Data compression Techniques in Modern Communication Networks for Enhanced Bandwidth Utilization

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***Abstract*:**

This study represents an exploration of the advantages of compression of data for storage and transmission .The significance of compressing data cannot be overestimated in light of the mushrooming applications and globalization of communication.

The study traces the development of communication networks in terms of their diversity of applications that we feel in our daily lives. Several compression algorithms have been developed to make transmission and storage of data more efficient as the volume of data transmitted grew. The study discusses the distinguishing features of these algorithms in terms of their applications. Simulation is an important tool for modeling a network to determine its performance characteristics. The study outlines the components of the simulation topology, i.e., nodes, links and arcs and simulation methodology pertaining to link utilization, WAN cloud, and message sources as a backdrop to simulation of data transmission. The core of the study is the analysis and discussion of simulation results. Simulations are done for different applications, i.e., e-mail using Huffman coding.

Keywords: *Compression, Huffman Coding, Link Utilization, channel utilization and e-mail application.*

The INCM (Intelligent Networks Conceptual Model) of ITU-T has four planes (see **Figure 1** [1]):

- **The Service Plane**
- **The Global Functional Plane**
- **The Distributed Service Plane**
- **The Physical Plane**

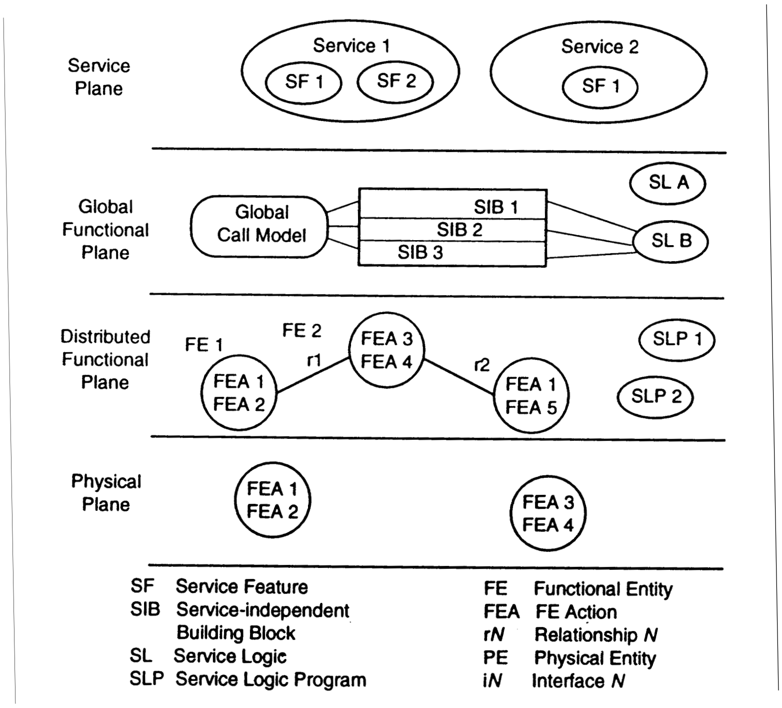


Figure 1: Conceptual Model of Intelligent Networks (INCM)

Numerous IN capabilities are referred to as capabilities sets (CSs). Requirements for one or more of the six essential groups of functions within most INs and AINs (Advanced Intelligent Networks) are: (a) Service Creation; (b) Service Management; (c) Service Interaction; (d) Network Management; (e) Service Processing; and (f) Network Interworking.

Service Plane and Global Functional Plane at Functional and Physical levels are shown in **Figures 1and 2** [1].

