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EVALUATION OF WIRELESS DATA COMMUNICATIONS AT KSC

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ABSTRACT

This project is motivated by the need for temporary or emergency provisioning of LAN service at KSC. The main goal of the project was to evaluate existing wireless bridge equipment in the KSC environment. Wireless bridge equipment can be used to make a wireless connection between two remotely located LAN segments. This report describes the experimental setup used to evaluate the equipment, including antenna connections, workstation connections, bridge software and workstation software. The rangefinder program on the bridge was used to gather data about how the RF propagation environment at KSC affects the performance of the wireless bridge. Data was gathered for indoor as well as outdoor propagation. The report concludes with recommendations on how to take into account the particular terrain and building structures at KSC to design future applications of wireless bridges.

SUMMARY

This project is motivated by the need for temporary or emergency provisioning of LAN service at KSC. There are two ways that wireless technology may be used in a LAN environment. One is to provide a wireless connection from a single terminal to a remote wired network. The other is a bridge connection between two remotely located network segments. In this project we will only be discussing wireless bridge equipment. This can address situations such as emergency disruption of LAN connectivity to a certain key location, or the need for LAN connectivity to temporary structures such as trailers. Additionally, wireless LAN technology can provide flexibility in managing network topology and reduce labor costs for cable installation in situations where the arrangement of work areas is subject to ongoing change in response to changing projects, personnel and equipment. The wireless bridge equipment available at KSC is the INTERSECT(TM) bridge made by PERSOFT Inc., of Madison, Wisconsin. The main goal of this project was to evaluate the capabilities of this existing equipment in the KSC environment.

The experimental setup consists of two remote sites linked by wireless transmission. At each site, the setup consists of a wireless bridge, antenna, and workstation. The antenna can be indoor or outdoor depending on whether the application calls for in building or out of building transmission. The indoor antenna is omni-directional patch antenna about six inches in size. The outdoor antenna is 4-element Yagi antenna, approximately 2 feet, or a 10-element Yagi, approximately 4 feet. If an outdoor antenna is used, it needs to be mounted on a proper mast, taking into account weather and safety considerations. Normally many workstations may be connected to the bridge at each site. In our experiment, only one workstation was connected to each bridge using UTP null-modem cable with RJ-45 connectors.

The bridge comes equipped with a range finder program that can be used to assess the quality of the radio link. Other features of the bridge software are the bridge configuration program which can be used to set up traffic screening and spanning tree parameters for traffic routing. These latter features were not used in our project. The workstations used were UNIX workstations with ftp (file transfer protocol) software. This allowed remote login, remote directory, and two-way file transfer between the workstations over the wireless link for demonstration purposes. Wireless file transfer was demonstrated indoors from the East end of the EDL building to the West end, and outdoors between EDL and CIF buildings.

The rangefinder software on the bridges was used to gather RF propagation data under various application situations, both indoors and outdoors. Data was gathered for indoor propagation and link quality at many locations throughout EDL building. Data for outdoor propagation was gathered by setting up one site in the EDL building, and the other site in a mobile van. Outdoor propagation data was gathered throughout the KSC industrial area, as far West as the KARS II park.

The propagation data show that equipment performance and radio link quality are seriously affected by physical structures that affect RF propagation. For outdoor propagation, these include high terrain, tall buildings, trees etc. For indoor propagation, the factors are, number of walls and construction materials, and propagation between floors. Plaster walls are quite forgiving, but masonry walls cause significant signal loss .

The final conclusion of the project is that the PERSOFT equipment is suitable for use at KSC, but the performance for any given application depends on the physical RF propagation

environment, which needs to be carefully considered. Guidelines for carrying out an evaluation of the propagation environment are included in this report.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

CIF	Central Instrumentation Facility
EDL	Engineering Development Laboratory
FCC	Federal Communications Commission
FTP	File Transfer Protocol
ISM	Instrumentation, Scientific and Medical
KSC	Kennedy Space Center
LAN	Local Area Network
TCP/IP	Transmission Control Protocol/Internet Protocol
UTP	Unshielded Twisted Pair

I. INTRODUCTION

This project is motivated by the need for temporary or emergency provisioning of LAN service at KSC. This can address situations such as emergency disruption of LAN connectivity to a certain key location, or the need for LAN connectivity to temporary structures such as trailers. Additionally, wireless LAN technology can provide flexibility in managing network topology and reduce labor costs for cable installation in situations where the arrangement of work areas is subject to ongoing change in response to changing projects, personnel and equipment [1].

