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**NANCY B. WHITE**
Assistant General Counsel - Florida

BellSouth Telecommunications, Inc.
150 South Monroe Street
Room 400
Tallahassee, Florida 32301
(305) 347-5558

August 3, 1998

Mrs. Blanca S. Bayó
Director, Division of Records and Reporting
Florida Public Service Commission
2540 Shumard Oak Boulevard
Tallahassee, FL 32399-0850

**Re: Docket No. 980696-TP (HB4785) Universal Service**

Dear Ms. Bayó:

Enclosed is an original and fifteen copies of BellSouth Telecommunications, Inc.'s Direct Testimony of Dr. Randall S. Billingsley, Dr. Robert M. Bowman, D. Daonne Caldwell, G. David Cunningham, Dr. Keven Duffy-Deno and Petor F. Martin, which we ask that you file in the captioned matter.

A copy of this letter is enclosed. Please mark it to indicate that the original was filed and return the copy to me. Copies have been served to the parties shown on the attached Certificate of Service.

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Sincerely,

Nancy B. White

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cc: All parties of record
A. M. Lombardo
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William J. Ellenberg II

Billingsley
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**CERTIFICATE OF SERVICE**
**DOCKET NO. 980696-TP (HB4785)**

I HEREBY CERTIFY that a true and correct copy of the foregoing was served via Federal Express this 3rd day of August, 1998 to the following:

**Jack Shreve, Esquire**
**Charles Beck, Esquire**
Office of Public Counsel
c/o The Florida Legislature
111 W. Madison Street, Rm. 812
Tallahassee, Florida 32399-1400
Tel. No. (850) 488-9330
Fax. No. (850) 488-4491

**Michael Gross, Esquire**
Assistant Attorney General
Office of the Attorney General
PL-0 1 The Capitol
Tallahassee, Florida 32399-1050
Tel. No. (850) 414-3300
Fax. No. (850) 488-6589

**Tracy Hatch, Esquire** (+)
AT&T
101 N. Monroe Street, Suite 700
Tallahassee, Florida 32301
Tel. No. (850) 425-6364
Fax. No. (850) 425-6361

**Richard D. Melson, Esquire**
Hopping, Green, Sams & Smith, P.A.
123 South Calhoun Street
Tallahassee, Florida 32314
Tel. No. (850) 425-2313
Fax. No. (850) 224-8551
Atty. for MCI

**Thomas K. Bond**
MCI Metro Access Transmission Services, Inc.
780 Johnson Ferry Road
Suite 700
Atlanta, GA 30342
Tel. No. (404) 267-6315
Fax. No. (404) 267-5992

**Robert M. Post, Jr.**
ITS
16001 S.W. Market Street
Indiantown, FL 34956
Tel. No. (561) 597-3113
Fax. No. (561) 597-2115

**Charles Rehwinkel**
Sprint-Florida, Inc.
1313 Blair Stone Road,
MC FLTHOO 107
Tallahassee, Florida 32301
Tel. No. (850) 847-0244
Fax. No. (850) 878-0777

**Carolyn Marek**
VP Regulatory Affairs
S.E. Region
Time Warner Comm.
2828 Old Hickory Boulevard
Apt. 713
Nashville, TN 37221
Tel. No. (615) 673-1191
Fax. No. (615) 673-1192

**Norman H. Horton, Jr., Esquire**
Messer, Caparello & Self P. A.
215 South Monroe Street
Suite 701
Tallahassee, Florida 32301
Tel. No. (850) 222-0720
Fax. No. (850) 224-4359
Represents e.spire™

**David B. Erwin, Esquire**
Attorney-at-Law
127 Riversink Road
Crawfordville, Florida 32327
Tel. No. (850) 926-9331
Fax. No. (850) 926-8448
Represents GTC, Frontier, ITS and TDS

**Floyd R. Self, Esquire**
Messer, Caparello & Self, P.A.
215 South Monroe Street
Suite 701
Tallahassee, FL 32301
Tel. No. (850) 222-0720
Fax. No. (850) 224-4359
Represents WorldCom

**Patrick Wiggins, Esquire**
**Donna L. Canzano, Esquire** (+)
Wiggins & Villacorta
2145 Delta Blvd.
Suite 200
Tallahassee, Florida 32302
Tel. No. (850) 385-6007
Fax. No. (850) 385-6008

**Kimberly Caswell, Esquire**
GTE Florida Incorporated
201 North Franklin Street
16th Floor
Tampa, Florida 33602
Tel. No. (813) 483-2617
Fax. No. (813) 204-8870

**Jeffry J. Wahlen, Esquire**
Ausley & McMullen
227 South Calhoun Street
Tallahassee, Florida 32301
Tel. No. (850) 425-5471 or 5487
Fax. No. (850) 222-7560
Represents ALLTEL, NEFTC, and Vista-United

**Tom McCabe**
TDS Telecom
107 West Franklin Street
Quincy, FL 32351
Tel. No. (850) 875-5207
Fax. No. (850) 875-5225

**Peter M. Dunbar, Esquire**
**Barbara D. Auger, Esquire**
Pennington, Moore, Wilkinson, & Dunbar, P. A.
215 South Monroe Street
2nd Floor
Tallahassee, Florida 32301
Tel. No. (850) 222-3533
Fax. No. (850) 222-2126

**Brian Sulmonetti**
WorldCom, Inc.
1515 South Federal Highway
Suite 400
Boca Raton, FL 33432
Tel. No. (561) 750-2940
Fax. No. (561) 750-2629

**Kelly Goodnight**
Frontier Communications
180 South Clinton Avenue
Rochester, New York 14646
Tel. No. (716) 777-7793
Fax. No. (716) 325-1355

**Laura Gallagher** (+)
VP-Regulatory Affairs
Florida Cable Telecommunications Association, Inc.
310 N. Monroe Street
Tallahassee, Florida 32301
Tel. No. (850) 681-1990
Fax. No. (850) 681-9676

**Mark Ellmer**
GTC Inc.
502 Fifth Street
Port St. Joe, Florida 32456
Tel. No. (850) 229-7235
Fax. No. (850) 229-8689

**Steven Brown**
Intermedia Communications, Inc.
3625 Queen Palm Drive
Tampa, Florida 33619-1309
Tel. No. (813) 829-0011
Fax. No. (813) 829-4923

**Harriet Eudy**
ALLTEL Florida, Inc.
206 White Avenue
Live Oak, Florida 32060
Tel. No. (904) 364-2517
Fax. No. (904) 364-2474

**Lynne G. Brewer**
Northeast Florida Telephone Co.
130 North 4th Street
Macclenny, Florida 32063
Tel. No. (904) 259-0639
Fax. No. (904) 259-7722

**James C. Falvey, Esquire**
e.spire™ Comm. Inc.
133 National Business Pkwy.
Suite 200
Annapolic Junction, MD 20701
Tel. No. (301) 361-4298
Fax. No. (301) 361-4277

**Lynn B. Hall**
Vista-United Telecomm.
3100 Bonnet Creek Road
Lake Buena Vista, FL 32830
Tel. No. (407) 827-2210
Fax. No. (407) 827-2424

**William Cox**
Staff Counsel
Florida Public Svc. Comm.
2540 Shumard Oak Blvd.
Tallahassee, FL 32399-0850
Tel. No. (850) 413-6204
Fax. No. (850) 413-6250

**Suzanne F. Summerlin, Esq.**
1311-B Paul Russell Road
Suite 201
Tallahassee, FL 32301
Tel. No. (850) 656-2288
Fax. No. (850) 656-5589

Nancy B. White
Nancy B. White (PW)

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# DIRECT TESTIMONY OF DR. ROBERT M. BOWMAN
## ON BEHALF OF BELLSOUTH TELECOMMUNICATIONS, INC.
## BEFORE THE FLORIDA PUBLIC SERVICE COMMISSION
## DOCKET NO. 980696-TP
## AUGUST 3, 1998

## INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Robert M. Bowman. My address is 10655 West Rowland Avenue, Littleton, Colorado, 80127. I am an independent telecommunications consultant.

Q. PLEASE DESCRIBE YOUR WORK EXPERIENCE AND EDUCATIONAL BACKGROUND.

A. My work experience includes testifying in many proceedings involving incremental costs over the past eighteen years, primarily as an employee of U S WEST Communications. Exhibit RMB-1 describes my background and experience in detail.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. I am testifying on behalf of BellSouth Telecommunications, Inc. (hereinafter "BellSouth"). The purpose of my testimony is to respond to the second issue specified by the Florida Public Service Commission regarding "the appropriate cost proxy model to determine the total forward-looking cost of providing local telecommunications service pursuant to Section 364.025(4)(b). I explain, from an engineering perspective, why the Benchmark Cost Proxy Model, Version 3.1 ("BCPM 3.1"), is the appropriate model for the Florida Public Service Commission to rely upon in estimating the costs of universal service for BellSouth's territory in Florida. I discuss how BCPM 3.1 is a superior cost proxy model because it designs a forward-looking network that efficiently provides universal service. This includes designing a network that has the ability to provide customers in rural and other high cost areas the capability to access advanced services comparable to that provided in urban areas as required by the Telecommunications Act of 1996 ("the Act"). I also explain how BCPM 3.1 integrates its customer location methodology with its network design to ensure that engineering design and constraints reflect the underlying customer location data.

Dr. Kevin Duffy-Deno's direct testimony, on behalf of BellSouth, focuses on BCPM 3.1's customer location methodology and explains why BCPM 3.1 locates customers as precisely as possible, given data that is currently, publicly available.

## II. BCPM 3.1 MODELS AN EFFICIENT, FORWARD-LOOKING NETWORK, BASED ON SOUND ENGINEERING PRINCIPLES

Q. ARE THERE ANY PROVISIONS IN THE ACT THAT HAVE IMPORTANT IMPLICATIONS FOR A COST PROXY MODEL'S NETWORK DESIGN?

A. Yes. Principles (2) and (3) in Section 254 of the Act have significant implications for the technical requirements with which the network complies. Principle (2) customer data within the Census Block based on the proportion of the road network within a Census Block that traverses a microgrid. Dr. Duffy-Deno describes this process in greater detail in his direct testimony.

It is at this point in the modeling process that engineering design plays a role. The microgrids and their underlying customer data are aggregated into larger grids, referred to as "ultimate grids," based on engineering constraints. These engineering constraints conform to the specifications of a forward-looking, efficient network design. That efficient network is based on the designation of a Carrier Serving Area. A Carrier Serving Area is a standard telephone design concept that consists of a geographic area that can be served by a single digital loop carrier (DLC) site. Each ultimate grid corresponds to a Carrier Serving Area. The physical size of the Carrier Serving Area varies, depending on the underlying microgrids' customer location data. Thus, the wire center is composed of these ultimate grids that vary in size based on the engineering constraints of the Carrier Serving Area.

Q. WHAT SIZE GRIDS DOES THE BCPM 3.1 USE?

A. BCPM 3.1 constrains the size of the ultimate grids to be no larger than approximately 12,000 feet by 14,000 feet. The rationale for this constraint on the ultimate grid size is to limit copper loop lengths from the DLC to the farthest customer to approximately 12,000 feet.

