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Modeling and Simulation of the Data Communication Network at the ASRM Facility

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Modeling and Simulation of the Data Communication Network at the ASRM Facility

Abstract

This paper describes the modeling and simulation of the communication network for the NASA Advanced Solid Rocket Motor (ASRM) facility under construction at Yellow Creek near Iuka, Mississippi. Manufacturing, testing, and operations at the ASRM site will be performed in different buildings scattered over a 1800 acre site. These buildings are interconnected through a Local Area Network (LAN), which will contain one logical Fiber Distributed Data Interface (FDDI) ring acting as a backbone for the whole complex. The network contains approximately 700 multi–vendor workstations, 22 multi–vendor workcells, and 3 VAX clusters interconnected via Ethernet and FDDI. The different devices produce appreciably different traffic patterns, each pattern will be highly variable, and some patterns will be very bursty. Most traffic is between the VAX clusters and the other devices. Comdisco's Block Oriented Network Simulator (BONeS) has been used for network simulation. The two primary evaluation parameters used to judge the expected network performance are throughput and delay.

1.0. Introduction

The Advanced Solid Rocket Motor (ASRM) facility at Yellow Creek near Iuka, Mississippi is part of a National Aeronautics and Space Administration (NASA) program to substantially improve the flight safety, reliability, productivity, and performance of the space shuttle's solid rocket motors. The facility is government–owned but contractor–operated. Lockheed Missiles and Space Company Inc. (LMSC) is the prime contractor. The operation of the facility is directed by the subcontractor Aerojet ASRM division (AAD); RUST International Corporation (RUST) is responsible for the engineering and construction of the facility [1].

The main aim of this paper is to present the overall communication network structure for the ASRM facility and describe the modeling and simulation of the network. The section on 'ASRM Communication Network Structure' concentrates on the network connectivity, the cabling, and the protocols. That section also explains the flow of data in the network. The section on 'BONeS Modeling' gives an overview of the BONeS simulator and describes the different BONeS models developed to simulate the ASRM environment. The 'Analysis and Results' section at the end of the paper comments on the network expectations and the network evaluation parameters. The section also summarizes the various plots of Mean Delay and Throughput versus Traffic Intensity obtained using BONeS and some important conclusions are drawn.

2.0. ASRM Communication Network Structure

2.1. Main Computing Center

Building 1000 (B_1000) provides an efficient means to plan, control, and document the manufacture of solid rocket motors for the ASRM project. All the workstations and workcells communicate only with the Operational Information System (OIS), the Business Information System (BIS), and the Area Supervisory Computers (ASCs) in B_1000; there is no peer–to–peer communication. B_1000 also provides a link between the business functions and the manufacturing functions of the facility. The interconnection between the devices in B_1000 is shown in Figure 1.

The OIS is a VAX cluster consisting of two VAX 6000 computers, each with one FDDI adapter. In addition to this OIS VAX cluster, there are two VAX 4000 computers, each with one Ethernet adapter. The BIS is a VAX cluster consisting of one VAX 6310 and two VAX 6420 computers. Each of the ASCs are VAX 4400 with an Ethernet adapter.