There are two ways that wireless technology may be used in a LAN environment. One is to provide a wireless connection from a single terminal to a remote wired network. The other is a bridge connection between two remotely located network segments. In this project we will only be discussing wireless bridge equipment.

The wireless bridge equipment available at KSC is the INTERSECT(TM) bridge made by PERSOFT Inc., of Madison, Wisconsin. The main goal of this project was to evaluate the capabilities of this existing equipment in the KSC environment. The nominal capabilities of the Intersect bridge are delivery of data at the rate of 2 Mb/s between remote locations upto 3 miles apart outdoor, or upto 800 feet indoors. The equipment uses 26 MHz of bandwidth in the FCC unlicensed ISM band (902-928 MHz). Spread spectrum technology is used to keep the transmitted power to only 250 mW. The receiver sensitivity is -72 dBm.

II. EXPERIMENTAL SETUP

2.1 Bridge connections

The Intersect remote bridge connections are first briefly described. Please refer to the User manual [2] for a more detailed description. There is one connector for the antenna cable. This connector is F-type. The antenna cable is 75-Ohm RG-6/U type cable. Each bridge has the function of forwarding traffic between a wired Ethernet segment and the wireless remote connection. There are three possible ways of connecting the Intersect bridge to the wired Ethernet segment. The default method is Unshielded Twisted Pair (UTP) cable to the hub of a standard 10BaseT ethernet. An RJ-45 port is provided for this. Other Ethernet adapter ports are provided for alternate connections to the Ethernet. An AUI port is available for connecting to 10Base5 standard equipment, also called thick ethernet. If this method is used an AUI drop cable and a transceiver would be required. A third alternative is available to interface to thinwire ethernet, also called 10Base2 or coaxial cable equipment. For this a BNC port is provided on the bridge. A coaxial cable would have to be connected from the BNC port to a T-connector on the ethernet cable. The network connection used in our experiment was a modified UTP connection, as will be described later.

2.2 Antenna Connections

Each bridge is supplied with two types of antennas. One is a flat antenna about 6 inch size that can be mounted on the wall and is for use in indoor wireless applications. The other is a 4-element Yagi antenna about 18 inch size, and is for outdoor applications. The wall-mount antenna is supplied with its own 5-feet cable with F-type termination to connect directly to the bridge. The outdoor antenna is supplied with an N-type connector. A separate 33 feet cable is required. This cable should be 75-Ohm cable with N-type termination on one end to connect to the antenna, and an F-type male termination on the other end to connect to the bridge.

2.3 Workstation connections

Any type of workstation with ethernet interface can be used to connect to the bridge. For normal operation, both the workstation as well as the bridge would be connected to a hub of the ethernet LAN segment. In our case, for demonstration purposes, it was decided that only one workstation would be used on each side of the wireless connection, instead of a LAN segment. Since there is only one workstation to be connected to the bridge, the hub can be eliminated, and the workstation can be connected directly to the bridge by UTP cable. But if this is done, it is necessary to cross-connect the receive and transmit terminals at the two ends of the cable. Such a cable is called a null-modem cable. A diagram showing the RJ-45 terminal pin connections that should be cross-connected is shown in Fig. 2.1.

