Alternative Communication Networking in Polar Regions

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Abstract – *Research is being conducted in the Polar Regions that generates significant quantities of important scientific data. Real-time exchange of this information in the field and access to the Internet is crucial. This paper presents a reliable, truly mobile, lightweight, and relatively inexpensive integrated data communications system to provide wireless Internet access in remote regions. It describes the work done as part of the Polar Radar for Ice Sheet Measurements (PRISM) project to support data communication requirements of science expeditions in the harsh climactic and technologically challenged regions of Greenland and Antarctica. An inverse multiplexed, multi-channel Iridium based system integrated with a long-range 802.11b network is developed to provide wireless Internet access at moderate speeds. Results of field experiments conducted at the North GRIP site in Greenland to evaluate the overall performance of the system are presented. The system has an average throughput of 9.26 Kbps and efficiency greater than 90%. The average time interval between call drops is observed to be 100 minutes with modem uptimes as high as 95%, which means the system is suitable for autonomous operation. Experiments conducted using the Wi-Fi system showed reliable communications over a distance of 10 Km with 802.11b throughputs varying from 4.8-0.23 Mbps depending on the signal to noise ratio at the receiver. The integrated communication system proved to be a reliable, lifeline alternative data/Internet connection in Polar Regions.*

1. Introduction

Modern telecommunication facilities have grown tremendously over last few decades. While the local area network speeds exceed hundreds of Mbytes/sec, wide area networks too have advanced from dial-up 56Kbytes/sec connections to T1 lines operating at 1.5 Mbps to fiber links at several Gigabits per second. But, these state-of-the-art technologies have evolved mainly in developed areas. To this day, there are places where these technologies have not penetrated for one reason or another. Some are developing nations; where as other regions are geographically remote. Arctic, Antarctic and other remote regions are such places where data and Internet access still remains an issue.

Though commercial broadband satellite systems have helped to solve the problem in some of the populated regions, they offer intermittent coverage in oceans and the Polar Regions. Such coverage ceases to exist beyond 70^0 N/S latitudes. On the other hand, research in Polar Regions involving data collection and telemetry has grown significantly over the past few years. Numerous field expeditions are being conducted at various locations year round. The telecommunication requirements of the Polar science community are continuously increasing. In 1999 the bandwidth requirement of the South Pole station alone is estimated at 14Gbytes/day [5]. Since the NASA satellites (ATS3, LES9, GEOS, TDRS1 and MARISAT2), currently providing broadband access to these regions [7] is either geostationary or geosynchronous, they have limited visibility window at poles as seen in figure 1. Further, they have a very low elevation angle (about 1-4 degrees) from Poles, which combined with high altitude of the satellite results in extremely large field equipment [3] (10-meter radii antennas) that had to be properly pointed towards the satellite. Hence, these systems cannot be used for small field camps and science expeditions

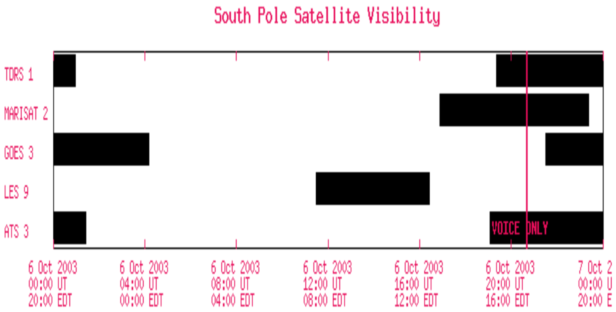

Figure 1 Satellite visibility at South Pole (Source: [8])

Thus, the need for a compact, easily portable and field deployable data communication system with round the clock coverage is clearly evident.

In this paper, we present a mobile lightweight integrated data communication system of moderate capacity based on Iridium satellite system, which is the only commercial satellite system with truly global coverage. In order to increase the otherwise low capacity (2.4 Kbps) of the Iridium system, packet level inverse multiplexing is implemented using Multi-link point-to-point protocol (MLPPP) [4]. This mechanism combines multiple channels to obtain a seamless data connection with a capacity approximately equal to the sum of the individual link rates providing a reliable round the clock data communication system with *scalable capacity*.