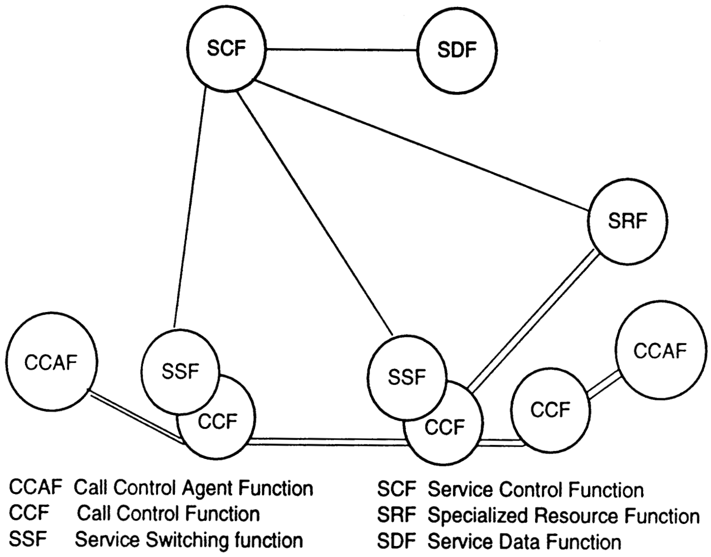
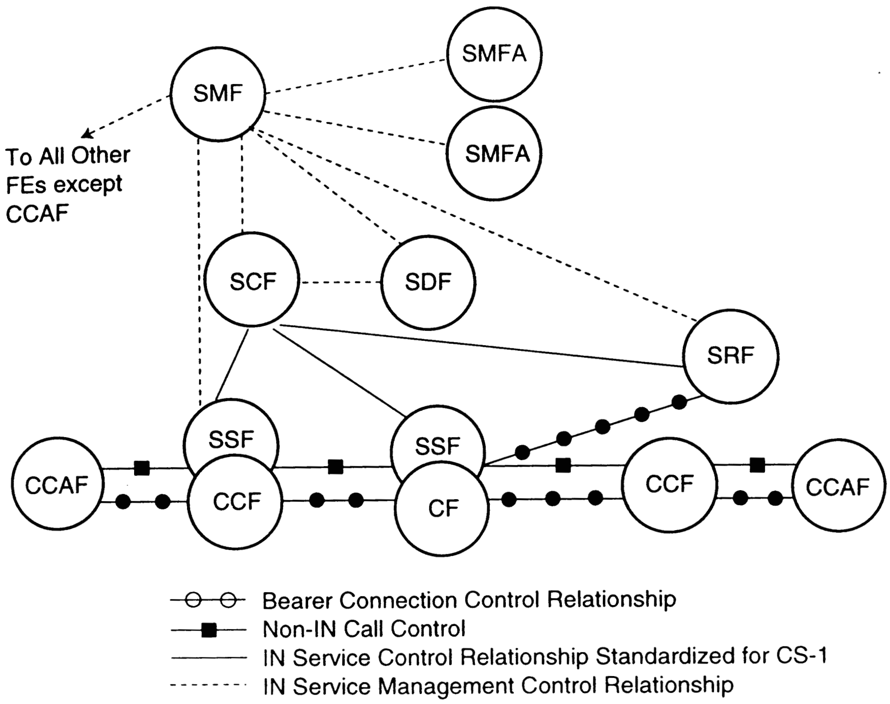


Figure 2: Functional Relationships for CS-1

(Q1211 specification). CCAF = call control access function; CCF = call control function; CF = control function; SCF = service control function; SDF = service data function; SMF = service management function; SMAF = service management access function; SRF = specialized resource function; SSF = service switching function



Computer Communications in Developing Countries (DCs) take on added significance in light of low telephone penetration. Computers can be used to rapidly distribute text materials (including graphics etc), which need not necessarily be viewed on a computer monitor, but can also be printed as hardcopy to be displayed as posters, put on conventional bulletin boards, filed in subject folders etc. This is as important as the direct use of email and news by the relatively few individuals with access to a computer and phone line. In addition, the computer access to libraries and databases that is so useful in developed countries, could be even more useful in developing countries where direct library services are so poor.

In developing countries e-mail should have an even greater advantage over fax due to the higher cost of dedicating a phone line to a fax machine (whereas it is comparatively easy for e-mail to use a no dedicated line shared with voice calls). The extremely low telephone penetration and lack of circuits between the capital cities and some major regional centers (let alone small towns and villages), severely limits the section of the population that can directly benefit from any form of telecommunications in developing countries.