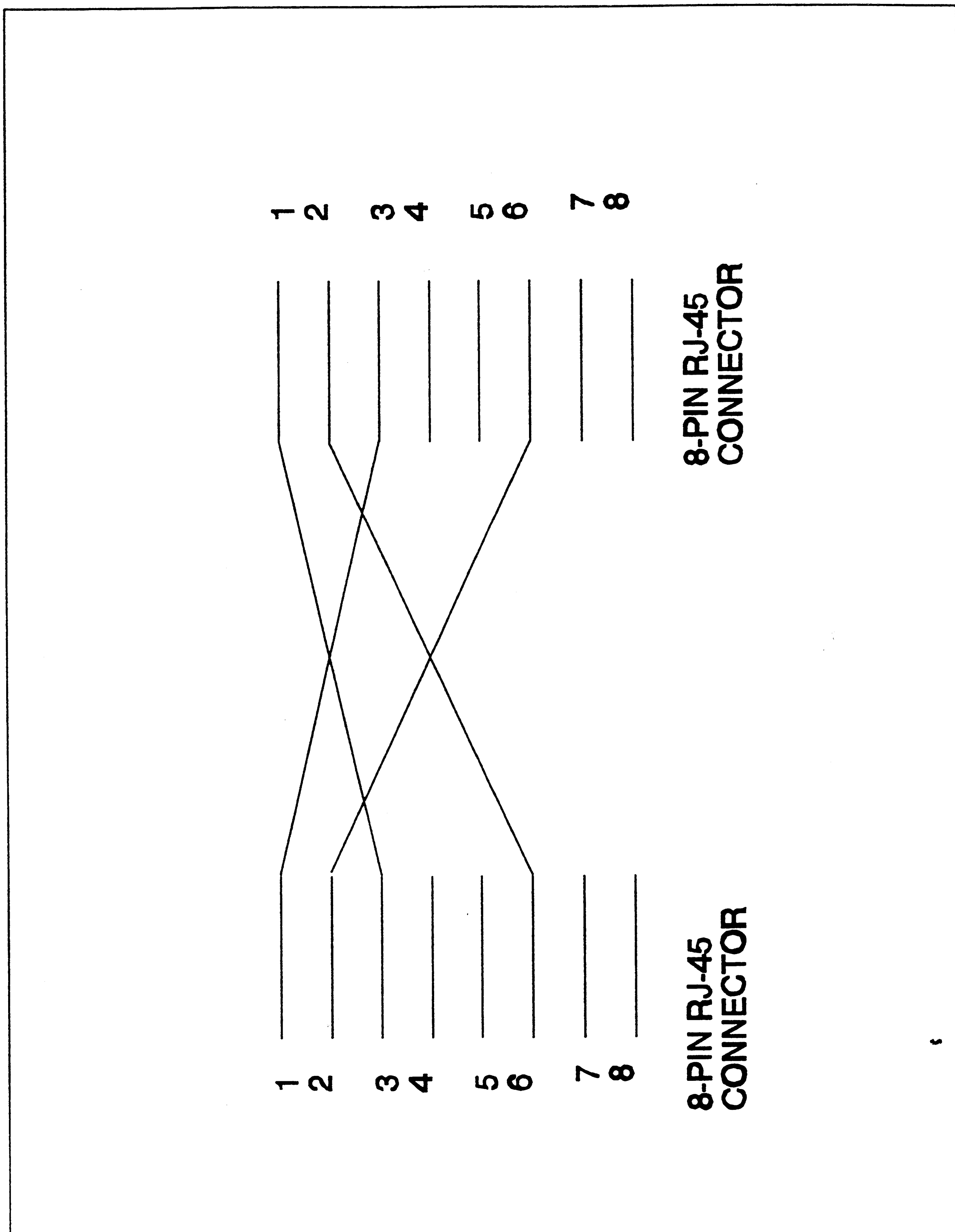

Figure 2.1 RJ-45 Connections for null-modem cable

2.4 Experimental setup

Fig. 2.2 shows the overall schematic of the experimental setup, including bridges, antennas and workstations. The connections between the elements of the setup were made as described above. Note that antenna may be an indoor antenna or an outdoor antenna.

2.5 Outdoor Antenna Installation

Outdoor antennas should be installed using manufacturer's recommended safety precautions.The antennas should be grounded to protect against lightning. Accidental contact with power lines during installation can cause injury or death. More complete instructions on safety precautions for roof-antenna installation are available from the Consumer Safety Commission. For this project, outdoor antennas were installed on CIF and EDL buildings, a distance of approximately 1 mile. A 10 element Yagi antenna supplied by Persoft was installed on the roof of the EDL building using U-bolt mounting to a vertical mast of 2 inch diameter aluminum pipe. It is important that mast height be chosen so as to allow line-of-sight access between the two antennas. Any intervening structures can cause problems with reception. A 75 feet long 75-Ohm cable was connected from the antenna to a window terminal in the building wall. The 30 foot long antenna cable supplied by Persoft was installed from the window terminal to the bridge terminal. In the CIF building, the 10-element Yagi antenna supplied by Persoft was installed on an existing antenna mast. An existing cable was used to connect to the bridge placed on the second floor of the CIF building. This cable is 200 feet long and is 50-Ohm rating. Antennas should be installed on both sides so that the antenna elements are vertical with the driven element (gray) up.

