SYNCHRONOUS CAUSES AND EFFECTS

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The synchronous communications used for high speed, long distance data communications are adversely affected by imperfect transmission channels. These channels, made up of modems or their equivalent (DCE) and transmission facilities (leased lines, dial-up lines, microwave links, unloaded metallic lines, fiber-optics, etc) introduce sporadic errors which are usually detected by the communications protocol in use, causing re-transmission of at least the block in error. These channels also introduce delays in the transmission of data, which, though they may be quite small, prevent full utilization of the apparent channel speed.

This paper examines the causes of these errors and delays, their measurement and their effects on point-to-point communications links. MODEM test and selection criteria are presented with emphasis on multiple parametric testing.

OUTLINE

Section I. Throughput over point-to-point links

A. Definition of throughput
B. Factors affecting throughput
   1. MODEM (DCE) speed
   2. Link error rate
   3. MODEM turnaround time
   4. Block size
   5. Protocol
      a. Half-duplex protocol
      b. Full-duplex protocol
      c. Protocol overhead characters
   6. Path length
   7. CPU/Interface servicing time
C. Calculation of throughput
D. Results

Section II. MODEM (DCE) test and selection

A. MODEM economics
B. Measurement of MODEM quality
   1. Live link testing
   2. Impairment distribution on US Bell System
   3. Simulated line testing
C. Comparative analysis
D. Results

Section I.

A. Definition of throughput

$$\text{Throughput} = \frac{\text{Number of bits correctly transmitted}}{\text{Time to correctly transmit the bits}}$$

The unit of measure used to express throughput here will be bits-per-second, abbreviated BPS.

B. Factors affecting throughput

1. MODEM (DCE) speed

In the U.S. synchronous MODEMS (Data Communications Equipment - DCE) are available at speeds ranging from 1200 to 230,400 BPS. MODEM equivalents (CSU/DSU or ISU) are available for use on strictly digital facilities at speeds of 2400, 4800, 9600, 19200 (with duo-plexer) and 56000 BPS.

Devices which attach to these DCE, namely Intelligent Network Processors (INPs), Synchronous Single Line Controllers (SSLCs), cluster controllers and multiplexers, etc. normally receive bit timing information from the DCE (i.e. when to send a bit or when a bit may be sampled for received data) as opposed to asynchronous equipment where the transmitting and receiving devices (Data Terminal Equipment - DTE) pace the communications rate based on internal clocking.

As a parameter taken alone, the faster the DCE speed, the higher the throughput in direct proportion.

2. Link error rate

The imperfection of a data communications link is expressed as:

$$\text{Error rate} = \frac{\text{Bits in error}}{\text{Bits transmitted}}$$

or

$$\text{Error rate} = \frac{\text{Blocks in error}}{\text{Blocks transmitted}}$$

The most common error rate abbreviations are BER for the bit error rate and BLER for the block error rate where a block is normally 1000 bits.

To measure the error rate of a channel, the DTE at the ends of the point-to-point link are replaced by Bit Error Rate Test set (BERTs). A BERT is capable of simultaneously transmitting and receiving a pseudo-random bit stream (PRBS) of fixed length, usually 63, 511, 2047 or 4095 bits. Longer tests are accomplished by simply repeating the fixed length PRBS. Receiver synchronization takes place in a period set by the binary root of the PRBS, (6 bit-times for 63-bit PRBS, 9 bit-times for 511-bit PRBS, 11 bit-times for 2047-bit PRBS, etc.) so it is not necessary to be terribly precise about starting the test at both ends of the line at exactly the same time.

BERTs may be set to transfer a fixed number of bits (1000 bits - 10^3, 10,000 bits - 10^4, 100,000 bits - 10^5, etc. to 1,000,000,000 bits - 10^9), may be set to transmit for a fixed period (5, 10 and 15 minutes are commonly used) or may be set to transmit continuously. By using a fixed number of bits, the error rate may be expressed independently of the line rate and test duration.

The link error rate is due to the combined imperfections in the communications facility and the DCE connected to the facility. Impairments which affect the error rate are composed of two types: Steady State and Transient.

Steady State Impairments
- Attenuation (Amplitude) Distortion
- Background Noise
- Frequency Shift (Offset)
- Envelope (Delay) Distortion
- Phase Jitter
- Non-Linear Distortion

Transient Impairments
- Impulse Noise
- Gain Hits
- Phase Hits
- Dropouts

Steady state impairments appear as random errors in error rate testing while transient impairments show up as bursts of errors.