A local area network (LAN) with an extended range is also required to share data and Internet access among the field participants and sensors, scattered over a wide area in the filed camps. Field camps in the past have known to use wired Ethernet LANs, which does not provide ubiquitous connectivity around the camp and suffers from the disadvantage of laying cables on the ice. A system of modems and a 400 MHz UHF radio telephone (Opti-phone) used for networking with other field camps has a low baud rate (9600 bps), requires Line of Sight and is not intended for mobile platforms. These issues could be addressed with a wireless LAN (WLAN) of a reasonable range in the Polar Regions. Long-range 802.11b installations in the past used parabolic antennas [6], which are unsuitable for mobile applications and do not provide ubiquitous coverage. Thus, an 802.11b system with external amplifiers and vertical collinear omni directional antennas is used here to provide wireless Internet and data access over a range of 10 Km for land-mobile and mobile-mobile systems.

2. System architecture and operation

2.1 Multi-Channel Iridium System

The remote subsystem system consists of 4 Motorola-Iridium modems connected to a rugged laptop with an USB-to-Serial converter as shown in figure 2. The antennas of these modems are installed on a metal plate of 1 sq ft that forms the ground plane. These four antennas are then mounted on a frame such that they are separated from each other by 2 ft in order to reduce the effects of interference. The PPP daemon (PPPD) on the remote terminal is configured as a PPP client so as to connect to the local terminal. The computer terminal at the local end has four PSTN modems connected to it via a multi port serial card and an octopus cable. This terminal is configured as a PPP server to receive call from the remote Iridium system through 4 PSTN phone lines.

The developed link management software configures the remote terminal as a PPP client, dials the Iridium modem to establish the serial connection with the mainland terminal and handles PPP negotiation to complete a point-to-point data connection. Once the basic connection is established, it dials the remaining modems and seamlessly attaches them to the first PPP connection, forming a single higher bandwidth pipe. Standard Internet protocols, TCP/IP are then used to provide end-to-end connectivity. This MLPPP system was developed in Linux and also monitors the satellite connection, detects any call drops during satellite hand-offs and immediately reconnects dropped modems. Further, it handles power failures and system resets providing a reliable and fully autonomous data link.

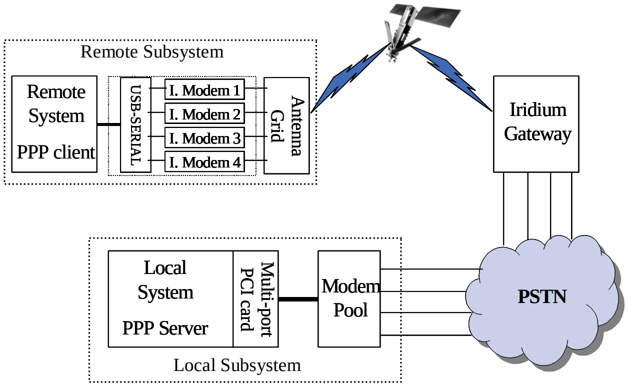

Figure 2: Four-channel Iridium communication system

The IP packets of a single application from the remote system are fragmented at the MLPPP layer into smaller segments depending upon the packet size, the link Maximum Transmission Unit (MTU) and the availability of the links. These segments are then sent simultaneously over multiple satellite links. The MLPPP layer at local system on the other end combines the received segments into the original data packet and checks for errors or segment loss. If the packet is successfully reconstructed, it is presented to the IP layer; else a packet error is reported. TCP/IP layer handles any errors or packet losses that occur. The same procedure is followed for packets going in the other direction (local system to remote system).

2.2 Wi-Fi System

The Wi-Fi system consists of a central base station that serves as an access point (using Orinoco AP-500) and is interfaced via Ethernet to the Iridium system. In order to increase the range of the access point and hence the wireless network, it is required to amplify the signal strength to overcome the propagation losses. Thus, the access point is connected to a 1-Watt bi-directional amplifier, which is connected directly to a 9-dBi vertical collinear antenna using a male-to-male UHF adapter and mounted on a mast 3 meters above the ground level. Cable connection from the amplifier to the antenna is avoided in order to minimize the losses and also reduce the noise figure of the receive system. The bi-directional amplifier in the receive mode acts as a low noise amplifier (LNA) directly connected to the antenna and thus minimizes the noise figure of the receive system. The vertical collinear antenna has a horizontal beamwidth of 360 degrees and a vertical beamwidth of 7 degrees.