2.6 Software

The bridges come supplied with software on floppy diskette. The floppy diskette is a 3.5 inch, 720K diskette. For protection against accidental deletion, a copy of the diskette supplied should be made using any IBM-compatible PC workstation. Each bridge has its own unique floppy diskette. The two diskettes should not be interchanged.

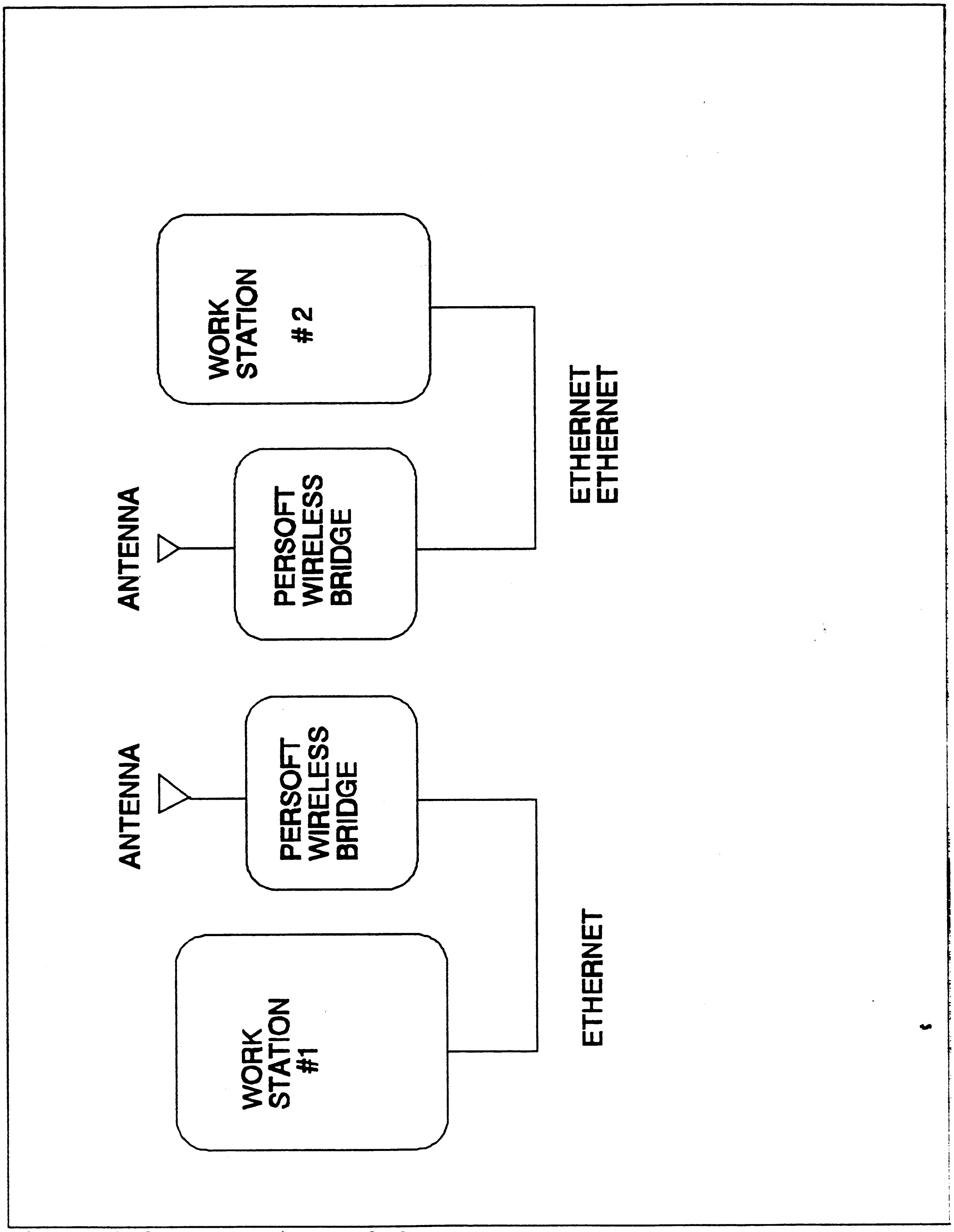

Figure 2.2 : Experimental Setup

2.7 Rangefinder software

When the bridge is powered up with the appropriate floppy diskette inserted in the floppy disk drive, a menu appears. Option no. 2 from the menu invokes a rangefinder program that can be used in measuring the quality of the radio link and in fine-tuning the antenna pointing. The rangefinder program transmits data packets between the two sites. Statistics of the link quality are displayed on the consoles at both ends. Thus it is possible to monitor the reception quality at both ends of the link from one end alone. The rangefinder program transmits a fixed 72 packets per second from each station. It displays the percentage of packets received without error. It also displays the signal quality, signal level and signal-to-noise ratio at both ends. The signal level can be from 0 to 36 dB. 18 dB is required for satisfactory operation. Signal-to-noise ratio can be from 40 to 80 dB. 60 dB is required for satisfactory operation. The signal quality factor can be 0 to 12. A quality factor of 7 is required for satisfactory operation.

2.8 Bridge configuration

Option no. 3 on the main menu of the bridge software allows customization of each bridge within its environment. The various parameters that can be set are briefly discussed. Each bridge is assigned a network id ranging from 0100 to 7FFF hexadecimal. All bridges of a given id will communicate with one another. This allows multiple pairs of remote bridges to operate on the same frequency band without interfering with one another. Other parameters that can be used to customize each bridge are spanning tree parameters and traffic screening parameters. Spanning tree parameters determine whether the Intersect bridge will become the root bridge or the preferred bridge in a situation where a loop of bridges develops [3]. The spanning tree parameters that can be chosen for each bridge are: Bridge id and priority, wireline port cost and wireless port cost. These parameters are more fully described in the references. Traffic screening parameters can be set to delimit the type of traffic that will be either forwarded or blocked by the bridge. Traffic to be forwarded or blocked can be identified by ethernet station id, or by TCP/IP traffic type.

2.9 Workstation network software