1. DATA COMPRESSION

One of the hottest imaging technologies is compression. In the early stages, compression was limited to JPEG, GIF and Group 3 fax. Compression technologies have multiplied. Now there are also Group 4, PNG, wavelet and fractal compression. Compression is applied to still images, audio and video. Three reasons to compress: save storage space, conserve bandwidth, and speed up application software.

Data compression has important application in the areas of data transmission and data storage. Many data processing applications require storage of large volumes of data, and the number of such applications is constantly increasing as the use of computers extends to new disciplines. At the same time, the proliferation of computer communication networks is resulting in massive transfer of data over communication links. Compressing data to be stored or transmitted reduces storage and/or communication costs. When the amount of data to be transmitted is reduced, the effect is that of increasing the capacity of communication channel. Similarly, compressing a file to half of its original size is equivalent to doubling the capacity of the storage medium. It may then become feasible to store the data at a higher, thus faster, level of the storage, hierarchy and reduce the load on the input/output channels of the computer system.

2. HUFFMAN CODING

Huffman coding converts the pixel brightness values in the original image to a new variable-length codes, based on their frequency of occurrence in the image.

Huffman coding is a statistical data-compression technique. This technique will reduce the average code length used to represent the symbols of data-brightness values. The Huffman coding ensures that the longest codes get assigned to the least frequent brightness and vice versa.

The brightness values are first listed in descending order of frequency of occurrence. The two at the bottom of the list (least frequent) are paired together into a node with a joint probability- the probabilities are combined. This new node is labeled 0 and 1. The next two lowest frequencies of occurrences are determined and paired. The new node gets the joint probability and is labeled 0 and 1. This continues until all brightness are paired.

Example:

A string of characters to be transmitted is ‘s_1 through s_8’. The relative frequency of each character is as follows:

$s_1, s_2 = 0.25, \quad s_3, s_4 = 0.14, \quad s_5, s_6, s_7, s_8 = 0.055$

According to Shannon’s formula, the minimum average number of bits/character (entropy H [22]) is 8.

$$H = - \sum_{i=1} p(s_i) \log_2 p(s_i) \text{ bits per codeword}$$

$$H = -(2 * 0.25 \log_2 0.25) + 2 * 0.14 \log_2 0.14 + 4 * 0.055 \log_2 0.055)$$
$$= 1 + 0.794 + 0.921 = 2.715 \text{ bits/codeword}$$

Codeword Generation: Huffman Code generation is presented in **Table -1**.

s_1 0.25	**s_1 0.25**	**s_1 0.25**	**s_1 0.25**	**s_{34} 0.28**	**s_{25678} 0.47**	**s_{134} 0.53 (1)**	**Root $s_{12345678}$ 1.00**
s_2 0.25	**s_2 0.25**	**s_2 0.25**	**s_2 0.25**	**s_1 0.25**	**s_{34} 0.28 (1)**	**s_{25678} 0.47 (0)**	
s_3 0.14	**s_3 0.14**	**s_3 0.14**	**s_{5678} 0.22**	**s_2 0.25 (1)**	**s_1 0.25 (0)**		
s_4 0.14	**s_4 0.14**	**s_4 0.14**	**s_3 0.14 (1)**	**s_{5678} 0.22 (0)**			
s_5 0.14	**s_{78} 0.11**	**s_{78} 0.11 (1)**	**s_4 0.14 (0)**				
s_6 0.055	**s_5 0.14 (1)**	**s_{56} 0.11 (0)**					
s_7 0.055 (1)	**s_6 0.055 (0)**						
s_8 0.055 (0)							

Weight order = 0.055 0.055 0.055 0.055 0.11 0.11 0.14 0.14 0.22 0.25 0.28 0.47 0.53

Huffman Code:

Symbol	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
$p(s_i)$	0.25	0.25	0.14	0.14	0.055	0.055	0.055	0.055
Codewords	10	01	111	110	0001	0000	0011	0010
#bits	2	2	3	3	4	4	4	4

Average number of bits/codeword using Huffman coding is:
2 (2 * 0.25) + 2 (3 * 0.14) + 4(4 * 0.055) = 2.72 bits/codeword that is, 99.8% of Shannon's value.