The basic WLAN setup shown in figure 3 extends the range of the access point to users and sensors situated within a few hundred meters of the base station. The users are provided with 802.11b wireless client cards that can be plugged into their laptops to enable Internet as well as data access. An extended 802.11b network is also provided to extend the coverage to mobile vehicles and other users situated at distances as far as 10 Km from the base station. The mobile vehicles consist of rugged laptops with 802.11b wireless clients connected to a 9-dBi vertical collinear antenna via a 1-watt bi-directional amplifier.

The choice of the amplifier and antenna are made based on a two-ray propagation model [1] that predicts a fourth power loss with distance. The height of the antenna mounted on the mobile vehicle also influences the received signal strength as predicted by the model and increases by 6 dB on doubling the height of the antenna. Based on this fact, the vertical collinear antenna is mounted on the mobile vehicle at a height of 3m from the ground to overcome the propagation losses and ensure reliable data communications over 10 Km.

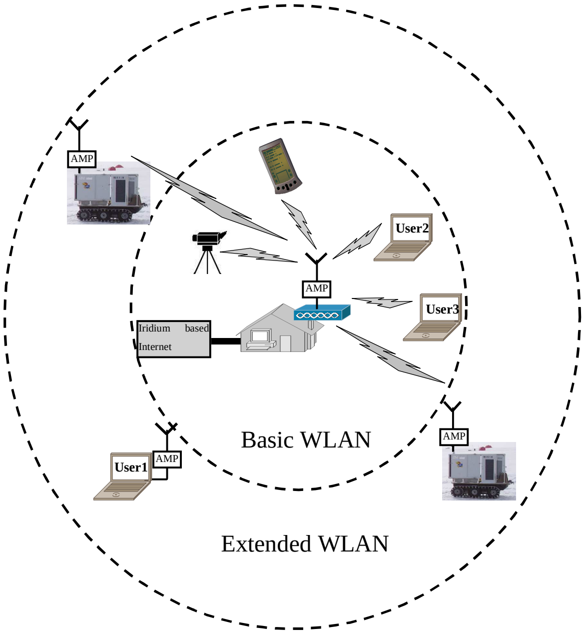

Figure 3: Long range wireless LAN

3. Network Architecture

The end-to-end network architecture that was used to provide data and Internet access to Polar field research camps/sites is shown in figure 4. A specific implementation of the system between the Polar (Greenland) Field camp and University of Kansas is used to illustrate the network architecture. This architecture could be generalized to provide Internet access to any remote field site from a mainland facility or to provide data connection between two remote field sites.

The remote field site is configured as a subnet of the mainland local network; like University of Kansas in the above example. The PPP client (system with multi-channel Iridium system) is configured as the default gateway of the Greenland subnet. Data from wired (Ruser4) and wireless users (Ruser1-Ruser3) of figure 4 is routed by the PPP client over the satellite link (through the PPP0 interface) to the PPP server in the University. PPP server being a part of the university's network routes the data packets through the University router to the World Wide Web.

Similarly, PPP server is configured as the default gateway to forward packets going from the University network and Internet to the remote (Greenland) network over the satellite channel. A static route on the University router forwards all the traffic intended for the remote subnet to the PPP server.

4. Field Experiments and Results

A goal of the summer 2003 Greenland field experiments was to determine the performance of integrated Iridium/Wi-Fi based data communication system in a polar environment. The field experiments were conducted at the NorthGRIP ice core drilling camp in Greenland (75° 06' N, 42° 20' W) from June 23-July 17, 2003.

4.1 Iridium System Performance

Field experiments were conducted to evaluate the performance of multi-link Iridium point-to-point communication system. Further, the goal was to obtain quantitative network performance data from the field, including 24hr access, call drops, packet loss and delay; this data would be used to evaluate the throughput and reliability of the system. The objectives also included evaluating the suitability of the link for the transfer of large files, e.g. non-real time video, and real time video/audio communications

4.1.1 Delay and Loss Performance

Ping measurements were done at various times during 24-hour period to determine the round trip delay of the multi-channel Iridium system. The experiment was repeated on several days to obtain the average delays. Table 1 shows the system round trip time (RTT) and packet loss observed.