Q. IS THIS A LEAST COST NETWORK?

A. This network design is consistent with BellSouth's engineering practices in

Florida. Furthermore, this is a least-cost network design, as opposed to a model that designs grids 18,000 feet by 18,000 feet in size. This is supported by two sets of model runs provided to the FCC by the BCPM model sponsors on December 11, 1997 for the five states specified by the FCC (Florida, Maryland, Georgia, Missouri, and Montana). The first run models 12,000-foot grids, and the second run models 18,000-foot grids. The results for the five states indicate that the 12,000-foot grids result in a lower per-line loop cost than the 18,000-foot grids.

Modeling considerably larger 18,000-foot grids requires the inclusion of an extended range line card that increases the costs considerably. It also requires a larger cable size, i.e., 24 gauge, rather than 26 gauge which also costs more. The extended range line card and the large cable size are necessary to provide basic telephony service, as well as to ensure comparable access to advanced services in rural and urban areas, as specified in principles (2) and (3) of the Act, when using 18,000-foot grids.

BCPM 3.1 uses 24 gauge cable only when the copper loop from the DLC to the furthest customer exceeds 11,100 feet. This distance is based on complying with engineering standards for the maximum dB loss permissible to maintain adequate service quality. An extended range line card is included for loops that extend beyond 13,600 feet from the DLC to the customer. This also is an engineering standard, but is a user adjustable input in the model.

Q. PLEASE ELABORATE ON THE IMPORTANT CHARACTERISTICS OF CARRIER SERVING AREAS.

A. Telephone plant engineers do not typically build plant on a customer-by-customer basis. Rather, they plan and build plant based on Carrier Serving Areas and Distribution Areas. A Carrier Serving Area typically contains no more than 1,000 living units, while a Distribution Area typically contains 200 to 600 living units. A Carrier Serving Area is composed of one or more Distribution Areas. In addition, the Carrier Serving Area is constrained in both the number of lines it can serve, and the length of copper loops from the DLC site. Thus, engineers recognize customer locations and natural clusters of customers when implementing standard engineering practices that try to maximize the efficient use of plant and ensure adequate service quality.

Exhibit RMB- 2 provides an illustration of a Carrier Serving Area as modeled by BCPM 3.1 in a rural area and an urban area. Note how the ultimate grid diminishes in size in more densely populated areas.

Q. WHAT CHALLENGES DO COST PROXY MODEL DEVELOPERS FACE WHEN DESIGNING ENGINEERING AREAS?

A. One of the major challenges of building a proxy model for universal service funding is reflecting customer locations in a way that integrates engineering practices based on this Carrier Serving Area and Distribution Area approach. BCPM 3.1 effectively integrates its customer location algorithm and engineering design by: 1) adhering to the Carrier Serving Area specifications described previously and 2) designing a network to serve customers based on the most precise depiction of customer locations. BCPM 3.1 designs a network the way actual telephone companies design networks.

Q. FOR PURPOSES OF ESTIMATING UNIVERSAL SERVICE COSTS, WHICH GEOGRAPHIC AREAS ARE PARTICULARLY IMPORTANT?

A. For purposes of estimating universal service costs, it is particularly important for a cost proxy model to provide reasonable and accurate cost estimates in the less densely populated areas, i.e. rural areas, that may need universal service support. Costs of serving customers increase significantly with the distance the customer is from the wire center and the lower density of rural customers.

Q. HOW DOES BCPM 3.1 REFLECT ENGINEERING DESIGN RULES IN ITS CALCULATIONS?

A. BCPM 3.1 reflects standard engineering guidelines as presented in AT&T's Outside Plant Engineering Handbook (August 1994). These or similar guidelines are used by every major telephone company. BCPM 3.1 designs loops to reflect standard transmission guidelines. Ultimate grids are designed such that copper distances beyond the DLC site are generally less than 12,000 feet. The copper/fiber breakpoint in feeder design is user-defined.

Also, BCPM 3.1 includes all components of the loop that are necessary for the safety of subscribers and their property. The engineering design standards embodied in BCPM 3.1 ensure that the subscribers' premises will not be damaged or destroyed because of insufficient electrical protection or missing anchors and guys.

Q. DO YOU HAVE AN ATTACHMENT TO YOUR TESTIMONY THAT

DISCUSSES EFFICIENT NETWORK DESIGN AND ENGINEERING STANDARDS?

A. Yes. Exhibit RMB-3, attached to my direct testimony, contains a section of the December 11, 1997, filing by the Joint Sponsors of the BCPM before the FCC. This section of the filing is entitled, "BCPM3 Designs the Most Efficient Proxy Network." This filing details how BCPM utilizes efficient design and engineering standards.

## II. MAJOR COMPONENTS OF THE LOOP NETWORK

Q. WHAT IS THE MOST SIGNIFICANT COMPONENT OF THE COST OF UNIVERSAL SERVICE?

A. The great majority of the costs of universal service are the costs of constructing the loop network. The loop network consists of the facilities from the central office switching center to the customer's premises.

Q. WHAT ARE THE MAJOR COMPONENTS OF THE LOOP NETWORK?

A. The loop includes feeder cable, distribution cable, Feeder Distribution Interfaces ("FDIs"), distribution terminals, drop wire and a Network Interface Device ("NID") at the customer's premises.

Q. WHAT IS THE NETWORK INTERFACE DEVICE?

A. In the residential environment, the loop network typically includes the facilities on the outside wall of the home known as the NID. For an apartment or a business location, the network interface is known as a protected terminal. In either case, the inside wire or cables are typically connected to the protected terminal or NID.

Q. WHAT IS THE DISTINCTION BETWEEN THE FEEDER AND DISTRIBUTION COMPONENTS OF THE LOOP NETWORK?

A. The facilities between the switching center and the terminal at the customer's premises are typically divided into feeder and distribution cable plant. Feeder facilities are the facilities between the switching center and the FDI. An FDI is generally the demarcation point between feeder and distribution facilities.

Distribution facilities begin at the FDI and end at the NID or at a building terminal. A distribution terminal or drop terminal is used to terminate drop wire and connect the drop wire to the distribution cable. Drop wire connects the distribution cable to the NID located at the customer's premises. Exhibit RMB-4 depicts the loop network currently used in the industry and its components.

Q. HOW DOES BCPM 3.1 DESIGN FEEDER ROUTES?

A. Each feeder route is designed from the serving wire center out to the most distant ultimate grid. A feeder route may include only copper cables, only fiber cables, or both copper and fiber cables depending upon the demand within each ultimate grid and the total loop distance to service it. The feeder cable ends in a feeder distribution interface where the feeder cable cross-connects the distribution cable.

Beyond 10,000 feet, each main feeder path is redirected towards the population centroid of BCPM 3.1, or is split into two paths, each directed toward the relevant population centroid. The resulting feeder distance is then compared to the feeder distance that would occur with a system of a main feeder that continues in a straight line with subfeeder running at right angles. The feeder approach that yields the shortest feeder design, and hence, lowest cost design, is used by the Model. This more readily reflects the feeder design that is actually used in real networks. This technique is superior to the assumption of a single straight feeder with subfeeder emanating at right angles.

Q. HOW ARE CARRIER SERVING AREAS REPRESENTED IN BCPM 3.1?

A. Each ultimate grid is designed to serve as a Carrier Serving Area. Within that Carrier Serving Area, a digital loop carrier is established at the road centroid , i.e. weighted average of the road coordinates, of the ultimate grid. Consequently, the ultimate grid not only reflects customer location, it reflects a natural network design area.

Q. HOW DOES BCPM 3.1 MODEL DISTRIBUTION FACILITIES?

A. With the exception of the most densely populated ultimate grid, four Distribution Quadrants are established within each ultimate grid from the road centroid of that grid (which corresponds to the DLC site). For each Distribution Quadrant, the area within 500 feet of the roads in the Distribution Quadrant is calculated. A Distribution Area is configured as a square whose area is equal to the area calculated as described above. The Distribution Area is centered about the road centroid of the Distribution Quadrant. A feeder distribution interface is placed at the center of the Distribution Area for those Distribution Quadrants with sufficient line demand. From the road centroid of the Distribution Quadrant (the FDI location), copper cables emanate in a tree and branch architecture running from the FDI to a terminal. In the case of service provided to a single family home, the terminal connects to the customer premises via drop wire, where it terminates at a network interface device. In the case of a multi-tenant building larger than a threeplex, a building terminal is used. Thus, BCPM 3.1 designs a network to reach all housing units and business from each serving wire center. BCPM 3.1 incorporates opportunities to share structure by multiple subfeeder routes. It also permits sharing of the FDI by Distribution Quadrants, and co-location of the FDI with the DLC, depending on line demand. These features reflect an efficient network design.

As a reasonableness check on cable requirements, the Model constrains the total cable length in the Distribution Quadrant area (including backbone, branch, vertical and horizontal connecting cables) to not exceed the length of the road network in that Distribution Quadrant.

Q. WHAT IS THE RESULT OF INCORPORATING THESE COMPONENTS OF THE LOOP NETWORK IN A COST MODEL?

A. The result is a model that includes all the loop cost elements necessarily incurred in providing subscribers with the capability of placing and receiving telephone calls.

## III. SWITCHING, TRANSPORT AND SIGNALING COSTS IN BCPM 3.1

Q. HOW DO YOU DEFINE THE TERMS SWITCHING, TRANSPORT AND

SIGNALING?

A. Switching is the process of opening and closing lines or circuits to connect end points carrying telephony transmission. This function is typically done by a device in a telephone company central office. Transport is the media over which transmission is carried. Signaling monitors the status of a line or circuit, alerts the arrival of a message, or transmits routing and designation signals over the network to set up calls between central offices.

Q. HOW DOES BCPM 3.1 TREAT THE DESIGN AND COSTING OF SWITCHING, TRANSPORT AND SIGNALING?

A. BCPM 3.1 designs a modern network of digital host, remote and stand-alone switches based on the actual in-place network. DMS-100 and 5ESS switches are used in the design process with the user having the option to specify a switch vendor. BCPM 3.1 also includes a new switching cost option for small switches. The interoffice network uses commercially available SONET ring sizes and develops costs for a Signaling System 7 (SS7) network that meets the actual traffic demands of the in-place network. These rings are self-healing and provide the network redundancy requirement by the FCC's September 3, 1997, guidelines on Switching, Interoffice Trunking, Signaling, and Local Tandem Investment.

After designing the network, the Model determines the portion that is applicable to the provisioning of basic service and computes the per line cost of that portion. As an example, after designing the switch network, the Model uses engineering determined partitioning algorithms derived from the Audited LEC Switching Models (ALSMs) to determine the realistic portion of each switch attributable to universal service.

More detailed information can be found in the BCPM 3.1 Model Methodology document, Chapters Seven (Switching), Eight (Transport) and Nine (Signaling), attached to Ms. Daonne Caldwell's testimony.