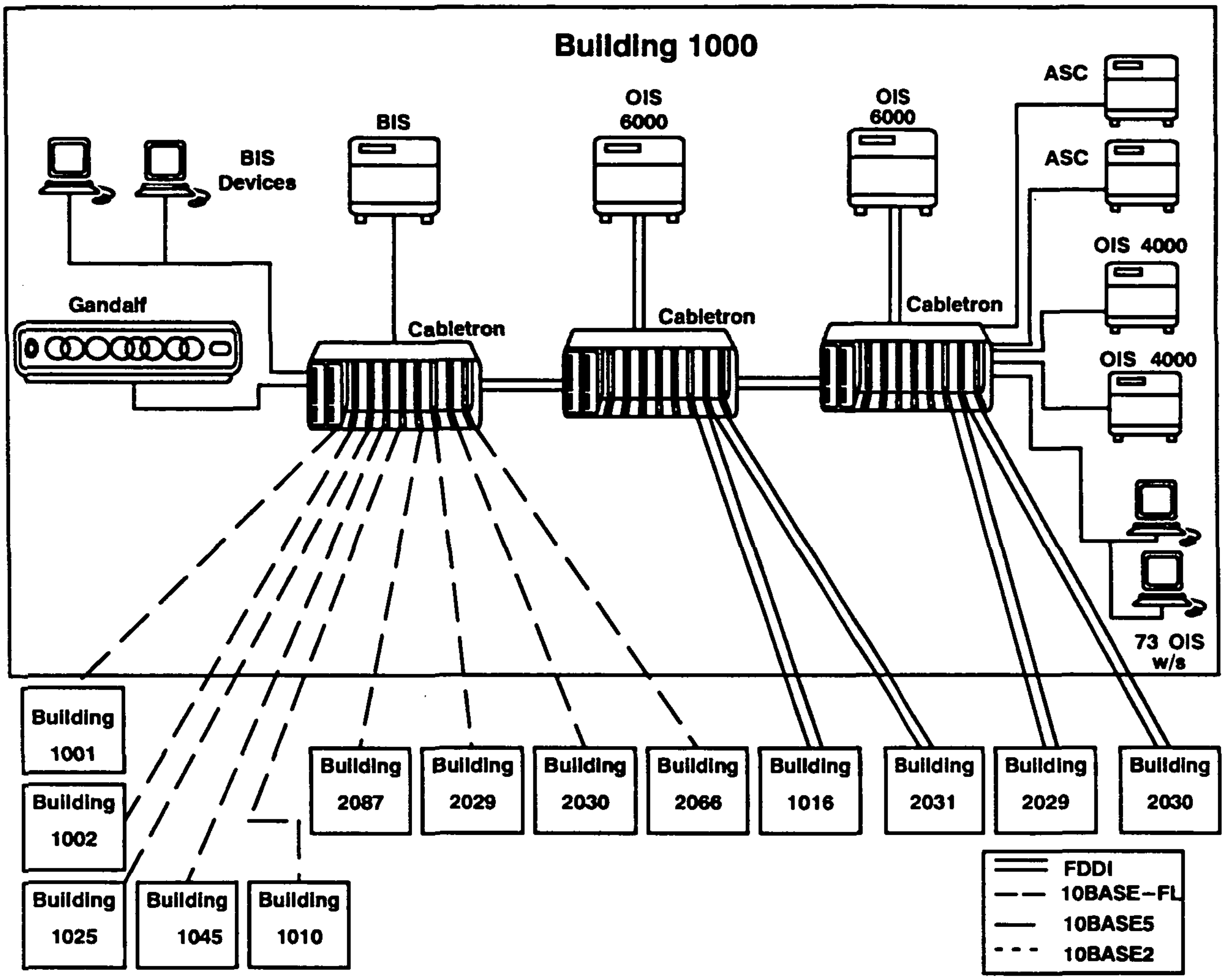

Figure 1 Inside Building 1000

B_ 1000 has a Gandalf terminal server. The Gandalf terminal server is a large terminal server with a multitude of RS–232 ports. The Gandalf can support 12 separate Ethernet channels. It is the only terminal server throughout the campus.

The OIS, the BIS, the ASCs, and the Gandalf terminal server in B_1000 are connected to the outside network complex by Cabletron Multi Media Access Centers (MMACs), the intelligent hubs. There is a fiber connection between the OIS and the Cabletron hubs. There is a copper connection between the BIS and its Cabletron hub, and between the ASCs, and their Cabletron hub.

In addition to the devices already mentioned, B_1000 has nine more Cabletron hubs distributed in two switch rooms for the BIS devices. The BIS devices includes 32 printers, 25 CAD workstations, and 400 Macintosh computers connected to the BIS hub by 10BASET; 50 PCs connected to the BIS hub by 10BASET; 31 Engineering workstations on 10BASE2; and 289 dumb terminals connected via Asynchronous Data Interface to the Gandalf. The connections of the BIS devices is as shown in Figure 2.

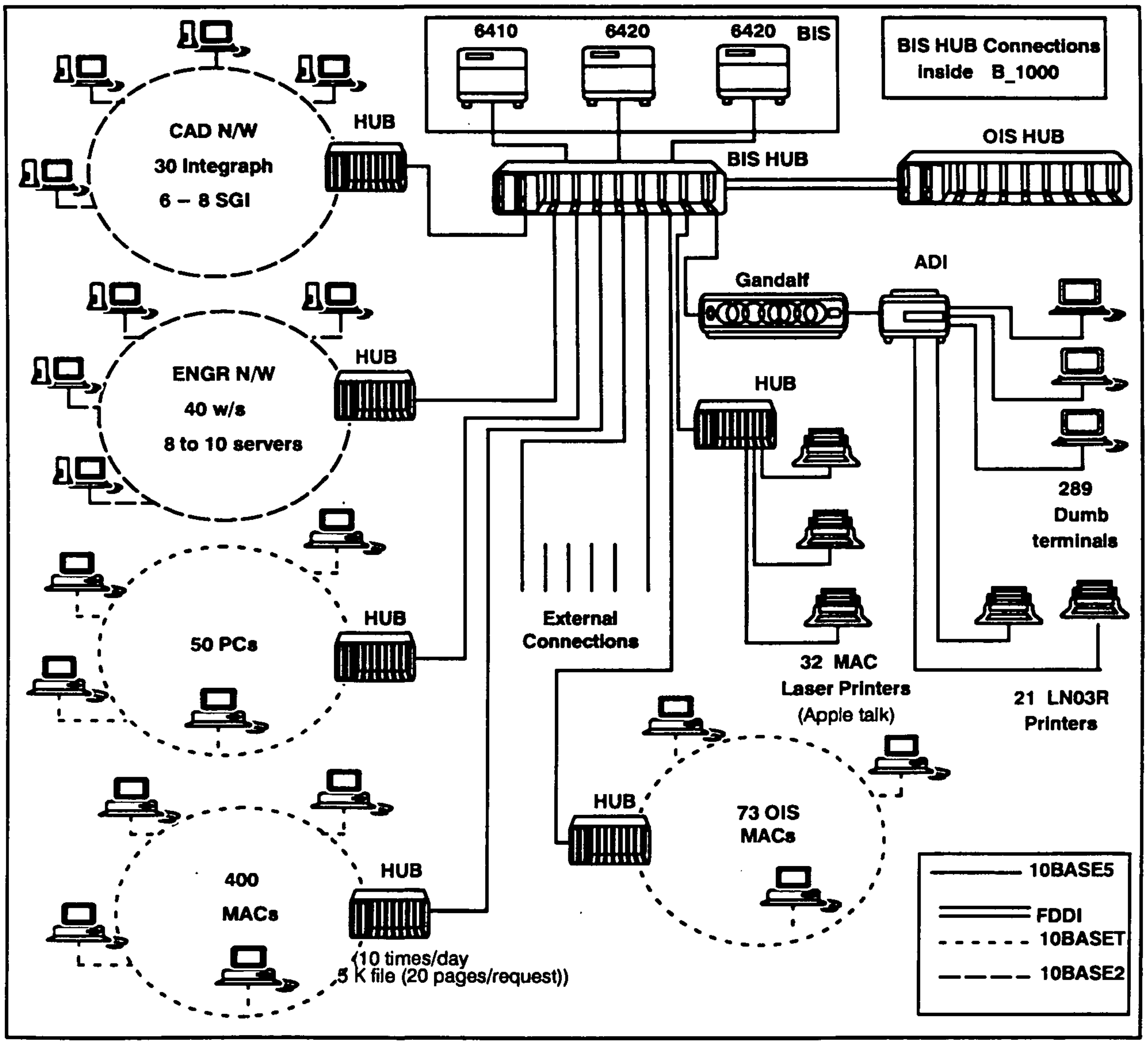

Figure 2 BIS Hub Connections

2.2. Network Cabling at the ASRM Site

At the ASRM site all the outdoor cabling and much of the indoor cabling is optical fiber. Thin–wire coax, thick–wire coax, and twisted–pair are also used in B_1000.