The causes, measurement and acceptable limits of error rates and line impairments are covered in the Bell System technical publications 41004 through 41009 and in the Hewlett-Packard manual "Data Communications Testing", part number 5952-4973 chapters 2 and 3.

3. MODEM turnaround

On all half-duplex (HDX, two way non-simultaneous) links and on full-duplex (FDX, two way simultaneous) links (point-to-point as well as multipoint) some time is required for the receiving DCE to synchronize with the transmitting DCE. To restrain the transmitting DTE from sending data during this synchronizing (training) period, the transmitting DCE provides a delay between the time the transmitting DTE turns Request-To-Send (RTS) ON and the time when the transmitting DCE turns Clear-To-Send (CTS) ON. This time period varies from about 7 milliseconds on short, slow speed circuits to over three seconds on long, high-speed circuits. Common values fall in the range of 7ms (ATTIS Model 201C FDX private line, switched carrier), 12-15 ms (fast-poll/ fast-train modems), 50 ms (ATTIS Model 208B with "50" switch pushed in on short dial-up lines) to 148-150 ms (ATTIS Models 201C and 208B dial-up lines with normal settings).

On FDX channels the RTS-CTS delay time will be incurred only at link establishment if one selects the constant-carrier mode for the DCE. Then, for the purposes of this discussion, the turnaround time may be considered to be 0.

Improper configuration of the MODEM and/or Communications controller (INP or SSLC) transmission mode may adversely affect throughput by causing the modems to re-synchronize on each and every transmission when in fact this is not required. For example, on a full-duplex circuit, if the MODEM is strapped for switched carrier and the INP or SSLC is set to Transmission Mode= 1 (TM=1 under CSDEVICES) each transmission will be subject to an RTS/CTS delay which is neither necessary or desirable.

4. Block Length

As the block length of the transmitted data block is increased, the number of protocol overhead characters becomes a proportionally smaller fraction of the overall block transmitted. However, as the block length is extended, the probability that an error will occur is increased.

Block length is a parameter of throughput over which an HP3000 user has some control. The parameter "Preferred Buffer Size" used to configure the communications controller sets the default block length (excluding protocol characters) in words, with maximum sizes of 1024 words (2048 bytes) on the INP and 4095 words (8190 bytes) on the SSLC. Communications subsystems may override the default settings as follows:

a. RJE

RJLINE — MAXRPB parameter sets number of records per block to be transferred. Size of block is the size of the records times the number of records per block.

RJIN — COMPRESS parameter is used to prevent the transmission of EBCDIC blanks or ASCII spaces within each record.

TRUNCATE parameter is used to prevent the transmission of EBCDIC blanks or ASCII spaces at the end of each record.

RJOUT — OUTSIZE parameter sets the length of the data records to be received.

b. Bisync DS — Configuring the monitor, IODSO as subtype 0 will cause DS to transmit data in uncompressed format while subtype 1 will cause DS to compress transmitted data. Subtype 1 is recommended below 56000 BPS.

DSLINE — LINEBUF parameter sets the maximum size of the transmitted data block in the range of 304 to 1024 words (608 to 2048 bytes) if an INP is being used or 304 to 4095 words (608 to 8190 bytes) if an SSLC is being used.

COMP parameter overrides the system configured default turning compression on.

NOCOMP parameter overrides the system configuration turning compression off.

c. X.25 DS — Configuring the monitor, IODSX0 as subtype 0 causes DS to transmit uncompressed data while subtype 1 causes DS to transmit compressed data. Subtype 1 is recommended below 56000 BPS.

NETCONF Line Characteristics Table: The PACKET SIZE parameter set the maximum number of data bytes in a packet in the range of 32 to 1024 bytes.

d. MTS

The maximum number of characters to be transmitted in one write is 4096 (SSLC only).

The maximum number of characters to be received in one read is 2048.

Writes to peripheral devices attached to MTS terminals should be treated very carefully. Since the attached device may use a transfer rate that is lower than the communications line rate, checking transfer status after writing each record should be avoided because the status won't be available until after the transfer to the peripheral has been completed or interrupted and the status won't be returned to the user's program until the group/device is next polled. It is faster but slightly less secure to write several records in a block (programmer is controlling block length here) and then checking transfer status.

Other subsytems (Bisync/SDLC, IMF, MRJE, NRJE and SNA/IMF override the default buffer size parameter but are dependent on the host/FEP (Front End Processor) configuration parameters.

5. Protocol Dependencies

a. Half-duplex protocols.