## IV. SUMMARY

Q. PLEASE SUMMARIZE YOUR TESTIMONY.

A. BCPM 3.1 is a superior cost proxy model because it integrates a forward-looking network design that efficiently provides universal service to areas that reflect actual customer locations as precisely as possible. Moreover, BCPM 3.1 efficiently designs a network with the capability to provide those customers in rural and other high cost areas of Florida access to advanced services comparable to that provided in urban areas. For these reasons, I highly recommend that the Florida Public Service Commission adopt BCPM 3.1 as the cost proxy model for determining universal service support for BellSouth in Florida.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes it does.

Robert M. Bowman
10655 West Rowland Avenue
Littleton, Colorado 80127
Home 303-979-5430, Work 303-896-1335

Education

I hold a Bachelor of Electrical Engineering degree, a Master of Electrical Engineering degree, and a Doctor of Philosophy in Electrical Engineering degree, all from the University of Virginia in Charlottesville, Virginia. My area of research was pattern recognition. I am a member of Eta Kappa Nu honorary engineering fraternity and Sigma Xi honorary scientific society. I have attended advanced seminars in economics and pricing at Stanford University, the University of Arizona, and New Mexico State University.

Experience

I was employed by Bell Telephone Laboratories in Holmdel, New Jersey for five years, where I worked on various projects related to engineering economic analysis and operations analysis of telephone products and services.

I was a member of the Economics Analysis Division of Mountain Bell in Denver, Colorado, for seven years, where I performed cost studies and pricing analyses of telephone terminal equipment.

I was District Staff Manager for Rates and Forecasts in Cheyenne, Wyoming, for seven years. I represented the company on tariff related matters before the Wyoming Public Service Commission, and testified on pricing, tariffs, and embedded and incremental costs. I was also responsible for local and administrative forecasting of telephone services and revenues in Wyoming for four of those years.

At divestiture, I was Director of Access Pricing for Mountain Bell in Denver, Colorado. I was responsible for the pricing and regulatory support, including testimony, of switched and special access services for the seven Mountain Bell states as well as for the federal tariff.

For the past eleven years, I have held various director positions in costs, economic analysis, and planning for U S WEST Communications in the Marketing Services area. I managed the development of incremental cost models for switching, access lines, and transmission services, incremental cost factor and cost study methods, market analysis, and competitive analysis. During this period, I represented and/or testified for U S WEST on costing issues in various regulatory proceedings and workshops before state commissions in Wyoming, Oregon, Washington, Montana, North Dakota, Colorado, New Mexico, and Arizona.

During the past three years, about 30 per cent of my time has been spent representing TeleWest (a cable/telephone new entrant in the United Kingdom) in industry Incremental Cost Working Groups before the Office of Telecommunications (OFTEL), the British regulator. I developed the original incremental network and exchange access cost models, which were modified by industry consensus and used in setting interconnect rates for BT in the United Kingdom. I also assist TeleWest on pricing and marketing issues on an ongoing basis.

Recent Papers/Presentations

Invited Presenter, National Regulatory Research Institute, " Workshop on Telephone Cost of Service," Denver, Colorado, August 1-5, 1988. Subjects: Elements of the Telephone Network, Uniform System of Accounts, and Selecting Functional Cost Categories.

Invited Presenter, Joint Bellcore/Bell Canada "Conference on Telecommunications Costing in a Dynamic Environment," San Diego, California, April, 1989. Papers:

"An Incremental Cash Flow Approach to Long Run Cost Analysis," by Richard W. Foster and Robert M. Bowman.

"Issues in Developing Switching Unit Investment Costs," by Richard W. Foster and Robert M. Bowman.

Invited Presenter, National Regulatory Research Institute, "Symposium on Marginal Cost Techniques for Telephone Services," Columbus, Ohio, and Seattle, Washington, Summer, 1990. Subject: "U S WEST's Switching Cost Models."

Invited Presenter, National Association of Regulatory Utility Commissioners (NARUC), "Biennial Symposium on Regulatory Issues," Columbus, Ohio, 1994. Subject: "Building Block Costs: The Oregon Experience" (with Marc Hellman, Oregon Public Utility Commission).

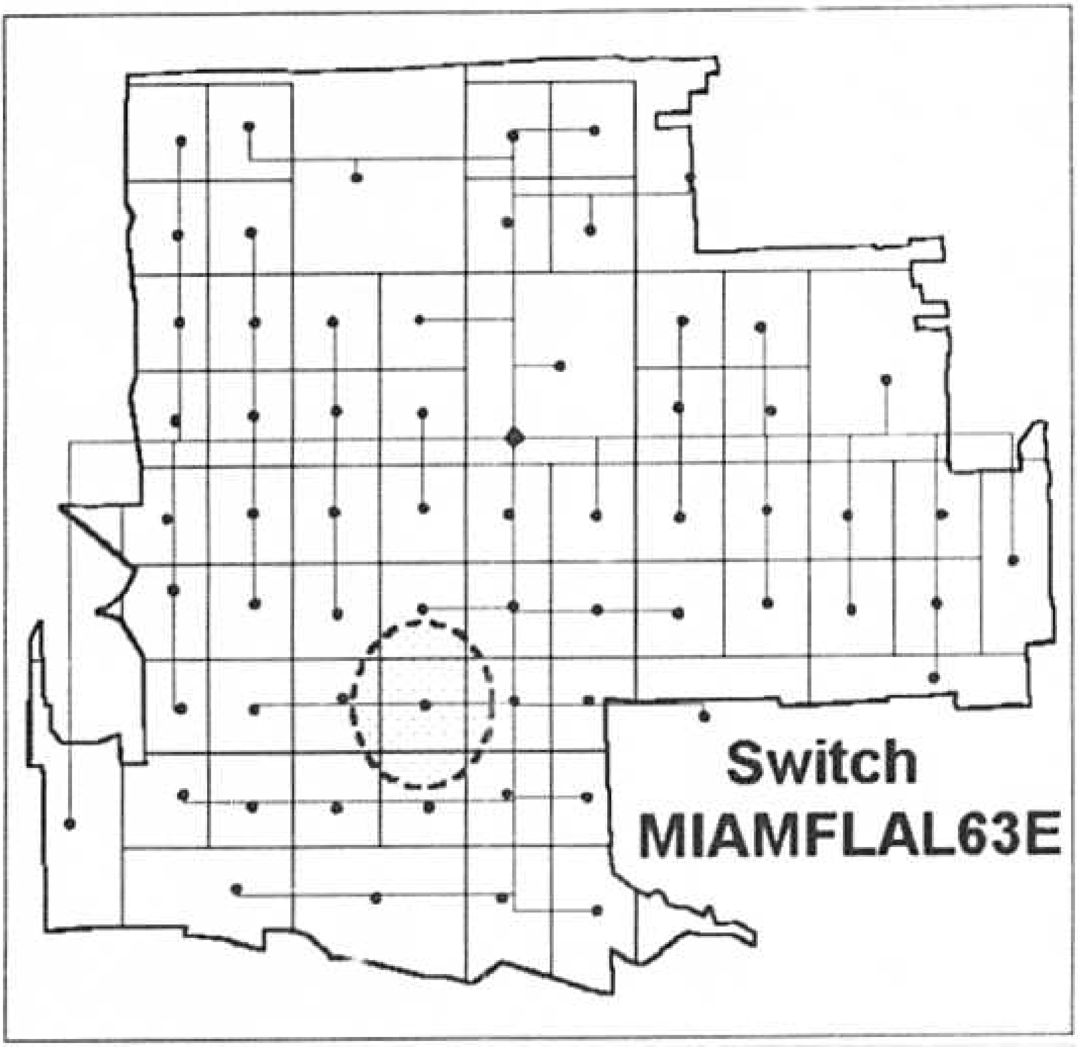
Invited Presenter, Visions in Business "Costing and Accounting for Interconnection," London, U. K., January, 1996. Subject: "Measuring the Economic Efficiency of an Incumbent Operator."

Invited Presenter, Visions in Business "Integrating Cost and Non-cost Data Analysis for Interconnect Pricing," Brussels, Belgium, March, 1997. Subject: "Incorporating Cost and Non-cost Data to set Interconnect Prices for Broadband and Internet."

1

Carrier Serving Areas: Urban Wire Center

Exhibit EMB-2




**Legend:**

Boundary of the wire center

Boundaries of the ultimate grids

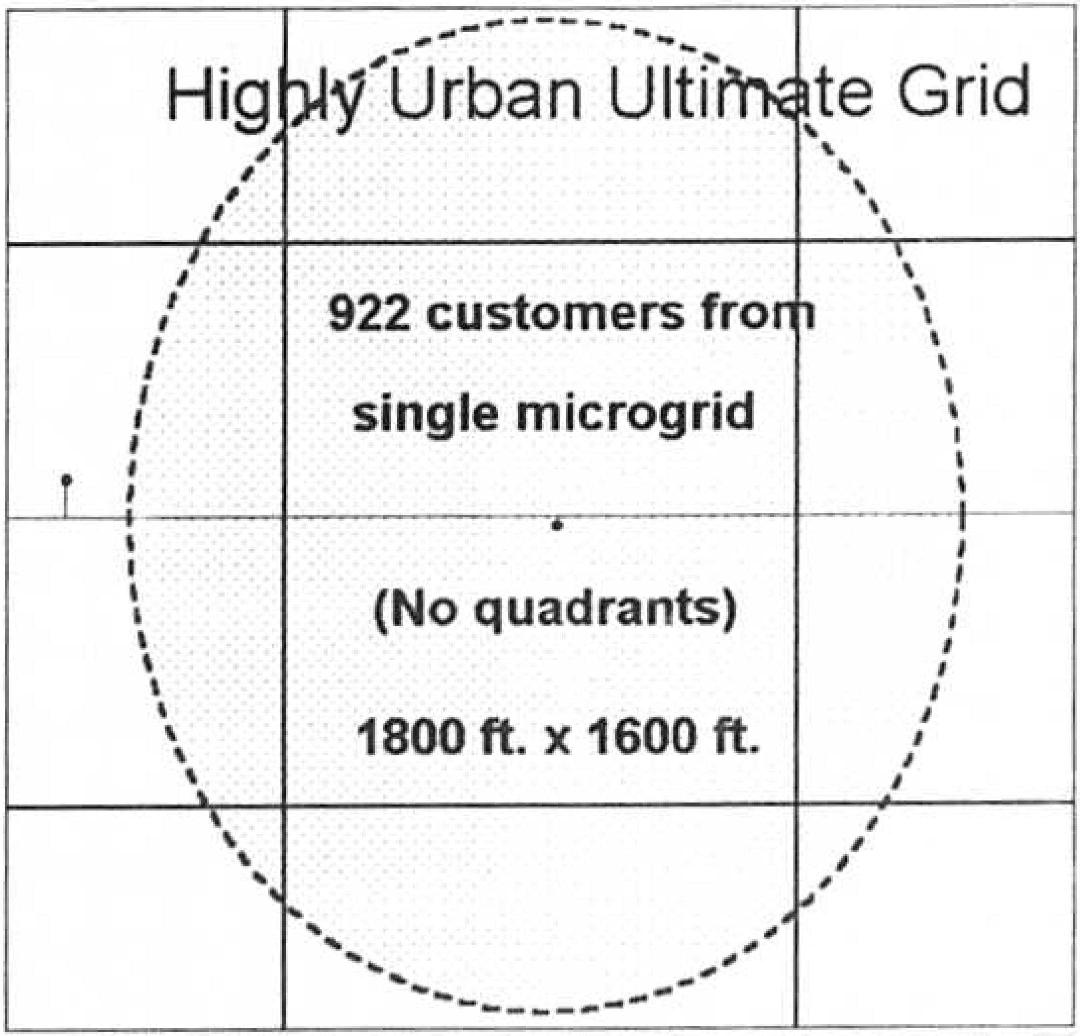
Location of the wire center switch

Paths of feeders and subfeeders

DLC locations (road centroid of ultimate grid)