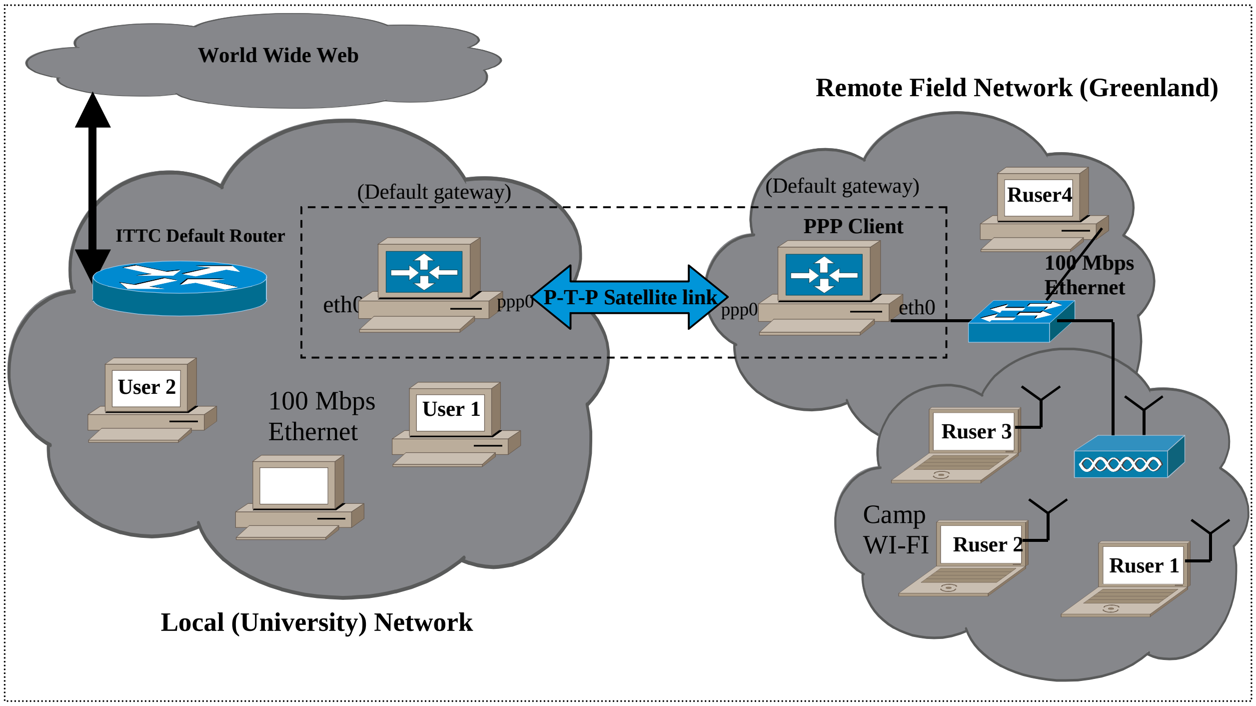

Figure 4: Network architecture to support data and Internet access to Polar Regions

Table 1: Round trip time and packet loss of system

Packets Sent	Packets Received	% Loss	RTT (sec)			
			Avg	Min	Max	Mdev
50	100	0	1.835	1.347	4.127	0.798
100	100	0	1.785	1.448	4.056	0.573
100	100	0	2.067	1.313	6.255	1.272
200	200	0	1.815	1.333	6.228	0.809

In order to understand the experimental results, first consider the theoretical end-to-end delay observed by a 64byte packet between Greenland and University of Kansas.

The Propagation segments are: Satellite uplink (from Greenland) – Iridium satellite channel – downlink at Hawaii gateway – PSTN link Kansas.
Distance traveled =800+8000+800+6000 =15600 Km
Propagation time = distance traveled/speed of light = 15600 Km/ (3e5) Km/sec= 52msec
Transmission time for a 64 bytes@2.4Kbps = 64*8/2400=213msec
Unknown parameters = inter satellite switching time + processing time at gateway + additional overheads
Theoretical end-to-end delay = 265 msec + unknown value

Though the theoretical RTT is 530 msec, the average RTT during field experiments, as seen in Table 2, was observed to be about 1.8 seconds. The additional delay could be attributed to the inter-satellite switching, processing at the gateway, call hand-offs and the constantly varying satellite constellation.

4.1.2 Throughput Performance

In order to determine the efficiency of the multi-link system, throughput measurements were done with increasing number of modems. Again, the experiments were repeated several times. Figure 5 displays the average throughput as a function of number of modems. These results were obtained using the TTCP and IPERF bandwidth measurement tools.