Half-duplex protocols require an acknowledgment block to be returned for each data block transmitted. Only the data block in error will be re-transmitted although there may be some additional protocol overhead when data blocks are not perceived to be in error (i.e. when the acknowledgment is with-held or is lost). The time required for these relatively infrequent occasions will not be a part of this paper.

Two examples of half duplex protocol are Bisync (BSC - Binary Synchronous Communications), used on any type of communications facility, and SDLC (Synchronous Data Link Control), used on multipoint facilities (for example SDLC/IMF, SNA/IMF and NRJE).

b. Full-duplex protocols.

Full-duplex protocols require positive acknowledgments only when the transmit window size is reached. Negative acknowledgments indicate the number of the frame received in error (or not received at all) and require the re-transmission of not only the frame in error but also each frame transmitted after the frame in error. On paths with little delay this normally involves only the transmission of 2 frames (the frame in error and the frame following) but in paths with large delays it may be necessary to transmit 3 or 4 or more frames to correct the error and continue the transmission.

Examples of full duplex protocol are HDLC and its subsets SDLC and LAP/LAP-B (used for X.25).

It should be further noted that higher levels in the communications subsystem may degrade throughput even more by requiring end-to-end acknowledgments for each packet. DS/X.25 uses the "D" bit ON, requiring an end-to-end packet acknowledgment when used with Public Data Networks (PDNs).

c. Protocol overhead

The addition of protocol characters for error detection, addressing, control information, etc. adversely affects throughput. For Bisync, approximately 8 characters are added per block (4 sync characters, STX, ETB/ETX, 2 block check characters). HDLC adds between 6 bytes (2 flags, address octet, control octet, 2 frame check octets) and 7 bytes (2 control octets are used with window sizes between 8 and 127) plus bit-stuffing bits depending on the content of the data.

The exact number of sync characters sent in Bisync can be obtained from the CSTRACE Information Display in the DOPTIONS bits 14:2 as follows:

0= Send 4 Sync bytes
1= Send 8 Sync bytes
2= Send 12 Sync bytes
3= Send 16 Sync bytes

Higher levels in the full-duplex protocols add additional overhead in the for of message headers for each level, the content and length of which are beyond the scope of this paper.

6. Path length

Signal propagation through free space is approximately 186,000 miles (300,000,000 meters) per second or, inversely, 5.4 microseconds per mile (3.3 microseconds per kilometer). Since not all of the communications path passes through free space, a longer transit time is imposed on signals. A common value used for propagation is 1 millisecond per 100 miles of actual circuit path (not straight line mileage) which is about double the free space transit time.

When a satellite is encountered in a communications path, an additional delay of 250 to 300 milliseconds (earth-station to earth-station) transit time must be added to the overall delay due to circuit delay.

7. CPU/Interface servicing time

The time required for servicing (generating an acknowledgment or starting the next transmission) in the CPU/Communications Controller may be quite variable. Interface response time is small compared to the delays introduced by the modems and line paths and will be ignored here. CPU response time is dependent on parameters outside of the scope of this paper and will also be ignored.

C. Calculation of throughput

A model for the throughput of a link including the first 6 items above becomes:

$$\text{Throughput} = \frac{I * L * (1-P)}{((L+O) * T/S) + D) * (1-P) + (N * P)}$$

where :

- D = Delay between block transmissions
- I = number of Information bits per character
- L = Length of data block in characters
- N = Number of blocks to be re-sent on error
- O = number of Overhead characters per block
- P = Probability of error in a block
- S = Modem speed in BPS
- T = Total number of bits per character

Assumptions: Lost blocks and lost acknowledgments are ignored.
Errors are single bit errors (worst case)

Evaluations:

Probability of errors in a block

$$P = 1 - (1 - E) \wedge ((I + O) * T)$$

where E = Link error rate

Values often used for E are:

Analog lines 10^-5
Digital Lines 10^-6

For existing lines the actual value of E may be measured with a Bit Error Rate Test set as described above.

An alternate method of obtaining the probability of error when the error rate of a dedicated link is not known is as follows:

1. :SHOWCOM NN;RESET at location A

2. Send 1000 fixed length blocks with the communications subsystem at hand from location A to location B.

3. :SHOWCOM NN;ERRORS at location A. The probability of error on the link in the direction from location A to location B is:

$$P = \frac{\text{Retransmissions}}{\text{Messages Sent}}$$

as long as there are no response timeouts indicated.