Ultimate Grid of that Urban Wire Center

Exhibit RMB-2




**Legend:**

Boundaries of the ultimate grids

Paths of feeders and subfeeders

• DLC locations (road centroid of ultimate grid)

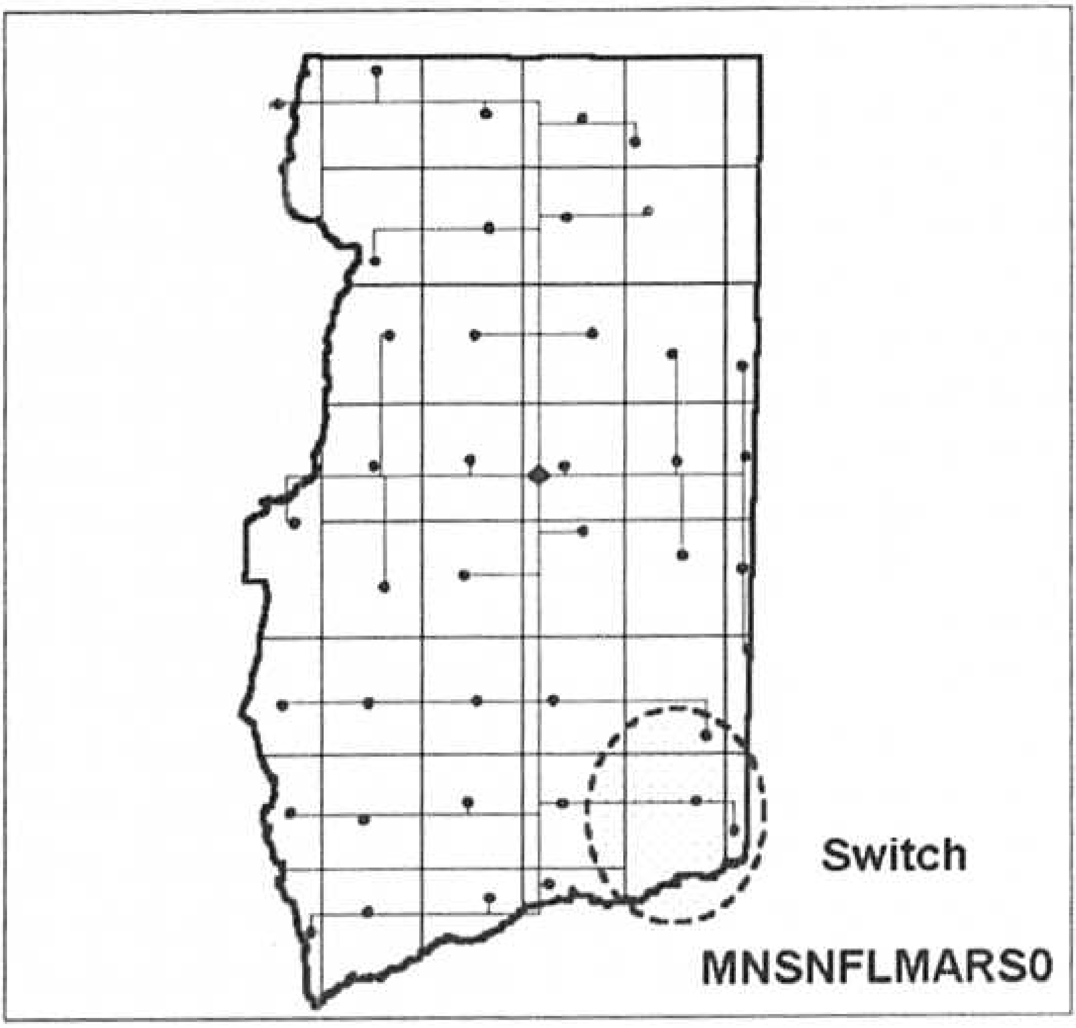
Division of ultimate grid into quadrants

----- Path of vertical/horizontal connecting cables

**3** Number of customers in a quadrant

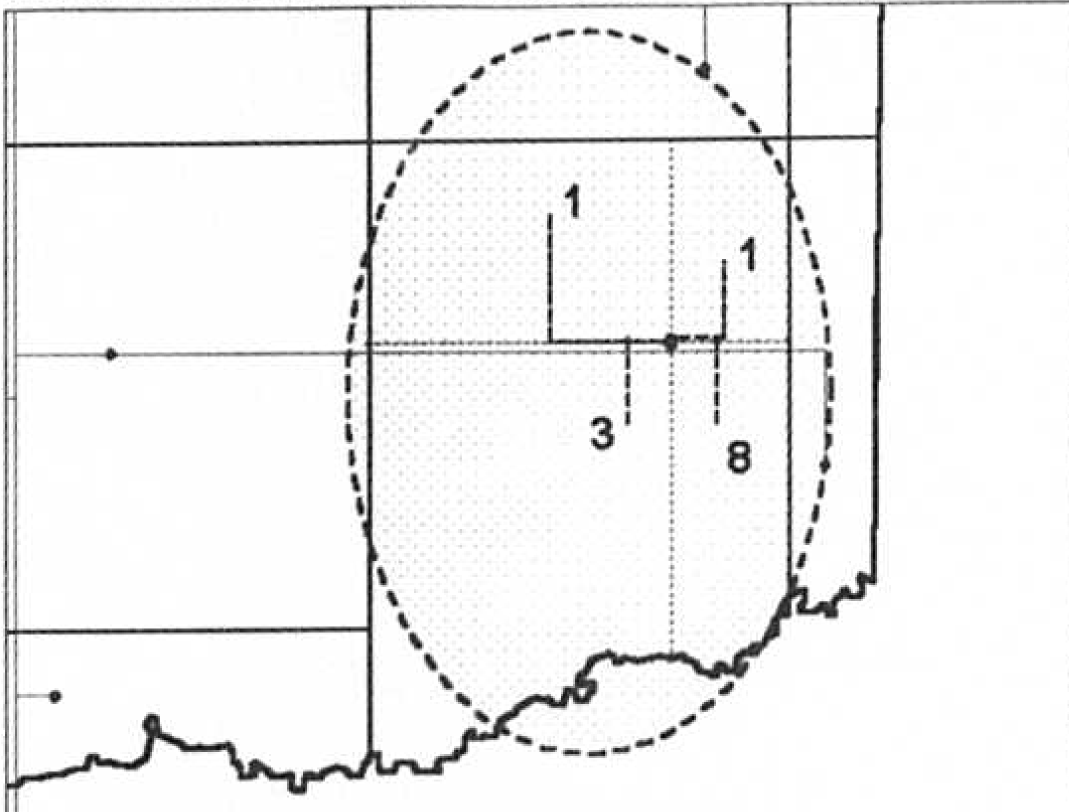
Carrier Serving Areas: Rural Wire Center

Exhibit RMB-2



Ultimate Grid of that Rural Wire Center

Exhibit RMB-2




**Rural Ultimate Grid: 2.9 mi. x 2.4 m**

**13 customers, in quadrants**

**Legend:**

Boundaries of the ultimate grids

Paths of feeders and subfeeders

• DLC locations (road centroid of ultimate grid)

Division of ultimate grid into quadrants

----- Path of vertical/horizontal connecting cables

**3** Number of customers in a quadrant

# BCPM3 DESIGNS THE MOST EFFICIENT PROXY NETWORK



## I. WHAT DEFINES THE MOST EFFICIENT NETWORK

The most efficient network is not necessarily the network which is lowest in cost. Rather, it is the network which is lowest in cost to provide a **defined set of services**. It is possible to build a low cost telephone network which will provide marginal voice grade services, but fail to provide minimal access to data and other services. Furthermore, it is not just the initial cost which must be considered, but the life cycle costs over the expected life of the network. For example, a network with a low first cost but high maintenance costs may be less efficient than a network with higher first cost and significantly lower maintenance costs. Similarly, a network with a low first cost, but which would be expensive to reinforce as customer demand grows could well be more costly. Finally, if customer demand for services exceeds the ability of the network to provide them, requiring costly overbuilds of the network, then the initial network can hardly be called efficient.

## II. WHAT SERVICES MUST THE CHOSEN PROXY NETWORK PROVIDE?

The services which must be provided by the network in the chosen proxy model are clearly spelled out in the Telecommunications Act of 1996...

> ***<u>Section 254(b) Universal Service Principles</u>* - The Joint Board and the Commission shall base policies for the preservation and advancement of universal service on the following principles:**

> *(2) Access to Advanced Services - Access to advanced telecommunications and information services should be provided in all regions of the Nation.*
> *(3) Access in Rural and High Cost Areas - Consumers in all regions of the Nation, including low-income consumers and those in rural, insular and high cost areas, should have access to telecommunications and information services, including interexchange services and advanced telecommunications and information services, that are reasonably comparable to those services provided in urban areas...*
> *(5) Specific and Predictable Support Mechanisms - There should be specific, predictable and sufficient Federal and State mechanisms to preserve and advance universal service.*

Furthermore, the Act provides for periodic review of the definition of universal service:

> *Section 254(c)(1) In General* - *Universal service is an evolving level of telecommunications services that the Commission shall establish periodically under this section, taking into account advances in telecommunications and information technologies and services.*

In selecting a proxy model, the Commission must first determine what definition of "advanced services" they should include in their criteria for evaluating the models, and to what degree the "efficient" network will provide for an expanding definition of universal service without the need for extensive and expensive overbuilds of the network.

The BCPM sponsors submit that a conservative approach to identifying the services which compromise "access to advanced services" today would be to test the networks built by the models for the capability to support data transmission over a 28.8 Kbps modem. Network access at the 28.8 speed is widely available today in urban areas and thus, at the direction of Congress, must be available to customers in all areas of the nation including rural and high cost areas. We say that this is a conservative measure since modem speeds of 33.6 Kbps and even 56 Kbps are becoming more and more common, and ISDN and xDSL technologies are in the initial stages of wide-spread deployment.