2.2.1. Outdoor Cabling at the ASRM Site

All the outdoor cabling is optical fiber. All optical fibers used are 62.5 / 125 micron multimode optical fibers. Every FDDI hub has at least three redundant paths, viz. Channel A and Channel B of FDDI and a 10BASE–FL backup. Also every FDDI hub has two redundant dual rings.

Link	Distance (feet)	Number of Workstations on the link.	Number of Workcells on the link.	Type of the Link
Link # 1 : (2029)	6700	29	04	Intensive and Non–Intensive
Link # 2 : (2031)	4650	15	00	Intensive
Link # 3 : (1016)	1450	27	16	Intensive
Link # 4 : (1000)	00	(19+73) + BIS Devices.	00	Non–Intensive
Link # 5 : (2066)	3550	09	00	Non–Intensive
Link # 6 : (2030)	5000	12	06	Intensive and Non–Intensive
Link # 7 : (1012)	950	14	00	Non–Intensive

Table 1: Distances of each hub from B_1000

The manufacturing intensive buildings have two FDDI data paths from B_1000 with automatic switch–over. One data path is buried, while the other is aerial. Buildings 1016, 2029, 2030, and 2031 are the manufacturing intensive buildings; each has a hub directly connected to a hub in B_1000. Buildings 2060 and 2076 are connected to the hub in building 2029. Each hub receives two pairs of fibers from the outside cable plant. All workstations and workcell devices will receive two fibers each from the respective hubs.

All the manufacturing non–intensive buildings in the complex receive two fibers for their hub via the outside cable plant. All the workstations inside the buildings get two fibers each from the respective hub.

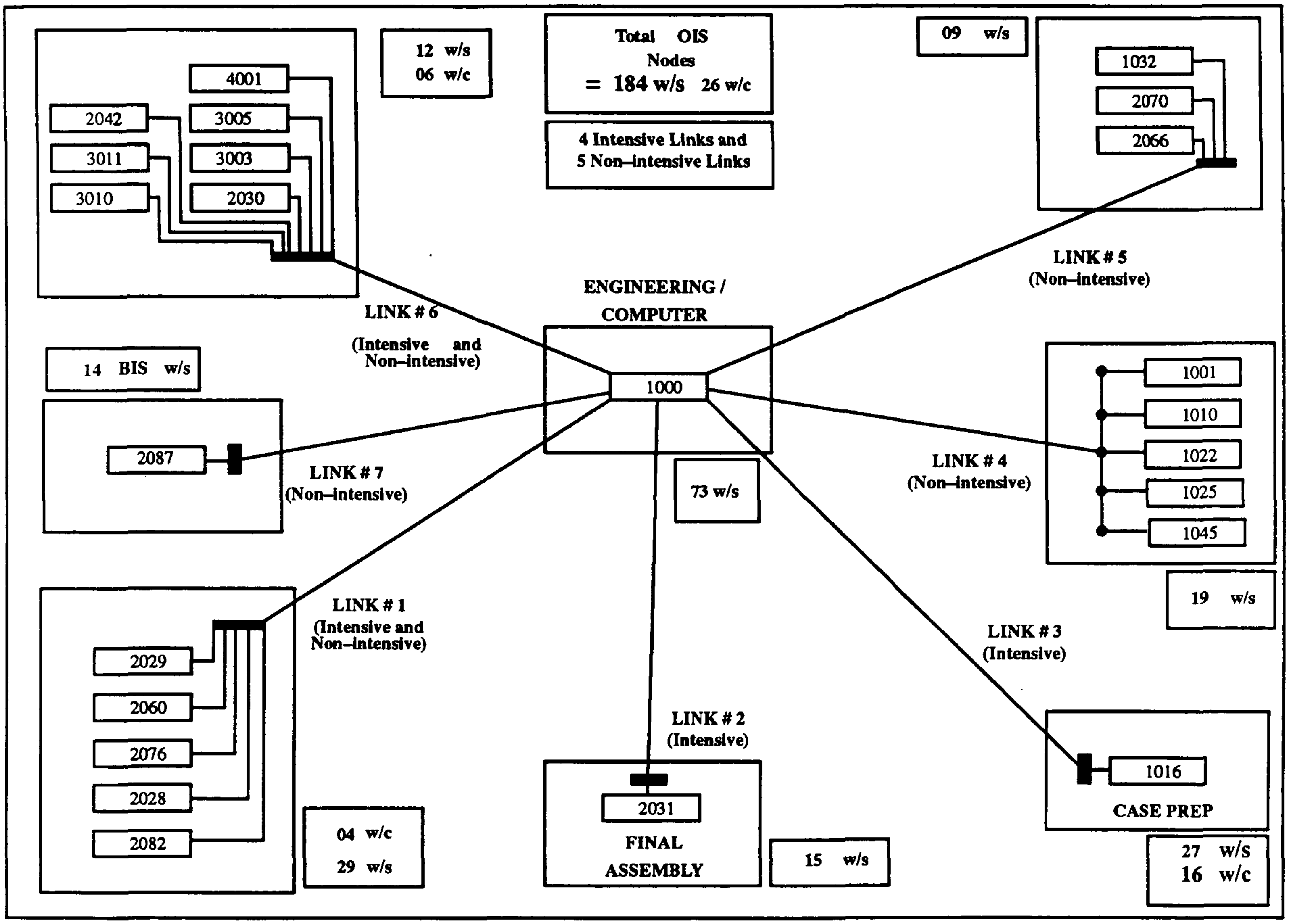

Figure 3 Hub Connections

2.2.2. Indoor Cabling at the ASRM Site

For the indoor cabling in the manufacturing intensive buildings, the 10BASE–FL protocol is used, mainly because it allows lower light levels and 16 redundant data paths [7].

2.3. Cabletron Devices

At the ASRM site all the Cabletron MMACs will be MMAC–8FNBs, which support up to seven Media Interface Modules (MIM). The first slot in the MMAC will be the EMME multichannel management / bridge module. The Cabletron hubs provide the necessary security, routing, and redundancy [7]. The different MIMs used in the network at the ASRM are listed in Table 2.