Delay between blocks

The delay between blocks is the sum of:

1. The propagation delay from source to destination
2. The RTS/CTS delay of the destination DCE
3. The time required to send the acknowledgment which is:

$$D = \frac{X * T}{S}$$

where:

T = Total bits per character
X = Number of characters in the acknowledgment block
S= Line speed in BPS

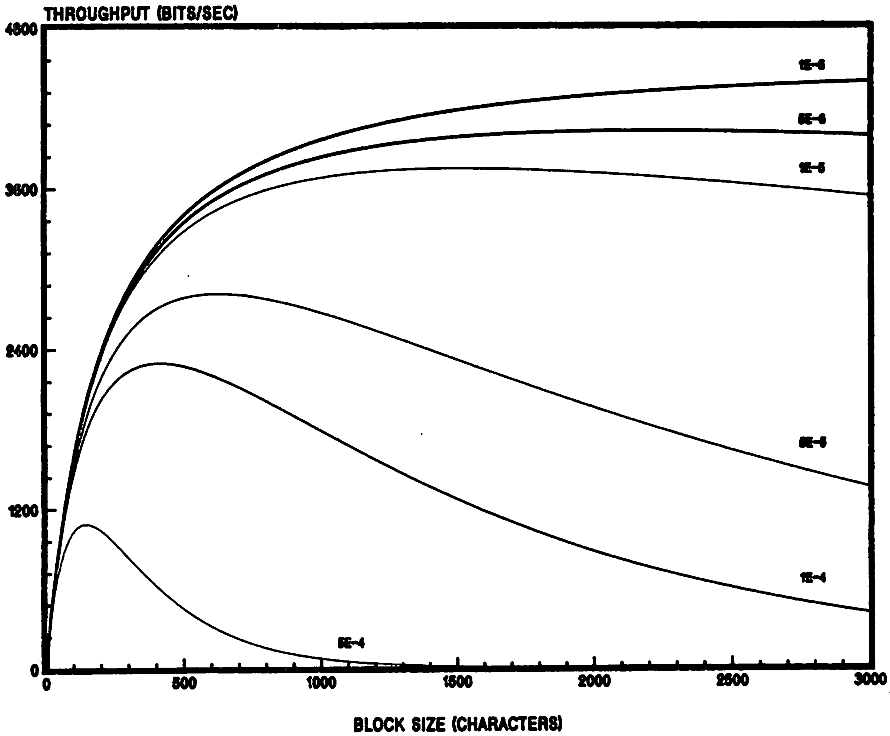
4. The RTS/CTS delay at the source DCE

D. Results

Results are presented below choosing block size as the independent variable because block size is the parameter most easily controlled by a computer user.

Figure 1 Throughput vs Line Error Rate
Figure 2 Throughput vs Modem/Line Type (Error Rate 1E-5)
Figure 3 Throughput vs Modem/Line Type (Error Rate 5E-5)
Figure 4 Throughput vs Propagation
Figure 5 Throughput vs Protocol

THROUGHPUT VS LINE ERROR RATE



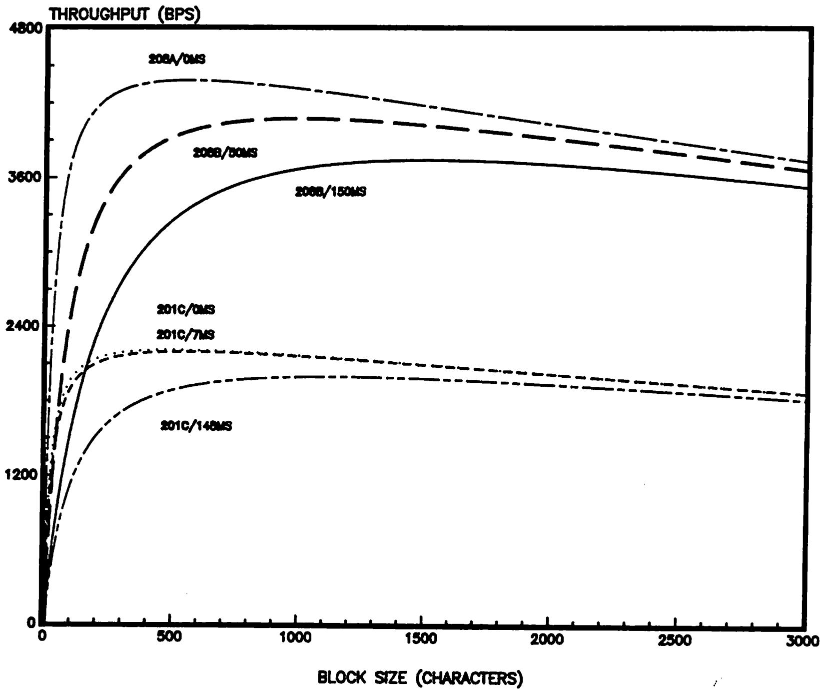
TEST CONDITIONS:

Data Bits/Char	8
Total Bits/Char	8
Overhead Char/Block	6
Modem Speed	4800 bits/sec
RTS/CTS Delay	150 MS
# Blocks Resent on Error	1
Length of Circuit	1000 Miles
Length of ACK Block	6

Figure 1

THROUGHPUT VS MODEM/LINE TYPE

ERROR RATE 1 IN 10^5



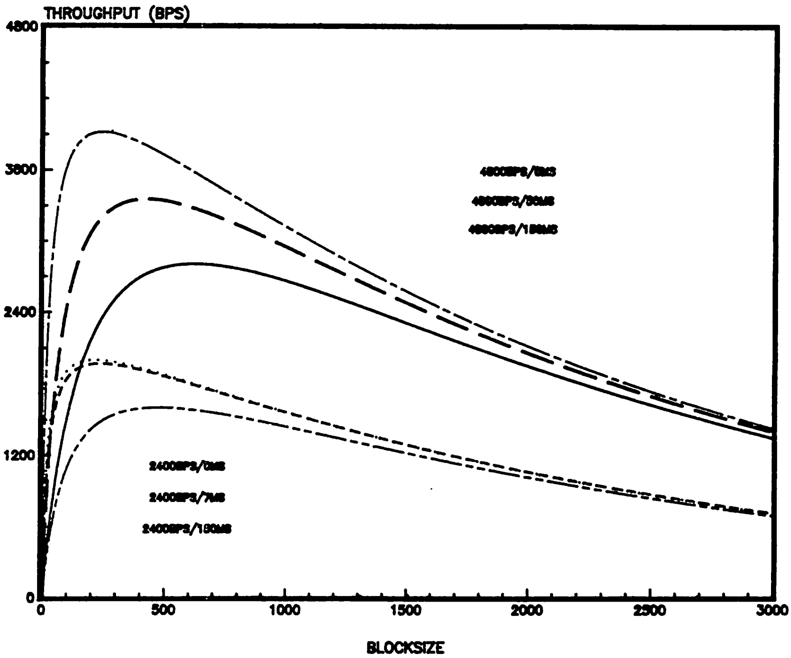
TEST CONDITIONS: (Error Rate 1E-5)

Data Bits/Char	8
Total Bits/Char	8
Overhead Char/Block	8
Blocks to Resend	1
Length of Circuit	1000 Miles
Length of ACK	6 Char