We use the 28.8 Kbps test for two reasons:

1. The Act states that services must be *reasonably comparable*, and
2. The Hatfield 5 and the HCPM will not be able to provide 28.8 connectivity to many customers, as we will demonstrate shortly. . . .

## III. WHAT ARE THE CRITERIA WHICH ARE PART OF AN EFFICIENT NETWORK DESIGN?

Following are quotes taken from the *Outside Plant Engineering Handbook* developed by AT&T Network Systems Customer Education and Training. They describe the type of factors which the Outside Plant Engineer must take into consideration when planning and designing the local network. The *Handbook* provides, in very plain straightforward language, a description of the types of analysis that the outside plant engineer must perform to design the optimal low-cost network. These are the very criteria which the BCPM sponsors use in designing their local networks, and which are reflected in the underlying network design assumptions of the BCPM3. The material in the Handbook is dated August 1994. The quotes which follow were selected to indicate the type of guidelines which are presented for the optimal planning and design of a local telephone network. Parenthetical references following each quotation refer to the section and page within the Handbook.

*EXCHANGE NETWORK DESIGN*

- *The outside facilities engineer is responsible for determining the type of outside facilities design that will best meet the needs of the company and the area to be served. There are three basic choices: (3-1)*

- *Aerial*
- *Underground*
- *Buried*

- *The engineer should evaluate the following for each type of facilities prior to proposing its construction: (3-1)*
  - *What is the Initial First Cost?*
  - *When is reinforcement of the facility likely to be required?*
  - *What are the potential maintenance costs and problems?*
  - *Is the potential for service disruption more likely with one type of facility than another due to storms, dig-ups, etc.?*
  - *Is there a governmental or company policy in place that dictates the type of facilities that must be constructed?*
- *The initial first cost, although an important consideration because it impacts today's money, should not be the only consideration. Evaluation of the remaining considerations may indicate a low initial first cost - but excessive future costs - either due to future reinforcement requirements or excessive maintenance costs. (3-2)*
- *Consideration must always be given to the next requirement that will affect an area currently being evaluated for relief. A job built today must not eliminate future alternatives; rather, it should be constructed considering the next relief requirement. (3-3)*
- *Copper primary (feeder) cable is normally sized to satisfy the growth requirements on a primary route for a period of 5 to 7 years. However there are many factors to consider that may affect the cable size and the growth period used to assist in determining cable size. For example: (3-7)*

  1. *Economic constraints may necessitate the placement of a less than optimum size primary cable.*
  2. *Company policy may dictate a shorter or longer growth period.*
  3. *Changes in anticipated growth patterns for an area may impact the amount of time a cable lasts, increasing or decreasing the amount of time the cable is able to satisfy requirements.*
  4. *The type of structure being utilized may affect the optimum size cable, for example:*
     - ***Aerial construction** - The lack of spare pole positions for additional aerial cable placement may necessitate the placing of a larger primary cable to avoid major rearrangements or structure reinforcement. This type of construction does have weight limitations, which can restrict the size or number of cables that can be installed.*
     - ***Underground construction** - Larger underground primary cables may be placed as the number of available spare ducts decreases. This practice can defer major conduit reinforcement for a significant period of time. Also,*

*deployment of fiber optic cables can defer or eliminate conduit reinforcement.*

- ***Buried construction** - Larger cables may be placed to avoid high construction costs associated with buying another cable in the not-too-distant future.*

*An economic analysis of the alternatives will assist the engineer in choosing the best solution. Good engineering judgment, however, is essential in applying these guidelines to actual field requirements.*

- *Interfaced secondary (distribution) cables are sized for the "ultimate" pair requirements. Accepted standards for pair allocations are as follows: (3-11)*
  - ***Residential** - two pairs per living unit. There are occasions when fewer than or more than two pairs per living unit are the optimum choice.*
  - ***Small business** - five pairs per business. When determining ultimate business lines, it is usually best to be liberal.*

*BURIED PLANT*

- *Buried plant is recommended as the first choice of providing outside plant (OSP) facilities beyond the underground network. (9-1)*
- *Filled polyethylene insulated conductor (PIC) cable is the only cable recommended for direct burial in the ground. (9-3)*
- *Buried distribution cables should be sized for the ultimate requirements of the living units and business locations within the area served by the cable. (9-3)*
- *In areas where both power and telephone utilities plan to bury their facilities, a joint trench is usually advantageous. Besides saving in installation cost, there is less likelihood of damage during construction. Successful joint operations require advance planning and close coordination with the utilities involved. **Joint trenching with power facilities should be employed only for distribution cables and service wires (drop), not for feeder or trunk cables.** (Emphasis in original) (9-6)*
- *Recommended depths for placing PIC cable. (9-12)*
  - *Toll, trunk cable 30 in.*
  - *Feeder, distribution cable 24 in.*
  - *Service wire 12 in.*
  - *Fiber optic cable 36 - 48 in.*
- *Trenching is preferred over plowing for installation in rocky soil, in urban or suburban environments with many obstacles, or in areas with difficult access. (9-15)*

*AERIAL PLANT*

- *Consider aerial design only if buried design is significantly more expensive or is not feasible. (10-1)*
- *The National Electric Safety Code (NESC) divides the United States into three storm loading areas based on the frequency, severity and damaging effects of ice*

*and wind storms. These areas and the design load data for each are defined below. (Maps and tables follow which provide additive factors) (10-7)*

*DIGITAL LOOP CARRIER SYSTEMS*

- *The goal is to have the entire local loop network ultimately capable of supporting a transmission rate of 64 kb/sec. Nonloaded 26-gauge cable is capable of providing this bit rate within 12,000 feet of the serving central office. Digital subscriber carrier is necessary to meet that bit rate beyond 12,000 feet. (13-1)*

...

## IV. THE CARRIER SERVING AREA (CSA) CONCEPT

It is not practical for the engineer to individually design the transmission characteristics of each central office area. For this reason, design standards or "rules-of-thumb" are developed and used throughout the telephone industry. Not only do these rules simplify the design process, but they also provide guidance for equipment manufacturers for the design of their products which are the building blocks of the network. They also assure that when loops are connected to networks in other parts of the country, or even in other parts of the world, that the resulting circuit will provide satisfactory end-to-end transmission.

Up until the 1980s, local networks were based on a standard called "Resistance Design". Loops over a given length (most recently 18 Kft) were "loaded" with electrical coils which preserved the quality of voice transmission. The emergence of digital services during the early 1980s presented a problem, however, since loaded loops do not pass digital signals. In their May 8, 1997 Universal Service Decision, the Commission recognized this reality and directed that load coils were not compatible with the type of network and service architecture which the 1996 Act requires and with a forward-looking economic cost study:

*The loop design incorporated into a forward-looking economic cost study or model should not impede the provision of advanced services. For example, loading coils should not be used because they impede the provision of advanced services.*[1]

The Carrier Serving Area (CSA) concept was specifically designed to allow for access to advanced telecommunications services within the context of an efficient local exchange distribution network. The goal of the CSA architecture is to have all loops in the network capable of supporting a transmission rate of 64 Kbps. This is achieved by utilizing 26 gauge copper facilities to serve customers within 12,000 of the central office, and serving customers beyond this distance from a Digital Loop Carrier (DLC) system connected to the central office by fiber facilities. A CSA is a distinct geographic area capable of being served by a DLC Remote Terminal (RT). The CSA design specifications provide that no loop can exceed 900 ohms of resistance, which generally equates to 9,000 feet of 26 gauge copper or 12,000 feet of 34 gauge copper facilities. Extended range line cards are available which extend the range of the RT to 1500 ohms, however the line cards to support this extended range cost roughly twice what the standard line card costs.[2] Other line cards are available which support the access to various levels of advanced services.

As the CSA architecture has become the design standard used by most local exchange carriers, it has also become the standard to which equipment manufacturers design their

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[1] Report and Order in CC Docket 96-45 Adopted May 7, 1997, Released May 8, 1997 at Paragraph 250.
[2] In Attachment 3 to this filing, the BCPM sponsors present runs of BCPM3 which were made using an 18,000 ft maximum copper loop design standard (similar to that employed in the Hatfield Model) for five test states. In four of the five states analyzed (FL, GA, MD, and MT) the 12,000 ft standard produced a lower investment than the 18,000 ft standard. In the fifth state (MO) the results were identical. This is so since the apparent savings from having the RT serve a larger area are more than offset by the extra costs associated with extended range line cards and the greater use of 24 gauge cable.

products. As such, a network designed to different specifications would require non-standard equipment which would cost substantially more. Indeed, the ubiquity of the CSA standard and the scale of manufacturing capacity that this has created has significantly driven down the cost of DLC equipment, making it the most efficient vehicle for providing basic telephone service with access capability to advanced services.

## V. WHAT IS REQUIRED TO PROVIDE ACCEPTABLE VOICE GRADE SERVICE AND 28.8 Kbps FUNCTIONALITY?

In December of 1996, Bellcore published a Technical Memorandum (TM-25704) which provided a methodology for estimating the maximum modem speed that can be maintained by a V.34 depending on various factors of the circuit over which the modem transmission occurs. The results of their analysis are summarized in Figure I, below, a full copy of the Technical Memorandum appears at the end of this section.

**Figure I - Predicted Modem Speeds**

**POINTS**

**1. CUSTOMER LOOP (each end)**
0 - 9 KΩ NL = 0 | 9 - 12 KΩ NL = 1 | 12 - 18 KΩ NL = 3
18 - 24 KΩ L = 7 | 24 - 30 KΩ L = 10 | > 30 KΩ L = 12

**2. LOOP CARRIER (each end)**
No DLC = 0 | IDLC = 2 | UDLC = 6

**3. SWITCH TYPE (each end)**
Analog = 0 | Digital = 1

**4. INTEROFFICE**
Digital Route = 2 | Analog Tandem = 4 | B/B - Car = 6

**SCORING:**
0 - 6 = 28.8 Kbps | 7 - 9 = 26.4 Kbps | 10 - 13 = 24.0 Kbps | 14 - 16 = 21.6 Kbps
17 - 20 = 19.2 Kbps | 21 - 25 = 14.4 Kbps | 26 - 30 = 9.6 Kbps

As can be seen, there are seven factors which determine the maximum speed which can be achieved - the loop on both ends of the circuit, the presence of Digital Loop Carrier on the two loops, the type of switch on either end of the circuit, and the type of circuit connecting the two central offices. Depending on the characteristics of each of these seven components, points are awarded. The number of points for the total circuit determines the maximum modem speed which can be maintained.

The relevance of this chart can be seen in the line relating to the customer loop. Loops under 9 Kft receive no points, loops from 9 to 12 Kft receive 1 point, while loops from 12 to 18 Kft receive 3 points. Since anything over six points prevents the achievement of the 28.8 Kbps speed, a design standard which routinely utilizes loops over 12 Kft can use up the full point allotment on the loop alone, even without consideration of the digital loop carrier (which will be utilized for most, if not all, rural customers), the central office switches and the interoffice transmission facility.