3. DATA COMPRESSION APPLICATIONS TO NETWORKS

Two most common applications: **(1) Data storage:** A body of data is compressed before it is stored on some digital storage device, for example, a computer disk or tape. This process allows more data to be placed on a given device. When data is retrieved from the device, it is decompressed; and **(2) Data communications:** Communication lines that are commonly used to transmit digital data include cables between a computer and storage devices, phone lines, and satellite channels. A sender can compress data before transmitting it and the receiver can decompress the data after receiving it.

E-mail

Along with the Web, electronic mail is one of the most popular Internet applications. E-mail is asynchronous- people send and read messages when it is convenient for them, without having to coordinate with other peoples' schedules. E-mail requires fully reliable data transfer, that is, no data loss. E-mail can make use of as much or as little bandwidth as happens to be available. Development of data compression algorithms has come close on the heels of the popularity of e-mail application. Two compression algorithms, Huffman Coding and Lempel-Ziv-Welch (LZW) are used in this study to simulate e-mail application (Ch

Typical compression rates used for simulation for different applications are shown in **Table 2** below.

Algorithms	**Huffman Coding**	**LZW**	**MPEG-1**	**MPEG-2**
Applications				
E-mail	compression rate: 40%	compression rate: 60%		

4. SIMULATION

Network simulation is a valuable tool because it provides a means for modeling a network to determine its performance characteristics. Performance assessment includes accuracy, reliability, queuing, traffic, versatility, etc. Network simulation provides a means of testing proposed changes prior to placing them into effect, performing what-if analysis concerning the reliability of key components in a network and the effects of losing a component, planning for future growth, and planning the initial design of a proposed network. The cost associated with the building and operating of a network make simulation a viable option in making choices in the building, modification, and performance analysis of a network.

4.1. Simulation Tools

Systems designers and network planners are increasingly looking for support tools to help them decide on the best design. They use the results from these tools to make their cases to clients and management. Companies like Compuware (formerly CACI) provide analysis tools for this purpose. COMNET III (a Compuware product), used in this study is a graphical software package. It is designed to accurately estimate the overall performance characteristics of computer and communication networks. A network description is created graphically using a window interface. The application was formulated primarily for the modeling of both Wide Area Networks (WANs) and Local Area Networks (LANs).

4.2. Link Utilization

We have three categories in links: **(1) Channel Utilization; (2) Utilization by Application;** and **(3) Utilization by Protocol.**

Channel Utilization

The channel utilization provides the breakdown of the utilization rates for links used to carry connectionless and VC messages. It presents the number of link layer frames delivered and resent due to error (rst/err), and transmission delays and link utilization.

- **Frames Delivered**
  are the number of frames removed from the output buffer at the transmitting node on the link and subsequently placed in the input buffer of the receiving node. Frames that are in transmission are not included as part of the data generated because of transmission delay and propagation delay.
- **Frames Resent/Error** (rst/err)
  are the number of retransmitted frames.

- **Transmission Delay**
  is the time between when the frame (contains part of a packet/several packets) is created at the input to the link and when the frame is delivered at the end of the link. It includes transmission and propagation time and the time is measured in milliseconds. The average, standard deviation, and maximum delay are observed for any packet across the link.
- **Link Utilization**
  The transmission time for a frame is calculated from its size divided by the link speed. The link is in use for this time. Utilization is the total usage time divided by the simulation run length.

Utilization by Application

The utilization by application provides a breakdown of link usage by application for connectionless and virtual circuit messages. In this category the number of packets delivered, packets/second, bytes delivered, kilobits/second (KBPS) delivered, the percentage of bytes in the category and the link utilization percentage produced by packets, are observed.