Many types of network software could be used for communicating between workstations such as ftp, email, etc. The network software takes application data and converts it to ethernet packets. In our experiment, the two workstations were both running Xenix operating system and were both supplied with ftp (file transfer protocol) program. With this program it is possible to login to the remote workstation, do a directory listing from the remote workstation, and transfer a file from remote to local (get command) or local to remote (put command). By measuring the time it takes to transfer a large file (approx. 1 Megabytes) we can get an idea of the link speed.

III. PROPAGATION TEST RESULTS

3.1 Indoor Network Test

The experimental setup described in Fig. 2 was set up in Room 140 of the EDL building. Remote login, remote directory and a file transfer from one workstation to the remote workstation was demonstrated to NASA personnel on June 7, 1995. During this demonstration two indoor antennas were used in close proximity. The rangefinder software showed that the signal level and quality were 12 and 80 dB respectively, the highest achievable values.

3.2 Indoor Propagation Test with Patch Antennas

For measuring radio propagation data, the two workstations were disconnected from the experimental setup of Fig. 2. Since the bridge generates its own traffic of Ethernet packets during the rangefinder test, a workstation is not necessary. Only a bridge and antenna are needed at each end of the link. One bridge and indoor antenna was left remaining in Room 140. The other bridge, along with monitor for display were placed on a cart. The rangefinder program was initialized at the stationary location. The site name was chosen as "Room 140." The screen then displayed the message "Waiting to synchronize with partner." At this point the mobile bridge was moved to a suitable location where AC power is available, and the rangefinder program was initiated. The site name was chosen as "mobile". At this point the two stations initiated wireless contact, and the monitor of the mobile station displayed signal statistics which were recorded. The rangefinder program was terminated at the mobile station. However, when the message "Notify partner to exit?" was displayed, the "no" option was chosen. Hence the stationary bridge in Room 140 remained in the original rangefinder mode, "waiting for partner to synchronize", even though the mobile station had exited the program and even powered down. The process was repeated at different locations around the EDL building, each time ensuring that the stationary bridge remained in the rangefinder mode. At each of the selected locations, signal level, quality, signal-to-noise ratio, and percentage of packets received correctly were recorded for both ends of the link. Table 3.1 shows the data obtained. The goal at this stage of the project was to test for successful link from one end of the EDL building to the other, i.e. from Room 140 on the West end of the first floor to Room 125 on the East end.