By utilizing the DSC architecture and the maximum 12 Kft copper loop, BCPM3 assures that the requirements for advanced telecommunications service access for remote rural customers is reasonably comparable to that enjoyed by urban customers, as mandated in the 1996 Act.

Bellcore
Bell Communications Research

# Memorandum Abstract

| Memorandum Number (IM or TM) | Title |
|---|---|
| TM-25704 | Guidelines for High Speed Analog Data Transmission in the Switched Netwo |
| Memorandum Completion Date: December 1996 | |

| Software/Product Name | | | | | | | | Release No | |
|---|---|---|---|---|---|---|---|---|---|
| Project No | WP/Task | Project No | WP/Task | Project No | WP/Task | Project No | WP/Task | Project No | WP/Task |
| 422241 | 01 | 5W3650 | 01 | 5W3651 | 01 | 6A3624 | 01 | | |

| Contact/SME(s) | Org. Code(s) | Loc. Code & Room No (s) | Tel No (s) |
|---|---|---|---|
| Ricardo J. Perez | 331H0 | MCC 1F131G | 201-829-2960 |

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Abstract (Abstract Text, Author Signature(s), Copy to Information)

This technical memorandum (TM) discusses guidelines for high speed analog data transmission on a switched network that reflects the transmission impairments associated with today's network configurations and new high speed modem technologies.

Ricardo J. Perez
Systems Engineer
Network Transport and Synchronization

# GUIDELINES FOR HIGH SPEED ANALOG DATA TRANSMISSION IN THE SWITCHED NETWORK

**CONTENTS**

# GUIDELINES FOR HIGH SPEED ANALOG DATA TRANSMISSION IN THE SWITCHED NETWORK

R. J. Perez

## 1. Introduction

This technical memorandum (TM) discusses guidelines for high speed analog data transmission on a switched network that reflects the transmission impairments associated with today's network configurations and new high speed modem technologies.

The original scope of this document was to indicate procedures for the local telephone companies to allow their customers to run V.34[1] modems at the highest data rate of 28,800 bits per second (bps). It became apparent that this is not always possible. It may never be possible depending on how each customer's service is provided to them and how the network routes each call to the far end. In many cases, it will be to an Internet Service Provider (ISP), and their facilities will influence the overall data connection. It will also depend on the modems that are being used.

V.34 technology is based on assumptions and compromises that the local telephone companies have no control over. However, an understanding of how V.34 modems make the connection will take some of the mystery out of the black box.

Laboratory tests were conducted to determine the effects of analog to digital (A/D) and digital to analog (D/A) conversions on V.34 modem connections. Also, various cables lengths with bridged-taps (BT) were put under test to understand their effects on data rate connections. A chart has been developed in an attempt to quantify the effects of the telephone network on any given connection.

# 2. V.34 Features

## 2.1 V.34 vs. V.32bis Comparison

As with the V.32bis specification, V.34 defines a 2 wire, full duplex dial and lease line modem supporting both synchronous and asynchronous operations. Likewise, the specification calls for automatic fallback compatibility with lower speed modems such as V.32 and V.22bis.

A brief comparison of the differences are listed below:

| | V.32bis | V.34 |
|---|---|---|
| Modem Type | Fixed Modulation | Adaptive Intelligence |
| Data Rates | 14.4 kbps - 7.2 kbps | 28.8 kbps - 2400 bps |
| Bandwidth | Fixed | Variable |
| Trellis Coding | 2-dimensional | 4-dimensional |
| Adaptive Equalization | Linear | Precoding |
| Mapping | 2-D Shell Mapping | 16-D Shell Mapping |
| Auxiliary Channel | None | 200 bps |
| Operating Modes | Full Duplex<br>Half Duplex (Fax) | Full Duplex<br>Half Duplex (Fax)<br>Asymmetric |

## 2.2 V.34 Features

These are the new features of V.34 modems that will respond to the telephone network:

1. Negotiation handshake
2. Line Probing
3. Precoding
4. Adaptive Pre-Emphasis
5. Adaptive Power Control
6. Multi-dimensional Trellis Coding
7. Shell Mapping (a.k.a. shaping)
8. Warping

How do they actually work? It is a complex negotiation sequence. The following is a brief discussion of the major features which are implemented in V.34 modems.

### 2.2.1 Mode Negotiation Handshake

A new handshake start up procedure developed specifically for V.34 based products, V.8, includes backward compatibility to all lower speed modems with provisions to recognize and interwork with the V.32bis defined Automode negotiation procedure. This is the first signal exchange that occurs between two V.34 modems when making a connection. As with other elements of the V.34 specification, V.8 is an intelligent procedure allowing V.34 modems to perform feature and mode negotiation quickly, utilizing V.21 (300 bps FSK) modulation to exchange information. Negotiation parameters include such information as:

- Identification of V.34 modems from all other types
- Data mode or Text Phone operation
- Modulation modes available
- V.42 and V.42bis support
- Wireline or Cellular operation

### 2.2.2 Line Probing

Line probing is the most significant enhancement in the new technology suite in the V.34 standard. It is the basic capability that allows a V.34 modem to intelligently choose the optimum operating parameters for any given telephone connection. It is also the area where manufacturers of modems determine the order of the features to be implemented.

Line probing is a bi-directional half duplex exchange which is performed immediately after V.8 negotiation. It involves the transmission of 21 tones ranging from 150 Hz to 3750 Hz that allows the distant receiver to analyze the characteristics of the telephone channel before entering data transmission. The modems use this line analysis information to choose several key operating parameters, including:

- Carrier Frequency and Symbol Rate: This determines the optimum bandwidth and placement (center frequency) of the transmitted signal within the available channel bandwidth. The modems have 11 possible combinations to choose from with 6 different symbol rates, each with 2 possible carrier frequencies. Three of the symbol rates are mandatory and three are optional.(see bandwidth requirements)

- Pre-Emphasis Selection: The modems choose the optimum transmit pre-emphasis filter from a menu of 10 defined filters in the V.34 specification. (see Adaptive Pre-emphasis)

- Power Control Selection: The modems choose the optimum transmitter output power level with a range of selection of 14 dB in 1 dB increments down from the nominal –9 dB transmitter level. (see Adaptive Power control)

Line probing is performed on every new connection as well as when a full retrain occurs, which can be performed at anytime during a connection. This allows V.34 modems to not only adapt to a broad range of different line types and distortions from call to call, but also accommodate varying line conditions over long periods of time on any given connection. With V.34 modems, as performance decays in the presence of time varying distortions, the modem can re-enter line probing at any time to adjust for, i.e. "adapt to" the prevailing conditions.

### 2.2.3 Precoding

Precoding is actually a modification on an adaptive equalizer technique developed in the 1970's known as Decisions Feedback Equalizations or DFE. Decision Feedback equalizers have been proven to be the optimum receiver equalization technique for analog voice grade modems and can compensate for Intersymbol Interference (ISI) caused by severely distorted channels. This is essential for high speed modems that need to utilize every ounce of the frequency spectrum available on the line.

The basic idea is to split the DFE between the transmitter and the receiver. In so doing, the V.34 receiver calculates the optimum equalizer coefficients as it would for a normal DFE, but relays them back to the transmitter where the transmitted signal is equalized before transmission. The result is the best of both worlds, Decision Feedback Equalization employing "pre"-equalization and Trellis "Coding" which is "Pre-Coding."

### 2.2.4 Adaptive Pre-Emphasis

This is another technology taken from the past (formally known as "compromise" equalization or "pre-emphasis") and enhanced with adaptive intelligence. In the past, manufacturers have employed a fixed version of this technology while in V.34 it is adaptive based on actual line characteristics. With pre-emphasis, the transmitted signal is passed through a spectral shaping filter which boosts signals in some parts of the transmitted spectrum while attenuating signals in other parts of the spectrum. Pre-emphasis is very effective against signal-dependent distortion. The idea is to again pre-compensate for known channel distortions learned in Line Probing. If for example, line probing detects that severe roll-off is present at the upper part of the chosen transmit spectrum then an appropriate pre-emphasis filter can be introduced in the transmitter to compensate. Not only is the direct effect of the channel distortion compensated for, but the more severe side effects of non-linear distortion are minimized as well.

The intelligence comes in with the selection of which pre-emphasis filter to utilize. The V.34 specification defines 10 different pre-emphasis filters to choose from. The information attained during line probing is the primary decision criteria in selecting the optimum pre-emphasis filter, the actual method of which is up to the implementor.

### 2.2.5 Adaptive Power Control

Proper selection of transmitter power is critical in high speed echo canceling modems. Unlike older 4 wire modems or lower speed V.22bis class modems, it is not true that higher transmit power is always better. Echo canceling modems need to strike a balance between high transmission power which can improve signal to noise ratio for the distant receiver, but can introduce undesired echo distortion for the local receiver. On the other hand, too low of a transmitted signal compromises basic signal to noise ratio. Adaptive power control is an intelligent, adaptive scheme which automatically selects the optimum transmit level based on line probing results. A relatively simple concept, but a critical and complex/delicate balance.

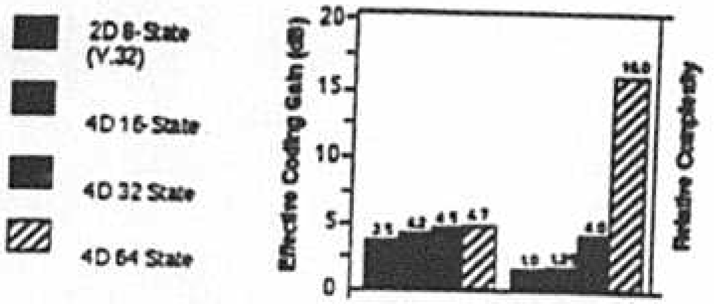
### 2.2.6 Multi-Dimensional Trellis Coding

Trellis coding, simply put is a forward error correction coding scheme. The value of the coding is expressed as a "coding gain" which is a measure of the modems error rate improvement over an uncoded modem. Figure 1 shows the effective coding gain of the three new codes employed in the V.34 specification as compared to the coding technique implemented in V.32bis modems.

The significant points relative to multi-dimensional coding are:

- V.34 employs three new 4-dimensional coding schemes compared to the 2-dimensional scheme employed in V.32bis. 4-dimensional coding has been found to provide the best trade-off between performance, delay and complexity of implementation.

- As can be seen by the performance gain vs. complexity trade off, the V.34 standards body has approached the limits of diminishing returns to achieve the desired performance.




- The 4-D Code Provides a Good Trade-off Between Performance, Delay and Complexity

**Figure 1**

### 2.2.7 Shell Mapping (Shaping)

In high speed modems each symbol transmitted contains a multiplicity of user data bits and coding bits. These bits are grouped into symbols and then mapped into a 2 dimensional signal constellation (as shown in Figure 2). The resulting signal point is then transformed to its analog signal equivalent for transmission over the analog voice channel. Shell mapping is a signal constellation mapping technique which attempts to distribute these signal points in the 2 dimensional space in such a way as to improve the resultant noise immunity by approximately 1 dB.