- **Packets Delivered**
  The number of packets per application routed by the link.
- **Packets/Second**
  The number of packets/second (pps), per application routed by the link.
- **Bytes Delivered**
  Number of bytes delivered per application by the link.
- **KBPS Delivered**
  Number of kilobits per second delivered by the link per application
- **% Bytes**
  Percentage of total bytes delivered by the link for each application using the link.
- **Utilization %**
  Percent utilization of the link per application

Utilization by Protocol

The utilization by protocol report provides a breakdown of link usage by protocol. The statistics in this category are identical to those in Utilization by Application.

5 . E-Mail

Along with the Web, electronic mail is one of the most popular Internet applications. E-mail is asynchronous- people send and read messages when it is convenient for them, without having to coordinate with other peoples' schedules. E-mail requires fully reliable data transfer, that is, no data loss. E-mail can make use of as much or as little bandwidth as happens to be available. Of course, the higher the bandwidth the better. Two compression algorithms, Huffman Coding and Lempel-Ziv-Welch (LZW) are used to simulate e-mail application.

The compression rates for Huffman coding and LZW are 40% and 60%, respectively. In each case, the message size is 100 bytes, warmup length (specifies the time in the simulation when the application will begin to collect data) is 10 seconds and replication length (the number of seconds of simulated time during which statistics are collected for each report) is 50 seconds. The bandwidth used for simulation run is 64kbps for each compression algorithm. Telecommunication traffic is often described as a Poisson process. The number of messages in successive time intervals has been observed. The distribution of the number of observations in an interval is Poisson distributed. The parameter entered for the Poisson distribution is the interarrival time (IAT, the time from the start of one message to the start of the next). The total number of simulation runs for both algorithms are 20. Each simulation ran for approximately 2 minutes. The simulation run statistics for compressed and uncompressed data for the first algorithm, Huffman Coding are shown in **Tables.1** and.**2**, respectively.

Examination of the data in **Tables 3** and **4**show that as the bandwidth increases:

1. IAT decreases
2. Packets/Second increase
3. Bits/Second increase
4. Simulation run time is the same for bandwidth runs and the message size used for E-mail is small.
5. The rate of transmission for compressed data at each bandwidth is less than for uncompressed data.

As the tables show, when IAT decreases, the number of packets/second increases linearly in both data types. This is depicted in**2** and **3**.

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As the tables show, when IAT decreases, the number of packets/second increases linearly in both data types. This is depicted in **Figures 3& 4**

Bandwidth: 64kbps, Replication Length: 50s					
Message Size: 100 bytes = 800 bits					
Huffman Code (40%)	**Bandwidth Used for Simulation**				
	50%	**60%**	**70%**	**80%**	**90%**
InterArrival Time (IAT) Poisson Distribution (poi)	0.0425	0.0354	0.0303	0.0263	0.0238
Packets/Second(pps)	24	28	33	38	43
Bits/Second(bps)	19200	22400	26400	30400	34400
Simulation Time (min)	2	2	2	2	2