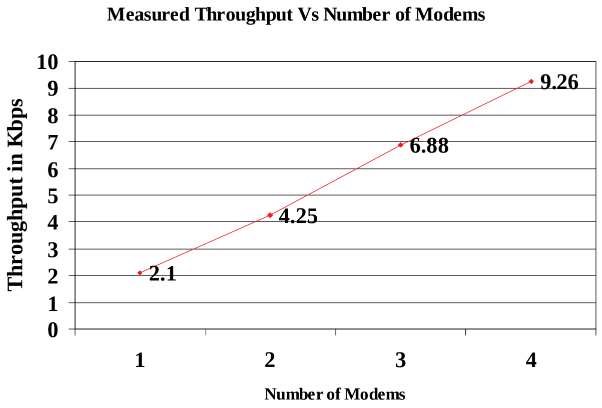

Figure 5: Throughput of the multi-link system

The maximum throughput observed with 4 modems was 9.7 Kbps with an average throughput of 9.26 Kbps. The system on an average was thus about 96% efficient. The system was also used to upload large video files from the field, ranging in size from 0.75 MB to 3.2 MB. The results of these file transfers using FTP are shown in Table 2.

Table 2: File transfer throughputs

File Size (MB)	Upload Time (min)	Throughput (bits/sec)
0.75	11	9091
3.2	60	7111
1.6	23	9275
2.3	45	6815
1.5	28	7143
2.5	35	9524

Modem call drops during the transfers resulted in the throughput being less than expected in some cases. However, it is important to note that these large files were successfully transferred automatically even in the presence of call drops, indicating that the link management software operated properly.

4.1.3 Reliability – Modem Call Drops

Initial studies on Iridium call drops [2], [6] have reported a call drop rate of 6-18% based on call duration of 10-15 minutes. This means 6-18% of the calls were dropped with in the first 15 minutes of the call. But, it should be noted that if the remaining 94-82% of the calls were to be continued for long periods of time, it is likely that they would eventually experience a call drop. Hence the performance criterion is not how many calls are dropped, but the interval between the call drops.

To determine the reliability of the system we conducted two 24-hour tests. During these tests the management software controlled the 4-channel communication system. The management software detects any call drops/link failures, logs the event, automatically redials the dropped link and attaches it to the multilink bundle. Figure 6 shows the call drop pattern on the first modem, which defines the basic connection itself. Since calls drop on the first modem results in the termination of the entire session, these call drops represent the system failures. During the 24-hour test 13 call drops were recorded. The average connection time between the call drops was observed to be approximately 100 minutes. The overall percentage up time on the first modem was about 96%. The longest up time without a call drop was observed as 618 minutes. The typical time to make a connection is 1 minute while on an average it takes 2 retries to reconnect after a call drop.

4.1.4 Reliability – Modem Up times

It should be noted that a drop on the first modem results in a complete loss of the communication link, whereas call drops on the other modems result in a brief reduction in the available bandwidth before the management software reconnects the dropped link and attaches it to the bundle. In order to determine the available bandwidth during the same 24-hour test period, the number of online modems vs. time is plotted in figure 7. The statistics obtained from this graph are shown in Table 3. It is seen that during 80% of the test time all the 4 modems were running providing full bandwidth of 9.6 Kbps. On the other hand we had at least one modem connected for 96% of the time.

Table 3: Statistics of the 24-hour test

Number of online modems	Up time (min)	% Up time
All the 4 modems	1161	80.6
At least 3 modems	1323	91.8
At least 2 modems	1365	94.7
At least 1 modem	1395	96.8

4.1.5 System Performance under Motion

The system was tested while the communications system, the four modems and their antennas, were in motion. The platform was transported at speeds up to 20 m/h. The system performance with and without motion was comparable. However, the number of attempts to complete a connection increased with the system in motion.

4.1.6 Qualitative Performance

The Iridium communication system was used for the transfer of large files to support the general activity of the NGRIP camp. Files as large as 7.2 MB were downloaded from various Internet hosts. In combination with a modified Wi-Fi deployment, the system provided Internet access for the entire NGRIP camp; this was the first time the camp had such a capability and it was very well received. The NetMeeting software was used to test the real time video/audio capabilities of the system. As expected, the long delays made real time interactions difficult.