TABLE 3.1 : Indoor Propagation Data with Patch Antennas

Loc.	Dist.	Mobile				Room 140			
		Sign al Qual.	S/N Ratio	Signal Level	% correct	Signal Qual.	S/N Ratio	Signal Level	% corr.
	feet		dB	dB			dB	dB	
Min. Req'd for proper operation		7	60	18		7	60	18	
Adjacent	0	12	80	35	100	12	80	35	100
Around corner	10	11	75	32	100	11	76	34	100
Outside Rm 128	200	10	50	10	98	10	50	10	98
Room 125	300	8	50	8	94	8	50	8	94

As the table shows, perfect reception was not achieved between Rooms 140 and 125, even though the distance is only 300 feet, and the equipment has a nominal range of 800 feet indoors. We will see later that this was due to two concrete walls that block the direct path of the radio wave between the two rooms. The walls are the West wall of the hallway adjacent to Room 110, and the East wall of Room 124. As a result perfect 100% correct reception was not possible, It should be noted that even when the percentage of correctly received packets is less than 100%, communication is still possible but at a rate proportionately reduced from the rated 2 Mb/s. It should also be noted that in this case since the straight line path was blocked by concrete walls, communication depends on radio waves reflected by building structures and traveling along hallways and through doors etc. This type of propagation mode is subject to so-called multipath effects, whereby drastic variation in signal strength is observed by small changes in location, antenna orientation etc. The table gives data for the best possible antenna location and orientation for a fixed workstation location. It was observed that in the presence of multipath, sometimes the best signal is obtained by pointing the antenna toward a corner facing the door, as if the radio wave enters the room through the door, is reflected from a corner and then picked up by the antenna. The best reception with the most range is possible when there is an unobstructed straight line path for radio waves between the two antennas. It was seen that the signal propagated through plasterboard without much loss, but was unable to propagate through masonry concrete walls. Notice that the loss characteristic of the radio signal through various materials is strongly dependent on the frequency of transmission used.

3.3 Indoor Propagation With One Directional Antenna

Since the first indoor test was not satisfactory, another test was conducted. This time the small omnidirectional patch antenna on the mobile site was replaced by a 4-element directional Yagi antenna. It was hoped that the increased antenna gain would improve performance so 100% of the packets would be correctly received. Please note that in taking the following data, the bridge in Room 140 was connected to an omnidirectional patch antenna, while the bridge on the mobile station was connected to a 4-element directional Yagi antenna. The data is presented in Table 3.2. For each location noted in the table, the data reflects the reading obtained with the best possible antenna location and orientation within a 5 foot radius of the fixed bridge location. It was observed that when a direct straight line unobstructed signal path was available, small changes in antenna location and orientation were not significant. But where the direct path was blocked by masonry or concrete wall, the received signal exhibited severe multipath effects, and in these cases, antenna location and orientation were very important for obtaining the best signal. All the readings were taken in the main hallway outside the referred room, except for Room 125, where an inside reading was also taken.

Table 3.2 : Indoor Propagation Data with One Yagi Antenna

Loc.	Dist.	Mobile				Room 140			
		Signal Qual.	S/N Ratio	Signal Level	% correct	Signal Qual.	S/N Ratio	Signal Level	% corr.
	feet		dB	dB			dB	dB	
Min. Req'd for proper operation		7	60	18		7	60	18	
Rm 144	10	11	75	32	100	11	75	32	100
Outside Rm102B	35	11	70	26	100	11	66	26	100
O.S. Rm 107	75	12	60	15	100	12	58	16	100
O.S. Rm 150	90	11	57	13	100	11	56	16	100
O.S. Rm 122(1)	140	11	52	8	100	10	53	11	94
O.S. Rm126(1)	200	10	51	7	100	9	51	9	100
O.S. Rm170(1)	230	9	50	6	100	9	50	8	97
Inside Rm170(2)	230	11	53	11	100	11	53	13	100
Rm198 N-E	150	9	54	11	100	8	55	14	100
Rm198 South	150	9	56	12	100	10	55	14	100
O.S. Rm125(1)	300	9	50	6	55-100	9	50	9	40-100
Rm 125 West(1)	300	6	49	6	0	6	50	8	0

Notes:

(1) The reception quality was very sensitive to antenna position and orientation, suggesting the existence of severe multipath. The best results were obtained with the antenna directed toward an arbitrary direction not necessarily toward the other site, suggesting that we were picking up a reflection from a building structural element.