The concept is basically that an optimum constellation would be a spherical shape, however, this is not possible. Shell mapping approximates the spherical shape by mapping a square grid constellation to a near-spherical shape with guassian distribution of the signal points in the 2 dimensional space. The net effect is that the constellation is expanded, and the signal to noise ratio is improved by approximately 1 dB. The V.34 specification supports 2 levels of shell mapping which are related in terms of the resulting constellation expansion; 12.5% and 25% expansion.

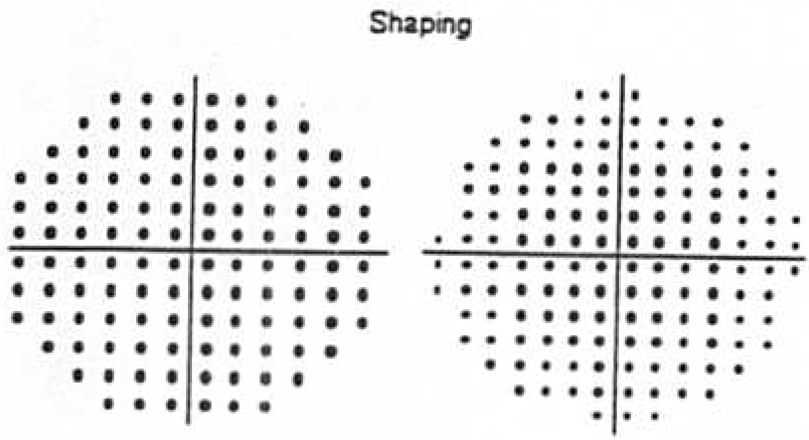



Figure 2

### 2.2.8 Warping (a.k.a. Non-linear Encoding)

Warping is another form of signal space coding specifically designed to combat the effects of signal dependent channel distortion also known as non-linear distortion or harmonic distortion. Non-linear distortion is present in all types of telephone channels and is by-in-large due to the PCM digital encoding of the analog signals. The non-linear nature of PCM coding compounded by the non-linear distortion introduced by analog components such as transformers and loading coils wreak havoc on these high speed modems.

Warping is a means of trading off signal to noise immunity for improvement in signal dependent distortion immunity. Figure 3 shows how warping does this.

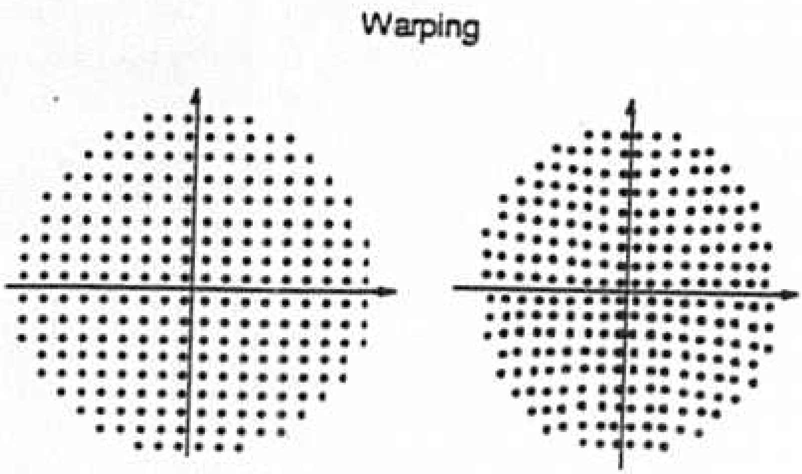



Figure 3

Knowing that non-linear distortion effects the outer constellation points more severely than the inner constellation points, the concept is to compromise the noise immunity of the inner points in favor of the more susceptible out points. The result is that the mean distance between points is increased in the outer fringe of the constellation (improving the immunity to all types of distortion, but particularly non-linear distortion) while the mean distance between the inner points is reduced.

### 2.2.9 Implementation

The V.34 standard does not mandate the full implementation of all features within the document. There are minimum requirements so that modems will function at the V.34 level but it leaves the details to the manufacturers. Each manufacturer decides which options will be used and in what order they will be processed. With this overview, it is understood that there are tradeoffs and compromises being made to optimize the V.34 modems performance with the connection over the network. The data rates will therefore be set to the highest possible level but to the lowest denominator of the modems for compatibility.

# 3. Transmission Parameters for V.34 Modems

With some understanding of what the V.34 modems are doing in response to the telephone network, a look at the transmission requirements is needed. The V.34 recommendation requirements are based on modem implementation and need to be redefined in telephony terms. The important parameters are bandwidth (frequency requirements), receive level, and noise requirement. As the V.34 overview tried to illustrate, the modems are designed to take the network variations into account and optimize the modem's performance.

## 3.1 Bandwidth Requirements for Data Rate Selection

The ITU Recommendation in this section is called Carrier Frequencies. It takes several tables and calculations to put it into terms that make sense in the telephone world. The table below shows the relationship between symbol rate, bandwidth and data rate. Symbol rate is the term now used to express baud rate. Each symbol encodes as many as nine (9) bits of data which yields the data rate. Each symbol rate except 3429 has two center frequencies to chose from and they are called high and low. There is approximately a 200 Hz difference in the bandwidth used. This is to compensate for frequency roll-off at either the high or low ends of the spectrum.

| Symbol Rate per sec | | Center Frequency | Bandwidth Requirements | Maximum data Rate Kbps |
|---|---|---|---|---|
| 2400 | Low | 1600 Hz | 400 - 2800 Hz | 21.6 |
| | High | 1800 Hz | 600 - 3000 Hz | 21.6 |
| 2743 • | Low | 1646 Hz | 274 - 3018 Hz | 24.0 |
| | High | 1829 Hz | 457 - 3200 Hz | 24.0 |
| 2800 • | Low | 1680 Hz | 280 - 3080 Hz | 24.0 |
| | High | 1867 Hz | 467 - 3267 Hz | 24.0 |
| 3000 | Low | 1800 Hz | 300 - 3300 Hz | 26.4 |
| | High | 2000 Hz | 500 - 3500 Hz | 26.4 |
| 3200 | Low | 1829 Hz | 229 - 3429 Hz | 28.8 |
| | High | 1920 Hz | 320 - 3520 Hz | 28.8 |
| 3429 • | | 1959 Hz | 244 - 3674 Hz | 28.8 |

• Optional Symbol Rate

Telephone tariff requirements are usually written around 300 to 3000 Hz. As the table illustrates, V.34 modems go well beyond these numbers. In reality, the network has more bandwidth than the tariffs state, but there are no guarantees. Different transport systems will limit the bandwidth. While this does not effect voice connections, it will change the performance of a V.34 modem. It should be understood that these modems are probing the very limits of the telephone spectrum and trying to adapt to the conditions that are there.

## 3.2 Receive Level (Carrier Detect)

The ITU recommendation on threshold levels for carrier detection is a level greater than -43 dBm. This is the modem's term for receive level. It has been observed that most V.34 modems need a level of -40 dBm at the high end of the bandwidth to set the symbol rate and bit rate. For example, if a modem registers a level of -42 dBm at 3400 Hz, then it would select a symbol rate of 3200 and use the lower center frequency of 1829 Hz. The data rate would be set at 26.4 Kbps if all other parameters were adequate.

### 3.3 Noise Requirement

The ITU V.34 recommendation does not directly address the noise requirements. It was necessary to check with modem manufacturers. As the overview indicated, the constellation of the V.34 modem is very compact. Signal-to-Noise Ratio (SNR) was the parameter that was needed to be met. The lower limit that has been quoted is 32 to 34 dB. This is the lowest SNR needed to be able to connect at 28.8 Kbps on V.34 modems. Most tariff requirements are written to guarantee only a 24 dB SNR. The network has improved and this number is achieved in the switched network, but older types of network elements are still deployed and, as such, a SNR of 32 or greater cannot be guaranteed.

Bellcore's TM-25202[7] reported signal-to-noise ratios for digital connections. When an analog-to-digital (A/D), then a digital-to-analog (D/A) conversion occurs, there is a SNR of 36 to 38 dB measured through the transport. A universal digital loop carrier (UDLC) is a typical example found in the network. Two of these transports would result in a SNR of 33 to 35 dB. When a local switch and cable is added into the equation, the SNR would fall to 32 or less. This would drop the data rate one level.

## 4. Local Observations

There have been reports from local companies having to do with short local loops. It was determined that loops with less than 3 dB of loss were running lower than expected data rates. Through trial and error, performance was sometimes improved by adding additional loss to the loop. The underlying factor was poor return loss and some modems could not cancel out the near end echo that was produced. The modems would interpret the echo as noise and adjust the data rate down to compensate. This is a fundamental issue that has been taken up by the EIA/TIA standards body on analog modems. A new network model has been proposed to more accurately reflect the actual switched telephone network.

These same short loops can generate higher current through some modem transformers and cause poor performance. Customers have had to add balanced resistors to the line to reduce the current flow through their modems. Another issue is with modems that have electronic termination which regulates the current. If these modems are connected to a digital loop carrier (DLC) channel unit that adjusts transmission levels based on loop resistance, the modems will receive a hot level and have return loss problems.

The customer's home environment can effect V.34 modem performance. Customer premises wire can pick up noise when twisted cable pairs is not used. Also, a direct run from the protector may give some improvement. The other source of noise can come from other telephone sets on the same line as well as Fax machines and answering machines. Removing these devices from the data line could help in improving data connections.