Table 3: E-mail (Huffman) Simulation Run Statistics for Compressed Data

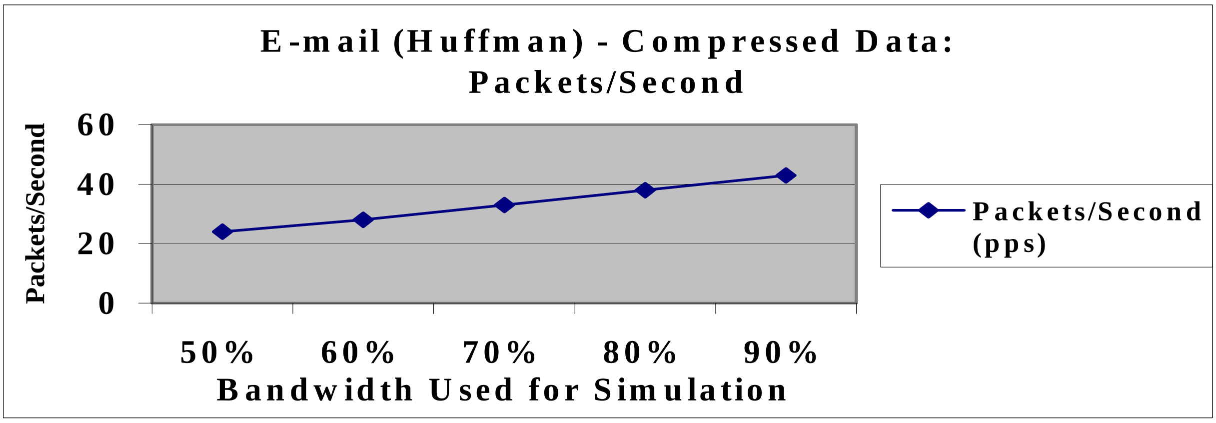

Figure 3: E-mail (Huffman) - Compressed Data: Packets/Second

Bandwidth: 64kbps, Replication Length: 50s					
Message Size: 100 bytes = 800 bits					
Huffman Code (40%)	**Bandwidth Used for Simulation**				
	50%	**60%**	**70%**	**80%**	**90%**
InterArrival Time (IAT) Poisson Distribution (poi)	0.025	0.021	0.018	0.016	0.014
Packets/Second(pps)	40	48	56	64	72
Bits/Second(bps)	32000	38400	44800	51200	57600
Simulation Time (min)	2	2	2	2	2

Table 4: E-mail (Huffman) Simulation Run Statistics for Uncompressed Data

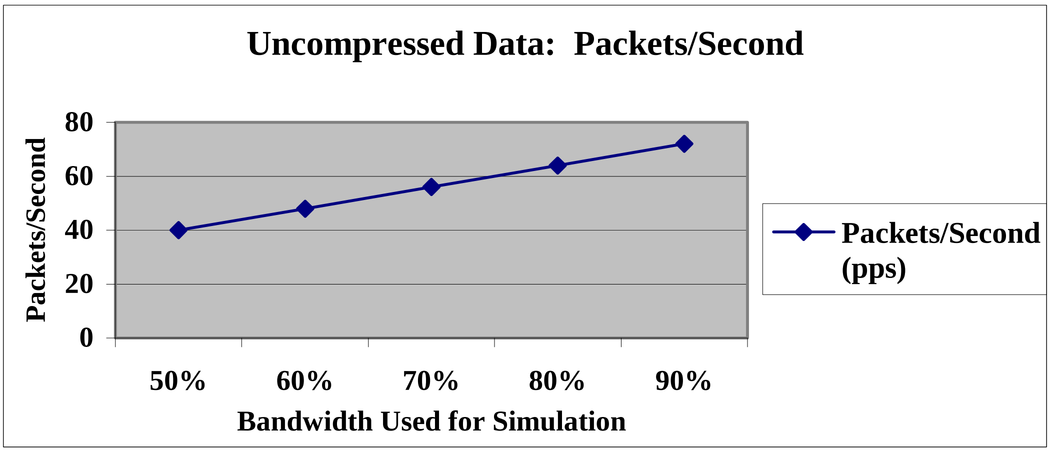

Figure 4: E-mail (Huffman) - Uncompressed Data: Packets/Second

Huffman coding

Huffman Coding is chosen for E-mail compression because text compression seems natural for it. In text, we have a discrete alphabet that has relatively stationary probabilities. For example, the probability model for a particular message will not differ significantly from that of another message.

Reports are produced automatically at the end of each simulation run. COMNET III generates a statistical report of Link Utilization for various processing nodes as shown in **Tables3** and **4** for compressed and uncompressed data, respectively. The number of frames delivered is equal to the number of packets delivered from each link for E-mail application.

