands on the network are higher than it was designed for, then problems such as congestion arise and constitute a negative externality.

[60] The term 'stock' refers to the amount or quantity of a good in the market. See (Bain, 1964)p.9

Then forecasting the growth in capacity and revenues becomes a classical dynamic adjustment stock modeling problem, provided (1) and (2) above are true. Two widely used models for this purpose are the Gompertz curve and the Logistic curves. In this analysis the Gompertz curve is used.[61]
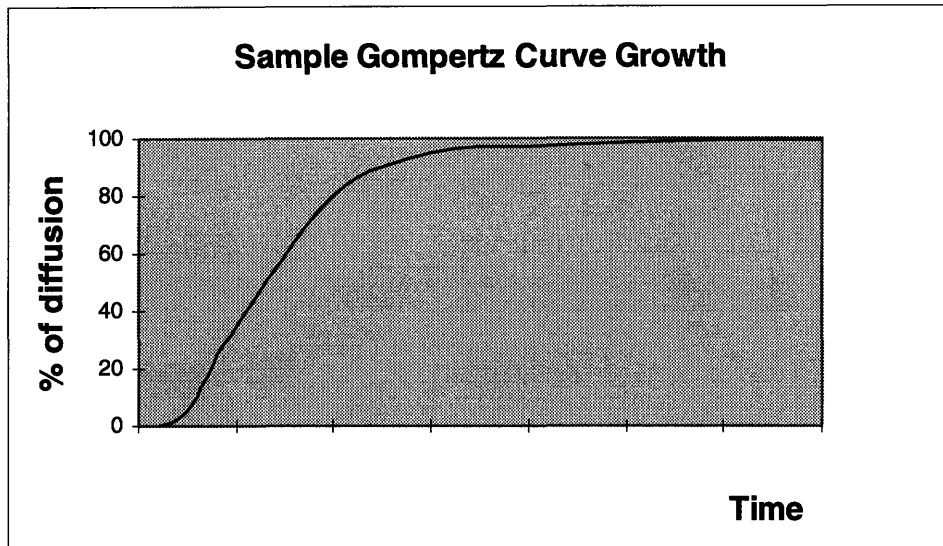

Figure C-1: Shape of Gompertz curve for determining capacity growth

C.2 The Model

Consider the case of two goods, "data" and "voice". We can define the stocks for both these goods to be y_d and y_v respectively, the saturation levels s_d and s_v, and revenues as R_d and R_v. Then to characterize the dynamics of growth or demand, we may use the Gompertz curve to describe the growth and revenue behavior in both goods as a function of time.

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[61] Both of these curves can be used. They each have limitations that affects their applicability in a particular model. See (Bain, 1964) and (Chow, 1957) for examples and instances where each one is applied.
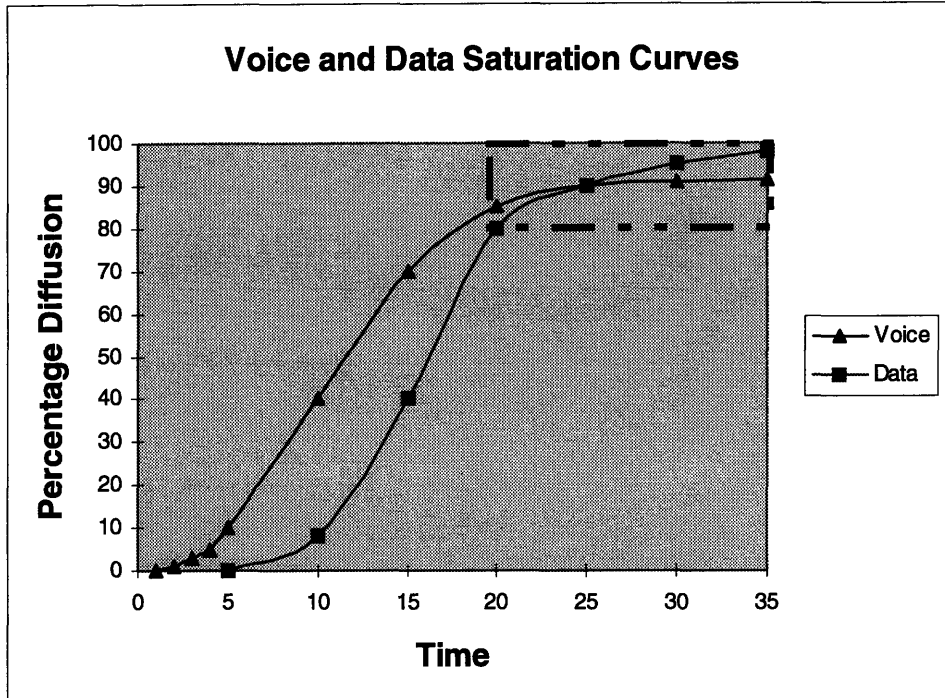
Voice and Data Saturation Curves

Percentage Diffusion

100
90
80
70
60
50
40
30
20
10
0

0   5   10   15   20   25   30   35

— Voice
— Data

Time

Figure C-2: The Gompertz curves for two "goods": voice and data

Now, we focus our attention and the subsequent analysis on the boxed area in the figure above. From the voice curve, I note that we could approximate annual compounded growth by a rate r_v, and from the data curve, we can also approximate annual compounded growth by r_d.[62]

The capacity required to support either "good" can be determined by the Gompertz equation, $\partial x/\partial t = \beta x(\log s - \log x)$ where x is the level of capacity demand at time t, β measures the speed of the process, and s is the saturation capacity level. Based on this equation, the plots of data and voice capacities can be obtained as was done in Chapter 2, and a parallel analysis to that in Chapter 3 can be developed.

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[62] These should be obtained by curve-fitting.

D

Switch Vendor Data

In this appendix, I present data from switch vendors that illustrates the rapid growth of data switching equipment.[63] I first consider the growth in the installed base of packet-switched data equipment for the same period that I did for 1993-1996. In table D-1, I show the growth of the installed based of General Datacomm industries' (GDC) ATM WAN equipment. The average value of GDC's 'r_d' is found to be about 3.6.

Table D-1: Growth in GDC's installed base of ATM switches.

Year	1993	1994	1995
Installed Capacity (Mbps)	13145.5	45619.14	273128.5

Table D-2 presents FORE's 1993-1996 growth in the installed base of ATM ports.[64] Based on this data, the average value of r_d for FORE is about 3.7.

Table D-2: Growth in Fore's installed base of ATM Ports

Year	1993	1994	1995	1996
Installed Base (ATM Ports)	612	3790	20172	64721

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[63] The data presented in Tables D-1 and D-2 was obtained through interviews with key GDC and Fore personnel. GDC is a worldwide provider of ATM switches to carriers and service providers. According to International Data Corporation, GDC had 24.4% of the worldwide market for ATM enterprise switches in 1996. Fore Systems is a leading provider of various ATM switch solutions: LAN, Workgroup, and WAN.

[64] Although Fore provides various ATM solutions, the increase in port deployment closely follows their WAN product trends, notably their backbone ATM switches currently account for close to 90% of their switch sales.

In table D-3, I present Newbridge Networks' revenues attributed to WAN packet switches. As can be seen from the table, this revenue growth corresponds to an i_d of 1.

Table D-3[65]: Newbridge Networks' revenues on WAN packet switches (1994-1997)

Year	1994	1995	1996	7
Internet Revenues ($ Millions)	41.5	167	195	334

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[65] This data was obtained from a report published on May 23, 1996 by *Needham & Company*, an industry research and analysis firm.

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