Name of the Card	Type of the Card	Protocol	Number of ports	Comments
EMME	Ethernet Bridge	Ethernet	4 ports	Used as a management module in all the MMACS
FDMMIM	FDDI to Ethernet Bridge	—	8 ports	Connects 10 Mbps Ethernet to 100 Mbps FDDI
MT8–MIM	DELNI Card	—	8 ports	AUI Transceiver
FORMIM–22	10BASE–FL card	Ethernet	12 ports	Provides connectivity for 12 ethernet channels
TPRMIM–36	10BASE–T Card	Ethernet	24 ports	Provides connectivity for 24 ethernet channels
CXRMIM	DEMPR Card	Ethernet	12 ports	Provides connectivity for 12 ethernet channels
GX–M	GatorStar Card	LocalTalk	24 ports	24 port LocalTalk repeater with a LocalTalk to Ethernet router
FDMMIM–04	FDDI Concentrator	FDDI	4 ports	Provides 4 concentrator ports FDDI connections

Table 2: Cabletron MIMs used at ASRM

2.4. Protocols used at the ASRM Site

For the communication network at the ASRM site, two protocols are specified, FDDI and CSMA/CD. All the manufacturing intensive buildings are connected to B_1000 by links with FDDI protocol, and all the manufacturing non–intensive buildings are connected to B_1000 by links with 10BASE–FL protocol (i.e. CSMA/CD on optical fiber). The protocol inside the manufacturing intensive buildings and the manufacturing non–intensive buildings is 10BASE–FL.

2.5. Data Flow over the Network

2.5.1. Manufacturing Intensive Buildings

The manufacturing intensive buildings have FDDI data paths from B_1000. The manufacturing intensive buildings viz. 1016, 2029, 2030, and 2031 each has a hub directly connected to an OIS hub in B_1000. The workstations in these buildings communicate with the OIS 6000 computers. The workcells in these buildings communicate via the OIS hub with the two ASCs.

2.5.2. Manufacturing Non–Intensive Buildings

The manufacturing non–intensive buildings 1001, 1002, 1010, 1025, and 1045 have 10BASE–FL data paths from B_1000. All other manufacturing non–intensive buildings are connected to B_1000 through the nearest manufacturing non–intensive hub in buildings 2029, 2066, and 2030. The workstations in all the manufacturing non–intensive buildings communicate via the BIS hub with the two OIS 4000 computers.

2.6. Research Objective

The main objective of the research is to simulate and analyze the network to determine its performance under different load conditions. Comdisco's Block Oriented Network Simulator (BONeS) is used to evaluate the performance of the network with the given topology and protocols. The two primary evaluation parameters that are used to judge the network performance are the throughput and the delay. The aim of the simulations is to look into the loading of the OIS, the BIS, the ASCs, and the network links due to the traffic generated by the workstations and the workcells over the entire site.

3.0. BONeS Modeling

3.1. Different Methods of Network Modeling [4]

The network modeling can be done by several different means, each having its advantages and disadvantages. The first method is by developing a mathematical model of the network, normally using queueing theory. This model can then be used to provide results of the performance of the network. Due to the simplifying assumptions required to use with this type of modeling, it is often not the best possible model and often is not feasible.

The second approach to analyze the performance of a network is to actually build the network. Although this approach provides very good results, it is normally very expensive, both in time and resources.

The third approach is that of computer simulation. Using a computer simulation the user can model the network to as close to reality as desired. This approach is less expensive than building the network; however, the major disadvantage of this approach is insuring that the simulation model accurately models the real–world network.

3.2. BONeS Simulator [6]

The Block Oriented Network Simulator (BONeS) provides an interactive graphical environment for simulation–based analysis and design of a broad range of communication networks. In the BONeS environment, the network model is specified in terms of the network topology, traffic, packet and message (data) structures, and protocol functions. The user constructs the network graphically and hierarchically using the building blocks from the BONeS model library. The user can also write the components of a model in C and incorporate them into the BONeS modeling environment. BONeS translates the network model into a C program, executes an event–driven Monte Carlo simulation, computes statistical measures of network performance, and displays the results graphically.

3.3. Network Modeling using BONeS

Simulation model design consists of three elements : data structures, modules, and a system. The modules in BONeS control the flow of the data structures. Many basic modules are provided with BONeS, such as decision nodes, random traffic generators, and fixed delays. These can be combined to form new modules to meet the specific needs of the simulation [6].

BONeS is an event driven simulation. All events except traffic generators are triggered by a previous event called a Trigger. If a block is not triggered then there will be no output. Thus when building a model using the provided blocks, race conditions such as parallel inputs must be avoided. Instead, blocks should be cascaded to prevent the race conditions.

The different nodes that are constructed in this simulation are workstations and workcells. Models of other nodes, such as CSMA/CD nodes, FDDI nodes, and bridges are included in the BONeS library. The default parameters of the CSMA/CD nodes are set to the IEEE 802.3 CSMA/CD standard. The packet size is set to the smallest possible size of 64 bytes for a worst case analysis. If the packet size is small the transmission time will be small with respect to the propagation delay, and more collisions will occur [5].

A Cabletron MIM is an add–on card that can be plugged into a slot of a MMAC. Each MIM has ports on its faceplate to support cabling. Each MIM functions uniquely as a repeater or as a bridge. The model of the repeater MIM passes all frames that are received on the receive port to all transmitting ports with delay. The delay information for each MIM was obtained from [7].