(2) It is interesting that the signal quality is poor just outside the door to Room 170, and is acceptable just inside. This is because the location just inside Room 170 is outside the "shadow" created by the concrete walls that are on the West side of Room 110, and on the East side of Room 124.

After the above data were taken, the two workstations were connected to the bridges and an ftp connection was demonstrated between Room 140 to a location just outside the door to Room 125.

3.4 Outdoor Propagation Data

Outdoor propagation data are presented in Table 3.3. These data were taken on June 23, 1995, using a mobile studio van.The conditions were wet and cloudy. A 6 dB Yagi antenna with 50 feet of 50-Ohm cable was mounted on the van. The van has the capability to raise, lower and rotate the antenna. It can also supply AC power for the bridge. The stationary site was established on the 2nd floor at the West end of the EDL building. A 10-element Yagi antenna was mounted on the roof of the EDL building. It was connected outdoors to an existing window terminal by a 75 foot length of 75-Ohm antenna. The inside of the window terminal was connected to the bridge by the Persoft-supplied 30 foot 75-Ohm cable. The antenna was directed West toward the CIF building. Data were taken by driving the van in a Westward direction.

Table 3.3 : Outdoor Propagation Data

Loc.	Dist.	Mobile				EDL			
		Sign al Qual.	S/N Ratio	Signal Level	% correct	Signal Qual.	S/N Ratio	Signal Level	% corr.
	feet		dB	dB			dB	dB	
Min. Req'd for proper operation		7	60	18		7	60	18	
EDL Lot (Ant. up)	100	12	75	24	100	12	75	24	100
Robotics Trailer	600	12	61	21	100	12	65	20	100
O&C Tank	1200	12	64	23	100	12	65	20	100
O&C lot West	1800	12	61	22	100	12	63	19	100
H.Q. Lot East	2200	12	60	20	100	12	63	18	100
H.Q. lot West	3200	12	59	17	100	12	60	16	100
C Ave	3700	12	57	15	100	12	57	13	100
CIF lot (Xfrmr) See note(1)	4400	12	54	10	100	12	52	8	100
CIF lot (Ant. up 30')	4400	12	55	13	100	12	56	12	100
A Ave.	6500	12	56	14	100	12	56	12	100
Guard gate	6000	No	signal	O&C	sha- dow				
NASA Blvd at S.R. 3	7500	No	signal	due to	trees	sha- dow			

KARS II East	7600	12	51	8	100	12	50	7	98
KARS II West	8400	11	48	6	0	8	47	4	0
KARS II W. (ant. up)	8400	12	52	8	100	12	51	7	100
Cause-way bet. SR3 and Space port	9300	No	signal	due to	sha-dow				
Space port	1100 0	No	signal						

Notes:
1. By rotating the antenna in this location it was seen that good signal quality is maintained over a 90 degree range.

From the above data it is seen that although the equipment is rated for 3 mile range, in practice the range is greatly affected by the shadowing effects of buildings, trees, and by land features such as high and low spots. We note that in the KARS II location, no signal was obtained with the antenna lowered. But when the antenna was raised so it cleared the treetops, then a good signal was obtained.

3.5 EDL to CIF Networking Test

For this demonstration one 10-element Yagi antenna was installed on the roof of EDL and CIF buildings each. In the EDL building the antenna was connected to a window terminal (West end of second floor) with a 75 foot long 75-Ohm cable. Another 30 foot long 75-Ohm cable (RG-6/U) was connected from the window terminal to the bridge . This type of cable is rated for a loss of 6-10 dB per 100 feet depending on the manufacturer. In the CIF building an existing 200 foot long run of 50-Ohm cable was used to connect from the roof antenna to the bridge located in a second floor lab. When both bridges were powered up, they automatically enter normal bridge operation mode in 30 seconds. It turned out that it was difficult to find suitable antenna positions on the two buildings that provided unobstructed line-of-sight view from one antenna to the other. The water tower on the O&C building creates an obstruction. Because of this the mast on the EDL building used for the outdoor propagation data proved to be unsuitable for the networking demonstration. The 8 foot mast was replaced by a 10 foot mast, and the demonstration was conducted for NASA personnel on July 6, 1995.