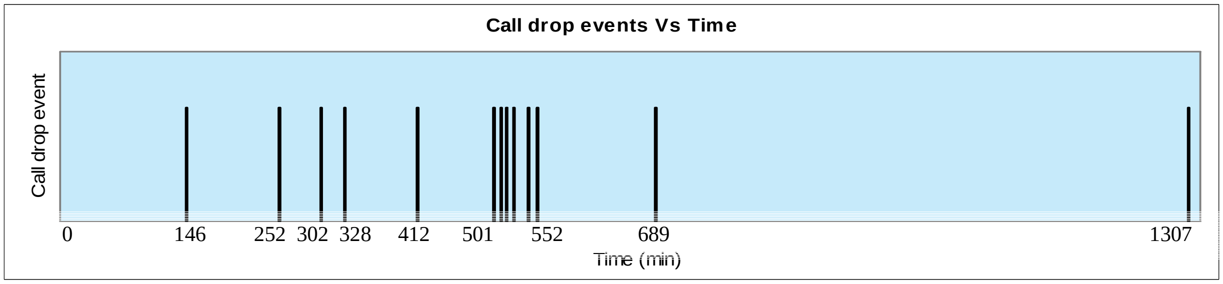

Figure 6: Call drop pattern of the first modem during the first 24 hour test

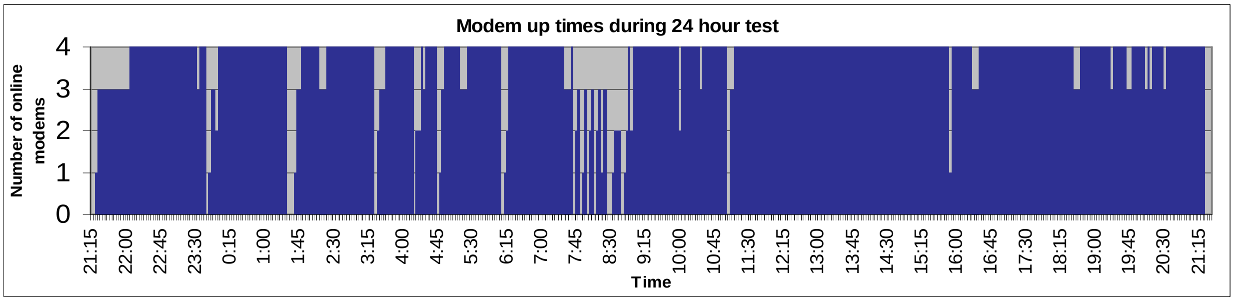

Figure 7: Availability of modems during the first 24 hour tests

4.2 802.11b system performance

Basic WLAN and Extended WLAN tests were carried out with the Wi-Fi system installed at the NorthGRIP site in Greenland. It was required to determine variation of the received signal strength with distance, which in turn determines the range and throughput achievable in both these networks.

4.2.1 Basic WLAN measurements

The hardware setup for the basic WLAN measurements consisted of the base station with the access point connected to external amplifier and antenna as shown in Figure 4. Measurements involved plugging an Orinoco 802.11b wireless client into a rugged laptop and moving to different locations in the vicinity of the base station. The signal to noise ratio (SNR) and throughput are measured at each location. Experiments are conducted at a time when no other user is allowed to access the Internet, and all the four modems of the Iridium system are operational at the start of the experiments. Results of the basic WLAN measurements shown in figure 8 reveal a range of around 1 Km and throughputs varying from 8.9-9.67 Kbps over this range.

4.2.2 Extended WLAN - Received signal strength and radio propagation model

In an extended WLAN, peer-to-peer field experiments are carried out between a base station and a mobile vehicle as shown in figure 3. The access point in the base station is replaced with a Orinoco 802.11b client plugged into a rugged laptop and connected to the external 1 watt amplifier and 9 dBi vertical collinear antenna. A Garmin GPS 12 receiver is connected to the RS-232 port of the rugged laptop on the mobile vehicle to log the latitude and longitude along a traverse.

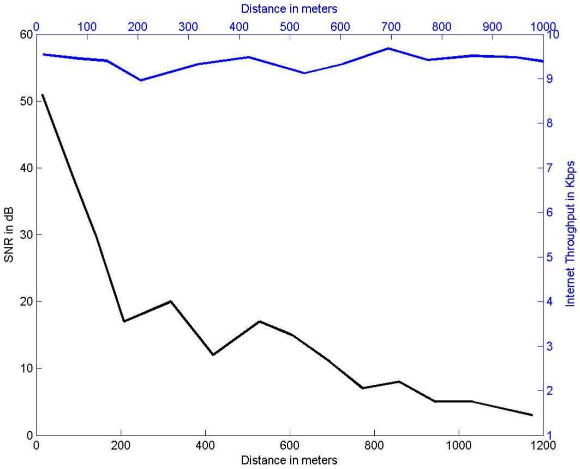

Figure 8: SNR and throughput in a basic WLAN

Once the hardware is installed and antenna fixed at a particular height, the mobile vehicle is used to traverse along the ice to measure the received signal strength, SNR and throughput up to a distance of 8 km from the base station. The Orinoco client manager software logs the received signal strength, noise level, SNR and the corresponding time stamp measured every 2 seconds. The latitude, longitude and altitude information from the GPS with the corresponding time stamp is also logged every 2 seconds.