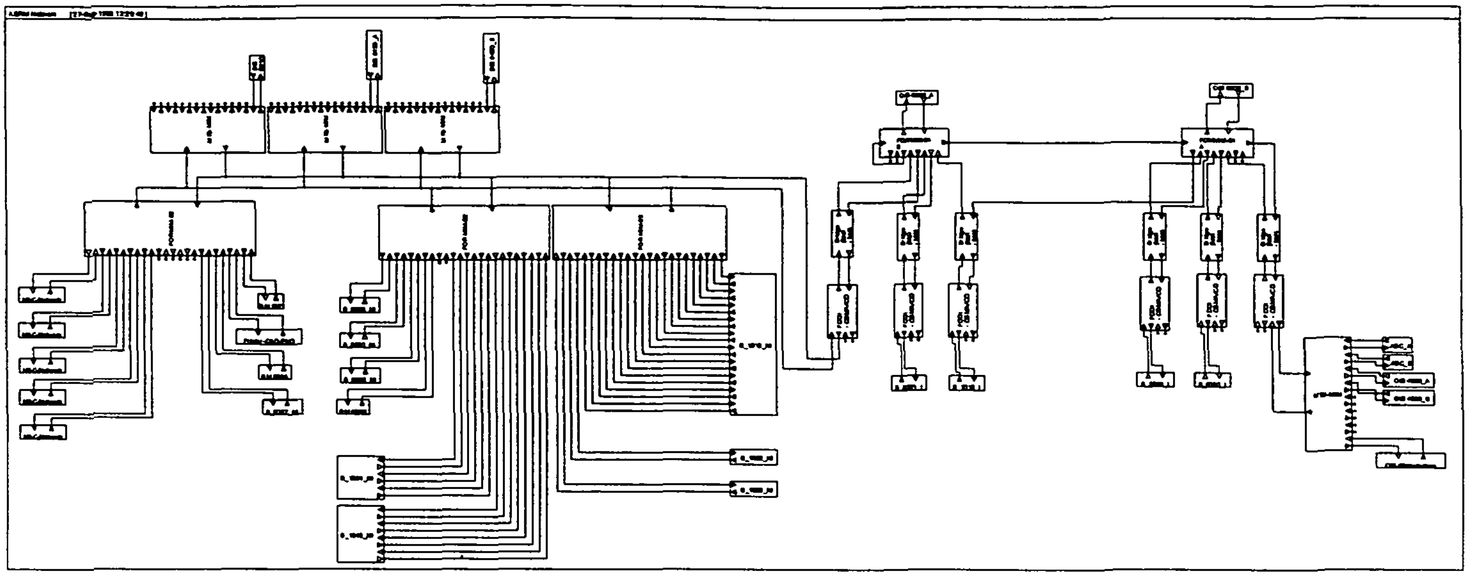

Figure 4 BONeS Model of ASRM Network

A traffic source model has been developed to model a workstation sending a block of data such as a text or graphics screen. The traffic source model sends a set number of packets at an inter–arrival rate set by the user, in this case a Poisson distribution because traffic on a LAN tends to have a Poisson distribution.

3.4. Probes Setting and the Simulation Iterations

Several probes were placed throughout the network to gather statistics during the simulation. The mean delay per packet, received throughput, transmitted throughput, and the number of completed packets were collected for each separate link. Each iteration interval was divided into ten batches in order to collect these statistics.

These statistics were collected by placing a Generic Probe on the Media Access Control (MAC) Statistics module in each link. The MAC Statistics module was used to measure the delay and throughput for all CSMA/CD workstation models on one link. All CSMA/CD workstation model MAC instances share the same memory. Therefore, all the CSMA/CD workstation models write the delay and throughput into one memory.

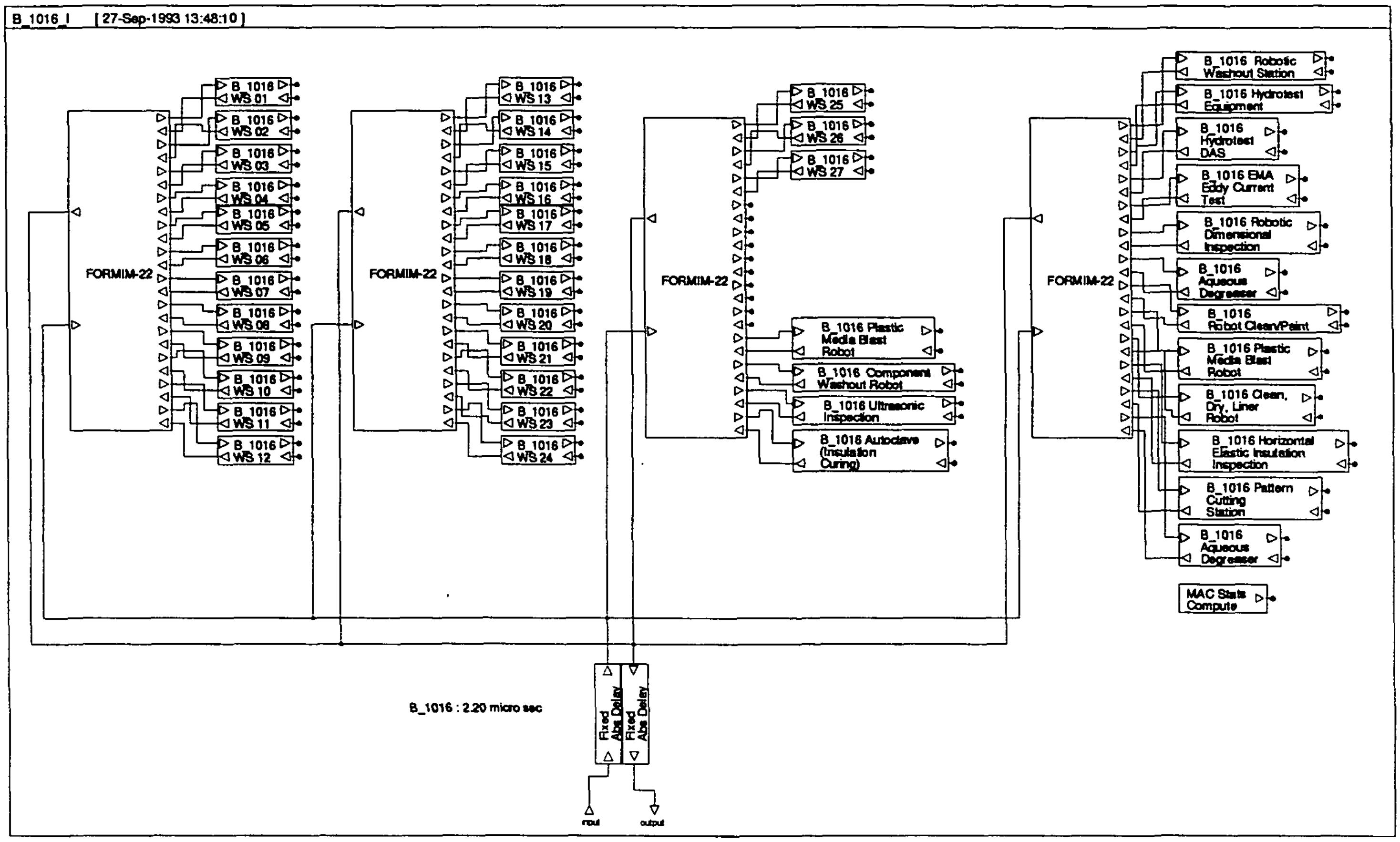

Figure 5 BONeS Model of Building 1016

These statistics are then made available to the Post Processor in BONeS by placing a Generic Probe on the MAC Statistics Compute module.