Figure 2

THROUGHPUT VS MODEM/LINE TYPE

ERROR RATE 5 IN 10^5

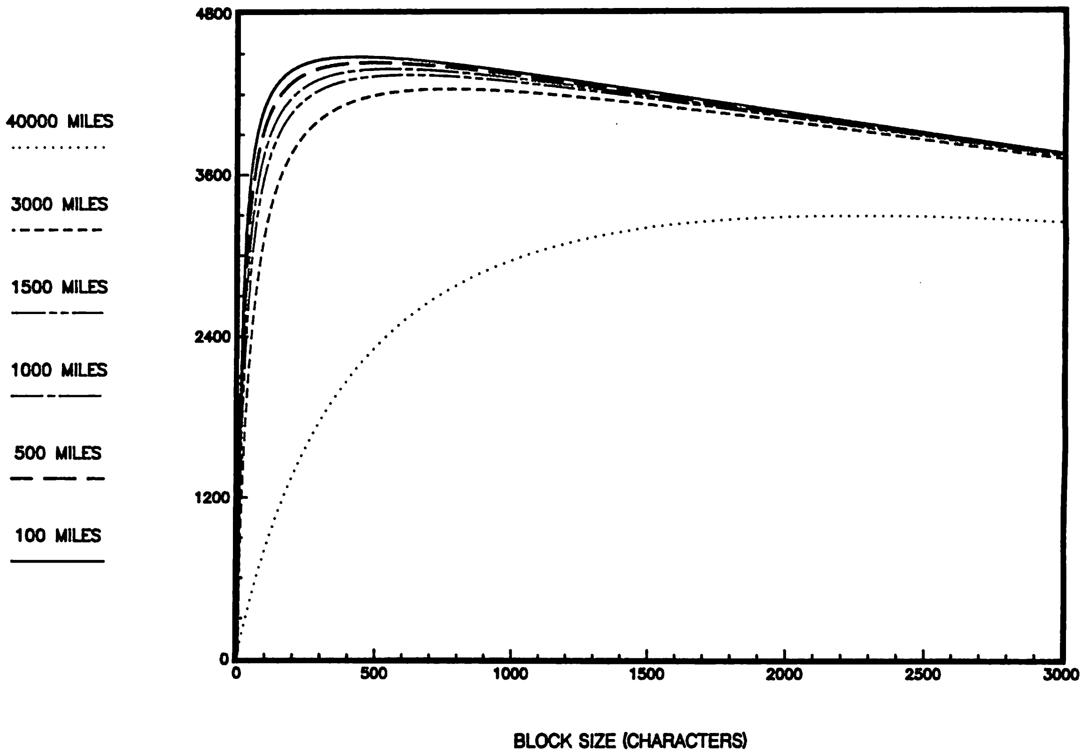


TEST CONDITIONS: (Error Rate 5E-5)

# Data Bits/Char	8
Total Bits/Char	8
#Overhead Char/Block	8
#Blocks to Resend	1
Length of Circuit	1000 Miles
Length of ACK	6 Char

Figure 3

THROUGHPUT VS PROPAGATION

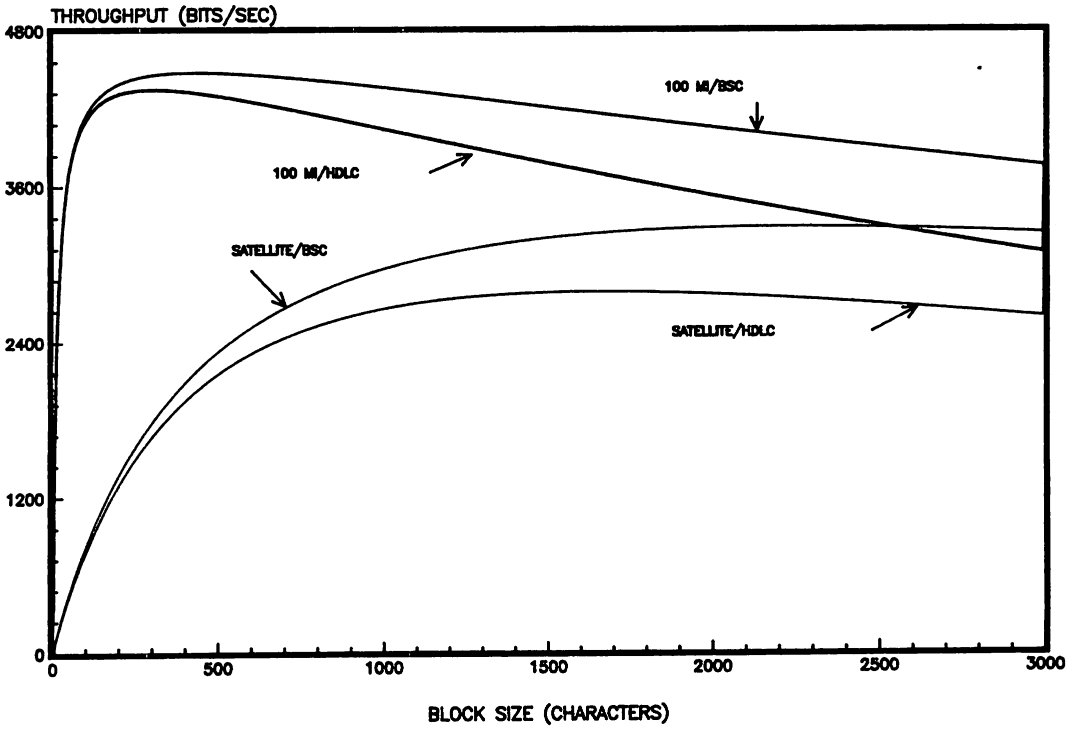


TEST CONDITIONS:

Error Rate	1E-5
Data Bits/Char	8
Total Bits/Char	8
Overhead Char/Block	8
Blocks to Resend	1
Length of ACK	6 Char
Speed	4800 Bits/Sec
RTS/CTS	0 MS

Figure 4

THROUGHPUT VS PROTOCOL



TEST CONDITIONS:

Line Speed	4800 Bits/Sec
RTS/CTS	0 MS
Length of ACK	8 Char
Data Bits/Char	8
Total Bits/Char	8
Error Rate	1E-5
Overhead Char/Block	8 Char

Figure 5

Section II.

A. MODEM Economics

Currently available synchronous modems vary widely in price (from under $300.00 to over $15,000.00), in speed (1200 to 56,000 BPS), in features (no frills to modems with internal 16-bit processors, network management, built-in diagnostic test equipment, keyboards, displays .. even modems that know their own serial numbers) and in support (send it back to the factory, spare-in-the-air, on-site same day service).