# 5. Modem Testing

## 5.1 System Configuration

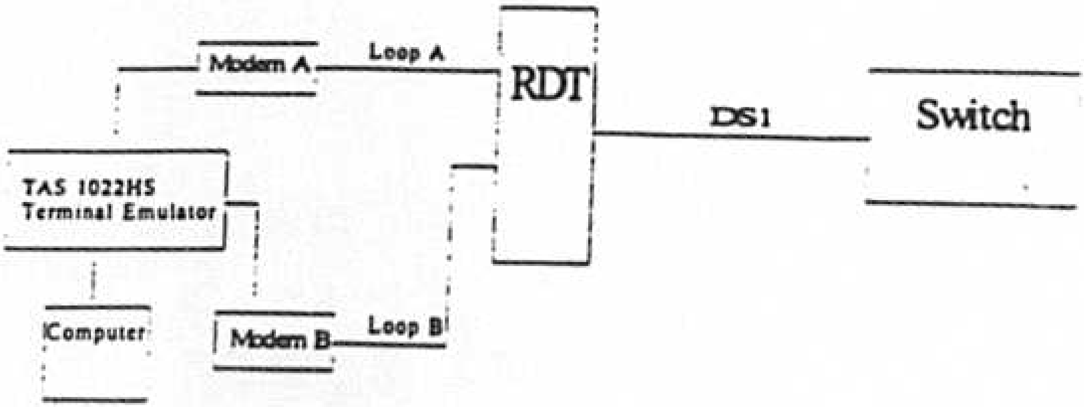



**Figure 4 Modem Test Configuration**

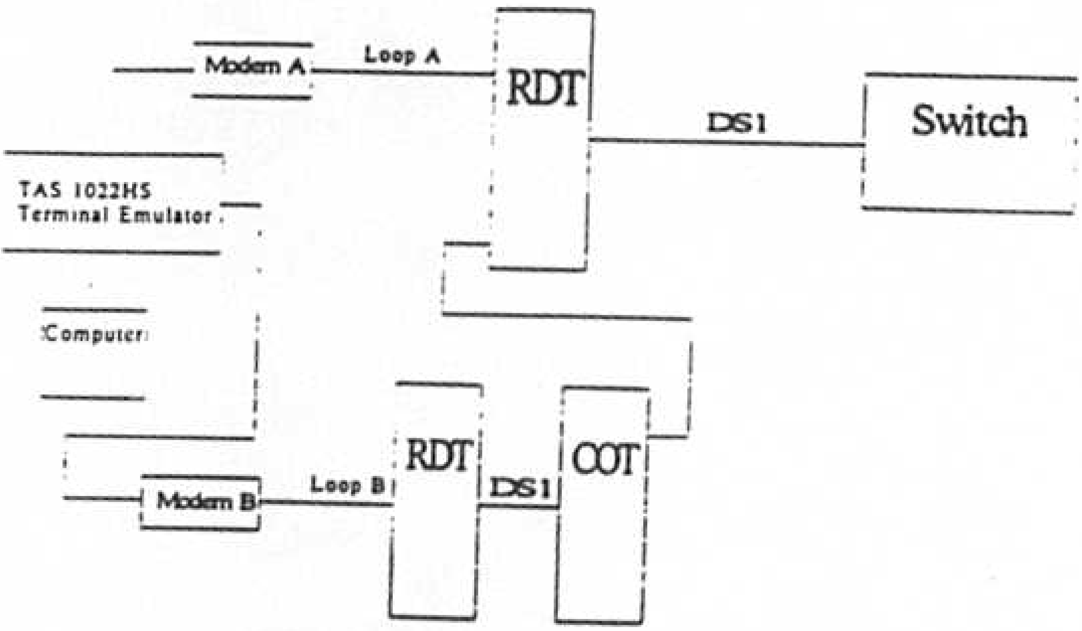



**Figure 5 Modem Test Configuration with Additional Conversion**

The test setups detailed in Figures 4 and 5 involved a SLC 96 COT and RT with appropriate POTS and UVG LUs. The access system in Figure 4 was installed as integrated DLC with the switch located at the Bellcore facility in Red Bank, NJ. The DLC systems were located at the Bellcore facility in Morristown. Bellcore corporate network MUXs were used for the DS1 connections between Morristown and Red Bank. In all cases, each system was externally timed from a Stratum 1 level cesium clock source.

## 5.2 Test Procedures

The goal of these tests was to determine the maximum data rates under different conditions. A file was transferred between modems to insure a valid connection.

A Telcom Analysis Systems TAS 1022HS terminal emulator was used to control the modems. Procomm PLUS for Windows was used to communicate with the TAS 1022HS. A script file, written in Procomm's Windows Aspect Script (WAS) language was used to automate the TAS 1022HS dialing, file transfer and to capture test results.

## 5.3 Results

### 5.3.1 Tests with PCM Conversions

The table below shows results of tests where the number of analog to digital conversions and the loop lengths are varied.

| Number of conversions | A side Loop | B side Loop | dB Loss at 1004 Hz | dB Loss at 3604 Hz | A Data Rate | B Data Rate |
|---|---|---|---|---|---|---|
| 1 | na | na | 4.6 | 13.8 | 28.8 | 28.8 |
| 1 | 3 Kft | 3 Kft | 7.7 | 18.4 | 28.8 | 28.8 |
| 2 | 3 Kft | 1.5 Kft | 10.0 | 30.2 | 21.6 | 24.0 |
| 2 | 6 Kft | 1.5 Kft | 10.5 | 33.4 | 21.6 | 24.0 |
| 2 | 9 Kft | 1.5 Kft | 12.0 | 36.2 | 21.6 | 24.0 |
| 2 | 12 Kft | 1.5 Kft | 13.5 | 39.2 | 19.2 | 24.0 |

As seen in the table, one digital conversion resulted in a maximum connect rate of 28.8 Kbps. However, there was either no loop attached or a very short loop was present. The result was little frequency roll off at the high end. When an additional conversion is present, the data rate drops in both directions. There is no additional effect with loop length until after the 9 Kft section is reached. The level at 3604 Hz starts to gets closer to the -40 dBm point at 9 Kft and at 12 Kft, it is close enough to it that the data rate goes down another level.

### 5.3.2 Local Cable Tests

Below is a table which shows the connect rates when using the fifteen loops found in TR-NWT-000393[3]. These loops were used to determine the effects of different cable lengths and bridged-taps (BT) on modem connect rates. They are actual cables located in the Bellcore Morristown Lab. The B side of the test configuration was set at 1.5 Kft of 26 gauge cable to represent an Internet Service Provider on a short loop, either to a local switch or a Digital Loop Carrier (DLC). The A side represented typical residential users. Only one digital conversion is present in this set of tests.

| Loop # | Length of A Side (Kft) | BT (Kft) | dB Loss at 1004 Hz | dB Loss at 3604 Hz | A Receive Data Rate | B Receive Data Rate |
|---|---|---|---|---|---|---|
| 15 | 12 | 0 | 11.4 | 26.9 | 26.4 | 26.4 |
| 14 | 14 | 3.5 | 11.4 | 28.5 | 26.4 | 26.4 |
| 13 | 12 | 3 | 11.2 | 27.6 | 26.4 | 26.4 |
| 12 | 13.5 | 0 | 11.3 | 27.5 | 26.4 | 26.4 |
| 11 | 12 | 1.5 | 11.3 | 27.3 | 26.4 | 26.4 |
| 10 | 16.5 | 1 | 12.3 | 29.3 | 26.4 | 26.4 |
| 9 | 10.5 | 4.5 | 11.4 | 27.6 | 26.4 | 26.4 |
| 8 | 16 | 1 | 12.5 | 29.6 | 24.0 | 24.0 |
| 7 | 13.5 | 0 | 12.2 | 28.8 | 26.4 | 26.4 |
| 6 | 17.5 | 1 | 12.8 | 30.6 | 24.0 | 26.4 |
| 5 | 15 | 1.5 | 12.3 | 29.4 | 24.0 | 24.0 |
| 4 | 17 | 0 | 13.0 | 30.4 | 24.0 | 24.0 |
| 3 | 15 | 3 | 13.0 | 31.3 | 24.0 | 24.0 |
| 2 | 16.5 | 1.5 | 13.5 | 31.6 | 24.0 | 26.4 |
| 1 | 18 | 0 | 14.3 | 32.7 | 21.6 | 24.0 |

The results indicate that bridged-tap does not directly affect the data rates of V.34 modems. It is more dependant on the actual length of the cable. The data rate is constant between 10.5 Kft and 16.5 Kft. The data rate goes down one level at 15 Kft and drops again at 18 Kft. The relationship is in the power loss at the high end of the spectrum. The B modem would be transmitting at a nominal level of -10 dBm. The receive level is then -36.9 dBm for loop #15 and -42.7 dBm for loop #1. The actual level is what is determining the data rate.

## 6. General Assumptions

With the observations and testing that has been done, some general assumptions can be made. To achieve a 28.8 Kbps connection on the Public Switched Telephone Network (PSTN), three conditions would always need to be met. One and two are non-loaded cables at both ends of the connection with a length of no more than 9 Kft. The third condition is only one A/D and D/A conversion on the connection. Any thing less than will probably result in a connect rate less than 28.8 Kbps. On the average, the majority of the V.34 modem users will realize a connect rate of 24.0 to 26.4 Kbps.

The table below could be used as an aid to determine the most optimistic data rate for a V.34 modem over the Intra LATA Network. It is assumed that there are no trouble conditions and all loops are within normal parameters. It is not advisable to attempt to assign relative values to the numbers.

Choose one item from each applicable category and place the number in the parenthesis in the value box to the right.

| | | | |
|---|---|---|---|
| Customer loop | 0-9 Kft NL (0)<br>18 - 24 Kft L (7) | 9 - 12 NL Kft (1)<br>24-30 Kft L (10) | 12- 18 Kft NL (3)<br>> 30 Kft L (12) |
| | | | Loop Value = |

| | | | |
|---|---|---|---|
| Loop Cxr | No DLC (0) | IDLC (2) | UDLC (6)<br>Loop Cxr Value = |
| Switch Type | | Analog (0) | Digital (1)<br>Switch Value = |
| Interoffice Facility | Digital Route (2) | Analog tandem (4) | B/B T-Cxr (6)<br>Facility Value = |
| Switch Type | | Analog (0) | Digital (1)<br>Switch Value = |
| Loop Cxr | No DLC (0) | IDLC (2) | UDLC (6)<br>Loop Cxr Value = |
| Customer loop | 0-9 Kft NL (0)<br>18 - 24 Kft L (7) | 9 - 12 NL Kft (1)<br>24-30 Kft L (10) | 12- 18 Kft NL (3)<br>> 30 Kft L (12)<br>Loop Value = |
| Add the six values to obtain the Sum of Values | | | *Sum of all Values=* |

Take the Sum of Values and find the range that identifies the most optimistic possible data rate for this connection.

0-6 = 28.8 Kbps     7-9 = 26.4 Kbps     10-13 = 24.0 Kbps     14-16 = 21.6 Kbps

17-20 = 19.2 Kbps     21-25 = 14.4 Kbps     26-30 = 9.6 Kbps

## 7. Conclusions

The results of this report clearly indicate that V.34 modem performance will vary greatly over the switched telephone network. This is due, in part, to the varied facilities that exist in the network, but on how modem manufacturers have implemented the V.34 recommendation.

The telephone network is made up of PCM links with A/D and D/A conversions. Each link will degrade a V.34 modem connection by one level due to the addition of quantization noise introduced by the µ-law encoding and decoding. When local cable is added to the equation, a length of more than 9 Kft or greater will degrade a modem connect rate due to the frequency roll-off at the high end of the spectrum. Therefore, if a telephone company had only digital switches, and all digital trunking between them and had only local cable that never extended 9 Kft, all their customers would be happily running their data lines at 28.8 Kbps. However, this environment does not exist at this time. Many modem users will have data connections at less than 28.8 Kbps but because of how V.34 modems operate, they will run at the most optimum rate possible.

## 8. References

1. ITU-T Recommendation V.34. *A Modem Operating at Data Signaling Rates of up to 28.800 bit/s for use on the General Switched Telephone Network an don Leased Point-to-Point 2-wire Telephone-type Circuits*, September 1994

2. TM-25202, *Engineering Guidelines For Facility Design to Meet Enhanced Data Conditioning Transmission Requirements*, September 29, 1995, Published by Bellcore

3. TR-NWT-000393, *Generic Requirements for ISDN Basic Access Digital Subscriber Lines*. Issue 2, January 1991, Published by Bellcore