The traffic intensity per node was varied from 10 Kbps to 90 Kbps at twelve points during the simulation. The traffic intensity was varied with an exponential function to show the knees of the curves. The simulation time per iteration was set to one second. The actual computer time to do the simulation was approximately 30 hours on a moderately loaded Sun 600/MP with 128 Megabytes of memory.

4.0. Analysis and Results

4.1. Network Expectations

The network should be reliable and have redundant links since the control of the manufacturing will be accomplished over the LAN. Large amounts of data will be required due to the extensive monitoring and documentation required for the manufacture of the solid rocket motors in the Space Shuttle program [2].

4.2. Network Evaluation Parameters

The two primary evaluation parameters used to judge the network performance are throughput and delay. The throughput is the effective bit rate of the system in bits per second (bps). It does not include the overhead bits used by the protocol or the packets that have to be re–transmitted. The delay in a LAN is determined by the mean delay per packet [3].

The delay in a LAN is mostly caused by the following three factors: the propagation delay, the delay in a transceiver, and the queuing delay in a bridge. Also the user response time is important. These delays are modeled using several different techniques in the simulation.

4.2.1. Propagation Delay

The propagation delay of the light signal traveling down the fiber is modeled by using a fixed delay model provided by BONeS. The link delay is calculated by dividing the distance by the speed at which the light travels down the fiber (0.67 times the speed of light) [2].

4.2.2. Delay in a Transceiver

The worst case collision detection time of a particular CSMA/CD commercial transceiver was found to be 900 nanoseconds [8]. The worst case packet delay of a particular commercial optical hub was found to be 630 nanoseconds [8]. This delay is caused by the optical–to–electrical and electrical–to–optical conversion. These delays are also modeled by a fixed delay in the simulation [2].

4.2.3. Queue Delay in a Bridge

In the simulation model each of the CSMA/CD networks is connected to the FDDI backbone by a bridge. A bridge converts the CSMA/CD packet to an FDDI packet and buffers the incoming packets until they are serviced. If a packet enters the bridge and the queue is full, the packet is discarded. If the queue is large but not full, then the packet will be delayed.

4.3. Mean Delay and Throughput Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 7, 9, and 11. The throughput versus the offered traffic intensity plots are shown in figures 6, 8, and 10.

4.4. Observations and Results from the Plots

The statistics collected with the probes during the simulation are plotted to judge the performance of the network. The mean delay per packet and throughput are plotted versus the offered traffic intensity. These plots are created using the Post Processor in BONeS and show the performance of the network at each iteration of the traffic intensity during the simulation.

4.4.1. Mean Delay Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 7, 9, and 11. The BIS devices delay plot shows a rising curve; the OIS devices (Intensive and Non–Intensive) delay plot shows a knee curve.