A method of normalization is suggested here: Select a minimum set of required features and compute **THROUGHPUT vs. PRICE.**

As can be seen from the graphs in section I, the error rate of the DCE and line combination has a pronounced effect on throughput (Figure 1). If a half-duplex MODEM is required, synchronization/training time becomes a factor; however, this is a figure which may be obtained directly from the manufacturers data sheet.

Error rate, on the other hand, while it may be mentioned, is not usually accompanied by much supporting data. Asking the vendor "What were the measurement conditions - signal-to-noise ratio, amplitude distortion, phase jitter, etc.?" or "Were the impairments used in testing this MODEM applied one at a time or if applied in combination, what were the combinations?" usually elicits a vague response of "Hmmm, uh, I guess I'd have to call the factory for that information but our company tests our MODEMs real well," if there is any response at all.

In addition to the MODEM error rate question above, how does the communications facility measure up? Will a conditioned line be required? Should a digital facility be considered?

The answers to these questions can be obtained by a judicious choice of how to test the candidate MODEMs.

B. Measuring Modem Quality

1. Live link testing

Probably the simplest method of determining the quality of a particular model of MODEM is to connect the candidate MODEM pair to an existing line and comparing the throughput of the candidate pair with that of the pair previously in use by applying one of the error rate test methods noted above.

This method has severe limitations in that it tests the candidate MODEM pair under only one set of line conditions, namely that set of conditions existing at the time of the test on the live circuit.

How can we tell how the MODEM will react under other conditions on other lines?

2. Impairment Distribution

Studies performed on the U.S. Bell telephone system between 1959 and 1970 (1970 is the latest survey for which results have been published) have provided information on the distribution of impairments to be found on a very large number of lines. A summary of these studies is included as Figure 6.

PERCENT OF LINES

IMPAIRMENT	10	20	30	40	50	60	70	80	90	95
ATTENUATION	C4	C2	C1	C1	C1	C1	C1	UN	UN*	
DELAY	C4	C2	C2	C2	C1	C1	C1	C1	C1	C1
SIGNAL/NOISE	43	41	40	39	38	36	34	33	28	27
FREQ. SHIFT	0	0	0	0	.1	.2	.4	.7	1.1	2
PHASE JITTER	2	3	3.5	3.8	4	5	6	7	8	9
2ND HARMONIC	47	44	42	41	39	37	36	34	31	29
3RD HARMONIC	45	44	43	41	39	36	35	34	32	31*

*UNCONDITIONED LINE LIMIT

Figure 6

In the first two rows of Figure 6, the designations C1, C2, C4 and UN refer to the leased line conditioning specifications. A summary of these specifications is provided as Figure 7.

CONDITIONING LEVEL

	UNCONDITIONED	C1	C2	C4
FREQ RANGE	300-3000Hz	3000-3000Hz	300-3000Hz	300-3200Hz
RESPONSE RANGE / DB VAR.	300-3000 / -3 TO +12 500-2500 / -2 TO +8	300-2700 / -2 TO +6 1000-2400 / -1 TO +3 300-3000 / -3 TO +12	300-3000 / -2 TO +6 500-2800 / -1 TO +3	300-3200 / -2 TO +6 500-3000 / -2 TO +3
DELAY DIST.(uS) VALUE / FREQ	<1750uS / 800-2600Hz.	<1000uS / 1000-2400Hz <1750uS / 800-2600Hz.	<500uS / 1000-2600 Hz <1500uS / 600-2600Hz <3800uS / 500-2800 Hz	<300uS / 1000-2600Hz <500uS / 800-2800Hz <1500uS / 600-3000Hz <3000uS / 500-3000Hz
IMPULSES	15 COUNTS / 15 MIN.	15 COUNTS / 15 MIN.	15 COUNTS / 15 MIN.	15 COUNTS / 15 MIN.

Figure 7

Please note that in reading Figure 6, the entries represent that a line in a particular percentile column will have impairments no greater than the amount shown.

The problem now is to find a hundred or so lines to sample that fall into the summary chart within the percentage of confidence that we'd like to have in our choice of MODEM and then test our candidate MODEM pair on each of these lines.

Fortunately there is a better solution and it might be designated ' multiple parameter simulation ' for want of a shorter name.