When operating in its normal mode, the bridge console, if connected displays traffic statistics in both directions. This data was not recorded for this project. A workstation was connected to the bridge at each end, and an ftp connection was established between the two workstations. A file of approximately 1 MByte size was transferred, and the process took about 30 seconds. This indicates a transfer rate of about 250Kb/s, which is less than the rated data rate of 2 Mb/s. The reason for this is that with only one workstation transmitting at a time, the data rate is limited by the disk access time needed to access the file to be transferred. In order to load the bridge to a level of 2 Mb/s traffic, it will be necessary to have multiple workstations on each end sending data simultaneously. This experiment was not conducted during this project.

3.6 Indoor Propagation Data with Two Directional Antennas

For these data, directional antennas were used on both sites. The stationary site was again set up in Room 140 of the EDL building, with the antenna directed East, so that the signal would propagate down the main hallway. Most of the readings were taken along this direction. For the last few readings, beginning with location no. 17, the antenna in Room 140 was reaimed to point toward the mobile. The mobile was equipped with a battery backed UPS (Uninterruptible Power Supply) that allowed readings to be taken without turning power off and outdoors. The data is shown in Table 3.4.

Table 3.4 : Indoor Propagation Data with Two Yagis

Loc.	Dist.	Mobile				Room 140			
		Sign al Qual.	S/N Ratio	Signal Level	% correct	Signal Qual.	S/N Ratio	Signal Level	% corr.
	feet		dB	dB			dB	dB	
Min. Req'd for proper operation		7	60	18		7	60	18	
1	275	12	51	9	100	12	52	11	100
2(1)	140	12	58	14	100	12	58	18	100
3	220	9	51	6	30	7	51	9	38
4	230	7	51	6	0	12	54	9	0
5	320	9	50	7	0	10	50	8	0
6	310	12	52	12	100	12	53	13	100
7	300	8	49	7	0	9	53	11	0
8	200	8	49	6	5	7	49	8	0
9	190	11	52	9	91	10	52	11	100
10	160	12	54	13	100	12	57	15	100
11	170	8	53	10	100	10	55	14	100
12	150	12	65	23	100	12	65	24	100
13	140	11	60	16	100	8	63	18	100
14	80	12	63	20	100	12	63	22	100
15	70	12	69	25	100	12	68	27	100
16	60	12	80	35	100	12	80	35	100
17	40	12	68	25	100	12	70	27	100
18	40	12	73	29	100	12	71	28	100
19	30	12	77	33	100	12	76	34	100
20(1)	80	10	60	17	0-100	10	60	17	0-100

Description of Numbered Locations

1. Room 123, antenna pointed to N.W. top corner of room
2. Room 198, North side
3. Hallway between Rooms 128 and 170
4. Room 128 West
5. Room 132
6. Hallway between Rooms 132 and 125
7. Room 125 West, antenna pointed to N-W corner
8. Room 126
9. Room 126 West, close to concrete wall.
10. Room 124 West
11. Room 124 near door, Antenna pointing toward door
12. Hallway near door to Room 122
13. Inside Room 122 (20 feet)
14. Hallway near Room 106 (restrooms). Note that there is a concrete wall to the West.
15. Room 150. Approximately 20 feet to the South of location 14, so the receiver is out of the "shadow" caused by the concrete wall.
16. Hallway outside entrance to Room 104.
17. Outside the building, West, 20 feet, antenna pointed to main glass door.
18. Same as loc. 17. Antenna pointed to steel entrance door to Room 102, i.e. more toward stationary antenna in Room 140.
19. Directly West of stationary antenna, just outside West external concrete wall.
20. Directly North of stationary antenna, just outside North external concrete wall.

Notes
1. By turning the cart, it was observed that signal quality was maintained over a 90 degree angle.

IV. CONCLUSIONS

The Persoft equipment used was found function satisfactorily and user-friendly. The equipment is suitable for incorporation into KSC networks for the purposes stated in the introduction. The maximum range specified for the equipment can be obtained only with line-of-sight contact between the two antennas. In practice, the range of the equipment is very much dependent on building materials for indoor use, and terrain for outdoor use. For any given application, careful consideration should be given to such factors as intervening masonry walls (for indoor use), intervening buildings, high terrain and trees (for outdoor use). This report incorporates general propagation data that should be helpful in evaluating each intended application. Based on the numerical data the propagation loss can be modeled as approximately 1 dB loss for every 7 feet. Concrete walls add approximately 5 dB loss. Outdoor propagation loss can be modeled as approximately 1 dB per 150 feet. The reception is improved in clear areas that are far away from buildings etc.

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