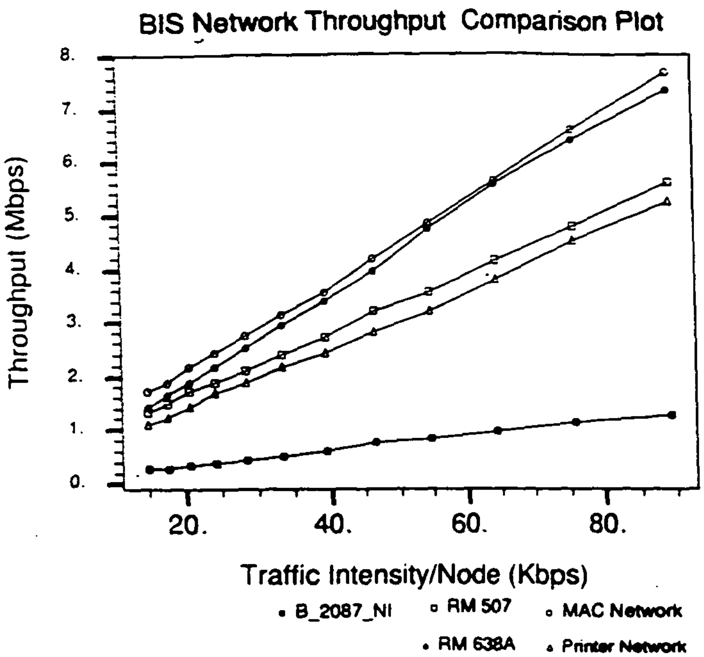

Figure 6 BIS Network Throughput Comparison Plot

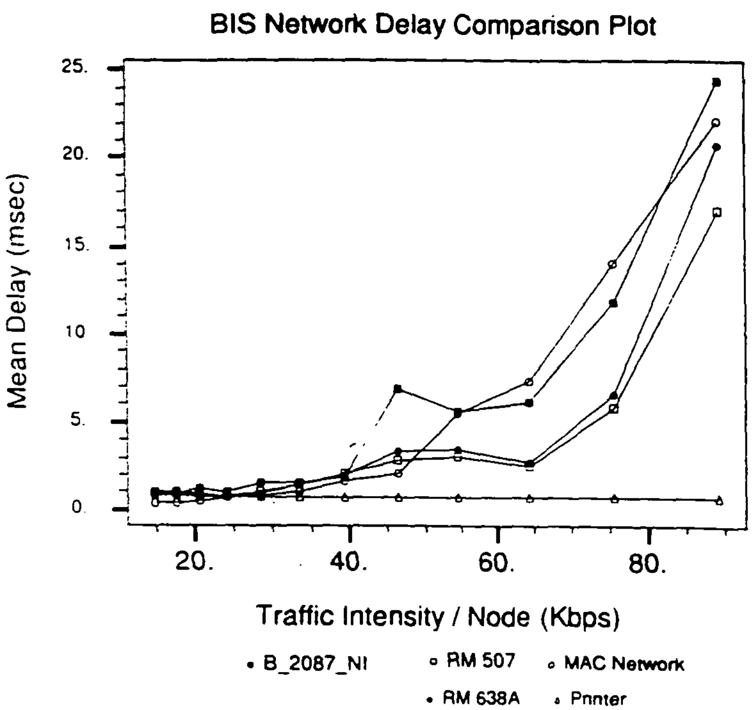

Figure 7 BIS Network Delay Comparison Plot

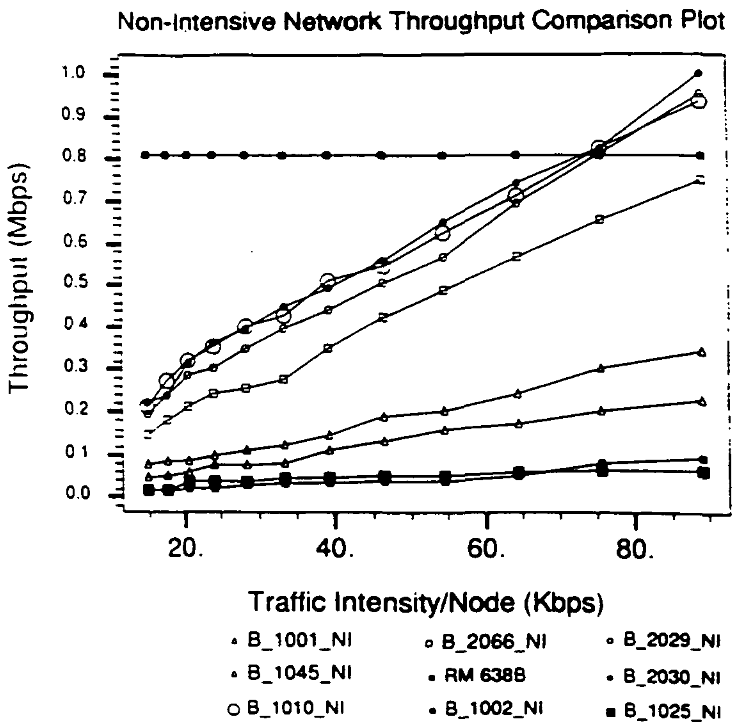

Figure 8 Non–Intensive Network Throughput Comparison Plot

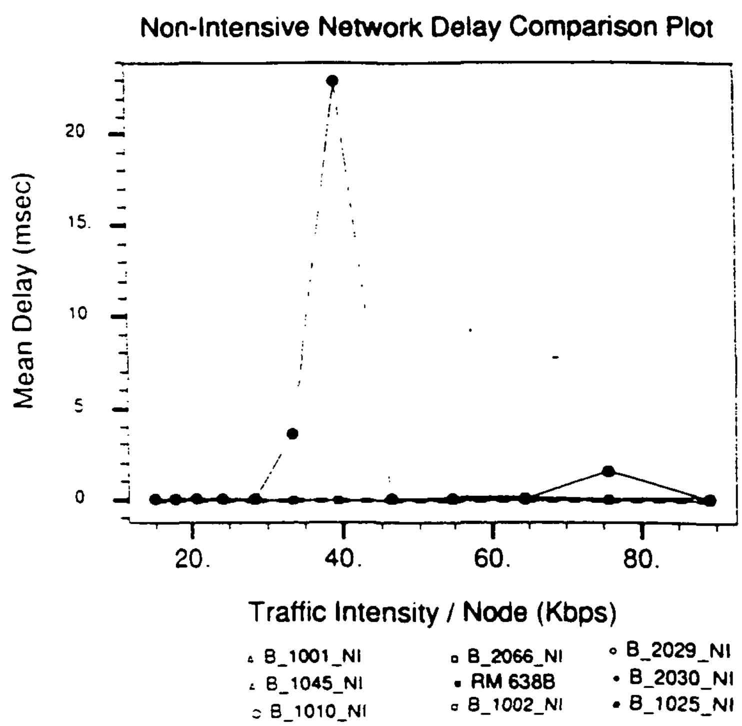

Figure 9 Non–Intensive Network Delay Comparison Plot

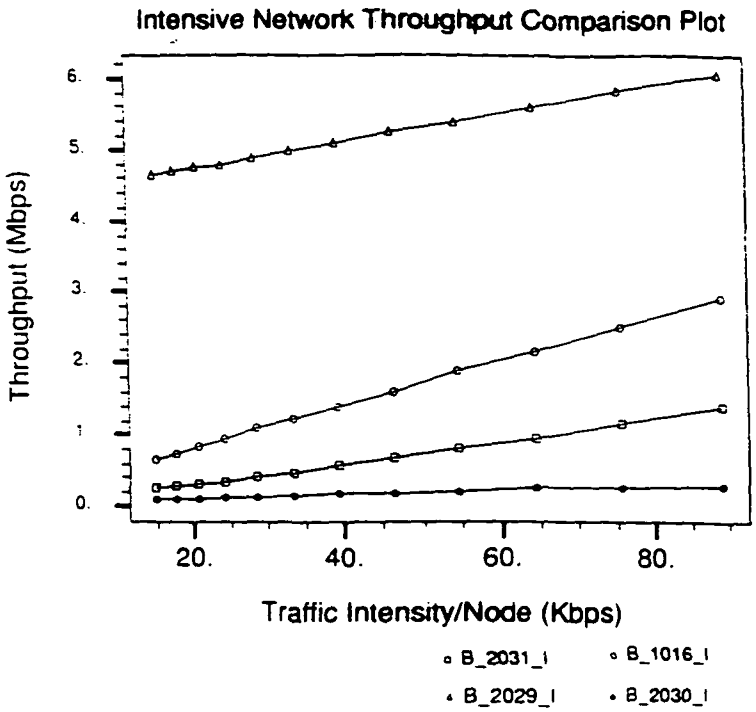

Figure 10 Intensive Network Throughput Comparison Plot

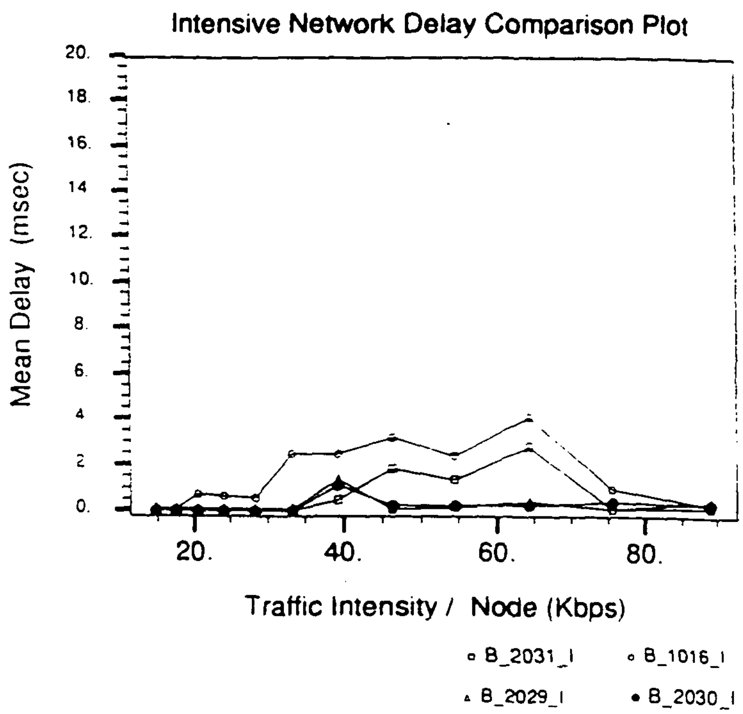

Figure 11 Intensive Network Delay Comparison Plot

In the case of the BIS devices plot, the mean delay per packet increases as the offered traffic intensity increases. The delay curves level out close to a traffic intensity of 40 Kbps per node and then start to climb linearly. This agrees with the generally accepted assumption that a CSMA/CD network overloads at somewhere between 30% and 50% of its maximum transmission speed [3]. Note that the transmission speed of a link (10 Mbps for Ethernet) equals the traffic intensity per node times the number of nodes. There are approximately 80 nodes per link in the BIS section; 80 nodes transmitting at 40 Kbps is 3.2 Mbps. The simulation only calculates delays per packet for successful packet transmissions and does not include lost packets.

In the case of the OIS devices, all the links show a knee at a particular traffic intensity. The mean delay per packet decreases beyond this traffic intensity, because the number of completed packets decreases beyond the knee of each link. Even though the traffic intensity is being increased, many nodes are not given access to the channel. The packets that do get through have a smaller delay because the mean delays are only calculated for successful transmissions of the packets in the simulation. This shows that the links are overloaded and only a few nodes can communicate. All other nodes are locked out by the excessive traffic.

4.4.2. Throughput Plots

The throughput versus the offered traffic intensity plots are shown in figures 6, 8, and 10. The BIS and OIS devices throughput plot shows a rising curve.

The curves in these figures show that the throughput increases linearly with the offered traffic intensity per node. But the analysis of the mean delay per packet shows that the links are overload beyond a certain traffic intensity. This is because only a few nodes are able to transmit and all others cannot. The throughput beyond this knee is only available to a few nodes. So the throughput for each of the links should be determined at the traffic intensity where the maximum delay per packet occurred.