Measurements were carried out for different combinations of antenna height at the base station and the mobile vehicle to gain a better understanding of the radio propagation model for communication over ice. The antenna at each end could be raised to one of the four different heights of 1.4,2,3 and 5m using a variable length mast on which the antenna is mounted. Further, the above-mentioned tests were repeated along different tracks, each of length 8 km from the base station.

The variation of the received signal strength with distance for six different combinations of antenna heights at the base station and mobile vehicle was analyzed and compared with the theoretically predicted received signal strength The effects of using a multi-element vertical collinear antenna that is used during the field experiments is included in the two-ray propagation model to obtain a realistic prediction of the received signal power. The measurements and the corresponding theoretically expected results for two specific cases (base station antenna height=3m, mobile antenna height=3m and base station antenna height=3m, mobile antenna height=1.4m) are shown in figures 9-10.

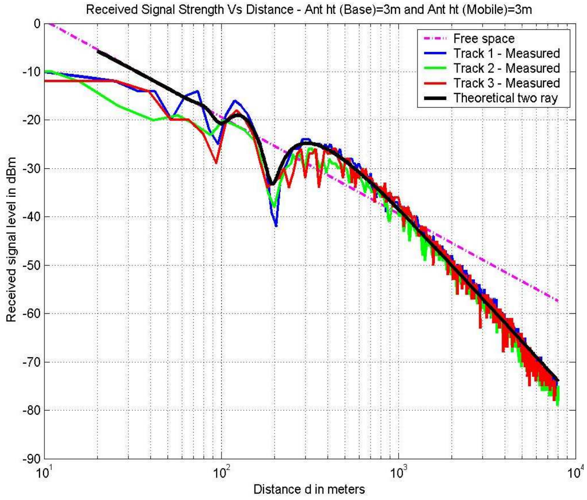

Figure 9: Received signal strength variation with distance for base station and mobile antenna heights of 3m with a GPS error of +10m

It is seen from these plots that the received signal strength variation matches very well with theoretical two-ray propagation model. The lobing pattern observed in the measured results before the Fresnel break point is well accounted by the effects of using a multi-element antenna over the flat ice surface and the results confirm the validity of using the two-ray propagation model for communication over the flat ice sheets in Polar Regions.

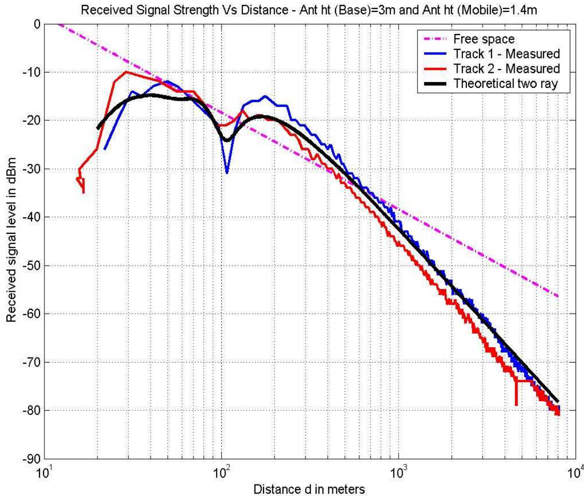

Figure 10: Received signal strength variation with distance for base station and mobile antenna heights of 3 and 1.4m respectively with a GPS error of -10m

4.2.3 Throughput performance of extended WLAN

Peer-to-peer throughput and signal to noise ratio (SNR) measurements are made every 0.5 km along a particular track and the results for four specific cases (equal antenna heights on the base station and mobile vehicle) along track1 are plotted in figures 11-12. Theoretical 802.11b data rates of 11 Mbps are not achievable in practice due to the packet overhead, Request to send / Clear to send (RTS/CTS), acknowledgement times etc.