3. Simulation testing

The simulation testing method is quite simple. Only three pieces of equipment are required:

1. A candidate MODEM
2. A Bit Error Rate Test set (BERT)
3. A line simulator.

The test procedure consists of completing the following steps:

1. Connect the output of the candidate MODEM to the input of the line simulator.
2. Connect the input of the candidate MODEM to the output of the line simulator.
3. Connect the BERT to the candidate MODEM.
4. Power up all of the equipment.
5. **SET UP THE LINE SIMULATOR FOR THE APPROPRIATE TEST CONDITIONS**.
6. Start the BERT.
7. Record the results.
8. Repeat steps 5, 6 and 7 a few hundred times.

The key to success here, of course, is knowing how to set up the line simulator.

C. Comparative testing

Examining the ranges of the parameters in Figures 6 and 7 and translating them into combinations useful for the limited number of tests which can be run economically is not difficult. Combinations of impairments might be chosen so that the tests run are statistically representative of the universe of actual circuits but that is another thing that is beyond the scope of this paper. Let us choose a set of tests that are useful in COMPARING the performance of our candidate MODEMS under varying line conditions by subjecting them to test conditions which are likely to occur on a large percentage of available lines.

The error rates determined in these tests will lead to the

THROUGHPUT VS PRICE

used to select the most economic unit.

Figure 8 shows a mapping of the digits 0 through 9 to the quantized impairment levels which were not exceeded in 95% of the lines tested in the 1969/1970 U.S. Bell System survey.

IMPAIRMENT	RANDOM NUMBER 0	1	2	3	4	5	6	7	8	9
ATTENUATION	C4	C2	C1	C1	C1	C1	C1	UN	UN*	UN
DELAY	C4	C2	C2	C2	C1	C1	C1	C1	C1	C1
SIGNAL/NOISE	43	41	40	39	38	36	34	33	28	27
FREQ. SHIFT	0	0	0	0	.1	.2	.4	.7	1.1	2
PHASE JITTER	2	3	3.5	3.8	4	5	6	7	8	9
2ND HARMONIC	47	44	42	41	39	37	36	34	31	29
3RD HARMONIC	45	44	43	41	39	36	35	34	32	31*
IMPULSE NOISE	-18	-16	-14	-12	-10	-8	-6	-4	-2	0

*UNCONDITIONED LINE LIMIT

Figure 8

To determine the parametric combinations necessary to set up the line simulator simply generate a series of random numbers of N digits (one digit for each type of impairment covered by the line simulator) and apply each of the digits to a corresponding parameter type and level.

For example, if the random number is **42633409** the line simulator setup might be:

digit	parameter	level
4	Attenuation Distortion	C1
2	Envelope (delay) Distortion	C2
6	Signal-to noise ratio	34 dB
3	Frequency Shift (offset)	0 Hz.
3	Phase Jitter	3.5 Degrees
4	Second Harmonic Distortion	-39 dB
0	Third Harmonic Distortion	-45 dB
9	Impulse Noise	0 dB.

Impulse noise repetition rate should be set to create 15 *counts per 15* minutes of test duration.

If a bit error rate test of 10^6 bits is to be performed on a 4800 BPS MODEM each test setup will require about 3.5 minutes (10^6 bits / 4800 bits per second) to complete. Allowing 2.5 minutes to note the end of test, record the result and set up the next test, shows that 100 test will take about 10 hours. If you were to test all of the 8 impairment types with the ten levels shown in Figure 8, the time required would be approximately 190 years neglecting time out for coffee breaks.

D. Presenting the results

Since each of the 100 or so tests performed above has an individual result, comparing candidate MODEMs on a test-by-test basis can still be difficult. However, if one simply multiplies the number of bits per test by the number of test performed, subtracts the total number of errors and divides by the number of tests times the time per test, the results will be:

$$\text{Throughput} = \frac{\text{Number of bits correctly transmitted}}{\text{Time to correctly transmit the bits}}$$

It is now a simple matter to **COMPARE** candidate MODEMs using

THROUGHPUT VS PRICE

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Biography

Sallie Kay Stodghill has been with AMFAC Distribution for just over 1 year during which she has participated in the design of AMFAC's network of over 100 HP3000 computers. She is currently in the process of installing and managing this network. A graduate of Mills College in Oakland, California, with degrees in mathematics and computer science, Mrs. Stodghill has been employed by both Hewlett-Packard and Tandem Computer Co. in the field of data communications for .... years.

Jack Hymer has been employed by Hewlett-Packard for 10 years in the Bellevue, Washington Sales and Service office. He is currently a Network Consultant. Mr. Hymer graduated from the University of Washington in 1973 with a BSEE after working as a communications technician for 9 years.