Link	No of nodes	Mean delay/packet at traffic intensity of 40 kbps in msec	Throughput at traffic intensity of 40 kbps in Mbps.
MAC Network	80	1.5	3.2
Printer Network	56	0.5	2.2
B_2087_NI	14	2.0	0.5
RM 507	57	2.0	2.3
RM 638A	80	1.8	3.4

Table 3: Delay per packet and throughput for the BIS devices

Link	No of nodes	Maximum delay/ packet (msec)	Traffic intensity at maximum delay/packet (kbps)	Throughput at maximum delay per packet (Mbps)
B_1001_NI	3	0.004	38	0.11
B_1045_NI	4	0.004	38	0.10
B_1010_NI	10	23	38	0.46
B_2066_NI	4	0.007	38	0.32
RM 638B	1	0.002	38	0.81
B_1002_NI	1	0.006	38	0.04
B_2029_NI	9	23	38	0.4
B_2030_NI	9	23	38	0.38
B_1025_NI	1	0.006	38	0.04
B_2031_I	15	3.0	65	1.0
B_2029_I	24	1.5	38	5.0
B_1016_I	43	4.0	65	2.4
B_2030_I	9	1.0	38	0.3

Table 4: Maximum delay per packet and throughput for the OIS devices

4.5. Conclusions

This paper has introduced the basic operating characteristics of the network installed at the ASRM site located in Iuka, Mississippi. An overview of the network topology, communication protocols, and hardware devices was presented.

The main objective of the research was to model, simulate, and analyze the network to determine its performance. The two primary evaluation parameters used to judge the network performance were the throughput and the delay.

From the results obtained it can be concluded that,

1. For the BIS devices the mean delay per packet increases as the offered traffic intensity increases, while for the OIS devices all the links show a knee at a particular traffic intensity.

2. The throughput for all the sub–networks increases linearly with the traffic intensity per node.

3. Among all the sub–networks the Intensive buildings experiences the lowest maximum delays.

4. From the delay plots it can be seen that the BIS network is the most heavily loaded network. This can be attributed to 400 Macintosh workstations connected to the BIS.

5. The buffer capacity of the bridges does appear to produce a bottleneck for the network.

6. The FDDI backbone ring seems to provide ample bandwidth as was expected.

7. The FDDI backbone causes only a negligible delay compared to the other delay–causing factors considered in section 4.2.

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