Analysis

- **Compressed Data**

The number of packets delivered from Mumbai to Trivandrum is 1223 at 50% bandwidth, but at 60% bandwidth, it is 1191, a decrease of 3 percent. As shown in **Table 4**, the link utilization rate went down as well by 0.03% at 60%, from 30.58% to 29.78%. The number of packets delivered at 70% increased to 1567, up by 31.5% from 60% bandwidth, but decreased to 1224 at 80% and again increased to 1613 at 90%. From Mumbai to Bangalore link, notice a gradual increase from 50% to 60% bandwidth, but a decrease at 70% and an increase at 80% and 90%. From Hyderabad to Bangalore and Trivandrum to Hyderabad, however, the number of packets delivered increases as bandwidth increases. The link utilization also goes up for both links.

Application: E-mail (64kbps), Huffman Code (40%) Message Size = 100 bytes, Replication Length = 50s, Simulation Time = 2min					
Compressed Data	**Bandwidth Used for Simulation**				
Link	**50% 19.2kbps**	**60% 22.4kbps**	**70% 26.4kbps**	**80% 30.4kbps**	**90% 34.4kbps**
From Mumbai-Trivandrum					
Frames/Packets Delivered	1223	1191	1567	1224	1613
Packets/second	24.460	23.820	31.340	24.480	32.260
Bytes Delivered	122300	119100	156700	122400	161300
KBPS Delivered	19.568	19.056	25.072	19.584	25.808
Utilization (%)	30.58	29.78	39.18	30.60	40.33
From Mumbai-Bangalore					
Frames/Packets Delivered	1592	1629	1593	1707	1867
Packets/second	31.840	32.580	31.860	34.140	37.340
Bytes Delivered	159200	162900	159300	170700	186700
KBPS Delivered	25.472	26.064	25.488	27.312	29.872
Utilization (%)	39.83	40.73	39.85	42.70	46.68
From Hyderabad-Bangalore					
Frames/Packets Delivered	1347	1365	1545	2257	2463
Packets/second	26.940	27.300	30.900	45.140	49.260
Bytes Delivered	134700	136500	154500	225700	246300
KBPS Delivered	21.552	21.840	24.720	36.112	39.408
Utilization (%)	33.68	34.13	38.63	56.43	61.60
From Trivandrum-Hyderabad					
Frames/Packets Delivered	1308	1433	1611	1889	2321
Packets/second	26.160	28.660	32.220	37.780	46.420
Bytes Delivered	130800	143300	161100	188900	232100
KBPS Delivered	20.928	22.928	25.776	30.224	37.136
Utilization (%)	32.70	35.83	40.28	47.23	58.03

Table 5: E-mail (Huffman) - Links: Channel Utilization/Utilization by Application for Compressed Data

Uncompressed Data

There is an increase in the number of packets delivered from Mumbai-Trivandrum from 1515 at 50% bandwidth to 3275 at 70% bandwidth, as shown in **Table 6.** The number of packets delivered at 80% (3049) and 90% (2863) bandwidths decreases by 7% and 6%, respectively. The utilization of Mumbai-Trivandrum link increases from 50% to 70% and decreases at 80% and 90% bandwidths. From Mumbai-Bangalore link notice a gradual increase in the number of packets delivered from 1747 (at 50%), to 2738 (at 60%). However, the number of packets delivered at 70% is 2441, a decrease of 11%. At 80% (3032) and 90% (3364) bandwidths the number of packets delivered increases again by 24% and 11%, respectively. Similarly, an increase in the number of packets delivered from Hyderabad-Bangalore link is observed, 2272 at 50%, 2664 at 60%, 2118 at 70%, 3014 at 80% and 3655 at 90%. The utilization rate of both Mumbai-Bangalore and Hyderabad-Bangalore links decreases at 70%. From Trivandrum-Hyderabad link the number of packets delivered and utilization rate increase linearly from 50% bandwidth to 90% bandwidth.