Measured data rates vary from 0.2-4.9 Mbps depending on the SNR, which in turn depends on the distance of separation and the antenna height. It is seen in figures 11-12 that the throughput does not monotonically decrease with distance as may be expected to occur due to a general drop in signal to noise ratio with distance. There are data points where the throughput may be higher for larger distances compared to a smaller distances of separation. This is primarily attributed to the large variation in the round trip times (RTT) that are encountered in 802.11b networks and also the response of the underlying TCP protocol to random packet errors that may occur even at high signal to noise ration (SNR) and that are predominant at low values of SNR.

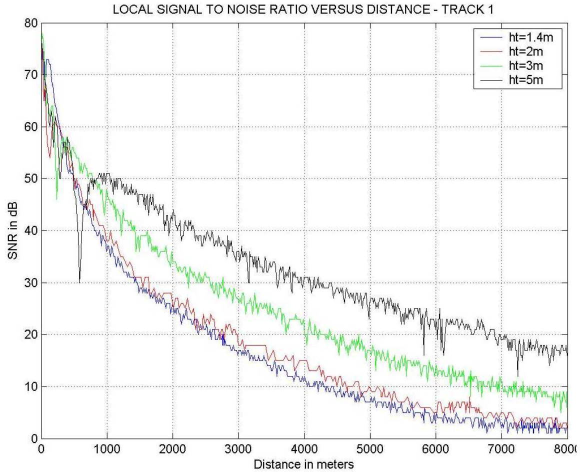

Figure 11: SNR variation along track1 for antenna heights of 1.4, 2, 3 and 5 meter on the base station and mobile vehicle

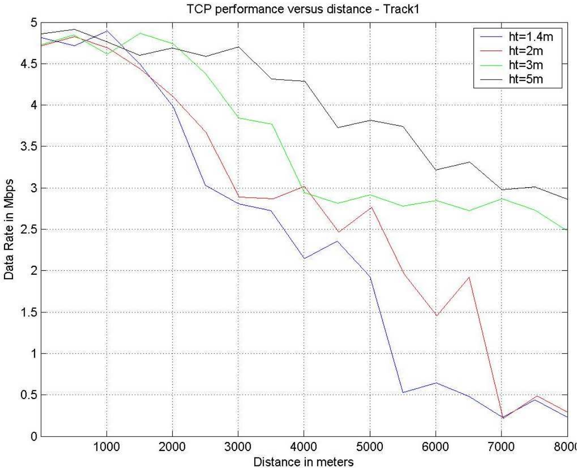

Figure 12: TCP Throughput variation along track1 for antenna heights of 1.4, 2, 3 and 5 meter on the base station and mobile vehicle

However, the bandwidth available is still high enough to exchange video data between the mobile vehicle and the base station. Seamless communication between the two peers implies a highly reliable link, and that wireless Internet would be continuously available over this long range because replacing the base station with an access point would make this an infrastructure network with Internet access available to any node such as the one installed on the mobile vehicle in these experiments.

5. Conclusions

In this paper, we presented an integrated Iridium/Wi-Fi communication system as a reliable, truly mobile and lightweight alternative to the data communication and Internet needs in remote regions.

The system was implemented at NGRIP; Greenland during the Summer 2003 field season and the performance was studied. Using MLPPP technology, a 4-modem Iridium system provided Internet access and data access to home institutions at speeds up to 9.8 Kbps from the field camp, with efficiencies over 90%. The system had an up time of 94% with at least one modem and 80% with all the four modems. Further, we have developed management software that handles call drops, system and power failures providing a fully autonomous operation. This can provide a reliable lifeline data/Internet connection to all the polar field camps. Further research is being conducted to understand and possibly reduce the round trip time (1.8 sec) of the Iridium system, which impairs real-time communications.

We have demonstrated two different wireless local area networks. Using external amplifier and antenna at the access point, a network of approximately 1 km radius is formed serving wireless laptops with widely available 802.11b cards. An extended network of 10 km radius was achieved by using similar antenna and amplifier on the mobile user end too. We obtained LAN data rates of 4.828 Mbps at close separation distances and 0.2 Mbps for distances up to 10 Km from the base station.

6. Acknowledgements

This work was supported by the National Science Foundation (grant #OPP-0122520), the National Aeronautics and Space Administration (grants #NAG5-12659 and NAG5-12980), the Kansas Technology Enterprise Corporation, and the University of Kansas.

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