Application: E-mail (64kbps), Huffman Code (40%) Message Size = 100 bytes, Replication Length = 50s, Simulation Time = 2min					
Uncompressed Data	Bandwidth Used for Simulation				
Link	50% 32kbps	60% 38.4kbps	70% 44.8kbps	80% 51.2kbps	90% 57.6kbps
Mumbai-Trivandrum					
Frames/Packets Delivered	1515	2299	3275	3049	2863
Packets/second	30.300	45.980	65.500	60.980	57.260
Bytes Delivered	151500	229900	327500	304900	286300
KBPS Delivered	24.240	36.784	52.400	48.874	45.808
Utilization (%)	37.88	57.50	81.88	76.25	71.60
Mumbai-Bangalore					
Frames/Packets Delivered	1747	2738	2441	3032	3364
Packets/second	34.940	54.760	48.820	60.640	67.280
Bytes Delivered	174700	273800	244100	303200	336400
KBPS Delivered	27.952	43.808	39.056	48.512	53.824
Utilization (%)	43.68	68.45	61.03	75.83	84.13
Hyderabad-Bangalore					
Frames/Packets Delivered	2272	2664	2118	3014	3655
Packets/second	45.440	53.280	42.360	60.280	73.100
Bytes Delivered	227200	266400	211800	301400	365500
KBPS Delivered	36.352	42.624	33.888	48.224	58.480
Utilization (%)	56.80	66.60	52.95	75.35	91.40
Hyderabad-Trivandrum					
Frames/Packets Delivered	1933	2294	2641	2806	3523
Packets/second	38.660	45.880	52.820	56.120	70.460
Bytes Delivered	193300	229400	264100	280600	352300
KBPS Delivered	30.928	36.704	42.256	44.896	56.368
Utilization (%)	48.33	57.33	66.05	70.15	88.08

Table 6: E-mail (Huffman) - Links: Channel Utilization/Utilization by Application for Uncompressed Data

Thus First row in Tables 3 and 4 represents packets delivered during the simulation. They fluctuate for some links and increase as the bandwidth increases for others. This fluctuation could be a function of network delay and/or link/node failure.

Fluctuations in:

- Packets/Second (Packets Delivered/Replication Length, 50s);
- Bytes Delivered (Packets Delivered * Message Size);

- KBPS (Packets/Second * Message Size * 8bits); and
- Link Utilization

can be seen as reflections of the fluctuations in packets delivered. Thus the utilization rate for compressed data is consistently lower than for uncompressed data. This implies that compression permits transmission of larger volume of data in shorter intervals.

E-mail (Huffman)	**Link Utilization (%)**	
Link	**Compressed Data**	**Uncompressed Data**
From Mumbai=Trivandrum		
50%	30.58	37.88
60%	29.78	57.50
70%	39.18	81.88
80%	30.60	76.25
90%	40.33	71.60
From Mumbai-Bangalore		
50%	39.83	43.68
60%	40.73	68.45
70%	39.85	61.03
80%	42.70	75.83
90%	46.68	84.13
From Hyderabad-Bangalore		
50%	33.68	56.80
60%	34.13	66.60
70%	38.63	52.95
80%	56.43	75.35
90%	61.60	91.40
From Trivandrum-Hyderabad		
50%	32.70	48.33
60%	35.83	57.33
70%	40.28	66.05
80%	47.23	70.15
90%	58.03	88.08

Table 7: E-mail (Huffman) - Comparison of Utilization (%) for Compressed & Uncompressed Data

		Ranges	
Application	**Compression Algorithm**	**Compressed Data**	**Uncompressed Data**
E-mail	**Huffman**		
Packets Delivered		330 – 750	225 – 610
Packets Dropped		129 – 347	161 – 435
Drop Rate (%)		30 – 75	41 – 142

Conclusion

Simulation runs ranged over applications like e-mail. Links and Message and Response Sources are used in simulating the results. Five bandwidth percentages are used to observe the variation in utilization rate (Links), drop rate and packets-dropped/packets-delivered ratio (Message and Response Sources). Channel utilization rate, in the case of links, is an accurate reflection of the difference in efficiency between transmission of compressed and uncompressed data.

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